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SI 1001 part 2.2 | **תקן ישראלי ת"י 1001 חלק 2.2**

June 2004 | תמוז התשס"ד - יוני 2004

ICS CODE: 13.220.20
91.140.30

בטיחות אש בבניינים: מערכות בקרת עשן - בניינים, למעט בנייני מגורים שגובהם עד 12 מטר

Fire safety in buildings: Smoke control systems - Buildings, except residential buildings up to 12 meter height

מכון התקנים הישראלי
The Standards Institution of Israel

רח' חיים לבנון 42, תל-אביב 69977, טל' 03-6465154, פקס' 03-6412762, www.sii.org.il

תקן זה הוכן על ידי ועדת מומחים בהרכב זה:

יורם אורדן, אנקה בלומר, ריקרדו גורה, ירמי לימור, שמואל נתנאל, צבי רונן (יו"ר)

תקן זה אושר על ידי הוועדה הטכנית 116 - בטיחות אש, בהרכב זה:

אגודת חוקרי דלקות בישראל	-	יצחק דגון
איגוד חברות הביטוח בישראל	-	אורי כהן
איגוד לשכות המסחר בישראל	-	יורם אורדן
הטכניון - הפקולטה להנדסה אזרחית	-	רחל בקר
התאחדות הקבלנים והבונים בישראל	-	איתמר הילדסהיימר
התאחדות התעשיינים בישראל	-	איל ארציאלי, לימור ירמיהו
לשכת המהנדסים והאדריכלים	-	לאה קפלן (יו"ר)
מכון התקנים הישראלי - אגף תעשייה	-	ריכרדו גורה
משרד הבינוי והשיכון	-	לזר פלדמן
משרד הפנים	-	דוד פילזר
נציבות כבאות והצלה	-	אנקה בלומר

ליאה פישר ריכזה את עבודת הכנת התקן.

הודעה על מידת התאמת התקן הישראלי לתקנים או למסמכים זרים

תקן זה, למעט השינויים והתוספות המצוינים בו,
זהה לתקן של האגודה הלאומית האמריקנית להגנה מפני אש
NFPA 92A - 2000

מילות מפתח:

בטיחות אש בבניינים, גלאי עשן, גלאי אש.

Descriptors:

fire safety in buildings, smoke detectors, fire detectors.

עדכניות התקן

התקנים הישראליים עומדים לבדיקה מזמן לזמן, ולפחות אחת לחמש שנים, כדי להתאימם להתפתחות המדע והטכנולוגיה.
המשתמשים בתקנים יוודאו שבידיהם המהדורה המעודכנת של התקן על גיליונות התיקון שלו.
מסמך המתפרסם ברשומות כגיליון תיקון, יכול להיות גיליון תיקון נפרד או תיקון המשולב בתקן.

רשמיות התקן

יש לבדוק אם המסמך רשמי, או אם חלקים ממנו רשמיים. תקן רשמי או גיליון תיקון רשמי (במלואם או בחלקם) נכנסים לתוקף 60 יום מפרסום ההודעה ברשומות, אלא אם בהודעה נקבע מועד מאוחר יותר לכניסה לתוקף.

סימון בתו תקן

כל המייצר מוצר, המתאים לדרישות התקנים הישראליים החלים עליו,
רשאי, לפי היתר ממכון התקנים הישראלי, לסמנו בתו תקן:

הקדמה לתקן הישראלי

תקן ישראלי זה הוא התקן של האגודה הלאומית האמריקנית להגנה מפני אש NFPA 92A משנת 2000, שאושר כתקן ישראלי בשינויים ובתוספות.

בשפה העברית מובאים:

- סעיף תחום התקן בשינויים ובתוספות
- פירוט השינויים והתוספות לסעיפי התקן האמריקני

לאחר החלק העברי מובא התקן האמריקני כלשונו.

תקן זה הוא חלק מסדרת תקנים ישראליים הדנים בבטיחות אש בבניינים.

חלקי הסדרה הם:

ת"י 1001 חלק 1	-	בטיחות אש בבניינים: מערכות מיזוג אוויר ואוורור
ת"י 1001 חלק 2.1	-	בטיחות אש בבניינים: מערכות בקרת עשן - בנייני מגורים שגובהם עד 12 מטר
ת"י 1001 חלק 2.2	-	בטיחות אש בבניינים: מערכות בקרת עשן - בניינים, למעט בנייני מגורים שגובהם עד 12 מטר
ת"י 1001 חלק 2.3[א]	-	בטיחות אש בבניינים: מערכות בקרת עשן - חללים גדולים ואטריום (atria)
ת"י 1001 חלק 3	-	בטיחות אש בבניינים: מדפי אש
ת"י 1001 חלק 4[ב]	-	בטיחות אש בבניינים: מדפי עשן
ת"י 1001 חלק 5[ב]	-	בטיחות אש בבניינים: סוגר אוטומטי לבקרת עשן
ת"י 1001 חלק 6	-	בטיחות אש בבניינים: אוורור והגנה מפני אש במערכות-בישול מסחריות

תחום התקן (סעיף 1.2 של התקן האמריקני בשינויים ובתוספות)

תקן זה דן בכללים לתכן, להתקנה, לבדיקה, להפעלה ולתחזוקה של מערכות בקרת עשן.

הכללים שבתקן זה חלים גם על מערכות מכניות לטיפול באוויר, המשמשות גם כמערכות בקרת עשן.

התקן דן הן במערכות חדשות והן במערכות מחודשות (retrofitted).

התקן אינו דן בבקרת עשן במקומות אלה:

- בנייני מגורים שגובהם עד 12 מטר, שהתקן הישראלי ת"י 1001 חלק 2.1 דן בהם;
- בחללים גדולים ובאטריום, שהתקן הישראלי ת"י 1001 חלק 2.3 דן בהם.

[א] יוכן בעתיד. עד לפרסומו ניתן למצוא כללים לתכנון מערכות אלה בתקן האמריקני NFPA 92B.

[ב] יוכן בעתיד.

פירוט השינויים והתוספות לסעיפי התקן האמריקני

Chapter 1 General Information

Definitions .1.4

Authority Having Jurisdiction .1.4.3

ההגדרה אינה חלה, ובמקומה יחול:

רשות מוסמכת .1.4.3

רשות הכבאות וההצלה כמוגדר בחוק שירותי הכבאות.

Design Parameters .1.6

הסעיף חל בתוספת זו:

לאחר סעיף 1.6.6 יוספו סעיפים 1.6.7 ו-1.6.8 כלהלן:

אמות מידה לתכנון .1.6.7

נוסף על הנדרש בסעיפים 1.6.1 עד 1.6.6 שלעיל, ישתמש המתכנן באמות מידה אלה לתכנון המערכת:

- הפרשי לחץ מינימלי ומקסימלי: כנקוב בסעיף 2.2 בתקן זה;
- מהירות מינימלית של זרימת אוויר דרך דלת פתוחה: 1 מטר לשנייה;
- מהירות מתוכננת של זרימת אוויר בפירים: (6-12) מטרים לשנייה;
- מיקום המפוחים והמרחק ביניהם: ייקבעו על ידי המתכנן, בהתחשב בגורמים כגון אלה:
  - כיווני רוח אופייניים באזור;
  - המבנה הגאומטרי של אזור הבניין שהמפוחים מותקנים בו;
  - כיוון הפתחים לשחרור עשן;
  - מיקום המפוחים יבטיח, שעשן היוצא דרך מפוחי שחרור העשן לא יחדור חזרה לבניין דרך מפוחי הדיחוס.
- מספר דלתות הפתוחות בו-זמנית: כנקוב בסעיף 2.3.7.

הספקת זרם חשמל בעת חירום .1.6.8

תתוכנן הספקת זרם חשמל בעת חירום באמצעות גנרטור חשמלי, כנדרש בחוק התכנון והבנייה.

Chapter 2 Smoke-Control Systems and Applicability

Introduction .2.1

Basic System Types .2.1.3

הסעיף חל בשינוי זה:

הכתוב במשפט האחרון אינו חל, ובמקומו יחול:

ניהול עשן קומתי או/וגם דיחוס חדר המדרגות ייעשו בהתאם לנדרש בחוק התכנון והבנייה.

הערה:

סעיף זה ייכנס לתוקף לאחר פרסום המהדורה החדשה של תקנות התכנון והבנייה, במסגרת הרוויזיה המתוכננת.

Stairwell Pressurization Systems .2.3

Number of Doors Open .2.3.7

בסוף הסעיף יוסף:

אם לא נדרש אחרת על ידי הרשות המוסמכת (ראו הגדרה 1.4.3), מומלץ שהמספר המינימלי של דלתות הפתוחות בו-זמנית יהיה כלהלן:

- עבור 10 הקומות ה"ראשונות": המספר המקסימלי של דלתות חדר המדרגות בשלוש קומות סמוכות + דלת הכניסה לחדר המדרגות;
- עבור כל 10 קומות נוספות או חלק מהן, יוסף המספר המקסימלי של דלתות חדר המדרגות בקומה אחת.

הערות:

1. דלת דו-אגפית נחשבת לשתי דלתות לצורך החישוב שלעיל.
2. מומלץ שלא להתקין בחדר המדרגות שום רכיב, כגון דלת אטומה, שימנע זרימה חופשית של אוויר בכל גובה חדר המדרגות.

Chapter 3 Building Equipment and Controls

Smoke Dampers .3.3

לאחר הפסקה הראשונה יוסף:

למרות האמור לעיל, מותר להתקין מדפי עשן המאושרים במעבדות מוכרות של מדינות אלה: אנגליה, גרמניה, ארה"ב.

Materials .3.6

.3.6.1 ההפניה לתקן האמריקני NFPA 90A אינה חלה, ובמקומה יחול:
התקן הישראלי 1001 חלק 1.

.3.6.2 הסעיף חל בתוספת זו:
פח פלדה בעובי מינימלי 1.25 מ"מ יתאים לדרישות סעיף זה.

Electric Services Installation .3.7

.3.7.1 ההפניה לתקן האמריקני NFPA 70 אינה חלה, ובמקומה יחול:
חוק החשמל הישראלי התשי"ד-1954 על תקנותיו ועדכוניו.

Chapter 5 Testing

Operational Testing .5.2

.5.2.4 ההפניה לתקן האמריקני NFPA 72 אינה חלה, ובמקומה יחול:
התקן הישראלי ת"י 1220 על חלקיו.

5.4. Periodic Testing

5.4.1. ההפניה לתקן האמריקני NFPA 90A אינה חלה, ובמקומה יחול:
התקן הישראלי ת"י 1001 חלק 1.

Chapter 6 Referenced Publications

הפרק חל בשינויים ובתוספות אלה:

- במקום חלק מן התקנים האמריקניים המאוזכרים בתקן והמפורטים בסעיפי פרק זה חלים תקנים ישראליים, כלהלן:

התקן האמריקני המוזכר	התקן או המסמך הישראלי שחל במקומו
NFPA 70	חוק החשמל הישראלי התשי"ד-1954 על תקנותיו ועדכוניו
NFPA 72	ת"י 1220 על חלקיו - מערכות גילוי אש
NFPA 90A	ת"י 1001 חלק 1 - בטיחות אש בבניינים: מערכות מיזוג אוויר ואוורור
UL 555	ת"י 1001 חלק 3 - בטיחות אש בבניינים: מדפי אש

- לפרק יוסף:

תקנים ישראליים

ת"י 1001 חלק 2.1 - בטיחות אש בבניינים: מערכות בקרת עשן - בנייני מגורים שגובהם עד 12 מטר

ת"י 1001 חלק 2.3[א] - בטיחות אש בבניינים: מערכות בקרת עשן - חללים גדולים ואטריום (atria)

מסמכים ישראליים

חוק שירותי הכבאות התשי"ט-1959 על תקנותיו ועדכוניו

חוק התכנון והבנייה התשכ"ה-1965 על תקנותיו ועדכוניו

Appendix A Explanatory Material

A.1.4.1 Approved

הסעיף אינו חל.

A.1.4.3 Authority Having Jurisdiction

הסעיף אינו חל.

A.1.7 ההפניה לתקן האמריקני NFPA 13 אינה חלה, ובמקומה יחול:
התקן הישראלי ת"י 1596 חלק 1.

A.2.4.1(5) ההפניה לתקן האמריקני ASME/ANSI A 17.1 אינה חלה, ובמקומה יחול:
התקן הישראלי ת"י 24 על חלקיו.

Example of a Fire Fighters' Smoke-Control Station A.3.4.3.4

Control Action and Priorities (d)

ON-OFF; OPEN-CLOSE (1)

ההפניה לתקן האמריקני UL 555 אינה חלה, ובמקומה יחול:
התקן הישראלי ת״י 1001 חלק 3.

Appendix B Referenced Publications

הנספח חל בשינוי זה:

במקום חלק מן התקנים האמריקניים המאוזכרים בתקן לצורך מידע בלבד והמפורטים בסעיפי נספח זה חלים תקנים ישראליים, כלהלן:

התקן האמריקני המוזכר	התקן הישראלי שחל במקומו
NFPA 13	ת״י 1596 - מערכות מתזים: התקנה
NFPA 72	ת״י 1220 על חלקיו - מערכות גילוי אש
ASME/ANSI A17.1	ת״י 24 על חלקיו - מעליות נוסעים ומעליות משא
UL 555	ת״י 1001 חלק 3 - בטיחות אש בבניינים: מדפי אש

NFPA 92A

Recommended Practice for Smoke-Control Systems

2000 Edition

NFPA, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101
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NFPA 92A

Recommended Practice for

Smoke-Control Systems

2000 Edition

This edition of NFPA 92A, *Recommended Practice for Smoke-Control Systems*, was prepared by the Technical Committee on Smoke Management Systems and acted on by the National Fire Protection Association, Inc., at its World Fire Safety Congress and Exposition™ held May 14–17, 2000, in Denver, CO. It was issued by the Standards Council on July 20, 2000, with an effective date of August 18, 2000, and supersedes all previous editions.

This edition of NFPA 92A was approved as an American National Standard on August 18, 2000.

Origin and Development of NFPA 92A

The NFPA Standards Council established the Technical Committee on Smoke Management Systems in October of 1985 and charged it with addressing the need for guidelines and materials on building fire smoke management. With help from a former subcommittee on smoke control of the Technical Committee on Air Conditioning, members were appointed to the Smoke Management Systems Committee in 1986. As a first attempt at addressing smoke management, a draft was prepared of a new document, NFPA 92A, that addressed smoke-control utilizing barriers, airflows, and pressure differences so as to confine the smoke of a fire to the zone of fire origin and thus maintain a tenable environment in other zones.

The 1993 edition helped to refine the science and art of smoke control by incorporating the latest in technology. The 1996 edition added guidelines on control system supervision and instrumentation; it also provided substantial appendix material on testing for leakage of smoke-control enclosures.

The 2000 edition is a complete revision and adds information based on recent research on the design and testing of smoke-control systems for areas of refuge, elevator lobbies and hoistways, and vestibules. A chapter addressing computer models has been added, and the criteria for control systems and fire fighters' control stations have been refined and clarified.

Technical Committee on Smoke Management Systems

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University of Maryland, MD [SE]

Daniel L. Arnold, The RJA Group, Inc., GA [SE]
Donald W. Belles, Koffel Assoc., Inc., TN [M]
Rep. American Architectural Mfrs. Assn.
Jack B. Buckley, Houston, TX [SE]
Paul J. Carrafa, Building Inspection Underwriters, Inc., PA [E]
Elmer F. Chapman, Fire Dept. New York, NY [E]
Paul David Compton, Colt International, Ltd., England [M]
Michael Earl Dillon, Dillon Consulting Engr, Inc., CA [SE]
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Douglas H. Evans, Clark County Building Dept., NV [E]
Gunnar Heskestad, FM Global, MA [I]
Winfield T. Irwin, Irwin Services, PA [M]
Rep. North American Insulation Mfrs. Assn.
Daniel J. Kaiser, Underwriters Laboratories Inc., IL [RT]
John E. Kampmeyer, Triad Fire Protection Engr Corp., PA [SE]
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Gary D. Lougheed, Nat'l Research Council of Canada, ON, Canada [RT]
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This list represents the membership at the time the Committee was balloted on the final text of this edition. Since that time, changes in the membership may have occurred. A key to classifications is found at the back of this document.

NOTE: Membership on a committee shall not in and of itself constitute an endorsement of the Association or any document developed by the committee on which the member serves.

Committee Scope: This Committee shall have primary responsibility for documents on the design, installation, testing, operation, and maintenance of systems for the control, removal, or venting of heat or smoke from fires in buildings.

Contents

NFPA 92A

Recommended Practice for

Smoke-Control Systems

2000 Edition

NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates that explanatory material on the paragraph can be found in Appendix A.

Information on referenced publications can be found in Chapter 6 and Appendix B.

Chapter 1 General Information

1.1 Introduction. All fires produce smoke that, if not controlled, will spread throughout the building or portions of the building, thereby damaging property and potentially endangering life.

A smoke-control system should be designed to inhibit the flow of smoke into means of egress, exit passageways, areas of refuge, or other similar areas of a building. Limiting fire size by providing automatic sprinklers or other means of automatic suppression is generally necessary for effective and economical control of smoke in most occupancies. Other systems can be appropriate for specialized occupancies or existing facilities. Where smoke-control systems are provided, they should be activated during the early stages of a fire emergency in order to limit migration of fire gases and to maintain a tenable environment in the areas to be protected. The smoke-control system should be functional during the period of evacuation of the areas protected by the system. Such systems are intended to control the migration of smoke into protected areas so as to provide areas of refuge or additional time for egress, but it should not be expected that such areas would be completely free of smoke. Smoke-control systems should be engineered for the specific occupancy and building design. Additionally, smoke-control systems design should be coordinated with other life safety systems so that they complement, rather than counteract, one another.

1.2 Scope. This recommended practice applies to the design, installation, testing, operation, and maintenance of new and retrofitted mechanical air-handling systems also used as smoke-control systems. This recommended practice also applies to smoke-control systems. *(See NFPA 90A, Standard for the Installation of Air-Conditioning and Ventilating Systems, for requirements for the shutdown of smoke-control systems and the use of smoke compartmentation.)* The problem of maintaining tenable conditions within large zones of fire origin, such as atria and shopping malls, is not addressed by this document. *(See NFPA 92B, Guide for Smoke Management Systems in Malls, Atria, and Large Areas, for maintaining tenable conditions within large zones of fire origin, and NFPA 204, Guide for Smoke and Heat Venting.)*

1.3 Purpose. The purpose of this recommended practice is to provide guidance in implementing systems using pressure differences to accomplish one or more of the following:

(1) Inhibit smoke from entering stairwells, means of egress, areas of refuge, elevator shafts, or similar areas
(2) Maintain a tenable environment in areas of refuge and means of egress during the time required for evacuation
(3) Inhibit the migration of smoke from the smoke zone
(4) Provide conditions outside the fire zone that enable emergency response personnel to conduct search and rescue operations and to locate and control the fire
(5) Contribute to the protection of life and to the reduction of property loss

1.4 Definitions. For the purposes of this recommended practice, the following terms will have the meanings given in this chapter.

1.4.1* Approved. Acceptable to the authority having jurisdiction.

1.4.2 Area of Refuge. An area of the building separated from other spaces by fire-rated smoke barriers in which a tenable environment is maintained for the period of time that such areas may need to be occupied at time of fire.

1.4.3* Authority Having Jurisdiction. The organization, office, or individual responsible for approving equipment, materials, an installation, or a procedure.

1.4.4* Design Pressure Difference. The desired pressure difference between the protected space and an adjacent space measured at the boundary of the protected space under a specified set of conditions with the smoke-control system operating.

1.4.5 End-to-End Verification. A self-testing method that provides positive confirmation that the desired result (e.g., airflow or damper position) has been achieved when a controlled device has been activated, such as during smoke control, testing, or manual override operations, where failure or cessation of such positive confirmation results in an off-normal indication.

1.4.6* Fire Fighters' Smoke-Control Station (FSCS). A system that provides graphical monitoring and manual overriding capability over smoke-control systems and equipment at designated location(s) within the building for the use of the fire department.

1.4.7 Pressurized Stairwells. A type of smoke-control system in which stair shafts are mechanically pressurized, with respect to the fire area, with outdoor air to keep smoke from contaminating them during a fire incident.

1.4.8 Recommended Practice. A document that is similar in content and structure to a code or standard but that contains only nonmandatory provisions using the word "should" to indicate recommendations in the body of the text.

1.4.9 Should. Indicates a recommendation or that which is advised but not required.

1.4.10 Smoke. The airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion, together with the quantity of air that is entrained or otherwise mixed into the mass.

1.4.11* Smoke Barrier. A continuous membrane, either vertical or horizontal, such as a wall, floor, or ceiling assembly, that is designed and constructed to restrict the movement of smoke.

1.4.12 Smoke-Control Mode. A predefined operational configuration of a system or device for the purpose of smoke control.

1.4.13 Smoke-Control System. An engineered system that uses mechanical fans to produce pressure differences across smoke barriers to inhibit smoke movement.

1.4.14 Smoke-Control Zone. A space within a building enclosed by smoke barriers, including the top and bottom, that is part of a zoned smoke-control system.

1.4.15* Smoke Exhaust System. A mechanical or gravity system intended to move smoke from the smoke zone to the exterior of the building, including smoke removal, purging, and venting systems, as well as the function of exhaust fans utilized to reduce the pressure in a smoke zone.

1.4.16 Smoke Zone. The smoke-control zone in which the fire is located.

1.4.17 Stack Effect. The vertical airflow within buildings caused by the temperature-created density differences between the building interior and exterior or between two interior spaces.

1.4.18 Tenable Environment. An environment in which smoke and heat is limited or otherwise restricted to maintain the impact on occupants to a level that is not life threatening.

1.4.19 Zoned Smoke Control System. A smoke-control system that includes smoke exhaust for the smoke zone and pressurization for all contiguous smoke-control zones.

1.5 Principles of Smoke Control.

1.5.1 Basic Principles. Frequently, smoke flow follows the overall air movement within a building. Although a fire might be confined within a fire-resistive compartment, smoke can readily spread to adjacent areas through openings such as construction cracks, pipe penetrations, ducts, and open doors. The principal factors that cause smoke to spread to areas outside a compartment are as follows:

(1) Stack effect
(2) Temperature effect of fire
(3) Weather conditions, particularly wind and temperature
(4) Mechanical air-handling systems

The factors listed in 1.5.1(1) through (4) cause pressure differences across partitions, walls, and floors that can result in the spread of smoke. The movement of smoke can be controlled by altering these pressure differences. Building components and equipment such as walls, floors, doors, dampers, and smokeproof stairwells can be utilized along with the heating, ventilating, and air-conditioning (HVAC) systems to aid in the control of the movement of smoke. Proper overall building design and tight construction are essential to smoke control.

The dilution of smoke in the fire area of a compartmented building is not a means of achieving smoke control. Smoke control cannot be achieved simply by supplying air to and exhausting air from the compartment.

Smoke control can be stated in two basic principles as follows:

(1) Air pressure differences of sufficient magnitude acting across barriers will control smoke movement.
(2) Airflow by itself will control smoke movement if the average air velocity is of sufficient magnitude.

1.5.2 Pressurization. The primary means of controlling smoke movement is by creating air pressure differences across partitions, floors, and other building components. The basic concept of building pressurization is to establish a higher pressure in adjacent spaces than in the smoke zone. In this way, air moves into the smoke zone from adjacent areas and smoke is inhibited from dispersing throughout the building.

1.5.3* Airflow. Airflow at sufficient velocity can restrict smoke movement. This principle is most commonly used to control smoke movement through openings. The flow of air through the opening into the smoke zone must be of sufficient velocity to limit migration of smoke from that zone through such openings. The doors in these openings are not open for long periods of time, so this represents a transient condition that is necessary in order to provide egress from, or access to, the smoke zone. *(See NFPA 92B, Guide for Smoke Management Systems in Malls, Atria, and Large Areas, for further discussion on the use of airflow for smoke control.)*

1.6 Design Parameters.

1.6.1 General. An understanding with the authority having jurisdiction of the expected performance of the system and the acceptance test procedures should be established early in the design. *(Detailed engineering design information is contained in ASHRAE/SFPE, Design of Smoke Management Systems, and the NFPA publication, Smoke Movement and Control in High-Rise Buildings.)*

1.6.2 Leakage Areas. Small openings in smoke barriers, such as construction joints, cracks, closed-door gaps, and similar clearances, should be addressed in terms of maintaining an adequate pressure difference across the smoke barrier, with the positive pressure outside of the smoke zone. Typical leakage areas are listed in Table 4.5.

Large openings in smoke barriers, such as doors intended to be open and other sizable openings, should be addressed. These openings should be evaluated based on geometric area.

1.6.3* Weather Data. The temperature differences between the exterior and interior of the building cause stack effect and determine its direction and magnitude. The effects of temperature and wind velocity vary with building height, configuration, leakage, and openings in wall and floor construction. The system designer requires summer and winter design temperatures. For full analysis, wind data also should be considered.

1.6.4 Pressure Differences. The maximum and minimum allowable pressure differences across the boundaries of smoke-control zones should be considered. The maximum allowable pressure difference should not result in door-opening forces that exceed the requirements of NFPA *101*®, *Life Safety Code*®, or local codes and regulations. The minimum allowable pressure difference should be such that there will be no significant smoke leakage during building evacuation. For the system to be effective, the pressure should be enough that it is not overcome by the forces of wind, stack effect, or buoyancy of hot smoke.

1.6.5 Airflow. Airflow can be used to limit smoke migration when doors in smoke-control barriers are open. The design velocity through an open door should be sufficient to inhibit smoke backflow during building evacuation. The design velocity should take into consideration the same variables as used in the selection of design pressure differences. *(Design information is provided in ASHRAE/SFPE, Design of Smoke Management Systems.)*

1.6.6 Number of Doors Open. The number of doors that could be open simultaneously should be considered. This number depends largely on the building occupancy and the type of smoke-control system. In some systems, doors most likely are open for only short periods of time and smoke leakage is negligible. *(For the number of doors open in a stairwell pressurization system, see 2.3.7.)*

1.7* Fire Suppression Systems. Automatic sprinkler and other fire suppression systems are an integral part of many fire protection designs, and the reliability and efficiency of such systems in controlling building fires is well documented. It is important to recognize that the functions of both suppression and smoke-control systems are important. Automatic suppression systems can extinguish a fire early in its growth, thereby eliminating additional smoke generation. On the other hand, well-designed smoke-control systems can maintain a tenable environment along critical egress routes during the time it takes the fire suppression system or fire service personnel to achieve final extinguishment.

In addition to the fact that the fire suppression and smoke-control systems perform different functions, it is important to consider the interaction between the smoke-control and fire suppression systems. For example, in a fully sprinklered building, pressure differences and airflows needed to control smoke movement might 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.

A smoke-control system can adversely affect the performance of gaseous suppression agents, such as the clean agents as defined in NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*, where the smoke-control and suppression systems are located in a common space. In the event that both systems are activated concurrently, the smoke-control system might dilute the gaseous agent in the space. Because gaseous suppression systems commonly provide only one application of the agent, the potential arises for renewed growth of the fire. Gaseous suppression systems and smoke-control systems cannot perform their intended functions simultaneously when they are located within the same space.

Chapter 2 Smoke-Control Systems and Applicability

2.1 Introduction.

2.1.1 Purpose. This chapter discusses various types of smoke-control systems and reviews the advantages and disadvantages of each type.

Determination of system objectives and performance criteria should be made prior to design or construction.

2.1.2 Dedicated and Nondedicated Systems.

2.1.2.1 Dedicated Systems. Dedicated smoke-control systems are installed for the sole purpose of providing smoke control. They are separate systems of air-moving and distribution equipment that do not function under normal building operating conditions. Upon activation, these systems operate specifically to perform the smoke-control function.

Advantages of dedicated systems include the following:

(1) Modification of system controls after installation is less likely.
(2) Operation and control of the system is generally simpler.
(3) Reliance on or impact by other building systems is limited.

Disadvantages of dedicated systems include the following:

(1) System impairments might go undiscovered between periodic tests or maintenance activities.
(2) Systems can require more physical space.

2.1.2.2 Nondedicated Systems. Nondedicated systems are those that share components with some other system(s) such as the building HVAC system. Activation causes the system to change its mode of operation in order to achieve the smoke-control objectives.

Advantages of nondedicated systems include the following:

(1) Impairments to shared equipment required for normal building operation are likely to be corrected promptly.
(2) Limited additional space for smoke-control equipment is necessary.

Disadvantages of nondedicated systems include the following:

(1) System control might become elaborate.
(2) Modification of shared equipment or controls can impair smoke-control functionality.

2.1.3 Basic System Types. Systems for controlling smoke movement in a building can generally be divided into two separate types: shaft protection and floor protection. Shaft protection can be further divided into stairwell pressurization systems and elevator hoistway systems. Floor protection encompasses several variations of zoned smoke control. Use of a particular system or combination of systems is dependent on building and fire code requirements, as well as the specific occupancy and life safety requirements of the situation being considered.

2.1.4 Tenable Environment. A nonsmoke zone of a zoned smoke-control system can be used as an area intended to protect occupants for the period of time needed for evacuation or can be used to provide an area of refuge.

2.1.5 System Integrity. Smoke-control systems should be designed, installed, and maintained such that the system will remain effective during evacuation of the protected areas. Other considerations could dictate that a system should remain effective for longer periods of time. Items that should be considered are as follows:

(1) Reliability of power source(s)
(2) Arrangement of power distribution
(3) Method and protection of controls and system monitoring
(4) Equipment materials and construction
(5) Building occupancy

2.2 Pressure Differences.

2.2.1* Table 2.2.1 presents suggested minimum design pressure differences developed for a gas temperature of 1700°F (925°C) next to the smoke barrier. These pressure differences are recommended for designs that are based on maintaining minimum pressure differences between specified spaces.

Table 2.2.1 Suggested Minimum Design Pressure Differences Across Smoke Barriers[1]

Building Type[2]	Ceiling Height	Design Pressure Difference[3] (in. w.g.)
AS	Any	0.05
NS	9 ft	0.10
NS	15 ft	0.14
NS	21 ft	0.18

For SI units, 1 ft = 0.305 m; 0.1 in. w.g. = 25 Pa.
[1]For design purposes, a smoke-control system should maintain these minimum pressure differences under likely conditions of stack effect or wind.
[2]AS — sprinklered, NS — nonsprinklered.
[3]For zoned smoke-control systems, the pressure difference is measured between the smoke zone and adjacent spaces while the affected areas are in the smoke-control mode.

If it is desired to calculate pressure differences for gas temperatures other than 1700°F (925°C), the method described in A.2.2.1 can be used. Pressure differences produced by smoke-control systems tend to fluctuate due to the wind, fan pulsations, doors opening, doors closing, and other factors. Short-term deviations from the suggested minimum design pressure difference might not have a serious effect on the protection provided by a smoke-control system. There is no clear-cut allowable value of this deviation. It depends on tightness of doors, tightness of construction, toxicity of smoke, airflow rates, and on the volumes of spaces. Intermittent deviations up to 50 percent of the suggested minimum design pressure difference are considered tolerable in most cases.

2.2.2* Similar to the pressure differences across smoke barriers, the pressure differences across doors should not exceed the values given in Table 2.2.2, so that the doors can be operated while the pressurization system is operating. These pressure difference values are based on the 30-lbf (133-N) maximum force permitted to begin opening the door stipulated in NFPA *101, Life Safety Code.*

Table 2.2.2 Maximum Pressure Differences Across Doors[1,2,3,4]

Door Closer Force[5] (lbf)	Door Width (in. w.g.)[6]				
	32	36	40	44	48
6	0.45	0.40	0.37	0.34	0.31
8	0.41	0.37	0.34	0.31	0.28
10	0.37	0.34	0.30	0.28	0.26
12	0.34	0.30	0.27	0.25	0.23
14	0.30	0.27	0.24	0.22	0.21

For SI units, 1 lbf = 4.4 N; 1 in. = 25.4 mm; 0.1 in. w.g. = 25 Pa.
Notes:
1. Total door opening force is 30 lbf.
2. Door height is 7 ft.
3. The distance from the doorknob to the knob side of the door is 3 in.
4. For other door-opening forces, other door sizes, or hardware other than a knob — for example, panic hardware — use the calculation procedure provided in the ASHRAE/SFPE publication, *Design of Smoke Management Systems.*
5. Many door closers require less force in the initial portion of the opening cycle than that required to bring the door to the fully open position. The combined impact of the door closer and the imposed pressure combine only until the door is opened enough to allow air to pass freely through the opening. The force imposed by a closing device to close the door is often different from that imposed on opening.
6. Door widths apply only if the door is hinged at one end; otherwise, use the calculation procedure provided in ASHRAE/SFPE, *Design of Smoke Management Systems.*

2.3 Stairwell Pressurization Systems.

2.3.1 General. The performance goal of pressurized stairwells is to provide a tenable environment within the stairwell in the event of a building fire. A secondary objective is to provide a staging area for fire fighters. On the fire floor, a pressurized stairwell needs to maintain a pressure difference across a closed stairwell door so that smoke infiltration is limited. The stairwell pressurization system should be designed to meet or exceed the minimum design pressure differences given in Table 2.2.1 but should not exceed the maximum pressure differences given in Table 2.2.2. *(Refer to Section 2.7.1 where stairwell pressurization systems are used in combination with other smoke-control systems.)*

2.3.2 Noncompensated and Compensated Systems.

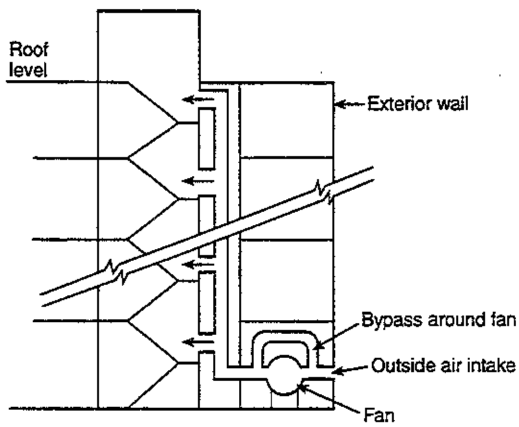
2.3.2.1 In a noncompensated system, supply air is injected into the stairwell by actuating a single-speed fan, thus providing one pressure difference with all doors closed, another difference with one door open, and so on.

2.3.2.2 Compensated systems adjust to various combinations of doors that are open and closed, while maintaining positive pressure differences across such openings. Systems compensate for changing conditions either by modulating supply airflows or by relieving excess pressure from the stairwell.

The response time of the control system should be closely evaluated to ensure that pressures do not fall below the short-term values given in Table 2.2.1. The location of the exhaust inlet(s) from the stairwell relative to the supply outlet(s) into the stairwell should be such that short-circuiting will not occur.

2.3.2.2.1 Modulating Supply Airflow. In a modulating supply airflow 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 2.3.2.2.1 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 pressure differences between the stairwell and the building are prevented. The same effect can be achieved by the use of relief dampers on the supply duct when the fan is located outside the building. Supply airflow modulation can also be accomplished by varying fan speed, inlet vanes, variable pitch fan blades, or the number of fans operating. Response times of the controls with any system should be considered.

FIGURE 2.3.2.2.1 Stairwell pressurization with bypass around supply fan.



Notes:
1. Fan bypass controlled by one or more static pressure sensors located between the stairwell and the building interior.
2. A ground-level supply fan is shown; however, fan(s) could be located at any level.

2.3.2.2.2 Overpressure Relief. Compensated system operation can also be accomplished by overpressure relief. In this instance, pressure buildup in the stairwell as doors close is relieved directly from the stairwell to the outside. The amount of air relieved varies with the number of doors open, thus attempting to achieve an essentially constant pressure in the stairwell. Exterior relief openings can be subject to adverse effects from the wind; thus windbreaks or windshields are recommended.

If overpressure relief is to be discharged into the building, the effects on the integrity of the stairwells and the interaction with other building HVAC systems should be closely studied. Systems using this principle should have combination fire/smoke dampers in the stairwell wall penetrations.

Overpressure relief can be accomplished by one of the following four methods.

(a) Barometric dampers with adjustable counterweights can be used to allow the damper to open when the maximum interior pressure is reached. This represents the simplest, least expensive method of overpressure relief because there is no physical interconnection between the dampers and the fan. The location of the dampers should be chosen carefully because dampers located too close to the supply openings can operate too quickly and not allow the system to meet the pressure requirements throughout the stairwell. The dampers can be subject to chattering during operation. Figure 2.3.2.2.2 illustrates overpressure relief using barometric dampers.

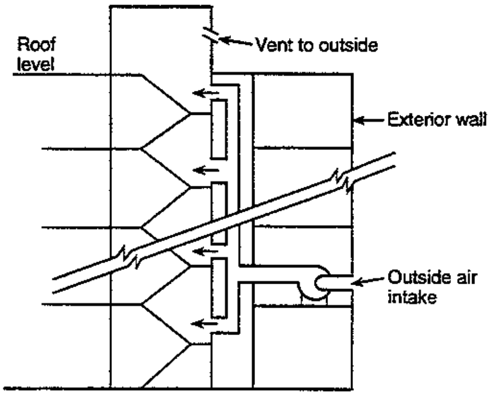
(b) Motor-operated dampers with pneumatic or electric motor operators are another option for overpressure relief. These dampers are to be controlled by differential pressure controls located in the stairwell. This method provides more positive control over the stairwell pressures than barometric dampers. It requires more control than the barometric dampers and therefore is more complicated and costly.

(c) An alternative method of venting a stairwell is through an automatic-opening stairwell door or vent to the outside at ground level. Under normal conditions this door would be closed and, in most cases, locked for security reasons. Provisions should be made to ensure 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 opening to the exterior at ground level as a vent. Occasionally, high local wind velocities develop near the exterior stairwell door. Such local winds are difficult to estimate in the vicinity of new buildings without expensive modeling. Adjacent objects can act as windbreaks or windshields. Systems utilizing vents to the outside at ground level are more effective under cold conditions, with the stack effect assisting the stair pressurization system for stairwells primarily above grade.

(d) An exhaust fan can be used to prevent excessive pressure 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 specified 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. To achieve the desired performance, it is believed that the exhaust fan control should be of a modulating type as opposed to an on–off type. Because an exhaust fan will be adversely affected by the wind, a windshield is recommended.

FIGURE 2.3.2.2.2 Stairwell pressurization with vent to the outside.



Note: Supply fan could be located at any level.

2.3.3 Location of Supply Air Source.

2.3.3.1 The supply air intake should be separated from all building exhausts, outlets from smoke shafts and roof smoke and heat vents, open vents from elevator shafts, and other building openings that might expel smoke from the building in a fire. This separation should be as great as is practicable. 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 the location of the fire, the location of points of smoke leakage from the building, the wind speed and direction, and the temperature difference between the smoke and the outside air. At present, sufficient information is not available about such outdoor smoke movement to warrant general recommendations favoring ground-level intakes rather than roof-level intakes.

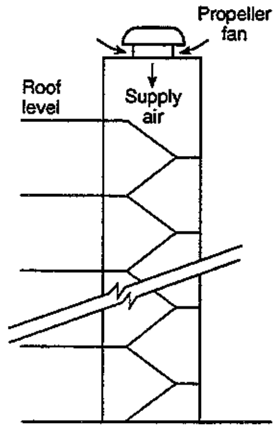
2.3.3.2 With any stairwell pressurization system, there is a potential for smoke feedback into the pressurized stairwell from smoke entering the stairwell through the pressurization fan intake. Therefore, the capability of automatic shutdown in the event of smoke feedback should be considered.

2.3.4 Supply Air Fans.

2.3.4.1 Propeller Fans. Advantages and limitations on the use of propeller fans are described in 2.3.4.1.1 through 2.3.4.1.3.

2.3.4.1.1 Simple single-point injection systems such as that illustrated in Figure 2.3.4.1.1 can use a roof or exterior wall-mounted propeller fan to supply air to stairwells. The use of propeller fans without windshields is not recommended because of the extreme effect wind can have on the performance of such fans.

FIGURE 2.3.4.1.1 Stairwell pressurization by roof-mounted propeller fan.



2.3.4.1.2 One major advantage of using propeller fans for stairwell pressurization is that they have a relatively flat pressure response curve with respect to varying flow. Therefore, as doors are opened and closed, propeller fans quickly respond to airflow changes in the stairwell without major pressure fluctuations. A second advantage of using propeller fans is that they are less costly than other types of fans and can provide adequate smoke control with lower installed costs.

2.3.4.1.3 A disadvantage of using propeller fans is that they often require windshields at the intake because they operate at low pressures and are readily affected by wind pressure on the building. This is less critical on roofs where the fans are often protected by parapets and where the direction of the wind is at right angles to the axis of the fan.

Propeller fans mounted on walls pose the greatest susceptibility to the adverse effects of wind pressures. The adverse effect is at a maximum when wind direction is in direct opposition to the fan airflow, resulting in a lower intake pressure and thus significantly reducing fan effectiveness. Winds that are variable in intensity and direction also pose a threat to the ability of the system to maintain control over the stairwell static pressure.

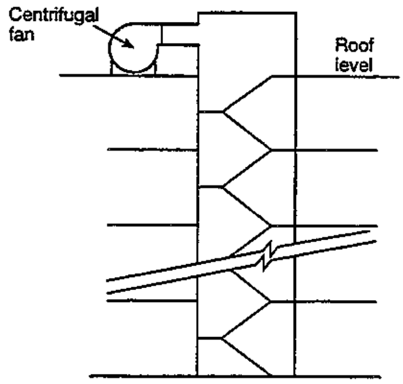
2.3.4.2 Other Types of Fans. Other single-injection systems and multiple-injection systems might require the use of a centrifugal or an in-line axial fan to overcome the increased resistance to flow in the supply ductwork to the stairwell.

2.3.5 Single- and Multiple-Injection Systems.

2.3.5.1 Single-Injection Systems.

2.3.5.1.1 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 of the stairwell, as illustrated in Figure 2.3.5.1.1.

FIGURE 2.3.5.1.1 Stairwell pressurization by top injection.



2.3.5.1.2 Single-injection systems can fail when a few doors are open near the air supply injection point. All the pressurization air can be lost through these open doors, at which time the system fails to maintain positive pressures across doors farther from the injection point.

2.3.5.1.3 Because a ground-level stairwell door is likely to be in the open position much of the time, a single-bottom-injection system is especially prone to failure. Consideration of this specific situation as well as overall careful design analysis is required for all single-bottom-injection systems and for all other single-injection systems for stairwells in excess of 100 ft (30.5 m) in height.

2.3.5.2 Multiple-Injection Systems.

2.3.5.2.1 A multiple-injection system is one in which air is supplied to the stairwell at multiple points. Figures 2.3.5.2.1(a) and 2.3.5.2.1(b) are two examples of the 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.

FIGURE 2.3.5.2.1(a) Stairwell pressurization by multiple injection with the fan located at ground level.

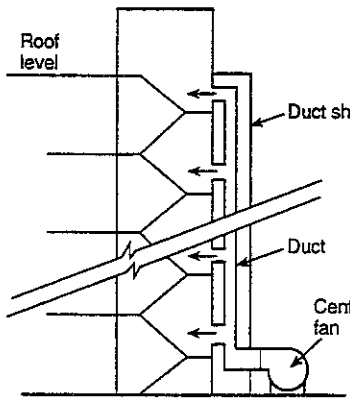
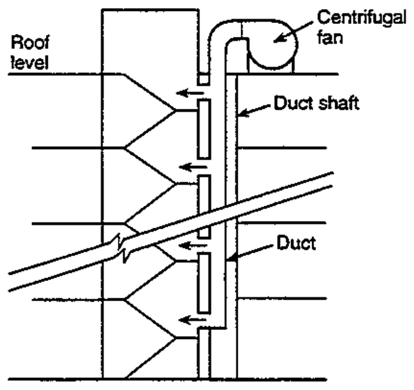


FIGURE 2.3.5.2.1(b) Stairwell pressurization by multiple injection with roof-mounted fan.



2.3.5.2.2 In Figures 2.3.5.2.1(a) and 2.3.5.2.1(b), 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 stair enclosure itself. Care should be taken so that the duct does not reduce the required exit width or become an obstruction to orderly building evacuation.

2.3.5.2.3 Many multiple-injection systems have been built with supply air injection points on each floor. These systems represent the ultimate in preventing loss of pressurization air through a few open doors; however, that many injection points might not be necessary. For system designs with injection points more than three stories apart, the designer should use a computer analysis such as the one in ASHRAE/SFPE, *Design of Smoke Management Systems*. The purpose of this analysis is to ensure that loss of pressurization air through a few open doors does not lead to substantial loss of stairwell pressurization.

2.3.6 Vestibules. Stairwells that do not have vestibules can be pressurized adequately using systems currently available. Some buildings are constructed with vestibules because of building code requirements. These vestibules can be either nonpressurized or pressurized.

2.3.6.1 Nonpressurized Vestibules. Stairwells that have nonpressurized vestibules can have applications in existing buildings. With both vestibule doors open, the two doors in series provide an increased resistance to airflow compared to a single door. This increased resistance will reduce the required airflow so as to produce a given pressure in the stairwell. This subject is discussed in detail in ASHRAE/SFPE, *Design of Smoke Management Systems*.

In buildings with low occupant loads, it is possible that one of the two vestibule doors might be closed, or at least partially closed, during the evacuation period. This will further reduce the required airflow to produce a given pressure.

2.3.6.2 Pressurized Vestibules. Closing both doors to a vestibule can limit the smoke entering a vestibule and provide a tenable environment as an area of refuge. The adjacent stairwell is indirectly pressurized by airflow from the pressurized vestibule. However, this pressurization can be lost if the exterior door is open. Also, smoke can flow into the stairwell through any leakage openings in the stairwell walls adjacent to the floor space. Such walls should be constructed to minimize leakages for a stairwell protected by a pressurized vestibule system.

2.3.6.3 Pressurized Vestibules and Stairwells. To minimize the amount of smoke entering a vestibule and stairwell, both the vestibule and stairwell can be pressurized. The combined system will enhance the effectiveness of the stairwell pressurization system. Also, the pressurized vestibule can provide a temporary area of refuge.

2.3.6.4 Purged or Vented Vestibules. Purged or vented vestibule systems fall outside the scope of this document. A hazard analysis would be required using the procedures provided in the SFPE *Handbook of Fire Protection Engineering*. An engineering analysis should be performed to determine the benefits, if any, of pressurizing, purging, or exhausting vestibules on the stairwell.

2.3.7* Number of Doors Open. For a stairwell pressurization system that has not been designed to accommodate the opening of doors, pressurization will drop when any doors open, and smoke can infiltrate the stairwell. For a building of low occupant density, the opening and closing of a few doors during evacuation has little effect on the system. For a building with a high occupant density and total building evacuation, it can be expected that most of the doors will be open at some time during evacuation. The methods provided in ASHRAE/SFPE, *Design of Smoke Management Systems*, can be used to design systems to accommodate anywhere from a few open doors to almost all the doors being open. The effect of opening a door to the outside is usually much greater than that of opening interior doors. If systems are designed for open doors and total building evacuation, the number of open doors should include the exterior stairwell door.

2.4 Elevator Smoke Control.

2.4.1 Historically, elevator hoistways have proved to be a readily available conduit for the movement of smoke throughout buildings. The reason is that elevator doors have not been tightfitting and elevator hoistways have been provided with openings in their tops. The building stack effect has provided the driving force that has readily moved smoke into and out of the loosely constructed elevator hoistways. Several methods of correcting this problem have been proposed and investigated. These methods include the following:

(1) Exhaust of the fire floor
(2) Pressurization of enclosed elevator lobbies
(3) Construction of smoketight elevator lobbies
(4) Pressurization of the elevator hoistway
(5) *Closing of elevator doors after automatic recall

2.4.2 The methods listed in 2.4.1(1) through (5) have been employed either singly or in combination. However, their application to a particular project, including the effect of any vents in the elevator hoistway, should be closely evaluated. The open vent at the top of the elevator hoistway might have an undesirable effect on elevator smoke-control systems.

2.4.3* Fires have shown the tendency of smoke to migrate into elevator hoistways. Therefore, the use of elevators for egress purposes has not been favored. Research has shown that use of an elevator during a fire is feasible, provided the elevator system is protected against heat, flame, smoke, loss of electrical power, loss of elevator machine room cooling, water intrusion, and inadvertent activation of controls.

2.5 Zoned Smoke Control.

2.5.1 General.

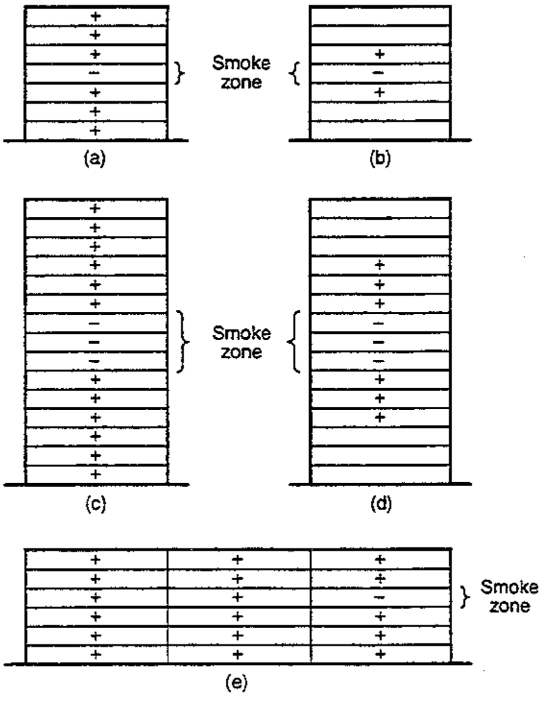
2.5.1.1 The pressurized stairwells discussed in Section 2.3 are intended to control smoke to the extent that they inhibit smoke infiltration into the stairwell. However, in a building with a pressurized stairwell as the sole means of smoke control, smoke can flow through cracks in floors and partitions and through other shafts to threaten life and to damage property at locations remote from the fire. The concept of zoned smoke control discussed in this section is intended to limit this type of smoke movement within a building.

2.5.1.2 Limiting fire size (mass burning rate) increases the reliability and viability of smoke-control systems. Fire size can be limited by fuel control, compartmentation, or automatic sprinklers. It is possible to provide smoke control in buildings not having fire-limiting features, but in those instances, careful consideration must be given to fire pressure, high temperatures, mass burning rates, accumulation of unburned fuels, and other outputs resulting from uncontrolled fires.

2.5.2 Smoke-Control Zones.

2.5.2.1 Some buildings can be divided into a number of smoke-control zones, each zone separated from the others by partitions, by floors, and by doors that can be closed to inhibit the movement of smoke. A smoke-control zone can consist of one or more floors, or a floor can consist of one or more smoke-control zones. Arrangements of some smoke-control zones are illustrated in Figure 2.5.2.1. The zoned smoke-control system should be designed such that the pressure differences between the adjacent nonsmoke zones and the smoke zone meet or exceed the minimum design pressure differences given in Table 2.2.1, and at locations with doors, the pressure difference should not exceed the values given in Table 2.2.2.

FIGURE 2.5.2.1 Arrangements of smoke-control zones.



In Figure 2.5.2.1, 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 could be pressurized, as in (a) and (c), or only nonsmoke zones adjacent to the smoke zone could be pressurized, as in (b) and (d). A smoke zone can also be limited to a part of a floor, as in (e).

2.5.2.2 In the event of a fire, pressure differences and airflows produced by mechanical fans can be used to limit smoke spread to the zone in which the fire initiated. The concentration of smoke in this smoke zone might render it untenable. Accordingly, in zoned smoke-control systems, building occupants should evacuate the smoke zone as soon as possible after fire detection.

2.5.2.3* Smoke-zones should be kept as small as practicable so that evacuation from these zones can be readily achieved and so that the quantity of air required to pressurize the surrounding spaces can be kept to a manageable level. However, these zones should be large enough so that heat buildup from the fire will become sufficiently diluted with surrounding air so as to prevent failure of major components of the smoke control system.

2.5.2.4 When a fire occurs, all of the nonsmoke zones in the building can be pressurized as shown in Figure 2.5.2.1, parts (a), (c), and (e). This system requires large quantities of outside air. The comments concerning location of supply air inlets of pressurized stairwells *(see 2.3.3)* also apply to the supply air inlets for nonsmoke zones.

2.5.2.5 In cold climates, the introduction of large quantities of outside air can cause serious damage to building systems. Therefore, serious consideration should be given to emergency preheat systems that temper the incoming air and help to avoid or limit damage. Alternatively, pressurizing only those zones immediately adjacent to the smoke zones could limit the quantity of outside air required, as in Figure 2.5.2.1, parts (b) and (d). However, the disadvantage of this limited approach is that it is possible to have smoke flow through shafts past the pressurized zone and into unpressurized spaces. When this alternative is considered, a careful examination of the potential smoke flows involved should be accomplished and a determination of acceptability made.

2.5.2.6 Signals from fire alarm systems can be used to activate the appropriate zoned smoke-control system(s). Such use of the fire alarm system requires that the alarm zones be arranged to coincide with the smoke-control zones so as to avoid activation of the wrong smoke-control system(s).

2.5.2.7 Unless venting or exhaust is provided in the fire zones, the pressure differences will not be developed; eventually pressure equalization between the fire zone and the unaffected zones will become established and there will be nothing to inhibit smoke spread into all the zones.

2.6* Areas of Refuge.

Smoke control for areas of refuge can be provided by pressurization. For areas of refuge adjacent to stairwells or elevators, provisions should be made to prevent the loss of pressure or excessive pressures due to the interaction of the area of refuge smoke control and the shaft smoke control.

2.7 Combination of Systems.

2.7.1 General. On some occasions, more than one smoke-control system will operate simultaneously. For example, pressurized stairwells can connect to floor areas that are part of a zoned smoke-control system. Elevator hoistways that are part of an elevator smoke-control system can connect to floor areas that are part of a zoned smoke-control system. The elevator smoke-control system can be connected to areas of refuge that in turn are connected with floor areas that are part of a zoned smoke-control system. Further, there can be pressurized stairwells that are also connected to the area of refuge.

An example of a simple system is one consisting of pressurized stairwells as the building's sole means of smoke control. Even then, the interaction between stairwells through the building, particularly when doors are opened and closed, must be considered.

Often these systems are designed independently to operate under the dynamic forces they will encounter (for example, buoyancy, stack effect, wind). Once the design is completed, it is necessary to study the impact the smoke-control system(s) will have on one another. For example, an exhausted smoke zone operating in conjunction with a stairwell pressurization system can tend to improve the performance of the stair pressurization system. At the same time, it could increase the pressure difference across the door, causing difficulty in opening the door into the stairwell. For complex systems, it is recommended that a computer network model, such as those discussed in Chapter 4, be used for the analysis.

2.7.2 Fire Floor Exhaust. Exhausting the fire floor can improve the performance of stairwell pressurization. A benefit of this system is the reduction of pressure on the fire floor, thus increasing the pressure difference across the stairwell door. This system might or might not be a part of the zoned smoke-control system. The fire floor exhaust should discharge to the outside of the building and can be either fan-powered or nonfan-powered, depending on the particular building conditions. Design of such a system should include an engineering analysis of the stack and wind effects.

Chapter 3 Building Equipment and Controls

3.1 General. With some modification, conventional building HVAC systems can be used to provide building smoke control. Various types of building equipment are discussed in this chapter; however, it is impractical to cover all types. This chapter provides general information on equipment and controls and provides guidelines for adapting the majority of systems encountered.

3.2 Heating, Ventilating, and Air-Conditioning (HVAC) Equipment.

3.2.1 General. Heating, ventilating, and air-conditioning (HVAC) systems normally provide a means of supplying, returning, and exhausting air from a conditioned space. The HVAC equipment can be located within the conditioned space, within adjacent spaces, or within remote mechanical equipment rooms. Most HVAC systems in buildings where smoke control is considered can be adapted for zoned smoke control.

3.2.2 Outside Air. HVAC systems should be provided with adequate outside air for supply so that sufficient pressure differences can be achieved across barriers to inhibit migration of smoke into uninvolved areas. Mechanical exhaust to the outside from the smoke zone is also necessary. Some HVAC systems have this capability without a need for modification. Where supply and return are interconnected as part of normal HVAC operation, smoke dampers should be provided to separate the supply and exhaust during smoke-control operation.

3.2.3 HVAC Air-Handling System Types. Various types and arrangements of air-handling systems are commonly used in different types of buildings. Some types are more readily adaptable for smoke-control applications than others. Examples of typical air-handling systems are described in 3.2.3.1 through 3.2.3.8.

3.2.3.1 Individual Floor Systems. The use of individual air-handling units serving one floor or part of a floor is a common design approach. These HVAC units might or might not have separate return/exhaust fans. Where these fans are not separate, a means for providing relief of the fire floor pressures, either through relief dampers on the duct system or by other means, should be investigated. Outdoor air can be supplied to each air-handling unit by one of the following means:

(1) Exterior louvers and dampers
(2) A common duct system sized to handle the required quantities of air
(3) A common duct system having a variable-speed supply fan
(4) Individual variable-speed supply fans

Air-handling units can be used for smoke control if sufficient outside air and exhaust air capability is available.

3.2.3.2 Centralized Multifloor Systems. Some buildings utilize centralized HVAC equipment in main mechanical areas that serve multiple floors within the building. HVAC systems of this type might require fire and smoke shaft dampering in order to provide exhaust of the fire floor and pressurization of the adjacent floors with outside air. Because these central fans can be of large capacity, care must be taken in designing systems to include a means of avoiding excessive pressures within the duct system to prevent rupture, collapse, or other damage. Means should be provided to control pressures within exits and corridors that could inhibit doors from being opened or closed.

3.2.3.3 Fan/Coil Units and Water Source Heat Pump Units. Fan/coil and water source heat pump types of air-handling units are often located around the perimeter of a building floor to condition the perimeter zones. They can also be located throughout the entire floor area to provide air conditioning for the entire space. Because the fan/coil and water source heat pump units are comparatively small in outside air capacity and are typically difficult to reconfigure for smoke-control purposes, they are generally not suitable for performing smoke-control functions. If these units have outside air intake provisions, such units within the smoke zone should be shut down when the zone is to be negatively pressurized.

The fan/coil and water source heat pump units are typically used in combination with larger central HVAC equipment or individual interior zone air-handling units. The zone smoke-control functionality should be provided by the larger central or interior zone air-handling units.

3.2.3.4 Induction Systems. Induction-type air-handling units located around the perimeter of a building are primarily used to condition the perimeter zone of older multistory structures.

A central HVAC system supplies high-pressure heated or cooled air to each perimeter induction unit. Room air is then induced into the induction unit, mixed with the primary air from the central HVAC system, and discharged into the room.

Induction units within the smoke zone should be shut down or should have the primary air closed off on initiation of smoke control in smoke zones.

3.2.3.5 Dual Duct and Multizone Systems. HVAC units used in dual duct and multizone systems contain cooling and heating coils, each in a separate compartment or deck within the unit.

Dual duct systems have separate hot and cold ducts connected between the decks and mixing boxes that mix the air supplied to the space served. For high-pressure systems, the mixing boxes also reduce the system pressure.

Multizone systems mix heated and cooled air at the unit and supply the mixture through low-pressure ducts to each space.

Smoke control can be achieved by supplying maximum air to areas adjacent to the smoke zone. This should be accomplished using the cold deck because it is usually sized to handle larger air quantities. For the smoke zone, supply fans should be shut off.

3.2.3.6 Variable Air Volume (VAV) Systems. Variable air volume (VAV) systems are either individual floor systems *(see 3.2.3.1)* or centralized multifloor systems *(see 3.2.3.2)* that are provided with terminal devices that typically supply cooling only. Individual areas served by the system usually have other sources of heating (e.g., baseboard or cabinet heaters).

VAV systems vary the quantity of cold air supplied to the occupied space based on actual space demands. Some VAV systems bypass supply air to the return air inlet of the fan, reducing supply air volumes and resultant pressure to avoid fan or ductwork damage. In the smoke-control mode, such bypasses must be closed. For smoke control, the speed of the VAV system supply fan(s) should be increased and VAV terminal unit controls should be configured to open the terminals in the nonsmoke zone to supply maximum volume of outside air to pressurize spaces if sufficient air is available. Bypass dampers on systems using this method must be closed. It is possible to achieve smoke control with the VAV system supplying minimal air, but care must be taken to ensure that adequate pressure is developed in the space.

3.2.3.7 Fan-Powered Terminal Systems. A fan-powered terminal unit receives variable air volumes of primary cooled air and return air that blend in the terminal unit to provide a constant volume of variable temperature supply air to the occupied spaces. The terminal unit consists of a constant air volume fan for supplying the blended air to the occupied space, a damper-controlled primary air connection, and a return air opening. Terminal units serving perimeter zones can have a heating coil to provide additional heat for the perimeter zone. In the smoke-control mode, terminal unit fans located in the smoke zone should be shut off and the primary air damper closed. Terminal units serving zones adjacent to the smoke zone can continue to operate.

3.2.3.8 Mixed Systems. Combinations of the examples described in 3.2.3.1 through 3.2.3.7 are sometimes used, especially for building areas being altered for use other than originally intended. Care must be exercised in the application of different types of variable volume terminal units to determine their effect on zoned smoke control. Designs must be based on the capability of system configurations to achieve positive or negative pressures as needed for smoke control.

3.2.4 Ventilation Systems. In certain instances, specialized systems with no outside air are used for primary cooling and heating. These systems include self-contained air conditioners, radiant panel systems, and computer room units. Because these systems provide no outside air, they are not suitable for smoke control application.

Because building codes require ventilation for all occupied locations, a separate system for providing outside air is needed. The system supplying outside air can be used for smoke control, although the quantity of air provided might not be adequate for full pressurization.

3.2.5 Special-Use Systems. Laboratories, animal facilities, hospital facilities, and other unusual occupancies sometimes use once-through outdoor air systems to avoid contamination and could have special filtration and pressurization requirements. These special-use systems can be suitable for a smoke-control application. Care should be exercised to avoid contamination of bacteria-free areas, experiments, processes, and similar areas.

3.3 Smoke Dampers. Smoke dampers used to protect openings in smoke barriers or used as safety-related dampers in engineered smoke-control systems should be classified and labeled in accordance with UL 555S, *Standard for Safety Leakage Rated Dampers for Use in Smoke Control Systems.*

Dampers in smoke-control systems should be evaluated for their ability to operate under anticipated conditions of system operation.

3.4 Controls.

3.4.1 Coordination. The control system should fully coordinate smoke-control system functions among the fire alarm system, sprinkler system, fire fighters' smoke-control system, and any other related systems with HVAC and other building smoke-control equipment.

3.4.2 HVAC System Controls.

3.4.2.1 Operating controls of the HVAC system should be designed or modified to accommodate the smoke-control mode, which must have the highest priority over all other control modes.

3.4.2.2* Various types of control systems are commonly used for HVAC systems. These control systems utilize pneumatic, electric, electronic, and programmable logic-based control units. All these control systems can be adapted to provide the necessary logic and control sequences to configure HVAC systems for smoke control. Programmable electronic logic-based (i.e., microprocessor-based) control units, which control and monitor HVAC systems as well as provide other building control and monitoring functions, are readily applicable for providing the necessary logic and control sequences for an HVAC system's smoke-control mode of operation.

3.4.3 Smoke-Control System Activation and Deactivation. Smoke- control system activation is the initiation of the operational mode of a smoke-control system. Deactivation is the cessation of the operational mode of the smoke-control system. Smoke-control systems normally should be activated automatically; however, under certain circumstances, manual activation can be appropriate. Under either automatic or manual activation, the smoke-control system should be capable of manual override.

Based on the design and intended performance of the smoke-control system, consideration should be given to the position (i.e., open or closed) of smoke dampers on loss of power and on shutdown of the fan systems that the dampers serve.

3.4.3.1 Automatic Activation. Automatic activation (or deactivation) includes all means whereby a specific fire detection device or combination of devices causes activation of one or more smoke-control systems without manual intervention. For purposes of automatic activation, fire detection devices include automatic devices such as smoke detectors, waterflow switches, and heat detectors.

3.4.3.2* Manual Activation. Manual activation (or deactivation) covers all means whereby an authorized person activates one or more smoke-control systems by means of controls provided for the purpose. For purposes of manual activation, the location of the controls can be at a controlled device, at a local control panel, at the building's main control center, or at the fire command station. The specific location(s) should be as required by the authority having jurisdiction. Manual fire alarm pull stations generally should not be used to activate smoke-control systems, which, to operate correctly, require information on the location of the fire, because of the likelihood of a person signaling an alarm from a station outside the zone of fire origin.

3.4.3.3* Response Time. Smoke-control system activation should be initiated immediately after receipt of an appropriate automatic or manual activation command. Smoke-control systems should activate individual components (e.g., dampers, fans) in the sequence necessary to prevent physical damage to the fans, dampers, ducts, and other equipment. The total response time necessary for individual components to achieve their desired state or operational mode should not exceed the following time periods:

(1) Fan operation at the desired state: 60 seconds
(2) Completion of damper travel: 75 seconds

3.4.3.4* Fire Fighters' Smoke-Control Station (FSCS).

3.4.3.4.1 A fire fighters' smoke-control station (FSCS) should be provided for all smoke-control systems. The FSCS should provide complete status indication and manual control of all smoke-control systems and equipment. Status indicators and controls should be logically and clearly arranged and labeled to convey the intended system objectives to fire fighters who may be unfamiliar with the system. Operator controls should be provided for each smoke-control zone, each piece of equipment capable of activation for smoke control, or a combination of these approaches. Diagrams and graphic representations of the system should be used; however, they might not be necessary where acceptable to the authority having jurisdiction.

3.4.3.4.2 The layout, labeling, and location of the FSCS should be reviewed and approved by the fire department or fire official prior to installation.

3.4.3.4.3 The FSCS should have the highest priority control over all smoke-control systems and equipment. Where manual controls for control of smoke-control systems are also provided at other building locations, the control mode selected from the FSCS should prevail. FSCS control should override or bypass other building controls such as hand-off-auto and start/stop switches located on fan motor controllers, freeze detection devices, and duct smoke detectors. FSCS control should not take precedence over fire suppression, electrical, or personnel protection devices.

The FSCS fan control capability need not bypass hand-off-auto or start/stop switches located on motor controllers of nondedicated smoke-control system fans, where the following conditions exist:

(1) Such fan motor controllers are located in mechanical or electrical equipment rooms or in other areas accessible only to authorized personnel.
(2) The use of such a motor controller switch to turn a fan on or off will cause an off-normal indication at the building's main control center during normal HVAC or building control operations of the nondedicated fan.

3.4.3.4.4 Positive status indication (on and off) should be provided for dedicated smoke-control system fans and all nondedicated fans having a capacity in excess of 2000 ft^3/min (57 m^3/min) and used for smoke control. On status should be sensed by a pressure difference, an airflow switch, or some other proof of airflow. Indirect indication of fan status is not positive proof of airflow. Additional indications such as damper position can be provided where warranted by the complexity of the system. The status of individual fans need not be provided for fans whose operation is included in the status indication of a smoke-control zone.

3.4.4 Controls for Stair Pressurization Systems. The criteria for activation of stair pressurization systems should be as recommended in 3.4.4.1 and 3.4.4.2.

3.4.4.1 Automatic Activation. Operation of any zone of the building fire alarm system should cause all stair pressurization fans to start. In limited instances, it can be desirable to pressurize only some stairwells due to particular building configurations and conditions. A smoke detector should be provided in the air supply to the pressurized stairwell. On detection of smoke, the supply fan(s) should be stopped.

3.4.4.2 Manual Activation. A manual override switch should be provided at the FSCS to restart the stairwell pressurization fan(s) after shutdown from the smoke detector, if it is determined that a lesser hazard exists from smoke entering the stairwell via the fan than smoke migrating into the stairwell from adjoining spaces.

3.4.5 Controls for Zoned Smoke-Control Systems.

3.4.5.1 General. The criteria for activation of zoned smoke-control systems should be as given in 3.4.5.1 and 3.4.5.2.

3.4.5.1.1 Automatic Activation. An automatic smoke detection system can be used to automatically activate a zoned smoke-control system. The smoke detection system can be of limited coverage having spacing greater than 900 ft^2 (84 m^2) per detector, provided that the smoke detectors are so located as to detect smoke before it leaves the smoke zone. The location of smoke detectors and the zoning of the detectors should be carefully analyzed to achieve a smoke detection system that will reliably indicate the correct smoke zone.

Automatic actuation of a zoned smoke-control system, which is designed to exhaust the fire area and supply air to other areas, should be given careful consideration before being undertaken because of the possibility of activation of a detector outside the zone of fire origin.

A waterflow switch or heat detector serving the smoke zone can be used to activate the zoned smoke-control system where piping and wiring of such devices coincide with the smoke-control zone.

3.4.5.1.2 Manual Activation. Manual activation and deactivation control of the stair pressurization systems should be provided at the FSCS as well as at the building's control center. In addition, the FSCS should be capable of overriding the automatic shutdown of a stair pressurization fan upon smoke detection, in accordance with the judgment of the fire incident commander.

Zoned smoke-control systems should not be activated from manual fire alarm boxes connected to the building fire alarm system. There is no assurance that the manual fire alarm box is located in the smoke zone. These fire alarm boxes can be used to cause doors in smoke barrier walls to close prior to smoke control system activation.

Key-operated manual switches located within a smoke zone that are clearly marked to identify their function can be used to manually activate the zone's smoke-control system. If an FSCS is provided, zoned smoke-control systems should be capable of being manually activated from the FSCS by switches clearly marked to identify the zone and function. In addition, if the building is provided with a main control center, zoned smoke-control systems should also be capable of being manually activated from the building's main control center.

Extreme care should be exercised when selecting a manual-only activation to ensure that suitably trained personnel are available 24 hours a day, 7 days a week. If this cannot be guaranteed, an automatic system with manual backup should be used.

3.4.5.2* Sequence of Control and Priorities. The automatic and manual activation (or deactivation) of zoned smoke-control systems should be subject to the sequences of control and priorities given in 3.4.5.2.1 and 3.4.5.2.2.

3.4.5.2.1 Automatic Activation. Automatic activation of systems and equipment for zoned smoke control should have the highest priority over all other sources of automatic control within the building. Where equipment used for smoke control is also used for normal building operation, control of this equipment should be preempted or overridden as required for smoke control. This equipment includes air supply/return fans and dampers subject to automatic control according to building occupancy schedules, energy management, or other purposes. The following controls should not be automatically overridden:

(1) Static pressure high limits
(2) Duct smoke detectors on supply air systems

3.4.5.2.2 Manual Activation and Deactivation. Manual activation or deactivation of zoned smoke-control systems and equipment should have priority over automatic activation of smoke-control systems and equipment, as well as over all other sources of automatic control within the building. If equipment used for zoned smoke control is subject to automatic activation in response to an alarm from an automatic fire detector of a fire alarm system, or if such equipment is subject to automatic control according to building occupancy schedules, energy management strategies, or other nonemergency purposes, such automatic control should be preempted or overridden by manual activation or deactivation of the smoke-control equipment. Manual controls provided specifically for this purpose should be clearly marked to indicate the zone and function served. Manual controls that are shared for both smoke-control functions and other building control purposes, as in a building's main control center, should fully cover the smoke-control functionality in operational documentation for the control center.

3.4.5.3 Sequence. Separate smoke-control systems should be activated in a specific overall sequence to ensure maximum benefit and minimize any damage or undesirable effects on ducts or equipment.

3.4.5.4* Schedule. Each different smoke-control system configuration should be fully defined in a schedule format that includes, but is not limited to, the following parameters:

(1) Fire zone in which a smoke-control system automatically activates.
(2) Type of signal that activates a smoke-control system, such as sprinkler waterflow or smoke detector.
(3) Smoke zone(s) where maximum mechanical exhaust to the outside is implemented and no supply air is provided.
(4) Positive pressure smoke-control zone(s) where maximum air supply is implemented and no exhaust to the outside is provided.
(5) Fan(s) ON as required to implement the smoke-control system. Multiple-speed fans should be further noted as FAST or MAX. VOLUME to ensure that the intended control configuration is achieved.
(6) Fan(s) OFF as required to implement the smoke-control system.
(7) Damper(s) OPEN where maximum airflow must be achieved.
(8) Damper(s) CLOSED where no airflow should take place.
(9) Auxiliary functions might be required to achieve the smoke-control system configuration or might be desirable in addition to smoke control. Changes or override of normal operation static pressure control set points should also be indicated if applicable.
(10) Damper position at fan failure.

3.4.5.5* Automatic Response to Multiple Signals. In the event that signals are received from more than one smoke zone, the system should continue automatic operation in the mode determined by the first signal received. However, systems designed for operation of multiple zones using only heat-activated detection devices can expand the control strategy to accommodate additional zones, up to the limits of the mechanical system design.

3.4.6* Control System Verification. Every dedicated smoke-control system and dedicated smoke-control element in a nondedicated smoke-control system should have means of ensuring it will operate if activated. The means and frequency will vary according to the complexity and importance of the system.

3.5 Energy Management. Energy management systems, particularly those that cycle supply, return, and exhaust fans for energy conservation, should be overridden when their control or operation is in conflict with a smoke-control mode. Because smoke control is an abnormal but critical mode of operation, it should take priority over all energy management and other nonemergency control modes.

3.6 Materials.

3.6.1 Materials used for systems providing smoke control should conform to NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*, and other applicable NFPA documents.

3.6.2 Duct materials should be selected and ducts should be designed to convey smoke, withstand additional pressure (both positive and negative) by the supply and exhaust fans when operating in a smoke-control mode, and maintain their structural integrity during the period for which the system should operate.

3.6.3 Equipment including, but not limited to, fans, ducts, and balance dampers should be suitable for their intended use and the probable temperatures to which they might be exposed.

3.7 Electric Services Installation.

3.7.1 All electrical installations should meet the requirements of NFPA 70, *National Electrical Code®*.

3.7.2 Normal electrical power serving air-conditioning systems generally has sufficient reliability for nondedicated zoned smoke-control systems.

3.7.3 Whether standby power is needed should be considered for smoke-control systems and their control systems.

Chapter 4 Smoke-Control System Analysis

4.1 General. Design analysis of smoke-control systems can be performed with design equations or a network computer flow program.

4.2 Design Equations. The equations that can be used for analysis of pressurized stairwells and elevator smoke control are based on idealizations concerning similar building leakage from floor to floor and no leakage through floors. *(These equations are provided in ASHRAE/SFPE, Design of Smoke Management Systems.)*

4.3* Computer Network Model. A computer network model provides a means to calculate the airflows and pressure differences throughout a building in which a smoke-control system is operating. In a network program, a building is represented by a network of spaces or nodes, each at a specific pressure and temperature. Air flows through leakage paths from regions of high pressure to regions of low pressure. These leakage paths are doors and windows that can be opened or closed. Leakage can also occur through partitions, floors, and exterior walls and roofs. *(See ASHRAE/SFPE, Design of Smoke Management Systems, for a discussion of the method used to combine multiple leakage paths into one equivalent path.)* The airflow through a leakage path is a function of the pressure difference across the leakage path.

In network models, air from outside the building can be introduced by a pressurization system into any building space, and the building space can be exhausted to the outside. Network models allow simulation of stairwell pressurization, elevator shaft pressurization, zoned smoke control, and any other type of smoke-control system. The pressures throughout the building and steady flow rates through all the flow paths are obtained by solving the airflow network, including the driving forces such as wind, the pressurization system, and the inside-to-outside temperature difference. There are many network models that use a variety of terminology and have many features.

4.4 Extent of Analysis. Design calculations are recommended for the following conditions:

(1) Winter design conditions with low building leakage
(2) Summer design conditions with low building leakage
(3) Winter design conditions with high building leakage
(4) Summer design conditions with high building leakage

4.5* Leakage Areas. In the design of smoke-control systems, airflow paths must be identified and evaluated. Some leakage paths are obvious, such as gaps around closed doors, open doors, elevator doors, windows, and air transfer grilles. Construction cracks in building walls and floors are less obvious but no less important. The flow area of most large openings can be calculated easily. The flow area of construction cracks is dependent on workmanship, for example, how well a door is fitted or how well weather stripping is installed. Typical leakage areas of construction cracks in walls and floors of commercial buildings are listed in Table 4.5.

Table 4.5 Typical Leakage Areas for Walls and Floors of Commercial Buildings

Construction Element	Tightness	Area Ratio[1]
Exterior building walls (includes construction cracks and cracks around windows and doors)	Tight[2]	0.50×10^{-4}
	Average[2]	0.17×10^{-3}
	Loose[2]	0.35×10^{-3}
	Very Loose[2]	0.12×10^{-2}
Stairwell walls (includes construction cracks, but not cracks around windows and 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 and gaps around doors)	Tight[3]	0.18×10^{-3}
	Average[3]	0.84×10^{-3}
	Loose[3]	0.18×10^{-2}
Floors (includes construction cracks and gaps around penetrations)	Tight[4]	0.66×10^{-5}
	Average[5]	0.52×10^{-4}
	Loose[4]	0.17×10^{-3}

[1]For a wall, the area ratio is the area of the leakage through the wall divided by the total wall area. For a floor, the area ratio is the area of the leakage through the floor divided by the total area of the floor.
[2]Values based on measurements of Tamura and Shaw (1976a), Tamura and Wilson (1966), and Shaw, Reardon, and Cheung (1993).
[3]Values based on measurements of Tamura and Wilson (1966) and Tamura and Shaw (1976b).
[4]Values extrapolated from average floor tightness based on range of tightness of other construction elements.
[5]Values based on measurements of Tamura and Shaw (1978).

4.6 Friction Losses in Shafts. Pressure losses due to friction of air flowing in stairwells are similar to those of air flowing in ducts. Friction loss data have been developed by Tamura and Shaw (1976b) for open and closed stair treads with various levels of occupant density.

Chapter 5 Testing

5.1 Introduction.

5.1.1* Absence of a consensus agreement for a testing procedure and acceptance criteria historically has created numerous problems at the time of system acceptance, including delays in obtaining a certificate of occupancy.

It is recommended that the building owner and building designer share their objectives and design criteria for smoke control with the authority having jurisdiction at the planning stage of the project. The design criteria should include a procedure for acceptance testing.

Contract documents should include operational and acceptance testing procedures so that all parties — designers, installers, owners, and authorities having jurisdiction — have a clear understanding of the system objectives and the testing procedure.

The smoke control systems discussed in this document are designed to limit smoke migration at the boundaries of a smoke-control area using pressure differences. A stairwell pressurization system is used to limit smoke movement from the floor area into the stairwell and thus provide a tenable environment during egress. For zoned smoke control, pressure differences are used to contain smoke within the smoke zone and limit the migration of smoke and fire gases to other parts of the building. Testing appropriate to the objective of the system consists of measuring the pressure difference between the smoke zone and the adjacent zones. The testing procedures provided in Section 5.3 are based on the measurement of pressure differences and door opening forces under the design conditions agreed on with the authority having jurisdiction.

5.1.2* This chapter provides recommendations for the testing of smoke-control systems. Each system should be tested against its specific design criteria. The test procedures described herein have been divided into the following three categories:

(1) Component systems testing
(2) Acceptance testing
(3) Periodic testing and maintenance

5.2 Operational Testing.

5.2.1 The intent of operational testing is to establish that the final installation complies with the specified design, is functioning properly, and is ready for acceptance testing. Responsibility for testing should be clearly defined prior to operational testing.

5.2.2 Prior to testing, the party responsible for this testing should verify completeness of building construction, including the following architectural features:

(1) Shaft integrity
(2) Firestopping
(3) Doors/closers
(4) Glazing
(5) Partitions and ceilings

5.2.3 The operational testing of each individual system component should be performed as it is completed during construction. These operational tests are normally performed by various trades before interconnection is made to integrate the overall smoke-control system. It should be certified in writing that each individual system component's installation is complete and the component is functional. Each component test should be individually documented, including such items as speed, voltage, and amperage.

5.2.4 Because smoke-control systems are usually an integral part of building operating systems, testing should include the following subsystems to the extent that they affect the operation of the smoke-control system:

(1) Fire alarm system *(See NFPA 72, National Fire Alarm Code®.)*
(2) Energy management system
(3) Building management system
(4) HVAC equipment
(5) Electrical equipment
(6) Temperature control system
(7) Power sources
(8) Standby power
(9) Automatic suppression systems
(10) Automatic operating doors and closers
(11) Dedicated smoke-control systems
(12) Nondedicated smoke-control systems
(13) Emergency elevator operation

5.3 Acceptance Testing.

5.3.1 General. The intent of acceptance testing is to demonstrate that the final integrated system installation complies with the specified design and is functioning properly. One or more of the following should be present to grant acceptance:

(1) Authority having jurisdiction
(2) Owner
(3) Designer

All documentation from operational testing should be available for inspection.

5.3.2 Test Equipment. Equipment for acceptance testing should be provided as follows:

(1) Calibrated instruments to read pressure difference [differential pressure gauges, inclined water manometers, or electronic manometers; instrument ranges 0–0.25 in. w.g. (0–62.5 Pa) and 0–0.50 in. w.g. (0–125 Pa) with 50 ft (15.2 m) of tubing]
(2) Spring scale
(3) Anemometer
(4) Flow-measuring hood (optional)
(5) Door wedges
(6) Signs indicating that a test of the smoke-control system is in progress and that doors must not be opened (or closed)
(7) Walkie-talkie radios to coordinate equipment operation and data recording

5.3.3* Testing Procedures. The acceptance testing should include the procedures described in 5.3.3.1 through 5.3.3.6.

5.3.3.1 Prior to beginning acceptance testing, all building equipment should be placed in the normal operating mode, including equipment that is not used to implement smoke control, such as toilet exhaust, elevator shaft vents, elevator machine room fans, and similar systems.

5.3.3.2 Wind speed, direction, and outside temperature should be recorded during each test.

5.3.3.3 If standby power has been provided for the operation of the smoke-control system, the acceptance testing should be conducted while on both normal and standby power. Disconnect the normal building power at the main service disconnect to simulate true operating conditions in this mode.

5.3.3.4 The acceptance testing should include demonstrating that the correct outputs are produced for a given input for each control sequence specified. Consideration should be given to the following control sequences, so that the complete smoke-control sequence is demonstrated:

(1) Normal mode
(2) Automatic smoke-control mode for first alarm
(3) Manual override of normal and automatic smoke-control modes
(4) Return to normal

5.3.3.5 It is acceptable to perform acceptance tests for the fire alarm system in conjunction with the smoke-control system. One or more device circuits on the fire alarm system can initiate a single input signal to the smoke-control system. Therefore, consideration should be given to establishing the appropriate number of initiating devices and initiating device circuits to be operated to demonstrate the smoke-control system operation.

5.3.3.6* Much can be accomplished to demonstrate smoke-control system operation without resorting to demonstrations that use smoke or products that simulate smoke. Where the authority having jurisdiction requires such demonstrations, they should be based on the objective of inhibiting smoke from migrating across smoke zone boundaries to other areas. Test criteria based on the system's ability to remove smoke from an area are not appropriate for zoned smoke-control systems, since these systems are designed for containment, not removal, of smoke.

5.3.4 Stairwell Pressurization Systems. This section applies where stairwell pressurization is the only smoke-control system in the building. If stairwell pressurization is used in combination with zoned smoke control, the recommendations in 5.3.8 should be applied.

5.3.4.1 With all building HVAC systems in normal operation, measure and record the pressure difference across each stairwell door while the door is closed. After recording the pressure difference across the door, measure the force necessary to open each door, using a spring-type scale. Establish a consistent procedure for recording data throughout the entire test, such that the stairwell side of the doors will always be considered as the reference point [0 in. w.g. (0 Pa)] and the floor side of the doors will always have the pressure difference value (positive if higher than the stairwell and negative when less than the stairwell). Because the stairwell pressurization system is intended to produce a positive pressure within the stairwell, all negative pressure values recorded on the floor side of the doors are indicative of a potential airflow from the stairwell to the floor.

5.3.4.2 Verify the proper activation of the stairwell pressurization system(s) in response to all means of activation, both automatic and manual, as specified in the contract documents. Where automatic activation is required in response to alarm signals received from the building's fire alarm system, each separate alarm signal should be initiated to ensure that proper automatic activation occurs.

5.3.4.3 With the stairwell pressurization system activated, measure and record the pressure difference across each stairwell door with all interior doors closed. If the exterior door would normally be open during evacuation, it should be open during testing. The HVAC system should be off unless the normal mode is to leave the HVAC system on during smoke-control operations. Use the same procedure established in 5.3.4.1 to record data throughout the entire test.

5.3.4.4 After recording the pressure difference across each closed door, measure and record the force necessary to open each stairwell door, using a spring-type scale. All other stairwell doors should be closed and the stairwell pressurization system should be activated.

5.3.4.5* With the stairwell pressurization system activated, open the number of doors used in the system design, and measure and record the pressure difference across each remaining closed door. After recording the pressure difference across each closed door, measure the force necessary to open each door, using a spring-type scale. Use the same procedure established in 5.3.4.1 to record data throughout the entire test. The local code and contract documents' requirements should be followed regarding the number and location of all doors that need to be opened for this test.

5.3.4.6 All pressure differences and door opening forces should be documented. The results should demonstrate that the system is functioning properly. No pressure difference should be less than the minimum design pressure differences in Table 2.2.1 or the pressures specified in the design documents. Door opening forces should not exceed those allowed by the building code. Any portion of the system not working properly should be repaired and retested.

5.3.4.7 Pressurized stairwell vestibules should be treated as a zone in a zoned smoke-control system.

5.3.5 Zoned Smoke-Control System.

5.3.5.1 Verify the exact location of each smoke-control zone and the door openings in the perimeter of each zone. If the plans do not specifically identify these zones and doors, the fire alarm system in those zones might have to be activated so that any doors magnetically held open will close and identify the zone boundaries.

5.3.5.2 Measure and record the pressure difference across all smoke-control zones that divide a building floor. The measurements should be made while the HVAC systems serving the floor's smoke zones are operating in their normal (non-smoke-control) mode and while all smoke barrier doors that separate the floor zones are closed. One measurement should be made across each smoke barrier door or set of doors, and the data should clearly indicate the higher and lower pressure sides of the doors.

5.3.5.3 Verify the proper activation of each zoned smoke-control system in response to all means of activation, both automatic and manual, as specified in the contract documents. Where automatic activation is required in response to alarm signals received from the building's fire alarm system, each separate alarm signal should be initiated to ensure that proper automatic activation of the correct zoned smoke-control system occurs. Verify and record the proper operation of all fans, dampers, and related equipment as outlined by the schedule(s) referenced in 3.4.5.4 for each separate zoned smoke-control system.

5.3.5.4 Simulate a fire alarm input to activate all zoned smoke-control systems that are appropriate for each separate smoke-control zone. Measure and record the pressure difference across all smoke barriers that separate the smoke zone from adjacent zones. The measurements should be made while all smoke barrier doors that separate the smoke zone from the other zones are fully closed. One measurement should be made across each smoke barrier or set of doors, and the data should clearly indicate the higher and lower pressure sides of the doors or barriers. Doors that have a tendency to open slightly due to the pressure difference should have one pressure measurement made while held closed and another made while not held closed.

5.3.5.5 Continue to simulate fire alarm inputs to activate the zoned smoke-control systems for all zones in turn, and make pressure difference measurements as described in 5.3.5.4. Ensure that after testing a smoke zone's smoke-control systems, the systems are properly deactivated and the HVAC systems involved are returned to their normal operating modes prior to activating another zone's smoke-control system. Also ensure that all controls necessary to prevent excessive pressure differences are functional so as to prevent damage to ducts and related building equipment.

5.3.5.6 All pressure differences and door opening forces should be documented. The results should demonstrate that the system is functioning properly. No pressure difference should be less than the minimum design pressure differences in Table 2.2.1 or the pressures specified in the design documents. Door-opening forces should not exceed those allowed by the building code. Any portion of the system not working properly should be repaired and retested.

5.3.6 Elevator Smoke-Control Systems.

5.3.6.1 Hoistway Pressurization Systems. This section applies where elevator hoistway pressurization is the only smoke-control system in the building. Where elevator hoistway pressurization is used in combination with zoned smoke control, the recommendations of 5.3.8 should be applied.

5.3.6.1.1 Verify the proper activation of the elevator pressurization system(s) in response to all means of activation, both automatic and manual, as specified in the contract documents. Where automatic activation is required in response to alarm signals received from the building's fire alarm system, each separate alarm signal should be initiated to ensure that proper automatic activation occurs.

5.3.6.1.2 With the elevator pressurization system activated, measure and record the pressure difference across each elevator door with all elevator doors closed. If the elevator door on the recall floor would normally be open during system pressurization, it should be open during testing. The HVAC system should be off unless the normal mode is to leave the HVAC system on during smoke-control operations.

5.3.6.1.3 Establish a consistent procedure for recording data throughout the entire test, such that the shaft side of the doors is always considered as the reference point [0 in. w.g. (0 Pa)] and the floor side of the doors always has the pressure difference value (positive if higher than the shaft and negative if less than the shaft).

5.3.6.1.4 Because the hoistway pressurization system is intended to produce a positive pressure within the hoistway, all negative pressure values recorded on the floor side of the doors are indicative of a potential airflow from the shaft to the floor.

5.3.6.1.5 If the elevator pressurization system has been designed to operate during elevator movement, the tests should be repeated under these conditions.

5.3.6.2 Lobby Pressurization Systems. This section applies where enclosed elevator lobby pressurization is the only smoke-control system in the building. Where elevator lobby pressurization is used in combination with zoned smoke control, the recommendations of 5.3.8 should be applied.

5.3.6.2.1 Enclosed elevator lobbies pressurized by an elevator lobby pressurization system, or enclosed elevator lobbies receiving secondary pressurization from the elevator hoistway, should be treated as a zone in a zoned smoke-control system. The tests outlined in 5.3.5 should be conducted.

5.3.6.2.2 With the elevator lobby pressurization system activated, measure the force necessary to open each lobby door, using a spring-type scale.

5.3.6.3 Test Results. All pressure differences and elevator lobby door opening forces should be documented. The results should demonstrate that the system is functioning properly. No pressure difference should be less than the minimum design pressure differences in Table 2.2.1 or the pressures specified in the design documents. Elevator lobby door opening forces should not exceed those allowed by the building code. Any portion of the system not working properly should be repaired and retested.

5.3.7 Area of Refuge. An area of refuge should be treated as a zone in a zoned smoke-control system. The tests outlined in 5.3.5 should be conducted.

5.3.8 Combination of Smoke-Control Systems.

5.3.8.1* Stairwell and Zoned Smoke-Control System. The stairwell pressurization system should be considered as one zone in a zoned smoke-control system. The tests outlined in 5.3.5 should be conducted. In addition, the tests outlined in 5.3.4.3 through 5.3.4.5 should be conducted. All tests should be conducted with both systems operating in response to a simulated fire alarm input.

5.3.8.2 Area of Refuge and Zoned Smoke-Control System. An area of refuge should be treated as a separate zone in a zoned smoke-control system. The tests outlined in 5.3.5 should be conducted.

5.3.8.3 Elevator Pressurization and Zoned Smoke-Control System. The elevator pressurization system should be considered as one zone in a zoned smoke-control system. Each elevator lobby in an enclosed elevator lobby pressurization system should be considered as one zone in a zoned smoke-control system. The tests outlined in 5.3.5 should be conducted. In addition, the tests outlined in 5.3.6.1, 5.3.6.2, or both should be conducted.

5.3.9 Testing Documentation. On completion of acceptance testing, a copy of all operational testing documentation should be provided to the owner. This documentation should be available for reference for periodic testing and maintenance.

5.3.10 Owner's Manuals and Instruction. Information should be provided to the owner that defines the operation and maintenance of the system. Basic instruction on the operation of the system should be provided to the owner's representatives. Because the owner can assume beneficial use of the smoke-control system on completion of acceptance testing, this basic instruction should be completed prior to acceptance testing.

5.3.11 Partial Occupancy. Acceptance testing should be performed as a single step when obtaining a certificate of occupancy.

However, if the building is to be completed or occupied in stages, multiple acceptance tests can be conducted in order to obtain temporary certificates of occupancy.

5.3.12 Modifications. All operational and acceptance testing should be performed on the applicable part of the system whenever the system is changed or modified. Documentation should be updated to reflect these changes or modifications.

5.4 Periodic Testing.

5.4.1 During the life of the building, maintenance is essential to ensure that the smoke-control system will perform its intended function under fire conditions. Proper maintenance of the system should, as a minimum, include the periodic testing of all equipment such as initiating devices, fans, dampers, controls, doors, and windows. The equipment should be maintained in accordance with the manufacturer's recommendations. *(See NFPA 90A, Standard for the Installation of Air-Conditioning and Ventilating Systems, for suggested maintenance practices.)*

5.4.2 This section describes the tests that should be performed on a periodic basis to determine that the installed systems continue to operate in accordance with the approved design. If the smoke-control system or the zone boundaries have been modified since the last test, acceptance testing should be conducted on the portion modified.

5.4.3 The system should be tested in accordance with the following schedule by persons who are thoroughly knowledgeable in the operation, testing, and maintenance of the smoke-control systems. The results of the tests should be documented in the operations and maintenance log and made available for inspection. Any portion of the system not functioning in accordance with the original design should be repaired immediately and the system retested.

5.4.3.1 Dedicated Systems, at Least Semiannually. Operate the smoke-control system for each control sequence in the current design criteria, and observe the operation of the correct outputs for each given input. Tests should also be conducted under standby power, if applicable.

5.4.3.2 Nondedicated Systems, at Least Annually. Operate the smoke-control system for each control sequence in the current design criteria and observe the operation of the correct output for each given input. Tests should also be conducted under standby power, if applicable.

5.4.4 Special arrangements might have to be made for the introduction of large quantities of outside air into occupied areas or computer centers when outside temperature and humidity conditions are extreme. Because smoke-control systems override limit controls, such as freezestats, tests should be conducted when outside air conditions will not cause damage to equipment and systems.

Chapter 6 Referenced Publications

6.1 The following documents or portions thereof are referenced within this recommended practice and should be considered as part of its recommendations. The edition indicated for each referenced document is the current edition as of the date of the NFPA issuance of this recommended practice. Some of these documents might also be referenced in this recommended practice for specific informational purposes and, therefore, are also listed in Appendix B.

6.1.1 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 70, *National Electrical Code®*, 1999 edition.

NFPA 72, *National Fire Alarm Code®*, 1999 edition.

NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*, 1999 edition.

NFPA 92B, *Guide for Smoke Management Systems in Malls, Atria, and Large Areas*, 2000 edition.

NFPA *101®*, *Life Safety Code®*, 2000 edition.

NFPA 204, *Guide for Smoke and Heat Venting*, 1998 edition.

NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*, 2000 edition.

George T. Tamura, *Smoke Movement and Control in High-Rise Buildings*, 1994 edition.

6.1.2 Other Publications.

6.1.2.1 ASHRAE Publication. American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 1791 Tullie Circle, N.E, Atlanta, GA 30329-2305.

ASHRAE/SFPE, *Design of Smoke Management Systems*, 1992.

6.1.2.2 SFPE Publication. Society of Fire Protection Engineers, 7315 Wisconsin Avenue, Suite 1225W, Bethesda, MD 20814.

SFPE, *Handbook of Fire Protection Engineering*, 1995.

6.1.2.3 UL Publications. Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062.

UL 555, *Standard for Safety Fire Dampers*, 1999.

UL 555S, *Standard for Safety Leakage Rated Dampers for Use in Smoke Control Systems*, 1999.

6.1.3 Additional Publications.

Shaw, C.Y., J.T., Reardon, and M.S. Cheung, "Changes in Air Leakage Levels of Six Canadian Office Buildings," *ASHRAE Journal*, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA, 1993.

Tamura, G.T., and C.Y. Shaw, "Studies on Exterior Wall Air Tightness and Air Infiltration of Tall Buildings," *ASHRAE Transactions*, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA, Vol. 82, Part 1, 1976a, pp. 122–134.

Tamura, G.T., and C.Y. Shaw, "Air Leakage Data for the Design of Elevator and Stair Shaft Pressurization Systems," *ASHRAE Transactions*, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA, Vol. 82, Part 2, 1976b, pp. 179–190.

Tamura, G.T., and C.Y. Shaw, "Experimental Studies of Mechanical Venting for Smoke Control in Tall Office Buildings," *ASHRAE Transactions*, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA, Vol. 86, Part 1, 1978, pp. 54–71.

Tamura, G.T., and A.G. Wilson, "Pressure Differences for a Nine-Story Building as a Result of Chimney Effect and Ventilation System Operation," *ASHRAE Transactions*, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA, Vol. 72, Part 1, 1966, pp. 180–189.

Appendix A Explanatory Material

Appendix A is not a part of the recommendations of this NFPA document but is included for informational purposes only. This appendix contains explanatory material, numbered to correspond with the applicable text paragraphs.

A.1.4.1 Approved. The National Fire Protection Association does not approve, inspect, or certify any installations, procedures, equipment, or materials; nor does it approve or evaluate testing laboratories. In determining the acceptability of installations, procedures, equipment, or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure, or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization that is concerned with product evaluations and is thus in a position to determine compliance with appropriate standards for the current production of listed items.

A.1.4.3 Authority Having Jurisdiction. The phrase "authority having jurisdiction" is used in NFPA documents in a broad manner, since jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the authority having jurisdiction may be a federal, state, local, or other regional department or individual such as a fire chief; fire marshal; chief of a fire prevention bureau, labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction.

A.1.4.4 Design Pressure Difference. Protected spaces include the nonsmoke zones in a zoned smoke-control system, the stairwells in a stairwell pressurization system, an area of refuge, and the elevator shaft in an elevator hoistway system.

A.1.4.6 Fire Fighters' Smoke-Control Station (FSCS). Other fire fighters' systems (such as voice alarm, public address, fire department communication, and elevator status and controls) are not covered in this document.

A.1.4.11 Smoke Barrier. A smoke barrier might or might not have a fire resistance rating. Such barriers might have protected openings.

A.1.4.15 Smoke Exhaust System. Maintenance of a tenable environment in the smoke zone is not within the capability of these systems.

A.1.5.3 Airflow can be used to limit smoke migration when doors in smoke-control barriers are open. The design velocity through an open door should be sufficient to limit smoke backflow during building evacuation. It should take into consideration the same variables as used in the selection of design pressure differences. Design information is provided in ASHRAE/SFPE, *Design of Smoke Management Systems.*

Although airflow can be used to inhibit smoke movement through a space, the flow rates needed to prevent smoke backflow are so large that there is concern about the amount of combustion air that is supplied to the fire. When airflow is used to manage smoke movement, the flow of air through the opening into the smoke zone must be of sufficient velocity to prevent smoke from leaving that zone through such openings. The air velocity necessary to inhibit smoke movement through large openings results in air quantities that are sufficient to support fire growth to approximately 10 times the size of fire growth without this additional airflow. More information on fire growth can be found in the SFPE *Handbook of Fire Protection Engineering.*

A.1.6.3 One source of data is ASHRAE, *Handbook of Fundamentals,* Chapter 26, Climatic Design Information. It is suggested that the 99.6 percent heating dry bulb (DB) temperature and the 0.4 percent cooling DB temperature be used as the winter and summer design condition, respectively. It is also suggested that the 1 percent extreme wind velocity be used as the design condition. Where available, more site-specific data should be consulted.

A.1.7 The performance objective of automatic sprinklers installed in accordance with NFPA 13, *Standard for the Installation of Sprinkler Systems,* is to provide fire control, which is defined as follows: limiting the size of a fire by distribution of water so as to decrease the heat release rate and pre-wet adjacent combustibles, while controlling ceiling gas temperatures to avoid structural damage. A limited number of investigations have been undertaken in which full-scale fire tests were conducted in which the sprinkler system was challenged but provided the expected level of performance (Madrzykowski and Vettori, 1992, and Lougheed et al., 1994). These investigations indicate that, for a fire control situation, the heat release rate is limited but smoke can continue to be produced. However, the temperature of the smoke is reduced and the pressure differences provided in this document for smoke-control systems in fully sprinklered buildings are conservative. In addition, with the reduced smoke temperatures, the temperature requirement for smoke-control components in contact with exhaust gases can be limited.

A.2.2.1 A smoke-control system should be designed to maintain the minimum design pressure differences under likely conditions of stack effect or wind. The minimum design pressure differences of Table 2.2.1 for nonsprinklered spaces are values that will not be overcome by buoyancy forces of hot gases. The method used to obtain the values of Table 2.2.1 for nonsprinklered spaces follows. The pressure difference due to buoyancy of hot gases is calculated by the following equation:

$$\Delta P = 7.64\left[\frac{1}{T_o} - \frac{1}{T_F}\right]h$$

where:

ΔP = pressure difference due to buoyancy of hot gases (in. w.g.)

T_o = absolute temperature of surroundings (°R)

T_F = absolute temperature of hot gases (°R)

h = distance above neutral plane (ft)

$$\Delta P = 3460\left[\frac{1}{T_o} - \frac{1}{T_F}\right]h$$

where:

ΔP = pressure difference due to buoyancy of hot gases (Pa)

T_o = absolute temperature of surroundings (K)

T_F = absolute temperature of hot gases (K)

h = distance above neutral plane (m)

The neutral plane is a horizontal plane between the fire space and a surrounding space at which the pressure difference between the fire space and the surrounding space is zero. For Table 2.2.1, h was conservatively selected at two-thirds of the floor to ceiling height, the temperature of the surroundings was selected at 70°F (20°C), the temperature of the hot gases was selected at 1700°F (927°C), and a safety factor of 0.03 in. w.g. (7.5 Pa) was used.

For example, calculate the minimum design pressure difference for a ceiling height of 12 ft as follows:

$$T_o = 70 + 460 = 530°R$$

$$T_F = 1700 + 460 = 2160°R$$

$$h = (12)(^2/_3) = 8 \text{ ft}$$

From the above equation, ΔP = 0.087 in. w.g. Adding the safety factor and rounding off, the minimum design pressure difference is 0.12 in. w.g.

A.2.2.2 The forces on a door in a smoke control system are illustrated in Figure A.2.2.2. The force required to open a door in a smoke control system is

$$F = F_r + \frac{5.2(WA)\Delta P}{2(W-d)}$$

where:

F = total door opening force (lb)

F_r = force to overcome the door closer and other friction (lb)

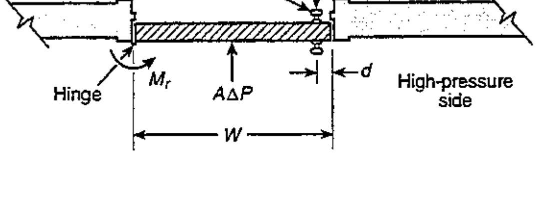
W = door width (ft)

A = door area (ft²)

ΔP = pressure difference across the door (in. w.g.)

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

FIGURE A.2.2.2 Forces on a door in a smoke control system.



A.2.3.7 During the time that occupants of the smoke zone are exiting the area, the conditions in the smoke zone are still tenable. Although opening the stairwell door on the fire floor during this time might release some smoke into the stairwell, it will not create untenable conditions there. Once conditions in the smoke zone become untenable, it is unlikely that the door to the fire floor would be opened by occupants of that floor. For this reason, designing for an open stairwell door on the fire floor is normally not required. Doors blocked open in violation of applicable codes are beyond the capability of the system.

The importance of the exterior stairwell door can be explained by considering the conservation of mass of the pressurization air. This air comes from the outside and must eventually flow back to the outside. For an open interior door, the rest of the building on that floor acts as flow resistance to the air flowing out the open doorway. When the exterior door is open, there is no other flow resistance, and the flow can be 10 to 30 times more than through an open interior door.

A.2.4.1(5) Rule 211.3a, Phase I Emergency Recall Operations, of ASME/ANSI A17.1, *Safety Code for Elevators and Escalators,* requires that elevator doors open and remain open after the elevators are recalled. This results in large openings into the elevator hoistways, which can greatly increase the airflow required for pressurization. NFPA 80, *Standard for Fire Doors and Fire Windows,* permits closing of elevator doors after a predetermined time when required by the authority having jurisdiction. Local requirements on operation of elevator doors should be determined and incorporated into the system design.

A.2.4.3 The following references discuss research concerning elevator use during fire situations: Klote and Braun (1996); Klote (1995); Klote, Levin, and Groner (1995); Klote, Levin, and Groner (1994); Klote (1993); Klote, Deal, Donoghue, Levin, and Groner (1992); and Klote, Alvord, Levin, and Groner (1992).

A.2.5.2.3 Design guidance on dilution temperature is provided in ASHRAE/SFPE, *Design of Smoke Management Systems.*

A.2.6 Methods of design for areas of refuge are presented in the ASHRAE Transactions paper, "Design of Smoke Control Systems for Areas of Refuge" (Klote 1993).

A.3.4.2.2 The control system should be designed as simply as possible to attain the required functionality. Complex controls, if not properly designed and tested, can have a low level of reliability and can be difficult to maintain.

A.3.4.3.2 *Controls for Nonsmoke Control Purposes.* Manual controls exclusively for other building control purposes, such as hand-off-auto switches located on a thermostat, are not considered to be manual controls in the context of smoke control. Manual activation and deactivation for smoke control purposes should override manual controls for other purposes.

Manual Pull Stations. Generally, stairwell pressurization systems can be activated from a manual pull station, provided the response is common for all zones. Other systems that respond identically for all zone alarms can also be activated from a manual pull station. An active-tracking stairwell pressurization system that provides control based on the pressure measured at the fire floor should not be activated from a manual pull station.

A.3.4.3.3 Activation of the smoke-control system should occur immediately after receipt of the activation command. To prevent damage to equipment, it might be necessary to delay activation of certain equipment until other equipment has achieved a prerequisite state (i.e., delay starting a fan until its associated damper is partially or fully open). The times given for components to achieve their desired state are measured from the time each component is activated.

A.3.4.3.4 Example of a Fire Fighters' Smoke-Control Station. Considerations for a fire fighters' smoke-control station should include the following:

(a) *Location and Access.* The FSCS should be located in proximity to other fire fighters' systems as can be provided within the building. Means should be provided to ensure only authorized access to the FSCS. Where acceptable to the authority having jurisdiction, the FSCS should be provided within a specific location or room, separated from public areas by a suitably marked and locked door. If the FSCS is located in a separate room, the room location, size, access means, and other physical design considerations should be acceptable to the authority having jurisdiction.

(b) *Physical Arrangement.* The FSCS should be designed to graphically depict the physical building arrangement, smoke-control systems and equipment, and the areas of the building served by the equipment. Following is a summary of the status indicators and smoke-control capability applicable to the FSCS smoke-control graphic(s). Status indicators should be provided for all smoke-control equipment by pilot lamp–type indicators as follows:

(1) Smoke-control fans and other critical operating equipment in the operating state: green
(2) Smoke-control equipment and other critical equipment that may have two or more states or positions, such as dampers: green (i.e., open), yellow (i.e., closed). The position of each piece of equipment should be indicated by lamps and appropriate legends. Intermediate positions (e.g., modulating dampers that are not fully open or fully closed) can be indicated by not illuminating either of their pilot lamps.
(3) Smoke-control system or equipment faults: amber/orange

The positions of multiposition control switches should not be used to indicate the status of a controlled device in lieu of pilot lamp–type status indicators as described in A.3.4.3.4(b)(1) through (3).

Provision should be included for testing the pilot lamps on the FSCS smoke-control panel(s) by means of one or more "LAMP TEST" momentary push buttons or other self-restoring means.

(c) *Smoke-Control Capability.* The FSCS should provide control capability over all smoke-control system equipment or zones within the building.

Wherever practical, it is recommended that control be provided by zone, rather than by individual equipment. This approach will aid fire fighters in readily understanding the operation of the system and will help to avoid problems caused by manually activating equipment in the wrong sequence or by neglecting to control a critical component. Control by zone should be accomplished as follows:

PRESSURE-AUTO-EXHAUST control over each zone that can be controlled as a single entity relies on system programming to properly sequence all devices in the zone to produce the desired effect. In systems utilizing common supply or return ducts, or both, inclusion of an ISOLATE mode is desirable. To enable use of the system to flush smoke out of a zone after the fire has been extinguished, a PURGE (equal supply and exhaust) mode may also be desirable.

If control over individual pieces of equipment is deemed necessary, the following control options should be provided:

(1) ON-AUTO-OFF control over each individual piece of operating smoke-control equipment that can also be controlled from other sources within the building. Controlled components include all stairway pressurization fans; smoke exhaust fans; HVAC supply, return, and exhaust fans in excess of 2000 ft³min (57 m³/min); elevator shaft fans; atrium supply and exhaust fans; and any other operating equipment used or intended for smoke-control purposes.
(2) ON-OFF or OPEN-CLOSE control over all smoke-control and other critical equipment associated with a fire or smoke emergency and that can be controlled only from the FSCS
(3) OPEN-AUTO-CLOSE control over all individual dampers relating to smoke control and that are also controlled from other sources within the building
(4) HVAC terminal units, such as VAV mixing boxes that are all located within and serve one designated smoke-control zone, which can be controlled collectively in lieu of individually. HVAC unit coil face bypass dampers that are so arranged as not to restrict overall airflow within the system can be exempted.

Additional controls might be required by the authority having jurisdiction.

(d) *Control Action and Priorities.* The FSCS control action should be as follows:

(1) *ON-OFF, OPEN-CLOSE.* These control actions should have the highest priority of any control point within the building. Once issued from the FSCS, no automatic or manual control from any other control point within the building should contradict the FSCS control action.

    If automatic means are provided to interrupt normal nonemergency equipment operation or produce a specific result to safeguard the building or equipment (e.g., duct freezestats, duct smoke detectors, high-temperature cutouts, temperature-actuated linkage, and similar devices), such means should be capable of being overridden or reset to levels not exceeding levels of imminent system failure, by the FSCS control action, and the last control action as indicated by each FSCS switch position should prevail.

    Control actions issued from the FSCS should not override or bypass devices and controls intended to protect against electrical overloads, provide for personnel safety, and prevent major system damage. These devices include overcurrent protection devices and electrical disconnect switches, high-limit static pressure switches, and combination fire/smoke dampers beyond their degradation temperature classifications meeting UL 555, *Standard for Safety Fire Dampers*, or UL 555S, *Standard for Safety Leakage Rated Dampers for Use in Smoke Control Systems.*
(2) *AUTO.* Only the AUTO position of each three-position FSCS control should allow automatic or manual control action from other control points within the building. The AUTO position should be the normal, nonemergency, building control position. When an FSCS control is in the

AUTO position, the actual status of the device (on, off, open, closed) should continue to be indicated by the status indicator(s).

(3) *FSCS Response Time.* For purposes of smoke control, the FSCS response time should be the same as for automatic or manual smoke-control action initiated from any other building control point. *(See 3.4.3.3.)* FSCS pilot lamp indication of the actual status of each piece of equipment should not exceed 15 seconds after operation of the respective feedback device.

(e) *Graphic Depiction.* The location of smoke-control systems and equipment within the building should be indicated by symbols within the overall FSCS graphic panel. Where zoned smoke control is used, a sufficient number of smoke-control components to convey the intended operation of the smoke-control systems and equipment should be shown. These components would normally include major ducts, fans, and dampers that are part of the smoke-control system. Where control is provided over individual fans and dampers used for smoke control, these components should be shown on the FSCS graphic panel and, where appropriate, should be shown connected to their respective ducts, with a clear indication of the direction of airflow. In either case, the building areas served by the smoke-control systems should be shown on the FSCS graphic panel.

Status indication for damper position should be shown where their inclusion would aid in understanding the operation of the system and can be omitted where their inclusion would hinder understanding of the system, such as on an already densely populated panel. Damper position indication can also be omitted where no separate control over damper position is provided.

A.3.4.5.2 Manual controls used exclusively for other building control purposes, such as hand-off-auto switches located on a thermostat, are not considered to be manual controls in the context of smoke control. Manual activation and deactivation for smoke control purposes should override manual controls for other purposes.

A.3.4.5.4 Examples of auxiliary functions that can be useful but are not required are the opening and closing of terminal boxes while pressurizing or exhausting a smoke zone. These functions are considered auxiliary if the desired state is achieved without these functions. These functions can, however, help to achieve the desired state more readily.

A.3.4.5.5 During a fire, it is likely that enough smoke to activate a smoke detector might travel to other zones and subsequently cause alarm inputs for other zones. Systems activated by smoke detectors should continue to operate according to the first alarm input received, rather than diverting controls to respond to any subsequent alarm input(s).

Systems initiated by heat-activated devices, and designed with sufficient capacity to exhaust multiple zones, can expand the number of zones being exhausted to include the original zone and subsequent additional zones, up to the limit of the mechanical system's ability to maintain the design pressure difference. Exceeding the design capacity will likely result in the system's failing to adequately exhaust the fire zone so as to achieve the desired pressure differences. If the number of zones that can be exhausted while still maintaining the design pressure is not known, this number should be assumed to be one.

A.3.4.6 Verification devices can include the following:

(1) End-to-end verification of the wiring, equipment, and devices in a manner that includes provision for positive confirmation of activation, periodic testing, and manual override operation
(2) The presence of operating power downstream of all circuit disconnects
(3) Positive confirmation of fan activation by means of duct pressure, airflow, or equivalent sensors that respond to loss of operating power, problems in the power or control circuit wiring, airflow restrictions, and failure of the belt, shaft coupling, or motor itself
(4) Positive confirmation of damper operation by contact, proximity, or equivalent sensors that respond to loss of operating power or compressed air; problems in the power, control circuit, or pneumatic lines; and failure of the damper actuator, linkage, or damper itself
(5) Other devices or means as appropriate

Items (1) through (5) describe multiple methods that can be used, either singly or in combination, to verify that all portions of the controls and equipment are operational. For example, conventional (electrical) supervision can be used to verify the integrity of the conductors from a fire alarm system control unit to the relay contact within 3 ft (1m) of the control system input *(see NFPA 72, National Fire Alarm Code®, Section 3.9)*, and end-to-end verification can be used to verify operation from the control system input to the desired end result. If different systems are used to verify different portions of the control circuit, controlled equipment, or both, then each system would be responsible for indicating off-normal conditions on its respective segment.

End-to-end verification, as defined in 1.4.5, monitors both the electrical and mechanical components of a smoke-control system. End-to-end verification provides positive confirmation that the desired result has been achieved during the time that a controlled device is activated. The intent of end-to-end verification goes beyond determining whether a circuit fault exists but instead ascertains whether the desired end result (i.e., airflow or damper position) is achieved. True end-to-end verification, therefore, requires a comparison of the desired operation to the actual end result.

An open control circuit, failure of a fan belt, disconnection of a shaft coupling, blockage of an air filter, failure of a motor, or other abnormal condition that could prevent proper operation is not expected to result in an off-normal indication when the controlled device is not activated, since the measured result at that time matches the expected result. If a condition that prevents proper operation persists during the next attempted activation of the device, an off-normal indication should be displayed.

A.4.3 Over the past three decades, several network computer models have been written to calculate steady state airflow and pressures throughout a building. At one time, ASCOS *(see ASHRAE/SFPE, Design of Smoke Management Systems)* was the most widely used model for smoke control analysis, and it has been validated against field data from flow experiments at an eight-story tower in Champs Sur Marne, France (Klote and Bodart 1985).

Wray and Yuill (1993) evaluated several flow algorithms to find the most appropriate one for analysis of smoke control systems. The best algorithm from this study based on computational speed and use of computer memory has been incorporated in the CONTAM computer model developed by Walton (1997). CONTAM is a significant improvement over ASCOS with respect to both numerics and ease of use.

Network computer models should be used for the design of smoke-control systems in complex buildings for which algebraic equations are not applicable or are impractical to use. This includes the analysis of stairwell pressurization systems with open doors, combination smoke-control systems, and smoke-control systems in asymmetric buildings.

A.4.5 Leakage areas for exterior building walls have typically been based on the measurements of Tamura and Shaw (1976) and Tamura and Wilson (1966). Recently, several buildings used in the previous studies were retested after they were retrofitted for energy efficiency [Shaw, Reardon, and Cheung (1993)]. The values for leakage areas of exterior building walls were based on these new values.

A.5.1.1 Door-opening forces include frictional forces, the forces produced by the door hardware, and the forces produced by the smoke-control system. In cases where frictional forces are excessive, the door should be repaired.

A.5.1.2 Although not part of the formal testing procedure, the testing of buildings to determine the amount of leakage between smoke zones can be of value in developing the initial system. Testing for this purpose can often use airflow measuring equipment existing in the systems. This section describes the normal arrangement of a variety of systems and testing methods that can be used for determining the leakage of enclosures. Leakage in buildings comes from a variety of sources, such as the following:

(1) Curtain wall construction where leakage paths can be formed between the outer surface and the floor slab
(2) Drywall partitions where gaps in the drywall behind cover moldings can form leakage paths
(3) Electric switches and outlets in drywall partitions that form leakage paths through the partitions
(4) Installation of doors with undercuts, latching mechanisms, and other gaps forming leakage paths
(5) Interface of drywall partitions at fluted metal deck requiring seals in the flute
(6) Electric outlets in floor slabs within the space or above the space and providing leakage to other floors of the building
(7) Duct penetrations through walls where there can be leakage around the duct behind angles that hold fire dampers in place
(8) Perimeter induction systems that often have gaps around ducts through floor slabs that are hidden behind air distribution enclosures
(9) Pipe, conduit, and wireway penetrations through walls and floors requiring listed through-penetration seals

Building HVAC Systems Suitable for Enclosure Tightness Testing. Many building HVAC systems can be used to measure the leakage through enclosures. These systems typically contain a central fan that can draw large quantities of outside air into the building for pressurizing. Because all these systems contain openings, ductwork, and sometimes fans to return the air from the enclosure to the central air handler, it is important that these systems be shut off during the test. The use of smoke dampers at the points where the ducts leave the enclosure will give more assurance that leakage from the space through this source will be minimized.

(a) *Single-Floor VAV Systems.* Many modern office buildings are provided with a separate air handler on each floor of the building to supply conditioned air to the space. These systems are arranged as variable volume systems, whereby the thermostats vary the amount of air delivered to the space rather than the temperature of that air. This arrangement requires a variable frequency controller on the fan that responds to pressure in the duct system. As the variable volume control device is closed, the pressure builds up in the duct and the fan speed is slowed in response to that pressure. Normally these systems contain air-measuring devices in the supply and return ducts that are used to synchronize the return fan operation with the supply fan, so a constant quantity of outside air can be introduced into the space to maintain indoor air quality. These airflow measuring devices can be used to measure the airflow introduced into the space, and the speed of the fan can be adjusted to control the pressure across the enclosure barriers.

(b) *Central Fan VAV Systems.* Central fan VAV systems are a variation of the single-floor VAV system. A single fan will supply 10 or more floors, each of which has a number of variable volume boxes. As in the case of the single-floor system, the fan responds to a pressure sensor in the duct. A flow-measuring station at the fan is used to track the return fan with the supply fan in order to maintain constant outside air, as in the case of the single-floor VAV system. Generally, these systems are provided with a motor-operated shut-off damper at each floor, since the system can be economically used to supply only a portion of the floors when other floors are vacant.

These systems can be used for testing of spaces by commanding that all of the supply dampers to the floors be closed except on the floor being tested. In this manner, the airflow onto the floor can be measured as the pressure across the barriers is adjusted.

The leakage characteristics of the main duct system as well as those of the dampers that are to be shut must be known so the corrections for duct and damper leakage in the system of the floor under test can be determined ahead of time. This can be accomplished by shutting all the dampers on the system, pressurizing the duct system to various pressures using the supply fans, and measuring the airflow at the air-measuring station in the supply duct.

One variation of a multifloor VAV system has air-measuring stations on each floor of the building. The purpose of these stations is to verify that a particular tenant is not creating so much load on the floor that more airflow is used than is designed into the system. When overload is encountered, the airflow can be measured directly on the floor so that adjustments for main duct leakage are unnecessary.

(c) *Constant Volume Multizone Systems.* Constant volume multizone systems mix hot and cold air at a central air-handling unit and have a separate duct system that goes out to various spaces. Typically, they are not provided with air-measuring stations that would have to be retrofitted to the ducts delivering air to the spaces. The spaces need to coincide with the enclosures being tested. Typically, there is also no means of varying the flow to each space. Varying the flow requires the addition of either manual or motorized dampers in the duct system that are adjusted to achieve the test pressure or pressures.

(d) *Constant Volume Terminal Reheat System.* Constant volume terminal reheat systems are the most difficult to use for testing for enclosure tightness. Typically, these systems contain central fans that deliver air to a duct system at a set temperature. The duct system is distributed throughout the building, and reheated coils are placed at various locations to temper the air to maintain space conditions. There are typically no measuring stations or any automatic dampers in the system. To use this system for testing, it is first necessary to retrofit it with air-measuring stations and dampers to coincide with the enclosures being tested.

Building HVAC Systems Not Suitable for Enclosure Tightness Testing. A number of HVAC systems have little or no value in testing the tightness of an enclosure, because they introduce a limited amount of airflow into the space or are arranged so that there are multiple duct entrances into the space. Therefore, making airflow measurement in such systems is impractical. A summary of these systems follows.

(a) *Unitary Heat Pump/Fan Coil Systems.* Unitary heat pump/fan coil systems come in a number of configurations. These systems are similar, in that the space is provided with a number of separate units, each with limited airflow capacity. Outside air to the space is introduced in one of the following three manners:

(1) Units are located on the perimeter with a separate outside air duct for each unit. This typically has a small penetration through the outside wall of the building with no ductwork attached. The amount of outside air introduced is so small and the capacity of the systems to pressurize the space is so limited that the systems cannot be used for testing the integrity of the space. In these instances, the units will be detrimental to the operation of any system in the space designed to pressurize it unless each outside air duct is fitted with a tight-closing automatic damper.
(2) Units are located only on the perimeter, and outside air is introduced through a separate duct system. In this instance, the units are used in conjunction with an interior duct system. The outside air duct for the perimeter is of limited capacity and should be fitted with tight-closing automatic dampers to maintain the integrity of the enclosure. Testing of the space should be done through the interior duct system.
(3) Units are distributed throughout both the perimeter and interior. In this instance, outside air is introduced into the space through a separate duct system that distributes throughout the entire floor area. This duct system is sized to handle the minimum outside air quantities needed in the space and might or might not have sufficient flow to provide pressure in the space. Whether this system can be used for the pressure testing must be decided on a case by case basis. It will be necessary to provide the system with air-measuring stations and possibly shut-off dampers if the system serves multiple floors.

(b) *Perimeter Induction Systems.* Perimeter induction systems are typically arranged to handle only the perimeter of the building. These systems are arranged with a terminal unit along the perimeter under the windows, each provided with a duct to a central air distribution system. The ducts typically are small [under 20 in.^{2} (129 cm^2) per unit] and either penetrate the floor to a distribution system on the floor below or connect to a vertical riser that extends up through the building and supplies four to six units per floor. These systems do not lend themselves to testing of spaces because of the multiple duct connections on each floor. The duct connections should be provided with tight-closing automatic dampers so that pressurization of the space will be possible.

There is generally an interior system provided, which is one of the types previously described, that can be used for the testing and pressurization.

A.5.3.3 Guidance on test procedures can be found in the publications of organizations such as the Associated Air Balance Council (AABC); National Environmental Balancing Bureau (NEBB); the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE); and the Sheet Metal and Air Conditioning Contractors National Association (SMACNA).

A.5.3.3.6 The test methods described in Chapter 5 should provide an adequate means to evaluate the smoke-control system's performance. Other test methods have been used historically in instances where the authority having jurisdiction requires additional testing. These test methods have limited value in evaluating certain system performance, and their validity as methods of testing a smoke-control system is questionable. Examples of other test methods that have been used are as follows:

(1) Chemical smoke tests
(2) Tracer gas tests
(3) Real fire tests

Chemical smoke tests have achieved a degree of popularity out of proportion to the limited information they are capable of providing. The most common sources of chemical smoke are the commercially available "smoke candle" (sometimes called a smoke bomb) and the smoke generator apparatus. In this test, the smoke candle is usually placed in a metal container and ignited. The purpose of the metal container is protection from heat damage after ignition; it does not inhibit observation of the movement of the chemical smoke. Care needs to 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. Smoke from a sprinklered fire has little buoyancy, and so it might 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.

The question arises as to what information can be obtained from a cold chemical smoke test. If a smoke-control system does not achieve a high enough level of pressurization, the pressures due to hot, buoyant smoke could overcome that system. The ability to control cold chemical smoke provides no assurance of the ability to control hot smoke in the event of a real fire.

Chemical smoke is also used to evaluate the effectiveness of so-called smoke "purging" systems. Even though such systems are not smoke-control systems, they are closely related and thus are briefly addressed here. For example, consider a system that has six air changes per hour when in the smoke purge mode. Some testing officials have mistaken this number of air changes to mean that the air is completely changed every 10 minutes and that 10 minutes after the smoke candle is out, all the smoke should be gone from the space. Of course, this is not what happens. In a purging system, the air entering the space mixes to some extent with the air and smoke in the space. If the purging system is part of the HVAC system, it has been designed to promote a rather complete degree of mixing. If the concentration of smoke is close to uniform within the space, then the method of analysis for purging presented in Section 2.3 of ASHRAE/SFPE, *Design of Smoke Management Systems,* is appropriate. Based on such perfect mixing, after 10 minutes, 37 percent of the original smoke remains in the space.

A.5.3.4.5 In lieu of specific direction in the local code or contract documents, choose the doors to be opened as follows in order to produce the most severe conditions:

(a) For the differential pressure test, the open doors should include those for which the highest pressure difference was measured in the tests with all doors closed *(see 5.3.4.3)*. When measured with the stairwell as the reference, as described in 5.3.4.1, these doors have the greatest negative values.

(b) When systems are designed for open stairwell doors and total building evacuation, the number of open doors should include the exterior stairwell door.

(c) Because the pressure in the stairwell must be greater than the pressure in the occupied areas, it is not necessary to repeat the door-opening force tests with open doors. Opening any door would decrease the pressure in the stairwell and thereby decrease the door-opening force on the remaining doors.

A.5.3.8.1 When testing the combination of zoned smoke-control systems and stairwell pressurization systems, the tests applicable to each stand-alone system should be conducted. Differential pressure tests are specified in both 5.3.4 and 5.3.5. When the two systems are used in combination, the stairwell should be treated as a zone in a zoned smoke-control system. The minimum design pressures specified in Table 2.2.1 apply only to the differential pressure tests specified in 5.3.5.

Differential pressure tests conducted as directed in 5.3.4.3 are used to determine the doors that should be opened during the tests specified in 5.3.4.4 and 5.3.4.5. It is not expected that these values will comply with the minimum design pressures specified in Table 2.2.1, except at the fire floor.

In lieu of specific direction in the local code or contract documents, choose the doors to be opened as follows in order to produce the most severe conditions:

(a) For the differential pressure test, the open doors should include those for which the highest pressure difference was measured in the tests with all doors closed *(see 5.3.4.3)*, excluding the door on the fire floor *(see A.2.3.7 for rationale)*. When measured with the stairwell as the reference, as described in 5.3.4.1, these doors have the greatest negative values.

(b) When systems are designed for open stairwell doors and total building evacuation, the number of open doors should include the exterior stairwell door.

(c) For the door-opening force test, the open doors should include any doors (up to the specified number) found in the tests with all doors closed *(see 5.3.4.3)* to have pressure in the occupied area greater than the pressure in the stairwell. Opening these doors adds pressure to the stairwell, thereby increasing door-opening forces on the remaining doors. When measured with the stairwell as the reference, as described in 5.3.4.1, these doors have the greatest positive values. If no doors meet these criteria, it is not necessary to repeat the door-opening force tests with open doors, since opening any door would decrease the pressure in the stairwell and thereby decrease the door-opening force on the remaining doors.

Appendix B Referenced Publications

B.1 The following documents or portions thereof are referenced within this recommended practice for informational purposes only and are thus not considered part of its recommendations. The edition indicated here for each reference is the current edition as of the date of the NFPA issuance of this recommended practice.

B.1.1 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 13, *Standard for the Installation of Sprinkler Systems,* 1999 edition.

NFPA 72, *National Fire Alarm Code®*, 1999 edition.

NFPA 80, *Standard for Fire Doors and Fire Windows,* 1999 edition.

B.1.2 Other Publications

B.1.2.1 ASHRAE Publications. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329-2305.

ASHRAE/SFPE, *Design of Smoke Management Systems,* 1992.

ASHRAE, *Handbook of Fundamentals,* 1997.

B.1.2.2 ASME Publication. American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990.

ASME/ANSI A17.1, *Safety Code for Elevators and Escalators,* 1993.

B.1.2.3 SFPE Publication. Society of Fire Protection Engineers, 7315 Wisconsin Avenue, Suite 1225W, Bethesda, MD 20814.

SFPE, *Handbook of Fire Protection Engineering,* 1995.

B.1.2.4 UL Publication. Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062.

UL 555, *Standard for Safety Fire Dampers,* 1999.

UL 555S, *Standard for Safety Leakage Rated Dampers for Use in Smoke Control Systems,* 1999.

B.1.3 Additional Publications.

Klote, J.H., "Design of Smoke Control Systems for Areas of Refuge," *ASHRAE Transactions,* American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA, Vol. 99, Part 2, 1993, pp. 793–807.

Klote, J.H., "A Method for Calculation of Elevator Evacuation Time," *Journal of Fire Protection Engineering,* Vol. 5, 1993, pp. 83–96.

Klote, J.H., "Design of Smoke Control Systems for Elevator Fire Evacuation Including Wind Effects," 2nd Symposium on Elevators, Fire and Accessibility, Baltimore, ASME, New York, 1995, pp. 59–77.

Klote, J.H., D.M. Alvord, B.M. Levin, and N.E. Groner, "Feasibility and Design Considerations of Emergency Evacuation by Elevators," NISTIR 4870, National Institute of Standards and Technology, Gaithersburg, MD, 1992.

Klote, J.H., and X. Bodart, "Validation of Network Models for Smoke Control Analysis," *ASHRAE Transactions,* American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA, Vol. 91, Part 2B, 1985, pp. 1134–1145.

Klote, J.H., and E. Braun, "Water Leakage of Elevator Doors with Application to Building Fire Suppression," NISTIR 5925, National Institute of Standards and Technology, Gaithersburg, MD, 1996.

Klote, J.H., S.P. Deal, E.A. Donoghue, B.M. Levin, and N.E. Groner, "Fire Evacuation by Elevators," *Elevator World*, 1993, pp. 66–75.

Klote, J.H., B.M. Levin, and N.E. Groner, "Feasibility of Fire Evacuation by Elevators at FAA Control Towers," NISTIR 5445, National Institute of Standards and Technology, Gaithersburg, MD, 1994.

Klote, J.H., B.M. Levin, and N.E. Groner, "Emergency Elevator Evacuation Systems," 2nd Symposium on Elevators, Fire and Accessibility, Baltimore, ASME, New York, 1995, pp. 131–150.

Lougheed, G.D., J.R. Mawhinney, and J. O'Neill, "Full-Scale Fire Tests and the Development of Design Criteria for Sprinkler Protection of Mobile Shelving Units," *Fire Technology*, Vol. 30, 1994, pp. 98–133.

Madrzykowski, D., and R. Vettori. "A Sprinkler Fire Suppression Algorithm," *Journal of Fire Protection Engineering*, Vol. 4, 1992, 151–164.

Shaw, C.Y., J.T. Reardon, and M.S. Cheung, "Changes in Air Leakage Levels of Six Canadian Office Buildings," *ASHRAE Journal*, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA, 1993.

Tamura, G.T., and C.Y. Shaw, "Studies on Exterior Wall Air Tightness and Air Infiltration of Tall Buildings," *ASHRAE Transactions*, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA, Vol. 82, Part 1, 1976, pp. 122–134.

Tamura, G.T., and A.G. Wilson, "Pressure Differences for a Nine-Story Building as a Result of Chimney Effect and Ventilation System Operation," *ASHRAE Transactions*, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA, Vol. 72, Part 1, 1966, pp. 180–189.

Walton, G.N., "CONTAM96 User Manual," NISTIR-6056, National Institute of Standards and Technology, Gaithersburg, MD, 1997.

Wray, C.P., and G.K. Yuill, "An Evaluation of Algorithms for Analyzing Smoke Control Systems," *ASHRAE Transactions*, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA, Vol. 99, Part 1, 1993, pp. 160–174.

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