DESIGN OF SMOKE CONTROL SYSTEMS FOR BUILDINGS

NBS Handbook 141

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ABSTRACT

This book consolidates and systematically presents data and calculational procedures necessary to smoke control systems designers and discusses design criteria. The book was originally intended for use by mechanical engineers. However, it also may be useful to fire protection engineers and code officials. Included are discussions of the driving forces of smoke movement, the principles of smoke control, calculation of effective flow areas, concept of symmetry, and design parameters. A computer program for analysis of smoke control systems is presented. Concepts of stairwell pressurization and zoned smoke control are presented. Numerous hand calculated examples and computer calculated examples are included.

Key words: air flow; bibliographies; computer programs; fire protection; fire safety; smoke control; smoke movement; stairwells.

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PREFACE

This book provides a consolidation and systematic presentation of data and calculational procedures necessary for smoke control system design. It also includes discussion of selection and appropriateness of various design criteria. Although initially envisioned for use by mechanical design engineers, this book should also serve as a useful tool for fire protection engineers and code officials.

Research and development of smoke control methods have been conducted worldwide, with the majority having been performed in Japan, England, Canada, United States, France, and West Germany. This research has consisted of field tests, full-scale tests, and computer simulation of smoke movement and smoke control in buildings. The calculational procedures presented for the design of pressurized stairwells and zoned smoke control systems are based on test data and fundamental principles of engineering. Since this book is intended for practical use by design engineers, the test data upon which these procedures are based are not detailed herein. However, the data are available in published form and are cited in the bibliography presented in appendix H.

Smoke control systems for pressurized elevators, pressurized corridors, and atriums are only briefly mentioned in chapter 1. Currently there are insufficient test data to ensure the validity of system concepts or of specific calculational procedures for their design. It is hoped that this book will encourage future development in these areas and that some future edition will include procedures for designing these systems.

This book represents the first attempt to consolidate and present practical procedures for smoke control system design. It is hoped that the readers and users of this book will provide comments on its content and suggestions for additional material to be included in future editions. To facilitate recording and processing of such information, all comments and questions must be written. Please mail comments or questions to:

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Fundamental to this work was the need for valid data, as indicated in the preface. As a result, the content of this manual is heavily dependent upon the work of many years performed by George Tamura and his associates of the National Research Council of Canada. Without their work, a great deal of this book would not have been possible and a mere acknowledgment is truly inadequate to express the value of their contribution.

CHAPTER 1.
INTRODUCTION

Smoke is recognized as the major killer in fire situations [1]*. Smoke often migrates to building locations remote from the fire space, threatening life and damaging property. Stairwells and elevator shafts frequently become smoke-logged, thereby blocking evacuation and inhibiting fire fighting.

There is a general unawareness of how fast a fire can grow and of the quantities of smoke that can be produced by a fire. Because such an awareness is necessary to the evaluation of design parameters for smoke control systems, the following example is provided.

This example is fire test N-54 performed at the Health Care Test Facility at the National Bureau of Standards Annex in Gaithersburg, MD. For technical details of this unsprinklered fire test the reader is referred to a report by O'Neill, Hayes, and Zile [2]. The floor plan of the test facility is shown in figure 1.1.

In this test, various fabrics representing materials found in clothing today were hung on wire coat hangers and arranged loosely in a wooden wardrobe. A cardboard box containing crumpled newspaper was placed on the floor of the wardrobe. The test started when the crumpled newspaper was ignited by a match. Following ignition, the left hand door was closed tightly while the right hand door was left partially open resulting in a 3 in (76 mm) opening along the vertical edge of the door.

The photographs shown in figure 1.2 were taken from the observation port (see figure 1.1) across the corridor from the burn room and 2.21 ft (0.67 m) above the floor. At one second after ignition, the technician is closing the left hand wardrobe door and no flame or smoke is visible. At 80 seconds,

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*Figures in brackets refer to references at the end of each chapter.

flames are visible flowing from the top of the wardrobe, a layer of smoke is covering the ceiling of the burn room, and smoke has flowed into the corridor and formed a one foot thick layer at the corridor ceiling. At 110 seconds, flames are flowing from the top two-thirds of the opening of the wardrobe door, and the smoke flowing out of the burn room doorway has increased significantly. At 120 seconds after ignition, flames are flowing from the entire opening of the wardrobe door, and the layer of smoke in the corridor and lobby has increased to approximately 4 ft (1.2 m) above the floor.

Such very rapid fire growth and accompanying smoke production represent a real possibility in actual wardrobe fires and perhaps even in closet fires. Many other fire scenarios are possible. For a latex or a polyurethane filled mattress fire started by an adjacent wastebasket fire, approximately six minutes are required for the fire to reach a stage of development equivalent to the wardrobe test N-54 at two minutes.

As a solution to the smoke problem, the concept of smoke control has developed. Smoke control makes use of fans to produce airflows and pressure differences that can control smoke movement. The use of airflows and pressure differences to control the flow of undesired airborne matter has been

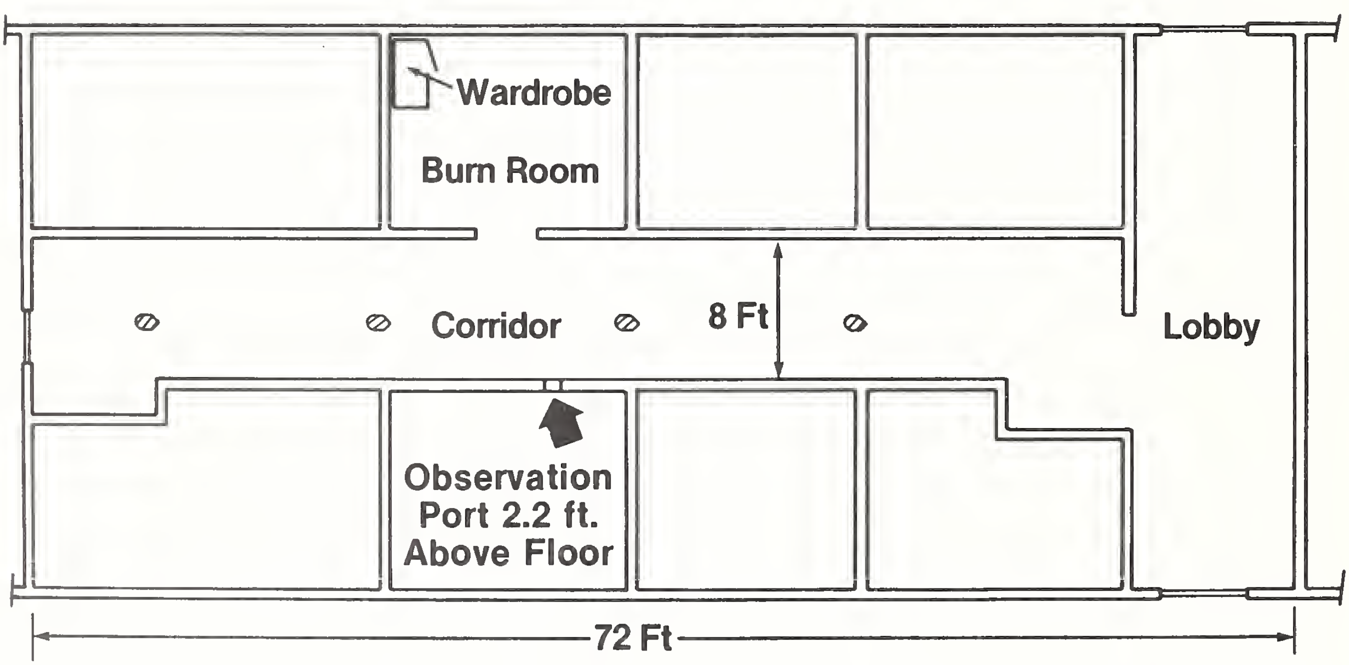


Figure 1.1. Floor plan of the Health Care Test Facility at the NBS Annex

1 second

80 seconds

110 seconds

120 seconds

Figure 1.2. Example of rapid fire growth and smoke production from test N-54 at the Health Care Test Facility at the NBS Annex

practiced for at least 40 years. For example, they have been used in buildings, such as experimental laboratories, where there is a danger of poison gas or bacteriological material migrating from one area to another; they have been used to control the entrance of contaminants where a dust-free environment is necessary; they have been used where radiation migration and contamination could occur; and they have been used in hospitals to prevent the migration of bacteria to sterile areas. However, the use of airflow and pressurization to control the migration of smoke from building fires is a fairly recent adaptation.

In this book, the term "smoke" is used in accordance with the ASTM and NFPA definition which states that smoke consists of the airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion [3,4].

1.1 SCOPE

The intent of this book is to provide practical state-of-the-art design information to mechanical engineers who have been charged with the design of smoke control systems. This chapter contains general background information. Chapter 2 contains the fundamental concepts upon which smoke control is based. These concepts are included because it is believed that an understanding of them is essential for intelligent smoke control design. These concepts include a discussion of the driving forces of smoke movement, the principles of smoke control, and the parameters necessary for the design of smoke control systems. These design parameters are:

- The leakage areas of flow paths throughout the building.

- The design weather data.

- Pressure differences across boundaries of smoke control systems.

- Airflows through openings in boundaries of smoke control systems.

- The number of doors likely to be open in the boundary of a smoke control system.

Chapter 3 contains a description of the NBS computer program for analysis of smoke control systems. Chapters 4 and 5 pertain to stairwell pressurization and chapter 6 to zoned smoke control, and the important topic of acceptance testing is treated at the end of the book in chapter 7.

It may be noticed that pressurized corridors, pressurized elevators and the smoke control of atriums have been omitted. This is because there is insufficient test data to ensure the validity of system concepts or of specific calculational procedures for their design. However, some comments about atriums are in order. Generally a fan powered exhaust is located at the top of the atrium. Ideally this exhausts smoke that has risen by virtue of its buoyancy to the atrium top. Obviously, water spray from sprinklers cools smoke and reduces it buoyancy. It is unknown how such a system will perform when smoke has been cooled by sprinklers. However, it can be recommended that an atrium building have pressurized stairwells and, if possible, zoned smoke control in nonatrium spaces.

Even though insufficient test data exist to discuss smoke control systems for elevators, corridors, and atriums, the fundamentals of smoke control presented in chapter 2 still apply. In addition, the methods of computer airflow analysis by network modeling presented in chapter 3 are appropriate for pressurized elevators and pressurized corridors but not for analysis of atrium smoke control systems.

1.2 SMOKE CONTROL SYSTEM PERFORMANCE

The primary objective of a smoke control system is to reduce fire deaths and injuries from smoke. However, another important objective is to reduce property loss from smoke damage.

Theoretically, a smoke control system can be designed to provide either a safe escape route or a safe refuge area (see section 6.3) or both. It is obvious that a smoke control system can meet its objectives, even if a small amount of smoke infiltrates protected areas. However, for most of this work, smoke control systems are designed on the basis that no smoke infiltration will occur.

1.3 PRELIMINARY DESIGN CONSIDERATIONS

Many factors will affect the design of a smoke control system. Before the actual mechanical design of the system can proceed, the potential constraints on the system should be determined and the design criteria established. This section introduces some considerations peculiar to smoke control system design, some of which are merely listed below, since a detailed discussion is beyond the scope of this book. However, published works on some of these subjects are cited in the bibliography in appendix H. Those considerations listed below that are within the scope of this book are followed by a notation indicating where they are discussed.

- Occupancy type and characteristics.
- Evacuation plan.
- Refuge areas.
- Distribution of occupant density.
- Human life support requirements.
- Form of detection and alarm.
- Fire service response-to-alarm characteristics.
- Fire suppression system characteristics (section 1.5).
- Type of building heating, ventilation and air-conditioning (HVAC) system.
- Energy management system (section 1.6).
- Building security provisions
- Controls (section 1.8).
- Status of doors during potential fire condition (section 2.9.4).
- Potential fire threats.
- Internal compartmentation and architectural characteristics.
- Building characteristics.
- Building leakage paths (section 2.8).
- Exterior temperatures (section 2.9.1).
- Wind velocity (section 2.9.1).

1.4 SYSTEM FLEXIBILITY

The concept of system flexibility consists of using design features that allow for easy adjustment of a smoke control system in order to achieve acceptable performance.

During the design of a new building the leakage paths throughout the building can only be estimated. Therefore, the smoke control design calculations constitute only an approximate representation of the pressures and airflows that will occur as a result of the smoke control system in the actual building. The introduction of flexibility into a smoke control system allows for variations in leakage from the originally estimated values. Because it is difficult to measure leakage paths in existing buildings, the concept of flexibility is also useful for retrofit of smoke control systems in existing buildings.

In many systems, flexibility can be achieved by the use of fans with sheaves to allow several flow rates or by dampers that can be manually adjusted to obtain desired pressure differences. The concept of flexibility is discussed in greater detail where it applies to specific types of smoke control systems.

1.5 FIRE SUPPRESSION SYSTEMS

Automatic suppression systems are an integral part of many fire protection designs, and the efficacy of such systems in controlling building fires is well documented. However, it is important to recognize that while the functions of fire suppression and smoke control systems are both desirable fire safety features, they should not be readily substituted for each other. Automatic suppression systems limit the growth rate and the maximum size of a fire but do not necessarily reduce or eliminate the movement of smoke. On the other hand, well designed smoke control systems can maintain tolerable conditions along critical egress routes but will have little effect on the fire.

In addition to the fact that the systems perform different functions, it is important that the designer consider the interaction between the smoke control and fire suppression systems. For example, in the case of a fully sprinklered building, pressure differences and airflows needed to control smoke movement may be less than in an unsprinklered building due to the likelihood that the maximum fire size will be significantly smaller than in an unsprinklered building.

Similarly, there are situations where the effects of one of the systems on the other will be adverse. It is well established that water sprays will create resistance to airflow. Therefore, while the phenomenon is not well documented for the conditions relevant to smoke control design, it is conceivable that a water spray curtain resulting from activation of a sprinkler or water deluge system might interfere with the flow of air to a smoke exhaust or an outside air pressurization system.

Conversely, a smoke control system can adversely affect performance of a gaseous agent (such as Halon, CO_2 or N_2) suppression system when the systems are located in a common space. In the event that both systems are activated concurrently, the smoke exhaust system may exhaust the suppressant gas from the room, replacing it with outside air. Since gas suppression systems commonly provide only a single application of the agent, the potential arises for renewed growth of the fire.

A general guideline would be that the gaseous agent suppression system should take precedence over the smoke control system. An extremely desirable feature in such spaces would be the ability to purge the residual smoke and the suppressant gas after the fire was completely extinguished and to replace them with fresh air. This ability to replace the atmosphere in these spaces in the post-fire period is very important from a life-safety viewpoint, since some gas suppressants are asphyxiants at normal design concentrations.

1.6 ENERGY CONSERVATION

Situations can occur where energy conservation methods can defeat a smoke control system. The smoke control system must be designed to override the local controls in a variable air volume HVAC system so that the air supply necessary to pressurize nonfire spaces is supplied. Also, if there is an energy management system or a 24-hour clock system, the designer must ensure that the smoke control system will take precedence over the local control system, so that the necessary air is supplied for pressurization in a fire situation.

As with conflicts described between suppression systems and smoke control systems, there are probably additional cases not yet identified where conflicts between energy conservation systems and smoke control systems can occur.

1.7 CONTROL

Automatic activation of a smoke control system should be considered, with the primary means of activation being an alarm from a smoke detector system located in a building space. Such an activation scheme has the advantage that the smoke control system will in all probability be activated in the early stages of a fire. Because of the problem of false alarms from smoke detectors, smoke control system activation upon alarm from two or more smoke detectors in a smoke zone (see chapter 6 for discussion of smoke zones) should be considered.

Because of the long response time and the maintenance problem of clogging with airborne particles, smoke detectors located in HVAC ducts are not recommended as the primary means of smoke control system activation. However, an alarm from a duct-located smoke detector or a sprinkler system can be used in addition to a building-space-located smoke detector for smoke control system activation. If only pressurized stairwells are used, the system can also be activated from a pull box. However, activation of zoned smoke control should not be by a pull box because a pull box, can be pulled in a zone other than the zone in which the fire exists.

Smoke control systems should be equipped with a remote control center from which the smoke control system can be manually overridden and to which there is easy access by the fire department.

The lack of feedback on the status of equipment is a problem. The indicator light on a control panel can indicate that a piece of equipment is operational when, in fact, it has failed. Positive feedback, such as a flowmeter, differential pressure transducer, or damper position indicator, can eliminate this problem.

1.8 REFERENCES

[1] Berl, W. G. and Halpin, B. M., Human Fatalities from Unwanted Fires, Johns Hopkins APL Technical Digest, Vol. 1, No. 2, p. 129-134, 1980.

[2] O'Neill, J. G., Hayes, W. D., and Zile, R. H., Full-Scale Tests with Automatic Sprinklers in a Patient Room Phase II, Nat. Bur. Stand. (U.S.), NBSIR 80-2097, July 1980.

[3] Annual Book of ASTM Standards, Part 18, ASTM E176-80, American Society for Testing and Materials, Philadelphia, PA, 1980.

[4] Standard for the Installation of Air Conditioning and Ventilating Systems, NFPA 90A-1981, National Fire Protection Association, Inc., Quincy, MA, 1981.

CHAPTER 2.
FUNDAMENTALS OF SMOKE CONTROL

A smoke control system must be designed so that it is not overpowered by the driving forces that cause smoke movement. For this reason, an understanding of the fundamental concepts of smoke movement and of smoke control is a prerequisite to intelligent smoke control design. While general concepts of smoke movement and smoke control have evolved in the last few years, there is no single source document. Therefore, this chapter briefly discusses the fundamental concepts of smoke movement and smoke control.

2.1 SMOKE MOVEMENT

The major driving forces causing smoke movement are stack effect, buoyancy, expansion, wind and the HVAC system. Generally, in a fire situation, smoke movement will be caused by a combination of these driving forces. The following is a discussion of each driving force as it would act without the presence of any other driving force.

2.1.1 Stack Effect

When it is cold outside, there often is an upward movement of air within building shafts, such as stairwells, elevator shafts, dumbwaiter shafts, mechanical shafts, or mail chutes. This phenomenon is referred to as normal stack effect. The air in the building has a buoyant force because it is warmer and less dense than the outside air. This buoyant force causes air to rise within the shafts of buildings. The significance of normal stack effect is greater for low outside temperatures and for tall shafts. However, normal stack effect can exist in a one story building.

When the outside air is warmer than the building air, a downward airflow frequently exists in shafts. This downward airflow is called reverse stack effect. The pressure difference due to either normal or reverse stack effect is expressed as:

$$\Delta P = (\rho_O - \rho_I)\, gh$$

where:

ρ_O = air density outside the shaft

ρ_I = air density inside the shaft

g = gravitational constant

h = distance from the neutral plane

The neutral plane is an elevation where the hydrostatic pressure inside the shaft equals the hydrostatic pressure outside the shaft. Using the ideal gas law ($P = \rho RT$), the above relation can be expressed as:

$$\Delta P = \frac{gP}{R}\left(\frac{1}{T_O} - \frac{1}{T_I}\right) h$$

where:

P = absolute atmospheric pressure

R = gas constant of air

T_O = absolute temperature of outside air

T_I = absolute temperature of air inside the shaft

This equation is valid for the engineering system or the SI system of units as listed in tables I.1 and I.2 (appendix I). Unless otherwise noted, this is true of other equations in this book. For standard atmospheric pressure of air the above relation becomes:

$$\Delta P = K_s \left(\frac{1}{T_O} - \frac{1}{T_I}\right) h \qquad (2.1)$$

where:

ΔP = pressure difference, in H_2O (Pa)

T_O = absolute temperature of outside air, ^oR (K)

T_I = absolute temperature of air inside shaft, ^oR (K)

h = distance above neutral plane, ft (m)

K_s = coefficient, 7.64 (3460)

Because the Fahrenheit and Celsius temperature scales are so commonly used by design engineers, these scales are used exclusively in the discussions in the text and in figures. However, the reader is cautioned to use absolute temperatures in calculations where such temperatures are stipulated. Table I.6 lists relations that can be used to convert from one temperature scale to another.

For a building 200 ft (60 m) tall, with a neutral plane at the mid-height, an outside temperature of $0^{o}F$ ($-18^{o}C$) and an inside temperature of $70^{o}F$ ($21^{o}C$), the maximum pressure difference due to stack effect would be 0.22 in H_2O (55 Pa). This means that at the top of the building, a shaft would have a pressure of 0.22 in H_2O (55 Pa) greater than the outside pressure. At the bottom of the shaft, the shaft would have a pressure of 0.22 in H_2O (55 Pa) less than the outside pressure. Figure 2.1 is a diagram of the pressure difference between a building shaft and the outside. In the diagram, a positive pressure difference indicates that the shaft pressure is higher than the outside pressure and a negative pressure difference indicates the opposite.

Stack effect is usually thought of as existing between a building and the outside. The air movement in buildings caused by both normal and reverse stack effect is illustrated in figure 2.2. In this case, the pressure difference expressed in equation (2.1) would actually refer to the pressure difference between the shaft and the outside of the building.

Figure B.1 (appendix B) can be used to determine the pressure difference due to stack effect. For normal stack effect, the term, $\Delta P/h$, is positive, and the pressure difference is positive above the neutral plane and negative below it. For reverse stack effect, the term, $\Delta P/h$, is negative, and the pressure difference is negative above the neutral plane and positive below it.

In unusually tight buildings with exterior stairwells, reverse stack effect has been observed even with low outside air temperatures [1]. In this situation, the exterior stairwell temperature was considerably lower than the building temperature. The stairwell was the cold column of air and other shafts within the building were the warm columns of air.

When considering stack effect between a building and the outside, if the leakage paths are fairly uniform with height, the neutral plane will be located near the mid-height of the building. However, when the leakage paths are not uniform, the location of the neutral plane can vary considerably, as in the case of vented shafts. McGuire and Tamura [2] provide methods for calculating the location of the neutral plane for some vented conditions.

Smoke movement from a building fire can be dominated by stack effect, as evidenced in the following descriptions of different types of smoke movement resulting from normal and reverse stack effect.

In a building with normal stack effect, the existing air currents (as shown in figure 2.2) can move smoke considerable distances from the fire origin. If the fire is below the neutral plane, smoke moves with the building air into and up the shafts. This upward smoke flow is enhanced by any buoyancy forces on the smoke existing due to its temperature. Once above the neutral plane, the smoke flows out of the shafts into the upper floors of the building. If the leakage between floors is negligible, the floors below the neutral plane, except the fire floor, will be smoke-free.

Smoke from a fire located above the neutral plane is carried by the building airflow to the outside through openings in the exterior of the building. If the leakage between floors is negligible, all floors other than the fire floor will remain smoke-free. When the leakage between floors is considerable, there is an upward smoke movement to the floor above the fire floor.

The air currents caused by reverse stack effect are also shown in figure 2.2. These forces tend to affect the movement of relatively cool smoke in the reverse of normal stack effect. In the case of hot smoke, buoyancy forces can be so great that smoke can flow upward even during reverse stack effect conditions.

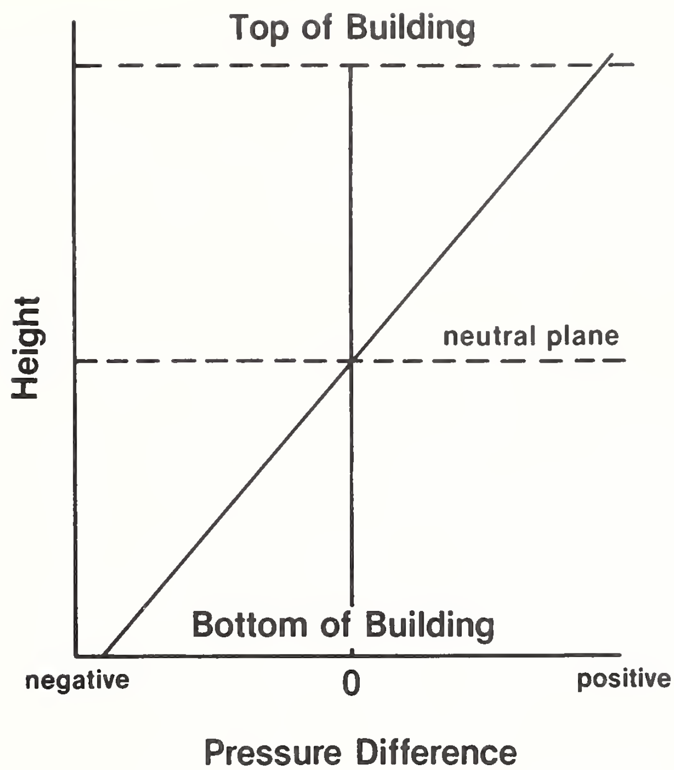
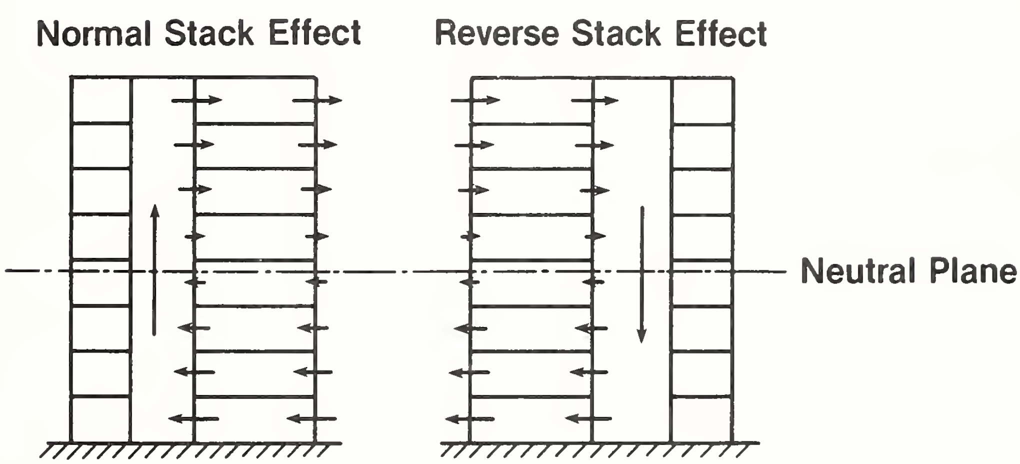


Figure 2.1. Pressure difference between a building shaft and the outside due to normal stack effect



Note: Arrows indicate direction of air movement

Figure 2.2. Air movement due to normal and reverse stack effect

2.1.2 Buoyancy

High temperature smoke from a fire has a buoyancy force due to its reduced density. The pressure difference between a fire compartment and its surroundings can be expressed by an equation of the same form as equation (2.1):

$$\Delta P = K_s \left(\frac{1}{T_O} - \frac{1}{T_F} \right) h \qquad (2.2)$$

where:

ΔP = pressure difference, in H_2O (Pa)

T_O = absolute temperature of the surroundings, ^oR (K)

T_F = absolute temperature of the fire compartment, ^oR (K)

h = distance above the neutral plane, ft (m)

K_s = coefficient, 7.64 (3460)

The pressure difference due to buoyancy can be obtained from figure B.2 for the surroundings at 68^oF (20^oC). The neutral plane is the plane of equal hydrostatic pressure between the fire compartment and its surroundings. For a fire with a fire compartment temperature of 1470^oF (800^oC), the pressure difference 5 ft (1.52 m) above the neutral plane is 0.052 in H_2O (13 Pa). Fang [3] has studied pressures caused by room fires during a series of full-scale fire tests. During these tests, the maximum pressure difference reached was 0.064 in H_2O (16 Pa) across the burn room wall at the ceiling.

Much larger pressure differences are possible for tall fire compartments where the distance, h, from the neutral plane can be larger. If the fire compartment temperature is 1290^oF (700^oC), the pressure difference 35 ft (10.7 m) above the neutral plane is 0.35 in H_2O (88 Pa). This amounts to an extremely large fire and the pressures produced by it are beyond the state-of-the-art of smoke control. However, the example is included here to illustrate the extent to which equation (2.2) can be applied.

In a building with leakage paths in the ceiling of the fire room, this buoyancy induced pressure causes smoke movement to the floor above the fire floor. In addition, this pressure causes smoke to move through any leakage paths in the walls or around the doors of the fire compartment. As smoke travels away from the fire, its temperature drops due to heat transfer and dilution. Therefore, the effect of buoyancy generally decreases with distance from the fire.

2.1.3 Expansion

In addition to buoyancy, the energy released by a fire can cause smoke movement due to expansion. In a fire compartment with only one opening to the building, building air will flow into the fire compartment and hot smoke will flow out of the fire compartment. Neglecting the added mass of the fuel which is small compared to the airflow, the ratio of volumetric flows can simply be expressed as a ratio of absolute temperatures.

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

where:

Q_{out} = volumetric flow rate of smoke out of the fire compartment, cfm (m^3/s)

Q_{in} = volumetric flow rate of air into the fire compartment, cfm (m^3/s)

T_{out} = absolute temperature of smoke leaving fire compartment, ^oR (K)

T_{in} = absolute temperature of air into fire compartment, ^oR (K)

For a smoke temperature of 1290^oF (700^oC) the ratio of volumetric flows would be 3.32. The reader is reminded to use absolute temperatures for calculation. In such a case, if the air flowing into the fire compartment is 3180 cfm (1.5 m^3/s), then the smoke flowing out of the fire compartment would be 10,600 cfm (4.98 m^3/s). In this case, the gas has expanded to more than three times its original volume.

For a fire compartment with open doors or windows, the pressure difference across these openings is negligible because of the large flow areas involved. The relationship between flow area and pressure difference is discussed in section 2.3.2. However, for a tightly sealed fire compartment the pressure differences due to expansion may be important.

2.1.4 Wind

In many instances, wind can have a pronounced effect on smoke movement within a building. The pressure, P_w, that the wind exerts on a surface can be expressed as:

$$P_w = \frac{1}{2} C_w \rho_0 V^2 \qquad (2.3)$$

where:

C_w = dimensionless pressure coefficient
ρ_0 = outside air density
V = wind velocity

For an air density of 0.075 lb/ft^3 (1.20 kg/m^3) this relation becomes

$$P_w = C_w K_w V^2 \qquad (2.3a)$$

where:

P_w = wind pressure, in H_2O (Pa)
V = wind velocity, mph (m/s)
K_w = coefficient, 4.82×10^{-4} (0.600)
Wind pressure can also be obtained from figure B.3.

The pressure coefficients, C_w, are in the range of -0.8 to 0.8, with positive values for windward walls and negative values for leeward walls. The pressure coefficient depends on building geometry and varies locally over the wall surface. In general, wind velocity increases with height in the boundary layer near the surface of the earth. Detailed information concerning wind velocity variations and pressure coefficients is available from a number of sources [4-7]. Specific information about wind data with respect to air infiltration in buildings has been generated by Shaw and Tamura [8].

A 35 mph (15.6 m/s) wind produces a pressure on a structure of 0.47 in H_2O (117 Pa) with a pressure coefficient of 0.8. The effect of wind on air movement within tightly constructed buildings with all doors and windows closed is slight. However, the effects of wind can become important for loosely constructed buildings or for buildings with open doors or windows. Usually, the resulting airflows are complicated, and, for practical purposes, computer analysis is required.

Frequently in fire situations, a window breaks in the fire compartment. If the window is on the leeward side of the building, the negative pressure caused by the wind vents the smoke from the fire compartment. This can greatly reduce smoke movement throughout the building. However, if the broken window is on the windward side, the wind forces the smoke throughout the fire floor and even to other floors. This both endangers the lives of building occupants and hampers fire fighting. Pressures induced by the wind in this type of situation can be relatively large and can easily dominate air movement throughout the building.

2.1.5 HVAC System

Before the development of the concept of smoke control, HVAC systems were shut down when fires were discovered.

The HVAC system frequently transports smoke during building fires. In the early stages of a fire, the HVAC system can serve as an aid to fire detection. When a fire starts in an unoccupied portion of a building, the HVAC system can transport the smoke to a space where people can smell the smoke and be alerted to the fire. However, as the fire progresses, the HVAC system will transport smoke to every area that it serves, thus endangering life in all those spaces. The HVAC system also supplies air to the fire space, which aids combustion. These are the reasons HVAC systems traditionally have been shut down when fires have been discovered. Although shutting down the HVAC system prevents it from supplying air to the fire, shutting down the HVAC system does not prevent smoke movement through the supply and return air ducts, air shafts, and other building openings due to stack effect, buoyancy, or wind.

2.2 SMOKE MANAGEMENT

The term "smoke management", as used in this book, includes all methods that can be used singly or in combination to modify smoke movement for the benefit of occupants and fire fighters and for the reduction of property damage. The use of barriers, smoke vents, and smoke shafts are traditional methods of smoke management.

The effectiveness of a barrier in limiting smoke movement depends on the leakage paths in the barrier and on the pressure difference across the barrier. Holes where pipes penetrate walls or floors, cracks where walls meet floors, and cracks around doors are a few possible leakage paths. The pressure difference across these barriers depends on stack effect, buoyancy, wind and the HVAC system, as discussed in section 2.1.

The effectiveness of smoke vents and smoke shafts depends on their proximity to the fire, the buoyancy of the smoke, and the presence of other driving forces. In addition, when smoke is cooled due to sprinklers the effectiveness of smoke vents and smoke shafts is greatly reduced.

Elevator shafts in buildings have been used as smoke shafts. Unfortunately, this prevents their use for fire evacuation and these shafts frequently distribute smoke to floors far from the fire. Specially designed smoke shafts, which have essentially no leakage on floors other than the fire floor, can be used to prevent the smoke shaft from distributing smoke to nonfire floors.

The effectiveness of barriers in a traditional smoke management system are limited to the extent to which the barriers are free of leakage paths. Smoke vents and smoke shafts are limited to the extent that the smoke must be sufficiently buoyant to overcome any other driving forces that might be present.

In the last few decades, fans have been employed with the intent of overcoming the limitations of the traditional systems. The systems with fans are called smoke control systems and they rely on pressure differences and airflows to limit smoke movement as discussed in the next section.

2.3 PRINCIPLES OF SMOKE CONTROL

Smoke control uses the barriers (walls, floors, doors, etc.) used in traditional smoke management in conjunction with airflows and pressure differences generated by mechanical fans.

Figure 2.3 illustrates a pressure difference across a barrier acting to control smoke movement. Within the barrier is a door. The high pressure side of the door can be either a refuge area or an escape route. The low pressure side is exposed to smoke from a fire. Airflow through the cracks around the door and through other construction cracks prevents smoke infiltration to the high pressure side.

When the door in the barrier is opened, airflow through the open door results. When the air velocity is low, smoke can flow against the airflow into the refuge area or escape route, as shown in figure 2.4. This smoke backflow can be prevented if the air velocity is sufficiently large, as shown in figure 2.5. The magnitude of the velocity necessary to prevent backflow depends on the energy release rate of the fire, as discussed in section 2.3.1.

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

- Airflow by itself can control smoke movement if the average air velocity is of sufficient magnitude.

- Air pressure differences across barriers can act to control smoke movement.

The use of air pressure differences across barriers to control smoke is frequently referred to as pressurization. Pressurization results in airflows of high velocity in the small gaps around closed doors and in construction cracks, thereby preventing smoke backflows through these openings. Therefore, in a strict physical sense, the second principle is a special case of the first principle. However, considering the two principles as separate is advantageous for smoke control design. For a barrier with one or more large openings, air velocity is the appropriate physical quantity for both design

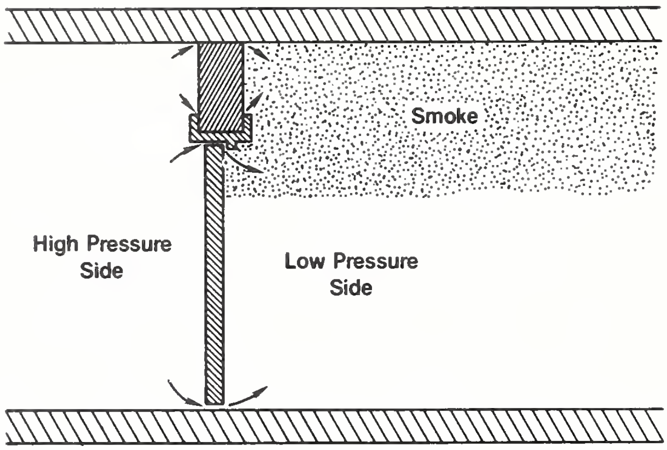


Figure 2.3. Pressure difference across a barrier of a smoke control system preventing smoke infiltration to the high pressure side of the barrier

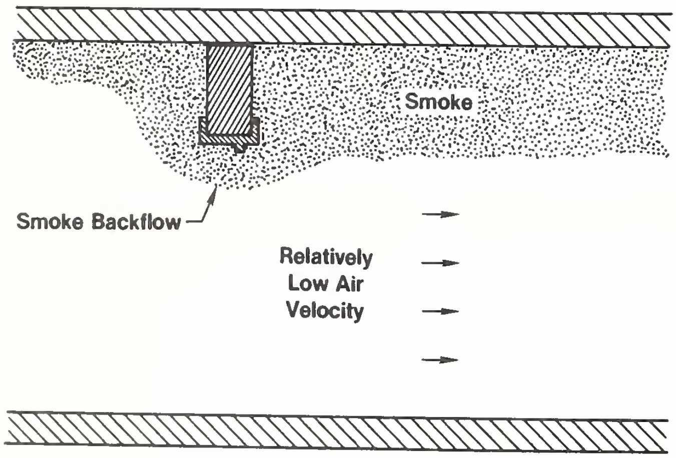


Figure 2.4. Smoke backflow against low air velocity through an open doorway

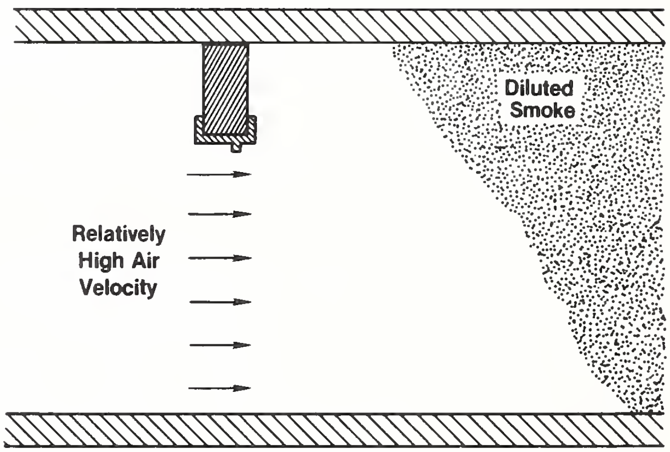


Figure 2.5. No smoke backflow with high air velocity through an open doorway

considerations and for acceptance testing. However, when there are only small cracks, such as around closed doors, designing to and measuring air velocities is impractical. In this case, the appropriate physical quantity is pressure difference. Consideration of the two principles as separate has the added advantage that it emphasizes the different considerations that need to be given for open and closed doors.

Because smoke control relies on air velocities and pressure differences produced by fans, it has the following three advantages in comparison to the traditional methods of smoke management:

- Smoke control is less dependent on tight barriers. Allowance can be made in the design for reasonable leakage through barriers.

- Stack effect, buoyancy, and wind are less likely to overcome smoke control than passive smoke management. In the absence of smoke control, these driving forces cause smoke movement to the extent that leakage paths allow. However, pressure differences and airflows of a smoke control system act to oppose these driving forces.

- Smoke control can be designed to prevent smoke flow through an open doorway in a barrier by the use of airflow. Doors in barriers are opened during evacuation and are sometimes accidentally left open or propped open throughout fires. In the absence of smoke control, smoke flow through these doors is common.

Smoke control systems should be designed so that a path exists for smoke movement to the outside; such a path can allow smoke to escape.

The smoke control designer should be cautioned that dilution of smoke in the fire space is not a means of achieving smoke control, i.e., smoke movement cannot be controlled by simply supplying and exhausting large quantities of air from the space or zone in which the fire is located. This supplying and exhausting of air is sometimes referred to as purging the smoke. Because of the large quantities of smoke produced in a fire, purging cannot assure breathable air in the fire space. In addition, purging in itself cannot control smoke movement because it does not provide the needed airflows at open doors and the pressure differences across barriers. However, for spaces separated from the fire space by smoke barriers, purging can significantly limit the level of smoke.

The following sections discuss the basic principles of smoke control.

2.3.1 Airflow

Theoretically, airflow can be used to stop smoke movement through any space. However, the two places where air velocity is most commonly used to control smoke movement are open doorways and corridors. The problem of preventing smoke movement through doorways is currently being researched. Thomas [9] has developed an empirical relation for the critical velocity to prevent smoke from flowing upstream in a corridor:

$$V_k = K \left(\frac{gE}{W \rho c T} \right)^{1/3} \tag{2.4}$$

where:

V_k = critical air velocity to prevent smoke backflow

E = energy release rate into corridor

W = corridor width

ρ = density of upstream air

c = specific heat of downstream gases

T = absolute temperature of downstream mixture of air and smoke

K = constant of the order of 1

g = gravitational constant

The downstream properties are considered to be taken at a point sufficiently far downstream of the fire for the properties to be uniform across the cross section. The critical air velocity can be evaluated at ρ = 0.081 lb/ft^3 (1.3 kg/m^3), c = 0.24 Btu/lb$^{\circ}$F (1.005 kJ/kg$^{\circ}$C) T = 81°F (27°C), and K = 1.

$$V_k = K_v \left(\frac{E}{W} \right)^{1/3} \tag{2.4a}$$

where:

V_k = critical air velocity to prevent smoke backflow, fpm (m/s)

E = energy release rate into corridor, Btu/hr (W)

W = corridor width, ft (m)

K_v = coefficient, 5.68 (0.0292)

This relation can be used when the fire is located in the corridor or when the smoke enters the corridor through an open door, air transfer grille, or other opening. The critical velocities calculated from the above relation are approximate because only an approximate value of K was used. However, critical velocities calculated from this relation are indicative of the kind of air velocities required to prevent smoke backflow from fires of different sizes.

Equation (2.4) can be evaluated from figure B.4. For an energy release rate of 0.512×10^6 Btu/hr (150 kW) into a corridor 4.00 ft (1.22 m) wide, the above relation yields a critical velocity of 286 fpm (1.45 m/s). However, for a larger energy release rate of 7.2×10^6 Btu/hr (2.1 MW), the relation yields a critical velocity of 690 fpm (3.50 m/s) for a corridor of the same width.

In general, a requirement for a high air velocity results in a smoke control system that is expensive and difficult to design. The use of airflow is most important in preventing smoke backflow through an open doorway that serves as a boundary of a smoke control system. Thomas [9] indicated that equation (2.4) can be used to obtain a rough estimate of the airflow needed to prevent smoke backflow through a door. Many designers feel that it is prohibitively expensive to design systems to maintain air velocities in doorways greater than 300 fpm (1.5 m/s). Section 2.9.2 provides a discussion of what constitutes an appropriate design air velocity in a smoke control system.

Equation (2.4) is not appropriate for sprinklered fires having small temperature differences between the upstream air and downstream gases. Shaw and Whyte [10] provide an analysis with experimental verification of a method to determine the velocity needed through an open doorway to prevent backflow of contaminated air. This analysis is specifically for small temperature differences and includes the effects of natural convection. If this method is used for a sprinklered fire where the temperature difference is only 3.6°F (2°C), then an average velocity of 50 fpm (0.25 m/s) would be the minimum velocity needed through a doorway to prevent smoke backflow. This temperature difference is small, and it is possible that larger values may be appropriate in many situations. Further research is needed in this area.

Even though airflow can be used to control smoke movement, it is not the primary method because the quantities of air required are so large. The primary means is by air pressure differences across partitions, doors, and other building components.

2.3.2 Pressurization

The airflow rate through a construction crack, door gap, or other flow path is proportional to the pressure difference across that path raised to the power n. For a flow path of fixed geometry, n is theoretically in the range of 0.5 to 1. However, for all flow paths, except extremely narrow cracks, using n = 0.5 is reasonable and the flow can be expressed as:

$$Q = CA\sqrt{\frac{2\Delta P}{\rho}} \qquad (2.5)$$

where:

- Q = volumetric airflow rate
- C = flow coefficient
- A = flow area (also called leakage area)
- ΔP = pressure difference across the flow path
- ρ = density of air entering the flow path

The flow coefficient depends on the geometry of the flow path as well as on turbulence and friction. In the present context, the flow coefficient is generally in the range of 0.6 to 0.7. For ρ = 0.075 lb/ft^3 (1.2 kg/m^3) and C = 0.65, the flow equation above can be expressed as:

$$Q = K_f\ A\ \sqrt{\Delta P} \qquad (2.5a)$$

where:

Q = volumetric flow rate, cfm (m^3/s)

A = flow area, ft^2 (m^2)

ΔP = pressure difference across flow path, in H_2O (Pa)

K_f = coefficient, 2610 (0.839)

Airflow rate can also be determined from figure B.5. The flow area is frequently the same as the cross sectional area of the flow path; an exception being the flow area of an open stairwell doorway as discussed in section 2.8. A closed door with a crack area of 0.11 ft^2 (0.01 m^2) and with a pressure difference of 0.01 in H_2O (2.5 Pa) would have an air leakage rate of approximately 29 cfm (0.013 m^3/s). If the pressure difference across the door were increased to 0.30 in H_2O (75 Pa), then the flow would be 157 cfm (0.073 m^3/s).

Frequently in field tests of smoke control systems, pressure differences across partitions or closed doors have fluctuated by as much as 0.02 in H_2O (5 Pa). These fluctuations have generally been attributed to the wind, although they could have been due to the HVAC system or some other source. Pressure fluctuations and the resulting smoke movement are a current topic of research. To control smoke movement, the pressure differences produced by a smoke control system must be sufficiently large that they are not overcome by pressure fluctuations, stack effect, smoke buoyancy, and the forces of the wind. However, the pressure difference produced by a smoke control system should not be so large that door opening problems result (see sections 2.4 and 2.9.2).

2.3.3 Purging

In general the systems discussed in this book are based on the two basic principles of smoke control. However, it is not always possible to maintain sufficiently large airflows through open doors to prevent smoke from infiltrating a space that is intended to be protected. Ideally such occurrences of open doors will only happen for short periods of time during evacuation. Smoke that has entered such a space can be purged, i.e. diluted by supplying outside air to the space.

Consider the case where a compartment is isolated from a fire by smoke barriers and self closing doors, so that no smoke enters the compartment when the doors are closed. However, when one or more of the doors is open, there is insufficient airflow to prevent smoke backflow into the compartment from the fire space. In order to facilitate analysis, it is considered that smoke is of uniform concentration throughout the compartment. When all the doors are closed, the concentration of contaminant in the compartment can be expressed as:

$$\frac{C}{C_o} = e^{-at} \tag{2.6}$$

where:

C_o = initial concentration of contaminant

C = concentration of contaminant at time, t

a = purging rate in number of air changes per minute

t = time after doors closed in minutes

e = constant approximately 2.718

The concentrations C_o and C must both be in the same units, and they can be any units appropriate for the particular contaminant being considered. McGuire, Tamura, and Wilson [11] evaluated the maximum levels of smoke obscuration from a number of tests and a number of proposed criteria for tolerable levels of smoke obscuration. Based on this evaluation, they state that the maximum levels of smoke obscuration are greater by a factor of 100 than those relating to the limit of tolerance. Thus, they indicate that an area can be considered "reasonably safe" with respect to smoke obscuration if its atmosphere will not be contaminated to an extent greater than 1% by the atmosphere prevailing in the immediate fire area. It is obvious that such dilution would also reduce the concentrations of toxic smoke components. Toxicity is a more complicated problem, and no parallel statement has been made regarding the dilution needed to obtain a safe atmosphere with respect to toxic gases.

Equation (2.6) can be solved for the purging rate.

$$a = \frac{1}{t} \log_e \left(\frac{C_o}{C}\right) \tag{2.7}$$

If when doors are open, the contaminant in a compartment is 20% of the burn room, and at six minutes after the door is closed, the contaminant concentration is 1% of the burn room, then equation (2.7) indicates the compartment must be purged at a rate of one air change every two minutes.

In reality, it is impossible to assure that the concentration of the contaminant is uniform throughout the compartment. Because of buoyancy, it is likely that higher concentrations of contaminant would tend to be near the ceiling. Therefore, an exhaust inlet located near the ceiling and a supply outlet located near the floor would probably purge the smoke even faster than the above calculations indicate. Caution should be exercised in the location of the supply and exhaust points to prevent the supply air from blowing into the exhaust inlet and thus short circuiting the purging operation.

2.4 DOOR OPENING FORCES

As mentioned in section 2.3.2, the door opening forces resulting from the pressure differences produced by a smoke control system must be considered in any design. Unreasonably high door opening forces can result in occupants having difficulty or being unable to open doors to refuge areas or escape routes. This problem is discussed in more detail in section 2.9.2.

The force required to open a door is the sum of the forces to overcome the pressure difference across the door and to overcome the door closer. This can be expressed as:

$$F = F_{dc} + \frac{K_d W A \Delta P}{2(W - d)} \tag{2.8}$$

where:

F = the total door opening force, lb (N)

F_{dc} = the force to overcome the door closer, lb (N)

W = door width, ft (m)

A = door area, ft^2 (m^2)

ΔP = pressure difference across the door, in H_2O (Pa)

d = distance from the doorknob to the knob side of the door, ft (m)

K_d = coefficient, 5.20 (1.00)

This relation assumes that the door-opening force is applied at the knob. Door-opening forces due to pressure difference can be determined from figure B.6. The force to overcome the door closer is usually greater than 3 lb (13 N) and, in some cases, can be as large as 20 lb (90 N). For a door that is 7 ft (2.13 m) high and 36 in (0.91 m) wide, subject to a pressure difference of 0.25 in H_2O (62 Pa), the total door opening force is 25 lb (110 N), if the force to overcome the door closer is 10 lb (44 N).

2.5 BUILDING AIR FLOW ANALYSIS

The performance of a smoke control system depends on the total airflow in the building in which the system is located. Therefore, analysis of a smoke control system includes a total building airflow analysis.

The methods of hand calculation presented in the following chapters are based on the principle of conservation of mass, the hydrostatic equation, and the flow equation (section 2.3.2). There are many situations where the building is complicated or where there are several driving forces, so that hand calculation is not practical. These cases can be more readily analyzed with the aid of a digital computer.

Several general purpose computer programs have been developed to simulate smoke movement in buildings. A specialized computer program to perform steady state analysis of smoke control systems has been developed by NBS and is discussed in detail in chapter 3.

2.6 EFFECTIVE FLOW AREAS

The concept of effective flow areas is quite useful for analysis of smoke control systems. The paths in the system can be in parallel with one another, in series, or a combination of parallel and series 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 the same pressure difference over the total system of flow paths. This is analogous to the flow of electric current through a system of electrical resistances.

2.6.1 Parallel Paths

Three parallel leakage areas from a pressurized space are illustrated in figure 2.6. The pressure difference, ΔP, is the same across each of the leakage areas. The total flow, Q_T, from the space is the sum of the flows through the leakage paths:

$$Q_T = Q_1 + Q_2 + Q_3 \tag{2.9}$$

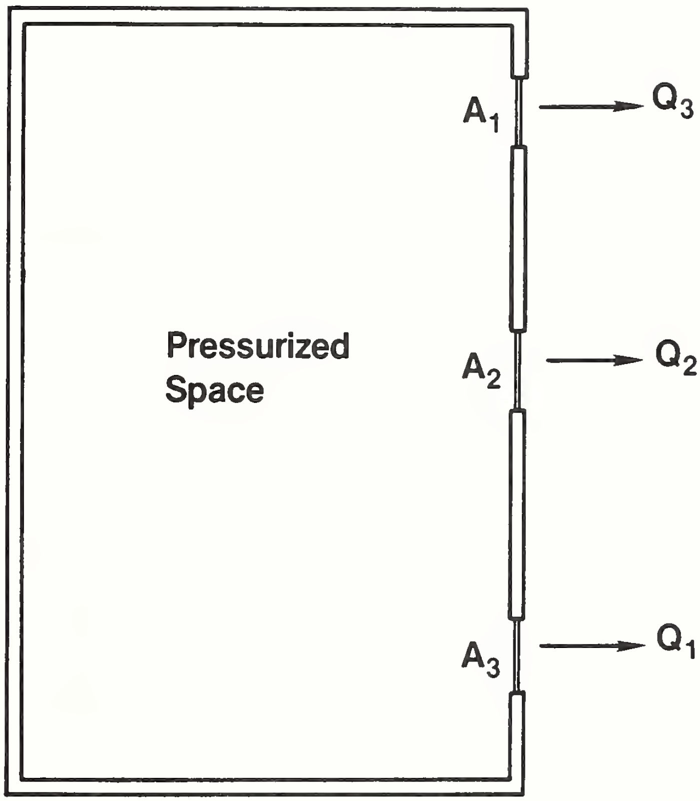


Figure 2.6. Leakage paths in parallel

The effective area, A_e, for this situation is that which results in the total flow, Q_T. Therefore, the total flow can be expressed as:

$$Q_T = CA_e\sqrt{\frac{2\Delta P}{\rho}} \quad (2.10)$$

The flow through area A_1 can be expressed as:

$$Q_1 = CA_1\sqrt{\frac{2\Delta P}{\rho}}$$

The flows for Q_2 and Q_3 can be expressed in a similar manner. Substituting the expressions for Q_1, Q_2, and Q_3 into equation (2.9) and collecting like terms yields:

$$Q_T = C(A_1 + A_2 + A_3)\sqrt{\frac{2\Delta P}{\rho}}$$

Comparing this with equation (2.10), yields:

$$A_e = A_1 + A_2 + A_3$$

In figure 2.6, if A_1 is 1.08 ft^2 (0.10 m^2) and A_2 and A_3 are 0.54 ft^2 (0.05 m^2) each, then the effective flow area, A_e, is 2.16 ft^2 (0.20 m^2).

The above logic can be extended to any number of flow paths in parallel; i.e., it can be stated that the effective area is the sum of the individual leakage paths.

$$A_e = \sum_{i=1}^{n} A_i \quad (2.11)$$

where n is the number of flow areas, A_i, in parallel.

2.6.2 Series Paths

Three leakage areas in series from a pressurized space are illustrated in figure 2.7. The flow rate, Q, is the same through each of the leakage areas. The total pressure difference, ΔP_T, from the pressurized space to the outside is the sum of pressure differences ΔP_1, ΔP_2, and ΔP_3 across each of the respective flow areas, A_1, A_2, and A_3:

$$\Delta P_T = \Delta P_1 + \Delta P_2 + \Delta P_3 \quad (2.12)$$

The effective area for flow paths in series is the flow area that results in the flow, Q, for a total pressure difference of ΔP_T. Therefore, the flow, Q, can be expressed as:

$$Q = CA_e \sqrt{\frac{2 \Delta P_T}{\rho}} \quad (2.13)$$

Solving for ΔP_T yields:

$$\Delta P_T = \frac{\rho}{2} \left(\frac{Q}{CA_e} \right)^2 \quad (2.14)$$

The pressure difference across A_1 can be expressed as:

$$\Delta P_1 = \frac{\rho}{2} \left(\frac{Q}{CA_1} \right)^2$$

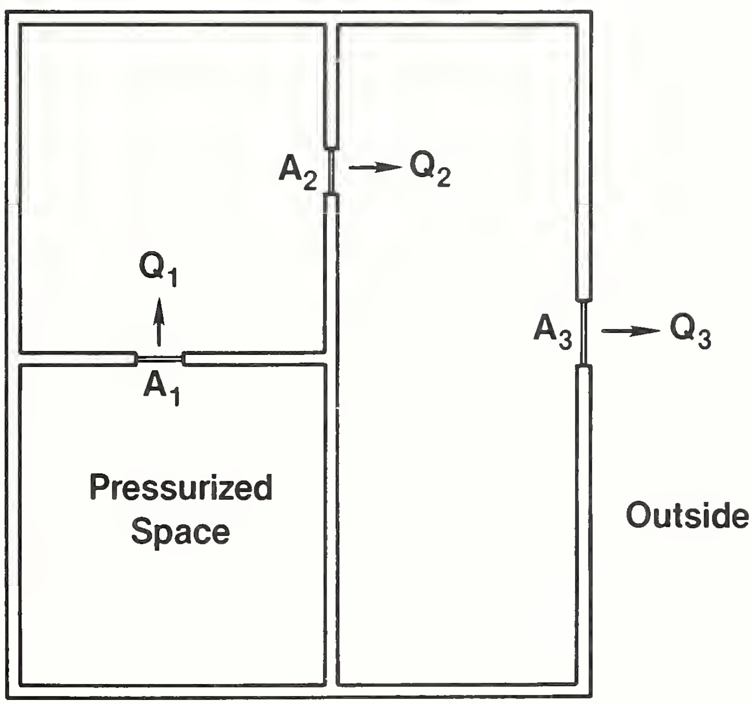


Figure 2.7. Leakage paths in series

The pressure differences, ΔP_2 and ΔP_3, can also be expressed in a similar manner. Substituting equation (2.14) and the expressions for ΔP_1, ΔP_2, and ΔP_3 into equation (2.12) and cancelling like terms yields the following:

$$\frac{1}{A_e^2} = \frac{1}{A_1^2} + \frac{1}{A_2^2} + \frac{1}{A_3^2}$$

That is:

$$A_e = \left(\frac{1}{A_1^2} + \frac{1}{A_2^2} + \frac{1}{A_3^2} \right)^{-1/2}$$

This same reasoning can be extended to any number of leakage areas in series to yield:

$$A_e = \left[\sum_{i=1}^{n} \frac{1}{A_i^2} \right]^{-1/2} \qquad (2.15)$$

where n is the number of leakage areas, A_i, in series. In smoke control analysis, there are frequently only two paths in series. For this case, the effective leakage area is:

$$A_e = \frac{A_1 A_2}{\sqrt{A_1^2 + A_2^2}} \qquad (2.16)$$

Example 2.1

Calculate the effective leakage area of two equal flow paths of 0.2 ft^2 in series.

Let $A = A_1 = A_2 = 0.22\ ft^2\ (0.02\ m^2)$

$$A_e = \frac{A^2}{\sqrt{2A^2}} = \frac{A}{\sqrt{2}} = 0.15\ ft^2\ (0.014\ m^2)$$

Example 2.2

Calculate the effective area of two flow paths in series, where $A_1 = 0.22\ ft^2\ (0.02\ m^2)$ and $A_2 = 2.2\ ft^2\ (0.2\ m^2)$.

$$A_e = \frac{A_1 A_2}{\sqrt{A_1 + A_2}} = 0.214\ ft^2\ (0.0199\ m^2)$$

This example illustrates that, when two areas are in series and one is much larger than the other, the effective area is approximately equal to the smaller area.

2.6.3 Combination of Paths in Parallel and Series

The method of developing an effective area for a system of both parallel and series paths is to systematically combine groups of parallel paths and series paths. The system illustrated in figure 2.8 is analyzed as an example.

The figure shows that A_2 and A_3 are in parallel; therefore, their effective area is:

$$A_{23_e} = A_2 + A_3$$

Areas A_4, A_5, and A_6 are also in parallel, so their effective area is:

$$A_{456_e} = A_4 + A_5 + A_6$$

These two effective areas are in series with A_1. Therefore, the effective flow area of the system is given by:

$$A_e = \left[\frac{1}{A_1^2} + \frac{1}{A_{23_e}^2} + \frac{1}{A_{456_e}^2}\right]^{-1/2}$$

Example 2.3

Calculate the effective area of the system in figure 2.8, if the leakage areas are $A_1 = A_2 = A_3 = 0.22$ ft^2 (0.02 m^2) and $A_4 = A_5 = A_6 = 0.11$ ft^2 (0.01 m^2).

$$A_{23_e} = 0.44 \text{ ft}^2 \ (0.04 \text{ m}^2)$$
$$A_{456_e} = 0.33 \text{ ft}^2 \ (0.03 \text{ m}^2)$$
$$A_e = 0.16 \text{ ft}^2 \ (0.015 \text{ m}^2)$$

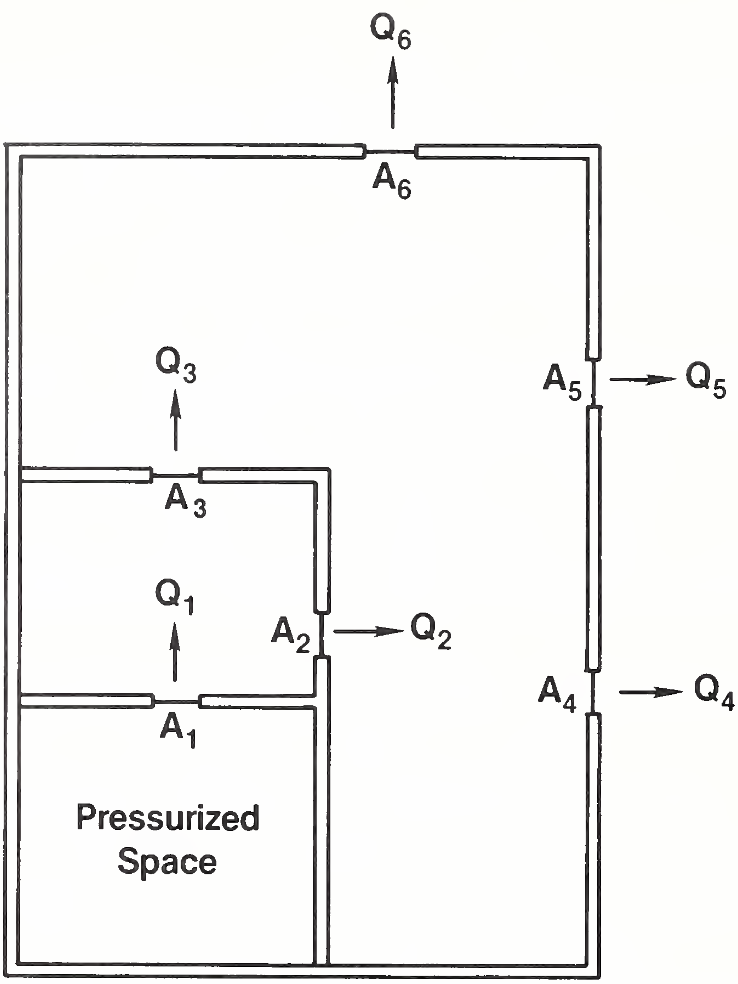


Figure 2.8. Combination of leakage paths in parallel and series

2.7 SYMMETRY

The concept of symmetry is useful in simplifying problems and thereby easing solutions. Figure 2.9 illustrates the floor plan of a multistory building that can be divided in half by a plane of symmetry. Flow areas on one side of the plane of symmetry are equal to corresponding flow areas on the other side. For a building to be so treated, every floor of the building must be such that it can be divided in the same manner by the plane of symmetry. If wind effects are not considered in the analysis or if the wind direction is parallel to the plane of symmetry, then the airflow in only one half of the building need be analyzed. It is not necessary that the building be geometrically symmetric, as shown in figure 2.9; it must be symmetric only with respect to flow.

2.8 FLOW AREAS

In the design of smoke control systems, airflow paths must be identified and evaluated. Some leakage paths are obvious, such as cracks around closed doors, open doors, elevator doors, windows, and air transfer grilles. Construction cracks in building walls are less obvious but no less important.

The flow area of most large openings, such as open windows, can be calculated easily. However, flow areas of cracks are more difficult to evaluate. The area of these leakage paths is dependent on workmanship, i.e., how well a door is fitted or how well weather stripping is installed. A door that is 36 in by 7 ft (0.9 x 2.1 m) with an average crack width of 1/8 in (3.2 mm) has a leakage area of 0.21 ft^2 (0.020 m^2). However, if, by accident, this door is installed with a 3/4 in (19 mm) undercut, the leakage area is 0.32 ft^2 (0.030 m^2). This is a significant difference. The leakage area of elevator doors has been measured in the range of 0.55 to 0.70 ft^2 (0.051 to 0.065 m^2) per door.

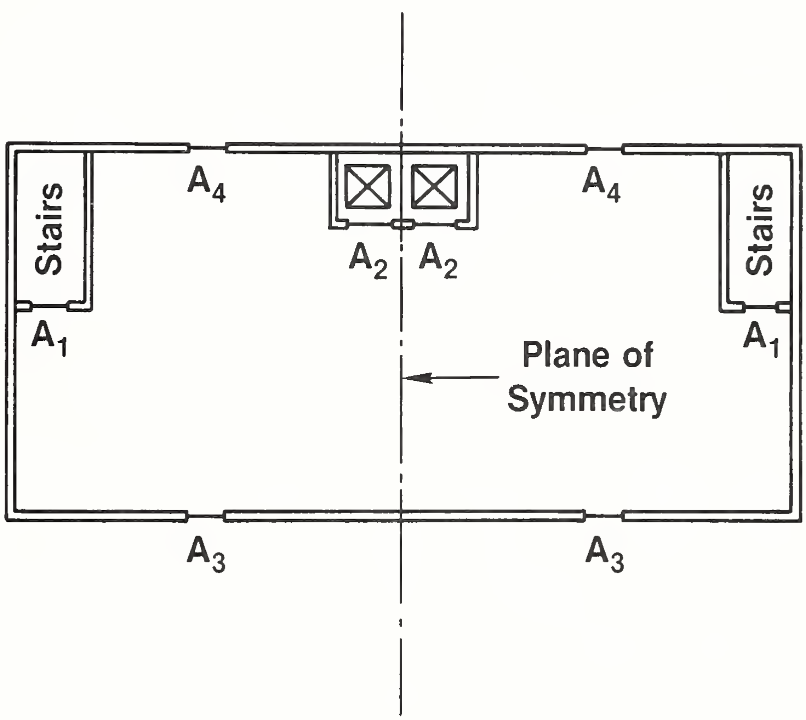


Figure 2.9. Building floor plan illustrating symmetry concept

For open stairwell doorways, Cresci [12] found that complex flow patterns exist and that the resulting flow through open doorways was considerably below the flow calculated by using the geometric area of the doorway as the flow area in equation (2.5a). Based on this research, it is recommended that the flow area of an open stairwell doorway be half that of the geometric area (door height times width) of the doorway. An alternate approach for open stairwell doorways is to use the geometric area as the flow area and use a reduced flow coefficient. Because it does not allow the direct use of equation (2.5a), this alternate approach is not used in this book.

Typical leakage areas for walls and floors of commercial buildings are tabulated in appendix C. These data are based on a relatively small number of tests performed by the National Research Council of Canada, as referenced in appendix C. It is believed that actual leakage areas are primarily dependent on workmanship rather than construction materials, and, in some cases, the flow areas in particular buildings may vary from the values listed. Considerable data concerning air leakage through building components is also provided in ASHRAE Handbook-1981 Fundamentals, chapter 22 [13].

The determination of the flow area of a vent is not always straightforward, because the vent surface is usually covered by a louver and screen. Thus the flow area is less than the vent area (vent height times width). Because the slats in louvers are frequently slanted, calculation of the flow area is further complicated. Manufacturers' data should be sought for specific information.

2.9 DESIGN PARAMETERS

Ideally, codes should contain design parameters leading to the design of safe and economical smoke control systems. Unfortunately, because smoke control is a new field, consensus has not yet been reached as to what constitutes reasonable design parameters. Clearly, the designer has an obligation to adhere to any smoke control design criteria existing in appropriate codes or standards. However, such criteria should be scrutinized to determine whether or not they will result in an effective system. If necessary, the designer should seek a waiver of the local codes, to ensure an effective smoke control system.

Five areas for which design parameters must be established are (1) leakage areas, (2) weather data, (3) pressure differences, (4) airflow, and (5) number of open doors in the smoke control system.

Leakage areas have already been discussed. An additional consideration affecting pressure differences and airflow is whether or not a window in the fire compartment is broken. This factor is included in the following discussion of these parameters.

In the absence of code requirements for specific parameters, the following discussion may be helpful to the designer.

2.9.1 Weather Data

The state-of-the-art of smoke control is such that little consideration has been given to the selection of weather data specifically for the design of smoke control systems. However, design temperatures for heating and cooling during winter and summer are recommended in the ASHRAE Handbook-1981 Fundamentals chapter 24 [14]. For example, this source provides 99 percent and 97.5 percent winter design temperatures. These values represent the temperatures that are equaled or exceeded in these portions of the heating season*.

A designer may wish to consider using these design temperatures for the design of smoke control systems. It should be remembered that in a normal winter, there would be approximately 22 hours at or below the 99 percent design value and approximately 54 hours at or below the 97.5 percent design value. Furthermore, extreme temperatures can be considerably lower than the winter design temperatures. For example, the ASHRAE 99 percent design temperature for Tallahasse, Florida is 27°F (-3°C), but the lowest temperature

*The heating season usually consists of three winter months. A more exact definition of these temperatures is available in ASHRAE Handbook-1981 Fundamentals, chapter 24 [14].

observed there by the National Climatic Center [14] was -2^{o}F (-19^{o}C) on February 13, 1899.

Temperatures are generally below the design values for short periods of time, and because of the thermal lag of building materials, these short intervals of low temperature usually do not result in problems with respect to heating systems. However, the same cannot necessarily be said of a smoke control system. There is no time lag for a smoke control system, i.e., a smoke control system is subjected to all the forces of stack effect that exist at the moment it is being operated. If the outside temperature is below the winter design temperature for which a smoke control system was designed, then problems from stack effect may result. A similar situation can result with respect to summer design temperatures and reverse stack effect.

Wind data is needed for a wind analysis of a smoke control system. At present, no formal method of such an analysis exists, and the approach most generally taken is to design the smoke control system so as to minimize any effects of wind. This approach is followed in this book.

The development of temperature and wind data for design of smoke control systems is an area for future effort.

2.9.2 Pressure Differences

It is appropriate to consider both the maximum and minimum allowable pressure differences across the boundaries of smoke control zones. The maximum allowable pressure difference should be a value that does not result in excessive door-opening forces, but, it is difficult to determine what constitutes excessive door opening forces. Clearly, a person's physical condition is a major factor in determining a reasonable door opening force for that person. Section 5-2.1.1.4.3 of the National Fire Protection Association (NFPA) Life Safety Code [15] states that the force required to open any door in a means of egress shall not exceed 50 lb (222 N). NFPA is currently evaluating proposals to reduce its maximum door opening force to 30 lb (133 N). Many smoke control designers feel that a value lower than 50 lb (222 N) should be used, especially in occupancies involving the elderly, children, or the handicapped. Also, exposure to smoke during a fire can adversely affect a person's physical capabilities, further complicating the determination. In section 2.4, a method of determination of the door opening force is provided. If, for a particular application, a maximum door opening force of 40 lb (178 N) is considered appropriate, and the force to overcome the door closer is 11 lb (49 N), then a door 36 x 84 in (0.91 x 2.13 m) would have a maximum allowable pressure difference of 0.49 in H_2O (122 Pa).

The criterion used in this book for selecting a minimum allowable pressure difference across a boundary of a smoke control system is that no smoke leakage shall occur during building evacuation*. In this case, the smoke control system must produce sufficient pressure differences so that it is not overcome by the forces of wind, stack effect, or buoyancy of hot smoke. The pressure differences due to wind and stack effect can become very large in the event of a broken window in the fire compartment. Evaluation of these pressure differences depends on evacuation time, rate of fire growth, building configuration, and the presence of a fire suppression system. In the absence of a formal method of analysis, such evaluations must, of necessity, be based on experience and engineering judgment.

A method for determining the pressure difference across a smoke barrier resulting from the buoyancy of hot gases is provided in section 2.1.2. For a particular application, it may be considered necessary to design a smoke control system to withstand an intense fire next to a door in a boundary of a smoke control zone. It was stated in section 2.1.2 that, in a series of full-scale fire tests, the maximum pressure difference reached was 0.064 in H_2O (16 Pa) across the burn room wall at the ceiling. In order to prevent smoke infiltration, the smoke control system should be designed to maintain a slightly higher pressure in nonfire conditions. A minimum pressure difference in the range of 0.08 to 0.10 in H_2O (20 to 25 Pa) is suggested.

If a boundary is exposed to hot smoke from a remote fire, a lower pressure difference due to buoyancy will result. For a smoke temperature of

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*Other criteria might involve maintaining a number of smoke free egress routes or preventing smoke infiltration to a refuge area. Discussion of all possible alternatives is beyond the scope of this book.

750°F (400°C), the pressure difference caused by the smoke 5.0 ft (1.53 m) above the neutral plane would be 0.04 in H_2O (10 Pa). In this situation, it is suggested that the smoke control system be designed to maintain a minimum pressure in the range of 0.06 to 0.08 in H_2O (15 to 20 Pa).

Water spray from fire sprinklers cools smoke from a building fire and reduces the pressure differences due to buoyancy. In such a case it is probably wise to allow for pressure fluctuations (section 2.3.2). Accordingly a minimum pressure difference in the range of 0.02 to 0.04 in H_2O (5 to 10 Pa) is suggested.

Windows in the fire compartment can break due to exposure to high temperature gases. In such cases, the pressure due to the wind on the building exterior can be determined from equation (2.3). If this window is the only opening to the outside on the fire floor and the window faces into the wind, the boundary of the smoke control system could be subjected to higher pressures. One possible solution is to vent the fire floor on all sides to relieve such pressures. For a building that is much longer than it is wide, it may be necessary to vent only on the two longer sides.

In addition to wind effects, stack effect can be increased in the event of a broken fire compartment window. With a fire on a lower floor during cold weather, stack effect will increase pressures of the fire floor above surrounding spaces. Even though little research has been done on the subject, the chances of a window breaking in the fire compartment are reduced by the operation of fire sprinklers.

2.9.3 Airflow

When the doors in the boundaries of smoke control systems are open, smoke can flow into refuge areas or escape routes unless there is sufficient airflow through the open door to prevent smoke backflow, as discussed in section 2.3. One criterion for selecting a design velocity through an open door is that no smoke backflow shall occur during building evacuation.* Selection of this velocity depends on evacuation time, rate of fire growth, building configuration, and the presence of a fire suppression system. In the absence of a formal method of analysis, such an evaluation must be based on experience and engineering judgment.

At present, there is still much to be learned about the critical velocity needed to stop smoke backflow through an open door. In the absence of a specific relationship for doorways, the method of analysis presented for corridors in section 2.3.1 can be used to yield approximate results. The width of the doorway may be used in place of the width of the corridor. The technique used in 2.3.1 is based on the assumption that smoke properties are uniform across the cross section. As an example, for a particular application, it may be considered necessary to design for an intensive fire, such as one with an energy release rate of 8×10^6 Btu/hr (2.4 MW). A critical velocity of approximately 800 fpm (4 m/s) would be required to stop smoke.

In another application, it may be estimated that the building would be subjected to a much less intense fire with an energy release rate of 427,000 Btu/hr (125 kW). To protect against smoke backflow during evacuation, the critical velocity would be 300 fpm (1.5 m/s).

In a sprinklered building, it might be considered that the smoke away from the immediate fire area would be cooled to near ambient temperature by the water spray from the sprinklers. In such a case a design velocity in the range of 50 to 250 fpm (0.25 to 1.25 m/s) may be used. Research is needed to fully evaluate the effect of sprinklers on smoke control design parameters.

2.9.4 Number of Open Doors

The need for air velocity through open doors in the perimeter of a smoke control system was discussed in section 2.9.2. Another design consideration is the number of doors that could be opened simultaneously when the smoke

*Other criteria might include the allowance of limited smoke leakage into areas to be protected. Under such criteria, the toxicity of the smoke is a factor that must be considered.

control system is operational. A design that allows for all doors to be opened simultaneously may ensure that the system will always work, but it will probably add to the cost of the system.

Deciding how many doors will be opened simultaneously depends largely on the building occupancy. For example, in a densely populated building, it is very likely that all the doors will be opened simultaneously during evacuation. However, if a staged evacuation plan or refuge area concept is incorporated in the building fire emergency plan or if the building is sparsely occupied, only a few of the doors may be opened simultaneously during a fire.

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CHAPTER 3.
COMPUTER ANALYSIS

The computer program described in this chapter provides a means to calculate the airflows and pressure differences throughout a building in which a smoke control system is operating. This computer program has been previously published* [1]. The following description is presented here as a convenience to the reader, the appendices contain a program listing and examples.

A number of computer programs applicable to smoke control have been developed. Some calculate steady state airflow and pressures throughout a building [2,3]. Other programs go beyond this to calculate the smoke concentrations that would be produced throughout a building in the event of a fire [4-8].

In general, most of these programs are capable of analyzing smoke control systems. However, the program described in this chapter has been specifically written for analysis of smoke control systems and is an extension of a program specifically written for analysis of pressurized stairwells and elevators [9]. While the basic theory of this program is the same as that of the stairwell and elevator program, it has been extended to include analysis of (1) stairwells with vestibules, (2) elevators with elevator lobbies, (3) zoned smoke control systems, and (4) pressurized corridors. The data input has been designed to minimize the quantity of required data and still maintain a high level of generality in the model. The output consists of the pressure differences across all of the building shafts, as well as the flows and pressures throughout the building.

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*A computer tape of this program is available from the National Technical Information Service (NTIS), Springfield, VA 22161. Request "Tape of the computer program for analysis of smoke control systems, NTIS Accession No. PB82-254822."

This program was originally intended as a research tool to investigate the feasibility of specific smoke control systems and to determine the interaction between these systems and the rest of the building. The predecessor [9] of this program has already been used to analyze pressurized stairwells without vestibules and to evaluate factors affecting the performance of these systems [10]. This program has been used to analyze example problems in subsequent chapters.

In time, other computer programs will be developed to meet the specific needs of designers of smoke control systems. Such programs will have assumptions and capabilities specifically suited for design analysis and undoubtedly will have improved numerical techniques. Until such a time, it is believed that the computer program discussed in this chapter may be useful for smoke control design.

3.1 PROGRAM CONCEPT

In this computer program, a building is represented by a network of spaces or nodes, each at a specific pressure and temperature. The stairwells and other shafts are modeled by a vertical series of spaces, one for each floor. Air flows through leakage paths from regions of high pressure to regions of low pressure. These leakage paths are doors and windows that may be opened or closed. Leakage can also occur through partitions, floors, and exterior walls and roofs. The airflow through a leakage path is a function of the pressure difference across the leakage path.

In this model, air from outside the building can be introduced by a pressurization system into any level of a shaft or even into other building spaces. This allows simulation of stairwell pressurization, elevator shaft pressurization, stairwell vestibule pressurization, and pressurization of any other building space. In addition, any building space can be exhausted. This allows analysis of zoned smoke control systems where the fire zone is exhausted and other zones are pressurized. The pressures throughout the building and flow rates through all the flow paths are obtained by solving the airflow network, including the driving forces such as wind, the pressurization system, or an inside-to-outside temperature difference.

3.2 ASSUMPTIONS AND LIMITATIONS

1. Each space is considered to be at one specific pressure and one specific temperature.

2. The flows and leakage paths are assumed to occur at mid-height of each level.

3. The net air supplied by the air handling system or by the pressurization system is assumed to be constant and independent of building pressure.

4. The outside air temperature is assumed to be constant.

5. The barometric pressure at ground level is assumed to be standard atmospheric pressure (101325 Pa)*.

3.3 EQUATIONS

A. Flow equation

$$\dot{m} = CA\sqrt{2\rho\Delta P} \qquad (3.1)$$

where:

$\dot{m}$ = mass flow rate

C = flow coefficient

A = flow area

ρ = density of air in flow path

ΔP = pressure difference across flow path

The flow coefficient is dimensionless, and for smoke control analysis it is generally taken to be in the range of 0.6 to 0.7. Because of the large number of flow calculations performed during the computer analysis, the flow

*The results of the program are not very sensitive to changes in atmospheric pressure. For altitudes considerably different from sealevel, a more accurate value of barometric pressure can be substituted by changing an assign statement in the subroutine INPUT and one in the subroutine CORR.

equation is rewritten in the program as $\dot{m} = C' \sqrt{\Delta P}$. Using the ideal gas law, the adjusted flow coefficient, C', can be expressed as

$$C' = CA \sqrt{\frac{2 \; P_{atm}}{RT}} \tag{3.2}$$

where:

P_{atm} = absolute barometric pressure at ground level

R = gas constant of air

T = absolute temperature of air in flow path

B. Mass balance equations

For building compartment* i

$$\sum_{j=1}^{N_c} \dot{m}_{(i,j)} + \sum_{k=1}^{N_o} \dot{m}_{o(i,k)} + \dot{m}_{f(i)} = 0 \tag{3.3}$$

and for shafts

$$\sum_{i=N_1}^{N_2} \left[\sum_{j=1}^{N_c} \dot{m}_{(i,j)} + \sum_{k=1}^{N_o} \dot{m}_{o(i,k)} + \dot{m}_{f(i)} \right] = 0 \tag{3.4}$$

where:

$\dot{m}_{(i,j)}$ = mass flow rate from space j to space i. For building compartments this flow can be either horizontal or vertical; however, for shafts this flow can only be horizontal.

$\dot{m}_{o(i,k)}$ = mass flow rate from direction k outside of the building to space i.

$\dot{m}_{f(i)}$ = net mass flow rate of air due to the air handling system or due to a pressurization system.

*In this book the term "building compartment" refers to a space in a building other than in a shaft.

N_c = number of building spaces connected to space i.

N_o = number of connections to the outside from space i.

N_1 is the space number at the bottom level of the shaft and the spaces in the shaft are numbered consecutively up to N_2, which is the space number at the top of the shaft.

C. Shaft pressures

The following relationship is used to calculate the gauge pressure, $P_{(i)}$, at floor i of a shaft in terms of $P_{(i-1)}$ at floor i - 1.

$$P_{(i)} = P_{(i-1)} - P_z - P_f \tag{3.5}$$

where:

P_z = hydrostatic pressure difference

P_f = pressure loss due to friction

The following equation is used to calculate the hydrostatic pressure difference.

$$P_z = \frac{g\bar{P}}{R\bar{T}} \left(h_{(i)} - h_{(i-1)} \right) \tag{3.6}$$

where:

$h_{(i)}$ = height of point i

$h_{(i-1)}$ = height of point i-1

g = gravitational constant

R = gas constant

$$\bar{T} = \frac{T_{(i)} + T_{(i-1)}}{2}$$

$$\bar{P} = \frac{P_{(i)} + P_{(i-1)}}{2} + P_b$$

P_b is a constant used to convert an average gauge pressure to the average absolute pressure, $\bar{P}$.

The following equation is used to calculate the pressure loss due to friction.

$$P_f = S \left(\frac{\dot{m}_u}{C_s} \right)^2 \tag{3.7}$$

where:

$\dot{m}_u$ = upward mass flow from i-1 to i in shaft

C_s = shaft flow coefficient

S = sign of $\dot{m}_u$

D. Outside pressures

Outside pressures can be entered by the user or can be calculated by the following method.

$$P_{o(i)} = P_{h(i)} + C_w P_{w(i)} \tag{3.8}$$

where:

$P_{o(i)}$ = outside gauge pressure at height h(i) above absolute pressure at ground level

$P_{h(i)}$ = hydrostatic pressure difference between h(i) and ground level

$P_{w(i)}$ = dynamic pressure due to the wind at height h(i)

C_w = pressure coefficient

Because the outside temperature is constant

$$P_{h(i)} = P_{atm} \exp \left(- \frac{gh(i)}{RT_{out}} \right) - P_b \tag{3.9}$$

where:

P_{atm} = absolute barometric pressure at ground level

T_{out} = outside absolute temperature

When the outside pressures are calculated by the computer the wind velocities are assumed to be described by the power law.

$$V = V_o \left(\frac{h}{h_o} \right)^n$$

where:

V_o = wind velocity at height h_o

n = wind exponent

This relationship has been extensively used to describe the boundary layer velocity profile of the wind near the surface of the earth. It assumes that there are no large obstructions near the building that could produce local wind effects. A value of 0.16 for the wind exponent should be used for flat terrain. The wind exponent increases with rougher terrain, and for very rough terrain, such as urban areas, a value of 0.40 should be used.

The equation for the dynamic pressure at height h(i) is obtained by substituting the velocity from the power law into the usual relation for wind dynamic pressure, equation (2.3).

$$P_w = \frac{\rho V_o^2}{2} \left(\frac{h_{(i)}}{h_o} \right)^{2n} \tag{3.10}$$

where ρ is the outside air density.

The pressure coefficients are in the range of -0.8 to 0.8, where positive values are for windward walls and negative values are for leeward walls. The pressure coefficient depends upon building geometry and varies locally over the wall surface. Numerical values for C_w and n, as well as practical engineering information, are available from a number of sources [11-14].

3.4 PROGRAM DESCRIPTION

This program is written in ANSI-1977 FORTRAN and a program listing is provided in appendix G. The following is a detailed description of the main program and the major subroutines.

3.4.1 Main Program

The main program calls the subprograms that read the data, calculate the adjusted flow coefficients, calculate the initial values of pressures and iteratively solve for the pressures according to the logic illustrated in the flow chart of figure 3.1.

3.4.2 INPUT Subroutine

This routine reads the data that are necessary for a flow analysis of the smoke control system, including an analysis of the rest of the building. These data consist of the following:

1. Outside temperature.

2. Temperature throughout the building.

3. Outside pressures. These can be entered or calculated as described earlier.

4. Description of the flow network including flow coefficients and flow areas for all connections and the net airflows to each space due to the air conditioning system or due to a pressurization system.

The data above can be entered in either SI units or in engineering units. Appendix D contains a detailed description of the data input method.

In addition to reading data, this subroutine provides temperature and pressure data, as well as, a complete description of the flow network. The routine also calculates initial estimates of the hydrostatic pressure

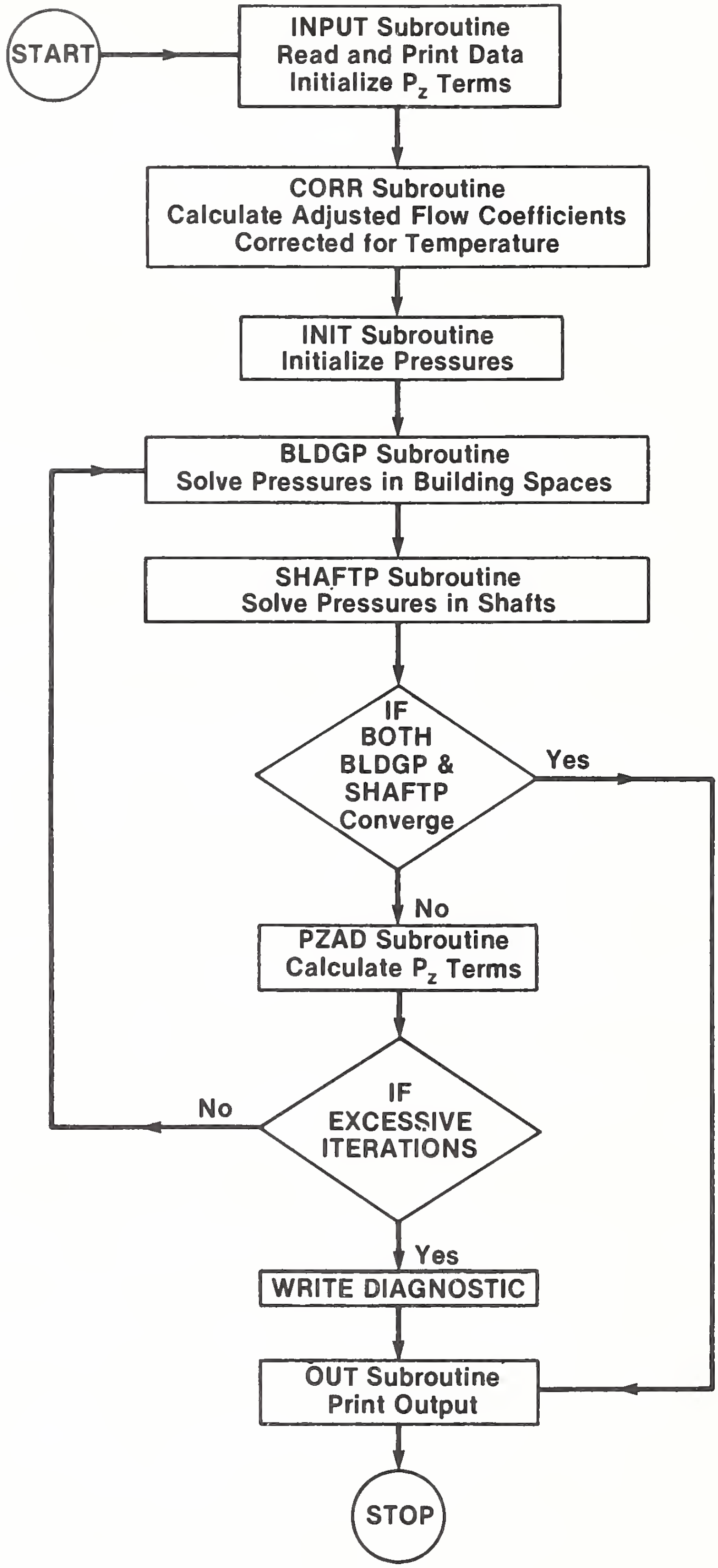

Figure 3.1. Flow chart for main program logic

differences. When data are entered in engineering units, the subroutine UNITS is called which converts all units to the SI system.

3.4.3 CORR Subroutine

This routine calculates adjusted flow coefficients for all flow paths using equation (3.2). Two sets of these coefficients are calculated for each flow path to allow for flow in either direction.

3.4.4 INIT Subroutine

This routine calculates initial estimates of the building pressures by a technique used by Sander [2]. In this technique, mass flows are considered linear functions of pressure difference; therefore, the flow equations can be expressed and solved in matrix form. In this estimate, shaft pressures are considered hydrostatic, and the resulting pressures form a starting point for the iterative solution that follows.

3.4.5 BLDGP Subroutine

The iterative solution for the building pressures and flows consists of the three subroutines, BLDGP, SHAFTP, and PZAD. The subroutine BLDGP operates on the building compartments sequentially. The sum of all the mass flows into compartment i is calculated. If the absolute value of this sum is less than a convergence limit, then equation (3.3) is considered satisfied and the computer proceeds to the next compartment or returns to the main program. However, if the absolute value of the sum is greater than the convergence limit, then an improved estimate of the pressure at compartment i is obtained by the <u>regula falsi</u> method [15]. When none of the pressures need to be modified, this routine passes a convergence signal to the main program.

3.4.6 SHAFTP Subroutine

The structure of this routine is very similar to that of BLDGP, except that it operates on shafts sequentially. The sum of all the mass flows into shaft i is calculated. If the absolute value of this sum is less than the convergence limit, then equation (3.4) is also considered satisfied and the computer proceeds to the next shaft or returns to the main program. However, if the absolute value of the sum is greater than the convergence limit, then improved estimates of the shaft pressure are calculated. This is done by changing the pressures at the bottom of the shaft and then recalculating the shaft pressure by equation (3.5). Again, the regula falsi method is used, and if none of the shaft pressures requires modification, a convergence signal is passed to the main program. It can be seen from figure 3.1 that if convergence is achieved in both BLDGP and SHAFTP, then the subroutine OUT will print the solution. Otherwise, the hydrostatic pressure differences are adjusted in the subroutine PZAD.

3.4.7 PZAD Subroutine

This routine calculates hydrostatic pressure differences by equation (3.6) using the most recent pressure estimates.

3.4.8 OUT Subroutine

This routine prints mass flows and pressures for the flow network, as well as the pressure differences across each shaft. If the data input was in engineering units, then appropriate variables are converted to the engineering system before output.

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CHAPTER 4.
FUNDAMENTALS OF STAIRWELL PRESSURIZATION

Many pressurized stairwells are designed and built with the goal of providing a smoke-free escape route in the event of a building fire. A secondary objective is to provide a smoke-free staging area for fire fighters. On the fire floor, a pressurized stairwell must maintain a pressure difference across a closed stairwell door so that smoke infiltration is prevented. This chapter discusses the fundamental concepts of stairwell pressurization and provides a method of calculation for a simple system.

4.1 PRESSURIZATION SYSTEMS

It is impossible to provide detailed design methods for the almost infinite number of possible stairwell pressurization systems. The intent of this book is to discuss, in general, some systemic considerations and alternatives and to provide detailed analyses of a few systems. For the analysis of other systems, designers can, in many cases, use the same principles employed in this book to perform their own analyses.

4.1.1 Single and Multiple Injection

A single injection system is one that has pressurization air supplied to the stairwell at one location. The most common injection point is at the top as illustrated in figure 4.1. With this system, there is the potential for smoke feedback into the pressurized stairwell; which is smoke entering the stairwell through the pressurization fan intake. Therefore, the capability of automatic shutdown in such an event should be considered.

For tall stairwells, single injection systems can fail when a few doors are open near the air supply injection point. All of the pressurization air can be lost through these open doors, and the system will then fail to maintain positive pressures across doors further from the injection point.

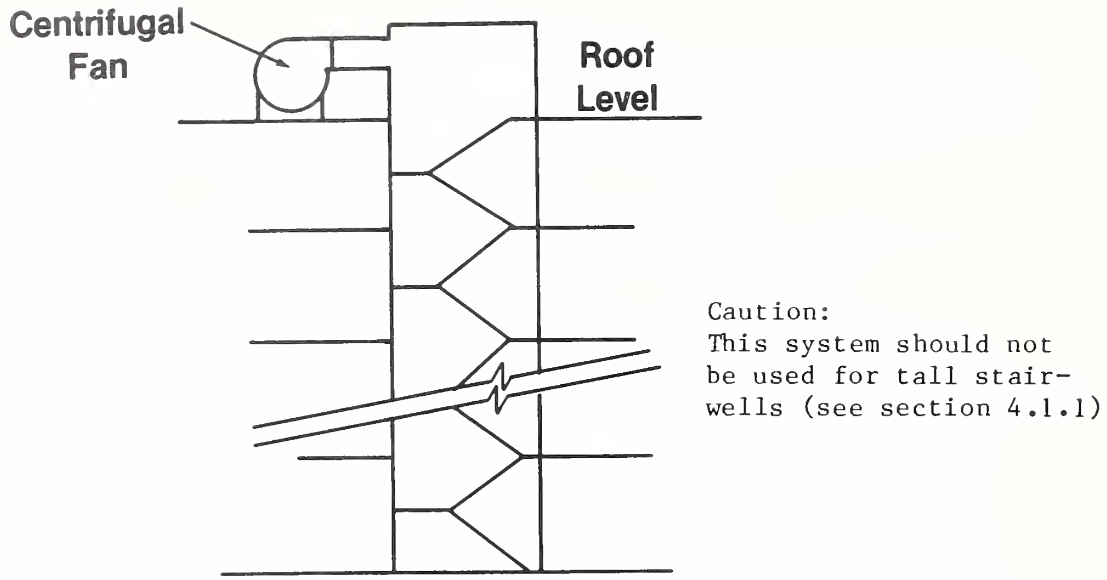


Figure 4.1. Stairwell pressurization by top injection

Such a failure mode is especially likely with bottom injection systems when a ground level stairwell door is open. To prevent this, some smoke control designers limit the height of top injection stairwells to eight stories; however, other designers feel this limit can be extended to twelve stories. Careful design is recommended for top injection stairwells in excess of eight stories and for all bottom injection stairwells.

Figures 4.2 and 4.3 are two examples of many possible multiple injection systems that can be used to overcome the limitations of single injection systems. The pressurization fans can be located at ground level, roof level or at any location in between. Obviously, the supply air intake should be separated from exhausts, outlets from smoke shafts and roof smoke and heat vents, or open vents from elevator shafts or other building openings that might expel smoke from the building in a fire situation. Ideally, this separation should be as great as is practically possible. Because hot smoke rises, consideration should be given to locating supply air intakes below such critical openings. However, outdoor smoke movement that might result in smoke feedback depends on location of fire, location of points of smoke leakage from the building, wind speed and direction, and on the temperature difference between the smoke and the outside air. At present, too little information is available about such outdoor smoke movement to warrant general recommendations favoring ground level fans over roof mounted fans.

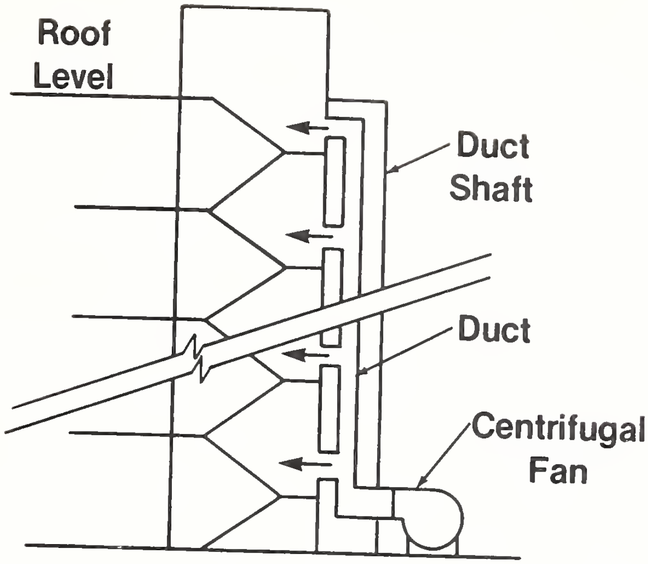


Figure 4.2. Stairwell pressurization by multiple injection with the fan located at ground level

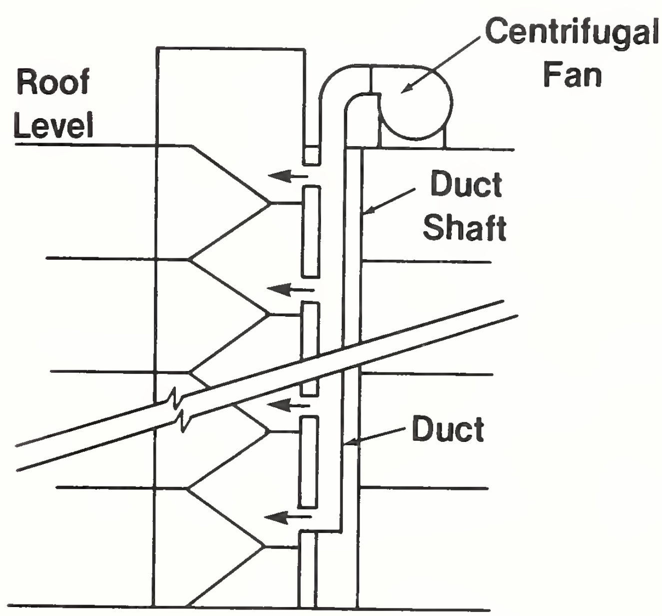


Figure 4.3. Stairwell pressurization by multiple injection with roof mounted fan

In figures 4.2 and 4.3, the supply duct is shown in a separate shaft. However, systems have been built that have eliminated the expense of a separate duct shaft by locating the supply duct in the stairwell itself. If the duct is located inside the stairwell, care must be taken that the duct does not become an obstruction to orderly building evacuation.

Many multiple injection systems have been built with supply air injection points on each floor. These represent the ultimate in preventing loss of pressurization air through a few open doors; however, that many injection points may not be necessary. There is some difference of opinion as to how far apart injection points can be safely located. Some designers feel that injection points should not be more than three floors apart, while others feel that a distance of eight stories is acceptable. For designs with injection points more than three stories apart, the designer probably should determine by computer analysis that loss of pressurization air through a few open doors does not lead to loss of stairwell pressurization.

4.1.2 Compartmentation

An alternative to multiple injection is compartmentation of the stairwell into a number of sections, as illustrated in figure 4.4. Each compartment has at least one supply air injection point. Compartmentation can also allow pressurization of stairwells that would be too tall to be otherwise satisfactorily pressurized. Unfortunately, when the doors between compartments are open, the effect of compartmentation is lost. For this reason, compartmentation is inappropriate for densely populated buildings, where total building evacuation by the stairwell is planned in the event of a fire. Compartmentation can be an effective means of providing stairwell pressurization for very tall buildings, when a staged evacuation plan is used and when the system is designed to successfully operate when the maximum number of doors between compartments are open. This maximum number of doors open between compartments would need to be determined by an evacuation analysis. Compartmentation does have a disadvantage from an architectural standpoint in that it probably cannot be achieved without increased stairwell landing space at some or all floors.

Note:
Each four floor compartment has at least one supply air injection point

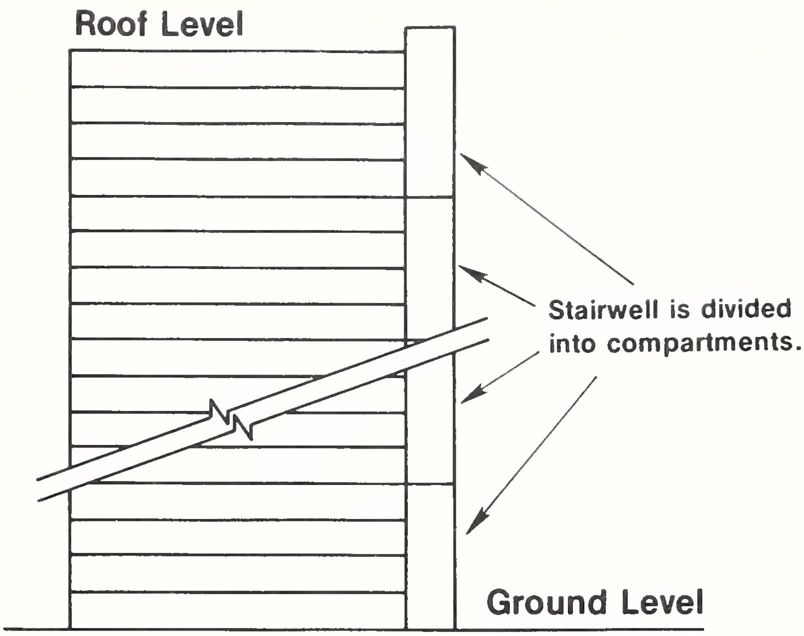


Figure 4.4. Compartmentation of a pressurized stairwell

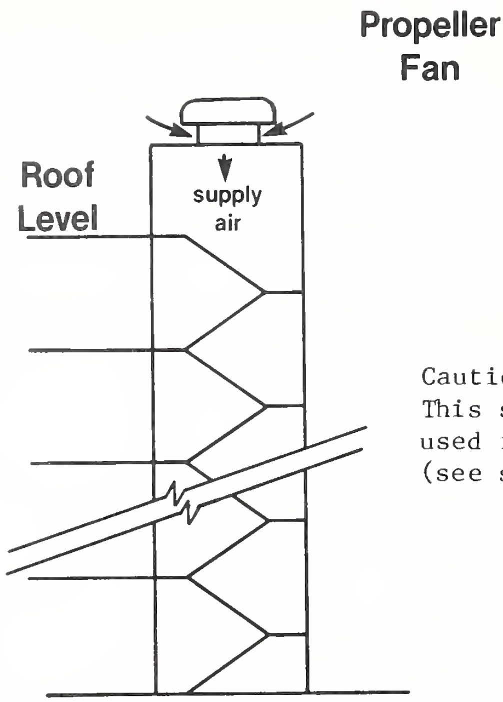
4.1.3 Vestibules

A number of pressurized stairwells have been built with vestibules, which can be either pressurized or not pressurized. Vestibules provide an additional barrier around a stairwell and, to some extent, a vestibule can reduce the possibility of an open-door connection existing between the stairwell and the building. An evacuation analysis can be performed to determine the extent to which both vestibule doors are likely to be opened simultaneously.

Analysis of a pressurized stairwell with an unpressurized vestibule can be performed using the same methods employed for analyzing a system without a vestibule, except that the effective leakage areas from the stairwell to the building would be used. These effective areas can be determined by methods presented in section 2.6.

4.1.4 Supply Air Source

In the pressurization systems illustrated in figures 4.1, 4.2, and 4.3, centrifugal fans supply pressurization air to the stairwell. Figure 4.5 shows a system with a roof mounted propeller fan. Such a fan should have a wind



Caution:
This system should not be used for tall stairwells (see section 4.1.1).

Figure 4.5. Stairwell pressurization by roof mounted propeller fan

shield to reduce the effect of wind on the system. The use of wall-mounted propeller fans without wind shields is not generally recommended, because of the extreme effect wind can have on the performance of such propeller fans.

All of the fans discussed above are specifically dedicated to stairwell pressurization. However, a fan normally used for some other purpose can be used to pressurize a stairwell in a fire situation. HVAC system fans have been so used with modulating dampers controlled by differential pressure sensors. However, some smoke control designers feel that HVAC fans should not be used for stairwell pressurization, because the controls for the pressurization system may be damaged during HVAC system maintenance or modification.

4.2 PRESSURE PROFILES

At first it might appear that the pressure differences across a stairwell would be essentially the same over the height of the stairwell. Unfortunately, this is often not the case.

To facilitate analysis, the following discussion is limited to buildings that have the same leakage areas on each floor. Figure 4.6 shows pressure profiles for pressurized stairwells located in three buildings with different leakage characteristics, all of which have the same stairwell and outside temperatures. These profiles represent winter conditions; that is, an outside temperature less than the inside temperature.

In a building without vertical leakage between floors or through shafts other than the stairwell, the pressure profile of a pressurized stairwell is a straight line. The slope of that straight line depends on the temperature difference between the stairwell and the outside, and on the building leakage areas. This relation is discussed in section 4.3.1.

Figure 4.6 shows the pressure profiles of pressurized stairwells in a building with leakage between the floors and in a building without leakage between floors which are similar, except at the top and the bottom of the buildings. The extent of the deviation depends on the magnitude of the leakage area between floors.

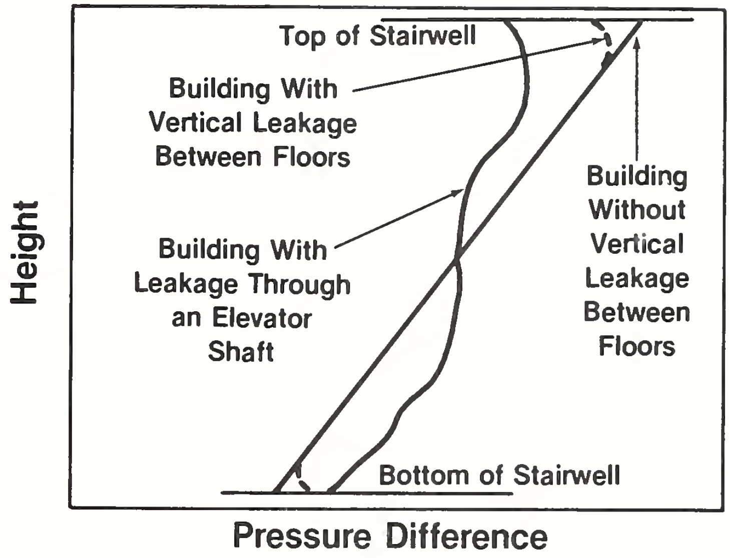


Figure 4.6. Pressure profile for pressurized stairwells in three buildings with different leakage characteristics

In a building with leakage through an elevator shaft, the pressure profile is considerably different. The curve shown in figure 4.6 is only one of many possible curve shapes for this type of building. The pressure profiles depend on the leakage areas of the stairwell, the elevator shaft, and the exterior walls, as well as the temperatures of the building, the stairwell, and the outside air. Analysis of such a building is complicated and is generally feasible only with the aid of a digital computer.

It is obvious that the pressure difference across a stairwell at one height can be much larger than at another height. Therefore, in addition to being concerned with the average pressure difference across a stairwell, a designer should also be concerned with both the minimum and maximum pressure differences. These are analyzed in section 4.3.

Another problem with pressurized stairwells is that when stairwell doors are open, the pressure difference across closed doors can drop to as low as 0.01 in H_2O (2.5 Pa). Problems of open doors in pressurized stairwells are discussed in chapter 5.

4.3 STAIRWELL ANALYSIS

In this section, a method of analysis is presented for a pressurized stairwell in a building without vertical leakage. The performance of pressurized stairwells in buildings without elevators may be closely approximated by this method of analysis which is also useful for buildings with vertical leakage in that it yields conservative results. This analysis considers only one pressurized stairwell in a building, however, it can be extended to any number of stairwells by use of the concept of symmetry (section 2.7). The analysis does not include consideration of open stairwell doors.

This analysis is for buildings where the leakage areas are the same for each floor of the building and where the only significant driving forces are the stairwell pressurization system and the temperature difference between the indoors and outdoors.

4.3.1 Pressures

In this analysis, the absolute pressure in the stairwell is considered hydrostatic. This means that the pressure loss in the stairwell due to friction of the moving air is neglected. For many applications of pressurized stairwells, the vertical flows within the stair shaft are low enough so that these friction losses can be neglected. This is particularly true of the simple stairwell system discussed in section 4.5.

The absolute air pressure, P_S, in a stairwell can be written as:

$$P_S = P_{Sb} - \rho_S gy \tag{4.1}$$

where:

P_{Sb} = air pressure at stairwell bottom
ρ_S = air density within the stairwell
y = distance above stairwell bottom

For the case where the wind velocity is essentially zero, the outside air pressure, P_O, is also hydrostatic and can be expressed in the same manner.

$$P_O = P_{Ob} - \rho_O gy \tag{4.2}$$

The pressure difference, ΔP_{SO}, from the stairwell to the outside can be expressed as:

$$\Delta P_{SO} = P_S - P_O = \Delta P_{SOb} + gy\,(\rho_O - \rho_S) \tag{4.3}$$

where ΔP_{SOb} is the pressure difference at the bottom of the stairwell. The above analysis assumes constant densities, ρ_S and ρ_O. This introduces a negligible error into the above equation for short buildings, and even for a 100 story building the resulting error would be less than 4 percent. This error is conservative in that the pressure difference predicted by equation (4.3) is high. By substituting the ideal gas law into equation (4.3), ΔP_{SO} can be expressed as a function of temperature.

$$\Delta P_{SO} = \Delta P_{SOb} + by \qquad (4.4)$$

where b is the temperature factor and is expressed as:

$$b = \frac{gP}{R}\left(\frac{1}{T_O} - \frac{1}{T_S}\right) \qquad (4.5)$$

where:

T_O = absolute temperature of outside air

T_S = absolute temperature of stairwell air

The effective leakage area from the stairwell through the building to the outside (per floor) can be expressed as

$$A_{SBOe} = \frac{A_{SB}\,A_{BO}}{\sqrt{A_{SB}^2 + A_{BO}^2}} \qquad (4.6)$$

where:

A_{SB} = flow area between the stairwell and the building (per floor)

A_{BO} = flow area between the building and the outside (per floor)

In such a case, the pressure difference, ΔP_{SB}, between the stairwell and the building can be expressed as:

$$\Delta P_{SB} = \Delta P_{SBb} + \frac{by}{1 + \left(\frac{A_{SB}}{A_{BO}}\right)^2} \qquad (4.7)$$

The pressure differences ΔP_{SO} and ΔP_{SB} are related as follows:

$$\Delta P_{SB} = \frac{\Delta P_{SO}}{1 + \left(\frac{A_{SB}}{A_{BO}}\right)^2} \qquad (4.8)$$

4.3.2 Pressurization Air

For the case where a stairwell is positively pressurized throughout (i.e., the direction of air flow is from the stairwell to the outside over the entire stairwell height), the flow from the stairwell to the outside can be written in differential form as:

$$dQ = CA_{he} \sqrt{\frac{2\ \Delta P_{SO}}{\rho}}\ dy \qquad (4.9)$$

The term A_{he} is the distributed effective flow area per unit height which is uniform vertically. This distributed flow area can be related to the effective leakage area, A_{SBOe}, by means of the stairwell height, H, and the number of floors, N.

$$A_{he} = \frac{N\ A_{SBOe}}{H}$$

Substituting this and equation (4.4) into equation (4.9) gives:

$$dQ = \frac{N\ C\ A_{SBOe}}{H} \sqrt{2(\Delta P_{SOb} + by)/\rho}\ \ dy \qquad (4.9a)$$

This can be integrated from y = 0 to y = H to give the total flow, Q_{SBO}, from the stairwell to the building and to the outside.

$$Q_{SBO} = \frac{2}{3}\ N\ C\ A_{SBOe} \sqrt{\frac{2}{\rho}} \left(\frac{\Delta P_{SOt}^{3/2} - \Delta P_{SOb}^{3/2}}{\Delta P_{SOt} - \Delta P_{SOb}} \right) \qquad (4.10)$$

Where ΔP_{SOt} is the pressure difference between the stairwell and the outside at the stairwell top (y = H).

Because the ΔP_{SB} is a linear function of ΔP_{SO} as expressed in equation (4.8), equation (4.10) can be written in terms of the pressure from the stairwell to the building.

$$Q_{SB} = \frac{2}{3}\ N\ C\ A_{SB} \sqrt{\frac{2}{\rho}} \left(\frac{\Delta P_{SBt}^{3/2} - \Delta P_{SBb}^{3/2}}{\Delta P_{SBt} - \Delta P_{SBb}} \right) \qquad (4.11)$$

Because there is no vertical flow in the building, $Q_{SB} = Q_{SBO}$. This is the flow rate of supply air to the stairwell necessary to maintain the pressure differences, ΔP_{SBb} at the stairwell bottom and ΔP_{SBt} at the top.

In a building with vertical air leakage, the exact evaluation of the system would require that the effect of three or more columns of air at different temperatures be included. Such an analysis is cumbersome and for practical purposes a digital computer is needed. For this reason the method of analysis presented in this chapter for hand calculation is based on a building without vertical leakage. In order to make this analysis conservative when applied to buildings with vertical leakage, the stairwell temperature is replaced by the building temperature. Thus equation (4.5) becomes:

$$b = \frac{gP}{R}\left(\frac{1}{T_O} - \frac{1}{T_B}\right) \tag{4.12}$$

For a building temperature of 70^{o}F (21^{o}C) and for winter conditions, the temperature factor, b, can be obtained from figure B.7.

The flow from a pressurized stairwell can be expressed by equations (4.10) and (4.11). These equations can be written for C = 0.65 and $\rho = 0.075\ lb/ft^3$ ($1.20\ km/m^3$).

$$Q = G\ N\ A_e \tag{4.13}$$

where:

Q = volumetric flow rate from stairwell to building, cfm (m^3/s)

A_e = effective flow area per floor, ft^2 (m^2)

G = the flow factor, fpm (m/s)

$$G = K_g\left(\frac{\Delta P_t^{3/2} - \Delta P_b^{3/2}}{\Delta P_t - \Delta P_b}\right) \tag{4.14}$$

where:

ΔP_t = pressure difference across flow path at stairwell top, in H_2O (Pa)

ΔP_b = pressure difference across flow path at stairwell bottom, in H_2O (Pa)

K_g = coefficient, 1740 (0.559)

This equation can be applied either to the flow, Q_{SBO}, from the stairwell through the building to the outside or to the flow, Q_{SB}, from the stairwell to the building. The flow factor, G, can be obtained from figure B.8.

Equations (4.13) and (4.14) apply when the effective flow area, A_e, is the same for each floor. In many cases, A_e varies from floor to floor. These equations can be applied piecewise to vertical stairwell sections where the values of A_e are the same at each floor. To apply equations (4.13) and (4.14) in this manner, the following terms must be redefined:

ΔP_b = pressure difference at the bottom of the section or piece to be analyzed, in H_2O (Pa)

ΔP_t = pressure difference at the top of the section or piece to be analyzed, in H_2O (Pa)

A_e = effective flow area per floor of section being analyzed, ft^2 (m^2)

N = number of floors in section being analyzed

4.3.3 Average Pressure Difference

The average pressure difference, $\overline{\Delta P}$, can be defined as a pressure difference uniform over the stairwell height that would result in the same total flow as a nonuniform pressure profile. The flow from the stairwell can be expressed as:

$$Q = N A_e C \sqrt{\frac{2 \overline{\Delta P}}{\rho}} \tag{4.15}$$

where $\overline{\Delta P}$ is the average pressure difference across the flow path. Equations (4.11), (4.13) and (4.14) can be combined and solved for $\overline{\Delta P}$ to give:

$$\overline{\Delta P} = \frac{4}{9} \left(\frac{\Delta P_t^{3/2} - \Delta P_b^{3/2}}{\Delta P_t - \Delta P_b} \right)^2 \tag{4.16}$$

This relation can be approximated by:

$$\overline{\Delta P} = \frac{1}{2}\left(\Delta P_t + \Delta P_b\right) \tag{4.17}$$

The maximum error in this relation is approximately 6 percent and occurs when $\Delta P_b = 0$.

Equations (4.15) and (4.16) can be applied piecewise to stairwell sections in the same manner as equations (4.13) and (4.14).

4.4 HEIGHT LIMIT

As stated in section 4.2, two problems with pressurized stairwells are that the minimum pressure difference may be unacceptably low and that the maximum pressure difference may be unacceptably high. These problems are most likely to exist in tall buildings during periods of extreme outside temperature.

In some cases, satisfactory pressurization of a stairwell can be impossible when all the stairwell doors are closed. By satisfactory pressurization it is meant that nowhere over the stairwell height is the pressure difference greater than the maximum allowable pressure difference or less than the minimum allowable pressure difference.

For a building without vertical leakage, equation (4.5) can be substituted into equation (4.7) and solved for the height limit, Hm, below which satisfactory pressurization is possible.

$$Hm = \frac{R}{gP}\,\frac{\left(\Delta P_{max} - \Delta P_{min}\right)}{\left|\frac{1}{T_O} - \frac{1}{T_B}\right|}\left[1 + \left(\frac{A_{SB}}{A_{BO}}\right)^2\right] \tag{4.18}$$

where:

ΔP_{max} = maximum allowable pressure difference between the stairwell and the building

ΔP_{min} = minimum allowable pressure difference between the stairwell and the building

T_O = outside design temperature (absolute)

T_B = building temperature (absolute)

It can be observed that T_S was replaced by T_B in equation (4.18), this was done so that the equation would yield conservative values of Hm for buildings with vertical leakage. In such buildings, the actual pressure profiles depend on three or more columns of air at different temperatures. If the stairwell temperature is between the outside temperature and the building temperature, then equation (4.18) will yield conservative results.

The absolute value of the temperature term is used in equation (4.18) so that the equation will apply to both winter conditions ($T_B > T_O$) and summer conditions ($T_O > T_B$). In many cases, A_{SB} is much smaller than A_{BO}, and, in such cases, equation (4.18) can be simplified to

$$Hm = \frac{R}{gP} \frac{\left(\Delta P_{max} - \Delta P_{min}\right)}{\left|\frac{1}{T_O} - \frac{1}{T_B}\right|} \qquad (4.19)$$

For a building temperature of 70°F (21°C) and for winter conditions, the height limit, Hm, can be obtained from figure B.9.

Example

Is it possible to pressurize a 217 ft (66 m) stairwell if the outside design temperature is 0°F (-18°C)? The maximum allowable force to open the 36 in (0.91 m) wide door has been determined to be 50 lb (222 N) for this particular building. The force to overcome the door closer is 14 lb (62 N). The minimum allowable pressure difference across the closed stairwell door is 0.10 in H_2O (25 Pa).

The maximum allowable force due to pressure difference is 50 - 14 = 36 lb (160 N).

From figure B.6, for a 36 in (0.91 m) wide door, ΔP_{max} = 0.60 in H_2O (149 Pa).

$\Delta P_{max} - \Delta P_{min} = 0.60 - 0.10 = 0.50$ in H_2O (124 Pa).

From figure B.9 for $T_0 = 0^oF$ (-18^oC), Hm = 223 ft (69 m).

Because Hm is greater than the height of the stairwell, satisfactory pressurization of the stairwell is possible.

If Hm had been less than the stairwell height, it would not necessarily mean that satisfactory pressurization is impossible, because the estimate of Hm from equation (4.19) (Fig. B.9) is conservative. In such a case, a more exact analysis considering vertical leakage may be appropriate. If such an analysis indicated that satisfactory pressurization was not possible at extreme outside temperatures, stairwell compartmentation may be used (see section 4.1.2).

4.5 CALCULATION METHOD FOR A SIMPLE SYSTEM

A simple stairwell pressurization system has a supply air system that supplies air continuously to the stairwell in the event of a building fire. The single and multiple injection systems discussed in section 3.1.1 are all simple systems. The supply fan can be a centrifugal type (Figs. 4.1 to 4.3) or a propeller fan (Fig. 4.5). When a propeller fan is used it should be roof mounted in the horizontal plane with a wind shield. Wall mounted propeller fans without wind shields are not recommended because the flow rates of these fans are highly dependent on the wind.

When all the stairwell doors are closed, the system must maintain satisfactory pressurization. Simple pressurization systems have two limitations:

1. They generally are not capable of producing the airflows through open stairwell doorways necessary to prevent smoke backflow when an outside stairwell door is also open.

2. When stairwell doors are open, the pressure difference across closed stairwell doors can drop to low levels.

These limitations obviously restrict applications which are appropriate for simple stairwell pressurization systems. However, no consensus currently exists as to what are appropriate applications.

4.5.1 Calculation Steps

The following analysis applies to simple stairwell pressurization. It is for a stairwell with a door to the building at each floor. The stairwell must also have negligible leakage from the stairwell directly to the outside other than through the ground floor exterior door when it opens. If this is not the case, the analysis should be modified accordingly.

Step 1. Establish design values.

The following areas are per floor and per stairwell.

A_{BOw} = wall area between the building and the outside

A_{SBw} = wall area between the stairwell and the building

A_{BO} = flow area between the building and the outside

A_{SB} = flow area between the stairwell and the building when stairwell doors are closed

N = number of floors of stairwell

H = height to top of highest floor served by the stairwell

T_O = outside design temperature

T_B = building temperature

ΔP_{max} = maximum allowable pressure difference between the stairwell and the building

ΔP_{min} = minimum allowable pressure difference between the stairwell and the building

Step 2. Calculate the temperature factor.

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

Step 3. Choose a value for the pressure difference, ΔP_{SBb}, between the stairwell and the building at the stairwell bottom when all the stairwell doors are closed. The ΔP_{SBb} should not be less than ΔP_{min}.

Step 4. Calculate the pressure difference, ΔP_{SBt}, between the stairwell and the building at the stairwell top when all the stairwell doors are closed.

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

It should be checked that ΔP_{SBt} does not exceed ΔP_{max}. If this is not the case, then a smaller value of ΔP_{SBb} can be chosen in step 3, provided it is not less than ΔP_{min}. If this is not possible see section 4.4.

Step 5. Calculate the flow, Q_{SB}, from the stairwell to the building when the stairwell doors are closed.

$$Q_{SB} = \frac{2}{3} CA_{SB}\sqrt{\frac{2}{\rho}}\left(\frac{\Delta P_{SBt}^{3/2} - \Delta P_{SBb}^{3/2}}{\Delta P_{SBt} - \Delta P_{SBb}}\right)$$

The flow rate is the total air flow rate needed to pressurize the stairwell.

4.5.2 Simple System Example

This example is an analysis of a 20 story stairwell. Each story is 10.8 ft (3.3 m) in height. The stairwell has a single-leaf door at each floor leading to the occupant space and one ground-level door to the outside. The exterior of the building has a wall area of 6030 ft^2 (560 m^2) per stairwell per floor. The exterior building walls and stairwell walls are of average leakiness. The stairwell wall area is 560 ft^2 (52 m^2) per floor. The area of the crack around each stairwell door to the building is 0.26 ft^2 (0.024 m^2). The exterior door to the stairwell is well gasketed, and its leakage can be neglected when it is closed.

For this example, the following design parameters are used: outside design temperature of 14°F (-10°C), minimum allowable pressure when all doors are closed of 0.052 in H_2O (13 Pa), maximum allowable pressure when all the doors are closed of 0.551 in H_2O (137 Pa).

Step 1. Establish design values.

$$A_{BOw} = 6030 \text{ ft}^2 \text{ (560 m}^2\text{)}$$
$$A_{SBw} = 560 \text{ ft}^2 \text{ (52 m}^2\text{)}$$

Using the leakage ratio for an exterior building wall of average tightness from table C.1, $A_{BO} = 6030\ (0.21 \times 10^{-3}) = 1.27$ ft^2 (0.118 m^2). Using leakage ratio for a stairwell wall of average tightness from table C.1, the leakage area of the stairwell walls is 560 $(0.11 \times 10^{-3}) = 0.06$ ft^2 (0.006 m^2). A_{SB} equals the leakage area of the stairwell wall plus the cracks around the closed doors.

$$A_{SB} = 0.06 + 0.26 = 0.32 \text{ ft}^2 \text{ (0.030 m}^2\text{)}$$
$$N = 20$$
$$H = 217 \text{ ft (66 m)}$$
$$T_O = 14^\circ\text{F } (-10^\circ\text{C})$$
$$T_B = 70^\circ\text{F } (21^\circ\text{C})$$
$$\Delta P_{max} = 0.551 \text{ in } H_2O \text{ (137 Pa)}$$
$$\Delta P_{min} = 0.052 \text{ in } H_2O \text{ (13 Pa)}$$

Step 2. Calculate b.

From figure B.7, for $T_0 = 14^oF$ (10^oC)

$b = 0.00170$ in H_2O/ft (1.39 Pa/m)

Step 3. Choose $\Delta P_{SBb} = 0.080$ in H_2O (20 Pa)

This was chosen larger than ΔP_{min} to provide an extra degree of protection.

Step 4. Calculated ΔP_{SBt}

$$\Delta P_{SBt} = 0.08 + \frac{0.0017\ (217)}{1 + \left(\frac{0.32}{1.27}\right)^2} = 0.426 \text{ in } H_2O \text{ (106 Pa)}$$

This is less than ΔP_{max}, so proceed to the next step.

Step 5. Calculate Q_{SBc} using figure B.8.

For $\Delta P_t - \Delta P_b = 0.426 - 0.08 = 0.346$ in H_2O (86 Pa) and

$\Delta P_b = 0.080$ in H_2O (20 Pa), G = 1280 fpm (6.50 m/s)

$Q_{SB} = GNA_{SB}$

$= 1280\ (20)\ (0.32) = 8200$ cfm (3.9 m^3/s)

This flow rate is highly dependent on the leakage area of cracks around the closed doors and upon the leakage area that exists in the stairwell walls. In practice, these leakage areas are difficult to determine and even more difficult to control. If the value of the flow area, A_{SB}, were 0.54 ft^2 (0.050 m^2) rather than 0.32 ft^2 (0.030 m^2), then a flow rate, Q_{SB}, of 13,800 cfm (6.5 m^3/s) would have been calculated in step 5. A fan with a sheave can be used to allow adjustment of supply air to offset for variations in actual leakage areas from the values used in the design calculations.

This analysis has the advantage that it lends itself to hand calculation. A limitation is that this technique does not allow for consideration of open stairwell doors. Chapter 5 presents an approach to overcome this limitation.

CHAPTER 5.
STAIRWELL PRESSURIZATION AND OPEN DOORS

The fundamental concepts of stairwell pressurization and a method of calculation for simple stairwell pressurization were presented in chapter 4. The simple pressurization system has two limitations regarding open doors. First, when a stairwell door to the outside and doors to the building are open, the simple system is not capable of providing sufficient air flows through doorways to the building to prevent smoke backflow. Second, when stairwell doors are open, the pressure difference across the closed doors can drop to low levels.

5.1 SYSTEMS

In this chapter, more complex systems are discussed. They can be grouped into three categories:

- Overpressure relief systems which vent or relieve part of the supply air when all the stairwell doors are closed.
- Supply fan bypass systems which bypass excess supply air back to the fan inlet.
- Combination stairwell pressurization and fire floor smoke venting systems.

The discussion of single and multiple injection, compartmentation, vestibules, and supply air source appearing in chapter 4 applies to the above systems.

5.1.1 Overpressure Relief

The total airflow rate is selected to provide at least the minimum air velocity when a specific number of doors are open. When all the doors are closed, part of this air is relieved through a vent in order to prevent excessive pressure buildup, which could otherwise result in excessive door-opening forces. This excess air can be vented either to the building or to the outside. Exterior vents can be subject to adverse effects of the wind, so wind shields are recommended.

Barometric dampers that close when the pressure drops below a specified value can be used to minimize the air losses through the vent when doors are open. Figure 5.1 illustrates a pressurized stairwell with overpressure relief vents to the building at each floor. In systems built with vents between the stairwell and the building, the vents typically have one or more fire dampers in series with the barometric damper. As an energy conservation feature, these fire dampers are normally closed and open when the pressurization system

Notes:

1. Vents to the building have a barometric damper and one or two fire dampers in series.

2. A roof mounted supply fan is shown, however the fan may be located at any level.

3. A manually operated damper may be located at the stairwell top for smoke purging by the fire department.

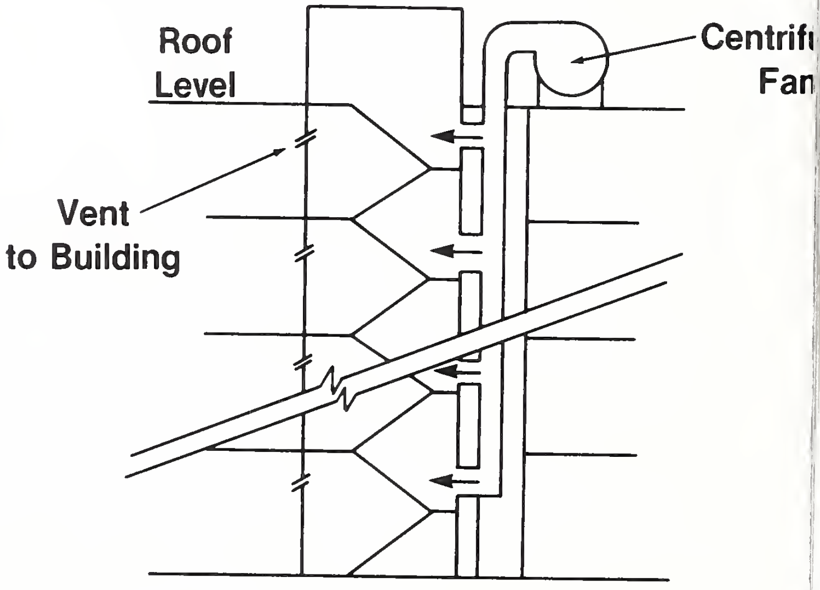


Figure 5.1. Stairwell pressurization with vents to the building at each floor

is activated. This arrangement also can reduce the possibility of annoying damper chatter that frequently occurs with barometric dampers.

An exhaust duct can be used in a pressurized stairwell as a means of overpressure relief. The intent of this system is that the normal resistance of a nonpowered exhaust duct acts to maintain pressure differences that are within the design limits.

Exhaust fans also can be used to prevent excessive pressures when all stairwell doors are closed. The fan should be controlled by a differential pressure sensor, so that it will not operate when the pressure difference between the stairwell and the building falls below a specific level. This should prevent the fan from pulling smoke into the stairwell when a number of open doors have reduced stairwell pressurization. Such an exhaust fan should be specifically sized so that the pressurization system will perform within design limits. Because an exhaust fan can be adversely affected by the wind, a wind shield is recommended.

An alternate method of venting a stairwell is through an automatically opening stairwell door to the outside at ground level. Under normal conditions this door would be closed and in most cases locked for security reasons. Provisions need to be made so that this lock does not conflict with the automatic operation of the system.

Possible adverse wind effects are also a concern with a system that uses an open outside door as a vent. Occasionally, high local wind velocities develop near the exterior stairwell door, and such local winds are difficult to estimate in the vicinity of new buildings without expensive modeling. Local objects on a wall can act as wind breaks (or wind shields). An example of this method of overpressure relief is provided in section 6.6.

5.1.2 Supply Fan Bypass

In this system the capacity of the supply fan is sized to provide at least the minimum air velocity when the design number of doors are open. Figure 5.2 illustrates such a system. The flow rate of air into the stairwell is varied by modulating bypass dampers, which are controlled by one or more static pressure sensors that sense the pressure difference between the stairwell and the building. When all the stairwell doors are closed, the pressure difference increases and the bypass damper opens to increase the bypass air and decrease the flow of supply air to the stairwell. In this manner, excessive stairwell pressures and excessive pressure differences between the stairwell and the building are prevented.

5.1.3 Stairwell Pressurization and Smoke Venting

Smoke venting of the fire floor can be used to improve the performance of the stairwell pressurization. This smoke removal may or may not be part of a zoned smoke control system (see chapter 6). Three different types of smoke removal can be considered: (1) exterior wall vents, (2) smoke shafts, and (3) fan powered exhaust.

Besides providing a path for smoke removal, exterior wall vents allow an increased pressure difference across a closed fire floor stairwell door and allow increased air velocity through an open fire floor stairwell door.

Notes:

1. Fan bypass controlled by one or more static pressure sensors located between the stairwell and the building.

2. A roof mounted supply fan is shown, however the fan may be located at any level.

3. A manually operated damper may be located at the stairwell top for smoke purging by the fire department.

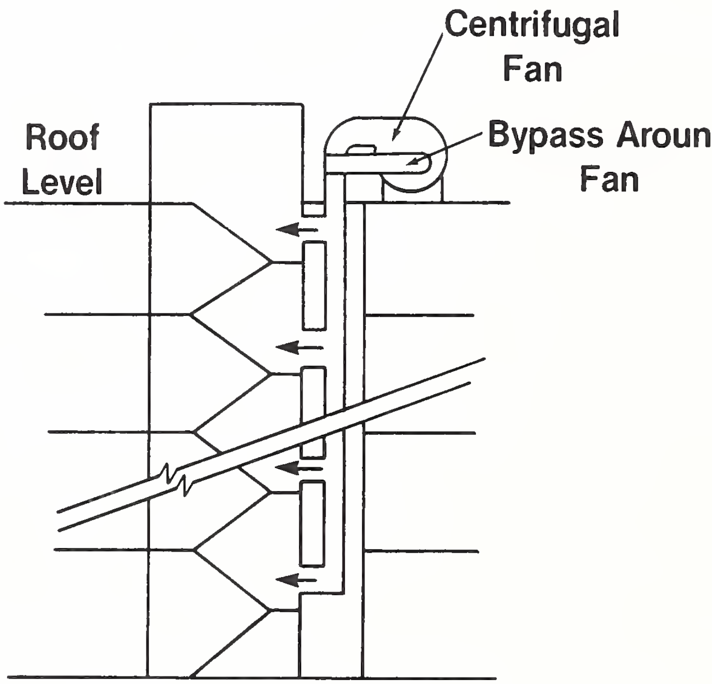


Figure 5.2. Stairwell pressurization with bypass around supply fan

Venting the fire floor is also a way to reduce the potential hazards resulting from a broken fire floor window (see section 2.9.2).

Smoke shafts are similar to external wall vents, except that smoke from the fire floor is vented through a shaft. The venting is aided by the buoyancy forces of hot smoke, as discussed in section 2.2. Smoke shafts should be constructed in accordance with local codes; specific engineering data regarding sizing of smoke shafts is available from Tamura and Shaw [1].

The effect of a fan powered smoke exhaust system on the performance of a pressurized stairwell is similar to that of exterior wall vents. The exhaust fans can be individually located on each floor or can be used in combination with a smoke exhaust shaft.

5.2 ANALYSIS APPROACH

The analysis of a pressurized stairwell designed to accommodate open doors is more complicated than the analysis of a simple stairwell system, as presented in chapter 4. This is because the vertical airflow in the stairwell is much larger with open doors; therefore, the pressure loss due to friction must be included in the analysis. In addition, it is more difficult to determine whether summer or winter design conditions dominate. For these reasons it is recommended that the design of such a system be based on a computer analysis using a program of the type described in chapter 3. This analysis should include both summer and winter design conditions, with all doors closed and with various combinations of the design number of doors open.

The shaft flow coefficient, C_S, for a stairwell is defined by equation (3.7). C_S is dependent on the horizontal cross sectional area, A, of the stairwell and may be expressed,

$$C_S = C'_S A \tag{5.1}$$

based on the research of Tamura and Shaw [2]. An average value of $C'_S = 650\ (210)$ is recommended for area in ft^2 (m^2), with pressure loss due to friction in inches of water (Pa), mass flow expressed as standard volumetric flow in cfm (L/s) at 70°F (21°C), and one atmosphere.

5.3 EXAMPLE ANALYSIS

This is an example of a building with two stairwells and an elevator shaft with two cabs. The building and both stairwells are 15 stories each. Each stairwell is pressurized by a centrifugal fan with bypass duct, as discussed in section 5.1.2. The stairwells are the same and can be analyzed on a per stairwell basis. The system is to be designed to maintain at least an average velocity of 49.2 fpm (0.25 m/s) through an open stairwell door when four stairwell doors are open. The stairwell doors are all 3 x 7 ft (0.914 x 2.13 m) in size. The building has an open floor plan on each floor, so there are no interior partitions to complicate airflow on each floor.

The other design values are:

- 12.0 ft (3.66 m) height between stories
- 14^{o}F (-10^{o}C) outside winter design temperature
- 93^{o}F (34^{o}C) outside summer design temperature
- 70^{o}F (21^{o}C) building design temperature
- 45^{o}F (7^{o}C) winter stairwell temperatures, which reflects a preheat coil in the stairwell pressurization system to prevent standpipe freezing
- 82^{o}F (28^{o}C) summer stairwell temperature. In summer the stairwell is pressurized with unconditioned outside air, accordingly this temperature was selected, based on engineering judgment, to be between the building design temperature and the outside summer design temperature
- 1.13 ft^2 (0.105 m^2) flow area per stairwell between the building and the outside
- 0.850 ft^2 (0.0790 m^2) flow area between floors of the building

- 0.323 ft^2 (0.030 m^2) flow area between the stairwell and the building on each floor with stairwell doors closed

- 10.5 ft^2 (0.975 m^2) flow area of open stairwell doors (half the geometric area of the open door, see section 2.8)

- 0.670 ft^2 (0.0622 m^2) flow area between the building and the elevator shaft per stairwell per floor

- 1.50 ft^2 (0.139 m^2) flow area of the vent from the top of the elevator shaft to the outside at the penthouse level, per stairwell (for the difference between vent area and flow area of a vent see section 2.8)

- 0.10 in H_2O (24.9 Pa) minimum allowable pressure difference between stairwell and building when all doors are closed

- 0.40 in H_2O (99.5 Pa) maximum allowable pressure difference between stairwell and building when all doors are closed

- 7.0×10^4 (2100), C_S for stairwell

- 2.4×10^5 (7200), C_S for elevator shaft

- 1030 cfm (0.487 m^3/s) minimum flow through stairwell door which corresponds to the average velocity of 49.2 fpm (0.25 m/s), based on the geometric area of the door

The computer program described in chapter 3 was used for this analysis. A number of different runs of the program were made to determine which four doors open would be the worst case and during which season of the year. Pressure differences and average velocities from eight runs are listed in table 5.1.

Table 5.1 Computer calculated* pressure differences and average velocities

Run	Season	Outside stairwell door	Floor on which doors are open	Total supply air to stairwell		Pressure difference across 7th floor door		Minimum pressure difference across closed door			Lowest average velocity through stairwell open doorway to building		
				cfm	(m^3/s)	in H_2O	(Pa)	floor	in H_2O	(Pa)	floor	fpm	(m/s)
1	summer	closed	none	7350	(3.47)	0.345	(85.8)	1	0.337	(83.8)	--	--	--
2	summer	open	1, 2, 3	19,500	(9.20)	0.186	(46.0)	4	0.113	(28.1)	1	49.9	(0.253)
3	summer	open	7, 8, 9	19,500	(9.20)	0.006	(1.5)	1	0.072	(17.9)	8	84.1	(0.427)
4	summer	open	13, 14, 15	19,500	(9.20)	0.135	(33.6)	1	0.082	(20.4)	15	89.4	(0.454)
5	winter	closed	none	7350	(3.47)	0.335	(83.3)	1	0.289	(71.9)	--	--	--
6	winter	open	1, 2, 3	19,500	(9.20)	0.245	(61.0)	4	0.163	(40.6)	1	71.0	(0.361)
7	winter	open	7, 8, 9	19,500	(9.20)	0.009	(2.2)	1	0.101	(25.1)	8	97.5	(0.495)
8	winter	open	13, 14, 15	19,500	(9.20)	0.169	(42.0)	1	0.109	(27.1)	15	89.9	(0.457)

*Data and computer output for this example are provided in appendix E.

The system can be designed with static sensors located at one floor or a number of floors. For the following discussion the system is considered to have only one static pressure sensor located at the seventh floor. The two runs with no doors open (table 5.1) and a total supply rate of 7350 cfm (3.47 m^3/s) results in acceptable pressure differences for both summer and winter.

The worst case of doors open was the exterior door and the three lowest stairwell doors to the building during the summer. This case is presented as run 2 in appendix E. In this case, a supply rate of approximately 19,500 cfm (9.20 m^3/s) is needed to provide the minimum flow rate of 1030 cfm (0.487 m^3/s) through the first floor stairwell door to the building. The pressure difference across the stairwell at the seventh floor is 0.186 in H_2O (46.0 Pa). Therefore, to operate successfully under this condition, the system must be able to supply 19,500 cfm (9.20 m^3/s) at 0.186 in H_2O (46.0 Pa).

In this example, the minimum average design velocity through an open doorway is the low value of 49.2 fpm (0.25 m/s). If a larger design velocity is required, design problems can result with this system. Increased flow through open doorways is accompanied by increased pressure difference across those doors that remain closed. For run 2 (Appendix E) the pressure difference across the closed doors ranged from 0.11 to 0.23 in H_2O (27 to 57 Pa). If, for the conditions of run 2, the supply air to the stairwell were increased to provide a minimum 100 pfm (0.51 m/s) through open stairwell doors, then the pressure difference across the closed doors would range from approximately 0.40 to 0.90 in H_2O (100 to 220 Pa). Obviously this is greater than the maximum allowable pressure difference for this example, because the resulting door opening forces would be unacceptable. Venting of the fire floor (Section 5.1.3) can be used to reduce this problem.

It should be noted that the unique determination of the worst case for open doors in this example is not valid for all pressurized stairwells in general, i.e., a different pressurization system or a different outside design temperature could result in a different combination of doors constituting the worst case.

An air supply injection point was located at each floor in the computer analysis; however, injection points can be located further apart, as discussed in chapter 4.

For winter design conditions with the stairwell doors closed, the stairwell has a relatively uniform pressure profile, as can be seen from run 5 in Appendix E. The difference between the maximum and minimum pressure difference is only 0.049 in H_2O (12.2 Pa). This computer analysis included vertical leakage between floors and through the elevator shaft. However, for a similar building without vertical leakage, the difference between the maximum and minimum pressure difference is approximately 0.28 in H_2O (70 Pa), as calculated by equation (4.7). This stairwell performance is dependent on the flow throughout the entire building. Factors such as a closed elevator vent, an enclosed elevator lobby, or variation in the leakage characteristics of the building walls can greatly affect such an analysis.

5.4 REFERENCES

[1] Tamura, G. T. and Shaw, C. Y., Basis for the Design of Smoke Shafts, Fire Technology, Vol. 9, No. 3, pp. 209-222, August 1973.

[2] Tamura, G. T. and Shaw, C. Y., Air Leakage Data for the Design of Elevator and Stair Shaft Pressurization Systems, ASHRAE Transactions 1976, Vol. 82, Part 2, pp. 179-190.

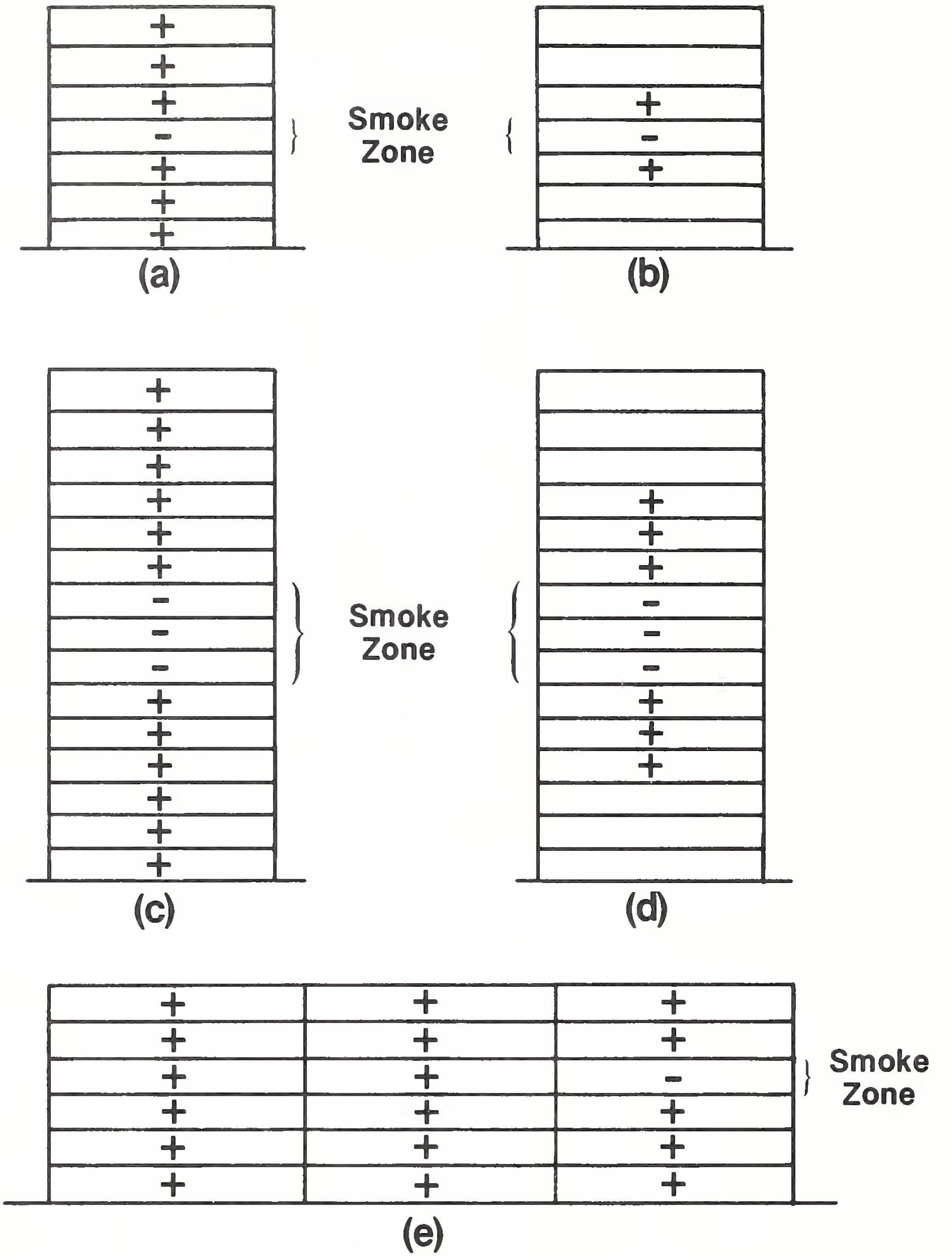
CHAPTER 6.
ZONED SMOKE CONTROL

The pressurized stairwells discussed in chapters 4 and 5 are intended to control smoke to the extent that they inhibit smoke infiltration to the stairwell. However, in a building with just a pressurized stairwell, smoke can flow through cracks in floors and partitions and through shafts to damage property and threaten life at locations remote from the fire. The concept of zone smoke control discussed in this chapter is intended to limit this type of smoke movement within a building.

6.1 SMOKE CONTROL ZONES

A building is divided into a number of smoke control zones, each zone separated from the others by partitions, floors, and doors that can be closed to inhibit the movement of smoke. In the event of a fire, pressure differences and airflows produced by mechanical fans are used to limit the smoke spread to the zone in which the fire initiated. The concentration of smoke in this smoke zone goes unchecked and accordingly, in zoned smoke control systems, it is intended that building occupants evacuate the smoke zone as soon as possible after fire detection.

Frequently, each floor of a building is chosen to be a separate smoke control zone. However, a smoke control zone can consist of more than one floor, or a floor can consist of more than one smoke control zone. Some arrangements of smoke control zones are illustrated in figure 6.1. When a fire occurs, all of the nonsmoke zones in the building, or only zones adjacent to the smoke zone, may be pressurized, as in figure 6.1 (b) and (d). The latter system is frequently called a pressure sandwich, and this concept design has the drawback that it is dependent upon proper construction of shafts. It is possible to have smoke flow through shafts past the pressurized zone and into unpressurized spaces, but pressurizing all nonsmoke zones reduces this possibility. The comments concerning location of supply air inlets of pressurized stairwells (Section 4.1.1) also apply to the supply air inlets for nonsmoke zones.



Note:

In the above figures, the smoke zone is indicated by a minus sign and pressurized spaces are indicated by a plus sign. Each floor can be a smoke control zone as in (a) and (b) or a smoke zone can consist of more than one floor as in (c) and (d). All the nonsmoke zones in a building may be pressurized as in (a) and (c) or only nonsmoke zones adjacent to the smoke zone may be pressurized as in (b) and (d). A smoke zone can also be limited to a part of a floor as in (e).

Figure 6.1. Some arrangements of smoke control zones

6.2 SMOKE ZONE VENTING

Venting of smoke from a smoke zone is important because it prevents significant overpressures due to thermal expansion of gases as a result of the fire. In addition, venting results in some reduction of smoke concentration in the smoke zone. Venting can be accomplished in three ways*:

- Exterior wall vents.
- Smoke shafts.
- Mechanical venting (or exhaust).

These concepts are discussed in detail later. Smoke purging, consisting of equal air supply and exhaust rates, is not considered here for smoke control, because it does not produce pressure differences or air flows that can control smoke movement. It is generally believed that such purging at the airflows available with HVAC systems cannot significantly reduce smoke concentrations in the smoke zone resulting from a large fire.

6.2.1 Exterior Wall Vents

Exterior wall vents can consist of windows or wall panels that open automatically when the smoke control system is activated. In order to minimize adverse effects of wind, the area of wall vents should be evenly distributed among all the exterior walls. For buildings that are much longer than wide, the vents can be evenly divided between the two long sides. Exterior wall venting is most appropriate for buildings with open floor plans and least suitable when the floor plan is divided into many compartments. Because the flow of hot gases through a wall vent can be substantial, precautions should be taken in the design of exterior walls to minimize the possibility of exterior fire spread to floors above the vent.

The following is a method for determining the size of exterior wall vents presented in essentially the same form as originally by Tamura [1]. In this analysis, each floor consists of a smoke control zone.

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*These three methods of smoke venting can be used outside the context of zoned smoke control, i.e., in passive smoke management (section 2.2) or in conjunction with stairwell pressurization (section 5.1.3).

When a building is pressurized, opening an exterior wall vent causes air to flow from adjacent floors to the vented floor (smoke zone) and through the vent to the outside, as illustrated in figure 6.2. If the supply and exhaust are shut down on the fire floor, the total air flow rate through the wall vents equals the total air flow rate into the vented floor from the surrounding smoke control zones:

$$A_v \sqrt{P_F - P_0} = A_e \sqrt{P_B - P_F} \qquad (6.1)$$

where:

A_v = flow area of the exterior wall vent, ft^2 (m^2)

A_e = effective flow area of the enclosure of the smoke zone, ft^2 (m^2)

P_F = smoke zone pressure, in H_2O (Pa)

P_0 = outside pressure, in H_2O (Pa)

P_B = building pressure on nonsmoke zones, in H_2O (Pa)

The effective flow area, A_e, includes the flow areas of the walls of vertical shafts, floor constructions, and duct openings (return and exhaust) of the smoke zone. Rearranging equation (6.1) yields

$$\frac{P_B - P_F}{P_F - P_0} = \left(\frac{A_v}{A_e}\right)^2 \qquad (6.2)$$

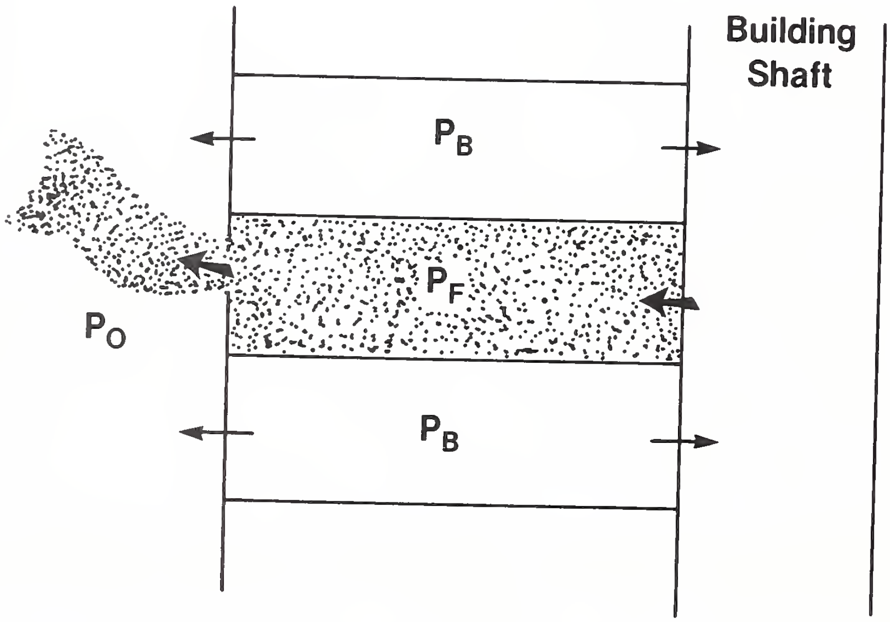


Figure 6.2. Flow pattern with venting of smoke zone

But: $P_B - P_O = (P_B - P_F) + (P_F - P_O)$

Let: $\Delta P_{BO} = P_B - P_O$

$\Delta P_{BF} = P_B - P_F$

$\Delta P_{FO} = P_F - P_O$

Then: $\Delta P_{BO} = \Delta P_{BF} + \Delta P_{FO}$

$\Delta P_{FO} = \Delta P_{BO} - \Delta P_{BF}$

Substituting the above into equation (6.2) and rearranging yields

$$\frac{\Delta P_{BF}}{\Delta P_{BO}} = \frac{(A_v/A_e)^2}{1 + (A_v/A_e)^2} \tag{6.3}$$

A plot of this equation is shown in figure 6.3. This shows that for particular values of ΔP_{BO} and A_e, the pressure difference, ΔP_{BF}, across the boundary of the smoke zone increases as the vent area, A_v, increases. For large values of A_v, ΔP_{BF} approaches ΔP_{BO}.

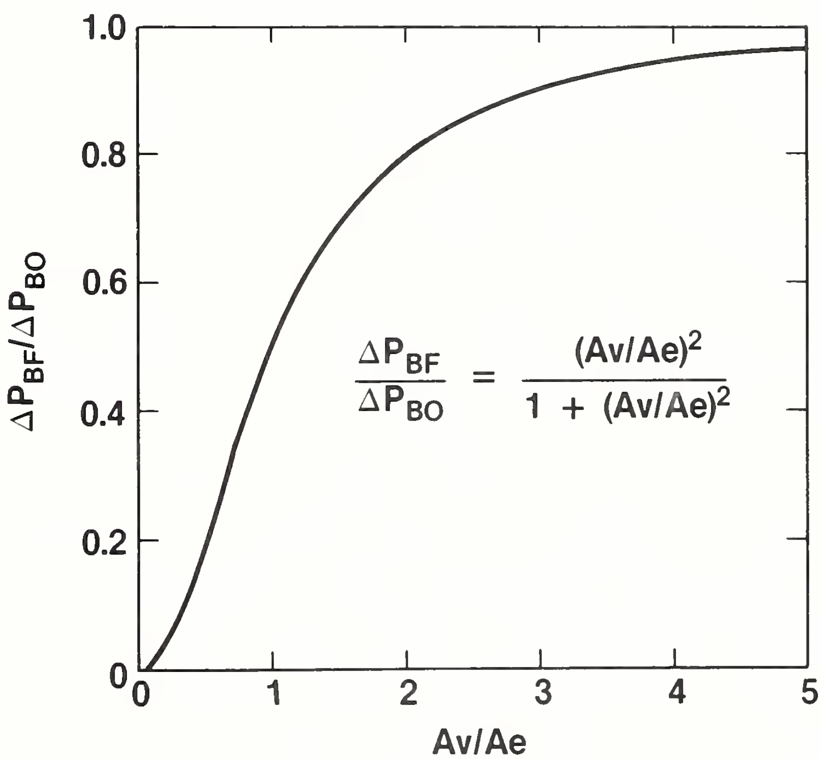


Figure 6.3. Variation of pressure differences with vent size

When the vent area is equal to the effective flow area of the enclosure of the smoke zone ($A_v/A_e = 1$), then the pressure difference across the boundary of the smoke zone is one-half of the building pressurization ($\Delta P_{BF}/\Delta P_{BO} = 0.50$). Also, when $A_v/A_e = 3.0$, $\Delta P_{BF}/\Delta P_{BO} = 0.90$. Increasing the vent area further will not significantly increase the pressure difference across the boundary of the smoke zone.

Opening a stairwell door on a floor of a nonsmoke zone increases the pressure difference across the closed stairwell door on the smoke zone. This can be explained by the use of the concept of the effective flow area (see section 2.6), and is left to the reader as an exercise. Opening doors in a stairwell on both a nonsmoke zone and the smoke zone results in considerable airflow from the stairwell to the smoke zone, which is accompanied by reduced pressure difference across the boundary of the smoke zone.

Opening only a stairwell door in the smoke zone will result in some air flow from the stairwell to the smoke zone. This flow rate depends on the level of pressurization of the nonsmoke zones and the leakage characteristics of the stairwell. It is possible that this flow rate may not be sufficient to prevent smoke backflow into the stairwell. For this reason, stairwell pressurization should be considered to provide an additional level of protection.

6.2.2. Smoke Shafts

A smoke shaft is a vertical shaft extending from the bottom to the top of a building, with openings at the top to the outside and openings to building spaces at each floor. These openings are fitted with normally closed dampers. In a fire situation, only the damper on the fire floor and the top outside damper open to vent smoke to the outside. Smoke shafts should be constructed in accordance with local codes. Tamura and Shaw [2] provide information concerning sizing smoke shafts. Smoke shafts are not a means of smoke control and by themselves cannot prevent smoke spread throughout the fire floor and to other floors. However, smoke shafts in conjunction with pressurization of nonsmoke zones can provide pressure differences to control smoke movement. In order to assure air flow through open stairwell doors sufficient to prevent smoke backflow, it may be necessary to pressurize stairwells as well.

Smoke shafts lend themselves to use in buildings with open floor plans. The air movement caused by smoke shafts operating under normal stack effect conditions tends to pull smoke toward the smoke shaft inlet on the fire floor. It is recommended that smoke shafts be located as far as possible from exit stairwells, so that smoke in the vicinity of the shaft inlet does not pose an increased hazard during evacuation or fire fighting. Because hot smoke frequently stratifies near the ceiling, it is recommended that smoke shaft inlets be located in or near the ceiling.

6.2.3 Mechanical Exhaust

A specially dedicated exhaust system or the exhaust fans of the HVAC system can be used to provide mechanical exhaust for the smoke zone. Mechanical exhaust of the smoke zone is generally used in conjunction with pressurization of nonsmoke zones. In such a system, stairwell pressurization can greatly reduce the chance of smoke backflow into stairwells.

Mechanical exhaust by itself can result in sufficient pressure differences for smoke control. However, in the event of window breakage or a large opening to the outside from the smoke zone, mechanical exhaust can no longer maintain favorable pressure differences. For this reason, mechanical exhaust alone does not constitute an adequate smoke control system when there is a significant probability of window breakage or an opening from the smoke zone to the outside.

Exhaust gases can be at high temperatures that have the potential to cause fan failure. The temperature of the smoke as it goes through the exhaust system decreases due to heat transfer and dilution. When the HVAC system is being used for smoke exhaust, the recommended approach is to choose a large enough smoke control zone so that dilution alone will lower the temperature of the gases at the fan to the point where an ordinary fan can be used safely. This approach depends on the fire being limited to only a fraction (such as one room) of the smoke zone. Then, even for a fire in the compartment nearest the fan, the temperature of the gases reaching the fan will be sufficiently diluted by cooler air being drawn into the fan from other compartments. In cases where this cannot be done, heat-rated fans can be used. Obviously, the ductwork in such a system should be such that it can withstand the temperatures to which it would be subjected. Low temperature smoke from a sprinklered fire will not pose such problems for the ductwork or the fans. However, even in the case of a sprinklered fire, it is believed that single-room smoke zones are beyond the state of present technology.

In the smoke zone, the location of the inlets of the mechanical exhaust is an important consideration. These inlets should be located away from exit stairs, so that smoke in the vicinity of the inlet does not pose an increased hazard during evacuation or fire fighting. Because hot smoke frequently stratifies near the ceiling, it is recommended that exhaust inlets be located in or near the ceiling.

6.3 REFUGE AREAS

A refuge area is a place within a building where building occupants are protected for a period of time from the heat and smoke produced by a building fire. In a limited sense, any nonsmoke zone of a zoned smoke control system is a refuge area intended to protect occupants for the period of time needed for evacuation. Theoretically, a refuge area could be designed to provide protection for any period of time. Consideration has been given to the concept of refuge areas in which building occupants could wait out large fires. However, the current state of smoke control technology is such that it is doubtful that long-term refuge areas can be successfully designed and built. For this reason, it is recommended that all refuge areas be connected to escape routes.

6.4 SMOKE DAMPERS

A smoke damper is a device, installed in an air distribution system, designed to resist the movement of air or smoke in the event of a building fire. At present, there is no published test standard for smoke dampers, although, a proposed standard (UL 555S) has been developed by Underwriters

Laboratories, Incorporated. A smoke damper can be used for either traditional smoke management or smoke control. In traditional smoke management, a smoke damper is intended to inhibit the passage of smoke under the forces of buoyancy, stack effect, and wind, as discussed in chapter 2. It is obvious that a smoke damper with low leakage characteristics is advantageous for such an application.

In a smoke control system, a smoke damper is used to inhibit the passage of air that may or may not contain smoke. Low leakage characteristics of a smoke damper are not necessary when outside (fresh) air is on the high pressure side of the smoke damper, as is the case for dampers that shut off supply air from a smoke zone or which shut off exhaust air from a nonsmoke zone. In these cases, moderate leakage of smoke free air through the damper will not adversely affect the control of smoke movement. It is best to design smoke control systems so that only smoke free air is on the high pressure side of a smoke damper.

6.5 SYSTEM CONSIDERATIONS

Most zoned smoke control systems use the fans of the HVAC system to control smoke movement as follows:

- Smoke Zone - In the smoke zone, 100 percent of the return air is exhausted to the outside and supply air to the smoke zone is shut off. Alternately exterior wall vents or smoke shafts may be used.

- Non-Smoke Zone - In the nonsmoke zones, supply air is 100 percent outside air and the exhaust air is shut off.

- Stairwells - To further protect escape routes, zoned smoke control systems may include stairwell pressurization.

The pressure differences across the boundary of the smoke control zone depend on the supply and exhaust rates and the leakage characteristics of the building. The supply and exhaust rates of zoned smoke control systems have, in the past, been determined by the capacity of the HVAC system, which is usually four to six air changes per hour. Based on tests by Tamura [1,3], these capacities can produce significant pressure differences across the boundary of the smoke control zone when all doors are closed. However, when stairwell doors are open both to the smoke zone and to nonsmoke zones, the pressure difference across the boundary of the smoke zone can drop as low as 0.01 in H_2O (2.5 Pa). Such a low level of pressurization may be sufficient to control smoke from a sprinklered fire or a smoldering fire, but it would not control the movement of hot, buoyant smoke from an unsprinklered fire.

By proper selection of the smoke zone, hot buoyant smoke can be controlled even when stairwell doors are open. If the smoke zone consists of the fire floor and the adjacent floors, then the smoke that migrates to the adjacent floors will be cooled due to dilution and heat transfer. Design of a system to control such cooled smoke is much less difficult than for hot smoke. Obviously, the adjacent floors as well as the fire floor should be evacuated as soon as possible after fire detection.

6.6 EXAMPLE ANALYSIS

This is an example of a twelve-story building with two stairwells and two elevator shafts with two cabs in each shaft. Each floor of the building is 126 x 146 ft (38.4 x 44.5 m) with a height between floors of 10.6 ft (3.23 m). The smoke zone consists of the fire floor and the floors directly above and below, and all other floors are nonsmoke zones. In the smoke control mode, the HVAC system supplies 4080 cfm (1.93 m^3/s) per floor of 100 percent outside air to all nonsmoke zones and exhausts 4080 cfm (1.93 m^3/s) per floor to the outside from the smoke zone. The building has an open floor plan on each floor, so there are no partitions to complicate air flow on each floor.

The stairwells are to be pressurized with an automatically opened ground floor door for overpressure relief. The project is a retrofit, and it has been determined that there are no unusually high local wind velocities near the exterior stairwell doors so that wind effects will not be significant. Stairwell pressurization air is supplied at a rate of 1200 cfm (0.566 m^3/s) at the 5th, 8th and 11th floors and 9200 cfm (4.34 m^3/s) at the 2nd floor.

The design temperatures are:

$14^{o}F$ ($-10^{o}C$) outside winter design temperature
$93^{o}F$ ($34^{o}C$) outside summer design temperature
$70^{o}F$ ($21^{o}C$) building design temperature

Because of symmetry, the building can be analyzed on a basis of one stairwell and one elevator shaft. The following design values are for half the floor area, one stairwell, and one elevator shaft.

- 1.22 ft^2 (0.113 m^2) flow area between building and the outside (based on a leaky building as listed in appendix C)
- 0.490 ft^2 (0.0455 m^2) flow area between floors of the building
- 0.323 ft^2 (0.030 m^2) flow area between the stairwell and the building on each floor with stairwell doors closed
- 10.5 ft^2 (0.075 m^2) flow area of open stairwell door (half the geometric area of the open stairwell door, see section 2.8)
- 1.75 ft^2 (0.163 m^2) flow area between the building and the elevator shaft, per floor
- 3.00 ft^2 (0.279 m^2) flow area of the vent from the top of the elevator shaft to the outside at the penthouse level (for the difference between vent area and flow area of a vent see section 2.8)
- 80 fpm (0.38 m/s) minimum velocity through an open stairwell doorway into the smoke zone
- 1680 cfm (0.793 m^3/s) minimum flow through an open stairwell doorway into the smoke zone, based on stairwell door area of 21 ft^2 (1.95 m^2)
- 0.08 in H_2O (20.0 Pa) minimum pressure difference across closed stairwell door to smoke zone

- 0.40 in H_2O (125 Pa) maximum pressure difference across closed stairwell door to smoke zone

- 7.0×10^4 (2100) C_S for stairwell

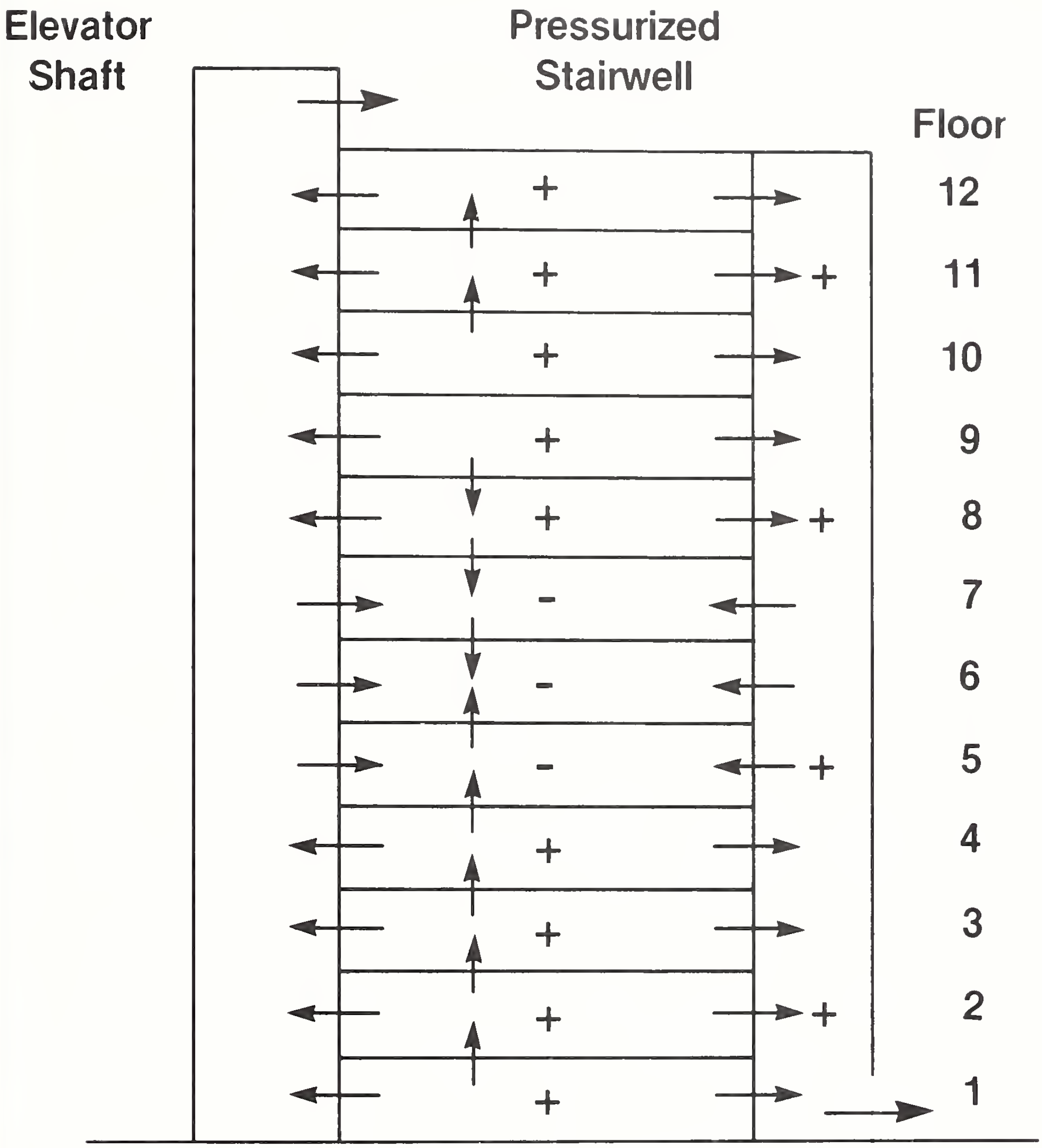
- 2.4×10^5 (7200) C_S for elevator shaft

The computer program described in chapter 3 was used for this analysis. Figure 6.4 shows the air flow directions when the 6th floor is the fire floor and all stairwell doors to the building are closed. Table 6.1 shows the pressure differences calculated by computer analysis across the closed stairwell fire floor door with all stairwell doors closed except the ground floor exterior door. These pressures are within the limits listed above.

Table 6.1 Computer calculated pressure difference across closed fire floor door with all stairwell doors to the building closed

Fire Floor	Smoke Zone Floors	Season	Pressure Difference in H_2O	(Pa)
1	1, 2	Summer	0.170*	(42.3)
6	5, 6, 7	Summer	0.163	(40.6)
12	11, 12	Summer	0.151	(37.6)
1	1, 2	Winter	0.150*	(37.3)
6	5, 6, 7	Winter	0.238	(59.2)
12	11, 12	Winter	0.317*	(78.9)

*Data and computer output for these cases are provided in appendix F.



Notes:

Arrows indicate the direction of air flow as determined by computer analysis.

\+ Indicates supply air which is 100% outside air; in building spaces so noted the return is shut off

\- Indicates 100% return to the outside and supply shut off

Figure 6.4. Building with example zoned smoke control system where 6th floor is fire floor

The average air velocity through the open fire floor stairwell door is listed in table 6.2 for a number of conditions. It is obvious that these velocities are always greater than the minimum allowable design velocity.

Table 6.2 Computer calculated average velocities through open stairwell doorways on the fire floor

Fire Floor	Smoke Zone Floors	Floors on which Doors are Open	Velocities Summer fpm	Summer (m/s)	Winter fpm	Winter (m/s)
1	1, 2	1	121	(0.615)	145	(0.737)
1	1, 2	1, 2	84	(0.427)	102	(0.518)
6	5, 6, 7	6	154*	(0.782)	217*	(1.10)
6	5, 6, 7	5, 6, 7	91*	(0.462)	128	(0.650)
6	5, 6, 7	3, 4, 6, 8, 9	165*	(0.838)	205	(1.04)
12	11, 12	12	129	(0.655)	189	(0.960)
12	11, 12	11, 12	95	(0.483)	143	(0.726)

*Data and computer output for these cases are provided in appendix F.

In all the cases, the smoke zone was at a lower pressure than the surrounding zones so that smoke would not infiltrate non-smoke zones. This system has the advantage that the pressure across closed smoke zone stairwell doors does not fall to very low levels when other stairwell doors are open. This can be observed from the selected computer output listed in appendix F.

6.7 REFERENCES

[1] Tamura, G. T., Exterior Wall Venting for Smoke Control in Tall Office Buildings, ASHRAE Journal, Vol. 20, No. 8, pp. 43-48, August 1978.

[2] Tamura, G. T. and Shaw, C. Y., Basis for the Design of Smoke Shafts, Fire Technology, Vol. 9, No. 3, pp. 209-222, August 1973.

[3] Tamura, G. T., Experimental Studies of Mechanical Venting for Smoke Control in Tall Office Buildings, ASHRAE Transactions 1978, Vol. 86, Part 1, pp. 54-71, 1978.

CHAPTER 7.
ACCEPTANCE TESTING

Acceptance tests can be considered from the viewpoint of the building owner or from the viewpoint of the local code official or even from both viewpoints. The building owner wants to be assured that the building has been constructed in accordance with the construction contract. The code official wants to be assured that the building has been constructed in accordance with the appropriate codes. Acceptance tests of smoke control systems should be designed to satisfy both requirements. In this chapter, procedures used for acceptance testing of smoke control systems are discussed.

Balancing of the smoke control system is a subject that should be considered before acceptance testing. It should be noted that many smoke control systems require balancing, particularly multiple-injection pressurized stairwells, relief vents (if provided) in pressurized stairwells, and supply air to pressurization systems.

An adequate acceptance test is composed of two levels of testing. The first level is of a functional nature to determine if everything in the system works as it is supposed to work; this is an initial checkout of the system components. The second level of testing is of a performance nature to determine if the system, as a system, performs under all required modes of operation. This part of the acceptance test may be performed by pressure and velocity testing, real fire testing, chemical smoke testing, tracer gas testing, or various combinations of these methods.

The minimum essential performance test is the pressure and velocity test, and any additional performance tests should be performed after that. An acceptance test is needed to assure the owner and the code official that the system, as built, will operate as intended.

7.1 INITIAL CHECKOUT

The initial checkout should be the first phase of any acceptance test. This consists of activating the smoke control system and determining that the fans, dampers, and other components are functioning properly. The importance of the initial checkout has become apparent because of many problems encountered during tests of smoke control systems. These problems include fans operating backward, fans to which no electrical power is supplied, and controls that do not operate. Depending on the type of smoke control system, it may be necessary to test several times for changes caused by differing fire locations and the corresponding modes of system operation.

Once any such problems are corrected, pressure and velocity tests should be performed under all required modes of operation.

7.2 PRESSURE AND VELOCITY TESTS

These tests consist of activating the smoke control system in its various operating modes and measuring the pressure differences and velocities at the boundary points in the system. Comprehensive testing at the system boundary under all operating modes should be conducted. The actual pressures and velocities are likely to be somewhat different from the design values because of differences in flow areas and the outside temperature. Acceptance of a smoke control system should be based on its ability to perform within the minimum and maximum pressure differences and the minimum and maximum velocities that were the design parameters of the system. In order to obtain such performance, it may be necessary to adjust the smoke control system. For this reason, the concept of system flexibility has been included in preceding chapters.

In many instances, this level of testing may be considered sufficient. However, in cases of complicated buildings or untried smoke control concepts, the application of one or more of the other forms of testing may be warranted.

Pressure and velocity testing can be performed only at a relatively small number of discrete points in the system boundary. These points generally are on the more obvious migration or infiltration routes. Therefore, during the pressure and velocity test, it is possible to miss a potential path of smoke movement. The intent of using real smoke, chemical smoke or a tracer gas is to uncover such a flow in a smoke control system.

7.3 REAL FIRES

A real fire is the most realistic method of testing the ability of a smoke control system to control smoke movement. However, this test has inherent danger to life and property because of the heat generated and the toxicity of the smoke. Therefore, remote instruments are used so that observers are not subjected to danger. The fire compartment and other areas must be fire-hardened to prevent property damage, but smoke damage can still occur at locations remote from the fire. In addition, construction and any other activities must be suspended in the building during a fire test.

7.4 CHEMICAL SMOKE

The most common source of chemical smoke is the commercially available "smoke candle" (sometimes called a smoke bomb). In this test, the smoke candle is usually placed in a metal container and ignited. The metal container is for protection from heat damage after ignition - it does not inhibit observation of the movement of the chemical smoke. Care must be exercised during observations, because inhalation of chemical smoke can cause nausea.

This type of testing is less realistic than real fire testing because chemical smoke is cold and lacks the buoyancy of smoke from a flaming fire. Such buoyancy forces can be sufficiently large to overpower a smoke control system that was not designed to withstand them. Chemical smoke tests have been conducted where the chemical smoke has been heated by a gas burner in order to overcome the drawback of little or no heat-induced buoyancy. Unfortunately, such a test has many of the drawbacks of a real fire test.

Smoke from a sprinklered fire has little buoyancy, and so it may be expected that such smoke movement is similar to the movement of unheated chemical smoke. This has not yet been confirmed by test data. Chemical smoke testing can identify leakage paths, and such tests are simple and inexpensive to perform.

7.5 TRACER GAS TESTS

In these tests, a constant flow rate of a tracer gas is released in a building. Samples are collected throughout the building and are analyzed to determine possible paths of smoke movement in the event of a real fire. The tracer gas most commonly used is sulfur hexaflouride (SF_6) because it is non-flammable, colorless, odorless, virtually nontoxic*, and chemically stable. These attributes result in tests that do not interfere with the normal operation of the facility being tested. In addition, SF_6 is virtually unused industrially, which essentially eliminates the chance of interference from another source.

SF_6 is commercially available and is stored as a liquid at 320 psi (2.2 MPa) at 70°F (21°C). A constant flow rate of gaseous SF_6 can be maintained by using a pressure regulator and a flowmeter such as a rotameter. The flowmeter should be specifically calibrated for SF_6. Flow rates in the ranges of 2 to 10 mL/min have been used.

Traditionally, air samples have been collected in hypodermic syringes and analyzed in a batch mode on a gas chromatograph fitted with an electron capture cell and an appropriate column for separation of SF_6 from other gases. Continuous sampling using a gas chromatograph is also possible. Gases of standard concentrations of SF_6 are commercially available for calibration of the gas chromatograph. Gas chromatographs can analyze SF_6 in the range of 0 to 180 ppb, and samples of higher concentration should be diluted for analysis. Caution should be exercised because, at high concentrations, SF_6 can permeate some materials and thus contaminate any air samples that might

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*OSHA concentration limit of SF_6 is 1,000 ppm as set forth in the Federal Register, Vol. 36, No. 157, August 13, 1971. However, in smoke control testing, concentrations generally do not exceed 2 ppm.

contact these materials. Because of the many possibilities of error, the tester must adhere rigorously to good testing methods.

Tracer gas testing has the advantage of identifying leakage paths and determining if a smoke control system can control the movement of a nonbuoyant gas. Because gaseous SF_6 is invisible, careful selection of the locations to be sampled is important.

A major drawback to the use of tracer gas testing is, again, the lack of buoyancy in the gas, i.e., the gas is typically at an ambient temperature when released. To overcome this deficiency, the air and SF_6 mixture can be heated, but caution should be exercised, because at high temperatures SF_6 can degenerate into toxic components. As with chemical smoke, unheated SF_6 movement is likely to be similar to that of smoke from a sprinklered fire, but, this has not yet been confirmed by test data.

Because of the many possibilities of error and the limitations discussed above, tracer gas tests should be conducted and evaluated with a high level of professional competance. It is not believed that tracer gas testing will become a routine method of acceptance testing smoke control systems.

APPENDIX A. NOTATION

A	area
a	purging rate
b	temperature factor
C	flow coefficient, general coefficient, or contaminant concentration
C_o	initial contaminant concentration
C_w	pressure coefficient
c	specific heat
d	distance from doorknob to knob side of door
E	energy release rate
F	force
G	flow factor
g	gravitational constant
H	height of stairwell
Hm	height limit
h	height
K_S	coefficient for stack effect and buoyancy equations
K_w	coefficient from wind pressure equation
K_v	coefficient from the Thomas equation for critical air velocity
K_f	coefficient from the flow equation
K_d	coefficient from the door opening force equation
K_g	coefficient from equation for flow factor, G
$\dot{m}$	mass flow rate

$\dot{m}_o$ mass flow from outside

$\dot{m}_f$ net mass flow rate due to HVAC system or to pressurization system

$\dot{m}_u$ upward mass flow in shaft

N number of floors

P pressure

P_{atm} atmospheric pressure

Q volumetric flow rate

R gas constant of air

T absolute temperature

t time

V velocity

W width

ΔP pressure difference

$\overline{\Delta P}$ average pressure difference

ρ density

Subscripts

B building

b bottom of stairwell or stairwell section

dc door closer

e equivalent

F fire compartment

g geometric

h distributed per unit height

I inside

k critical

max maximum

min minimum

O	outside
S	stairwell
T	total
t	top of stairwell or stairwell section
w	wind

APPENDIX B.
GRAPHS

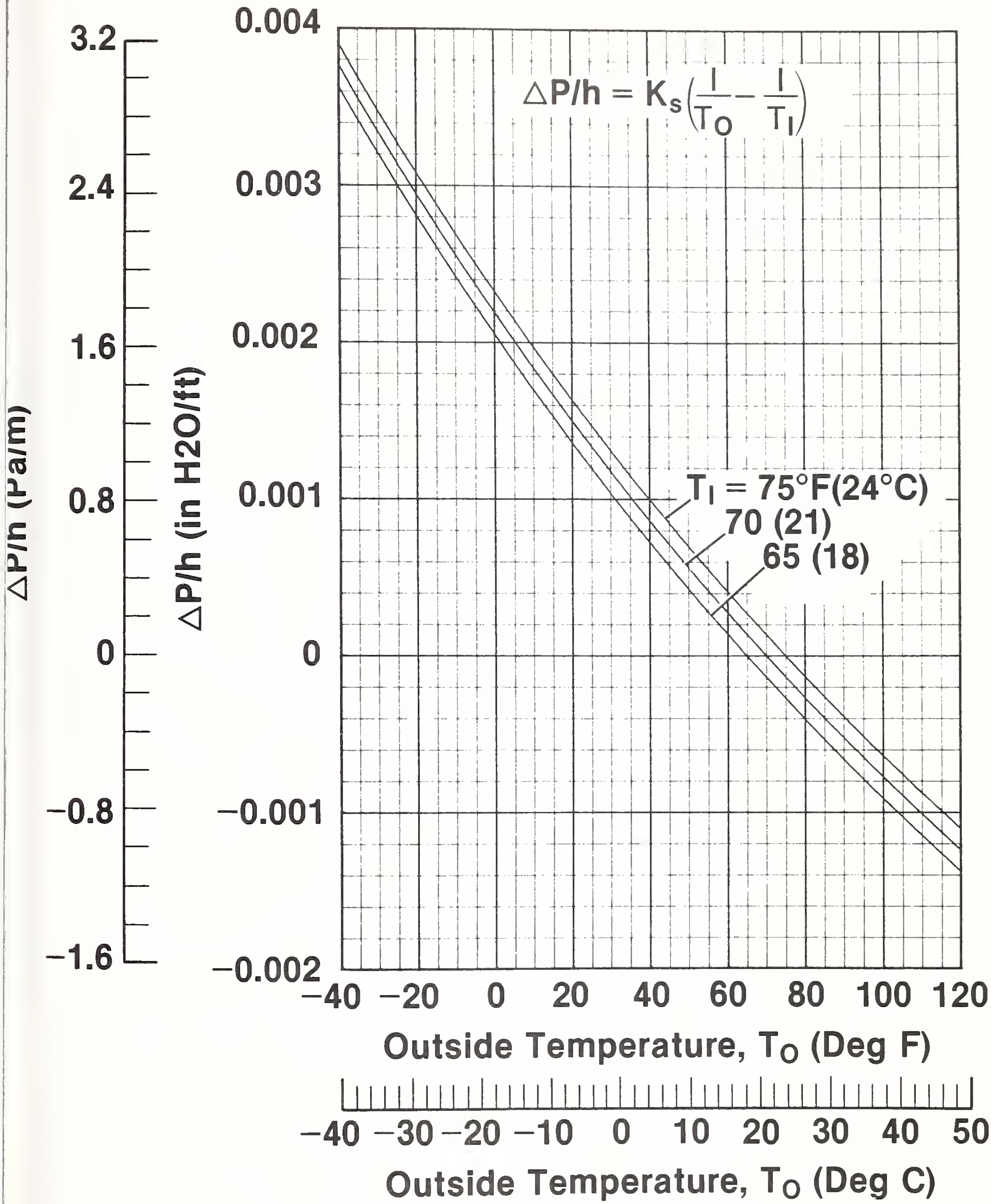

Figure B.1. Pressure difference due to stack effect (see Section 2.1.1).

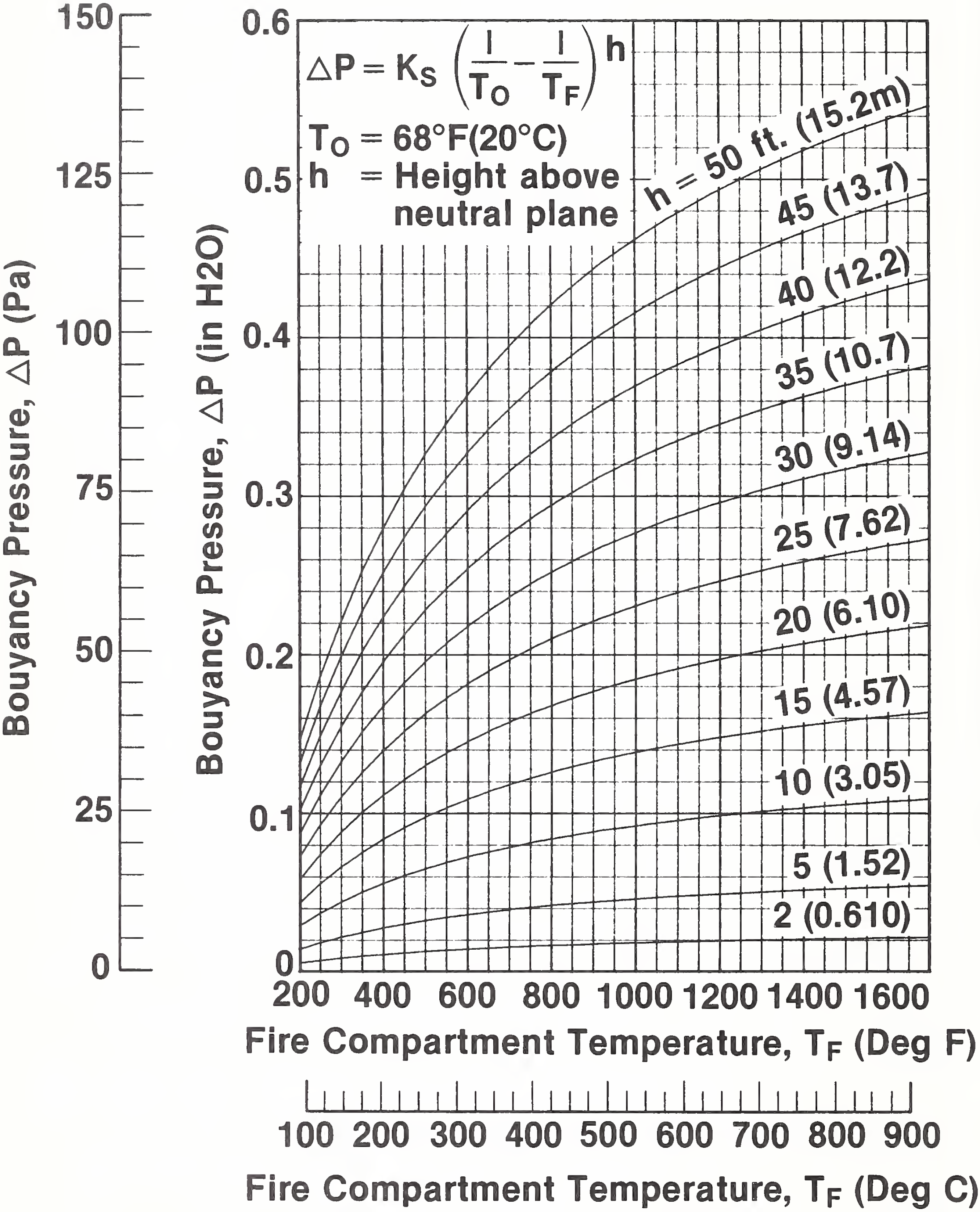

Figure B.2. Pressure difference due to buoyancy (see Section 2.1.2).

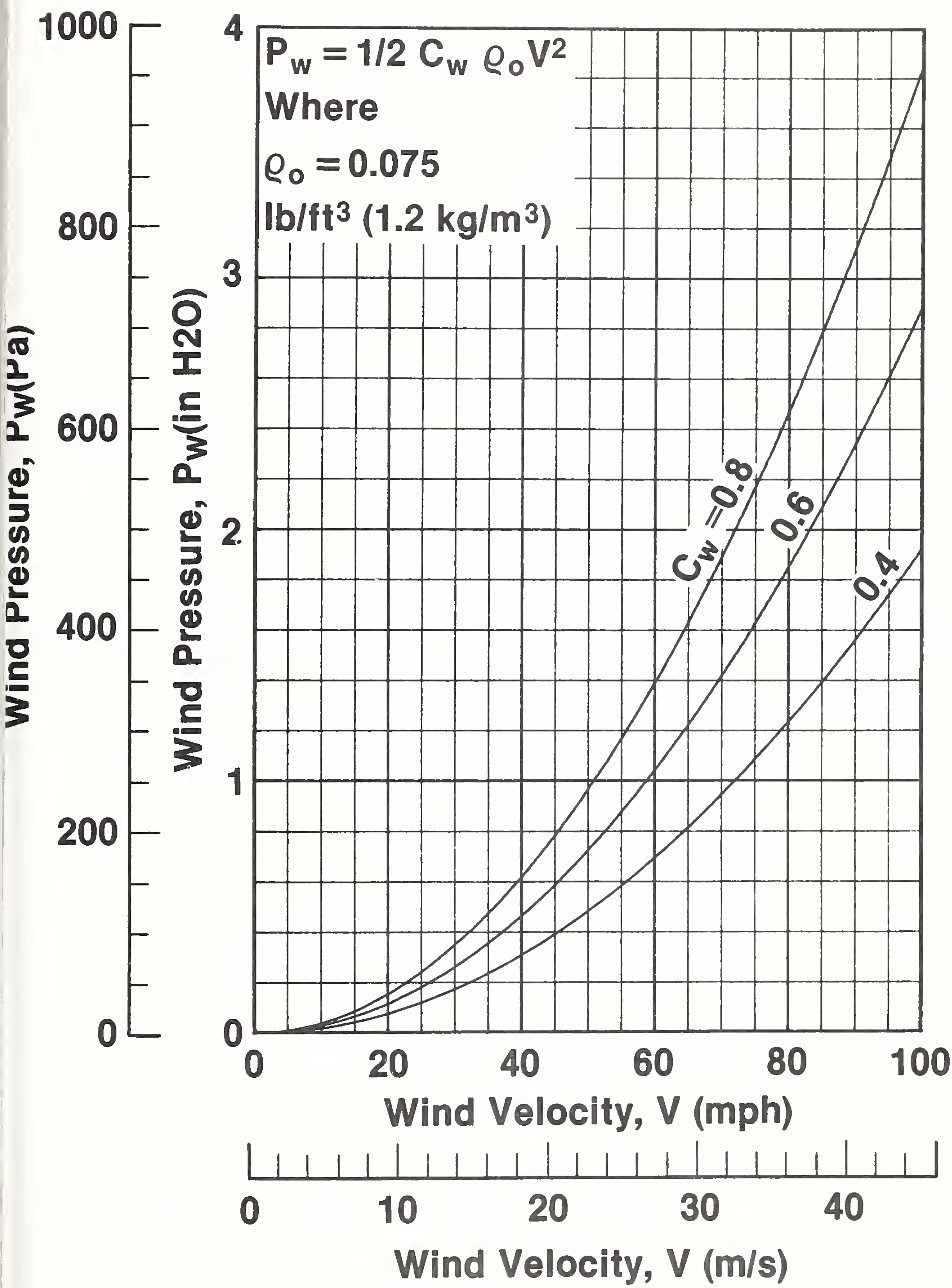

Figure B.3. Pressure due to wind
(see Section 2.1.4).

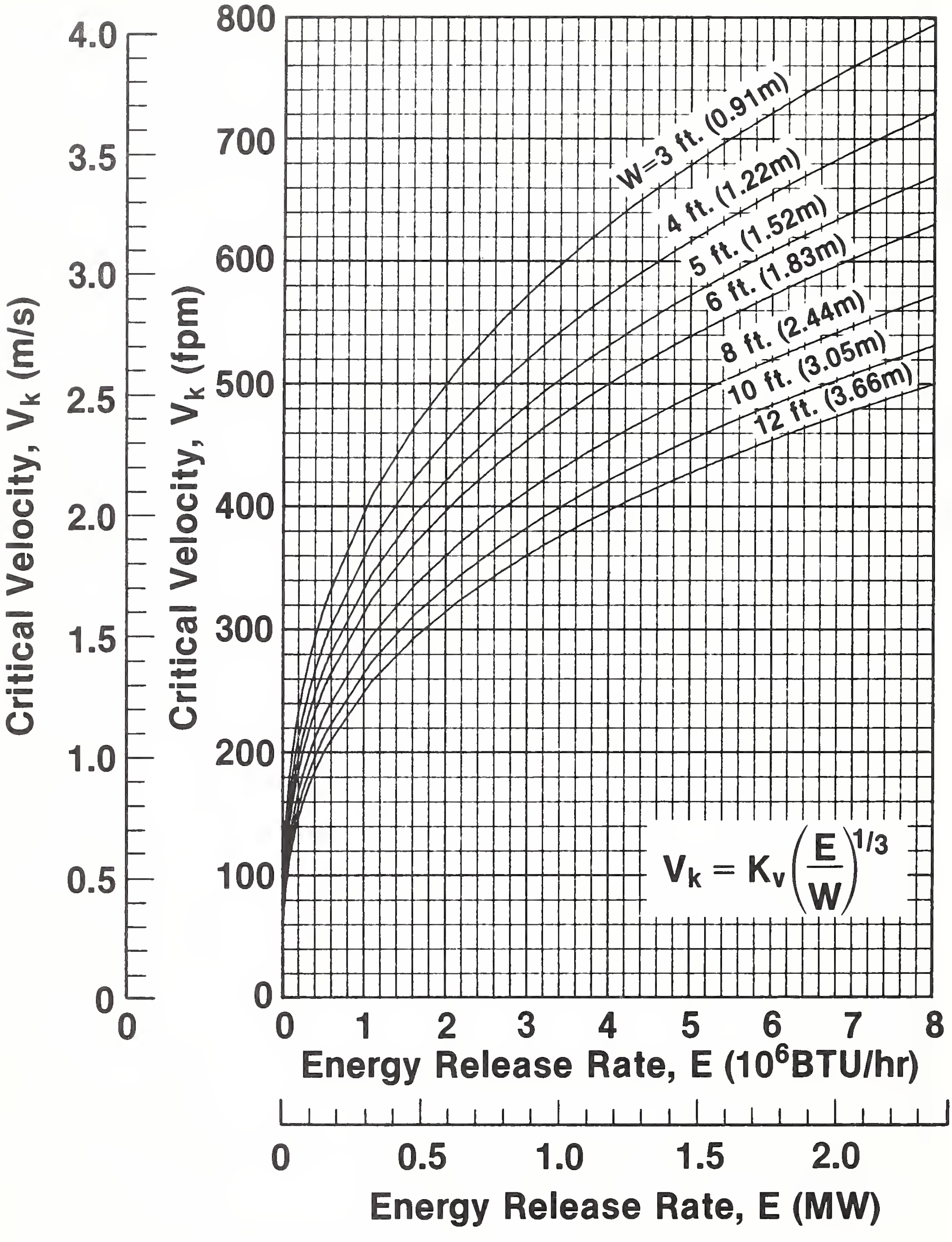

Figure B.4. Critical velocity to prevent smoke backflow

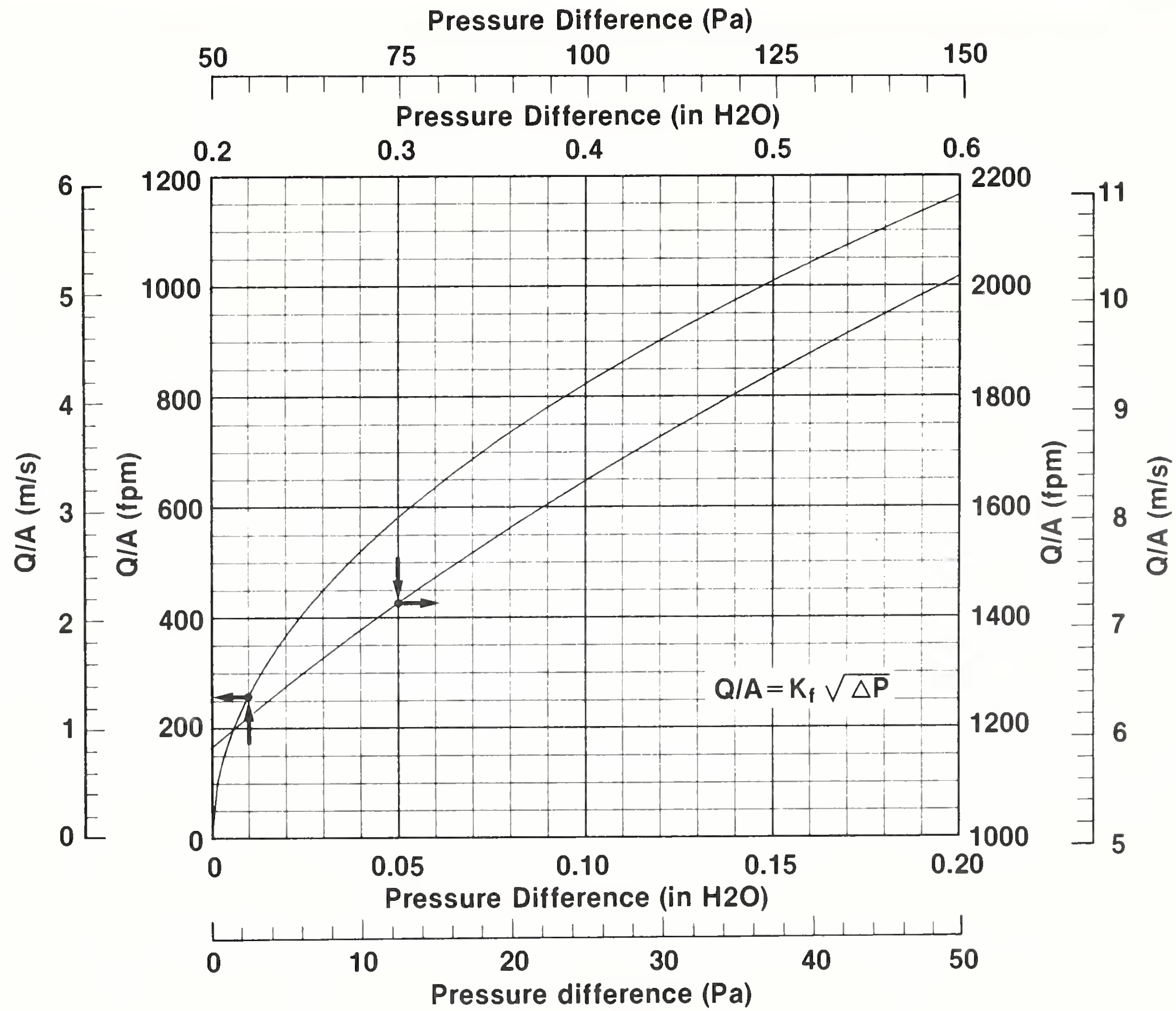

Figure B.5. Air flow due to differential pressure (see Section 2.3.2).

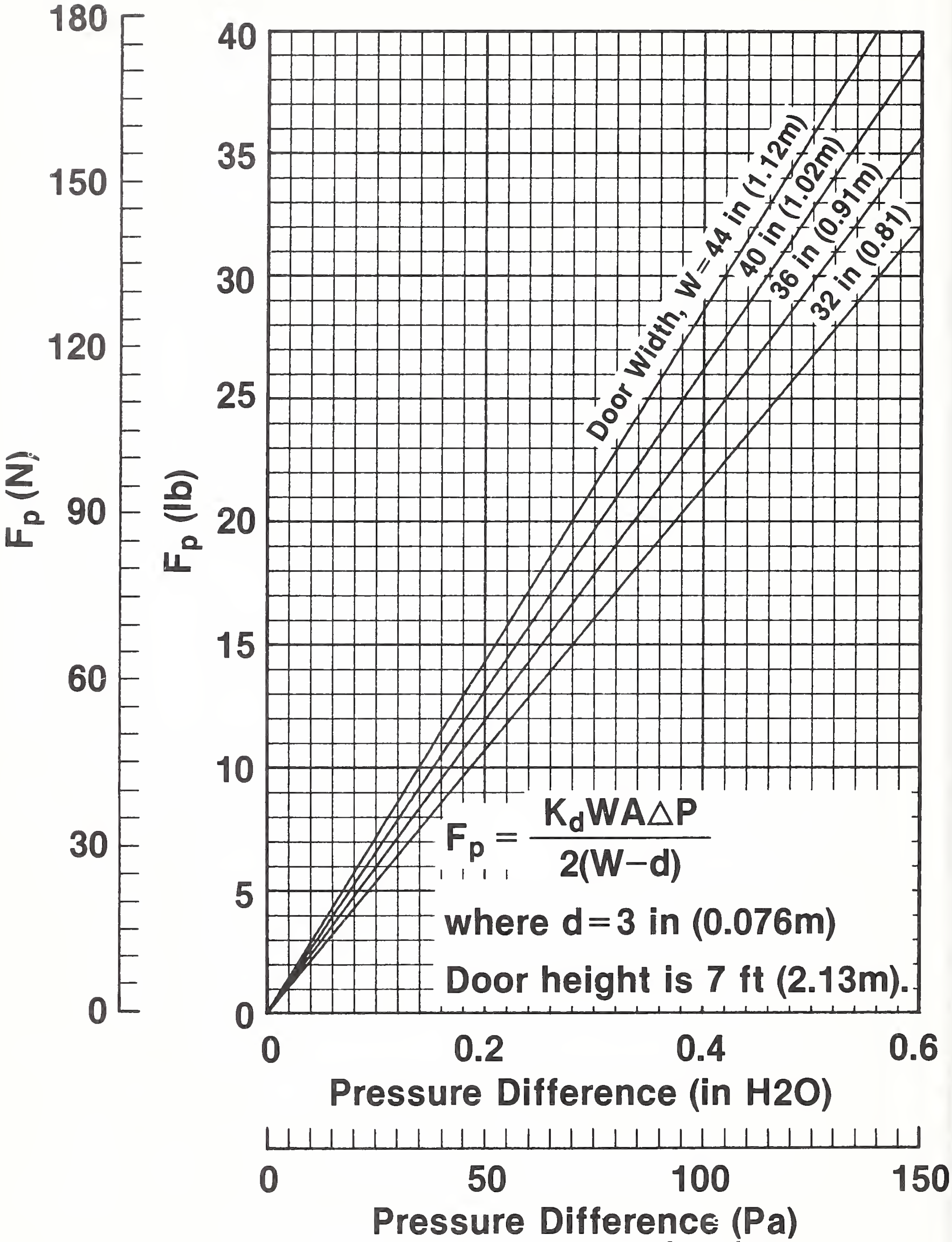

Figure B.6. Door opening force due to a pressure difference (see Section 2.4).

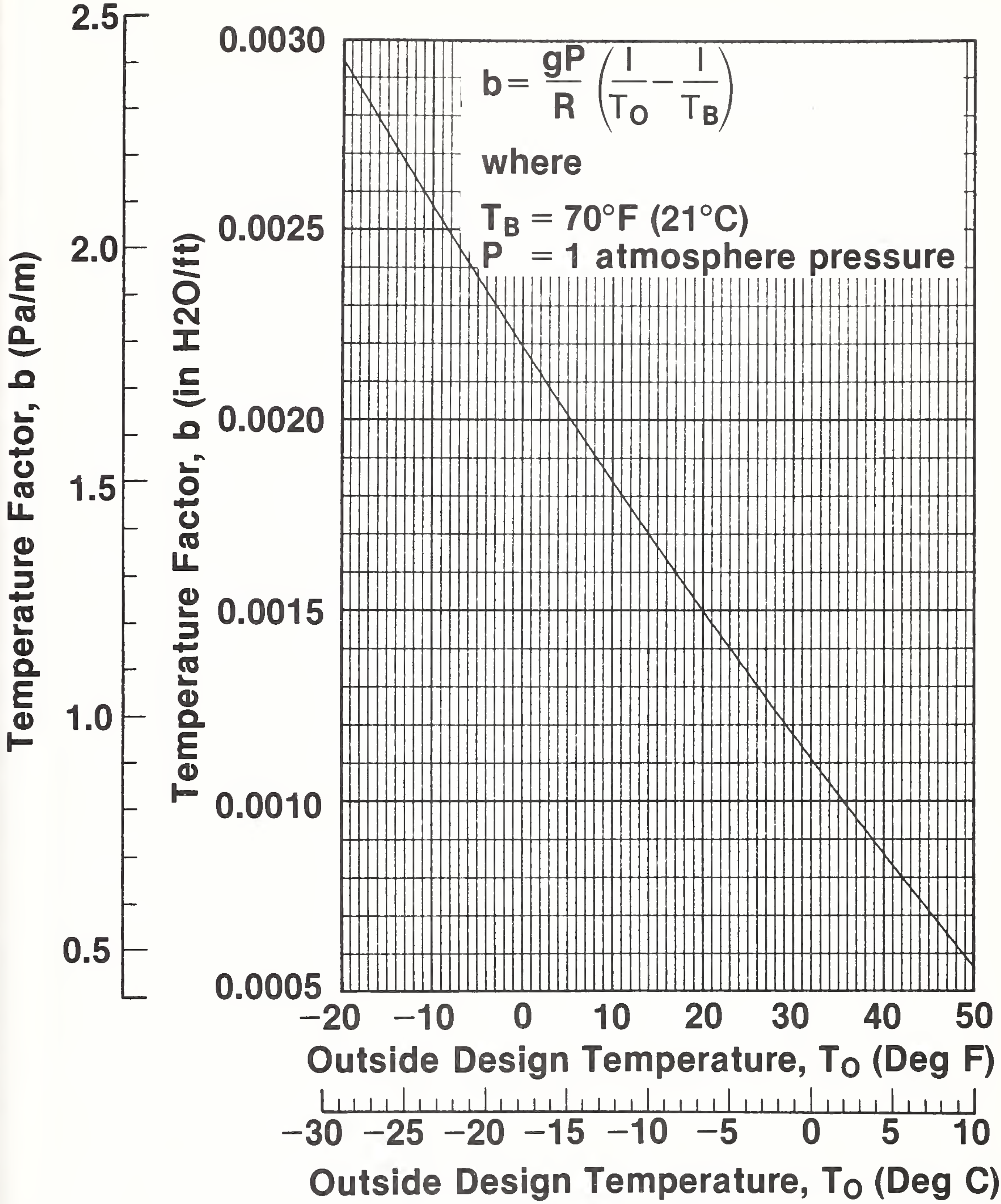

Figure B.7. Temperature factor (see Section 4.3.2).

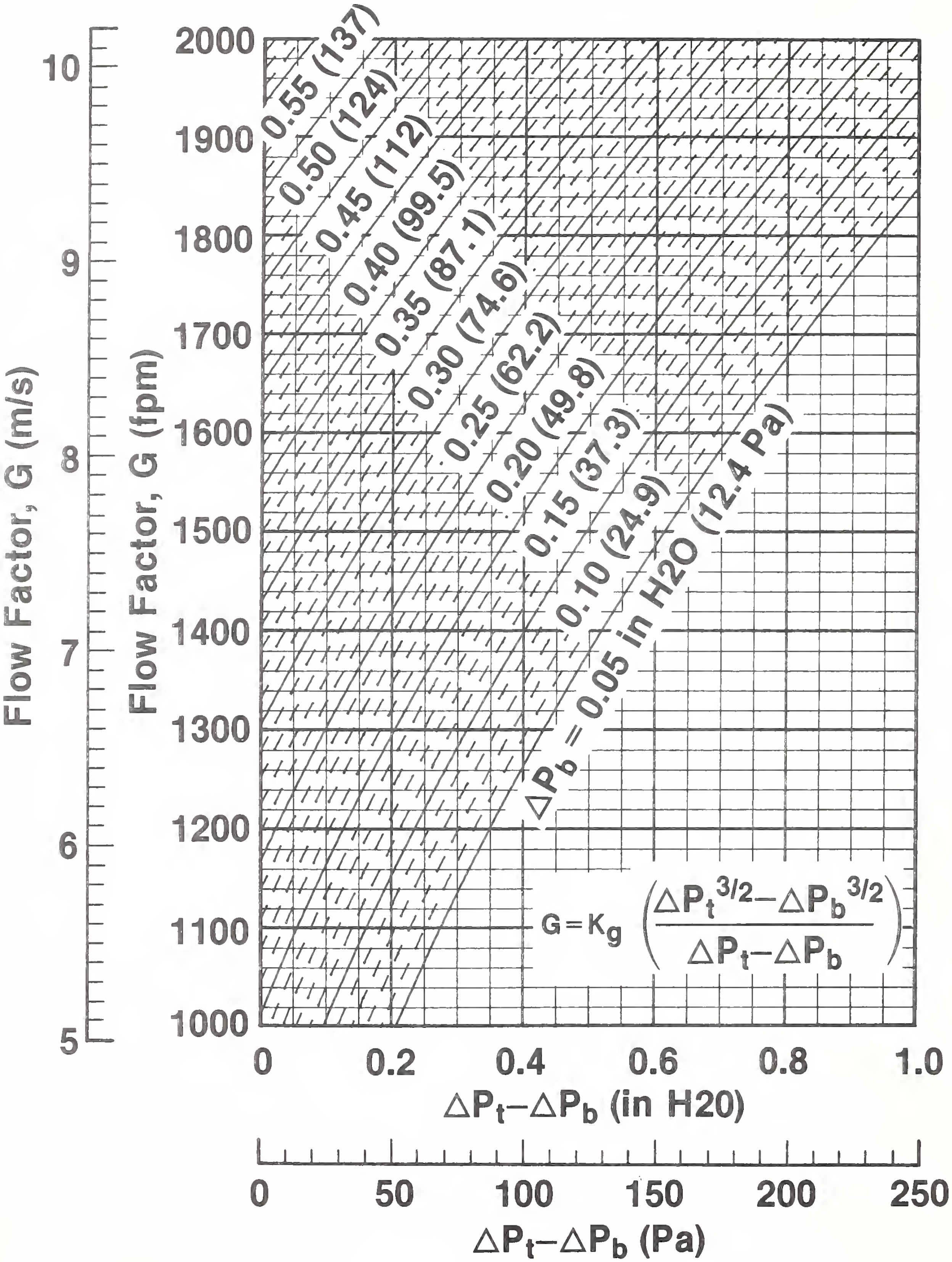

Figure B.8. Flow factor (see Section 4.3.2).

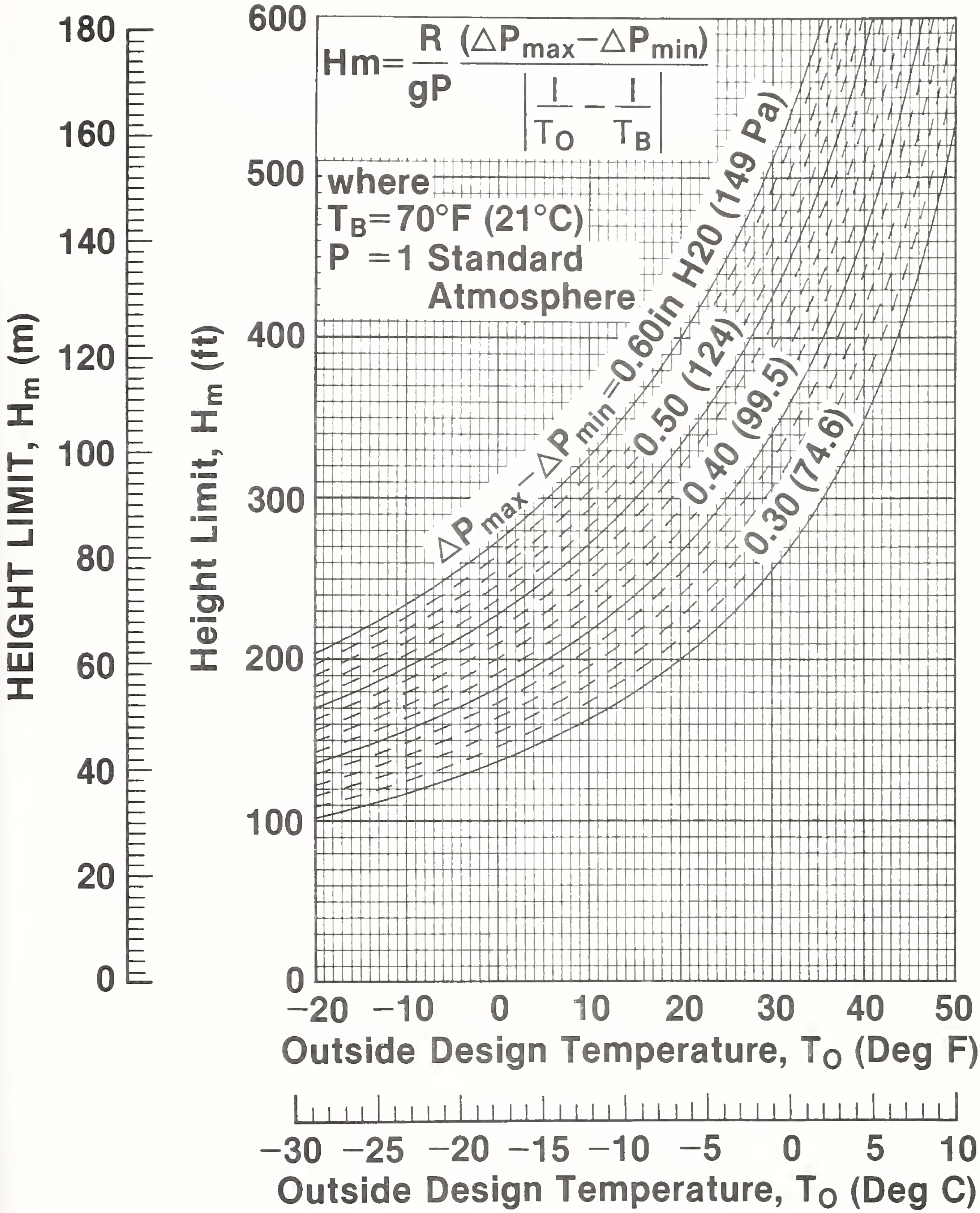

Figure B.9. Height limit for a pressurized stairwell in a building without vertical leakage (see Section 4.4.)

APPENDIX C.
TYPICAL LEAKAGE AREAS FOR WALLS AND FLOORS OF COMMERCIAL BUILDINGS

Construction Element	Wall Tightness	Area Ratio A/Aw
Exterior Building Walls (includes construction cracks, cracks around windows and doors)	Tight [1]	0.70×10^{-4}
	Average [1]	0.21×10^{-3}
	Loose [1]	0.42×10^{-3}
	Very Loose [2]	0.13×10^{-2}
Stairwell Walls (includes construction cracks but not cracks around windows or doors)	Tight [3]	0.14×10^{-4}
	Average [3]	0.11×10^{-3}
	Loose [3]	0.35×10^{-3}
Elevator Shaft Walls (includes construction cracks but not cracks around doors)	Tight [3]	0.18×10^{-3}
	Average [3]	0.84×10^{-3}
	Loose [3]	0.18×10^{-2}
		A/A_F
Floors (includes construction cracks and cracks around penetrations)	Average [4]	0.52×10^{-4}

A = leakage area
Aw = wall area
A_F = floor area

All of the above area ratios are based on a relatively small number of tests and actual values may vary considerably from the range indicated. Leakage areas are highly dependent upon the quality of construction. Area ratios are evaluated at typical air flows at 0.30 in H_2O (75 Pa) for walls, and 0.10 in H_2O (25 Pa) for floors based on field tests of buildings described in references below.

[1] Tamura, G. T. and Shaw, C. Y., Studies on Exterior Wall Air Tightness and Air Infiltration of Tall Buildings, ASHRAE Transactions 1976, Vol. 82, Part I, pp. 122-134, 1976.

[2] Tamura, G. T. and Wilson, A. G., Pressure Differences for a 9-Story Building as a Result of Chimney Effect and Ventilation System Operation, ASHRAE Transaction 1966, Vol. 72, Part I, pp. 180-189, 1966.

[3] Tamura, G. T. and Shaw, C. Y., Air Leakage Data for the Design of Elevator and Stair Shaft Pressurization Systems, ASHRAE Transaction 1976, Vol. 83, Part 2, pp. 179-190, 1976.

[4] Tamura, G. T. and Shaw, C. Y., Experimental Studies of Mechanical Venting for Smoke Control in Tall Office Buildings, ASHRAE Transaction 1978, Part 1, Vol. 86, pp. 54-71, 1978.

APPENDIX D. DATA INPUT DESCRIPTION FOR COMPUTER PROGRAM

Data input consists of the following elements:

1. Initial data;
2. building heights;
3. temperature profiles;
4. outside pressure profiles;
5. building data;
6. shaft data.

In the following sections, the input required for each of the six data elements is described in detail. Each block or group of blocks below represents an input card. Unless otherwise stated, these cards are unformatted, that is, the numbers do not have to be placed in specific columns and integers can be written with or without decimal points. However, separate pieces of numerical data must be separated by one or more spaces. Examples of input data are provided in Appendices E and F.

1. Initial data

project title (col. 1-72)

outside temperature (^oF, ^oC)	unit indication (2 for Eng, 1 for SI)	summary output (o for none, or file number)*

*The user must assign this file before program execution.

2. Building heights

N_h, no. of building levels

input parameter (either 0 or 1)

If input parameter = 0, then heights for each building level are to be individually entered as follows:

$h_{(1)}$ $h_{(2)}$ $h_{(3)}$ . . . $h_{(i)}$ . . . $H_{(N_h)}$

where $h_{(i)}$ is the height of the center of level 1 above the ground (ft, m). If input parameter = 1, then the following card must be entered.

$h_{(1)}$

distance between floors (ft, m)

3. Temperature profiles

no. of temperature profiles

For each temperature profile the following data must be supplied.

no. of temp. points	level no.	temperature (^oF, ^oC)	level no.	temperature (^oF, ^oC)	level no.	temperature (^oF, ^oC)

4. Outside pressure profiles

N_{po} no. of outside pressure profiles	input parameter (either 0 or 1)

If the input parameter = 0, each outside pressure profile is entered as follows:

$P_{o(1)}$	$P_{o(2)}$	$P_{o(3)}$		$P_{o(i)}$		$P_{o(N_h)}$
			. . .		. . .	

where $P_{o(i)}$ is the outside pressure at the center of level i.

If the input parameter = 1, the outside pressures are calculated and the following data are required.

V_o wind velocity (mph)	h_o height at which velocity is measured	n wind exponent

pressure coefficients for each pressure profile

$C_{W(1)}$ $C_{W(2)}$ . . . . $C_{W(Npo)}$

5. Building data

N_f
no. of levels (or floors)

All the following data in this input element are supplied for each level or consecutive groups of similar levels.

I_i	I_2	N_{com}
starting floor	ending floor	no. of compartments per floor

(Floor data is entered in ascending order of levels or floors. When data are for only one level, then $I_1 = I_2$, and the same number is supplied for both.)

For each compartment on a level the following data are supplied.

N_{CS}	N_{CA}	N_{CO}	N_f	
no. of connections to other compartments on the same level	no. of connections to compartments on the level above	no. of connections to the outside	net flow* (cfm, L/s)	temperature profile number

*All net flows are at standard conditions of 70°F (21°C) and one atmosphere.

For each connection between this compartment and another on the same floor the following data are required.

other compartment number on the same level	C flow coefficient	A flow area (ft^2, m^2)

For each connection between this compartment and one on the level above the following data are required.

other compartment number on floor above	C flow coefficient	A flow area (ft^2, m^2)

For each connection to the outside the following data are required.

outside pressure profile number	C flow coefficient	A flow area (ft^2, m^2)

6. Shaft data

no. of shafts

[ ]

All of the following data in this input element are required for each shaft.

shaft title (col. 1-20)

[ ]

C_s shaft flow coefficient	bottom level of shaft	top level of shaft	temperature profile number
[ ]	[ ]	[ ]	[ ]

Enter the following typical data, which applies to each level of the shaft. Exceptions can be entered later.

no. of connections between typical level of shaft and outside	F_f net flow into typical level of shaft (cfm, L/s)
[ ]	[ ]

The connection data to the building for a typical level are required.

compartment no. to which shaft is connected	C flow coefficient	A flow area (ft^2, m^2)
[ ]	[ ]	[ ]

For each connection to the outside, the connection data for a typical floor are required.

outside pressure profile	C flow coefficient	A flow area (ft^2, m^2)

The number of exceptions to the typical data is required.

no. of exceptions

All the following data in this input element are required for each exception.

exception type (1, 2, or 3)	level of shaft

The next card depends on the exception type. For exception type = 1, an exception to the net flow into the floor of the shaft is defined.

F_f
net flow
(cfm, L/s)

For exception type = 2, an exception to an outside connection for this shaft is defined.

outside pressure profile number	C flow coefficient	A flow area (ft^2, m^2)

For exception type = 3, an exception to the connection between the shaft and the building is defined.

compartment no. to which shaft is connected	C flow coefficient	A flow area (ft^2, m^2)

APPENDIX E.
DATA AND COMPUTER OUTPUT FOR STAIRWELL EXAMPLE OF CHAPTER 5

TABLE OF CONTENTS

Summary Table - Appendix E

Run	Exterior Stairwell Door	Floors on Which Doors Are Open	Season
1	Closed	None	Summer
2	Open	1,2,3	Summer
3	Open	7,8,9	Summer
4	Open	13,14,15	Summer
5	Closed	None	Winter
6	Open	1,2,3	Winter
7	Open	7,8,9	Winter
8	Open	13,14,15	Winter

Note: See chapter 6 for discussion of this example computer analysis of a pressurized stairwell system.

APPENDIX E - RUN 1 DATA

```
SUMMER - ALL DOORS CLOSED
93 2 0
16 1
6 12
2
1 1 70
1 1 82
1 1
0 1 1
1
15
1 15 1
0 1 1 0 1
1 .65 0.85
1 .65 1.13
2
STAIRWELL
7.0E4 1 15 2
0 490
1 .65 0.323
0
ELEVATOR
2.4E5 1 16 1
0 0
1 .65 0.67
1
2 16
1 .65 1.5
```

APPENDIX E - RUN 1 COMPUTER OUTPUT

SUMMER - ALL DOORS CLOSED

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	1	2.950	1	0.	FLOOR 2 COMPARTMENT 1	.001	2216.	.850	66.1
					STAIRWELL	.337	833.	.323	483.0
					ELEVATOR	.018	1746.	.670	236.6
					OUTSIDE DIRECTION 1	-.071	2945.	1.130	-785.6
									.1 NET
2	1	2.778	1	0.	FLOOR 3 COMPARTMENT 1	.002	2216.	.850	99.8
					FLOOR 1 COMPARTMENT 1	-.001	2216.	.850	-66.1
					STAIRWELL	.339	833.	.323	485.0
					ELEVATOR	.017	1746.	.670	230.7
					OUTSIDE DIRECTION 1	-.065	2945.	1.130	-749.0
									.4 NET
3	1	2.607	1	0.	FLOOR 4 COMPARTMENT 1	.003	2216.	.850	114.4
					FLOOR 2 COMPARTMENT 1	-.002	2216.	.850	-99.8
					STAIRWELL	.341	833.	.323	486.2
					ELEVATOR	.015	1746.	.670	216.9
					OUTSIDE DIRECTION 1	-.059	2945.	1.130	-717.5
									.2 NET
4	1	2.437	1	0.	FLOOR 5 COMPARTMENT 1	.003	2216.	.850	119.1
					FLOOR 3 COMPARTMENT 1	-.003	2216.	.850	-114.4
					STAIRWELL	.342	833.	.323	486.9
					ELEVATOR	.013	1746.	.670	197.3
					OUTSIDE DIRECTION 1	-.055	2945.	1.130	-688.6
									.3 NET
5	1	2.267	1	0.	FLOOR 6 COMPARTMENT 1	.003	2216.	.850	118.4
					FLOOR 4 COMPARTMENT 1	-.003	2216.	.850	-119.1
					STAIRWELL	.343	833.	.323	487.5
					ELEVATOR	.010	1746.	.670	173.6
					OUTSIDE DIRECTION 1	-.050	2945.	1.130	-660.0
									.3 NET
6	1	2.097	1	0.	FLOOR 7 COMPARTMENT 1	.003	2216.	.850	113.9
					FLOOR 5 COMPARTMENT 1	-.003	2216.	.850	-118.4
					STAIRWELL	.344	833.	.323	488.1
					ELEVATOR	.007	1746.	.670	146.5
					OUTSIDE DIRECTION 1	-.046	2945.	1.130	-629.8
									.3 NET
7	1	1.927	1	0.	FLOOR 8 COMPARTMENT 1	.002	2216.	.850	106.0
					FLOOR 6 COMPARTMENT 1	-.003	2216.	.850	-113.9
					STAIRWELL	.345	833.	.323	488.8
					ELEVATOR	.004	1746.	.670	116.1
					OUTSIDE DIRECTION 1	-.041	2945.	1.130	-596.7
									.4 NET

APPENDIX E - RUN 1 COMPUTER OUTPUT

SUMMER - ALL DOORS CLOSED

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
8	1	1.757	1	0.	FLOOR 9 COMPARTMENT	1	.002	2216.	.850	94.0
					FLOOR 7 COMPARTMENT	1	-.002	2216.	.850	-106.0
					STAIRWELL		.346	833.	.323	489.8
					ELEVATOR		.002	1746.	.670	81.2
					OUTSIDE DIRECTION	1	-.036	2945.	1.130	-558.8
										.1 NET
9	1	1.586	1	0.	FLOOR 10 COMPARTMENT	1	.001	2216.	.850	82.8
					FLOOR 8 COMPARTMENT	1	-.002	2216.	.850	-94.0
					STAIRWELL		.348	833.	.323	491.1
					ELEVATOR		.000	1746.	.670	34.6
					OUTSIDE DIRECTION	1	-.030	2945.	1.130	-514.2
										.2 NET
10	1	1.415	1	0.	FLOOR 11 COMPARTMENT	1	.002	2216.	.850	106.3
					FLOOR 9 COMPARTMENT	1	-.001	2216.	.850	-82.8
					STAIRWELL		.350	833.	.323	492.7
					ELEVATOR		-.001	1746.	.670	-54.4
					OUTSIDE DIRECTION	1	-.025	2945.	1.130	-461.5
										.4 NET
11	1	1.245	1	0.	FLOOR 12 COMPARTMENT	1	.003	2216.	.850	123.9
					FLOOR 10 COMPARTMENT	1	-.002	2216.	.850	-106.3
					STAIRWELL		.352	833.	.323	493.7
					ELEVATOR		-.003	1746.	.670	-99.4
					OUTSIDE DIRECTION	1	-.020	2945.	1.130	-411.8
										.1 NET
12	1	1.076	1	0.	FLOOR 13 COMPARTMENT	1	.004	2216.	.850	134.1
					FLOOR 11 COMPARTMENT	1	-.003	2216.	.850	-123.9
					STAIRWELL		.352	833.	.323	494.1
					ELEVATOR		-.006	1746.	.670	-139.0
					OUTSIDE DIRECTION	1	-.015	2945.	1.130	-365.1
										.3 NET
13	1	.908	1	0.	FLOOR 14 COMPARTMENT	1	.004	2216.	.850	133.8
					FLOOR 12 COMPARTMENT	1	-.004	2216.	.850	-134.1
					STAIRWELL		.352	833.	.323	494.1
					ELEVATOR		-.010	1746.	.670	-174.4
					OUTSIDE DIRECTION	1	-.012	2945.	1.130	-319.0
										.3 NET
14	1	.739	1	0.	FLOOR 15 COMPARTMENT	1	.002	2216.	.850	108.3
					FLOOR 13 COMPARTMENT	1	-.004	2216.	.850	-133.8
					STAIRWELL		.352	833.	.323	494.1
					ELEVATOR		-.014	1746.	.670	-203.6
					OUTSIDE DIRECTION	1	-.008	2945.	1.130	-264.6
										.4 NET

APPENDIX E - RUN 1 COMPUTER OUTPUT

SUMMER - ALL DOORS CLOSED

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
15	1	.570	1	0.	FLOOR 14 COMPARTMENT 1	-.002	2216.	.850	-108.3
					STAIRWELL	.354	833.	.323	495.0
					ELEVATOR	-.016	1746.	.670	-220.7
					OUTSIDE DIRECTION 1	-.003	2945.	1.130	-165.8
									.2 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX E - RUN 1 COMPUTER OUTPUT

SUMMER - ALL DOORS CLOSED

STAIRWELL

TEMPERATURE PROFILE 2
SHAFT FLOW COEFFICIENT 70000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	3.287	490.	FLOOR 1 COMPARTMENT 1	-.337	833.	.323	-483.0
2	3.118	490.	FLOOR 2 COMPARTMENT 1	-.339	833.	.323	-485.0
3	2.948	490.	FLOOR 3 COMPARTMENT 1	-.341	833.	.323	-486.2
4	2.779	490.	FLOOR 4 COMPARTMENT 1	-.342	833.	.323	-486.9
5	2.610	490.	FLOOR 5 COMPARTMENT 1	-.343	833.	.323	-487.5
6	2.441	490.	FLOOR 6 COMPARTMENT 1	-.344	833.	.323	-488.1
7	2.272	490.	FLOOR 7 COMPARTMENT 1	-.345	833.	.323	-488.8
8	2.103	490.	FLOOR 8 COMPARTMENT 1	-.346	833.	.323	-489.8
9	1.935	490.	FLOOR 9 COMPARTMENT 1	-.348	833.	.323	-491.1
10	1.766	490.	FLOOR 10 COMPARTMENT 1	-.350	833.	.323	-492.7
11	1.597	490.	FLOOR 11 COMPARTMENT 1	-.352	833.	.323	-493.7
12	1.429	490.	FLOOR 12 COMPARTMENT 1	-.352	833.	.323	-494.1
13	1.260	490.	FLOOR 13 COMPARTMENT 1	-.352	833.	.323	-494.1
14	1.092	490.	FLOOR 14 COMPARTMENT 1	-.352	833.	.323	-494.1
15	.923	490.	FLOOR 15 COMPARTMENT 1	-.354	833.	.323	-495.0
							.2 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

SUMMER - ALL DOORS CLOSED

ELEVATOR

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 240000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.968	0.	FLOOR 1 COMPARTMENT 1	-.018	1746.	.670	-236.6
2	2.796	0.	FLOOR 2 COMPARTMENT 1	-.017	1746.	.670	-230.7
3	2.623	0.	FLOOR 3 COMPARTMENT 1	-.015	1746.	.670	-216.9
4	2.450	0.	FLOOR 4 COMPARTMENT 1	-.013	1746.	.670	-197.3
5	2.277	0.	FLOOR 5 COMPARTMENT 1	-.010	1746.	.670	-173.6
6	2.104	0.	FLOOR 6 COMPARTMENT 1	-.007	1746.	.670	-146.5
7	1.932	0.	FLOOR 7 COMPARTMENT 1	-.004	1746.	.670	-116.1
8	1.759	0.	FLOOR 8 COMPARTMENT 1	-.002	1746.	.670	-81.2
9	1.587	0.	FLOOR 9 COMPARTMENT 1	.000	1746.	.670	-34.6
10	1.415	0.	FLOOR 10 COMPARTMENT 1	.001	1746.	.670	54.4
11	1.242	0.	FLOOR 11 COMPARTMENT 1	.003	1746.	.670	99.4
12	1.070	0.	FLOOR 12 COMPARTMENT 1	.006	1746.	.670	139.0
13	.898	0.	FLOOR 13 COMPARTMENT 1	.010	1746.	.670	174.4
14	.726	0.	FLOOR 14 COMPARTMENT 1	.014	1746.	.670	203.6
15	.554	0.	FLOOR 15 COMPARTMENT 1	.016	1746.	.670	220.7
16	.382	0.					
			OUTSIDE DIRECTION 1	.020	3828.	1.500	542.3
							.4 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX E - RUN 2 DATA

```
SUMMER - OUTSIDE,1ST,2ND,3RD FLOOR DOORS OPEN
93 2 0
16 1
6 12
2
1 1 70
1 1 82
1 1
0 1 1
1
15
1 15 1
0 1 1 0 1
1 .65 0.85
1 .65 1.13
2
STAIRWELL
7.0E4 1 15 2
0 1300
1 .65 0.323
4
2 1
1 .65 10.5
3 1
1 .65 10.5
3 2
1 .65 10.5
3 3
1 .65 10.5
ELEVATOR
2.4E5 1 16 1
0 0
1 .65 0.67
1
2 16
1 .65 1.5
```

APPENDIX E - RUN 2 COMPUTER OUTPUT

SUMMER - OUTSIDE,1ST,2ND,3RD FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	1	3.013	1	0.	FLOOR 2 COMPARTMENT 1	.021	2216.	.850	323.5
					STAIRWELL	.001	27063.	10.500	1047.7
					ELEVATOR	-.028	1746.	.670	-293.1
					OUTSIDE DIRECTION 1	-.134	2945.	1.130	-1078.3
									-.2 NET
2	1	2.861	1	0.	FLOOR 3 COMPARTMENT 1	.019	2216.	.850	301.4
					FLOOR 1 COMPARTMENT 1	-.021	2216.	.850	-323.5
					STAIRWELL	.003	27063.	10.500	1543.2
					ELEVATOR	-.049	1746.	.670	-388.4
					OUTSIDE DIRECTION 1	-.148	2945.	1.130	-1132.9
									-.3 NET
3	1	2.707	1	0.	FLOOR 4 COMPARTMENT 1	-.075	2216.	.850	-606.6
					FLOOR 2 COMPARTMENT 1	-.019	2216.	.850	-301.4
					STAIRWELL	.009	27063.	10.500	2537.5
					ELEVATOR	-.068	1746.	.670	-455.3
					OUTSIDE DIRECTION 1	-.159	2945.	1.130	-1174.7
									-.4 NET
4	1	2.459	1	0.	FLOOR 5 COMPARTMENT 1	-.010	2216.	.850	-217.1
					FLOOR 3 COMPARTMENT 1	.075	2216.	.850	606.6
					STAIRWELL	.113	833.	.323	280.0
					ELEVATOR	.007	1746.	.670	146.0
					OUTSIDE DIRECTION 1	-.077	2945.	1.130	-815.8
									-.3 NET
5	1	2.277	1	0.	FLOOR 6 COMPARTMENT 1	.000	2216.	.850	-42.0
					FLOOR 4 COMPARTMENT 1	.010	2216.	.850	217.1
					STAIRWELL	.148	833.	.323	319.8
					ELEVATOR	.017	1746.	.670	224.8
					OUTSIDE DIRECTION 1	-.060	2945.	1.130	-720.1
									-.4 NET
6	1	2.104	1	0.	FLOOR 7 COMPARTMENT 1	.001	2216.	.850	60.5
					FLOOR 5 COMPARTMENT 1	.000	2216.	.850	42.0
					STAIRWELL	.169	833.	.323	342.2
					ELEVATOR	.017	1746.	.670	227.1
					OUTSIDE DIRECTION 1	-.052	2945.	1.130	-672.1
									-.4 NET
7	1	1.932	1	0.	FLOOR 8 COMPARTMENT 1	.002	2216.	.850	107.6
					FLOOR 6 COMPARTMENT 1	-.001	2216.	.850	-60.5
					STAIRWELL	.186	833.	.323	358.8
					ELEVATOR	.016	1746.	.670	222.0
					OUTSIDE DIRECTION 1	-.045	2945.	1.130	-628.2
									-.2 NET

APPENDIX E - RUN 2 COMPUTER OUTPUT

SUMMER - OUTSIDE,1ST,2ND,3RD FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
8	1	1.762	1	0.	FLOOR 9 COMPARTMENT	1	.003	2216.	.850	124.5
					FLOOR 7 COMPARTMENT	1	-.002	2216.	.850	-107.6
					STAIRWELL		.198	833.	.323	370.5
					ELEVATOR		.014	1746.	.670	205.1
					OUTSIDE DIRECTION	1	-.041	2945.	1.130	-592.8
										-.4 NET
9	1	1.592	1	0.	FLOOR 10 COMPARTMENT	1	.003	2216.	.850	127.0
					FLOOR 8 COMPARTMENT	1	-.003	2216.	.850	-124.5
					STAIRWELL		.207	833.	.323	378.6
					ELEVATOR		.011	1746.	.670	180.0
					OUTSIDE DIRECTION	1	-.036	2945.	1.130	-561.5
										-.4 NET
10	1	1.423	1	0.	FLOOR 11 COMPARTMENT	1	.003	2216.	.850	122.0
					FLOOR 9 COMPARTMENT	1	-.003	2216.	.850	-127.0
					STAIRWELL		.213	833.	.323	384.5
					ELEVATOR		.007	1746.	.670	149.6
					OUTSIDE DIRECTION	1	-.032	2945.	1..130	-529.4
										-.3 NET
11	1	1.254	1	0.	FLOOR 12 COMPARTMENT	1	.003	2216.	.850	111.2
					FLOOR 10 COMPARTMENT	1	-.003	2216.	.850	-122.0
					STAIRWELL		.218	833.	.323	388.9
					ELEVATOR		.004	1746.	.670	114.6
					OUTSIDE DIRECTION	1	-.028	2945.	1.130	-493.0
										-.3 NET
12	1	1.084	1	0.	FLOOR 13 COMPARTMENT	1	.002	2216.	.850	93.7
					FLOOR 11 COMPARTMENT	1	-.003	2216.	.850	-111.2
					STAIRWELL		.222	833.	.323	392.3
					ELEVATOR		.002	1746.	.670	73.8
					OUTSIDE DIRECTION	1	-.023	2945.	1.130	-448.9
										-.3 NET
13	1	.914	1	0.	FLOOR 14 COMPARTMENT	1	.002	2216.	.850	87.2
					FLOOR 12 COMPARTMENT	1	-.002	2216.	.850	-93.7
					STAIRWELL		.226	833.	.323	395.3
					ELEVATOR		.000	1746.	.670	2.8
					OUTSIDE DIRECTION	1	-.018	2945.	1.130	-392.0
										-.4 NET
14	1	.743	1	0.	FLOOR 15 COMPARTMENT	1	.001	2216.	.850	79.9
					FLOOR 13 COMPARTMENT	1	-.002	2216.	.850	-87.2
					STAIRWELL		.228	833.	.323	397.8
					ELEVATOR		-.002	1746.	.670	-68.6
					OUTSIDE DIRECTION	1	-.012	2945.	1.130	-322.1
										-.1 NET

APPENDIX E - RUN 2 COMPUTER OUTPUT

SUMMER - OUTSIDE,1ST,2ND,3RD FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
15	1	.573	1	0.	FLOOR 14 COMPARTMENT	1	-.001	2216.	.850	-79.9
					STAIRWELL		.231	833.	.323	400.1
					ELEVATOR		-.003	1746.	.670	-93.1
					OUTSIDE DIRECTION	1	-.006	2945.	1.130	-227.4
										-.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX E - RUN 2 COMPUTER OUTPUT

SUMMER - OUTSIDE,1ST,2ND,3RD FLOOR DOORS OPEN

STAIRWELL

TEMPERATURE PROFILE 2
SHAFT FLOW COEFFICIENT 70000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	3.015	1300.	FLOOR 1 COMPARTMENT 1	-.001	27063.	10.500	-1047.7
			OUTSIDE DIRECTION 1	-.136	27063.	10.500	-9963.0
2	2.865	1300.	FLOOR 2 COMPARTMENT 1	-.003	27063.	10.500	-1543.2
3	2.716	1300.	FLOOR 3 COMPARTMENT 1	-.009	27063.	10.500	-2537.5
4	2.572	1300.	FLOOR 4 COMPARTMENT 1	-.113	833.	.323	-280.0
5	2.424	1300.	FLOOR 5 COMPARTMENT 1	-.148	833.	.323	-319.8
6	2.273	1300.	FLOOR 6 COMPARTMENT 1	-.169	833.	.323	-342.2
7	2.118	1300.	FLOOR 7 COMPARTMENT 1	-.186	833.	.323	-358.8
8	1.960	1300.	FLOOR 8 COMPARTMENT 1	-.198	833.	.323	-370.5
9	1.799	1300.	FLOOR 9 COMPARTMENT 1	-.207	833.	.323	-378.6
10	1.637	1300.	FLOOR 10 COMPARTMENT 1	-.213	833.	.323	-384.5
11	1.472	1300.	FLOOR 11 COMPARTMENT 1	-.218	833.	.323	-388.9
12	1.306	1300.	FLOOR 12 COMPARTMENT 1	-.222	833.	.323	-392.3
13	1.139	1300.	FLOOR 13 COMPARTMENT 1	-.226	833.	.323	-395.3
14	.972	1300.	FLOOR 14 COMPARTMENT 1	-.228	833.	.323	-397.8
15	.804	1300.	FLOOR 15 COMPARTMENT 1	-.231	833.	.323	-400.1
							-.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX E - RUN 2 COMPUTER OUTPUT

SUMMER - OUTSIDE,1ST,2ND,3RD FLOOR DOORS OPEN

ELEVATOR

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 240000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.985	0.	FLOOR 1 COMPARTMENT 1	.028	1746.	.670	293.1
2	2.812	0.	FLOOR 2 COMPARTMENT 1	.049	1746.	.670	388.4
3	2.639	0.	FLOOR 3 COMPARTMENT 1	.068	1746.	.670	455.3
4	2.466	0.	FLOOR 4 COMPARTMENT 1	-.007	1746.	.670	-146.0
5	2.293	0.	FLOOR 5 COMPARTMENT 1	-.017	1746.	.670	-224.8
6	2.121	0.	FLOOR 6 COMPARTMENT 1	-.017	1746.	.670	-227.1
7	1.948	0.	FLOOR 7 COMPARTMENT 1	-.016	1746.	.670	-222.0
8	1.775	0.	FLOOR 8 COMPARTMENT 1	-.014	1746.	.670	-205.1
9	1.603	0.	FLOOR 9 COMPARTMENT 1	-.011	1746.	.670	-180.0
10	1.431	0.	FLOOR 10 COMPARTMENT 1	-.007	1746.	.670	-149.6
11	1.258	0.	FLOOR 11 COMPARTMENT 1	-.004	1746.	.670	-114.6
12	1.086	0.	FLOOR 12 COMPARTMENT 1	-.002	1746.	.670	-73.8
13	.914	0.	FLOOR 13 COMPARTMENT 1	.000	1746.	.670	-2.8
14	.742	0.	FLOOR 14 COMPARTMENT 1	.002	1746.	.670	68.6
15	.570	0.	FLOOR 15 COMPARTMENT 1	.003	1746.	.670	93.1
16	.398	0.					
			OUTSIDE DIRECTION 1	.004	3828.	1.500	246.9
							-.4 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

```
SUMMER - OUTSIDE,7TH,8TH,9TH FLOOR DOORS OPEN
93 2 0
16 1
6 12
2
1 1 70
1 1 92
1 1
0 1 1
1
13
1 15 1
0 1 1 0 1
1 .65 0.35
1 .65 1.13
2
STAIRWELL
7.0E4 1 15 2
0 1300
1 .65 0.323
4
2 1
1 .65 10.5
3 7
1 .65 10.5
3 8
1 .65 10.5
3 9
1 .65 10.5
ELEVATOR
2.4E5 1 16 1
0 0
1 .65 0.67
1
2 16
1 .65 1.5
```

APPENDIX E - RUN 3 COMPUTER OUTPUT

SUMMER - OUTSIDE.7TH.8TH.9TH FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION	TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	1	2.936	1	0.	FLOOR 2 COMPARTMENT	1	.002	2216.	.850	98.3
					STAIRWELL		.072	833.	.323	222.6
					ELEVATOR		.049	1746.	.670	385.1
					OUTSIDE DIRECTION 1		-.057	2945.	1.130	-706.1
										-.2 NET
2	1	2.765	1	0.	FLOOR 3 COMPARTMENT	1	.004	2216.	.850	145.2
					FLOOR 1 COMPARTMENT	1	-.002	2216.	.850	-98.3
					STAIRWELL		.089	833.	.323	247.8
					ELEVATOR		.047	1746.	.670	377.1
					OUTSIDE DIRECTION 1		-.052	2945.	1.130	-672.2
										-.4 NET
3	1	2.597	1	0.	FLOOR 4 COMPARTMENT	1	.006	2216.	.850	175.1
					FLOOR 2 COMPARTMENT	1	-.004	2216.	.850	-145.2
					STAIRWELL		.100	833.	.323	263.0
					ELEVATOR		.042	1746.	.670	359.3
					OUTSIDE DIRECTION 1		-.049	2945.	1.130	-652.2
										-.1 NET
4	1	2.430	1	0.	FLOOR 5 COMPARTMENT	1	.010	2216.	.850	216.9
					FLOOR 3 COMPARTMENT	1	-.006	2216.	.850	-175.1
					STAIRWELL		.106	833.	.323	271.2
					ELEVATOR		.036	1746.	.670	331.7
					OUTSIDE DIRECTION 1		-.048	2945.	1.130	-644.9
										-.2 NET
5	1	2.267	1	0.	FLOOR 6 COMPARTMENT	1	.021	2216.	.850	320.4
					FLOOR 4 COMPARTMENT	1	-.010	2216.	.850	-216.9
					STAIRWELL		.107	833.	.323	271.7
					ELEVATOR		.027	1746.	.670	284.4
					OUTSIDE DIRECTION 1		-.050	2945.	1.130	-659.8
										-.2 NET
6	1	2.115	1	0.	FLOOR 7 COMPARTMENT	1	.094	2216.	.850	677.9
					FLOOR 5 COMPARTMENT	1	-.021	2216.	.850	-320.4
					STAIRWELL		.094	833.	.323	254.6
					ELEVATOR		.006	1746.	.670	131.3
					OUTSIDE DIRECTION 1		-.064	2945.	1.130	-743.7
										-.4 NET
7	1	2.036	1	0.	FLOOR 8 COMPARTMENT	1	.009	2216.	.850	215.1
					FLOOR 6 COMPARTMENT	1	-.094	2216.	.850	-677.9
					STAIRWELL		.006	27063.	10.500	2121.1
					ELEVATOR		-.088	1746.	.670	-517.7
					OUTSIDE DIRECTION 1		-.150	2945.	1.130	-1140.8
										-.1 NET

APPENDIX E - RUN 3 COMPUTER OUTPUT

SUMMER - OUTSIDE,7TH,8TH,9TH FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
8	1	1.873	1	0.	FLOOR 9 COMPARTMENT	1	.004	2216.	.850	140.7
					FLOOR 7 COMPARTMENT	1	-.009	2216.	.850	-215.1
					STAIRWELL		.004	27063.	10.500	1767.1
					ELEVATOR		-.097	1746.	.670	-544.6
					OUTSIDE DIRECTION	1	-.152	2945.	1.130	-1148.5
										-.3 NET
9	1	1.705	1	0.	FLOOR 10 COMPARTMENT	1	-.095	2216.	.850	-682.7
					FLOOR 8 COMPARTMENT	1	-.004	2216.	.850	-140.7
					STAIRWELL		.009	27063.	10.500	2514.4
					ELEVATOR		-.101	1746.	.670	-555.6
					OUTSIDE DIRECTION	1	-.149	2945.	1.130	-1135.8
										-.4 NET
10	1	1.437	1	0.	FLOOR 11 COMPARTMENT	1	-.008	2216.	.850	-191.9
					FLOOR 9 COMPARTMENT	1	.095	2216.	.850	682.7
					STAIRWELL		.115	833.	.323	281.8
					ELEVATOR		-.006	1746.	.670	-138.1
					OUTSIDE DIRECTION	1	-.046	2945.	1.130	-634.7
										-.1 NET
11	1	1.258	1	0.	FLOOR 12 COMPARTMENT	1	.000	2216.	.850	-31.4
					FLOOR 10 COMPARTMENT	1	.008	2216.	.850	191.9
					STAIRWELL		.131	833.	.323	301.1
					ELEVATOR		.001	1746.	.670	61.7
					OUTSIDE DIRECTION	1	-.032	2945.	1.130	-523.7
										-.3 NET
12	1	1.085	1	0.	FLOOR 13 COMPARTMENT	1	.001	2216.	.850	50.1
					FLOOR 11 COMPARTMENT	1	.000	2216.	.850	31.4
					STAIRWELL		.138	833.	.323	309.2
					ELEVATOR		.001	1746.	.670	66.5
					OUTSIDE DIRECTION	1	-.024	2945.	1.130	-457.2
										-.1 NET
13	1	.913	1	0.	FLOOR 14 COMPARTMENT	1	.001	2216.	.850	68.9
					FLOOR 12 COMPARTMENT	1	-.001	2216.	.850	-50.1
					STAIRWELL		.143	833.	.323	314.8
					ELEVATOR		.001	1746.	.670	53.5
					OUTSIDE DIRECTION	1	-.017	2945.	1.130	-387.5
										-.3 NET
14	1	.742	1	0.	FLOOR 15 COMPARTMENT	1	.001	2216.	.850	67.8
					FLOOR 13 COMPARTMENT	1	-.001	2215.	.850	-68.9
					STAIRWELL		.147	833.	.323	318.7
					ELEVATOR		.000	1746.	.670	-9.3
					OUTSIDE DIRECTION	1	-.011	2945.	1.130	-308.5
										-.2 NET

APPENDIX E - RUN 3 COMPUTER OUTPUT

SUMMER - OUTSIDE,7TH,8TH,9TH FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
15	1	.571	1	0.	FLOOR 14 COMPARTMENT 1	-.001	2216.	.850	-67.8
					STAIRWELL	.150	833.	.323	321.9
					ELEVATOR	-.001	1746.	.670	-54.2
					OUTSIDE DIRECTION 1	-.005	2945.	1.130	-200.0
									-.1 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX E - RUN 3 COMPUTER OUTPUT

SUMMER - OUTSIDE,7TH,8TH,9TH FLOOR DOORS OPEN

STAIRWELL

TEMPERATURE PROFILE 2
SHAFT FLOW COEFFICIENT 70000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	3.008	1300.	FLOOR 1 COMPARTMENT	1	-.072	833.	.323	-222.6
			OUTSIDE DIRECTION	1	-.129	27063.	10.500	-9719.3
2	2.854	1300.	FLOOR 2 COMPARTMENT	1	-.089	833.	.323	-247.8
3	2.697	1300.	FLOOR 3 COMPARTMENT	1	-.100	833.	.323	-263.0
4	2.536	1300.	FLOOR 4 COMPARTMENT	1	-.106	833.	.323	-271.2
5	2.374	1300.	FLOOR 5 COMPARTMENT	1	-.107	833.	.323	-271.7
6	2.209	1300.	FLOOR 6 COMPARTMENT	1	-.094	833.	.323	-254.6
7	2.043	1300.	FLOOR 7 COMPARTMENT	1	-.006	27063.	10.500	-2121.1
8	1.878	1300.	FLOOR 8 COMPARTMENT	1	-.004	27063.	10.500	-1767.1
9	1.713	1300.	FLOOR 9 COMPARTMENT	1	-.009	27063.	10.500	-2514.4
10	1.552	1300.	FLOOR 10 COMPARTMENT	1	-.115	833.	.323	-281.8
11	1.389	1300.	FLOOR 11 COMPARTMENT	1	-.131	833.	.323	-301.1
12	1.223	1300.	FLOOR 12 COMPARTMENT	1	-.138	833.	.323	-309.2
13	1.056	1300.	FLOOR 13 COMPARTMENT	1	-.143	833.	.323	-314.8
14	.889	1300.	FLOOR 14 COMPARTMENT	1	-.147	833.	.323	-318.7
15	.721	1300.	FLOOR 15 COMPARTMENT	1	-.150	833.	.323	-321.9
								-.4 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

APPENDIX E - RUN 3 COMPUTER OUTPUT

SUMMER - OUTSIDE,7TH,8TH,9TH FLOOR DOORS OPEN

ELEVATOR

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 240000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.985	0.	FLOOR 1 COMPARTMENT 1	-.049	1746.	.670	-385.1
2	2.812	0.	FLOOR 2 COMPARTMENT 1	-.047	1746.	.670	-377.1
3	2.639	0.	FLOOR 3 COMPARTMENT 1	-.042	1746.	.670	-359.3
4	2.466	0.	FLOOR 4 COMPARTMENT 1	-.036	1746.	.670	-331.7
5	2.294	0.	FLOOR 5 COMPARTMENT 1	-.027	1746.	.670	-284.4
6	2.121	0.	FLOOR 6 COMPARTMENT 1	-.006	1746.	.670	-131.3
7	1.948	0.	FLOOR 7 COMPARTMENT 1	.088	1746.	.670	517.7
8	1.776	0.	FLOOR 8 COMPARTMENT 1	.097	1746.	.670	544.6
9	1.604	0.	FLOOR 9 COMPARTMENT 1	.101	1746.	.670	555.6
10	1.431	0.	FLOOR 10 COMPARTMENT 1	.006	1746.	.670	138.1
11	1.259	0.	FLOOR 11 COMPARTMENT 1	-.001	1746.	.670	-61.7
12	1.087	0.	FLOOR 12 COMPARTMENT 1	-.001	1746.	.670	-66.5
13	.914	0.	FLOOR 13 COMPARTMENT 1	-.001	1746.	.670	-53.5
14	.742	0.	FLOOR 14 COMPARTMENT 1	.000	1746.	.670	9.2
15	.570	0.	FLOOR 15 COMPARTMENT 1	.001	1746.	.670	54.2
16	.398	0.					
			OUTSIDE DIRECTION 1	.004	3828.	1.500	230.8
							-.4 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

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SUMMER - OUTSIDE,13TH,14TH,15TH FLOOR DOORS OPEN
93 2 0
16 1
6 12
2
1 1 70
1 1 82
1 1
0 1 1
1
15
1 15 1
0 1 1 0 1
1 .65 0.85
1 .65 1.13
2
STAIRWELL
7.0E4 1 15 2
0 1300
1 .65 0.323
4
2 1
1 .65 10.5
3 13
1 .65 10.5
3 14
1 .65 10.5
3 15
1 .65 10.5
ELEVATOR
2.4E5 1 16 1
0 0
1 .65 0.67
1
2 16
1 .65 1.5
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APPENDIX E - RUN 4 COMPUTER OUTPUT

SUMMER - OUTSIDE,13TH,14TH,15TH FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	1	2.933	1	0.	FLOOR 2 COMPARTMENT 1	.002	2216.	.850	93.4
					STAIRWELL	.082	833.	.323	238.7
					ELEVATOR	.041	1746.	.670	353.4
					OUTSIDE DIRECTION 1	-.054	2945.	1.130	-685.7
									-.2 NET
2	1	2.762	1	0.	FLOOR 3 COMPARTMENT 1	.004	2216.	.850	132.9
					FLOOR 1 COMPARTMENT 1	-.002	2216.	.850	-93.4
					STAIRWELL	.101	833.	.323	263.9
					ELEVATOR	.039	1746.	.670	345.6
					OUTSIDE DIRECTION 1	-.049	2945.	1.130	-649.4
									-.4 NET
3	1	2.593	1	0.	FLOOR 4 COMPARTMENT 1	.004	2216.	.850	146.8
					FLOOR 2 COMPARTMENT 1	-.004	2216.	.850	-132.9
					STAIRWELL	.113	833.	.323	280.3
					ELEVATOR	.036	1746.	.670	329.3
					OUTSIDE DIRECTION 1	-.045	2945.	1.130	-623.9
									-.3 NET
4	1	2.424	1	0.	FLOOR 5 COMPARTMENT 1	.005	2216.	.850	149.7
					FLOOR 3 COMPARTMENT 1	-.004	2216.	.850	-146.8
					STAIRWELL	.122	833.	.323	291.3
					ELEVATOR	.031	1746.	.670	308.4
					OUTSIDE DIRECTION 1	-.042	2945.	1.130	-603.0
									-.4 NET
5	1	2.256	1	0.	FLOOR 6 COMPARTMENT 1	.004	2216.	.850	148.5
					FLOOR 4 COMPARTMENT 1	-.005	2216.	.850	-149.7
					STAIRWELL	.129	833.	.323	298.6
					ELEVATOR	.027	1746.	.670	285.0
					OUTSIDE DIRECTION 1	-.039	2945.	1.130	-582.7
									-.3 NET
6	1	2.088	1	0.	FLOOR 7 COMPARTMENT 1	.004	2216.	.850	146.0
					FLOOR 5 COMPARTMENT 1	-.004	2216.	.850	-148.5
					STAIRWELL	.133	833.	.323	303.4
					ELEVATOR	.022	1746.	.670	260.0
					OUTSIDE DIRECTION 1	-.036	2945.	1.130	-561.2
									-.3 NET
7	1	1.920	1	0.	FLOOR 8 COMPARTMENT 1	.004	2216.	.850	143.5
					FLOOR 6 COMPARTMENT 1	-.004	2216.	.850	-146.0
					STAIRWELL	.135	833.	.323	306.2
					ELEVATOR	.018	1746.	.670	233.5
					OUTSIDE DIRECTION 1	-.033	2945.	1.130	-537.6
									-.3 NET

APPENDIX E - RUN 4 COMPUTER OUTPUT

SUMMER - OUTSIDE,13TH,14TH,15TH FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION	TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
8	1	1.751	1	0.	FLOOR 9 COMPARTMENT	1	.004	2216.	.850	142.5
					FLOOR 7 COMPARTMENT	1	-.004	2216.	.850	-143.5
					STAIRWELL		.137	833.	.323	307.6
					ELEVATOR		.014	1746.	.670	204.8
					OUTSIDE DIRECTION 1		-.030	2945.	1.130	-511.7
										-.3 NET
9	1	1.583	1	0.	FLOOR 10 COMPARTMENT	1	.004	2216.	.850	146.0
					FLOOR 8 COMPARTMENT	1	-.004	2216.	.850	-142.5
					STAIRWELL		.137	833.	.323	308.0
					ELEVATOR		.010	1746.	.670	172.1
					OUTSIDE DIRECTION 1		-.027	2945.	1.130	-484.0
										-.4 NET
10	1	1.415	1	0.	FLOOR 11 COMPARTMENT	1	.006	2216.	.850	165.3
					FLOOR 9 COMPARTMENT	1	-.004	2216.	.850	-146.0
					STAIRWELL		.136	833.	.323	307.5
					ELEVATOR		.005	1746.	.670	129.2
					OUTSIDE DIRECTION 1		-.024	2945.	1.130	-456.5
										-.4 NET
11	1	1.248	1	0.	FLOOR 12 COMPARTMENT	1	.017	2216.	.850	290.3
					FLOOR 10 COMPARTMENT	1	-.006	2216.	.850	-165.3
					STAIRWELL		.135	833.	.323	305.5
					ELEVATOR		.000	1746.	.670	8.8
					OUTSIDE DIRECTION 1		-.022	2945.	1.130	-439.6
										-.3 NET
12	1	1.093	1	0.	FLOOR 13 COMPARTMENT	1	.117	2216.	.850	756.2
					FLOOR 11 COMPARTMENT	1	-.017	2216.	.850	-290.3
					STAIRWELL		.121	833.	.323	289.6
					ELEVATOR		-.017	1746.	.670	-227.9
					OUTSIDE DIRECTION 1		-.032	2945.	1.130	-528.0
										-.4 NET
13	1	1.037	1	0.	FLOOR 14 COMPARTMENT	1	.006	2216.	.850	178.4
					FLOOR 12 COMPARTMENT	1	-.117	2216.	.850	-756.2
					STAIRWELL		.007	27063.	10.500	2322.5
					ELEVATOR		-.133	1746.	.670	-637.8
					OUTSIDE DIRECTION 1		-.141	2945.	1.130	-1107.2
										-.4 NET
14	1	.872	1	0.	FLOOR 15 COMPARTMENT	1	.003	2216.	.850	128.9
					FLOOR 13 COMPARTMENT	1	-.006	2216.	.850	-178.4
					STAIRWELL		.004	27063.	10.500	1805.9
					ELEVATOR		-.140	1746.	.670	-652.9
					OUTSIDE DIRECTION 1		-.140	2945.	1.130	-1103.8
										-.3 NET

APPENDIX E - RUN 4 COMPUTER OUTPUT

SUMMER - OUTSIDE,13TH,14TH,15TH FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
15	1	.703	1	0.	FLOOR 14 COMPARTMENT 1	-.003	2216.	.850	-128.9
					STAIRWELL	.005	27063.	10.500	1877.2
					ELEVATOR	-.143	1746.	.670	-660.6
					OUTSIDE DIRECTION 1	-.137	2945.	1.130	-1088.1
									-.4 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

APPENDIX E - RUN 4 COMPUTER OUTPUT

SUMMER - OUTSIDE,13TH,14TH,15TH FLOOR DOORS OPEN

STAIRWELL

TEMPERATURE PROFILE 2
SHAFT FLOW COEFFICIENT 70000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	3.015	1300.	FLOOR 1 COMPARTMENT	1	-.082	833.	.323	-238.7
			OUTSIDE DIRECTION 1		-.136	27063.	10.500	-9994.2
2	2.863	1300.	FLOOR 2 COMPARTMENT	1	-.101	833.	.323	-263.9
3	2.706	1300.	FLOOR 3 COMPARTMENT	1	-.113	833.	.323	-280.3
4	2.547	1300.	FLOOR 4 COMPARTMENT	1	-.122	833.	.323	-291.3
5	2.385	1300.	FLOOR 5 COMPARTMENT	1	-.129	833.	.323	-298.6
6	2.221	1300.	FLOOR 6 COMPARTMENT	1	-.133	833.	.323	-303.4
7	2.055	1300.	FLOOR 7 COMPARTMENT	1	-.135	833.	.323	-306.2
8	1.888	1300.	FLOOR 8 COMPARTMENT	1	-.137	833.	.323	-307.6
9	1.720	1300.	FLOOR 9 COMPARTMENT	1	-.137	833.	.323	-308.0
10	1.551	1300.	FLOOR 10 COMPARTMENT	1	-.136	833.	.323	-307.5
11	1.383	1300.	FLOOR 11 COMPARTMENT	1	-.135	833.	.323	-305.5
12	1.214	1300.	FLOOR 12 COMPARTMENT	1	-.121	833.	.323	-289.6
13	1.045	1300.	FLOOR 13 COMPARTMENT	1	-.007	27063.	10.500	-2322.5
14	.876	1300.	FLOOR 14 COMPARTMENT	1	-.004	27063.	10.500	-1805.9
15	.708	1300.	FLOOR 15 COMPARTMENT	1	-.005	27063.	10.500	-1877.2
								-.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

APPENDIX E - RUN 4 COMPUTER OUTPUT

SUMMER - OUTSIDE,13TH,14TH,15TH FLOOR DOORS OPEN

ELEVATOR

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 240000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.974	0.	FLOOR 1 COMPARTMENT 1	-.041	1746.	.670	-353.4
2	2.801	0.	FLOOR 2 COMPARTMENT 1	-.039	1746.	.670	-345.6
3	2.628	0.	FLOOR 3 COMPARTMENT 1	-.036	1746.	.670	-329.3
4	2.455	0.	FLOOR 4 COMPARTMENT 1	-.031	1746.	.670	-308.4
5	2.283	0.	FLOOR 5 COMPARTMENT 1	-.027	1746.	.670	-285.0
6	2.110	0.	FLOOR 6 COMPARTMENT 1	-.022	1746.	.670	-260.0
7	1.938	0.	FLOOR 7 COMPARTMENT 1	-.018	1746.	.670	-233.5
8	1.765	0.	FLOOR 8 COMPARTMENT 1	-.014	1746.	.670	-204.8
9	1.593	0.	FLOOR 9 COMPARTMENT 1	-.010	1746.	.670	-172.1
10	1.420	0.	FLOOR 10 COMPARTMENT 1	-.005	1746.	.670	-129.2
11	1.248	0.	FLOOR 11 COMPARTMENT 1	.000	1746.	.670	-8.8
12	1.076	0.	FLOOR 12 COMPARTMENT 1	.017	1746.	.670	227.9
13	.904	0.	FLOOR 13 COMPARTMENT 1	.133	1746.	.670	637.8
14	.732	0.	FLOOR 14 COMPARTMENT 1	.140	1746.	.670	652.9
15	.560	0.	FLOOR 15 COMPARTMENT 1	.143	1746.	.670	660.6
16	.388	0.					
			OUTSIDE DIRECTION 1	.014	3828.	1.500	450.9
							-.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

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WINTER - ALL DOORS CLOSED
14 2 0
16 1
6 12
2
1 1 70
1 1 45
1 1
0 1 1
1
15
1 15 1
0 1 1 0 1
1 .65 0.85
1 .65 1.13
2
STAIRWELL
7.0E4 1 15 2
0 490
1 .65 0.323
0
ELEVATOR
2.4E5 1 16 1
0 0
1 .65 0.67
1
2 16
1 .65 1.5
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APPENDIX E' - RUN 5 COMPUTER OUTPUT

WINTER - ALL DOORS CLOSED

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	1	3.277	1	0.	FLOOR 2 COMPARTMENT 1	-.010	2216.	.850	-224.0
					STAIRWELL	.289	863.	.323	463.5
					ELEVATOR	-.117	1746.	.670	-597.3
					OUTSIDE DIRECTION 1	.013	3115.	1.130	358.0
									.2 NET
2	1	3.094	1	0.	FLOOR 3 COMPARTMENT 1	-.018	2216.	.850	-293.5
					FLOOR 1 COMPARTMENT 1	.010	2216.	.850	224.0
					STAIRWELL	.290	863.	.323	464.7
					ELEVATOR	-.107	1746.	.670	-570.5
					OUTSIDE DIRECTION 1	.003	3115.	1.130	175.5
									.4 NET
3	1	2.903	1	0.	FLOOR 4 COMPARTMENT 1	-.020	2216.	.850	-311.0
					FLOOR 2 COMPARTMENT 1	.018	2216.	.850	293.5
					STAIRWELL	.299	863.	.323	471.7
					ELEVATOR	-.089	1746.	.670	-521.4
					OUTSIDE DIRECTION 1	.000	3115.	1.130	67.4
									.2 NET
4	1	2.711	1	0.	FLOOR 5 COMPARTMENT 1	-.019	2216.	.850	-304.8
					FLOOR 3 COMPARTMENT 1	.020	2216.	.850	311.0
					STAIRWELL	.310	863.	.323	480.3
					ELEVATOR	-.069	1746.	.670	-460.2
					OUTSIDE DIRECTION 1	.000	2945.	1.130	-25.8
									.4 NET
5	1	2.519	1	0.	FLOOR 6 COMPARTMENT 1	-.017	2216.	.850	-290.6
					FLOOR 4 COMPARTMENT 1	.019	2216.	.850	304.8
					STAIRWELL	.320	863.	.323	488.2
					ELEVATOR	-.051	1746.	.670	-392.8
					OUTSIDE DIRECTION 1	-.001	2945.	1.130	-109.4
									.3 NET
6	1	2.330	1	0.	FLOOR 7 COMPARTMENT 1	-.015	2216.	.850	-270.0
					FLOOR 5 COMPARTMENT 1	.017	2216.	.850	290.6
					STAIRWELL	.329	863.	.323	494.6
					ELEVATOR	-.033	1746.	.670	-319.5
					OUTSIDE DIRECTION 1	-.004	2945.	1.130	-195.4
									.2 NET
7	1	2.142	1	0.	FLOOR 8 COMPARTMENT 1	-.012	2216.	.850	-238.8
					FLOOR 6 COMPARTMENT 1	.015	2216.	.850	270.0
					STAIRWELL	.335	863.	.323	499.2
					ELEVATOR	-.019	1746.	.670	-239.2
					OUTSIDE DIRECTION 1	-.010	2945.	1.130	-291.0
									.2 NET

APPENDIX E - RUN 5 COMPUTER OUTPUT

WINTER - ALL DOORS CLOSED

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
8	1	1.958	1	0.	FLOOR 9 COMPARTMENT 1	-.007	2216.	.850	-191.8
					FLOOR 7 COMPARTMENT 1	.012	2216.	.850	238.8
					STAIRWELL	.338	863.	.323	501.4
					ELEVATOR	-.007	1746.	.670	-149.2
					OUTSIDE DIRECTION 1	-.018	2945.	1.130	-398.9
									.3 NET
9	1	1.778	1	0.	FLOOR 10 COMPARTMENT 1	-.007	2216.	.850	-181.2
					FLOOR 8 COMPARTMENT 1	.007	2216.	.850	191.8
					STAIRWELL	.337	863.	.323	500.5
					ELEVATOR	.000	1746.	.670	7.7
					OUTSIDE DIRECTION 1	-.031	2945.	1.130	-518.8
									.0 NET
10	1	1.599	1	0.	FLOOR 11 COMPARTMENT 1	-.008	2216.	.850	-199.8
					FLOOR 9 COMPARTMENT 1	.007	2216.	.850	181.2
					STAIRWELL	.335	863.	.323	499.0
					ELEVATOR	.007	1746.	.670	141.1
					OUTSIDE DIRECTION 1	-.045	2945.	1.130	-621.4
									.2 NET
11	1	1.419	1	0.	FLOOR 12 COMPARTMENT 1	-.009	2216.	.850	-208.1
					FLOOR 10 COMPARTMENT 1	.008	2216.	.850	199.8
					STAIRWELL	.334	863.	.323	498.6
					ELEVATOR	.014	1746.	.670	210.2
					OUTSIDE DIRECTION 1	-.057	2945.	1.130	-700.3
									.2 NET
12	1	1.238	1	0.	FLOOR 13 COMPARTMENT 1	-.009	2216.	.850	-205.0
					FLOOR 11 COMPARTMENT 1	.009	2216.	.850	208.1
					STAIRWELL	.334	863.	.323	498.7
					ELEVATOR	.023	1746.	.670	265.7
					OUTSIDE DIRECTION 1	-.068	2945.	1.130	-767.2
									.4 NET
13	1	1.057	1	0.	FLOOR 14 COMPARTMENT 1	-.007	2216.	.850	-183.6
					FLOOR 12 COMPARTMENT 1	.009	2216.	.850	205.0
					STAIRWELL	.334	863.	.323	498.6
					ELEVATOR	.032	1746.	.670	310.3
					OUTSIDE DIRECTION 1	-.079	2945.	1.130	-830.0
									.3 NET
14	1	.879	1	0.	FLOOR 15 COMPARTMENT 1	-.003	2216.	.850	-126.1
					FLOOR 13 COMPARTMENT 1	.007	2216.	.850	183.6
					STAIRWELL	.333	863.	.323	497.3
					ELEVATOR	.038	1746.	.670	342.0
					OUTSIDE DIRECTION 1	-.093	2945.	1.130	-896.5
									.3 NET

APPENDIX E - RUN 5 COMPUTER OUTPUT

WINTER - ALL DOORS CLOSED

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
15	1	.703	1	0.	FLOOR 14 COMPARTMENT 1	.003	2216.	.850	126.1
					STAIRWELL	.327	863.	.323	493.2
					ELEVATOR	.042	1746.	.670	355.7
					OUTSIDE DIRECTION 1	-.110	2945.	1.130	-974.7
									.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX E - RUN 5 COMPUTER OUTPUT

WINTER - ALL DOORS CLOSED

STAIRWELL

TEMPERATURE PROFILE 2
SHAFT FLOW COEFFICIENT 70000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION	TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	3.566	490.	FLOOR 1	COMPARTMENT	1	-.289	863.	.323	-463.5
2	3.384	490.	FLOOR 2	COMPARTMENT	1	-.290	863.	.323	-464.7
3	3.203	490.	FLOOR 3	COMPARTMENT	1	-.299	863.	.323	-471.7
4	3.021	490.	FLOOR 4	COMPARTMENT	1	-.310	863.	.323	-480.3
5	2.840	490.	FLOOR 5	COMPARTMENT	1	-.320	863.	.323	-488.2
6	2.659	490.	FLOOR 6	COMPARTMENT	1	-.329	863.	.323	-494.6
7	2.477	490.	FLOOR 7	COMPARTMENT	1	-.335	863.	.323	-499.2
8	2.296	490.	FLOOR 8	COMPARTMENT	1	-.338	863.	.323	-501.4
9	2.115	490.	FLOOR 9	COMPARTMENT	1	-.337	863.	.323	-500.5
10	1.934	490.	FLOOR 10	COMPARTMENT	1	-.335	863.	.323	-499.0
11	1.753	490.	FLOOR 11	COMPARTMENT	1	-.334	863.	.323	-498.6
12	1.572	490.	FLOOR 12	COMPARTMENT	1	-.334	863.	.323	-498.7
13	1.392	490.	FLOOR 13	COMPARTMENT	1	-.334	863.	.323	-498.6
14	1.211	490.	FLOOR 14	COMPARTMENT	1	-.333	863.	.323	-497.3
15	1.030	490.	FLOOR 15	COMPARTMENT	1	-.327	863.	.323	-493.2
									.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX E - RUN 5 COMPUTER OUTPUT

WINTER - ALL DOORS CLOSED

ELEVATOR

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 240000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	3.160	0.	FLOOR 1 COMPARTMENT 1	.117	1746.	.670	597.3
2	2.987	0.	FLOOR 2 COMPARTMENT 1	.107	1746.	.670	570.5
3	2.814	0.	FLOOR 3 COMPARTMENT 1	.089	1746.	.670	521.4
4	2.642	0.	FLOOR 4 COMPARTMENT 1	.069	1746.	.670	460.2
5	2.469	0.	FLOOR 5 COMPARTMENT 1	.051	1746.	.670	392.8
6	2.296	0.	FLOOR 6 COMPARTMENT 1	.033	1746.	.670	319.5
7	2.123	0.	FLOOR 7 COMPARTMENT 1	.019	1746.	.670	239.2
8	1.951	0.	FLOOR 8 COMPARTMENT 1	.007	1746.	.670	149.2
9	1.778	0.	FLOOR 9 COMPARTMENT 1	.000	1746.	.670	-7.7
10	1.606	0.	FLOOR 10 COMPARTMENT 1	-.007	1746.	.670	-141.1
11	1.433	0.	FLOOR 11 COMPARTMENT 1	-.014	1746.	.670	-210.2
12	1.261	0.	FLOOR 12 COMPARTMENT 1	-.023	1746.	.670	-265.7
13	1.089	0.	FLOOR 13 COMPARTMENT 1	-.032	1746.	.670	-310.3
14	.917	0.	FLOOR 14 COMPARTMENT 1	-.038	1746.	.670	-342.0
15	.745	0.	FLOOR 15 COMPARTMENT 1	-.042	1746.	.670	-355.7
16	.573	0.					
			OUTSIDE DIRECTION 1	-.171	3910.	1.500	-1616.9
							.4 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX E - RUN 6 DATA

```
WINTER - OUTSIDE,1ST,2ND,3RD FLOOR DOORS OPEN
14 2 0
16 1
6 12
2
1 1 70
1 1 45
1 1
0 1 1
1
15
1 15 1
0 1 1 0 1
1 .65 0.85
1 .65 1.13
2
STAIRWELL
7.0E4 1 15 2
0 1300
1 .65 0.323
4
2 1
1 .65 10.5
3 1
1 .65 10.5
3 2
1 .65 10.5
3 3
1 .65 10.5
ELEVATOR
2.4E5 1 16 1
0 0
1 .65 0.67
1
2 16
1 .65 1.5
```

APPENDIX E - RUN 6 COMPUTER OUTPUT

WINTER - OUTSIDE,1ST,2ND,3RD FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	1	3.374	1	0.	FLOOR 2 COMPARTMENT	1	.005	2216.	.850	150.3
					STAIRWELL		.003	28038.	10.500	1491.6
					ELEVATOR		-.204	1746.	.670	-789.4
					OUTSIDE DIRECTION 1		-.084	2945.	1.130	-852.7
										-.2 NET
2	1	3.206	1	0.	FLOOR 3 COMPARTMENT	1	.002	2216.	.850	101.1
					FLOOR 1 COMPARTMENT	1	-.005	2216.	.850	-150.3
					STAIRWELL		.004	28038.	10.500	1817.8
					ELEVATOR		-.209	1746.	.670	-798.1
					OUTSIDE DIRECTION 1		-.109	2945.	1.130	-970.7
										-.3 NET
3	1	3.035	1	0.	FLOOR 4 COMPARTMENT	1	-.139	2216.	.850	-826.7
					FLOOR 2 COMPARTMENT	1	-.002	2216.	.850	-101.1
					STAIRWELL		.010	28038.	10.500	2795.1
					ELEVATOR		-.211	1746.	.670	-802.0
					OUTSIDE DIRECTION 1		-.131	2945.	1.130	-1065.7
										-.3 NET
4	1	2.723	1	0.	FLOOR 5 COMPARTMENT	1	-.030	2216.	.850	-386.3
					FLOOR 3 COMPARTMENT	1	.139	2216.	.850	826.7
					STAIRWELL		.163	863.	.323	348.1
					ELEVATOR		-.072	1746.	.670	-467.7
					OUTSIDE DIRECTION 1		-.012	2945.	1.130	-321.1
										-.3 NET
5	1	2.520	1	0.	FLOOR 6 COMPARTMENT	1	-.018	2216.	.850	-298.2
					FLOOR 4 COMPARTMENT	1	.030	2216.	.850	386.3
					STAIRWELL		.203	863.	.323	388.7
					ELEVATOR		-.041	1746.	.670	-355.4
					OUTSIDE DIRECTION 1		-.002	2945.	1.130	-121.7
										-.3 NET
6	1	2.329	1	0.	FLOOR 7 COMPARTMENT	1	-.014	2216.	.850	-260.2
					FLOOR 5 COMPARTMENT	1	.018	2216.	.850	298.2
					STAIRWELL		.228	863.	.323	411.5
					ELEVATOR		-.023	1746.	.670	-267.6
					OUTSIDE DIRECTION 1		-.004	2945.	1.130	-182.1
										-.2 NET
7	1	2.143	1	0.	FLOOR 8 COMPARTMENT	1	-.009	2216.	.850	-215.2
					FLOOR 6 COMPARTMENT	1	.014	2216.	.850	260.2
					STAIRWELL		.245	863.	.323	426.8
					ELEVATOR		-.010	1746.	.670	-173.7
					OUTSIDE DIRECTION 1		-.010	2945.	1.130	-298.2
										-.1 NET

APPENDIX E - RUN 6 COMPUTER OUTPUT

WINTER - OUTSIDE,1ST,2ND,3RD FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
8	1	1.961	1	0.	FLOOR 9 COMPARTMENT	1	-.007	2216.	.850	-178.7
					FLOOR 7 COMPARTMENT	1	.009	2216.	.850	215.2
					STAIRWELL		.255	863.	.323	435.7
					ELEVATOR		-.001	1746.	.670	-45.7
					OUTSIDE DIRECTION 1		-.021	2945.	1.130	-426.9
										-.3 NET
9	1	1.782	1	0.	FLOOR 10 COMPARTMENT	1	-.008	2216.	.850	-200.9
					FLOOR 8 COMPARTMENT	1	.007	2216.	.850	178.7
					STAIRWELL		.260	863.	.323	440.0
					ELEVATOR		.006	1746.	.670	130.5
					OUTSIDE DIRECTION 1		-.035	2945.	1.130	-548.5
										-.2 NET
10	1	1.601	1	0.	FLOOR 11 COMPARTMENT	1	-.009	2216.	.850	-212.9
					FLOOR 9 COMPARTMENT	1	.008	2216.	.850	200.9
					STAIRWELL		.265	863.	.323	444.1
					ELEVATOR		.014	1746.	.670	203.5
					OUTSIDE DIRECTION 1		-.047	2945.	1.130	-636.0
										-.4 NET
11	1	1.420	1	0.	FLOOR 12 COMPARTMENT	1	-.010	2216.	.850	-216.8
					FLOOR 10 COMPARTMENT	1	.009	2216.	.850	212.9
					STAIRWELL		.270	863.	.323	447.7
					ELEVATOR		.023	1746.	.670	262.6
					OUTSIDE DIRECTION 1		-.058	2945.	1.130	-706.6
										-.2 NET
12	1	1.238	1	0.	FLOOR 13 COMPARTMENT	1	-.009	2216.	.850	-211.2
					FLOOR 11 COMPARTMENT	1	.010	2216.	.850	216.8
					STAIRWELL		.273	863.	.323	450.4
					ELEVATOR		.032	1746.	.670	312.4
					OUTSIDE DIRECTION 1		-.068	2945.	1.130	-768.7
										-.2 NET
13	1	1.057	1	0.	FLOOR 14 COMPARTMENT	1	-.007	2216.	.850	-188.0
					FLOOR 12 COMPARTMENT	1	.009	2216.	.850	211.2
					STAIRWELL		.275	863.	.323	451.9
					ELEVATOR		.041	1746.	.670	353.4
					OUTSIDE DIRECTION 1		-.079	2945.	1.130	-828.6
										-.1 NET
14	1	.878	1	0.	FLOOR 15 COMPARTMENT	1	-.003	2216.	.850	-128.5
					FLOOR 13 COMPARTMENT	1	.007	2216.	.850	188.0
					STAIRWELL		.274	863.	.323	451.2
					ELEVATOR		.048	1746.	.670	382.7
					OUTSIDE DIRECTION 1		-.092	2945.	1.130	-893.6
										-.2 NET

APPENDIX E - RUN 6 COMPUTER OUTPUT

WINTER - OUTSIDE,1ST,2ND,3RD FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
15	1	.703	1	0.	FLOOR 14 COMPARTMENT 1	.003	2216.	.850	128.5
					STAIRWELL	.269	863.	.323	446.9
					ELEVATOR	.051	1746.	.570	395.6
					OUTSIDE DIRECTION 1	-.109	2945.	1.130	-971.4
									-.4 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX E - RUN 6 COMPUTER OUTPUT

WINTER - OUTSIDE,1ST,2ND,3RD FLOOR DOORS OPEN

STAIRWELL

TEMPERATURE PROFILE 2
SHAFT FLOW COEFFICIENT 70000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	3.377	1300.	FLOOR 1 COMPARTMENT	1	-.003	28038.	10.500	-1491.6
			OUTSIDE DIRECTION	1	-.087	28038.	10.500	-8252.8
2	3.210	1300.	FLOOR 2 COMPARTMENT	1	-.004	28038.	10.500	-1817.8
3	3.045	1300.	FLOOR 3 COMPARTMENT	1	-.010	28038.	10.500	-2795.1
4	2.886	1300.	FLOOR 4 COMPARTMENT	1	-.163	863.	.323	-348.1
5	2.723	1300.	FLOOR 5 COMPARTMENT	1	-.203	863.	.323	-388.7
6	2.557	1300.	FLOOR 6 COMPARTMENT	1	-.228	863.	.323	-411.5
7	2.388	1300.	FLOOR 7 COMPARTMENT	1	-.245	863.	.323	-426.8
8	2.216	1300.	FLOOR 8 COMPARTMENT	1	-.255	863.	.323	-435.7
9	2.042	1300.	FLOOR 9 COMPARTMENT	1	-.260	863.	.323	-440.0
10	1.867	1300.	FLOOR 10 COMPARTMENT	1	-.265	863.	.323	-444.1
11	1.689	1300.	FLOOR 11 COMPARTMENT	1	-.270	863.	.323	-447.7
12	1.511	1300.	FLOOR 12 COMPARTMENT	1	-.273	863.	.323	-450.4
13	1.332	1300.	FLOOR 13 COMPARTMENT	1	-.275	863.	.323	-451.9
14	1.152	1300.	FLOOR 14 COMPARTMENT	1	-.274	863.	.323	-451.2
15	.971	1300.	FLOOR 15 COMPARTMENT	1	-.269	863.	.323	-446.9
								-.4 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX E - RUN 6 COMPUTER OUTPUT

WINTER - OUTSIDE,1ST,2ND,3RD FLOOR DOORS OPEN

ELEVATOR

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 240000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	3.170	0.	FLOOR 1 COMPARTMENT 1	.204	1746.	.670	789.4
2	2.997	0.	FLOOR 2 COMPARTMENT 1	.209	1746.	.670	798.1
3	2.824	0.	FLOOR 3 COMPARTMENT 1	.211	1746.	.670	802.0
4	2.651	0.	FLOOR 4 COMPARTMENT 1	.072	1746.	.670	467.7
5	2.478	0.	FLOOR 5 COMPARTMENT 1	.041	1746.	.670	355.4
6	2.306	0.	FLOOR 6 COMPARTMENT 1	.023	1746.	.670	267.6
7	2.133	0.	FLOOR 7 COMPARTMENT 1	.010	1746.	.670	173.7
8	1.960	0.	FLOOR 8 COMPARTMENT 1	.001	1746.	.670	45.7
9	1.788	0.	FLOOR 9 COMPARTMENT 1	-.006	1746.	.670	-130.5
10	1.615	0.	FLOOR 10 COMPARTMENT 1	-.014	1746.	.670	-203.5
11	1.443	0.	FLOOR 11 COMPARTMENT 1	-.023	1746.	.670	-262.6
12	1.270	0.	FLOOR 12 COMPARTMENT 1	-.032	1746.	.670	-312.4
13	1.098	0.	FLOOR 13 COMPARTMENT 1	-.041	1746.	.670	-353.4
14	.926	0.	FLOOR 14 COMPARTMENT 1	-.048	1746.	.670	-382.7
15	.754	0.	FLOOR 15 COMPARTMENT 1	-.051	1746.	.670	-395.6
16	.582	0.					
			OUTSIDE DIRECTION 1	-.180	3910.	1.500	-1659.2
							-.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

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WINTER - OUTSIDE,7TH,8TH,9TH FLOOR DOORS OPEN
14 2 0
16 1
6 12
2
1 1 70
1 1 45
1 1
0 1 1
1
15
1 15 1
0 1 1 0 1
1 .65 0.85
1 .65 1.13
2
STAIRWELL
7.0E4 1 15 2
0 1300
1 .65 0.323
4
2 1
1 .65 10.5
3 7
1 .65 10.5
3 8
1 .65 10.5
3 9
1 .65 10.5
ELEVATOR
2.4E5 1 16 1
0 0
1 .65 0.67
1
2 16
1 .65 1.5
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APPENDIX E - RUN 7 COMPUTER OUTPUT

WINTER - OUTSIDE.7TH.8TH.9TH FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	1	3.274	1	0.	FLOOR 2 COMPARTMENT 1	-.009	2216.	.850	-207.6
					STAIRWELL	.101	863.	.323	273.9
					ELEVATOR	-.072	1746.	.670	-467.3
					OUTSIDE DIRECTION 1	.017	3115.	1.130	400.6
									-.4 NET
2	1	3.092	1	0.	FLOOR 3 COMPARTMENT 1	-.016	2216.	.850	-279.4
					FLOOR 1 COMPARTMENT 1	.009	2216.	.850	207.6
					STAIRWELL	.111	863.	.323	287.8
					ELEVATOR	-.063	1746.	.670	-437.6
					OUTSIDE DIRECTION 1	.005	3115.	1.130	221.5
									-.1 NET
3	1	2.903	1	0.	FLOOR 4 COMPARTMENT 1	-.017	2216.	.850	-290.6
					FLOOR 2 COMPARTMENT 1	.016	2216.	.850	279.4
					STAIRWELL	.126	863.	.323	306.4
					ELEVATOR	-.047	1746.	.670	-378.1
					OUTSIDE DIRECTION 1	.001	3115.	1.130	82.9
									.1 NET
4	1	2.713	1	0.	FLOOR 5 COMPARTMENT 1	-.006	2216.	.850	-170.4
					FLOOR 3 COMPARTMENT 1	.017	2216.	.850	290.6
					STAIRWELL	.140	863.	.323	322.9
					ELEVATOR	-.030	1746.	.670	-300.9
					OUTSIDE DIRECTION 1	-.002	2945.	1.130	-142.3
									-.3 NET
5	1	2.535	1	0.	FLOOR 6 COMPARTMENT 1	.005	2216.	.850	155.2
					FLOOR 4 COMPARTMENT 1	.006	2216.	.850	170.4
					STAIRWELL	.141	863.	.323	323.8
					ELEVATOR	-.024	1746.	.670	-269.5
					OUTSIDE DIRECTION 1	-.017	2945.	1.130	-380.0
									-.1 NET
6	1	2.367	1	0.	FLOOR 7 COMPARTMENT 1	.112	2216.	.850	742.7
					FLOOR 5 COMPARTMENT 1	-.005	2216.	.850	-155.2
					STAIRWELL	.129	863.	.323	310.3
					ELEVATOR	-.029	1746.	.670	-296.2
					OUTSIDE DIRECTION 1	-.042	2945.	1.130	-602.0
									-.4 NET
7	1	2.307	1	0.	FLOOR 8 COMPARTMENT 1	-.002	2216.	.850	-94.6
					FLOOR 6 COMPARTMENT 1	-.112	2216.	.850	-742.7
					STAIRWELL	.009	28038.	10.500	2722.9
					ELEVATOR	-.141	1746.	.670	-656.2
					OUTSIDE DIRECTION 1	-.174	2945.	1.130	-1229.7
									-.3 NET

APPENDIX E - RUN 7 COMPUTER OUTPUT

WINTER - OUTSIDE,7TH,8TH,9TH FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
8	1	2.132	1	0.	FLOOR 9 COMPARTMENT	1	-.008	2216.	.850	-197.1
					FLOOR 7 COMPARTMENT	1	.002	2216.	.850	94.6
					STAIRWELL		.005	28038.	10.500	2047.1
					ELEVATOR		-.139	1746.	.670	-652.1
					OUTSIDE DIRECTION 1		-.193	2945.	1.130	-1292.7
										-.2 NET
9	1	1.952	1	0.	FLOOR 10 COMPARTMENT	1	-.137	2216.	.850	-820.5
					FLOOR 8 COMPARTMENT	1	.008	2216.	.850	197.1
					STAIRWELL		.009	28038.	10.500	2589.8
					ELEVATOR		-.132	1746.	.670	-633.7
					OUTSIDE DIRECTION 1		-.205	2945.	1.130	-1333.0
										-.4 NET
10	1	1.643	1	0.	FLOOR 11 COMPARTMENT	1	-.033	2216.	.850	-400.8
					FLOOR 9 COMPARTMENT	1	.137	2216.	.850	820.5
					STAIRWELL		.144	863.	.323	326.8
					ELEVATOR		.005	1746.	.670	126.1
					OUTSIDE DIRECTION 1		-.088	2945.	1.130	-872.7
										-.1 NET
11	1	1.438	1	0.	FLOOR 12 COMPARTMENT	1	-.017	2216.	.850	-290.1
					FLOOR 10 COMPARTMENT	1	.033	2216.	.850	400.8
					STAIRWELL		.172	863.	.323	357.8
					ELEVATOR		.038	1746.	.670	338.9
					OUTSIDE DIRECTION 1		-.075	2945.	1.130	-807.7
										-.3 NET
12	1	1.248	1	0.	FLOOR 13 COMPARTMENT	1	-.012	2216.	.850	-243.9
					FLOOR 11 COMPARTMENT	1	.017	2216.	.850	290.1
					STAIRWELL		.183	863.	.323	369.4
					ELEVATOR		.055	1746.	.670	407.9
					OUTSIDE DIRECTION 1		-.078	2945.	1.130	-823.6
										-.2 NET
13	1	1.064	1	0.	FLOOR 14 COMPARTMENT	1	-.008	2216.	.850	-204.1
					FLOOR 12 COMPARTMENT	1	.012	2216.	.850	243.9
					STAIRWELL		.189	863.	.323	374.5
					ELEVATOR		.066	1746.	.670	450.2
					OUTSIDE DIRECTION 1		-.086	2945.	1.130	-864.8
										-.2 NET
14	1	.884	1	0.	FLOOR 15 COMPARTMENT	1	-.004	2216.	.850	-135.7
					FLOOR 13 COMPARTMENT	1	.008	2216.	.850	204.1
					STAIRWELL		.189	863.	.323	375.1
					ELEVATOR		.075	1746.	.670	477.5
					OUTSIDE DIRECTION 1		-.098	2945.	1.130	-921.2
										-.2 NET

APPENDIX E - RUN 7 COMPUTER OUTPUT

WINTER - OUTSIDE,7TH,8TH,9TH FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
15	1	.708	1	0.	FLOOR 14 COMPARTMENT	1	.004	2216.	.850	135.7
					STAIRWELL		.184	863.	.323	370.4
					ELEVATOR		.078	1745.	.670	489.0
					OUTSIDE DIRECTION	1	-.114	2945.	1.130	-995.2
										-.1 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX E - RUN 7 COMPUTER OUTPUT

WINTER - OUTSIDE,7TH,8TH,9TH FLOOR DOORS OPEN

STAIRWELL

TEMPERATURE PROFILE 2
SHAFT FLOW COEFFICIENT 70000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	3.375	1300.	FLOOR 1 COMPARTMENT	1	-.101	863.	.323	-273.9
			OUTSIDE DIRECTION	1	-.084	28038.	10.500	-8141.5
2	3.203	1300.	FLOOR 2 COMPARTMENT	1	-.111	863.	.323	-287.8
3	3.030	1300.	FLOOR 3 COMPARTMENT	1	-.126	863.	.323	-306.4
4	2.653	1300.	FLOOR 4 COMPARTMENT	1	-.140	863.	.323	-322.9
5	2.676	1300.	FLOOR 5 COMPARTMENT	1	-.141	863.	.323	-323.8
6	2.496	1300.	FLOOR 6 COMPARTMENT	1	-.129	863.	.323	-310.3
7	2.316	1300.	FLOOR 7 COMPARTMENT	1	-.009	28038.	10.500	-2722.9
8	2.138	1300.	FLOOR 8 COMPARTMENT	1	-.005	28038.	10.500	-2047.1
9	1.961	1300.	FLOOR 9 COMPARTMENT	1	-.009	28038.	10.500	-2589.8
10	1.786	1300.	FLOOR 10 COMPARTMENT	1	-.144	863.	.323	-326.8
11	1.610	1300.	FLOOR 11 COMPARTMENT	1	-.172	863.	.323	-357.8
12	1.432	1300.	FLOOR 12 COMPARTMENT	1	-.183	863.	.323	-369.4
13	1.253	1300.	FLOOR 13 COMPARTMENT	1	-.189	863.	.323	-374.5
14	1.073	1300.	FLOOR 14 COMPARTMENT	1	-.189	863.	.323	-375.1
15	.893	1300.	FLOOR 15 COMPARTMENT	1	-.184	863.	.323	-370.4
								-.4 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

WINTER - OUTSIDE,7TH,8TH,9TH FLOOR DOORS OPEN

ELEVATOR

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 240000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	3.202	0.	FLOOR 1 COMPARTMENT 1	.072	1746.	.670	467.3
2	3.029	0.	FLOOR 2 COMPARTMENT 1	.063	1746.	.670	437.6
3	2.856	0.	FLOOR 3 COMPARTMENT 1	.047	1746.	.670	378.1
4	2.684	0.	FLOOR 4 COMPARTMENT 1	.030	1746.	.670	300.9
5	2.511	0.	FLOOR 5 COMPARTMENT 1	.024	1746.	.670	269.5
6	2.338	0.	FLOOR 6 COMPARTMENT 1	.029	1746.	.670	296.2
7	2.166	0.	FLOOR 7 COMPARTMENT 1	.141	1746.	.670	656.2
8	1.993	0.	FLOOR 8 COMPARTMENT 1	.139	1746.	.670	652.1
9	1.820	0.	FLOOR 9 COMPARTMENT 1	.132	1746.	.670	633.7
10	1.648	0.	FLOOR 10 COMPARTMENT 1	-.005	1746.	.670	-126.1
11	1.475	0.	FLOOR 11 COMPARTMENT 1	-.038	1746.	.670	-338.9
12	1.303	0.	FLOOR 12 COMPARTMENT 1	-.055	1746.	.670	-407.9
13	1.131	0.	FLOOR 13 COMPARTMENT 1	-.066	1746.	.670	-450.2
14	.958	0.	FLOOR 14 COMPARTMENT 1	-.075	1746.	.670	-477.5
15	.786	0.	FLOOR 15 COMPARTMENT 1	-.078	1746.	.670	-489.0
16	.615	0.					
			OUTSIDE DIRECTION 1	-.213	3910.	1.500	-1802.5
							-.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

```
WINTER - OUTSIDE,13TH,14TH,15TH FLOOR DOORS OPEN
14 2 0
16 1
6 12
2
1 1 70
1 1 45
1 1
0 1 1
1
15
1 15 1
0 1 1 0 1
1 .65 0.85
1 .65 1.13
2
STAIRWELL
7.0E4 1 15 2
0 1300
1 .65 0.323
4
2 1
1 .65 10.5
3 13
1 .65 10.5
3 14
1 .65 10.5
3 15
1 .65 10.5
ELEVATOR
2.4E5 1 16 1
0 0
1 .65 0.67
1
2 16
1 .65 1.5
```

APPENDIX E - RUN 8 COMPUTER OUTPUT

WINTER - OUTSIDE,13TH,14TH,15TH FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION	TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	1	3.275	1	0.	FLOOR 2 COMPARTMENT	1	-.009	2216.	.850	-211.3
					STAIRWELL		.109	863.	.323	284.4
					ELEVATOR		-.069	1746.	.670	-458.7
					OUTSIDE DIRECTION	1	.015	3115.	1.130	385.5
										-.2 NET
2	1	3.093	1	0.	FLOOR 3 COMPARTMENT	1	-.017	2216.	.850	-284.6
					FLOOR 1 COMPARTMENT	1	.009	2216.	.850	211.3
					STAIRWELL		.121	863.	.323	299.8
					ELEVATOR		-.060	1746.	.670	-427.4
					OUTSIDE DIRECTION	1	.004	3115.	1.130	200.8
										.1 NET
3	1	2.904	1	0.	FLOOR 4 COMPARTMENT	1	-.019	2216.	.850	-303.5
					FLOOR 2 COMPARTMENT	1	.017	2216.	.850	284.6
					STAIRWELL		.137	863.	.323	319.8
					ELEVATOR		-.043	1746.	.670	-363.7
					OUTSIDE DIRECTION	1	.000	3115.	1.130	62.9
										.2 NET
4	1	2.712	1	0.	FLOOR 5 COMPARTMENT	1	-.015	2216.	.850	-271.8
					FLOOR 3 COMPARTMENT	1	.019	2216.	.850	303.5
					STAIRWELL		.154	863.	.323	338.4
					ELEVATOR		-.025	1746.	.670	-274.0
					OUTSIDE DIRECTION	1	-.001	2945.	1.130	-96.4
										-.3 NET
5	1	2.524	1	0.	FLOOR 6 COMPARTMENT	1	-.010	2216.	.850	-217.8
					FLOOR 4 COMPARTMENT	1	.015	2216.	.850	271.8
					STAIRWELL		.165	863.	.323	350.0
					ELEVATOR		-.010	1746.	.670	-171.1
					OUTSIDE DIRECTION	1	-.006	2945.	1.130	-232.9
										-.1 NET
6	1	2.342	1	0.	FLOOR 7 COMPARTMENT	1	-.008	2216.	.850	-197.5
					FLOOR 5 COMPARTMENT	1	.010	2216.	.850	217.8
					STAIRWELL		.168	863.	.323	354.0
					ELEVATOR		.000	1745.	.670	7.3
					OUTSIDE DIRECTION	1	-.017	2945.	1.130	-381.9
										-.3 NET
7	1	2.162	1	0.	FLOOR 8 COMPARTMENT	1	-.009	2216.	.850	-205.8
					FLOOR 6 COMPARTMENT	1	.008	2216.	.850	197.5
					STAIRWELL		.169	863.	.323	354.9
					ELEVATOR		.008	1746.	.670	155.4
					OUTSIDE DIRECTION	1	-.029	2945.	1.130	-502.1
										-.2 NET

APPENDIX E - RUN 8 COMPUTER OUTPUT

WINTER - OUTSIDE,13TH,14TH,15TH FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
8	1	1.980	1	0.	FLOOR 9 COMPARTMENT	1	-.008	2216.	.850	-192.5
					FLOOR 7 COMPARTMENT	1	.009	2216.	.850	205.8
					STAIRWELL		.170	863.	.323	355.5
					ELEVATOR		.017	1746.	.670	224.3
					OUTSIDE DIRECTION 1		-.041	2945.	1.130	-593.6
										-.4 NET
9	1	1.801	1	0.	FLOOR 10 COMPARTMENT	1	-.004	2216.	.850	-138.5
					FLOOR 8 COMPARTMENT	1	.008	2216.	.850	192.5
					STAIRWELL		.169	863.	.323	354.6
					ELEVATOR		.024	1746.	.670	270.6
					OUTSIDE DIRECTION 1		-.053	2945.	1.130	-679.6
										-.4 NET
10	1	1.624	1	0.	FLOOR 11 COMPARTMENT	1	.000	2216.	.850	-3.4
					FLOOR 9 COMPARTMENT	1	.004	2216.	.850	138.5
					STAIRWELL		.164	863.	.323	349.6
					ELEVATOR		.028	1746.	.670	291.6
					OUTSIDE DIRECTION 1		-.070	2945.	1.130	-776.5
										-.2 NET
11	1	1.452	1	0.	FLOOR 12 COMPARTMENT	1	.012	2216.	.850	246.5
					FLOOR 10 COMPARTMENT	1	.000	2216.	.850	3.4
					STAIRWELL		.155	863.	.323	340.1
					ELEVATOR		.028	1746.	.670	291.5
					OUTSIDE DIRECTION 1		-.090	2945.	1.130	-881.8
										-.4 NET
12	1	1.292	1	0.	FLOOR 13 COMPARTMENT	1	.112	2216.	.850	742.9
					FLOOR 11 COMPARTMENT	1	-.012	2216.	.850	-246.5
					STAIRWELL		.134	863.	.323	315.3
					ELEVATOR		.015	1746.	.670	217.3
					OUTSIDE DIRECTION 1		-.122	2945.	1.130	-1029.4
										-.4 NET
13	1	1.233	1	0.	FLOOR 14 COMPARTMENT	1	-.004	2216.	.850	-137.8
					FLOOR 12 COMPARTMENT	1	-.112	2216.	.850	-742.9
					STAIRWELL		.011	28038.	10.500	2910.3
					ELEVATOR		-.097	1746.	.670	-543.7
					OUTSIDE DIRECTION 1		-.255	2945.	1.130	-1486.3
										-.4 NET
14	1	1.057	1	0.	FLOOR 15 COMPARTMENT	1	-.007	2216.	.850	-190.9
					FLOOR 13 COMPARTMENT	1	.004	2216.	.850	137.8
					STAIRWELL		.006	28038.	10.500	2118.2
					ELEVATOR		-.093	1746.	.670	-532.7
					OUTSIDE DIRECTION 1		-.271	2945.	1.130	-1532.8
										-.4 NET

WINTER - OUTSIDE,13TH,14TH,15TH FLOOR DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
15	1	.877	1	0.	FLOOR 14 COMPARTMENT 1	.007	2216.	.850	190.9
					STAIRWELL	.005	28038.	10.500	1888.0
					ELEVATOR	-.086	1746.	.670	-511.0
					OUTSIDE DIRECTION 1	-.284	2945.	1.130	-1568.0
									-.1 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX E - RUN 8 COMPUTER OUTPUT

WINTER - OUTSIDE,13TH,14TH,15TH FLOOR DOORS OPEN

STAIRWELL

TEMPERATURE PROFILE 2
SHAFT FLOW COEFFICIENT 70000.

LOOR	PRESSURE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	3.384	1300.	FLOOR 1 COMPARTMENT	1	-.109	863.	.323	-284.4
			OUTSIDE DIRECTION 1		-.093	28038.	10.500	-8567.5
2	3.214	1300.	FLOOR 2 COMPARTMENT	1	-.121	863.	.323	-299.8
3	3.041	1300.	FLOOR 3 COMPARTMENT	1	-.137	863.	.323	-319.8
4	2.866	1300.	FLOOR 4 COMPARTMENT	1	-.154	863.	.323	-338.4
5	2.689	1300.	FLOOR 5 COMPARTMENT	1	-.165	863.	.323	-350.0
6	2.510	1300.	FLOOR 6 COMPARTMENT	1	-.168	863.	.323	-354.0
7	2.331	1300.	FLOOR 7 COMPARTMENT	1	-.169	863.	.323	-354.9
8	2.150	1300.	FLOOR 8 COMPARTMENT	1	-.170	863.	.323	-355.5
9	1.970	1300.	FLOOR 9 COMPARTMENT	1	-.169	863.	.323	-354.6
10	1.789	1300.	FLOOR 10 COMPARTMENT	1	-.164	863.	.323	-349.6
11	1.608	1300.	FLOOR 11 COMPARTMENT	1	-.155	863.	.323	-340.1
12	1.426	1300.	FLOOR 12 COMPARTMENT	1	-.134	863.	.323	-315.3
13	1.243	1300.	FLOOR 13 COMPARTMENT	1	-.011	28038.	10.500	-2910.3
14	1.062	1300.	FLOOR 14 COMPARTMENT	1	-.006	28038.	10.500	-2118.3
15	.882	1300.	FLOOR 15 COMPARTMENT	1	-.005	28038.	10.500	-1888.1
								-.4 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX E - RUN 8 COMPUTER OUTPUT

WINTER - OUTSIDE.13TH.14TH.15TH FLOOR DOORS OPEN

ELEVATOR

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 240000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION	TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	3.206	0.	FLOOR 1	COMPARTMENT 1	.069	1746.	.670	458.7
2	3.033	0.	FLOOR 2	COMPARTMENT 1	.060	1746.	.670	427.4
3	2.860	0.	FLOOR 3	COMPARTMENT 1	.043	1746.	.670	363.7
4	2.687	0.	FLOOR 4	COMPARTMENT 1	.025	1746.	.670	274.0
5	2.515	0.	FLOOR 5	COMPARTMENT 1	.010	1746.	.670	171.1
6	2.342	0.	FLOOR 6	COMPARTMENT 1	.000	1746.	.670	-7.3
7	2.169	0.	FLOOR 7	COMPARTMENT 1	-.008	1746.	.670	-155.4
8	1.997	0.	FLOOR 8	COMPARTMENT 1	-.017	1746.	.670	-224.3
9	1.825	0.	FLOOR 9	COMPARTMENT 1	-.024	1746.	.670	-270.6
10	1.652	0.	FLOOR 10	COMPARTMENT 1	-.028	1746.	.670	-291.6
11	1.480	0.	FLOOR 11	COMPARTMENT 1	-.028	1746.	.670	-291.5
12	1.308	0.	FLOOR 12	COMPARTMENT 1	-.015	1746.	.670	-217.3
13	1.136	0.	FLOOR 13	COMPARTMENT 1	.097	1746.	.670	543.7
14	.964	0.	FLOOR 14	COMPARTMENT 1	.093	1746.	.670	532.7
15	.792	0.	FLOOR 15	COMPARTMENT 1	.086	1746.	.670	511.0
16	.620	0.						
			OUTSIDE	DIRECTION 1	-.218	3910.	1.500	-1824.6
								-.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX F.
DATA AND COMPUTER OUTPUT FOR ZONE SMOKE CONTROL EXAMPLE OF CHAPTER 6

TABLE OF CONTENTS

Summary Table - Appendix F

Run	Fire Floor	Smoke Zone Floors	Season	Floors on Which Stairwell Doors to Building Are Open
1	1	1,2	Summer	None
2	1	1,2	Winter	None
3	12	11,12	Winter	None
4	6	5,6,7	Summer	6
5	6	5,6,7	Summer	5,6,7
6	6	5,6,7	Summer	3,4,6,8,9
7	6	5,6,7	Winter	6

Note: See chapter 7 for discussion of this example computer analysis of a zoned smoke control system.

```
SUMMER - FIRE FLOOR IS 1ST FL - NO DOORS OPEN
93 2 0
13 1
6 12
1
1 1 70
1 1
0 1 1
1
12
1 2 1
0 1 1 -2040 1
1 .65 .49
1 .65 1.22
3 12 1
0 1 1 2040 1
1 .65 .49
1 .65 1.22
2
STAIRWELL
7.0E4 1 12 1
0 0
1 .65 .323
5
2 1
1 .65 10.5
1 2
9200
1 5
1200
1 6
1200
1 11
1200
ELEVATOR
2.4E5 1 13 1
0 0
1 .65 1.75
1
2 13
1 .65 3
```

APPENDIX F - RUN 1 COMPUTER OUTPUT

SUMMER - FIRE FLOOR IS 1ST FL - NO DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	1	2.405	1	-2040.	FLOOR 2 COMPARTMENT 1	.018	1277.	.490	171.0
					STAIRWELL	.170	842.	.323	347.2
					ELEVATOR	.187	4561.	1.750	1970.5
					OUTSIDE DIRECTION 1	-.020	3180.	1.220	-449.1
									-.4 NET
2	1	2.250	1	-2040.	FLOOR 3 COMPARTMENT 1	.174	1277.	.490	532.7
					FLOOR 1 COMPARTMENT 1	-.018	1277.	.490	-171.0
					STAIRWELL	.183	842.	.323	360.0
					ELEVATOR	.169	4561.	1.750	1673.5
					OUTSIDE DIRECTION 1	-.031	3180.	1.220	-555.6
									-.3 NET
3	1	2.251	1	2040.	FLOOR 4 COMPARTMENT 1	.012	1277.	.490	138.3
					FLOOR 2 COMPARTMENT 1	-.174	1277.	.490	-532.7
					STAIRWELL	.011	842.	.323	89.4
					ELEVATOR	-.005	4561.	1.750	-323.6
					OUTSIDE DIRECTION 1	-.197	3180.	1.220	-1411.8
									-.3 NET
4	1	2.090	1	2040.	FLOOR 5 COMPARTMENT 1	.003	1277.	.490	73.3
					FLOOR 3 COMPARTMENT 1	-.012	1277.	.490	-138.3
					STAIRWELL	.002	842.	.323	38.6
					ELEVATOR	-.017	4561.	1.750	-586.6
					OUTSIDE DIRECTION 1	-.201	3180.	1.220	-1427.2
									-.3 NET
5	1	1.920	1	2040.	FLOOR 6 COMPARTMENT 1	.002	1277.	.490	53.7
					FLOOR 4 COMPARTMENT 1	-.003	1277.	.490	-73.3
					STAIRWELL	.001	842.	.323	31.5
					ELEVATOR	-.020	4561.	1.750	-639.8
					OUTSIDE DIRECTION 1	-.197	3180.	1.220	-1412.5
									-.4 NET
6	1	1.749	1	2040.	FLOOR 7 COMPARTMENT 1	.001	1277.	.490	48.1
					FLOOR 5 COMPARTMENT 1	-.002	1277.	.490	-53.7
					STAIRWELL	.001	842.	.323	23.9
					ELEVATOR	-.021	4561.	1.750	-666.4
					OUTSIDE DIRECTION 1	-.192	3180.	1.220	-1392.2
									-.3 NET
7	1	1.578	1	2040.	FLOOR 8 COMPARTMENT 1	.001	1277.	.490	44.9
					FLOOR 6 COMPARTMENT 1	-.001	1277.	.490	-48.1
					STAIRWELL	.001	842.	.323	20.4
					ELEVATOR	-.023	4561.	1.750	-687.3
					OUTSIDE DIRECTION 1	-.186	3180.	1.220	-1370.3
									-.3 NET

APPENDIX F - RUN 1 COMPUTER OUTPUT

SUMMER - FIRE FLOOR IS 1ST FL - NO DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
8	1	1.407	1	2040.	FLOOR 9 COMPARTMENT 1	.001	1277.	.490	37.5
					FLOOR 7 COMPARTMENT 1	-.001	1277.	.490	-44.9
					STAIRWELL	.001	842.	.323	20.0
					ELEVATOR	-.024	4561.	1.750	-705.4
					OUTSIDE DIRECTION 1	-.180	3180.	1.220	-1347.4
									-.2 NET
9	1	1.235	1	2040.	FLOOR 10 COMPARTMENT 1	.001	1277.	.490	33.8
					FLOOR 8 COMPARTMENT 1	-.001	1277.	.490	-37.5
					STAIRWELL	.000	842.	.323	4.4
					ELEVATOR	-.025	4561.	1.750	-717.8
					OUTSIDE DIRECTION 1	-.173	3180.	1.220	-1322.7
									.0 NET
10	1	1.063	1	2040.	FLOOR 11 COMPARTMENT 1	.001	1277.	.490	33.9
					FLOOR 9 COMPARTMENT 1	-.001	1277.	.490	-33.8
					STAIRWELL	.000	842.	.323	-15.6
					ELEVATOR	-.025	4561.	1.750	-727.8
					OUTSIDE DIRECTION 1	-.166	3180.	1.220	-1296.9
									-.3 NET
11	1	.891	1	2040.	FLOOR 12 COMPARTMENT 1	.000	1277.	.490	25.3
					FLOOR 10 COMPARTMENT 1	-.001	1277.	.490	-33.9
					STAIRWELL	-.001	842.	.323	-22.7
					ELEVATOR	-.026	4561.	1.750	-738.0
					OUTSIDE DIRECTION 1	-.160	3180.	1.220	-1270.7
									.0 NET
12	1	.720	1	2040.	FLOOR 11 COMPARTMENT 1	.000	1277.	.490	-25.3
					STAIRWELL	-.001	842.	.323	-28.2
					ELEVATOR	-.027	4561.	1.750	-744.2
					OUTSIDE DIRECTION 1	-.153	3180.	1.220	-1242.6
									-.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX F - RUN 1 COMPUTER OUTPUT

SUMMER - FIRE FLOOR IS 1ST FL - NO DOORS OPEN

STAIRWELL

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 70000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.575	0.	FLOOR 1 COMPARTMENT 1	-.170	842.	.323	-347.2
			OUTSIDE DIRECTION 1	-.190	27368.	10.500	-11931.4
2	2.433	9200.	FLOOR 2 COMPARTMENT 1	-.183	842.	.323	-360.0
3	2.262	0.	FLOOR 3 COMPARTMENT 1	-.011	842.	.323	-89.4
4	2.092	0.	FLOOR 4 COMPARTMENT 1	-.002	842.	.323	-38.6
5	1.922	1200.	FLOOR 5 COMPARTMENT 1	-.001	842.	.323	-31.5
6	1.750	0.	FLOOR 6 COMPARTMENT 1	-.001	842.	.323	-23.9
7	1.578	0.	FLOOR 7 COMPARTMENT 1	-.001	842.	.323	-20.4
8	1.407	1200.	FLOOR 8 COMPARTMENT 1	-.001	842.	.323	-20.0
9	1.235	0.	FLOOR 9 COMPARTMENT 1	.000	842.	.323	-4.4
10	1.063	0.	FLOOR 10 COMPARTMENT 1	.000	842.	.323	15.6
11	.891	1200.	FLOOR 11 COMPARTMENT 1	.001	842.	.323	22.7
12	.718	0.	FLOOR 12 COMPARTMENT 1	.001	842.	.323	28.2
							-.4 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX F - RUN 1 COMPUTER OUTPUT

SUMMER - FIRE FLOOR IS 1ST FL - NO DOORS OPEN

ELEVATOR

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 240000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.591	0.	FLOOR 1 COMPARTMENT	1	-.187	4561.	1.750	-1970.5
2	2.418	0.	FLOOR 2 COMPARTMENT	1	-.169	4561.	1.750	-1873.5
3	2.246	0.	FLOOR 3 COMPARTMENT	1	.005	4561.	1.750	323.6
4	2.073	0.	FLOOR 4 COMPARTMENT	1	.017	4561.	1.750	586.6
5	1.900	0.	FLOOR 5 COMPARTMENT	1	.020	4561.	1.750	639.8
6	1.728	0.	FLOOR 6 COMPARTMENT	1	.021	4561.	1.750	666.4
7	1.555	0.	FLOOR 7 COMPARTMENT	1	.023	4561.	1.750	687.3
8	1.383	0.	FLOOR 8 COMPARTMENT	1	.024	4561.	1.750	705.4
9	1.210	0.	FLOOR 9 COMPARTMENT	1	.025	4561.	1.750	717.8
10	1.038	0.	FLOOR 10 COMPARTMENT	1	.025	4561.	1.750	727.8
11	.865	0.	FLOOR 11 COMPARTMENT	1	.026	4561.	1.750	738.0
12	.693	0.	FLOOR 12 COMPARTMENT	1	.027	4561.	1.750	744.2
13	.521	0.						
			OUTSIDE DIRECTION	1	-.119	7820.	3.000	-2692.9
								.0 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

APPENDIX F - RUN 2 DATA

```
WINTER - FIRE FLOOR IS 1ST FL - NO DOORS OPEN
14 2 0
13 1
6 12
1
1 1 70
1 1
0 1 1
1
12
1 2 1
0 1 1 -2040 1
1 .65 .49
1 .65 1.22
3 12 1
0 1 1 2040 1
1 .65 .49
1 .65 1.22
2
STAIRWELL
7.0E4 1 12 1
0 0
1 .65 .323
5
2 1
1 .65 10.5
1 2
9200
1 5
1200
1 8
1200
1 11
1200
ELEVATOR
2.4E5 1 13 1
0 0
1 .65 1.75
1
2 13
1 .65 3
```

APPENDIX F - RUN 2 COMPUTER OUTPUT

WINTER - FIRE FLOOR IS 1ST FL - NO DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION	TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	1	2.698	1	-2040.	FLOOR 2 COMPARTMENT	1	-.002	1277.	.490	-54.7
					STAIRWELL		.150	842.	.323	326.2
					ELEVATOR		.087	4561.	1.750	1342.0
					OUTSIDE DIRECTION	1	.016	3363.	1.220	426.3
										-.2 NET
2	1	2.523	1	-2040.	FLOOR 3 COMPARTMENT	1	.115	1277.	.490	432.6
					FLOOR 1 COMPARTMENT	1	.002	1277.	.490	54.7
					STAIRWELL		.174	842.	.323	350.9
					ELEVATOR		.088	4561.	1.750	1356.0
					OUTSIDE DIRECTION	1	-.002	3180.	1.220	-154.4
										-.2 NET
3	1	2.465	1	2040.	FLOOR 4 COMPARTMENT	1	.007	1277.	.490	104.7
					FLOOR 2 COMPARTMENT	1	-.115	1277.	.490	-432.6
					STAIRWELL		.059	842.	.323	205.1
					ELEVATOR		-.026	4561.	1.750	-738.9
					OUTSIDE DIRECTION	1	-.137	3180.	1.220	-1178.3
										.0 NET
4	1	2.299	1	2040.	FLOOR 5 COMPARTMENT	1	.000	1277.	.490	-13.9
					FLOOR 3 COMPARTMENT	1	-.007	1277.	.490	-104.7
					STAIRWELL		.053	842.	.323	194.2
					ELEVATOR		-.033	4561.	1.750	-827.2
					OUTSIDE DIRECTION	1	-.164	3180.	1.220	-1288.6
										.4 NET
5	1	2.126	1	2040.	FLOOR 6 COMPARTMENT	1	-.002	1277.	.490	-59.3
					FLOOR 4 COMPARTMENT	1	.000	1277.	.490	13.9
					STAIRWELL		.054	842.	.323	195.7
					ELEVATOR		-.033	4561.	1.750	-825.3
					OUTSIDE DIRECTION	1	-.184	3180.	1.220	-1365.0
										.1 NET
6	1	1.951	1	2040.	FLOOR 7 COMPARTMENT	1	-.003	1277.	.490	-71.6
					FLOOR 5 COMPARTMENT	1	.002	1277.	.490	59.3
					STAIRWELL		.056	842.	.323	199.8
					ELEVATOR		-.031	4561.	1.750	-797.5
					OUTSIDE DIRECTION	1	-.202	3180.	1.220	-1430.1
										-.1 NET
7	1	1.776	1	2040.	FLOOR 8 COMPARTMENT	1	-.003	1277.	.490	-73.4
					FLOOR 6 COMPARTMENT	1	.003	1277.	.490	71.6
					STAIRWELL		.060	842.	.323	205.6
					ELEVATOR		-.027	4561.	1.750	-755.3
					OUTSIDE DIRECTION	1	-.219	3180.	1.220	-1488.9
										-.4 NET

APPENDIX F - RUN 2 COMPUTER OUTPUT

WINTER - FIRE FLOOR IS 1ST FL - NO DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
8	1	1.600	1	2040.	FLOOR 9 COMPARTMENT 1	-.003	1277.	.490	-72.0
					FLOOR 7 COMPARTMENT 1	.003	1277.	.490	73.4
					STAIRWELL	.063	842.	.323	211.8
					ELEVATOR	-.024	4561.	1.750	-708.6
					OUTSIDE DIRECTION 1	-.236	3180.	1.220	-1544.9
									-.3 NET
9	1	1.424	1	2040.	FLOOR 10 COMPARTMENT 1	-.003	1277.	.490	-68.9
					FLOOR 8 COMPARTMENT 1	.003	1277.	.490	72.0
					STAIRWELL	.066	842.	.323	217.0
					ELEVATOR	-.021	4561.	1.750	-661.1
					OUTSIDE OIRECTION 1	-.253	3180.	1.220	-1599.3
									-.3 NET
10	1	1.249	1	2040.	FLOOR 11 COMPARTMENT 1	-.002	1277.	.490	-63.0
					FLOOR 9 COMPARTMENT 1	.003	1277.	.490	68.9
					STAIRWELL	.069	842.	.323	221.8
					ELEVATOR	-.018	4561.	1.750	-615.4
					OUTSIDE DIRECTION 1	-.270	3180.	1.220	-1652.7
									-.4 NET
11	1	1.074	1	2040.	FLOOR 12 COMPARTMENT 1	-.001	1277.	.490	-47.3
					FLOOR 10 COMPARTMENT 1	.002	1277.	.490	63.0
					STAIRWELL	.072	842.	.323	225.8
					ELEVATOR	-.016	4561.	1.750	-575.9
					OUTSIDE DIRECTION 1	-.288	3180.	1.220	-1705.7
									-.2 NET
12	1	.901	1	2040.	FLOOR 11 COMPARTMENT 1	.001	1277.	.490	47.3
					STAIRWELL	.073	842.	.323	227.8
					ELEVATOR	-.015	4561.	1.750	-555.2
					OUTSIDE DIRECTION 1	-.306	3180.	1.220	-1760.2
									-.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX F - RUN 2 COMPUTER OUTPUT

WINTER - FIRE FLOOR IS 1ST FL - NO DOORS OPEN

STAIRWELL

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 70000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.848	0.	FLOOR 1 COMPARTMENT 1	-.150	842.	.323	-326.2
			OUTSIDE DIRECTION 1	-.134	27368.	10.500	-10018.7
2	2.697	9200.	FLOOR 2 COMPARTMENT 1	-.174	842.	.323	-350.9
3	2.525	0.	FLOOR 3 COMPARTMENT 1	-.059	842.	.323	-205.1
4	2.352	0.	FLOOR 4 COMPARTMENT 1	-.053	842.	.323	-194.2
5	2.180	1200.	FLOOR 5 COMPARTMENT 1	-.054	842.	.323	-195.7
6	2.008	0.	FLOOR 6 COMPARTMENT 1	-.056	842.	.323	-199.8
7	1.835	0.	FLOOR 7 COMPARTMENT 1	-.060	842.	.323	-205.6
8	1.663	1200.	FLOOR 8 COMPARTMENT 1	-.063	842.	.323	-211.8
9	1.491	0.	FLOOR 9 COMPARTMENT 1	-.066	842.	.323	-217.0
10	1.318	0.	FLOOR 10 COMPARTMENT 1	-.069	842.	.323	-221.8
11	1.146	1200.	FLOOR 11 COMPARTMENT 1	-.072	842.	.323	-225.8
12	.974	0.	FLOOR 12 COMPARTMENT 1	-.073	842.	.323	-227.9
							-.2 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX F - RUN 2 COMPUTER OUTPUT

WINTER - FIRE FLOOR IS 1ST FL - NO DOORS OPEN

ELEVATOR

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 240000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.785	0.	FLOOR 1 COMPARTMENT 1	-.087	4561.	1.750	-1342.0
2	2.612	0.	FLOOR 2 COMPARTMENT 1	-.088	4561.	1.750	-1356.0
3	2.439	0.	FLOOR 3 COMPARTMENT 1	.026	4561.	1.750	738.9
4	2.266	0.	FLOOR 4 COMPARTMENT 1	.033	4561.	1.750	827.2
5	2.094	0.	FLOOR 5 COMPARTMENT 1	.033	4561.	1.750	825.3
6	1.921	0.	FLOOR 6 COMPARTMENT 1	.031	4561.	1.750	797.5
7	1.748	0.	FLOOR 7 COMPARTMENT 1	.027	4561.	1.750	755.3
8	1.576	0.	FLOOR 8 COMPARTMENT 1	.024	4561.	1.750	708.6
9	1.403	0.	FLOOR 9 COMPARTMENT 1	.021	4561.	1.750	661.1
10	1.231	0.	FLOOR 10 COMPARTMENT 1	.018	4561.	1.750	615.4
11	1.058	0.	FLOOR 11 COMPARTMENT 1	.016	4561.	1.750	575.9
12	.886	0.	FLOOR 12 COMPARTMENT 1	.015	4561.	1.750	555.2
13	.713	0.					
			OUTSIDE DIRECTION 1	-.311	7820.	3.000	-4362.7
							-.4 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

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WINTER - FIRE FLOOR IS 12TH FL - NO DOORS OPEN
14 2 0
13 1
6 12
1
1 1 70
1 1
0 1 1
1
12
1 10 1
0 1 1 2040 1
1 .65 .49
1 .65 1.22
11 12 1
0 1 1 -2040 1
1 .65 .49
1 .65 1.22
2
STAIRWELL
7.0E4 1 12 1
0 0
1 .65 .323
5
2 1
1 .65 10.5
1 2
9200
1 5
1200
1 8
1200
1 11
1200
ELEVATOR
2.4E5 1 13 1
0 0
1 .65 1.75
1
2 13
1 .65 3
```

APPENDIX F - RUN 3 COMPUTER OUTPUT

WINTER - FIRE FLOOR IS 12TH FL - NO DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	1	2.825	1	2040.	FLOOR 2 COMPARTMENT 1	-.001	1277.	.490	-48.8
					STAIRWELL	.020	842.	.323	118.6
					ELEVATOR	-.053	4561.	1.750	-1052.9
					OUTSIDE DIRECTION 1	-.111	3180.	1.220	-1057.1
									-.3 NET
2	1	2.650	1	2040.	FLOOR 3 COMPARTMENT 1	-.004	1277.	.490	-79.2
					FLOOR 1 COMPARTMENT 1	.001	1277.	.490	48.8
					STAIRWELL	.042	842.	.323	171.9
					ELEVATOR	-.052	4561.	1.750	-1038.4
					OUTSIDE DIRECTION 1	-.129	3180.	1.220	-1143.3
									-.1 NET
3	1	2.474	1	2040.	FLOOR 4 COMPARTMENT 1	-.005	1277.	.490	-86.6
					FLOOR 2 COMPARTMENT 1	.004	1277.	.490	79.2
					STAIRWELL	.046	842.	.323	180.0
					ELEVATOR	-.048	4561.	1.750	-999.6
					OUTSIDE DIRECTION 1	-.146	3180.	1.220	-1213.4
									-.4 NET
4	1	2.296	1	2040.	FLOOR 5 COMPARTMENT 1	-.005	1277.	.490	-87.3
					FLOOR 3 COMPARTMENT 1	.005	1277.	.490	86.6
					STAIRWELL	.051	842.	.323	189.3
					ELEVATOR	-.044	4561.	1.750	-952.2
					OUTSIDE DIRECTION 1	-.161	3180.	1.220	-1276.7
									-.3 NET
5	1	2.119	1	2040.	FLOOR 6 COMPARTMENT 1	-.005	1277.	.490	-86.7
					FLOOR 4 COMPARTMENT 1	.005	1277.	.490	87.3
					STAIRWELL	.056	842.	.323	198.5
					ELEVATOR	-.039	4561.	1.750	-902.8
					OUTSIDE DIRECTION 1	-.177	3180.	1.220	-1336.6
									-.3 NET
6	1	1.941	1	2040.	FLOOR 7 COMPARTMENT 1	-.005	1277.	.490	-86.5
					FLOOR 5 COMPARTMENT 1	.005	1277.	.490	86.7
					STAIRWELL	.060	842.	.323	206.5
					ELEVATOR	-.035	4561.	1.750	-853.0
					OUTSIDE DIRECTION 1	-.192	3180.	1.220	-1394.1
									-.3 NET
7	1	1.764	1	2040.	FLOOR 8 COMPARTMENT 1	-.005	1277.	.490	-89.2
					FLOOR 6 COMPARTMENT 1	.005	1277.	.490	86.5
					STAIRWELL	.065	842.	.323	214.3
					ELEVATOR	-.031	4561.	1.750	-802.5
					OUTSIDE DIRECTION 1	-.208	3180.	1.220	-1449.4
									-.3 NET

APPENDIX F - RUN 3 COMPUTER OUTPUT

WINTER - FIRE FLOOR IS 12TH FL - NO DOORS OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
8	1	1.587	1	2040.	FLOOR 9 COMPARTMENT	1	-.007	1277.	.490	-103.5
					FLOOR 7 COMPARTMENT	1	.005	1277.	.490	89.2
					STAIRWELL		.070	842.	.323	222.4
					ELEVATOR		-.027	4561.	1.750	-746.9
					OUTSIDE DIRECTION 1		-.223	3180.	1.220	-1501.6
										-.3 NET
9	1	1.408	1	2040.	FLOOR 10 COMPARTMENT	1	-.017	1277.	.490	-165.8
					FLOOR 8 COMPARTMENT	1	.007	1277.	.490	103.5
					STAIRWELL		.076	842.	.323	232.5
					ELEVATOR		-.021	4561.	1.750	-663.8
					OUTSIDE DIRECTION 1		-.237	3180.	1.220	-1546.5
										-.1 NET
10	1	1.219	1	2040.	FLOOR 11 COMPARTMENT	1	-.199	1277.	.490	-569.7
					FLOOR 9 COMPARTMENT	1	.017	1277.	.490	165.8
					STAIRWELL		.093	842.	.323	256.9
					ELEVATOR		-.005	4561.	1.750	-336.2
					OUTSIDE DIRECTION 1		-.240	3180.	1.220	-1557.0
										-.2 NET
11	1	.847	1	-2040.	FLOOR 12 COMPARTMENT	1	-.025	1277.	.490	-200.6
					FLOOR 10 COMPARTMENT	1	.199	1277.	.490	569.7
					STAIRWELL		.292	842.	.323	454.9
					ELEVATOR		.192	4561.	1.750	2000.2
					OUTSIDE DIRECTION 1		-.061	3180.	1.220	-784.7
										-.4 NET
12	1	.651	1	-2040.	FLOOR 11 COMPARTMENT	1	.025	1277.	.490	200.6
					STAIRWELL		.317	842.	.323	473.6
					ELEVATOR		.216	4561.	1.750	2120.8
					OUTSIDE DIRECTION 1		-.056	3180.	1.220	-755.0
										.0 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

APPENDIX F - RUN 3 COMPUTER OUTPUT

WINTER - FIRE FLOOR IS 12TH FL - NO DOORS OPEN

STAIRWELL

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 70000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.845	0.	FLOOR 1 COMPARTMENT 1	-.020	842.	.323	-118.6
			OUTSIDE DIRECTION 1	-.130	27368.	10.500	-9880.9
2	2.692	9200.	FLOOR 2 COMPARTMENT 1	-.042	842.	.323	-171.9
3	2.519	0.	FLOOR 3 COMPARTMENT 1	-.046	842.	.323	-180.0
4	2.347	0.	FLOOR 4 COMPARTMENT 1	-.051	842.	.323	-189.3
5	2.174	1200.	FLOOR 5 COMPARTMENT 1	-.056	842.	.323	-198.5
6	2.002	0.	FLOOR 6 COMPARTMENT 1	-.060	842.	.323	-206.5
7	1.829	0.	FLOOR 7 COMPARTMENT 1	-.065	842.	.323	-214.3
8	1.657	1200.	FLOOR 8 COMPARTMENT 1	-.070	842.	.323	-222.4
9	1.484	0.	FLOOR 9 COMPARTMENT 1	-.076	842.	.323	-232.5
10	1.312	0.	FLOOR 10 COMPARTMENT 1	-.093	842.	.323	-256.9
11	1.139	1200.	FLOOR 11 COMPARTMENT 1	-.292	842.	.323	-454.9
12	.967	0.	FLOOR 12 COMPARTMENT 1	-.317	842.	.323	-473.6
							-.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX F - RUN 3 COMPUTER OUTPUT

WINTER - FIRE FLOOR IS 12TH FL - NO DOORS OPEN

ELEVATOR

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 240000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.771	0.	FLOOR 1 COMPARTMENT 1	.053	4561.	1.750	1052.9
2	2.598	0.	FLOOR 2 COMPARTMENT 1	.052	4561.	1.750	1038.4
3	2.426	0.	FLOOR 3 COMPARTMENT 1	.048	4561.	1.750	999.6
4	2.253	0.	FLOOR 4 COMPARTMENT 1	.044	4561.	1.750	952.2
5	2.080	0.	FLOOR 5 COMPARTMENT 1	.039	4561.	1.750	902.8
6	1.906	0.	FLOOR 6 COMPARTMENT 1	.035	4561.	1.750	853.0
7	1.733	0.	FLOOR 7 COMPARTMENT 1	.031	4561.	1.750	802.5
8	1.560	0.	FLOOR 8 COMPARTMENT 1	.027	4561.	1.750	746.9
9	1.387	0.	FLOOR 9 COMPARTMENT 1	.021	4561.	1.750	663.8
10	1.213	0.	FLOOR 10 COMPARTMENT 1	.005	4561.	1.750	336.2
11	1.040	0.	FLOOR 11 COMPARTMENT 1	-.192	4561.	1.750	-2000.2
12	.867	0.	FLOOR 12 COMPARTMENT 1	-.216	4561.	1.750	-2120.8
13	.694	0.					
			OUTSIDE DIRECTION 1	-.292	7820.	3.000	-4227.3
							-.1 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX F - RUN 4 DATA

```
SUMMER - FIRE FLOOR IS 5TH FL - 5TH FL DR OPEN
93 2 0
13 1
6 12
1
1 1 70
1 1
0 1 1
1
12
1 4 1
0 1 1 2040 1
1 .65 .49
1 .65 1.22
5 7 1
0 1 1 -2040 1
1 .65 .49
1 .65 1.22
8 12 1
0 1 1 2040 1
1 .65 .49
1 .65 1.22
2
STAIRWELL
7.0E4 1 12 1
0 0
1 .65 .323
6
3 6
1 .65 10.5
2 1
1 .65 10.5
1 2
9200
1 5
1200
1 8
1200
1 11
1200
ELEVATOR
2.4E5 1 13 1
0 0
1 .65 1.75
1
2 13
1 .65 3
```

APPENDIX F - RUN 4 COMPUTER OUTPUT

SUMMER - FIRE FLOOR IS 6TH FL - 6TH FL DR OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	1	2.563	1	2040.	FLOOR 2 COMPARTMENT 1	.000	1277.	.490	23.8
					STAIRWELL	-.039	842.	.323	-167.0
					ELEVATOR	-.015	4561.	1.750	-555.9
					OUTSIDE DIRECTION 1	-.178	3180.	1.220	-1340.9
									-.1 NET
2	1	2.390	1	2040.	FLOOR 3 COMPARTMENT 1	.000	1277.	.490	-23.6
					FLOOR 1 COMPARTMENT 1	.000	1277.	.490	-23.8
					STAIRWELL	-.019	842.	.323	-116.7
					ELEVATOR	-.015	4561.	1.750	-562.3
					OUTSIDE DIRECTION 1	-.171	3180.	1.220	-1314.1
									-.4 NET
3	1	2.217	1	2040.	FLOOR 4 COMPARTMENT 1	-.007	1277.	.490	-108.1
					FLOOR 2 COMPARTMENT 1	.000	1277.	.490	23.6
					STAIRWELL	-.019	842.	.323	-115.3
					ELEVATOR	-.015	4561.	1.750	-556.2
					OUTSIDE DIRECTION 1	-.163	3180.	1.220	-1283.9
									.0 NET
4	1	2.037	1	2040.	FLOOR 5 COMPARTMENT 1	-.114	1277.	.490	-430.9
					FLOOR 3 COMPARTMENT 1	.007	1277.	.490	108.1
					STAIRWELL	-.012	842.	.323	-90.4
					ELEVATOR	-.008	4561.	1.750	-401.7
					OUTSIDE DIRECTION 1	-.149	3180.	1.220	-1225.3
									-.2 NET
5	1	1.750	1	-2040.	FLOOR 6 COMPARTMENT 1	.088	1277.	.490	379.7
					FLOOR 4 COMPARTMENT 1	.114	1277.	.490	430.9
					STAIRWELL	.102	842.	.323	269.3
					ELEVATOR	.106	4561.	1.750	1485.0
					OUTSIDE DIRECTION 1	-.027	3180.	1.220	-525.2
									-.3 NET
6	1	1.666	1	-2040.	FLOOR 7 COMPARTMENT 1	-.081	1277.	.490	-364.0
					FLOOR 5 COMPARTMENT 1	-.088	1277.	.490	-379.7
					STAIRWELL	.014	27368.	10.500	3225.4
					ELEVATOR	.018	4561.	1.750	604.6
					OUTSIDE DIRECTION 1	-.108	3180.	1.220	-1046.6
									-.2 NET
7	1	1.412	1	-2040.	FLOOR 8 COMPARTMENT 1	.112	1277.	.490	427.6
					FLOOR 6 COMPARTMENT 1	.081	1277.	.490	364.0
					STAIRWELL	.097	842.	.323	261.8
					ELEVATOR	.099	4561.	1.750	1433.4
					OUTSIDE DIRECTION 1	-.020	3180.	1.220	-447.1

APPENDIX F - RUN 4 COMPUTER OUTPUT

SUMMER - FIRE FLOOR IS 6TH FL - 6TH FL DR OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
8	1	1.352	1	2040.	FLOOR 9 COMPARTMENT	1	.011	1277.	.490	134.3
					FLOOR 7 COMPARTMENT	1	-.112	1277.	.490	-427.6
					STAIRWELL		-.014	842.	.323	-98.0
					ELEVATOR		-.013	4561.	1.750	-526.8
					OUTSIDE DIRECTION 1		-.125	3180.	1.220	-1122.2
										-.3 NET
9	1	1.190	1	2040.	FLOOR 10 COMPARTMENT	1	.003	1277.	.490	75.0
					FLOOR 8 COMPARTMENT	1	-.011	1277.	.490	-134.3
					STAIRWELL		-.024	842.	.323	-130.4
					ELEVATOR		-.024	4561.	1.750	-712.0
					OUTSIDE DIRECTION 1		-.128	3180.	1.220	-1138.7
										-.2 NET
10	1	1.021	1	2040.	FLOOR 11 COMPARTMENT	1	.002	1277.	.490	54.3
					FLOOR 9 COMPARTMENT	1	-.003	1277.	.490	-75.0
					STAIRWELL		-.027	842.	.323	-138.0
					ELEVATOR		-.028	4561.	1.750	-760.5
					OUTSIDE DIRECTION 1		-.124	3180.	1.220	-1121.1
										-.4 NET
11	1	.851	1	2040.	FLOOR 12 COMPARTMENT	1	.001	1277.	.490	36.2
					FLOOR 10 COMPARTMENT	1	-.002	1277.	.490	-54.3
					STAIRWELL		-.028	842.	.323	-141.4
					ELEVATOR		-.030	4561.	1.750	-784.7
					OUTSIDE DIRECTION 1		-.119	3180.	1.220	-1095.8
										-.1 NET
12	1	.679	1	2040.	FLOOR 11 COMPARTMENT	1	-.001	1277.	.490	-36.2
					STAIRWELL		-.029	842.	.323	-143.4
					ELEVATOR		-.030	4561.	1.750	-795.6
					OUTSIDE DIRECTION 1		-.112	3180.	1.220	-1065.2
										-.4 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

APPENDIX F - RUN 4 COMPUTER OUTPUT

SUMMER - FIRE FLOOR IS 6TH FL - 6TH FL DR OPEN

STAIRWELL

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 70000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.523	0.	FLOOR 1 COMPARTMENT	1	.039	842.	.323	167.0
			OUTSIDE DIRECTION	1	-.139	27368.	10.500	-10184.2
2	2.371	9200.	FLOOR 2 COMPARTMENT	1	.019	842.	.323	116.7
3	2.198	0.	FLOOR 3 COMPARTMENT	1	.019	842.	.323	115.3
4	2.025	0.	FLOOR 4 COMPARTMENT	1	.012	842.	.323	90.4
5	1.852	1200.	FLOOR 5 COMPARTMENT	1	-.102	842.	.323	-269.3
6	1.680	0.	FLOOR 6 COMPARTMENT	1	-.014	27368.	10.500	-3225.4
7	1.509	0.	FLOOR 7 COMPARTMENT	1	-.097	842.	.323	-261.8
8	1.338	1200.	FLOOR 8 COMPARTMENT	1	.014	842.	.323	98.0
9	1.166	0.	FLOOR 9 COMPARTMENT	1	.024	842.	.323	130.4
10	.994	0.	FLOOR 10 COMPARTMENT	1	.027	842.	.323	138.0
11	.822	1200.	FLOOR 11 COMPARTMENT	1	.028	842.	.323	141.4
12	.650	0.	FLOOR 12 COMPARTMENT	1	.029	842.	.323	143.4
								.0 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

APPENDIX F - RUN 4 COMPUTER OUTPUT

SUMMER - FIRE FLOOR IS 6TH FL - 6TH FL DR OPEN

ELEVATOR

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 240000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.548	0.	FLOOR 1 COMPARTMENT 1	.015	4561.	1.750	555.9
2	2.375	0.	FLOOR 2 COMPARTMENT 1	.015	4561.	1.750	562.3
3	2.202	0.	FLOOR 3 COMPARTMENT 1	.015	4561.	1.750	556.2
4	2.029	0.	FLOOR 4 COMPARTMENT 1	.008	4561.	1.750	401.7
5	1.856	0.	FLOOR 5 COMPARTMENT 1	-.106	4561.	1.750	-1485.0
6	1.683	0.	FLOOR 6 COMPARTMENT 1	-.018	4561.	1.750	-604.6
7	1.511	0.	FLOOR 7 COMPARTMENT 1	-.099	4561.	1.750	-1433.4
8	1.338	0.	FLOOR 8 COMPARTMENT 1	.013	4561.	1.750	526.7
9	1.166	0.	FLOOR 9 COMPARTMENT 1	.024	4561.	1.750	712.0
10	.993	0.	FLOOR 10 COMPARTMENT 1	.028	4561.	1.750	760.5
11	.821	0.	FLOOR 11 COMPARTMENT 1	.030	4561.	1.750	784.7
12	.649	0.	FLOOR 12 COMPARTMENT 1	.030	4561.	1.750	795.6
13	.476	0.					
			OUTSIDE DIRECTION 1	-.074	7820.	3.000	-2132.6
							.0 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

APPENDIX F - RUN 5 DATA

```
SUMMER - FIRE FLOOR IS 6TH FL - 5,6,7TH FL DR OPEN
93 2 0
13 1
6 12
1
1 1 70
1 1
0 1 1
1
12
1 4 1
0 1 1 2040 1
1 .65 .49
1 .65 1.22
5 7 1
0 1 1 -2040 1
1 .65 .49
1 .65 1.22
8 12 1
0 1 1 2040 1
1 .65 .49
1 .65 1.22
2
STAIRWELL
7.0E4 1 12 1
0 0
1 .65 .323
8
3 5
1 .65 10.5
3 7
1 .65 10.5
3 6
1 .65 10.5
2 1
1 .65 10.5
1 2
9200
1 5
1200
1 8
1200
1 11
1200
ELEVATOR
2.4E5 1 13 1
0 0
1 .65 1.75
1
2 13
1 .65 3
```

APPENDIX F - RUN 5 COMPUTER OUTPUT

SUMMER - FIRE FLOOR IS 6TH FL - 5,6,7TH FL DR OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	1	2.566	1	2040.	FLOOR 2 COMPARTMENT 1	.000	1277.	.490	17.9
					STAIRWELL	-.069	842.	.323	-220.5
					ELEVATOR	-.011	4561.	1.750	-484.6
					OUTSIDE DIRECTION 1	-.181	3180.	1.220	-1352.6
									.2 NET
2	1	2.393	1	2040.	FLOOR 3 COMPARTMENT 1	.000	1277.	.490	-15.4
					FLOOR 1 COMPARTMENT 1	.000	1277.	.490	-17.9
					STAIRWELL	-.052	842.	.323	-192.8
					ELEVATOR	-.011	4561.	1.750	-488.8
					OUTSIDE DIRECTION 1	-.174	3180.	1.220	-1325.4
									-.3 NET
3	1	2.220	1	2040.	FLOOR 4 COMPARTMENT 1	-.004	1277.	.490	-80.9
					FLOOR 2 COMPARTMENT 1	.000	1277.	.490	15.4
					STAIRWELL	-.052	842.	.323	-192.6
					ELEVATOR	-.011	4561.	1.750	-486.0
					OUTSIDE DIRECTION 1	-.166	3180.	1.220	-1296.3
									-.4 NET
4	1	2.043	1	2040.	FLOOR 5 COMPARTMENT 1	-.053	1277.	.490	-293.3
					FLOOR 3 COMPARTMENT 1	.004	1277.	.490	80.9
					STAIRWELL	-.048	842.	.323	-185.1
					ELEVATOR	-.007	4561.	1.750	-391.6
					OUTSIDE DIRECTION 1	-.155	3180.	1.220	-1251.1
									-.2 NET
5	1	1.817	1	-2040.	FLOOR 6 COMPARTMENT 1	-.001	1277.	.490	-32.6
					FLOOR 4 COMPARTMENT 1	.053	1277.	.490	293.3
					STAIRWELL	.004	27368.	10.500	1786.7
					ELEVATOR	.045	4561.	1.750	970.9
					OUTSIDE DIRECTION 1	-.095	3180.	1.220	-978.4
									-.1 NET
6	1	1.644	1	-2040.	FLOOR 7 COMPARTMENT 1	.001	1277.	.490	49.4
					FLOOR 5 COMPARTMENT 1	.001	1277.	.490	32.6
					STAIRWELL	.005	27368.	10.500	1916.1
					ELEVATOR	.046	4561.	1.750	977.5
					OUTSIDE DIRECTION 1	-.087	3180.	1.220	-936.1
									-.4 NET
7	1	1.473	1	-2040.	FLOOR 8 COMPARTMENT 1	.057	1277.	.490	304.7
					FLOOR 6 COMPARTMENT 1	-.001	1277.	.490	-49.4
					STAIRWELL	.004	27368.	10.500	1727.0
					ELEVATOR	.044	4561.	1.750	961.3
					OUTSIDE DIRECTION 1	-.081	3180.	1.220	-903.9
									-.4 NET

APPENDIX F - RUN 5 COMPUTER OUTPUT

SUMMER - FIRE FLOOR IS 6TH FL - 5,6,7TH FL DR OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
8	1	1.357	1	2040.	FLOOR 9 COMPARTMENT 1	.008	1277.	.490	111.3
					FLOOR 7 COMPARTMENT 1	-.057	1277.	.490	-304.7
					STAIRWELL	-.051	842.	.323	-189.3
					ELEVATOR	-.012	4561.	1.750	-509.5
					OUTSIDE DIRECTION 1	-.130	3180.	1.220	-1148.0
									-.1 NET
9	1	1.192	1	2040.	FLOOR 10 COMPARTMENT 1	.003	1277.	.490	67.7
					FLOOR 8 COMPARTMENT 1	-.008	1277.	.490	-111.3
					STAIRWELL	-.057	842.	.323	-201.5
					ELEVATOR	-.020	4561.	1.750	-646.1
					OUTSIDE DIRECTION 1	-.131	3180.	1.220	-1149.1
									-.3 NET
10	1	1.023	1	2040.	FLOOR 11 COMPARTMENT 1	.002	1277.	.490	51.4
					FLOOR 9 COMPARTMENT 1	-.003	1277.	.490	-67.7
					STAIRWELL	-.059	842.	.323	-205.2
					ELEVATOR	-.023	4561.	1.750	-689.7
					OUTSIDE DIRECTION 1	-.126	3180.	1.220	-1128.9
									-.1 NET
11	1	.852	1	2040.	FLOOR 12 COMPARTMENT 1	.001	1277.	.490	34.9
					FLOOR 10 COMPARTMENT 1	-.002	1277.	.490	-51.4
					STAIRWELL	-.060	842.	.323	-207.0
					ELEVATOR	-.024	4561.	1.750	-713.8
					OUTSIDE DIRECTION 1	-.120	3180.	1.220	-1102.9
									-.2 NET
12	1	.681	1	2040.	FLOOR 11 COMPARTMENT 1	-.001	1277.	.490	-34.9
					STAIRWELL	-.061	842.	.323	-208.2
					ELEVATOR	-.025	4561.	1.750	-725.0
					OUTSIDE DIRECTION 1	-.114	3180.	1.220	-1072.2
									-.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

APPENDIX F - RUN 5 COMPUTER OUTPUT

SUMMER - FIRE FLOOR IS 6TH FL - 5,6,7TH FL DR OPEN

STAIRWELL

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 70000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.497	0.	FLOOR 1 COMPARTMENT 1	.069	842.	.323	220.5
			OUTSIDE DIRECTION 1	-.112	27368.	10.500	-9172.6
2	2.340	9200.	FLOOR 2 COMPARTMENT 1	.052	842.	.323	192.8
3	2.168	0.	FLOOR 3 COMPARTMENT 1	.052	842.	.323	192.6
4	1.995	0.	FLOOR 4 COMPARTMENT 1	.048	842.	.323	185.1
5	1.822	1200.	FLOOR 5 COMPARTMENT 1	-.004	27368.	10.500	-1786.7
6	1.649	0.	FLOOR 6 COMPARTMENT 1	-.005	27368.	10.500	-1916.1
7	1.477	0.	FLOOR 7 COMPARTMENT 1	-.004	27368.	10.500	-1727.0
8	1.307	1200.	FLOOR 8 COMPARTMENT 1	.051	842.	.323	189.3
9	1.135	0.	FLOOR 9 COMPARTMENT 1	.057	842.	.323	201.5
10	.953	0.	FLOOR 10 COMPARTMENT 1	.059	842.	.323	205.2
11	.792	1200.	FLOOR 11 COMPARTMENT 1	.060	842.	.323	207.0
12	.619	0.	FLOOR 12 COMPARTMENT 1	.061	842.	.323	208.2
							-.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

APPENDIX F - RUN 5 COMPUTER OUTPUT

SUMMER - FIRE FLOOR IS 6TH FL - 5,6,7TH FL DR OPEN

ELEVATOR

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 240000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.554	0.	FLOOR 1 COMPARTMENT 1	.011	4561.	1.750	484.6
2	2.381	0.	FLOOR 2 COMPARTMENT 1	.011	4561.	1.750	488.8
3	2.209	0.	FLOOR 3 COMPARTMENT 1	.011	4561.	1.750	466.0
4	2.036	0.	FLOOR 4 COMPARTMENT 1	.007	4561.	1.750	391.6
5	1.863	0.	FLOOR 5 COMPARTMENT 1	-.045	4561.	1.750	-970.9
6	1.690	0.	FLOOR 6 COMPARTMENT 1	-.046	4561.	1.750	-977.5
7	1.517	0.	FLOOR 7 COMPARTMENT 1	-.044	4561.	1.750	-961.3
8	1.345	0.	FLOOR 8 COMPARTMENT 1	.012	4561.	1.750	509.5
9	1.172	0.	FLOOR 9 COMPARTMENT 1	.020	4561.	1.750	646.1
10	1.000	0.	FLOOR 10 COMPARTMENT 1	.023	4561.	1.750	689.7
11	.828	0.	FLOOR 11 COMPARTMENT 1	.024	4561.	1.750	713.8
12	.655	0.	FLOOR 12 COMPARTMENT 1	.025	4561.	1.750	725.0
13	.483	0.					
			OUTSIDE DIRECTION 1	-.081	7820.	3.000	-2225.6
							-.2 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

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SUMMER - FIRE FLOOR IS 6TH FL - 3,4,6,8,9 FL DR OPEN
93 2 0
13 1
6 12
1
1 1 70
1 1
0 1 1
1
12
1 4 1
0 1 1 2040 1
1 .65 .49
1 .65 1.22
5 7 1
0 1 1 -2040 1
1 .65 .49
1 .65 1.22
8 12 1
0 1 1 2040 1
1 .65 .49
1 .65 1.22
2
STAIRWELL
7.0E4 1 12 1
0 0
1 .65 .323
10
3 3
1 .65 10.5
3 4
1 .65 10.5
3 8
1 .65 10.5
3 9
1 .65 10.5
3 6
1 .65 10.5
2 1
1 .65 10.5
1 2
9200
1 5
1200
1 8
1200
1 11
1200
ELEVATOR
2.4E5 1 13 1
0 0
1 .65 1.75
1
2 13
1 .65 3
```

APPENDIX F - RUN 6 COMPUTER OUTPUT

SUMMER - FIRE FLOOR IS 6TH FL - 3.4.6.8.9 FL DR OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	1	2.559	1	2040.	FLOOR 2 COMPARTMENT 1	.000	1277.	.490	-4.5
					STAIRWELL	-.029	842.	.323	-144.0
					ELEVATOR	-.015	4561.	1.750	-563.1
					OUTSIDE DIRECTION 1	-.174	3180.	1.220	-1328.0
									.4 NET
2	1	2.386	1	2040.	FLOOR 3 COMPARTMENT 1	-.007	1277.	.490	-108.1
					FLOOR 1 COMPARTMENT 1	.000	1277.	.490	4.5
					STAIRWELL	-.008	842.	.323	-73.7
					ELEVATOR	-.015	4561.	1.750	-562.9
					OUTSIDE DIRECTION 1	-.167	3180.	1.220	-1299.5
									.4 NET
3	1	2.206	1	2040.	FLOOR 4 COMPARTMENT 1	.000	1277.	.490	-20.0
					FLOOR 2 COMPARTMENT 1	.007	1277.	.490	108.1
					STAIRWELL	.000	27368.	10.500	-476.0
					ELEVATOR	-.008	4561.	1.750	-410.2
					OUTSIDE DIRECTION 1	-.152	3180.	1.220	-1241.5
									.3 NET
4	1	2.033	1	2040.	FLOOR 5 COMPARTMENT 1	-.111	1277.	.490	-425.0
					FLOOR 3 COMPARTMENT 1	.000	1277.	.490	20.0
					STAIRWELL	.000	27368.	10.500	-19.6
					ELEVATOR	-.008	4561.	1.750	-404.9
					OUTSIDE DIRECTION 1	-.145	3180.	1.220	-1210.1
									.4 NET
5	1	1.749	1	-2040.	FLOOR 6 COMPARTMENT 1	.095	1277.	.490	392.8
					FLOOR 4 COMPARTMENT 1	.111	1277.	.490	425.0
					STAIRWELL	.111	842.	.323	280.2
					ELEVATOR	.103	4561.	1.750	1462.2
					OUTSIDE DIRECTION 1	-.027	3180.	1.220	-519.9
									.3 NET
6	1	1.671	1	-2040.	FLOOR 7 COMPARTMENT 1	-.087	1277.	.490	-377.7
					FLOOR 5 COMPARTMENT 1	-.095	1277.	.490	-392.8
					STAIRWELL	.016	27368.	10.500	3472.8
					ELEVATOR	.008	4561.	1.750	411.5
					OUTSIDE DIRECTION 1	-.114	3180.	1.220	-1073.5
									.3 NET
7	1	1.411	1	-2040.	FLOOR 8 COMPARTMENT 1	.108	1277.	.490	419.2
					FLOOR 6 COMPARTMENT 1	.087	1277.	.490	377.7
					STAIRWELL	.105	842.	.323	273.4
					ELEVATOR	.096	4561.	1.750	1410.1
					OUTSIDE DIRECTION 1	-.019	3180.	1.220	-440.3
									.1 NET

APPENDIX F - RUN 6 COMPUTER OUTPUT

SUMMER - FIRE FLOOR IS 6TH FL - 3,4,6,8.9 FL DR OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
8	1	1.347	1	2040.	FLOOR 9 COMPARTMENT 1	.001	1277.	.490	45.6
					FLOOR 7 COMPARTMENT 1	-.108	1277.	.490	-419.2
					STAIRWELL	.000	27368.	10.500	-64.4
					ELEVATOR	-.012	4561.	1.750	-502.2
					OUTSIDE DIRECTION 1	-.120	3180.	1.220	-1099.4
									.4 NET
9	1	1.175	1	2040.	FLOOR 10 COMPARTMENT 1	.014	1277.	.490	153.1
					FLOOR 8 COMPARTMENT 1	-.001	1277.	.490	-45.6
					STAIRWELL	.000	27368.	10.500	-548.4
					ELEVATOR	-.013	4561.	1.750	-527.6
					OUTSIDE DIRECTION 1	-.113	3180.	1.220	-1071.1
									.4 NET
10	1	1.017	1	2040.	FLOOR 11 COMPARTMENT 1	.004	1277.	.490	77.3
					FLOOR 9 COMPARTMENT 1	-.014	1277.	.490	-153.1
					STAIRWELL	-.014	842.	.323	-100.6
					ELEVATOR	-.028	4561.	1.750	-759.6
					OUTSIDE DIRECTION 1	-.120	3180.	1.220	-1103.6
									.4 NET
11	1	.849	1	2040.	FLOOR 12 COMPARTMENT 1	.001	1277.	.490	43.8
					FLOOR 10 COMPARTMENT 1	-.004	1277.	.490	-77.3
					STAIRWELL	-.018	842.	.323	-111.5
					ELEVATOR	-.031	4561.	1.750	-808.1
					OUTSIDE DIRECTION 1	-.117	3180.	1.220	-1086.6
									.3 NET
12	1	.677	1	2040.	FLOOR 11 COMPARTMENT 1	-.001	1277.	.490	-43.8
					STAIRWELL	-.019	842.	.323	-115.1
					ELEVATOR	-.033	4561.	1.750	-823.3
					OUTSIDE DIRECTION 1	-.111	3180.	1.220	-1057.5
									.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX F - RUN 6 COMPUTER OUTPUT

SUMMER - FIRE FLOOR IS 6TH FL - 3,4,6,8,9 FL DR OPEN

STAIRWELL

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 70000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO		DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.530	0.	FLOOR 1 COMPARTMENT	1	.029	842.	.323	144.0
			OUTSIDE DIRECTION	1	-.145	27368.	10.500	-10426.7
2	2.379	9200.	FLOOR 2 COMPARTMENT	1	.008	842.	.323	73.7
3	2.206	0.	FLOOR 3 COMPARTMENT	1	.000	27368.	10.500	476.0
4	2.033	0.	FLOOR 4 COMPARTMENT	1	.000	27368.	10.500	19.6
5	1.860	1200.	FLOOR 5 COMPARTMENT	1	-.111	842.	.323	-280.2
6	1.688	0.	FLOOR 6 COMPARTMENT	1	-.016	27368.	10.500	-3472.8
7	1.517	0.	FLOOR 7 COMPARTMENT	1	-.105	842.	.323	-273.4
8	1.346	1200.	FLOOR 8 COMPARTMENT	1	.000	27368.	10.500	64.4
9	1.175	0.	FLOOR 9 COMPARTMENT	1	.000	27368.	10.500	548.4
10	1.003	0.	FLOOR 10 COMPARTMENT	1	.014	842.	.323	100.6
11	.831	1200.	FLOOR 11 COMPARTMENT	1	.018	842.	.323	111.5
12	.659	0.	FLOOR 12 COMPARTMENT	1	.019	842.	.323	115.1
								.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX F - RUN 6 COMPUTER OUTPUT

SUMMER - FIRE FLOOR IS 6TH FL - 3,4,6,8,9 FL DR OPEN

ELEVATOR

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 240000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.544	0.	FLOOR 1 COMPARTMENT 1	.015	4561.	1.750	563.1
2	2.371	0.	FLOOR 2 COMPARTMENT 1	.015	4561.	1.750	562.9
3	2.198	0.	FLOOR 3 COMPARTMENT 1	.008	4561.	1.750	410.2
4	2.025	0.	FLOOR 4 COMPARTMENT 1	.008	4561.	1.750	404.9
5	1.852	0.	FLOOR 5 COMPARTMENT 1	-.103	4561.	1.750	-1462.2
6	1.680	0.	FLOOR 6 COMPARTMENT 1	-.008	4561.	1.750	-411.5
7	1.507	0.	FLOOR 7 COMPARTMENT 1	-.096	4561.	1.750	-1410.1
8	1.334	0.	FLOOR 8 COMPARTMENT 1	.012	4561.	1.750	502.2
9	1.162	0.	FLOOR 9 COMPARTMENT 1	.013	4561.	1.750	527.6
10	.989	0.	FLOOR 10 COMPARTMENT 1	.028	4561.	1.750	759.6
11	.817	0.	FLOOR 11 COMPARTMENT 1	.031	4561.	1.750	808.1
12	.645	0.	FLOOR 12 COMPARTMENT 1	.033	4561.	1.750	823.3
13	.473	0.					
			OUTSIDE DIRECTION 1	-.071	7820.	3.000	-2077.9
							.2 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

```
WINTER - FIRE FLOOR IS 5TH FL - 6TH FL DR OPEN
14 2 0
13 1
6 12
1
1 1 70
1 1
0 1 1
1
12
1 4 1
0 1 1 2040 1
1 .65 .49
1 .65 1.22
5 7 1
0 1 1 -2040 1
1 .65 .49
1 .65 1.22
8 12 1
0 1 1 2040 1
1 .65 .49
1 .65 1.22
2
STAIRWELL
7.0E4 1 12 1
0 0
1 .65 .323
6
3 6
1 .65 10.5
2 1
1 .65 10.5
1 2
9200
1 5
1200
1 8
1200
1 11
1200
ELEVATOR
2.4E5 1 13 1
0 0
1 .65 1.75
1
2 13
1 .65 3
```

APPENDIX F - RUN 7 COMPUTER OUTPUT

WINTER - FIRE FLOOR IS 6TH FL - 6TH FL DR OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	1	2.793	1	2040.	FLOOR 2 COMPARTMENT 1	-.002	1277.	.490	-53.9
					STAIRWELL	-.014	842.	.323	-99.6
					ELEVATOR	-.047	4561.	1.750	-992.2
					OUTSIDE DIRECTION 1	-.079	3180.	1.220	-894.7
									-.3 NET
2	1	2.619	1	2040.	FLOOR 3 COMPARTMENT 1	-.004	1277.	.490	-84.8
					FLOOR 1 COMPARTMENT 1	.002	1277.	.490	53.9
					STAIRWELL	-.003	842.	.323	-42.4
					ELEVATOR	-.046	4561.	1.750	-973.3
					OUTSIDE DIRECTION 1	-.098	3180.	1.220	-993.5
									-.2 NET
3	1	2.441	1	2040.	FLOOR 4 COMPARTMENT 1	-.014	1277.	.490	-151.4
					FLOOR 2 COMPARTMENT 1	.004	1277.	.490	84.8
					STAIRWELL	.001	842.	.323	22.8
					ELEVATOR	-.041	4561.	1.750	-925.5
					OUTSIDE DIRECTION 1	-.113	3180.	1.220	-1070.9
									-.1 NET
4	1	2.254	1	2040.	FLOOR 5 COMPARTMENT 1	-.118	1277.	.490	-437.8
					FLOOR 3 COMPARTMENT 1	.014	1277.	.490	151.4
					STAIRWELL	.014	842.	.323	98.4
					ELEVATOR	-.027	4561.	1.750	-753.0
					OUTSIDE DIRECTION 1	-.120	3180.	1.220	-1099.5
									-.4 NET
5	1	1.964	1	-2040.	FLOOR 6 COMPARTMENT 1	.100	1277.	.490	404.7
					FLOOR 4 COMPARTMENT 1	.118	1277.	.490	437.8
					STAIRWELL	.130	842.	.323	303.7
					ELEVATOR	.090	4561.	1.750	1368.3
					OUTSIDE DIRECTION 1	-.022	3180.	1.220	-474.5
									.0 NET
6	1	1.892	1	-2040.	FLOOR 7 COMPARTMENT 1	-.119	1277.	.490	-440.6
					FLOOR 5 COMPARTMENT 1	-.100	1277.	.490	-404.7
					STAIRWELL	.028	27368.	10.500	4554.2
					ELEVATOR	-.011	4561.	1.750	-467.4
					OUTSIDE DIRECTION 1	-.143	3180.	1.220	-1201.8
									-.4 NET
7	1	1.600	1	-2040.	FLOOR 8 COMPARTMENT 1	.119	1277.	.490	441.3
					FLOOR 6 COMPARTMENT 1	.119	1277.	.490	440.6
					STAIRWELL	.147	842.	.323	322.9
					ELEVATOR	.108	4561.	1.750	1501.7
					OUTSIDE DIRECTION 1	-.044	3180.	1.220	-666.9
									-.4 NET

APPENDIX F - RUN 7 COMPUTER OUTPUT

WINTER - FIRE FLOOR IS 6TH FL - 6TH FL DR OPEN

FLOOR	COMPARTMENT	PRESSURE	TEMP PROFILE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
8	1	1.547	1	2040.	FLOOR 9 COMPARTMENT 1	.006	1277.	.490	101.3
					FLOOR 7 COMPARTMENT 1	-.119	1277.	.490	-441.3
					STAIRWELL	.028	842.	.323	141.6
					ELEVATOR	-.011	4561.	1.750	-479.6
					OUTSIDE DIRECTION 1	-.184	3180.	1.220	-1362.3
									-.3 NET
9	1	1.381	1	2040.	FLOOR 10 COMPARTMENT 1	.000	1277.	.490	-5.5
					FLOOR 8 COMPARTMENT 1	-.006	1277.	.490	-101.3
					STAIRWELL	.022	842.	.323	125.1
					ELEVATOR	-.017	4561.	1.750	-601.5
					OUTSIDE DIRECTION 1	-.210	3180.	1.220	-1457.0
									-.1 NET
10	1	1.209	1	2040.	FLOOR 11 COMPARTMENT 1	-.001	1277.	.490	-43.7
					FLOOR 9 COMPARTMENT 1	.000	1277.	.490	5.5
					STAIRWELL	.022	842.	.323	125.5
					ELEVATOR	-.017	4561.	1.750	-602.7
					OUTSIDE DIRECTION 1	-.230	3180.	1.220	-1525.0
									-.4 NET
11	1	1.035	1	2040.	FLOOR 12 COMPARTMENT 1	-.001	1277.	.490	-42.1
					FLOOR 10 COMPARTMENT 1	.001	1277.	.490	43.7
					STAIRWELL	.024	842.	.323	129.3
					ELEVATOR	-.016	4561.	1.750	-584.7
					OUTSIDE DIRECTION 1	-.249	3180.	1.220	-1586.5
									-.3 NET
12	1	.862	1	2040.	FLOOR 11 COMPARTMENT 1	.001	1277.	.490	42.1
					STAIRWELL	.025	842.	.323	132.2
					ELEVATOR	-.016	4561.	1.750	-568.8
					OUTSIDE DIRECTION 1	-.268	3180.	1.220	-1645.8
									-.3 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H2O
AREA IN FEET SQUARED

APPENDIX F - RUN 7 COMPUTER OUTPUT

WINTER - FIRE FLOOR IS 6TH FL - 6TH FL DR OPEN

STAIRWELL

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 70000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.779	0.	FLOOR 1 COMPARTMENT 1	.014	842.	.323	99.6
			OUTSIDE DIRECTION 1	-.065	27368.	10.500	-6986.3
2	2.616	9200.	FLOOR 2 COMPARTMENT 1	.003	842.	.323	42.4
3	2.442	0.	FLOOR 3 COMPARTMENT 1	-.001	842.	.323	-22.8
4	2.268	0.	FLOOR 4 COMPARTMENT 1	-.014	842.	.323	-98.4
5	2.094	1200.	FLOOR 5 COMPARTMENT 1	-.130	842.	.323	-303.7
6	1.920	0.	FLOOR 6 COMPARTMENT 1	-.028	27368.	10.500	-4554.2
7	1.748	0.	FLOOR 7 COMPARTMENT 1	-.147	842.	.323	-322.9
8	1.576	1200.	FLOOR 8 COMPARTMENT 1	-.028	842.	.323	-141.6
9	1.403	0.	FLOOR 9 COMPARTMENT 1	-.022	842.	.323	-125.1
10	1.231	0.	FLOOR 10 COMPARTMENT 1	-.022	842.	.323	-125.5
11	1.059	1200.	FLOOR 11 COMPARTMENT 1	-.024	842.	.323	-129.3
12	.887	0.	FLOOR 12 COMPARTMENT 1	-.025	842.	.323	-132.2
							.0 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

APPENDIX F - RUN 7 COMPUTER OUTPUT

WINTER - FIRE FLOOR IS 6TH FL - 6TH FL DR OPEN

ELEVATOR

TEMPERATURE PROFILE 1
SHAFT FLOW COEFFICIENT 240000.

FLOOR	PRESSURE	FIXED FLOW	CONNECTION TO	DIFFERENTIAL PRESSURE	ADJUSTED FLOW COEFFICIENT	FLOW AREA	FLOW
1	2.746	0.	FLOOR 1 COMPARTMENT 1	.047	4561.	1.750	992.2
2	2.573	0.	FLOOR 2 COMPARTMENT 1	.046	4561.	1.750	973.3
3	2.400	0.	FLOOR 3 COMPARTMENT 1	.041	4561.	1.750	925.5
4	2.227	0.	FLOOR 4 COMPARTMENT 1	.027	4561.	1.750	753.0
5	2.054	0.	FLOOR 5 COMPARTMENT 1	-.090	4561.	1.750	-1368.3
6	1.882	0.	FLOOR 6 COMPARTMENT 1	.011	4561.	1.750	467.4
7	1.709	0.	FLOOR 7 COMPARTMENT 1	-.108	4561.	1.750	-1501.7
8	1.536	0.	FLOOR 8 COMPARTMENT 1	.011	4561.	1.750	479.6
9	1.364	0.	FLOOR 9 COMPARTMENT 1	.017	4561.	1.750	601.5
10	1.191	0.	FLOOR 10 COMPARTMENT 1	.017	4561.	1.750	602.7
11	1.019	0.	FLOOR 11 COMPARTMENT 1	.016	4561.	1.750	584.7
12	.847	0.	FLOOR 12 COMPARTMENT 1	.016	4561.	1.750	568.8
13	.674	0.					
			OUTSIDE DIRECTION 1	-.272	7820.	3.000	-4078.8
							-.1 NET

THE FOLLOWING UNITS ARE USED FOR OUTPUT

FLOW IN CFM AT 70 DEG F AND 1 ATM
PRESSURE IN INCHS H20
AREA IN FEET SQUARED

APPENDIX G.
LISTING OF COMPUTER PROGRAM

```
C
C     COMPUTER PROGRAM FOR AIR FLOW ANALYSIS IN BUILDINGS
C      SPECIFICALLY FOR ANALYSIS OF SMOKE CONTROL SYSTEMS
C
C
C     PROGRAM VARIABLES
C     AI      LEAKAGE AREA OF INTERNAL CONNECTION
C     AO      LEAKAGE AERA OF CONNECTION TO OUTSIDE
C     C       FLOW COEFFICIENT BETWEEN BUILDING POINTS
C     CO      FLOW COEFFICIENT TO OUTSIDE
C     CS      FLOW COEFFICIENT OF SHAFT
C     E       LIMIT WITHIN WHICH CONVERGENCE IS ACCEPTABLE
C     F       NET FLOW INTO POINT I
C     FC      FLOW BETWEEN INTERNAL POINTS
C     FF      FIXED FLOW INTO POINT I
C     FO      FLOW TO OUTSIDE
C     FSS     NET FLOW INTO SHAFT IS
C     H       HEIGHT FROM GROUND TO MIDPOINT OF FLOOR
C     IBUG    OUTPUT VARIABLE
C     ICONV   INTEGER USED IN SUBROUTINES BLDGP AND SHAFTP
C             IF ICONV = 0 THEN  THE PRESSURES WERE UNCHANGED
C     IFLOOR  FLOOR LEVEL WHERE POINT IS LOCATED
C     IT      POINTER TO TEMP PROFILE FOR POINT I
C     ITS     POINTER TO TEMPERATURE PROFILE OF SHAFT
C     JC      POINT NO. CONNECTED TO POINT I
C     JOC     DIRECTION OF OUTSIDE CONNECTION
C     N       NO. OF BUILDING COMPARTMENTS
C     NC      NO. OF INTERNAL POINTS CONNECTED TO POINT I
C     NCO     NO. OF OUTSIDE CONNECTIONS
C     NFS1    BOTTOM FLOOR OF SHAFT
C     NFS2    TOP FLOOR OF SHAFT
C     NH      NO. OF FLOORS
C     NPO     NO. OF OUTSIDE PRESSURE PROFILES
C     NS      NO. OF SHAFTS
C     NS1     I VALUE FOR START OF SHAFT
C     NS2     I VALUE FOR END OF SHAFT
C     NT      TOTAL NO. OF POINTS (BLDG AND SHAFT)
C     NTP     NO. OF TEMPERATURE PROFILES
C     P       PRESSURE AT POINT I
C     PFO     OUTSIDE PRESSURE PROFILES
C     PO      OUTSIDE PRESSURE
C     PS      PRESSURE PROFILE OF SHAFT - WORKSPACE
C     PZ      PRESSURE DUE TO ELEVATION DIFFERENCE
C     T       TEMPERATURE PROFILE ARRAY
C     TITLE   PROJECT TITLE
C     TITSH   SHAFT TITLE
C
C
C     PROGRAM PARAMETERS
C     MB      MAX NO. OF BUILDING COMPARTMENTS
C     MM      MAX NO. OF POINTS
C     MS      MAX NO. OF SHAFTS
C     MC      MAX NO. OF CONNECTIONS FOR ANY POINT
C     MPO     MAX NO. OF OUTSIDE PRESSURE PROFILES
C     MTP     MAX NO. OF TEMPERATURE PROFILES
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C       MFL     MAX NO. OF FLOORS
C
C
        PARAMETER  (MM=140,MS=8,MC=9,MPO=2,MTP=2,MFL=25,MB=50)
        COMMON NT,    P(MM),C(MM,MC),NC(MM),JC(MM,MC),ITS(MS),
       1 FC(MM,MC),PZ(MM,MC),PO(MM,MPO),CO(MM,MPO),F(MM),FFO(MFL,MPO),
       2 FF(MM),FO(MM,MPO),CS(MS),PS(MFL),NS1(MS),NS2(MS),
       3 FSS(MS),N,NS,NPC,ICONV,E,IBUG,AI(MM,MC),AO(MM,MPO),TITSH(MS,5),
       4 NH,H(MFL),IFLOOR(MM),T(MTP,MFL),NFS1(MS),NFS2(MS),IT(MB),NTP
       5 ,NCO(MM),JOC(MM,MPO),TOUT
        DOUBLE PRECISION P,PO,PS
        COMMON /RUN/IRUN
        DIMENSION B1(MM,MC),B2(MM,MPO)
        NITER=5000
        IRUN=1
C
C         CALL INPUT TO READ DATA
C
        CALL INPUT
C
        E=0.2
20      ICS=1
C
C          SAVE AI(I,J) IN B1(I,J) AND FIND
C            MAX VALUE OF AI(I,J)
C
        AZZ=0
        AMAX=0
        DO 10 I=1,NT
        DO 8 J=1,NC
        B1(I,J)=AI(I,J)
        IF(AI(I,J) .GT. AMAX)AMAX=AI(I,J)
8       CONTINUE
        DO 9 J=1,MPO
        B2(I,J)=AO(I,J)
        IF(AO(I,J) .GT. AMAX)AMAX=AO(I,J)
9       CONTINUE
10      CONTINUE
C
C          ADJUST FOR LARGE VALUES OF FLOW AREA
C
        IF(AMAX .LT. 0.3)GO TO 25
        AZZ=1
        AM=0.2/(AMAX-0.1)
        BB=0.1*(1.0-AM)
        DO 15 I=1,NT
        DO 12 J=1,NC
        IF(AI(I,J) .LT. 0.1)GO TO 12
        AI(I,J)=AM*AI(I,J)+BB
12      CONTINUE
        DO 14 J=1,MPO
        IF(AO(I,J) .LT. 0.1)GO TO 14
        AO(I,J)=AM*AO(I,J)+BB
14      CONTINUE
15      CONTINUE
```

```
C
C        TEMPERATURE CORRECTION
C
25    CALL CORR
C
C        CALL INIT TO INITIALIZE PRESSURE ARRAY , P
C
22    CALL INIT
C
C
C        DO LOOP TO 30 IS ITERATIVE SOLUTION TO PRESSURE ARRAY
C
24    DO 30 ITER=1,NITER
C
C        CALL BLDGP TO SOLVE FOR BUILDING PRESSURES
C
      CALL BLDGP
      ICB=ICONV
      IF(ICB .EQ. 0 .AND. ICS .EQ. 0)GO TO 40
C
C        CALL SHAFTP TO SOLVE FOR SHAFT PRESSURES
C
      CALL SHAFTP
      ICS=ICONV
      IF(ICB .EQ. 0 .AND. ICS .EQ. 0)GO TO 40
C
C        CALL PZAD TO CALCULATE PZ TERMS
C
      CALL PZAD
30    CONTINUE
C
C        IF ROUTINE FAILS TO CONVERGE IN NITER
C        ITERATIONS PRINT ERROR MESSAGE
C
      WRITE(6,800)
40    CONTINUE
      WRITE(6,801)ITER
      IF(AZZ .EQ. 0.)GO TO 42
      AZZ = 0.
      DO 60 I=1,NT
      DO 50 J=1,NC
50    AI(I,J)=B1(I,J)
      DO 55 J=1,NPO
55    AO(I,J)=B2(I,J)
60    CONTINUE
      CALL CORR
      GO TO 24
C
C
C
C        CALL OUT TO OUTPUT SOLUTION
C
42    CALL OUT
C
      WRITE(6,805)
```

```
      STOP
C
C
C     FORMAT STATEMENTS
C
800   FORMAT(/////5X,35(1H1)//5X,
     +35HFAILURE OF MAIN PROGRAM TO CONVERGE  //5X,35(1H1)//)
801   FORMAT(    10X,I5,3X,11HITERATIONS    )
805   FORMAT(1H1)
      END
```

```
      SUBROUTINE INPUT
C
C      THIS ROUTINE READS AND PRINTS DATA
C       AND INITIALIZES PZ ARRAY
C
      PARAMETER  (MM=140,MS=8,MC=9,MPO=2,MTP=2,MFL=25,MB=50)
      COMMON /PZZ/ PGZ
      COMMON  /IO/TITLE(18),IOUT,IUNIT,NCOMP(MFL),SNCCMF(MFL)
      COMMON NT,   P(MM),C(MM,MC),NC(MM),JC(MM,MC),ITS(MS),
     1 FC(MM,MC),PZ(MM,MC),PO(MM,MPO),CO(MM,MPO),F(MM),PFO(MFL,MPO),
     2 FF(MM),FC(MM,MPO),CS(MS),PS(MFL),NS1(MS),NS2(MS),
     3 FSS(MS),N,NS,NPC,ICONV,E,IBUG,AI(MM,MC),AO(MM,MPO),TITSH(MS,5),
     4 NH,H(MFL),IFLOOR(MM),T(MTP,MFL),NFS1(MS),NFS2(MS),IT(MB),NTP
     5 ,NCO(MM),JCC(MM,MPO),TOUT
      DOUBLE PRECISION P,PO,PS
      CHARACTER PAR*6
      DIMENSION II(MFL),TT(MFL),PAR(7),CW(MPO),PH(MFL),NZZ(MM)
      DATA  PAR/' MM',' MS',' MC','MPO','MTP','MFL',' MB'/
      IBUG=0
C
C       READ AND WRITE PROJECT TITLE
C
      READ(5,600)(TITLE(I),I=1,18)
      WRITE(6,601)(TITLE(I),I=1,18)
C
C
C       READ GENERAL DATA
C
C
C       TOUT = CUTSIDE TEMPERATURE
C       IUNIT = 1 FCR SI UNITS
C             = 2 FCR ENG UNITS
C       IOUT = 0 FCR NO SUMMARY OUTPUT
C       OTHERWISE IOUT IS FILE NO. TO
C       WHICH SUMMARY OUTPUT IS WRITTEN
C
      READ(5,700)TOUT,IUNIT,IOUT
      WRITE(6,411)TOUT,IUNIT,IOUT
      IF(IUNIT .GT. 2 .OR. IUNIT .LT. 1)GO TO 105
C
C       READ HEIGHTS
C       NN=0 FOR INPUT OF ALL HEIGHTS
C       NN=1 FOR CALCULATION OF HEIGHTS
C
      READ(5,700)NH,NN
      WRITE(6,412)NH,NN
      IF(NH .LE. MFL)GO TO 89
      IPAR=6
      GO TO 110
89    IF(NN .EQ. 1)GO TO 97
      READ(5,700)(H(I),I=1,NH)
      WRITE(6,413)(H(I),I=1,NH)
      GO TO 99
97    READ(5,700)H(1),DH
      WRITE(6,414)H(1),DH
```

```
      DO 98 I=2,NH
      IM=I-1
98    H(I)=H(IM)+DH
C
C       READ TEMPERATURE PROFILES
C
99    READ(5,700)NTP
      WRITE(6,415)NTP
      IF(NTP .LE. MTP)GO TO 90
      IPAR=5
      GO TO 110
90    DO 3 IP=1,NTP
      READ(5,700)NNN,(II(J),TT(J),J=1,NNN)
      WRITE(6,416)NNN,(II(J),TT(J),J=1,NNN)
      IF(NNN .GT. 1)GO TO 2
      DO 1 IFF=1,NH
1     T(IP,IFF)=TT(1)
      GO TO 3
2     J=1
      JP1=2
      DO 4 IFF=1,NH
      T(IP,IFF)=TT(J)+(TT(JP1)-TT(J))*(IFF-II(J))/(II(JP1)-II(J))
      IF(IFF .NE. II(JP1))GO TO 4
      IF(JP1 .EQ. NNN)GO TO 4
      J=JP1
      JP1=J+1
4     CONTINUE
3     CONTINUE
C
C
C       READ OUTSIDE PRESSURE PROFILES
C       NN=0 FOR INPUT OF ALL PRESSURES
C       NN=1 FOR CALCULATION BY POWER LAW
C
      READ(5,700)NPC,NN
      WRITE(6,417)NPC,NN
      IF(NPC .LE. MPO)GO TO 91
      IPAR=4
      GO TO 110
91    IF(NN .EQ. 1)GO TO 81
C
C       READ ALL OUTSIDE PRESSURES
C
      DO 6 I=1,NPO
6     READ(5,700) PGZ,(PFO(J,I),J=1,NH)
      WRITE(6,418)PGZ,(PFO(J,I),J=1,NH)
      GO TO 85
C
C       CALCULATE OUTSIDE PRESSURES
C       PATMOS IS ATMOSPHERIC PRESSURE (PA)
C
81    READ(5,700)VW,HW,XW,(CW(I),I=1,NPO)
      WRITE(6,419)VW,HW,XW,(CW(I),I=1,NPO)
      IF(IUNIT .EQ. 1)VW=VW*0.2778
      IF(IUNIT .EQ. 2)VW=VW*0.4470
```

```
      PATMOS=101325.
      TOO=TOUT+273.
      IF(IUNIT .EQ. 2)TOO=(TOUT+460.)/1.8
      PVA=176.4*VW*VW/TOO
      Z=-0.03417/TOO
      IF(IUNIT .EQ. 2)Z=0.3048*Z
      CWM=CW(1)
      IF(NPC .EQ. 1)GO TO 212
      DO 211 I=1,NPC
      IF(CW(I) .LT. CWM)CWM=CW(I)
211   CONTINUE
212   PGZ=PATMOS*EXP(H(NH)*Z)+CWM*PVA*((H(NH)/HW)**(2.*XW))-1
      DO 210 I=1,NH
      PH(I)=PATMOS*EXP(H(I)*Z)
210   CONTINUE
      DO 82 I=1,NPC
      DO 82 J=1,NH
      PFO(J,I)=PH(J)+CW(I)*PVA*((H(J)/HW)**(2.*XW))-PGZ
82    CONTINUE
C
C
C        BUILDING DATA INPUT
C       NFLS = NO. OF FLOORS IN BUILDING
C       IF1 = LOWER FLOOR IN SERIES OF SIMILAR FLOORS
C       IF2 = UPPER FLOOR IN SERIES OF SIMILAR FLOORS
C       NOC = NO. OF COMPARTMENTS PER FLOOR
C       NZ = NO. OF CONNECTIONS TO COMPARTMENTS ON SAME FLOO
C       NA = NO. OF CONNECTIONS TO COMPARTMENTS ON FLOOR ABO
C
85    I=0
      SNCOMP(1)=0.
      READ(5,700)NFLS
      WRITE(6,420)NFLS
      IF(NFLS .GT. NH)GO TO 106
7     READ(5,700)IF1,IF2,NOC
      WRITE(6,400)IF1,IF2,NOC
      IF(IF1 .GT. IF2)GO TO 107
      NCOMP(IF1)=NOC
      IFP=IF1+1
      SNCOMP(IFP)=SNCOMP(IF1)+NOC
      DO 10 IZ=1,NOC
      I=I+1
      READ(5,700)NZ,NA,NNO,FF(I),IT(I)
      WRITE(6,401)NZ,NA,NNO,FF(I),IT(I)
      NZZ(I)=NZ
      NN=NZ+NA
      IFLOOR(I)=IF1
      IF(NN .LE. MC)GO TO 111
      IPAR=3
      GO TO 110
111   IF(NNO .LE. MPC)GO TO 112
      IPAR=4
      GO TO 110
112   IF(IT(I) .GT. NTP .OR. IT(I) .LT. 1)GO TO 102
      NC(I)=NN
```

```
      IF(NZ .EQ. 0)GO TO 63
C
C       INPUT CONNECTIONS TO COMPARTMENTS ON SAME FLOOR
C
      READ(5,700)(JC(I,J),C(I,J),AI(I,J),J=1,NZ)
      WRITE(6,402)
      WRITE(6,403)(JC(I,J),C(I,J),AI(I,J),J=1,NZ)
      DO 62 J=1,NZ
62    JC(I,J)=JC(I,J)+SNCOMP(IF1)
63    IF(NA .EQ. 0)GO TO 8
C
C       INPUT CONNECTIONS TO COMPARTMENTS ON FLOOR ABOVE
C
      NP=NZ+1
      READ(5,700)(JC(I,J),C(I,J),AI(I,J),J=NP,NN)
      WRITE(6,404)
      WRITE(6,403)(JC(I,J),C(I,J),AI(I,J),J=NP,NN)
      DO 66 J=NP,NN
66    JC(I,J)=JC(I,J)+NCOMP(IF1)+SNCOMP(IF1)
8     NCO(I)=NNC
      IF(NNO .EQ. 0)GO TO 10
C
C       INPUT CONNECTION TO OUTSIDE
C
      READ(5,700)(JOC(I,JJ),CC(I,JJ),AC(I,JJ),JJ=1,NNO)
      WRITE(6,405)
      WRITE(6,403)(JOC(I,JJ),CC(I,JJ),AC(I,JJ),JJ=1,NNO)
      DO 9 JJ=1,NNC
      J=JOC(I,JJ)
9     PO(I,JJ)=FFO(IF1,J)
10    CONTINUE
      IF(IF1 .NE. IF2)GO TO 11
      IF(IF1 .EQ. NFLS)GO TO 20
      GO TO 19
C
C       ASIGN DATA FOR FLOORS SIMILAR TO FLOOR IF1
C
11    IFP=IF1+1
      DO 17 IFF=IFP,IF2
      NCOMP(IFF)=NOC
      IFFP=IFF+1
      SNCOMP(IFFP)=SNCOMP(IFF)+NOC
      DO 16 IZ=1,NOC
      I=I+1
      I1=IZ+SNCOMP(IF1)
      IFLOOR(I)=IFF
      FF(I)=FF(I1)
      IT(I)=IT(I1)
      NN=NC(I1)
      NNC=NCO(I1)
      NC(I)=NN
      NCO(I)=NNC
      IF(IFF .NE. NFLS)GO TO 23
      NN=NZZ(I1)
      NC(I)=NN
```

```
23    IF(NN .EG. 0)GO TO 14
      CO 12 J=1,NN
      C(I,J)=C(I1,J)
      AI(I,J)=AI(I1,J)
      JC(I,J)=JC(I1,J)+SNCOMP(IFF)-SNCOMP(IF1)
12    CONTINUE
14    IF(NNO .EG. 0)GO TO 16
      CO 15 JJ=1,NNO
      JOC(I,JJ)=JOC(I1,JJ)
      J=JOC(I,JJ)
      CO(I,JJ)=CC(I1,JJ)
      AO(I,JJ)=AC(I1,JJ)
15    FO(I,JJ)=FFO(IFF,J)
16    CONTINUE
17    CONTINUE
18    IF(IF2 .EG. NFLS)GC TO 20
19    CCNTINUE
      GC TO 7
20    N=I
      N2=N
      IF(N .LE. MB)GO TO 114
      IPAR=7
      GC TO 110
C
C       SHAFT DATA INPUT
C
114   READ(5,700)NS
      IF(NS .LE. MS)GC TO 113
      IPAR=2
      GO TO 110
113   DO 100 IS=1,NS
      READ(5,603)(TITSH(IS,I),I=1,5)
      WRITE(6,406)(TITSH(IS,I),I=1,5)
      READ(5,700)CS(IS),NFS1(IS),NFS2(IS),ITS(IS)
      WRITE(6,407)CS(IS),NFS1(IS),NFS2(IS),ITS(IS)
      N1=N2+1
      N2=N1+NFS2(IS)-NFS1(IS)
      NS1(IS)=N1
      NS2(IS)=N2
      IFF=NFS1(IS)-1
      READ(5,700)NNC,FFF,JCP,CC,AA
      WRITE(6,408)NNC,FFF,JCP,CC,AA
      IF(NNC .EG. 0)GC TC 21
      READ(5,700)(JOC(N1,J),CC(N1,J),AO(N1,J),J=1,NNO)
      WRITE(6,403)(JOC(N1,J),CO(N1,J),AC(N1,J),J=1,NNO)
21    DO 24 I=N1,N2
      NC(I)=1
      NCO(I)=NNC
      IFF=IFF+1
      IFLOOR(I)=IFF
      IF(IFF .GT. NFLS)GC TO 25
      FF(I)=FFF
      IF(JCP .GT. NCOMP(IFF))GO TO 25
      JC(I,1)=JCP+SNCOMP(IFF)
      C(I,1)=CC
```

```
      AI(I,1)=AA
26    IF(NNC .EG. 0)GC TO 24
      CC 22 J=1,NNC
      JJ=JCC(N1,J)
      FC(I,J)=PFC(IFF,JJ)
      JCC(I,J)=JJ
      CO(I,J)=CC(N1,J)
22    AC(I,J)=AC(N1,J)
      GC TO 24
25    NC(I)=0
      GC TO 26
24    CONTINUE
C
C        EXCEPTICNS TC GENERAL SHAFT INPUT
C        NNN = NC. CF EXCEPTICNS
C        KE = 1 FOR FF EXCEPTION
C        KE = 2 FOR CUTSIDE CONNECTION
C        KE = 3 FOR INTERNAL CONNECTION
C
      READ(5,700)NNN
      IF(NNN .EG. 0)GC TO 100
      CO 69 IK=1,NNN
      READ(5,700)KE,IFF
      WRITE(6,409)KE,IFF
      I=NS1(IS)+IFF-NFS1(IS)
      IF(KE .EQ. 1)GC TO 41
      IF(KE .EQ. 2)GC TO 42
      IF(KE .EQ. 3)GO TO 51
      GC TO 104
41    READ(5,700)FF(I)
      WRITE(6,410)FF(I)
      GC TO 69
42    READ(5,700)J,CCC,AAC
      WRITE(6,405)
      WRITE(6,403)J,CCC,AAC
      NNC=NCC(I)
      IF(NNC .EG. 0)GC TO 44
      CO 43 K=1,NNC
      IF(JOC(I,K) .EQ. J)GC TC 46
43    CONTINUE
44    NJO=NNC+1
      NCO(I)=NJC
47    FO(I,NJO)=PFO(IFF,J)
      JCC(I,NJO)=J
      CO(I,NJO)=CCO
      AO(I,NJO)=AAC
      GC TO 69
46    NJO =K
      KK=K+1
      IF(CCO .NE. 0)GC TC 47
      NJO=NNC-1
      NCO(I)=NJC
      IF(NJC .EG. 0)GC TO 69
      CO 49 K=KK,NNC
      KM=K-1
```

```
      FC(I,KM)=FC(I,K)
      JOC(I,KM)=JOC(I,K)
      CC(I,KM)=CC(I,K)
49    AO(I,KM)=AO(I,K)
      GO TO 69
51    READ(5,700)JCP,CC,AA
      WRITE(6,402)
      WRITE(6,403)JCP,CC,AA
      J=JCP+SNCOMP(IFF)
      NN=NC(I)
      IF(NN .EQ. 0)GO TO 53
      DO 52 K=1,NN
      IF(JC(I,K) .EQ. J)GO TO 55
52    CONTINUE
      IF(CC .NE. 0.)GO TO 53
      WRITE(6,520)IS,KE,IFF
      GO TO 69
53    NJ=NN+1
      NC(I)=NJ
54    JC(I,NJ)=J
      C(I,NJ)=CC
      AI(I,NJ)=AA
      GO TO 69
55    NJ=K
      KK=K+1
      IF(AA .NE. 0.)GO TO 54
      NJ=NN-1
      NC(I)=NJ
      IF(NJ .EQ. 0)GO TO 69
      DO 61 K=KK,NN
      KM=K-1
      JC(I,KM)=JC(I,K)
      C(I,KM)=C(I,K)
61    AI(I,KM)=AI(I,K)
69    CONTINUE
100   CONTINUE
      NT=N2
      IF(NT .LE. MM)GO TO 160
      IPAR=1
      GO TO 110
C
C       PRINT OUTSIDE TEMPERATURE
C
160   WRITE(6,601)(TITLE(I),I=1,12)
      IF(IUNIT .EQ. 1)WRITE(6,800)TOUT
      IF(IUNIT .EQ. 2)WRITE(6,500)TOUT
      IF(IUNIT .EQ. 2)TOUT=(TOUT-32.)/1.8
      TOUT=TOUT+273.
C
C       PRINT HEIGHT AND TEMPERATURE PROFILES
C
      IF(IUNIT .EQ. 1)WRITE(6,811)(IP,IP=1,NTP)
      IF(IUNIT .EQ. 2)WRITE(6,511)(IP,IP=1,NTP)
      WRITE(6,813)
      DO 30 IFF=1,NF
```

```
30    WRITE(6,812)H(IFF),(T(IP,IFF),IP=1,NTP)
C
C       CONVERT TEMPERATURES TO DEG K.
C
      DO 33 IFF=1,NH
      DO 33 IP=1,NTP
      IF(IUNIT .EQ. 2)T(IP,IFF)=(T(IP,IFF)-32.)/1.8
33    T(IP,IFF)=T(IP,IFF)+273.
C
C       PRINT OUTSIDE PRESSURE PROFILES
C
      IF(IUNIT .EQ. 1)GO TO 79
      WRITE(6,814)(IP,IP=1,NPC)
      WRITE(6,813)
      DO 76 IFF=1,NH
      DO 77 J=1,NPC
77    PFO(IFF,J)=PFO(IFF,J)/248.8
      WRITE(6,815)H(IFF),(PFO(IFF,J),J=1,NPO)
      DO 78 J=1,NPC
78    PFO(IFF,J)=PFO(IFF,J)*248.8
76    CONTINUE
      GO TO 83
79    WRITE(6,814)(IP,IP=1,NPC)
      WRITE(6,813)
      DO 31 IFF=1,NH
      WRITE(6,815)H(IFF),(PFO(IFF,J),J=1,NPO)
31    CONTINUE
C
C       CORRECT FOR CONNECTIONS ONLY INPUTED ONCE
C
83    DO 60 I=1,NT
      NN=NC(I)
      IF(NN .EQ. 0)GO TO 60
      DO 58 JJ=1,NN
      J=JC(I,JJ)
      IF(J .EQ. 0)GO TO 58
      NNJ=NC(J)
      IF(NNJ .EQ. 0)GO TO 57
      DO 56 IA=1,NNJ
      IF(JC(J,IA) .EQ. I)GO TO 58
56    CONTINUE
57    NNJ=NNJ+1
      IF(NNJ .LE. MC)GO TO 59
      IPAR=3
      GO TO 110
59    NC(J)=NNJ
      JC(J,NNJ)=I
      C(J,NNJ)=C(I,JJ)
      AI(J,NNJ)=AI(I,JJ)
      IF(J .GT. N .OR. I .GT. N)GO TO 58
      PZ(J,NNJ)=-PZ(I,JJ)
58    CONTINUE
60    CONTINUE
C
C       CORRECT UNITS
```

```
C
      IF(IUNIT .EQ. 2)CALL UNITS
C
C       INITIALIZE PZ FOR BUILD COMPARTMENTS
C
87    DO 40 I=1,N
      NN=NC(I)
      IF(NN .EQ. 0)GO TO 40
      IA=IT(I)
      IFI=IFLOOR(I)
      DO 38 JJ=1,NN
      J=JC(I,JJ)
      IFJ=IFLOOR(J)
      IF(IFI .EQ. IFJ)GO TO 38
      IB=IT(J)
      TEMPA=0.5*(T(IA,IFI)+T(IB,IFJ))
      PZ(I,JJ)=3462.*(H(IFJ)-H(IFI))/TEMPA
38    CONTINUE
40    CONTINUE
C
C       INITIALIZE PZ FOR SHAFTS
C
      DO 50 IS=1,NS
      N1=NS1(IS)
      N2=NS2(IS)-1
      ITT=ITS(IS)
      DO 45 I=N1,N2
      IFI=IFLOOR(I)
      IFJ=IFI+1
      TEMPA=0.5*(T(ITT,IFI)+T(ITT,IFJ))
      PZ(I,1)=3462.*(H(IFJ)-H(IFI))/TEMPA
45    CONTINUE
50    CONTINUE
C
C       CHECK SHAFT CONNECTIONS
C
      DO 240 IS=1,NS
      N1=NS1(IS)
      N2=NS2(IS)
      DO 239 I=N1,N2
      NN=NC(I)
      IF(NN .EQ. 0)GO TO 239
      DO 236 J=1,NN
      JJ=JC(I,J)
      IF(IFLOOR(I) .NE. IFLOOR(JJ))GO TO 103
236   CONTINUE
239   CONTINUE
240   CONTINUE
      RETURN
C
C
C       DIAGNOSTIC OUTPUT
C
102   WRITE(6,302)I,IT(I)
      GO TO 109
```

```
103   WRITE(6,903)
      GO TO 109
104   WRITE(6,904)
      GO TO 109
105   WRITE(6,905)
      GO TO 109
106   WRITE(6,906)
      GO TO 109
107   WRITE(6,907)
      GO TO 109
110   WRITE(6,910)PAR(IPAR)
C
C       PRINT CORRECTED BUILDING DATA
C
109   WRITE(6,940)
      DO 70 I=1,N
      NN=NC(I)
      IF(NN .GT. 0)GO TO 180
      WRITE(6,941)I,IFLOOR(I),IT(I),FF(I)
      GO TO 182
180   WRITE(6,942)I,IFLOOR(I),IT(I),FF(I),JC(I,1),C(I,1),AI(I,1)
      IF(NN .EQ. 1)GO TO 182
      WRITE(6,943)(JC(I,J),C(I,J),AI(I,J), J=2,NN)
182   NNC=NCC(I)
      IF(NNC .EQ. 0)GO TO 70
      WRITE(6,944)(JCC(I,J),CC(I,J),AO(I,J),J=1,NNC)
70    CONTINUE
C
C       PRINT CORRECTED SHAFT INPUT DATA
C
      DO 80 IS=1,NS
      WRITE(6,816)(TITSH(IS,I),I=1,5)
      WRITE(6,806)IS,CS(IS),ITS(IS)
      N1=NS1(IS)
      N2=NS2(IS)
      WRITE(6,807)
      DO 75 I=N1,N2
      NN=NC(I)
      IF(NN .GT. 0)GO TO 72
      WRITE(6,801)IFLOOR(I),FF(I)
      GO TO 74
72    WRITE(6,808)IFLOOR(I),FF(I),JC(I,1),C(I,1),AI(I,1)
      IF(NN .EQ. 1)GO TO 74
      WRITE(6,809)( JC(I,J),C(I,J),AI(I,J), J=2,NN)
74    NNC=NCC(I)
      IF(NNO .EQ. 0)GO TO 75
      WRITE(6,810)(JCC(I,J),CC(I,J),AO(I,J),J=1,NNO)
75    CONTINUE
80    CONTINUE
      STOP
C
C       FORMAT STATEMENTS
C
400   FORMAT(5X,5HIF1 =,I3,7H, IF2 =,I3,7H, NOC =,I3)
401   FORMAT(5X,4HNZ =,I3,6H NA = ,I3,7H, NNO = ,I3,6H, FF =,F3.1,
```

```
     + 7H,   IT =,I3)
402   FORMAT(5X,25HCONNECTION ON SAME FLOOR     )
403   FORMAT(5X,3HJ =,I3,5H, C =,F10.3,5H, A =,F9.4)
404   FORMAT(5X,26HCONNECTION TO FLOOR ABOVE     )
405   FORMAT(5X,22HCONNECTION TO OUTSIDE      )
406   FORMAT(5X,5A4)
407   FORMAT(5X,4HCS =,F9.1,8H, NFS1 =,I3,8H, NFS2 =,I3,7H, ITS =,I3)
408   FORMAT(5X,5HNNC =,I3,7H, FFF =,F6.1,5H, J =,I3,5H, C =, F10.3,
     + 5H, A = ,F9.4)
409   FORMAT(5X,4HKE =,I3, 7H, IFF =,I3)
410   FORMAT(5X,4HFF =,F8.1)
411   FORMAT(5X,6HTOUT =,F6.0,9H, IUNIT =,I3,8H, IOUT =,I3)
412   FORMAT(5X,4HNF =,I3,6H, NN =,I3)
413   FORMAT(5X,7HHEIGHTS /(10F8.2))
414   FORMAT(5X,6HH(1) =,F8.2,6H, DH =,F8.2)
415   FORMAT(6X,5HNTP =,I3)
416   FORMAT(5X,20HTEMPERATURE PROFILE  /I5,(10(I4,F7.1)))
417   FORMAT(5X,5HNPC =,I3,6H, NN =,I3)
418   FORMAT(5X,5HPGZ =,F12.1/17HPRESSURE PROFILE  /(10F12.1))
419   FORMAT(5X,4HVW =,F6.1,6H, HW =,F6.1,6H, XW =,F4.2,6H, CW =,
     + (10F4.2))
420   FORMAT(/5X,6HNFLS =,I3)
500   FORMAT(//10X,20HOUTSIDE TEMPERATURE    ,F6.1,2H F)
511   FORMAT(    ///5X,6HHEIGHT,5X,29HTEMPERATURE PROFILES (DEG F)    /
     + 7X,2HFT,3X,19I6)
514   FORMAT(////5X,6HHEIGHT ,5X,26HOUTSIDE PRESSURE PROFILES
     1 11H (IN H2O)    /7X,2HFT,3X,8I10)
515   FORMAT(F11.2,3X,8F10.3)
520   FORMAT(///5X,15HERROR IN SHAFT  ,I2,15HEXCEPTION KE =  ,I2,
     + 2X,5HFLOOR ,I3//)
600   FORMAT(18A4)
601   FORMAT(1H1///10X,18A4///)
603   FORMAT(5A4)
700   FORMAT( )
800   FORMAT(//10X,20HOUTSIDE TEMPERATURE    ,F6.1,2H C)
801   FORMAT(I13,F11.1)
806   FORMAT(    10X,12HSHAFT NUMBER ,I4/10X,17HSHAFT COEFFICIENT ,F10.1/
     1 10X,20HTEMPERATURE PROFILE  ,I4)
807   FORMAT(/21X,5HFIXED,25X,4HFLOW,12X,4HFLOW/10X,5HFLOOR,6X,
     1 4HFLOW,5X,12HCONNECTED TO  ,6X,11HCOEFFICIENT ,6X,8H  AREA
     2  /)
808   FORMAT(I13,F11.1,6X,5HPOINT,I5,F16.1,F15.4)
809   FORMAT(30X,5HPOINT,I5,F16.1,F15.4)
810   FORMAT(30X,7HOUTSIDE ,I3,F16.1,F15.4)
811   FORMAT(    ///5X,6HHEIGHT,5X,29HTEMPERATURE PROFILES (DEG C)    /
     + 7X,2HM ,3X,19I6)
812   FORMAT(F11.2,3X,19F6.1)
813   FORMAT(/)
814   FORMAT(////5X,6HHEIGHT ,5X,26HOUTSIDE PRESSURE PROFILES
     1 11H (PASCALS)    /7X,2HM ,3X,8I10)
815   FORMAT(F11.2,3X,8F10.1)
816   FORMAT(///10X,5A4)
817   FORMAT(10X,45HFLOW COEFFICIENTS CORRECTED FOR TEMPREATURE     )
902   FORMAT(10(/),10X,11HCOMPARTMENT  ,I4/
     1 10X,20HTEMPERATURE PROFILE  ,I4,17H  DOES NOT EXIST  /
```

```
     + 10X,16HPROGRAM STOPPED  ,10(/))
903   FORMAT(10(/),5X,23HSHAFT CONNECTION ERROR     ,
     1 /10X,16HPROGRAM STOPPED  ,10(/))
904   FORMAT(10(/),10X,40HINPUT ERROR IN EXCEPTIONS TO SHAFT DATA
     1 /10X,16HPROGRAM STOPPED  ,10(/))
905   FORMAT(10(/),10X,37HINPUT ERROR IN UNIT TYPE DESIGNATION     /
     1  10X,16HPROGRAM STOPPED    ,10(/))
906   FORMAT(10(/),10X,37HINPUT ERROR NO. OF FLOORS EXCEEDS NH    /
     1 10X,16HPROGRAM STOPPED  ,10(/))
907    FORMAT(10(/),10X,25HINPUT ERROR IF1 .GT. IF2    /
     1 10X,16HPROGRAM STOPPED  ,10(/))
910   FORMAT(10(/),10X,36HINPUT EXCEEDS DIMENSION PARAMETER  ,A3/
     + 10X,16HPROGRAM STOPPED  ,10(/))
930   FORMAT(10X,3A6)
935   FORMAT(// 10X,26HFLOW COEFFICIENTS AS READ  )
940   FORMAT(10X,15HBUILDING  DATA  //34X,11HTEMPERATURE  ,4X,5HFIXED,
     1 12X,2(11X,4HFLOW)/10X,11HCOMPARTMENT ,4X,5HFLOOR,6X,7HPROFILE,
     2 6X,4HFLOW,5X,13HCONNECTION TO ,4X,11HCOEFFICIENT ,4X,
     3 8H  AREA   )
941   FORMAT(/4X,3I12,F14.1)
942   FORMAT(/4X,3I12,F14.1,4X,5HPOINT,I7,F11.2,F15.4)
943   FORMAT(58X,5HPOINT,I7,F11.2,F15.4)
944   FORMAT(58X,9HOUTSIDE   ,I3,F11.2,F15.4)
      END
```

```
      SUBROUTINE CORR
C
C        THIS ROUTINE CALCULATES ADJUSTED FLOW COEFFICIENTS
C                        (C1,C2,CO1,CO2)
C
      PARAMETER  (MM=140,MS=3,MC=9,MPO=2,MTP=2,MFL=25,MB=50)
      COMMON /CORR/C1(MM,MC),C2(MM,MC),CO1(MM,MPO),CO2(MM,MPO)
      COMMON NT,    P(MM),C(MM,MC),NC(MM),JC(MM,MC),ITS(MS),
     1 FC(MM,MC),PZ(MM,MC),PO(MM,MPO),CO(MM,MPO),F(MM),PFO(MFL,MPO),
     2 FF(MM),FO(MM,MPO),CS(MS),PS(MFL),NS1(MS),NS2(MS),
     3 FSS(MS),N,NS,NFC,ICONV,E,IEUG,AI(MM,MC),AO(MM,MPO),TITSH(MS,5),
     4 NH,H(MFL),IFLOOR(MM),T(MTP,MFL),NFS1(MS),NFS2(MS),IT(MB),NTP
     5 ,NCO(MM),JOC(MM,MPO),TCUT
      DOUBLE PRECISION P,PO,PS
      DO 12 I=1,NT
C
C        CORRECT C
C
      PATMOS=101325.
      BB=1000.*SQRT(2.*PATMOS/287.)/1.2
      NN=NC(I)
      IF(I .GT. N)GO TO 1
      IP=IT(I)
      GO TO 4
1     DO 2 IS=1,NS
      IF(I .LE. NS2(IS) .AND. I .GE. NS1(IS))GO TO 3
2     CONTINUE
      WRITE(6,700)
      STOP
3     IP=ITS(IS)
4     IFF=IFLOOR(I)
      T1=T(IP,IFF)
      IF(NN .EQ. 0)GO TO 10
      DO 9 J=1,NN
      JJ=JC(I,J)
      C1(I,J)=BB*C(I,J)*AI(I,J)/SQRT(T1)
      IF(JJ .GT. N)GO TO 5
      IP=IT(JJ)
      GO TO 8
5     DO 6 IS=1,NS
      IF(JJ .LE. NS2(IS) .AND. JJ .GE. NS1(IS))GO TO 7
6     CONTINUE
      WRITE(6,700)
      STOP
7     IP=ITS(IS)
8     IFF=IFLOOR(JJ)
      T2=T(IP,IFF)
      C2(I,J)=BB*C(I,J)*AI(I,J)/SQRT(T2)
9     CONTINUE
C
C        CORRECT CO
C
10    NNC=NCO(I)
      IF(NNC .EQ. 0)GO TO 12
      DO 11 J=1,NNC
```

```
      CO1(I,J)=E8*CC(I,J)*AC(I,J)/SQRT(T1)
      CO2(I,J)=E8*CC(I,J)*AO(I,J)/SQRT(TOUT)
11    CONTINUE
12    CONTINUE
      RETURN
700   FORMAT(///10X,36HPROGRAM STOPPED IN SUBROUTINE CORR     //)
      END
```

```
      SUBROUTINE  INIT
C
C
C      THIS ROUTINE  INITIALIZES THE PRESSURE ARRAY
C
      PARAMETER   (MM=140,MS=3,MC=9,MPO=2,MTP=2,MFL=25,MB=50)
      PARAMETER   (MBP=MB+1)
      COMMON /CORR/C1(MM,MC),C2(MM,MC),CC1(MM,MPO),CC2(MM,MPO)
      COMMON NT,    P(MM),C(MM,MC),NC(MM),JC(MM,MC),ITS(MS),
     1 PC(MM,MC),PZ(MM,MC),PO(MM,MPO),CO(MM,MPO),F(MM),PFO(MFL,MPO),
     2 FF(MM),FC(MM,MPO),CS(MS),PS(MFL),NS1(MS),NS2(MS),
     3 PSS(MS),N,NS,NFL,ICONV,E,IBUG,AI(MM,MC),AC(MM,MPO),TITSH(MS,5),
     4 NH,H(MFL),IFLOOR(MM),T(MTP,MFL),NFS1(MS),NFS2(MS),II(MB),NTP
     5 ,NCO(MM),JCC(MM,MPO),TOUT
      DOUBLE PRECISION P,PC,PS
      DIMENSION SC(MS),SCO(MS)
      COMMON /MAT/A(MB,MBP),XX(MB),NNN
      DOUBLE PRECISION A,XX
      NNN=N
C
C       CALCULATE AVERAGE OUTSIDE PRESSURE
C
      SUM=0.
      DO 10  J=1,NPO
      DO 10  I=1,NH
10    SUM=SUM+PFO(I,J)
      PA=SUM/(NPO*NH)
C
C
C
C       THE DO LOOP TO STATEMENT 30 ESTIMATES
C         SHAFT PRESSURES
C
      DO 30  IS=1,NS
C
C       CALCULATE SHAFT PRESSURE DIFFERENCE , DP
C
      SUM=0.
      SUMN=0.
      N1=NS1(IS)
      N2=NS2(IS)
      DO 15  I=N1,N2
      SUM=SUM+FF(I)
      NN=NC(I)
      IF(NN .EQ. 0.)GO TO 16
      DO 15  J=1,NN
      SUMN=SUMN+C1(I,J)
15    CONTINUE
      SC(IS)=SUMN
16    NNC=NCO(I)
      IF(NNC .EQ. 0)GO TO 1?
      DO 17  J=1,NNC
      SUMN=SUMN+CC1(I,J)
17    CONTINUE
      SCO(IS)=SUMN-SC(IS)
```

```
18      CONTINUE
        DP2=SUM/SUMN
        SIGN=1.
        IF(DP2 .LT. 0.)SIGN=-1.
        DP=SIGN*(SIGN*DP2)**2
C
C         CALCULATE AVERAGE TEMP OF SHAFT
C
        SUM=0.
        IP=ITS(IS)
        DO 20 I=N1,N2
        IFF=IFLOOR(I)
20      SUM=SUM+T(IP,IFF)
        TA=SUM/(N2-N1+1)
C
C         ESTIMATE PRESSURE AT BOTTOM OF SHAFT , PBOT
C
        HH=0.5*(H(NH)-H(1))+H(1)
        NF1=NFS1(IS)
        PBOT=PA+DP+3462.*(HH-H(NF1))/TA
C
C         ESTIMATE OTHER SHAFT PRESSURES
C
        P(N1)=PBOT
        NM=N2-1
        DO 24 I=N1,NM
        IP1=I+1
24      P(IP1)=P(I)-PZ(I,1)
30      CONTINUE
C
C         END OF SHAFT PRESSURE ESTIMATES
C
C         SET UP MATRIX FOR BUILDING COMPARTMENTS
C
        NP1=N+1
        DO 50 I=1,N
        NN=NC(I)
        SUMII=0.
        SUMNP=0.
        IF(NN .EQ. 0.)GO TO 42
        DO 40 JJ=1,NN
        J=JC(I,JJ)
        IF(J .GT. N)GO TO 34
        A(I,J)=C1(I,JJ)
        SUMII=SUMII-C1(I,JJ)
        SUMNP=SUMNP-C1(I,JJ)*PZ(I,JJ)
        GO TO 40
34      SUMII=SUMII-C1(I,JJ)
        SUMNP=SUMNP-C1(I,JJ)*P(J)
40      CONTINUE
42      NNC=NCC(I)
        IF(NNC .EQ. 0)GO TO 46
        DO 45 K=1,NNC
        SUMII=SUMII-CC1(I,K)
45      SUMNP=SUMNP-CC1(I,K)*PO(I,K)
```

```
46      A(I,I)=SUMII
        A(I,NP1)=SUMNP-FF(I)
50      CONTINUE
C
C         WRITE MATRIX
C
        IF(IBUG .EQ. 0)GO TO 84
        WRITE(6,802)
        DO 52 I=1,N
52      WRITE(6,803)(A(I,J),J=1,NP1)
C
C
C         CALL ROUTINE TO SOLVE FOR INITIAL BUILDING PRESSURES
C
84      CALL SIMEQ
C
C         OUTPUT INITIAL PRESSURES
C
        IF(IBUG .EQ. 0)GO TO 89
        WRITE(6,800)
        WRITE(6,801)(I,XX(I),I=1,N)
        NN=NS1(1)
        WRITE(6,801)(I,P(I),I=NN,NT)
C
C
C        ASSIGN BUILDING PRESSURES
C
89      DO 90 I=1,N
90      P(I)=XX(I)
        RETURN
800     FORMAT(///8(6X,1HI,4X,3HP   )/)
801     FORMAT(8(I7,F7.1))
802      FORMAT(///10X,20HMATRIX COEFFICIENTS    /)
803     FORMAT(10X,11F11.1)
        END
```

```
      SUBROUTINE  BLDGP
C
C
C      THIS ROUTINE CALCULATES STEADY STATE PRESSURES
C           FOR BUILDING COMPARTMENTS
C
C
C
      PARAMETER  (MM=140,MS=8,MC=5,MPO=2,MTP=2,MFL=25,M3=50)
      COMMON NT,    P(MM),C(MM,MC),NC(MM),JC(MM,MC),ITS(MS),
     1 FC(MM,MC),PZ(MM,MC),PO(MM,MPO),CO(MM,MPO),F(MM),PFO(MFL,MPO),
     2 FF(MM),FO(MM,MPO),CS(MS),PS(MFL),NS1(MS),NS2(MS),
     3 FSS(MS),N,NS,NFC,ICONV,E,IBUG,AI(MM,MC),AO(MM,MPO),TITSH(MS,5),
     4 NH,H(MFL),IFLOOR(MM),T(MTP,MFL),NFS1(MS),NFS2(MS),IT(M3),NTP
     5 ,NCO(MM),JCO(MM,MPO),TOUT
      DOUBLE PRECISION P,PO,PS,PI
      IF(IBUG .GT. 0)WRITE(6,806)
      ITM=100
      ICONV=0
      DO 15 I=1,N
C
C     CALCULATE NET FLOW ,FI, INTO POINT I
      FI=PFLOW(I,P(I))
C
C     CHECK MAGNITUDE OF FI
      IF(ABS(FI) .LT. E)GO TO 15
      ICONV=ICONV+1
C
C     SET UP PARAMETERS FOR ITERATION
      DP=1.0
      IPHASE=1
      DPI=0.
      EE=0.2*ABS(FI)
      IF(EE .LT. E)EE=E
      SIGN=1
      IF(FI .LT. 0.)SIGN=-1
      IK=0
      IF(IBUG .GT. 0)WRITE(6,802)
C
C     ITERATION TO REDUCE MAGNITUDE OF FN
2     IK=IK+1
C
C     NEW ESTIMATE OF PRESSURE ,PI, AT POINT I
      PI=P(I)+SIGN*DP
C
C     CALCULATE NET FLOW ,FN, INTO POINT I USING PI
      FN=PFLOW(I,PI)
      IF(IBUG.GT.0)WRITE(6,804)I,IK,FI,FN,EP,DPI,DP,DPP,PI,IPHASE
C
C     CHECK MAGNITUDE OF FN
      IF(ABS(FN) .LT. EE)GO TO 10
C
C     CHECK NUMBER OF ITERATIONS
      IF(IK .GT. ITM)GO TO 25
C
```

```
C       CHECK PHASE
        IF(IPHASE .EQ. 2)GO TO 6
C
C       CHECK FOR TRANSITION FROM PHASE 1 TO PHASE 2
        IF(FI*FN .LT. 0.)GO TO 4
C
C       PHASE 1
        DPI=DP
        DP=3.0*DP
        FI=FN
        GO TO 2
C
C       PHASE 2
4       IPHASE=2
        GO TO 9
6       IF(FI*FN .GT. 0.)GO TO 5
C
C       NEW DP BETWEEN DPI AND DP
9       DPP=DP
        FP=FN
        DP=DPI+(DPP-DPI)*FI/(FI-FN)
        GO TO 2
C
C       NEW DP BETWEEN DP AND DPP
5       FI=FN
        DPI=DP
        DP=DPI+(DPP-DPI)*FN/(FN-FP)
        GO TO 2
10      F(I)=FI
15      CONTINUE
C
        RETURN
25      WRITE(6,800)
        STOP
C
C        FORMAT STATEMENTS
C
800     FORMAT(///10X,20(1H*)///10X,22HEXCESSIVE ITERATIONS    /
       + 10X,8HIN BLDGP ///10X,20(1H*)//////)
802     FORMAT(//11X,1HI,3X,2HIT,12X,2HFI,13X,2HFN,13X,2HFP,12X,3HDPI,
       +13X,2HDP,12X,3HDPP,13X,2HPI,3X,5HPHASE /)
804     FORMAT(3X,2I4,3E15.4,4F15.5,I5)
806     FORMAT(    ///10X,6HBLDGP   )
        END
```

```
      SUBROUTINE  SHAFTP
C
C
C      THIS ROUTINE CALCULATES STEADY STATE PRESSURES
C           FOR SHAFTS
C
C
      PARAMETER  (MM=140,MS=8,MC=9,MPO=2,MTP=2,MFL=25,ME=50)
      COMMON NT,    P(MM),C(MM,MC),NC(MM),JC(MM,MC),ITS(MS),
     1 FC(MM,MC),PZ(MM,MC),PO(MM,MPO),CO(MM,MPO),F(MM),PFO(MFL,MPO),
     2 FF(MM),FC(MM,MPC),CS(MS),PS(MFL),NS1(MS),NS2(MS),
     3 FSS(MS),N,NS,NFC,ICONV,E,IBUG,AI(MM,MC),AO(MM,MPC),TITSH(MS,5),
     4 NH,H(MFL),IFLOOR(MM),T(MTP,MFL),NFS1(MS),NFS2(MS),IT(MB),NTP
     5 ,NCO(MM),JCC(MM,MPC),TOUT
      DOUBLE PRECISION P,PO,PS,PI
      IF(IBUG .GT. 0)WRITE(6,806)
      ITM=100
      ICONV=0
      DO 15 I=1,NS
C
C     CALCULATE NET FLOW ,FI, INTO POINT I
      N1=NS1(I)
      FI=SFLOW(I,P(N1))
C
C     CHECK MAGNITUDE OF FI
      IF(ABS(FI) .LT. E)GO TO 15
      ICONV=ICONV+1
C
C     SET UP PARAMETERS FOR ITERATION
      DP=1.0
      IPHASE=1
      DPI=0.
      EE=0.2*ABS(FI)
      IF(EE .LT. E)EE=E
      SIGN=1
      IF(FI .LT. 0.)SIGN=-1
      IK=0
      IF(IBUG .GT. 0)WRITE(6,802)
C
C     ITERATION TO REDUCE MAGNITUDE OF FN
2     IK=IK+1
C
C     NEW ESTIMATE OF PRESSURE ,PI, AT BOTTOM OF SHAFT I
      PI=P(N1)+SIGN*DP
C
C      CALCULATE NET FLOW ,FN, INTO SHAFT I USING PI
      FN=SFLOW(I,PI)
      IF(IBUG.GT.0)WRITE(6,804)I,IK,FI,FN,FP,DPI,DP,DPP,PI,IPHASE
C
C     CHECK MAGNITUDE OF FN
      IF(ABS(FN) .LT. EE)GO TO 10
C
C     CHECK NUMBER OF ITERATIONS
      IF(IK .GT. ITM)GO TO 25
C
```

```
C       CHECK PHASE
        IF(IPHASE .EQ. 2)GO TO 6
C
C       CHECK FOR TRANSITION FROM PHASE 1 TO PHASE 2
        IF(FI*FN .LT. 0.)GO TO 4
C
C       PHASE 1
        DPI=DP
        DP=5.0*DP
        FI=FN
        GO TO 2
C
C       PHASE 2
4       IPHASE=2
        GO TO 9
6       IF(FI*FN .GT. 0.)GO TO 8
C
C       NEW DP BETWEEN DPI AND DP
9       DPP=DP
        FP=FN
        DP=DPI+(DPP-DPI)*FI/(FI-FN)
        GO TO 2
C
C       NEW DP BETWEEN DP AND DPP
8       FI=FN
        DPI=DP
        DP=DPI+(DPP-DPI)*FN/(FN-FP)
        GO TO 2
10      N2=NS2(I)
        DO 11 IF=N1,N2
        II=IF+1-N1
11      F(IF)=FS(II)
15      CONTINUE
C
        RETURN
25      WRITE(6,800)
        STOP
C
C        FORMAT STATEMENTS
C
800     FORMAT(///10X,20(1H*)///10X,22HEXCESSIVE ITERATIONS    /
       + 10X,5HIN SHAFTP  ///10X,20(1H*)//////)
802     FORMAT(//11X,1HI,2X,2HIT,12X,2HFI,13X,2HFN,13X,2HFP,12X,3HDPI,
       +13X,2HDP,12X,3HDPP,13X,2HPI,3X,5HPHASE /)
804     FORMAT(8X,2I4,3E15.4,4F15.6,I5)
806     FORMAT(    ///10X,6HSHAFTP)
        END
```

```
      SUBROUTINE  PZAD
C
C       THIS ROUTINE CORRECTS PZ TERMS FOR PRESSURE
C
      PARAMETER  (MM=140,MS=8,MC=9,MPO=2,MTP=2,MFL=25,MB=50)
      COMMON NT,    P(MM),C(MM,MC),NC(MM),JC(MM,MC),ITS(MS),
     1 FC(MM,MC),PZ(MM,MC),PO(MM,MPO),CO(MM,MPO),F(MM),FFO(MFL,MPO),
     2 FF(MM),FC(MM,MFC),CS(MS),PS(MFL),NS1(MS),NS2(MS),
     3 FSS(MS),N,NS,NPC,ICONV,E,IBUG,AI(MM,MC),AO(MM,MPC),TITSH(MS,5),
     4 NH,H(MFL),IFLOOR(MM),T(MTP,MFL),NFS1(MS),NFS2(MS),IT(MB),NTP
     5 ,NCO(MM),JCC(MM,MPC),TCUT
      COMMON /PZZ/ PGZ
      DOUBLE PRECISION P,PO,PS
      IF(IBUG .GT. -2)GO TO 1
      WRITE(6,800)
      DO 2 I=1,N
      NN=NC(I)
      IF(NN .EQ. 0)GO TO 2
      WRITE(6,801)(I,J,PZ(I,J),J=1,NN)
2     CONTINUE
      NP1=N+1
      WRITE(6,802)(IL,PZ(IL,1),IL=NP1,NT)
1     DO 10 I=1,N
      NN=NC(I)
      IF(NN .EQ. 0)GO TO 10
      IA=IT(I)
      IFI=IFLOOR(I)
      DO 8 JJ=1,NN
      J=JC(I,JJ)
      IFJ=IFLOOR(J)
      IF(IFI .EQ. IFJ)GO TO 8
      IB=IT(J)
      TEMPA=0.5*(T(IA,IFI)+T(IB,IFJ))
      PAVE=0.5*(P(I)+P(J))+PGZ
      PZ(I,JJ)=(0.03416*PAVE/TEMPA)*(H(IFJ)-H(IFI))
8     CONTINUE
10    CONTINUE
      DO 20 IS=1,NS
      N1=NS1(IS)
      N2=NS2(IS)-1
      ITT=ITS(IS)
      DO 15 I=N1,N2
      IFI=IFLOOR(I)
      IFJ=IFI+1
      TEMPA=0.5*(T(ITT,IFI)+T(ITT,IFJ))
      J=I+1
      PA=0.5*(P(I)+P(J))+PGZ
15    PZ(I,1)=(0.03416*PA/TEMPA)*(H(IFJ)-H(IFI))
20    CONTINUE
      RETURN
800   FORMAT(/10X,10HINITIAL PZ /)
801   FORMAT(10X,3HPZ(,I2,1H,,I2,4H) =  ,F12.4)
802   FORMAT(10X,3HPZ(,I2,6H,1) '  ,F12.4)
803   FORMAT(/10X,11HADJUSTED PZ  /)
      END
```

```
      SUBROUTINE CUT
C
C
C       THIS ROUTINE OUTPUTS FLOWS AND DIFFERENTIAL PRESSURES
C       FOR ALL SHAFTS AND BUILDING COMPARTMENTS
C
C
      PARAMETER  (MM=140,MS=8,MC=9,MPO=2,MTP=2,MFL=25,ME=50)
      COMMON /CORR/C1(MM,MC),C2(MM,MC),CO1(MM,MPO),CO2(MM,MPO)
      COMMON  /IC/TITLE(16),ICUT,IUNIT,NCOMP(MFL),SNCOMP(MFL)
      COMMON NT,    P(MM),C(MM,MC),NC(MM),JC(MM,MC),ITS(MS),
     1 FC(MM,MC),PZ(MM,MC),PO(MM,MPO),CO(MM,MPO),F(MM),PFO(MFL,MPO),
     2 FF(MM),FO(MM,MPO),CS(MS),PS(MFL),NS1(MS),NS2(MS),
     3 FSS(MS),N,NS,NFC,ICONV,E,IBUG,AI(MM,MC),AO(MM,MPO),TITSH(MS,8),
     4 NH,H(MFL),IFLOOR(MM),T(MTP,MFL),NFS1(MS),NFS2(MS),IT(MB),NTP
     5 ,NCO(MM),JCO(MM,MPO),TCUT
      DOUBLE PRECISION P,PO,PS
      INTEGER   COM
C
C       IUNIT = 1 FOR SI UNITS
C       IUNIT = 2 FOR ENG UNITS
C       WHEN IUNIT = 2 GO TO 100
      IF(IUNIT .EQ. 2)GO TO 100
C
C       BUILDING COMPARTMENT OUTPUT
C
1     I=0
      IL=0
      WRITE(6,800)TITLE
      DO 30 IFF=1,NH
      NNN=NCOMP(IFF)
      IF(NNN .EQ. 0)GO TO 30
      DO 29 IC=1,NNN
      I=I+1
      NN=NC(I)
      NNO=NCO(I)
      IL=IL+NN+NNO+2
      IF(IL .LT. 51)GO TO 2
      WRITE(6,800)TITLE
      IL=NN+NNO+2
2     IF(NN .GT. 0)GO TO 3
      WRITE(6,801)IFF,IC,P(I),IT(I),FF(I)
      GO TO 21
3     DO 20 J=1,NN
      JJ=JC(I,J)
      DP=P(JJ)-P(I)+PZ(I,J)
      CC=C2(I,J)
      IF(DP .LT. 0.)CC=C1(I,J)
      IF(JJ .LE. N)GO TO 10
      DO 5 IS=1,NS
      IF(JJ .GE. NS1(IS) .AND. JJ .LE. NS2(IS))GO TO 6
5     CONTINUE
6     IF(J .GT. 1)GO TO 7
      WRITE(6,802)IFF,IC,P(I),IT(I),FF(I),(TITSH(IS,K),K=1,8)
     + ,DP,CC,AI(I,1),FC(I,1)
```

```
      GO TO 20
7     WRITE(6,803)(TITSH(IS,K),K=1,5),DP,CC,AI(I,J),FC(I,J)
      GO TO 20
10    IFJ=IFLOOR(JJ)
      COM=JJ-SNCOMP(IFJ)
      IF(J .GT. 1)GO TO 12
      WRITE(6,804)IFF,IC,P(I),IT(I),FF(I),IFJ,COM,DP,CC,AI(I,1),FC(I,1)
      GO TO 20
12    WRITE(6,805)IFJ,COM,DP,CC,AI(I,J),FC(I,J)
20    CONTINUE
21    IF(NNO .EQ. 0)GO TO 29
      DO 23 J=1,NNO
      JJ=JOC(I,J)
      DP=PO(I,J)-P(I)
      CC=CO2(I,J)
      IF(DP .LT. 0.)CC=CO1(I,J)
23    WRITE(6,806)JJ,DP,CC,AO(I,J),FO(I,J)
29    WRITE(6,807)F(I)
30    CONTINUE
      WRITE(6,900)
C
C       SHAFT OUTPUT
C
      DO 60 IS=1,NS
      N1=NS1(IS)
      N2=NS2(IS)
32    WRITE(6,814)TITLE
      WRITE(6,808)(TITSH(IS,K),K=1,5),ITS(IS),CS(IS)
      DO 50 I=N1,N2
      NN=NC(I)
      IF(NN .GT. 0)GO TO 35
      WRITE(6,809)IFLOOR(I),P(I),FF(I)
      GO TO 41
35    DO 40 J=1,NN
      JJ=JC(I,J)
      DP=P(JJ)-P(I)
      CC=C2(I,J)
      IF(DP .LT. 0.)CC=C1(I,J)
      IFJ=IFLOOR(JJ)
      COM=JJ-SNCOMP(IFJ)
      IF(J .GT. 1)GO TO 36
      WRITE(6,810)IFLOOR(I),P(I),FF(I),IFJ,COM,DP,CC, AI(I,1),FC(I,1)
      GO TO 40
36    WRITE(6,811)IFJ,COM,DP,CC, AI(I,J),FC(I,J)
40    CONTINUE
41    NNO=NCO(I)
      IF(NNO .EQ. 0)GO TO 50
      DO 46 J=1,NNO
      JJ=JOC(I,J)
      DP=PO(I,J)-P(I)
      CC=CO2(I,J)
      IF(DP .LT. 0.)CC=CO1(I,J)
46    WRITE(6,812)JJ,DP,CC,AO(I,J),FO(I,J)
50    CONTINUE
      WRITE(6,813)FSS(IS)
```

```
      WRITE(6,900)
60    CONTINUE
      GO TO 165
C
C       BUILDING DATA OUTPUT  FOR IUNIT = 2
C
100   I=0
      IL=0
      WRITE(6,800)TITLE
      DO 130 IFF=1,NH
      NNN=NCOMP(IFF)
      IF(NNN .EQ. 0)GO TO 130
      DO 129 IC=1,NNN
      I=I+1
      FFI=F(I)/0.4719
      PIII=P(I)/248.8
      FFF=FF(I)/0.4719
      NN=NC(I)
      NNC=NCC(I)
      IL=IL+NN+NNC+2
      IF(IL .LT. 51)GO TO 102
      WRITE(6,800)TITLE
      IL=NN+NNC+2
102   IF(NN .GT. 0)GO TO 103
      WRITE(6,601)IFF,IC,PIII,IT(I),FFF
      GO TO 121
103   DO 120 J=1,NN
      FCCC=FC(I,J)/0.4719
      JJ=JC(I,J)
      DP=(P(JJ)-P(I)+PZ(I,J))/248.8
      AAI=AI(I,J)/0.0929
      CC=C2(I,J)
      IF(DP .LT. 0.)CC=C1(I,J)
      CC=CC*33.43
      IF(JJ .LE. N)GO TO 110
      DO 105 IS=1,NS
      IF(JJ .GE. NS1(IS) .AND. JJ .LE. NS2(IS))GO TO 106
105   CONTINUE
106   IF(J .GT. 1)GO TO 107
      WRITE(6,602)IFF,IC,PIII,IT(I),FFF   ,(TITSH(IS,K),K=1,5)
     + ,DP,CC,AAI,FCCC
      GO TO 120
107   WRITE(6,603)(TITSH(IS,K),K=1,5),DP,CC,AAI,FCCC
      GO TO 120
110   IFJ=IFLOOR(JJ)
      COM=JJ-SNCOMP(IFJ)
      IF(J .GT. 1)GO TO 112
      WRITE(6,604)IFF,IC,PIII,IT(I),FFF   ,IFJ,COM,DP,CC,AAI,FCCC
      GO TO 120
112   WRITE(6,605)IFJ,COM,DP,CC,AAI,FCCC
120   CONTINUE
121   IF(NNC .EQ. 0)GO TO 129
      DO 123 J=1,NNC
      FCC=FC(I,J)/0.4719
      JJ=JCC(I,J)
```

```
      DP=(PC(I,J)-P(I))/248.8
      AAC=AC(I,J)/0.0929
      CC=CO2(I,J)
      IF(DP .LT. 0.)CC=CO1(I,J)
      CC=CC*33.43
128   WRITE(6,606)JJ,DP,CC,AAC,FOO
129   WRITE(6,807)FFI
130   CONTINUE
      WRITE(6,901)
C
C       SHAFT OUTPUT FOR IUNIT = 2
C
      DO 160 IS=1,NS
      CSS=CS(IS)/0.02992
      FFI=FSS(IS)/0.4719
      N1=NS1(IS)
      N2=NS2(IS)
132   WRITE(6,814)TITLE
      WRITE(6,808)(TITSH(IS,K),K=1,5),ITS(IS),CSS
      DO 150 I=N1,N2
      FFF=FF(I)/0.4719
      PIII=P(I)/248.8
      NN=NC(I)
      IF(NN .GT. 0)GO TO 135
      WRITE(6,609)IFLOOR(I),PIII,FFF
      GO TO 141
135   DO 140 J=1,NN
      FCCC=FC(I,J)/0.4719
      JJ=JC(I,J)
      DP=(P(JJ)-P(I))/248.8
      AAI=AI(I,J)/0.0929
      CC=C2(I,J)
      IF(DP .LT. 0.)CC=C1(I,J)
      CC=CC*33.43
      IFJ=IFLOOR(JJ)
      COM=JJ-SNCOMP(IFJ)
      IF(J .GT. 1)GO TO 136
      WRITE(6,610)IFLOOR(I),PIII,FFF   ,IFJ,COM,DP,CC, AAI,FCCC
      GO TO 140
136   WRITE(6,611)IFJ,COM,DP,CC, AAI,FCCC
140   CONTINUE
141   NNC=NCC(I)
      IF(NNC .EQ. 0)GO TO 150
      DO 146 J=1,NNC
      FOO=FC(I,J)/0.4719
      JJ=JOC(I,J)
      DP=(PC(I,J)-P(I))/248.8
      AAO=AC(I,J)/0.0929
      CC=CO2(I,J)
      IF(DP .LT. 0.)CC=CO1(I,J)
      CC=CC*33.43
146   WRITE(6,612)JJ,DP,CC,AAC,FOO
150   CONTINUE
      WRITE(6,813)FFI
      WRITE(6,901)
```

```
160   CONTINUE
C
C        SUMMARY OUTPUT
C        USER INSERTS WRITE STATEMENTS TO FILE IOUT
C
165   CONTINUE
      RETURN
C
C
C        FORMAT STATEMENTS
C
601   FORMAT(/4X,I3,I10,F13.3,I8,F12.0)
602   FORMAT(/4X,I3,I10,F13.3,I8,F12.0,3X,5A4,F14.3,F15.0,F10.3,F11.1)
603   FORMAT(53X,5A4,F14.3,F15.0,F10.3,F11.1)
604   FORMAT(/4X,I3,I10,F13.3,I3,F12.0,3X,5HFLOOR,I3,12H COMPARTMENT,I3,
     1 F11.3,F15.0,F10.3,F11.1)
605   FORMAT(53X,5HFLOOR,I3,12H COMPARTMENT, I3,F11.3,F15.0,F10.3,F11.1)
606   FORMAT(53X,17HOUTSIDE DIRECTION,I3,F14.3,F15.0,F10.3,F11.1)
609   FORMAT(4X,I3,F10.3,F11.0)
610   FORMAT(4X,I3,F10.3,F11.0,3X,5HFLOOR,I3,12H COMPARTMENT,I3,F11.3,
     1 F15.0,F10.3,F11.1)
611   FORMAT(31X,5HFLOOR,I3,12H COMPARTMENT,I3,F11.3,F15.0,F10.3,F11.1)
612   FORMAT(31X,17HOUTSIDE DIRECTION ,I3,F14.3,F15.0,F10.3,F11.1)
900   FORMAT(1H1,20X,19A4,/93X,8HADJUSTED/33X,4HTEMP,7X,5HFIXED,28X,
     1 12HDIFFERENTIAL,5X,4HFLOW,9X,4HFLOW/4X,5HFLOOR,2X,11HCOMPARTMENT
     2 ,2X,8HPRESSURE,2X,7HPROFILE,5X,4HFLOW,3X,16HCONNECTION     TO ,
     312X,8HPRESSURE,4X,11HCOEFFICIENT,2X,8H   AREA   ,5X,4HFLOW /)
801   FORMAT(/4X,I3,I10,F13.1,I8,F12.0)
802   FORMAT(/4X,I3,I10,F13.1,I8,F12.0,3X,5A4,F14.1,F15.1,F10.4,F11.1)
803   FORMAT(53X,5A4,F14.1,F15.1,F10.4,F11.1)
804   FORMAT(/4X,I3,I10,F13.1,I3,F12.0,3X,5HFLOOR,I3,12H COMPARTMENT,I3,
     1 F11.1,F15.1,F10.4,F11.1)
805   FORMAT(53X,5HFLOOR,I3,12H COMPARTMENT, I3,F11.1,F15.1,F10.4,F11.1)
806   FORMAT(53X,17HOUTSIDE DIRECTION,I3,F14.1,F15.1,F10.4,F11.1)
807   FORMAT(115X,F8.1,4H NET)
808   FORMAT(////20X,5A4//20X,20HTEMPERATURE PROFILE   ,I3/ 20X,
     1 23HSHAFT FLOW COEFFICIENT   ,F10.0//72X,8HADJUSTED/24X,5HFIXED,
     2 23X,12HDIFFERENTIAL,5X,4HFLOW,9X,4HFLOW/4X,5HFLOOR,2X,8HPRESSURE,
     3 5X,4HFLOW,3X,16HCONNECTION     TO,12X,8HPRESSURE,4X,11HCOEFFICIENT
     4,2X,8H   AREA   ,5X,4HFLOW /)
809   FORMAT(4X,I3,F10.1,F11.0)
810   FORMAT(4X,I3,F10.1,F11.0,3X,5HFLOOR,I3,12H COMPARTMENT,I3,F11.1,
     1 F15.1,F10.4,F11.1)
811   FORMAT(31X,5HFLOOR,I3,12H COMPARTMENT,I3,F11.1,F15.1,F10.4,F11.1)
812   FORMAT(31X,17HOUTSIDE DIRECTION ,I3,F14.1,F15.1,F10.4,F11.1)
813   FORMAT(93X,F8.1,4H NET)
814   FORMAT(1H1,20X,19A4)
900   FORMAT(//15X,'THE FOLLOWING UNITS ARE USED FOR OUTPUT'
     1//5X,'FLOW IN  LITERS PER SECOND AT 21 DEG C AND 1 ATM'
     2/5X,'PRESSURE IN  PASCALS'/5X,'AREA IN  METERS SQUARED')
901   FORMAT(///,5X,'THE FOLLOWING UNITS ARE USED FOR OUTPUT'
     1 //5X,'FLOW IN  CFM AT 70 DEG F AND 1 ATM'
     2 /5X,'PRESSURE IN  INCHS H2O'/5X,'AREA IN  FEET SQUARED')
      END
```

```
      SUBROUTINE SIMEQ
C
C          CHOLESKY'S METHOD OF SOLUTION OF
C        SIMULTANEOUS LINEAR ALGEBRIC EQUATIONS
C
      PARAMETER  (MM=140,MS=8,MC=9,MPO=2,MTP=2,MFL=25,MB=50)
      PARAMETER  (MBP=MB+1)
      DOUBLE PRECISION A,X
      COMMON /MAT/ A(MB,MBP),X(MB),N
      NP1=N+1
      ZERO=1.0E-35
      K=0
C
C
C         SEE IF A(1,1) IS ZERO
C     IF SO ADD ANOTHER ROW TO ROW 1
      IF(ABS(A(1,1)) .GT. ZERO)GO TO 40
      DO 31 I=1,N
      IF(A(I,1) .NE. 0.)GO TO 32
   31 CONTINUE
   12 WRITE(6,304)K
      STOP
   32 DO 33 J=1,NP1
   33 A(1,J)=A(1,J)+A(I,J)
C
C     CALCULATE UPPER AND LOWER
C     TRIANGULAR MATRICES OVER ORIG
C     MATRIX A
   40 AA=A(1,1)
      DO 2 J=2,NP1
    2 A(1,J)=A(1,J)/AA
      DO 10 I=2,N
      K=0
C
C     STORE A(I,1) ... A(I,I) IN X ARRAY
C     IN CASE NEW A(I,I) IS ZERO
C     ROW I CAN BE RECALCULATED
    4 DO 5 J=1,I
    5 X(J)=A(I,J)
      K=K+1
      DO 10 J=2,NP1
      IF(J .GT. I)GO TO 8
      JM1=J-1
      AA=0.
      DO 3 IR=1,JM1
    3 AA=AA+A(I,IR)*A(IR,J)
      A(I,J)=A(I,J)-AA
C
C     CHECK IF A(I,I) IS ZERO
C     IF SO MULTIPLY OLD ROW I BY 2.
C
      IF(I .NE. J)GO TO 10
      IF(ABS(A(I,I)) .GT. ZERO)GO TO 10
      DO 6 JJ=1,I
    6 A(I,JJ)=X(JJ)
```

```
      DO 7 JJ=1,NP1
    7 A(I,J)=2.*A(I,J)
      IF(K .GT. 3)GO TO 12
      GO TO 4
    8 IM1=I-1
      AA=0.
      DO 9 IR=1,IM1
    9 AA=AA+A(I,IR)*A(IR,J)
      A(I,J)=(A(I,J)-AA)/A(I,I)
   10 CONTINUE
C     END OF CALCULATION OF TRIANGULAR MATRICES
C
C
C     BACKWARD SUBSTITUTION
C
      X(N)=A(N,NP1)
      DO 20 II=2,N
      AA=0.
      I=NP1-II
      IP1=I+1
      DO 15 J=IP1,N
   15 AA=AA+A(I,J)*X(J)
   20 X(I)=A(I,NP1)-AA
C
  804 FORMAT(//////10X,16HPROGRAM FAILURE  ,I3/////)
      END
```

```
      FUNCTION FLOW(PI,PJ,PZ,C)
      DOUBLE PRECISION PI,PJ
C
C     THIS FUNCTION CALCULATES FLOWS BETWEEN TWO POINTS
C
      IF(C .LT. 0.001)GO TO 10
      DP=PJ-PI+PZ
      SIGN=1.0
      IF(DP .LT. .0)SIGN=-1.
      FLOW=SIGN*C*SQRT(SIGN*DP)
      RETURN
10    FLOW=0.0
      RETURN
      END
```

```
      FUNCTION PFLOW(I,PI)
C
C
C     THIS FUNCTION CALCULATES NET FLOWS INTO POINT I
C
      PARAMETER  (MM=140,MS=8,MC=9,MPO=2,MTP=2,MFL=25,MB=50)
      COMMON /CORR/C1(MM,MC),C2(MM,MC),CO1(MM,MPO),CO2(MM,MPO)
      COMMON NT,    P(MM),C(MM,MC),NC(MM),JC(MM,MC),ITS(MS),
     1 FC(MM,MC),PZ(MM,MC),PO(MM,MPO),CO(MM,MPO),F(MM),PFO(MFL,MPO),
     2 FF(MM),FO(MM,MPO),CS(MS),PS(MFL),NS1(MS),NS2(MS),
     3 FSS(MS),N,NS,NPC,ICONV,E,IBUG,AI(MM,MC),AO(MM,MPO),TITSH(MS,5),
     4 NH,H(MFL),IFLOOR(MM),T(MTP,MFL),NFS1(MS),NFS2(MS),IT(MB),NTP
     5 ,NCO(MM),JCC(MM,MPO),TOUT
      DOUBLE PRECISION P,PO,PS,PI
      NN=NC(I)
      SUM=0.
      IF(NN .EQ. 0)GO TO 3
      DO 1 JJ=1,NN
      J=JC(I,JJ)
      CC=C1(I,JJ)
      IF(PI .LT. P(J))CC=C2(I,JJ)
      PZZ=PZ(I,JJ)
      IF(I .GT. N)PZZ=0.
      FC(I,JJ)=FLOW(PI,P(J),PZZ,CC)
1     SUM=SUM+FC(I,JJ)
3     NNC=NCO(I)
      IF(NNC .EQ. 0)GO TO 4
      DO 2 K=1,NNO
      CC=CO1(I,K)
      IF(PI .LT. PO(I,K))CC=CO2(I,K)
      FO(I,K)=FLOW(PI,PO(I,K),0,CC)
2     SUM=SUM+FO(I,K)
4     PFLOW=SUM+FF(I)
      IF(I .LE. N)F(I)=SUM+FF(I)
      RETURN
      END
```

```
      FUNCTICN SFLOW(IS,PI)
C
C
C     THIS ROUTINE CALCULATES NET FLOW INTO A SHAFT AND
C        SHAFT FRESSURE PROFILE '
C
C
      PARAMETER  (MM=140,MS=8,MC=9,MPO=2,MTP=2,MFL=25,MB=50)
      COMMON NT,    F(MM),C(MM,MC),NC(MM),JC(MM,MC),ITS(MS),
     1 FC(MM,MC),PZ(MM,MC),PO(MM,MPO),CO(MM,MPO),F(MM),PFO(MFL,MPO),
     2 FF(MM),FC(MM,MPC),CS(MS),PS(MFL),NS1(MS),NS2(MS),
     3 FSS(MS),N,NS,NPC,ICONV,E,IBUG,AI(MM,MC),AO(MM,MPO),TITSH(MS,5),
     4 NH,H(MFL),IFLOCR(MM),T(MTP,MFL),NFS1(MS),NFS2(MS),IT(MB),NTP
     5 ,NCO(MM),JOC(MM,MPO),TCUT
      DOUBLE PRECISION P,PO,PS,PI
      IF(IBUG .GT.1)WRITE(6,800)IS
      SUM=0.
      N1=NS1(IS)
      N2=NS2(IS)
      PS(1)=PI
      FUP=0.
      CSS=CS(IS)
      DO 10 I=N1,N2
      II=I+1-N1
      FLO=PFLOW(I,PS(II))
      FUP=FLO+FUP
      SUM=SUM+FLO
      IF(I .EQ. N2)GO TO 5
      IIP1=II+1
      SIGN=1
      IF(FUP .GT. 0.)SIGN=-1.
      PS(IIP1)=PS(II)-PZ(I,1)+SIGN*FUP*FUP/(CSS*CSS)
5     IF(IBUG .GT. 1)WRITE(6,801)I,II,PS(II),FLO,FUP,SUM
10    CONTINUE
      FSS(IS)=SUM
      SFLOW=SUM
      RETURN
C
C      FORMAT STATEMENTS
C
800   FORMAT(///5X,17HFLOW - SHAFT NO   ,I5/)
801   FORMAT(5X,3HI =,I3,5X,4HII =,I3,5X,4HPS =,
     + E15.7,5X,5HFLO =,E10.4,5X,5HFUP =,E10.4,5X,5HSUM =,E10.4/)
      END
```

APPENDIX H.
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APPENDIX I.
UNITS OF MEASUREMENT

Physical quantities such as length, weight, and time are expressed in terms of standard units of measurement. In this book, two systems are used: the engineering system and the international system (SI).

In both systems, there are base units in terms of which all other units are defined. For purposes of smoke control, the base units are listed in table I.1.

Newton's second law of motion is the relationship used to define force in terms of basic units.

$$F = ma$$

where:

F = force, lb (N)

m = mass, slug (kg)

a = acceleration, ft/sec^2 (m/s^2)

In the SI system, the unit of force is the newton, N, which is the force required to accelerate a mass of one kilogram at a rate of one meter per second squared. In the engineering system, the unit of force is the pound, lb, which is the force required to accelerate a mass of one slug at a rate of one foot per second squared. Frequently, mass is expressed in terms of the pound mass, lbm, which is the mass of a body that weighs one pound at sea level. One slug equals 32.174 lbm.

Units that are defined in terms of the basic units are called derived units. Table I.2 lists the derived units which are used in this book.

In the SI system, prefixes are used to form decimal multiples and submultiples of the SI units. The SI prefixes are listed in Table I.3. The conversion factors listed in Tables I.4 and I.5 have been rounded off to three or four significant figures, which is sufficient for most smoke control calculations.

Absolute temperature is measured in the Kelvin scale in the SI system and the Ramkine scale in the engineering system. In addition, temperature is frequently measured in the Celsius or the Fahrenheit scale. Because the Celsius and Fahrenheit scales are so commonly used by design engineers, these scales are used exclusively in the discussions in the text and in figures. However, caution should be exercised to assure that absolute temperatures are used in calculations where necessary. Table I.6 lists relations which can be used to convert from one temperature scale to another.

For further information concerning the SI system the reader is referred to the references below.

ASHRAE Metric Guide, 2nd ed., American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA, 1977.

American National Standard - Metric Practice, ANSI Z210.1-1976, Institute of Electrical and Electronics Engineers, Inc., New York, NY, 1976.

Table I.1. Base units

Quantity	SI System		Engineering System	
	Unit	Symbol	Unit	Symbol
length	meter	m	foot	ft
mass	kilogram	kg	slug	slug
time	second	s	second	sec
thermodynamic (absolute) temperature	kelvin	K	degree rankine	^{o}R

Table I.2. Derived units

Quantity	SI System			Engineering System		
	Unit	Symbol	Formula	Unit	Symbol	Formula
force	newton	N	$kg{\cdot}m/s^2$	pound	lb	slug ft/sec^2
pressure	pascal	Pa	N/m^2	--	--	lb/ft^2
energy, work or heat	joule	J	N•m	--	--	lb•ft
power, energy release rate	watt	W	J/s	--	--	lb•ft/sec

Table I.3. SI prefixes

Prefix	Symbol	Multiplication Factor
giga	G	10^9 = 1 000 000 000
mega	M	10^6 = 1 000 000
kilo	k	10^3 = 1000
centi*	c	10^{-2} = 0.01
milli	m	10^{-3} = 0.001
micro	μ	10^{-6} = 0.000 001
nano	n	10^{-9} = 0.000 000 001

*The prefix centi is to be avoided where possible.

Table I.4. Conversion factors from engineering units to SI units

Multiply	By	To Obtain
Btu	1055	J
Btu/hr	0.293	W
ft	0.3048	m
ft^2	0.0929	m^2
ft/min (fpm)	0.00508	m/s
ft^3/min (cfm)	4.72×10^{-4}	m^3/s
ft^3/min (cfm)	0.472	L*/s
inch of water (in H_2O)	248.8	Pa
mile per hour (mph)	0.447	m/s
pound mass (lbm)	0.454	kg
pound (lb)	4.448	N
pound per square inch (psi)	6895.	Pa
lbm/ft^3	16.0	kg/m^3

*L is the symbol for liter which is a cubic decimeter, i.e., 1000 L = 1 m^3.

Table I.5. Conversion factors within the engineering system

Multiply	By	To Obtain
Btu	1.285×10^{-3}	ft-lb
Btu/hr	0.2152	ft-lb/sec
Horsepower	550	ft-lb/sec
in	8.333×10^{-2}	ft
in^2	6.944×10^{-3}	ft^2
in^3	5.78×10^{-4}	ft^3
in H_2O	5.20	lb/ft^2
mile	1.89×10^{-4}	ft
mile per hour (mph)	1.467	ft/sec
pound mass (lbm)	3.108×10^{-2}	slug
lb/in^2 (psi)	144	lb/ft^2
lbm/ft^3	3.108×10^{-2}	$slug/ft^3$

Table I.6. Temperature conversion

$$K = {}^{o}C + 273$$
$${}^{o}R = {}^{o}F + 460$$
$${}^{o}C = ({}^{o}F - 32)/1.8$$
$${}^{o}F = 1.8\,{}^{o}C + 32$$

Table I.7 Some useful constants

g = gravitational constant at sealevel 32.174 ft/sec^2 (9.80665 m/s^2)

R = gas constant of air 53.3 ft-lb/lbm ^{o}R (287 J/kg K)

P_{atm} = standard atmospheric pressure 14.696 psi (101325 Pa)

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