SELECTION 3

Concepts of Egress Design

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This selection, reprinted from the 2003 edition of NFPA's Fire Protection Handbook, *offers information and statistics for planning how people will react when faced with an emergency fire situation. All internal cross references, figure numbers, and table numbers remain unchanged and refer to the original published material.*

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CHAPTER 3

Concepts of Egress Design

SECTION 4

Revised by
James K. Lathrop

Means of egress and their design should be based upon an evaluation of a building's total fire protection system and an analysis of the population characteristics and hazards to the occupants of that building. The means of egress design should be treated as an integral part of the total system that provides reasonable safety to life from fire.

This chapter covers the fundamental concepts of good egress design that are the basis for NFPA *101*®, *Life Safety Code*®, and *NFPA 5000*™, *Building Construction and Safety Code*™. NFPA *101* governs good practices to provide life safety features in existing buildings and structures and features that can be designed as integral parts of new construction to provide reasonable safety to occupants in fires. *NFPA 5000* addresses new construction only, but covers life safety from many hazards in addition to fire. The components of good means of egress are discussed in some detail, with their functions and relationships in the total concept of proper egress design. Computer modeling and simulation to assist the egress design process also are discussed.

FUNDAMENTALS OF DESIGN

The approach to designing means of egress first requires a familiarity with the reaction of people in fire emergencies. These reactions can differ widely, depending upon the physical and mental capabilities and conditions of building occupants. The psychological and physiological factors affecting the use of exits during emergencies are being identified and measured in research studies. Dr. John L. Bryan discusses in detail behavioral response to fire and smoke in Section 3, Chapter 12 of the *SFPE Handbook of Fire Protection Engineering*, third edition.[1]

Patterns of movement of people, singly and in crowded conditions, must also be understood. In buildings used as schools or theaters housing highly mobile occupants, for example, there are certain reproducible flow characteristics from persons exiting the buildings. These predictable flow characteristics have fostered computer simulation and modeling to aid the egress design process. However, no number of practical exit facilities can prevent injury or loss of life if the occupant egress flow is inhibited or prevented by the building itself, by personnel, or by fire and smoke conditions. An in-depth review of movement of people by Pauls can be found in Section 3, Chapter 13 of the *SFPE Handbook of Fire Protection Engineering*,[2] as well as in "Emergency Movement" by Nelson and MacLennon in Section 3, Chapter 14 of the same document.[3]

Human Factors

The design and capacity of passageways, stairways, and other components in the total means of egress are related to the physical dimensions of the human body. The tendency of people to avoid bodily contact with others should be recognized as a major factor in determining the number of persons who will occupy a given space at any given time. Given a choice, people usually automatically establish "territories" to avoid bodily contact with others.

Studies have shown that most adult men measure less than 20.7 in. (520 mm) across at the shoulder, with no allowance for additional thicknesses of clothing.[4] A "body ellipse" concept is used to develop the design of pedestrian systems. The major axis of the body ellipse measures 24 in. (609 mm), whereas the minor axis is 18 in. (457 mm). This ellipse equals 2.3 sq ft (0.21 m^2), which is assumed to help determine the maximum practical standing capacity of a space.

The movement of persons results in a swaying action that varies from male to female and, depending upon the type of motion, varies with movement on stairs, on level surfaces, or in dense crowds. Body sway has been observed to range 1½ in. (38 mm) left and right during normal free movement. Where movement is reduced to shuffling in dense crowds and to movement on stairs, a total sway range of almost 4 in. (101 mm) has been observed. In theory, this indicates that a total width of 30 in. (762 mm) would be required to accommodate a single file of pedestrians traveling up or down stairs.[5]

Crowding people into spaces where less than 3 sq ft (0.28 m^2) of space per person is available under nonemergency conditions may create a hazard. When the average area occupied per person is reduced to 2¾ sq ft (0.25 m^2) or less, contact will be unavoidable. Needless to say, under the psychological stresses imposed during a fire, such crowding and contact could contribute to crowd pressures, resulting in injuries. When a

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queue occurs because of an artificial, temporary situation or because of some permanent design feature, crowd control becomes difficult, and the well-being of individuals is threatened.

Factors Affecting Movement of People

There are several factors that determine how quickly people may pass through the means of egress.

In level walkways an average walking speed of 250 ft/min (76 m/min) is attained under free-flow conditions, with 25 sq ft (2.3 m^2) of space available per person. Speeds below 145 ft/min (44 m/min) show shuffling, which restricts motion. Figure 4.3.1, adapted from *Research Report No. 95* of the London Transport Board,[6] shows the rate of speed reduction for space concentrations of less than 7 sq ft (0.65 m^2) per person. Speeds of less than 145 ft/min (44 m/min) result in shuffling, and, finally, a jam point is reached with one person every 2 sq ft (0.18 m^2). The possibility of a significant nonadaptive behavior exists whenever egress movement is restricted, and the problem becomes urgent under fire exposure conditions, especially when there is more than one person every 3 sq ft (0.28 m^2).

Calculations of flow rates using velocity [ft/min (m/min)] and density [persons/sq ft (m^3)] will reveal flow [persons/min/ft (m) of width], which increases as the pedestrian area decreases. The flow increases will continue until forward movement becomes restricted to the point that the flow begins to drop. Interestingly, observations of flow rates in one study noted the same flow rate sometimes occurred even though walking speeds of people were significantly different. Investigation revealed that the rate of decrease in speed, accompanied by an increase in density, results in uniform flow rates over a wide range of conditions.

A study of footways indicates that for passageways over 4 ft (1.2 m) wide, flow rates are directly proportional to width. The London Transport Board *Research Report No. 95*[6] determined the flow rate in level passages to be 27 persons/min/ft (0.30 m) of width. Travel down stairways was determined at 21 persons/min/ft (0.30 m) of width, whereas upward travel was reduced to 19 persons/min/ft (0.30 m) of width. Where the width of a footway is less than 4 ft (1.2 m), the flow rate depends upon the number of possible traffic lanes. Absolute maximum flow rates occur when approximately 3 sq ft (0.28 m) is occupied per person, which is applicable to both level walkways and stairs. In observed and measured evacuations, however, it has been empirically determined that the maximum flow rates down stairs in high-rise buildings occur when from 4 to 5 sq ft of space (0.37 to 0.46 m^2) is occupied per person, as shown in Figure 4.3.2.[5] When flow in opposite directions takes place in a passageway up to the point where the two flows are of equal magnitude, there is no significant reduction in total flow below that which would be predicted on the basis of unidirectional flow in the same passageway.

Further, flow can be 50 percent greater in short passageways less than 10 ft (3.05 m) long than through a long passageway of the same width. Minor obstructions within a passageway do not appear to have a significant effect on flow. Within a 6 ft (1.82 m) wide passageway, there is no effect on flow rates when a 1-ft (0.45-m) projection is introduced. A 2-ft (0.61-m) projection resulting in a 33 percent reduction in width reduces the flow rate by approximately 10 percent. A major obstruction, though, such as that which occurs at a ticket booth or turnstile, may interrupt the movement of people and reduce flow rates.

Corners, bends, and slight grades up to 6 percent are apparently not factors in determining flow rates. A slight reduction in speed does occur, but the flow rate is maintained by an increased concentration of persons.

A center handrail or mullion, which may divide a passageway into narrower sections, can further reduce the capacity of the passageway. The observed capacity of a 6 ft (1.82 m) wide stairway reveals a reduction from 130 to 105 persons/min after installation of a center handrail.

Except for the very young and the very old, age does not appear to be a significant factor in determining travel speed. Studies have shown a significant reduction in walking speeds for persons

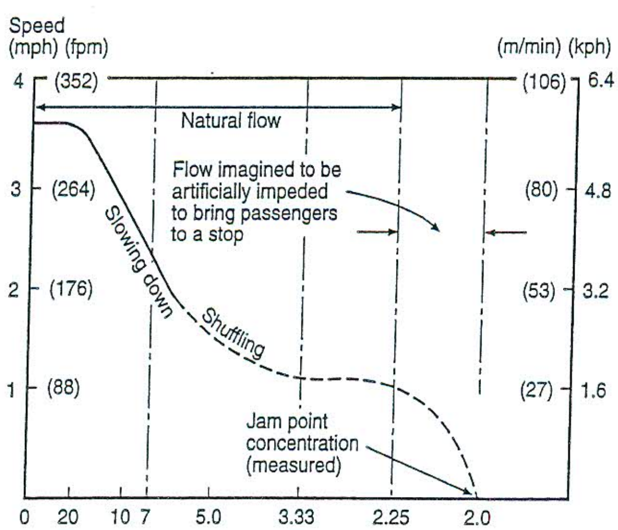


FIGURE 4.3.1 *Speed in Level Passageways (SI units; 1 ft/min = 0.305 m/min; 1 sq ft = 0.093 m^2)*

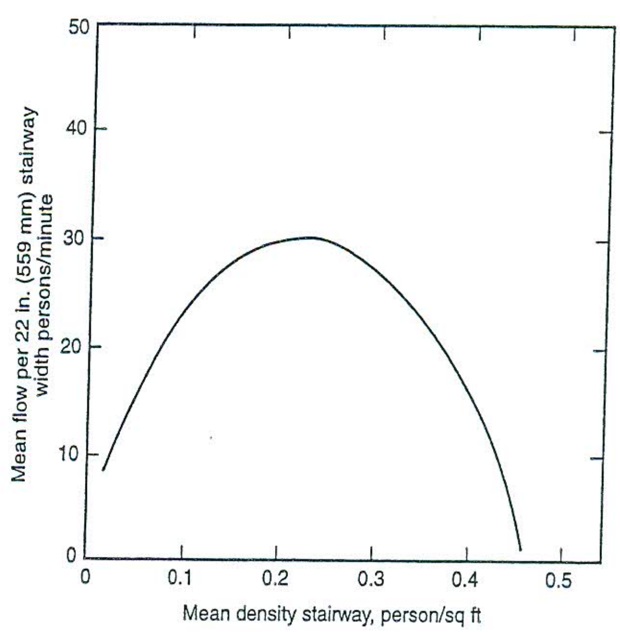


FIGURE 4.3.2 *Effect of Density on Flow Down Exit Stairways in Evacuations of High-Rise Office Buildings[5] (SI units: 1 sq ft = 0.032 m^2)*

over 65 years of age. Studies have further revealed that a 40 percent increase is possible in the normal walking speed, which tends to discount this factor as a major influence on flow rates.[4]

For additional information see Section 3, Chapter 13, of the *SFPE Handbook of Fire Protection Engineering.*

Methods of Calculating Exit Width

Two major principles are used to determine the necessary exit width. They are based on anticipated population characteristics identified with a specific occupancy.

The Flow Method. This method uses the theory of evacuating a building within a specified maximum period of time. Flow rates have traditionally been set at 60 persons per 22 in. (559 mm) width/min through level passageways and doorways. In older editions of NFPA *101* this 22 in. (59 mm) width was referred to as 1 "unit" of exit width. Credit was given only for whole units or ½ unit, a ½ unit being 12 in. The flow method may be applied in assembly occupancies, such as theaters, and educational occupancies where people are alert, awake, and assumed to be in good physical condition. Figure 4.3.3 illustrates the flow time in seconds relative to the effective stair width per person and the units of width.

Pauls's[7] effective stair width concept advocates the consideration of only the portion of the stair used in effective movement by the occupants, as observed in functional and practice evacuations. This width is established with 6-in. (150-mm) clearance from each side wall of the stair.

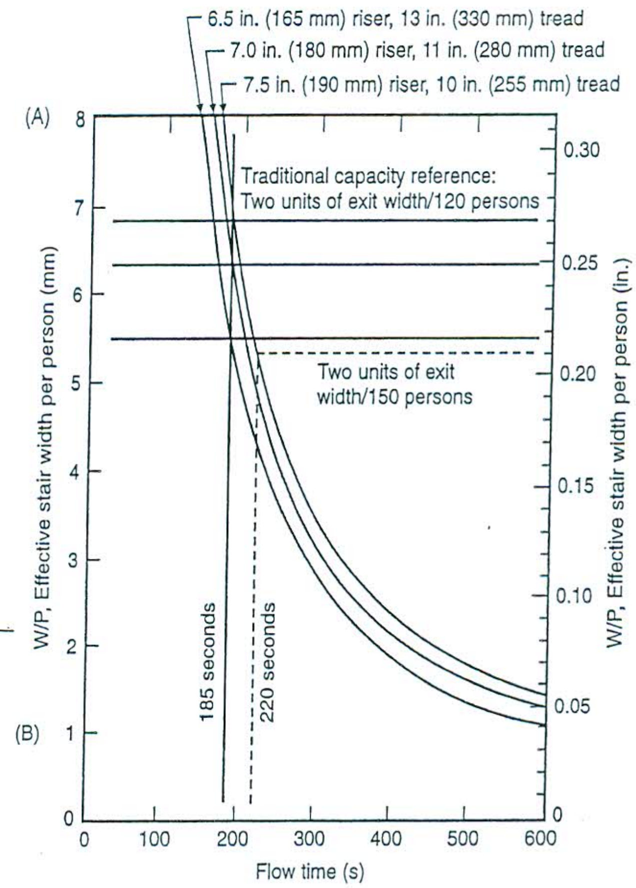


FIGURE 4.3.3 *Relationship between Effective Stair Width and Units of Exit Width per Person and Flow Time for Three Stair Geometries*[7]

The Capacity Method. This method is based on the theory that sufficient numbers of stairways should be provided in a building to adequately house all occupants of the building without requiring any movement, or flow, out of the stairways. In theory, assuming a stairwell provides a safe and protected area for all occupants within the protective barrier created by the stairway enclosure, evacuation of the building may then be more leisurely, permitting people to travel at a rate within their physical ability. The capacity method recognizes that evacuation from high-rise buildings is physically very demanding. Further, evacuation of a healthcare facility is likely to be slow. Thus, design criteria are established to permit holding occupants within exits or areas of refuge.

Application

The capacity and flow methods may both be applied to efficient egress design, depending upon specific circumstances. Where people are expected to be physically or mentally sick, aged, asleep, or incapacitated in any way, evacuation and use of the flow method is unwise. Therefore, the capacity method, which provides a place for everyone within an area of refuge, is the appropriate method.

There is little time between an alert and the use of an exit in assembly occupancies, and maximum flow rates that cause reductions in the area used by each person may result in reduced traffic flows. On the other hand, the control of children in an educational setting, coupled with their familiarity with the surroundings, their presumed high physical capabilities, and their experience with a program of drills should allow rapid evacuation times. The flow method appears to have its application in those occupancies where people are considered to be alert, awake, and of normal physical ability. Pauls has reviewed the historical and current literature relative to the principles of people movement, exit width determination, and the design of the means of egress.[8]

Design of Means of Egress

Designing a means of egress involves more than numbers, flow rates, and densities. Safe exit from a building requires a safe path of escape from the fire environment. The path is arranged for ready use in case of emergency and should be sufficient to permit all occupants to reach a safe place before they are endangered by fire, smoke, or heat. Proper egress design permits everyone to leave the fire-endangered areas in the shortest possible time with efficient exit use. If a fire is discovered in its incipient stage and the occupants are alerted promptly, effective evacuation may take place.

Evacuation travel distances are related to the content fire hazard. The higher the hazard, the shorter the travel distance to an exit.

Depending upon the physical environment of the structure, the characteristics of the occupants, and the fire detection and alarm facilities, fire or smoke may prevent the use of one means of egress. Therefore, at least one alternative means of egress remote from the first is essential. Provision of two separate means of egress is a fundamental safeguard, except where a building or room is small and arranged so that a second exit would not provide an appreciable increase in safety. There are fewer or no advantages to separate means of egress if there is travel through a common space or use of common structural features that result in the loss of the two distinct and physically separate means of egress.

One example of a "common" structure is a multistory building where scissors stairs are used. These are two stairs enclosed within a common shaft, separated by a partition common to both stairs. Scissors stairs are sometimes used to provide the required exit capacity while minimizing the loss of valuable floor space. Where a set of scissors stairs is the only means of egress when two remote exits are required, however, the fundamental principle of two separate means of egress design may be violated. If the common partition between the stairs fails, it would result in the simultaneous loss of both exits during a fire, leaving no alternative means of egress. With scissors stairs, the validity of the two separate means of egress, therefore, depends upon the design characteristics and construction of the common partition (Figure 4.3.4).

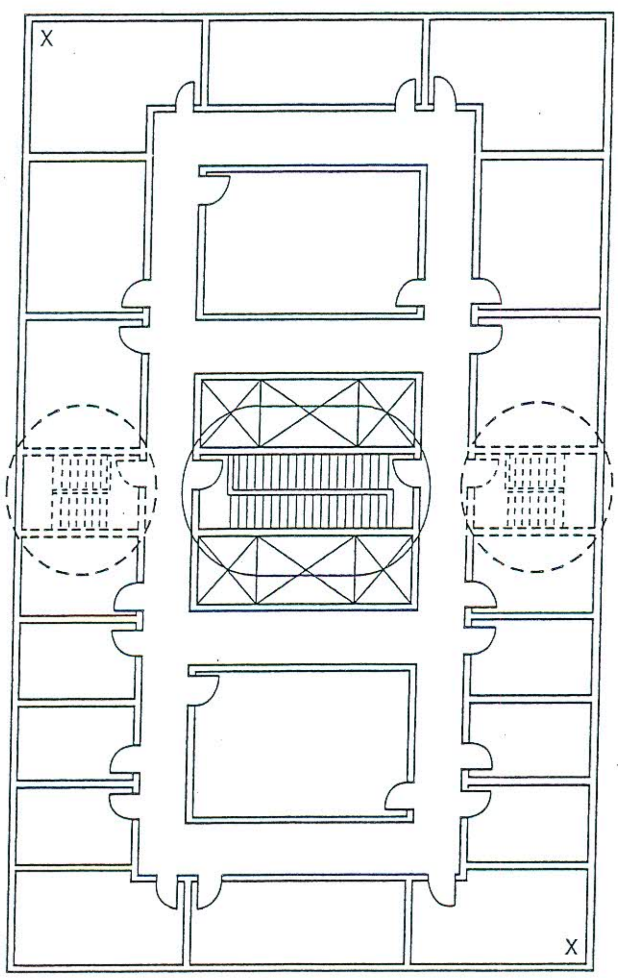


FIGURE 4.3.4 *Advantages and Disadvantages of Scissors Stairs versus Conventional Stairs. This set of scissors stairs provides the same degree of remote exit or entrance doors as the circled stairs shown by dotted lines—travel distance for all occupants is the same, even if the dotted exit stairs were located at opposite corners as denoted by the cross marks. Space is saved; however, the integrity of the separation of the two scissors stairs may remain in question.*

In some proposed egress designs, all the exits discharge through a single lobby at street level, even though this procedure results in egress travel through a common space. This design philosophy presumes that the lobby may be considered a safe area for all future egress needs during the life of the building. Where two remote means of egress are required, this type of egress design is unsuitable.

NFPA *101* limits openings in exit enclosures to those necessary for access to the enclosure from normally occupied spaces and for egress from the enclosure. Penetration of enclosures by ducts or other utilities constitutes a point of weakness and may result in contamination of the enclosure during a fire and should not be permitted. Furthermore, it is not good practice to use exit enclosures for any purpose that could interfere with their value as exits. For example, exit stair enclosures should not be used for storage or any other use not associated with egress or areas of refuge for mobility impaired persons.

The removal of handicapped persons is an important consideration in the design of an emergency means of egress from a building. A 32-in. (813-mm) doorway is considered the minimum width to accommodate a person in a wheelchair. Since handicapped employees or visitors may be found in all types of buildings, special life safety considerations are indicated. The 2000 edition of NFPA *101* contains several additional provisions to protect mobility impaired individuals.

LIFE SAFETY CODE

NFPA *101*, introduced in 1927 and revised and reissued in successive editions, is developed by several committees under the oversight of the Technical Correlating Committee on Safety to Life, a representative group dedicated to safety of life from fire. NFPA *101* is primarily concerned with the control of conditions that threaten the lives of individuals in building fires. This objective is different from fire protection provisions in building codes, which are concerned with the preservation of property, in addition to the preservation of life. In 2000, NFPA announced its intent to write a building code: *NFPA 5000™, Building Construction and Safety Code™*, first edition, due to be published in 2003. The provisions for means of egress in *NFPA 5000™* are written by the same committees that write NFPA *101*. Because of this, the discussion here will address NFPA *101*. It is equally applicable to *NFPA 5000™* when dealing with new construction.

Adequate means of egress alone are not a guarantee of life safety from fire. They do not protect an individual whose own carelessness causes a threat to life, such as setting his or her own clothes on fire. Neither do sufficient means of egress alone provide adequate protection in occupancies such as hospitals, nursing homes, prisons, assisted living facilities, and mental institutions, where occupants are confined or are physically or mentally unable to escape without effective and immediate assistance. NFPA *101* does recognize such situations and provides life safety measures, including low-flame-spread and reduced-smoke-producing materials for interior finish. In addition, automatic sprinkler and smoke management systems called for by NFPA *101* are designed to restrain the spread of fire and smoke and thus help to defend the occupants within an area of refuge until they are able to use the exits or until the fire has been extinguished.

In general, saving building occupants from a fire requires the following, all of which are identified in NFPA *101*:

1. Sufficient number of properly designed, unobstructed means of egress of adequate capacity and arrangement.
2. Provision of alternative means of egress for use if one means of egress is blocked by fire, heat, or smoke.
3. Protection of the means of egress against fire, heat, and smoke during the egress time determined by the occupant load, travel distance, and exit capacity.
4. Subdivision of areas by proper construction to provide areas of refuge in those occupancies where total evacuation is not a primary consideration.
5. Protection of vertical openings to limit the operation of fire protection equipment to a single floor.
6. Provision of detection or alarm systems to alert occupants and notify the fire department in case of fire.
7. Adequate illumination of the means of egress.
8. Proper marking of the means of egress, and the indication of directions.
9. Protection of equipment or areas of unusual hazard that could produce a fire capable of endangering the egressing occupants.
10. Initiation, organization, and practice of effective drill procedures.
11. Provision of instructional materials and verbal alarm systems in high-density and high-life-hazard occupancies to facilitate adaptive behavior.
12. Use of interior finish materials that prevent a high flame spread or dense smoke production that could endanger egressing occupants.

Figure 4.3.5 illustrates some of the principles of exit safety.

NFPA *101* recognizes that full reliance cannot be placed upon any single safeguard, since any single protective feature may not function due to mechanical or human failure. For this reason, redundant safeguards, any one of which will result in a reasonable level of life safety, should be provided. NFPA *101* also recommends the special protection of hazardous areas and specifies where automatic sprinkler, detection, and other protective systems are required.

NFPA *101* is used widely as a guide to good practice and as a basis for local laws or regulations. It differs from building codes since it generally provides little distinction among the different classes of building construction. However, where total evacuation of a building is not practical, due either to the occupant characteristics or the building environment, the construction type becomes an important variable and should be considered.

NFPA *101* also recognizes that all habitable buildings contain sufficient quantities of combustible contents to produce lethal quantities of smoke and heat.[9,10] In addition, casualty studies have established that the toxic properties of smoke are the principal hazard to life,[11] and this hazard is recognized in NFPA *101*.

NFPA *101* is intended to be applied to both new and existing buildings and is designed to provide a reasonable level of life safety from fire in both types of buildings. The Authority Having Jurisdiction is given considerable latitude in achieving conformance with existing buildings. Each existing building represents a special situation that requires individual attention

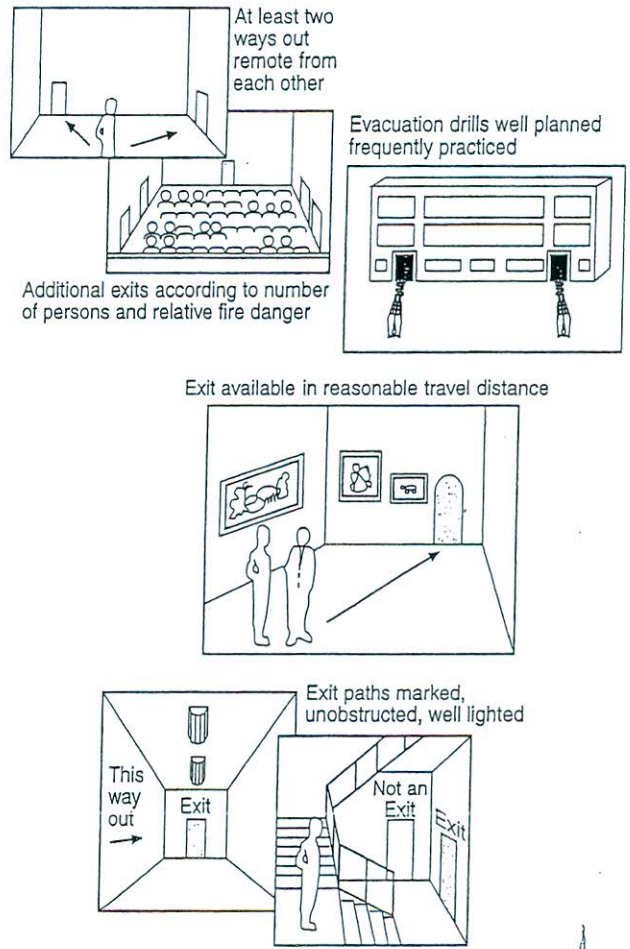


FIGURE 4.3.5 *Principles of Exit Safety*

for the most effective and economical method of achieving a reasonable level of life safety.

The argument that buildings constructed many years ago according to all the legal requirements are sufficiently safe now should not necessarily be accepted. If the economic cost of reasonable life safety is judged to be prohibitive, the occupancy or the structure should be changed or prohibited because there is no justification for subjecting building occupants to an unreasonable level of peril from a fire.

There may be a variety of differing opinions as to what constitutes reasonable life safety from a fire in any given case. It is not possible to guarantee occupants 100 percent life safety from a fire; beyond certain conditions, a building becomes hazardous to the life safety of the occupants in a fire. How should the Authority Having Jurisdiction establish the minimum conditions? NFPA *101* provides guidance for such decisions with the help of studies of major-loss-of-life fires,[12,13] fire development research,[10,14] personnel evacuation,[15–17] and human behavior.[18,19]

NFPA *101* examines the various occupancy populations according to their perceived life safety hazard, which includes psychological and sociological variables, in addition to the physiological and environmental factors. These occupancy classifications are assembly, educational, daycare, healthcare, ambulatory healthcare, detention/correctional, residential, residential board and care, mercantile, business, industrial, and storage. Additional provisions for special-purpose and high-rise structures are also included.

Separate and distinct means of egress provisions are made for each occupancy classification, with the various occupancy subgroups included. These classifications, based on the perceived hazard to life safety from a fire, often differ from older building code occupancy classifications. For example, mercantile and office occupancies were often grouped together in previous editions of building codes. However, there appears to be an increased hazard to life in mercantile properties, resulting from the displays of combustible merchandise, the greater density of the population, and the transient character of most of the occupants. These factors are not usually found in office and educational buildings, which have a relatively low combustibility content, a lower population density, and normally alert occupants who are in the building daily and presumably have the opportunity to familiarize themselves with the means of egress through functional use and evacuation drills.

INFLUENCES ON EGRESS

Influence of Hazard of Contents

An evaluation of the hazard of the building contents must take into account the relative probability of the ignition of combustibles, the spread of flames and heat, the probable smoke and gases expected to be generated by the fire, and the possibility of a fire-related explosion or other structural failure endangering occupants. The degree of hazard is usually determined by the flammability or toxicity of the contents and by the processes or operations conducted in the building. Most NFPA *101* requirements are based on the exposure created by contents with an ordinary hazard. Special requirements for areas with high-hazard contents usually consist of special protection systems, isolation of the hazard area via fire-rated construction, reduced travel distances, and additional means of egress.

To assist in evaluating the contents hazards, NFPA *101* establishes three classifications of contents: (1) low-, (2) ordinary-, and (3) high-hazard. They are discussed next. These should not be confused with the classifications established by NFPA 10, *Standard for Portable Fire Extinguishers,* or NFPA 13, *Standard for the Installation of Sprinkler Systems,* nor with those established by some model building codes.

Low-Hazard Contents. These are contents of such low combustibility that no self-propagating fire can occur in them. Consequently, the only probable danger requiring the use of emergency exits will be from smoke or from fire from some external source. These are extremely unusual. The storage of sheet metal without combustible packing is one example.

Ordinary-Hazard Contents. These are contents that are liable to burn with moderate rapidity and to give off a considerable volume of smoke. This class includes most buildings and is the basis for the general requirements of NFPA *101.*

High-Hazard Contents. These are contents that are liable to burn with extreme rapidity or from which explosions are to be feared in the event of fire. Examples are occupancies in which flammable liquids or gases are handled, used, or stored; in which combustible dust explosion hazards exist; in which hazardous chemicals or explosives are stored; in which combustible fibers are processed or handled in a manner that produces combustible flyings; and similar situations.

Influence of Building Construction and Design

A building of fire-resistance-rated construction is designed to permit a burnout of contents without structural collapse. Fire-resistance-rated design does not ensure the life safety of the occupants of such buildings.[12,18] However, the ability of a structural frame to maintain building rigidity under fire exposure is important to the maintenance of the fire-resistance protection of exit enclosures. Where a 2-hr fire-rated exit enclosure is required, a fire-resistance-rated structural frame capable of withstanding stresses imposed by fire for a similar period is also necessary. It is inconsistent to provide a 2-hr exit enclosure in a building with a structural frame rated at less than 1 hr, for example, unless special construction precautions are taken to prevent structural failure of the building from adversely affecting the protective construction of the exit enclosures.

The protection of vertical openings is one of the most significant factors in the design of multistory buildings, from the standpoint of life safety and exit design. Because of the natural tendency of fire to spread upward in a building, careful attention to details of design and construction are required to minimize this effect. One of the greatest hazards to life safety results from fires that start below the occupants and the means of egress, such as in basements or on the level of exit discharge. Similarly, fires in multistory buildings may result in smoke spread into enclosed exits before evacuation.[12,13,18] Conversely, escape from fires that occur above the occupants is relatively simple, provided sufficient warning is given and adequate means of egress are available.

The influence on the life safety of the occupants by the materials used in building construction depends primarily upon whether the materials will propagate flame, support combustion, or create dense amounts of smoke when exposed to a fire initially involving the building contents. Some materials used as insulation, for example, could contribute to rapid flame development and dense smoke production spread. Masonry walls enclosing a wood-frame interior provide no increased occupant life safety compared with a total wood-frame structure.

Exit requirements are based on buildings of conventional design. Unusual buildings, such as those without windows or those with unopenable windows, call for special consideration. Windows provide a number of advantages in a fire. Persons at openable windows have access to fresh air, can see fire department rescue operations in progress, are able to communicate verbally and visually with rescue personnel, and may thus be less subject to stress and anxiety. Windows provide a means of escape and accessibility to the building by the fire department for rescue and fire fighting. Automatic sprinklers are considered a primary requirement for life safety in windowless buildings, buildings with unopenable windows, and underground structures.

Velika dvorana

Influence of Interior Finish, Furnishings, and Decorations

The rapid spread of flame over the surface of walls, ceilings, or floor coverings may prevent occupant use of the means of egress. In general, NFPA *101* limits the flame-spread index classification of interior finish materials on walls and ceilings to a maximum of 200, based on the results of tests conducted in accordance with NFPA 255, *Standard Method of Test of Surface Burning Characteristics of Building Materials,* also known as ASTM E84. Lower ratings are prescribed for the interior finish materials used in exits and in exit accesses. Materials classified as having a lower flame-spread index are also required in certain areas in individual occupancies. A fire-retardant coating may be used on existing interior finish materials to reduce the rate of flame spread. In areas protected with automatic sprinklers, the use of materials with higher flame-spread index classifications sometimes is permitted. Table 4.3.1 summarizes the interior finish requirements contained in NFPA *101* for the various occupancy classifications. NFPA *101* also recognizes a new test method: NFPA 286, *Standard Methods of Fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth.* Any nontextile material that passes this test, based on the pass-fail criteria contained in NFPA *101,* can be used anywhere in a building.

The flame spread of floor coverings is evaluated by NFPA *101,* through the use of NFPA 253, *Standard Method of Test for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source,* also known as ASTM E648. Two classes of floor coverings are established: (1) Class I finishes, with a minimum critical radiant flux of 0.45 W/cm^2; and (2) Class II finishes, with a minimum critical radiant flux of 0.22 W/cm^2.

Furnishings and decorations—particularly furnishings—play an increasingly important role in loss of life by fire. Decorations can be treated with a flame retardant. Furnishings, on the other hand, are difficult to control and regulate as a fire hazard, since they are not attached to, or part of, the building construction or of the interior finish materials. Furnishings are moved, refurbished, and replaced. However, there are now test procedures for measuring the combustibility of upholstered furniture and its susceptibility to ignition.[19] Two NFPA standards address furniture combustibility: NFPA 260, *Standard Methods of Test and Classification System for Cigarette Ignition Resistance of Components of Upholstered Furniture;* and NFPA 261, *Standard Method of Test Determining Resistance of Mock-Up Upholstered Furniture Material Assemblies to Ignition by Smoldering Cigarettes.* NFPA 267, *Standard Method of Test for Fire Characteristics of Mattresses and Bedding Assemblies Exposed to Flaming Ignition Source,* assesses heat release of mattresses and bedding. The "Operating Features" of each occupancy chapter of NFPA *101,* 2000 edition, specifies that if new upholstered furniture or mattresses are introduced, they must meet the requirements of NFPA 260, 261, or 267. The "Operating Features" portion of each occupancy chapter of NFPA *101,* 2000 edition, specifies if new upholstered furniture or mattresses are introduced, they must meet the requirements of NFPA 260, 261, or 267. The U.S. Consumer Products Safety Commission (CPSC) also has a standard for evaluating the ignitibility of mattresses.[20] A number of fires have been documented in which severe conditions resulted from fire involvement of only a few furnishing items.[9,10,14]

Influence of Psychological and Physiological Factors on Egress

The psychological and physiological conditions of the occupant population must be considered, in addition to the physical configuration factors of the building, in planning means of egress. Studies indicate people usually behave adaptively and often altruistically in the stress of a fire.[21,22] A heterogeneous collection of persons under the influence of alcohol or drugs, as may be present in an assembly occupancy, may pose a greater probability of nonadaptive group behavior, with a competitive flight, panic-type behavior the likely result. Historically, this type of nonadaptive behavior has been documented, although studies indicate that the phenomenon is rare and depends upon unique, predetermined conditions involving both the population and the physical environment of the structure.[21–23]

In some cases, evacuation procedures and the creation of areas of refuge within high-rise buildings encourage occupant movement upward within the building. The effectiveness of this concept has not been completely validated in actual fires. Because of the orientation of some people toward total evacuation and escape from the building, it is possible that they may attempt to evacuate a building in the conventional "down and out" approach despite instruction to the contrary.[22]

Evacuation procedures in federal high-rise office buildings, as directed by vocal alarm systems, have continually obtained the selective movement of personnel in both upward and downward directions.[15] In both of two serious high-rise office building fires in São Paulo, Brazil, the occupants moved upward to the roof when their downward movement was inhibited by smoke and heat.[12] In the MGM Grand Hotel fire in Las Vegas, Nevada, in November 1980, there also was upward movement to areas of refuge in the stairways to the roof and to rooms on upper floors when downward travel was made untenable by smoke and heat.[13,21]

All exits need to be conspicuously marked, because people are likely to be unfamiliar with the various exits from an area under fire conditions and thus to neglect alternate means of egress. It is also important that the means of egress from a building be used as a matter of daily routine, so the occupants will be familiar with their location and operation. NFPA *101* requires that the main exit of assembly occupancies, which also serves as the entrance, be sized to handle at least one-half of the total occupant load of the building.

There are three critical parameters in the effective use of the zoned evacuation of personnel to areas of refuge within a building.[24]

1. Proper construction to provide compartmented areas that are protected from the effects of fire and smoke.
2. An effective verbal alarm system giving clear and comprehensive instructions, with provision for originating on-scene instructions from the fire department.[15]
3. Effective evacuation drills to familiarize the occupants with the way the system functions.

TABLE 4.3.1 *Summary of Life Safety Code Requirements for Interior Finishings*

Occupancy	Exits	Access to Exits	Other Spaces
Assembly—New			
> 300 occupant load	A	A or B	A or B
≤ 300 occupant load	A	A or B	A, B, or C
Assembly—Existing			
> 300 occupant load	A	A or B	A or B
≤ 300 occupant load	A	A or B	A, B, or C
Educational—New	A	A or B	A or B, C on low partitions[a]
Educational—Existing	A	A or B	A, B, or C
Daycare Centers—New	A I or II	A I or II	A or B NR
Daycare Centers—Existing	A or B	A or B	A or B
Group Daycare Homes—New	A or B	A or B	A, B, or C
Group Daycare Homes—Existing	A or B	A, B, or C	A, B, or C
Family Daycare Homes	A or B	A, B, or C	A, B, or C
Healthcare—New (sprinklers mandatory)	A or B	A or B, C on lower portion of corridor wall[a]	A or B, C in small individual rooms[a]
Healthcare—Existing	A or B	A or B	A or B
Detention and Correctional—New	A[a] I	A[a] I	A, B, or C
Detention and Correctional—Existing	A or B[a] I or II	A or B[a] I or II	A, B, or C
1- and 2-Family Dwellings, Lodging or Rooming Houses	A, B, or C	A, B, or C	A, B, or C
Hotels and Dormitories—New	A I or II	A or B I or II	A, B, or C
Hotels and Dormitories—Existing	A or B I or II[a]	A or B I or II[a]	A, B, or C
Apartment Buildings—New	A I or II[a]	A or B I or II[a]	A, B, or C
Apartment Buildings—Existing	A or B I or II[a]	A or B I or II[a]	A, B, or C
Residential Board and Care—*See Chapters 32 and 33*			
Mercantile—New	A or B	A or B	A or B
Mercantile—Existing Class A or Class B	A or B	A or B	Ceilings—A or B, walls—A, B, or C
Mercantile—Existing Class C	A, B, or C	A, B, or C	A, B, or C
Business and Ambulatory Health Care—New	A or B I or II	A or B I or II	A, B, or C
Business and Ambulatory Health Care—Existing	A or B	A or B	A, B, or C
Industrial	A or B	A, B, or C	A, B, or C
Storage	A or B	A, B, or C	A, B, or C

NR: No requirement.
Notes:
1. Class A interior wall and ceiling finish—flame spread 0–25, (new) smoke developed 0–450.
2. Class B interior wall and ceiling finish—flame spread 26–75, (new) smoke developed 0–450.
3. Class C interior wall and ceiling finish—flame spread 76–200, (new) smoke developed 0–450.
4. Class I interior floor finish—critical radiant flux, not less than 0.45 W/cm^2.
5. Class II interior floor finish—critical radiant flux, not less than 0.22 W/cm^2 but less than 0.45 W/cm^2.
6. Automatic sprinklers—where a complete standard system of automatic sprinklers is installed, interior wall and ceiling finish with flame spread rating not exceeding Class C is permitted to be used in any location where Class B is equired and with rating of Class B in any location where Class A is required; similarly, class II interior floor finish is permitted to be used in any location where Class I is required, and no critical radiant flux rating is required where Class II is required. These provisions do not apply to new health care facilities.
7. Exposed portions of structural members complying with the requirements for heavy timber construction are permitted.
[a]See corresponding chapters for details.
Source: NFPA *101®*, *Life Safety Code®*, 2000, pp. 101–306 and 101–307.

It has been advocated that occupants in fire-resistant, compartmented buildings used as hotels, motels, apartments, dormitories, hospitals, and other healthcare facilities should stay in their rooms rather than evacuate, since the rooms are the most adequate area of refuge.[25] This method has not been adopted by NFPA *101* or by the model building codes. However, the concept of areas of refuge has been used by NFPA *101* extensively in occupancies such as healthcare and detention and correctional facilities for many years and, more recently, to protect occupants with mobility impairments in all occupancies.

Influence of Fire Protection Equipment

It is unsuitable to rely totally on manual or automatic fire extinguishing systems in place of adequate means of egress, since fire extinguishing systems are subject to both human and mechanical failure. In addition, building areas may become untenable for human occupancy before the fire extinguishing systems are effective. Under no condition can manual or automatic fire suppression be accepted as a substitute for the provision and maintenance of proper means of egress.

Where a complete standard system is installed, automatic sprinklers are sufficiently reliable to have a major influence on life safety. In addition to providing an automatic alarm of fire, they quickly discharge water on the fire before smoke has spread dangerously. While automatic sprinklers should never be used in place of adequate means of egress, they are recognized in various ways by NFPA *101*. When total automatic sprinkler protection is provided, NFPA *101* permits increased travel distance to exits, the use of interior finish of greater combustibility, reductions in corridor requirements, and, in some occupancies, the use of combustible construction in situations where it would otherwise be prohibited. Provisions for areas of refuge are significantly easier to comply with in buildings protected throughout by automatic sprinklers. Sprinklers are particularly valuable in dealing with problems in existing buildings.

Automatic fire detection, or fire alarm, systems are valuable in notifying building occupants of a fire so they may evacuate promptly. Automatic fire detection systems only provide a warning of fire and do nothing themselves to suppress or limit the spread of fire and smoke. An automatic fire detection system is not a substitute for adequate means of egress.

Smoke detection systems can be useful to help mitigate problems in existing buildings. They can be especially useful where earlier egress may help solve problems, such as existing excessive common paths of travel, dead ends, and travel distance.

DEFINITION OF THE TERM "MEANS OF EGRESS"

NFPA *101* and most of the U.S. model building codes use the term "means of egress." A means of egress is a continuous path of travel from any point in a building or structure to a public way that is in the open air outside at ground level. Egress consists of three separate and distinct parts:

1. *The exit access.* Portion of a means of egress that leads to the entrance of an exit.
2. *Exit.* Portion of a means of egress that is separated from the area of the building from which escape is to be made by walls, floors, doors, or other means that provide the protected path necessary for the occupants to proceed with reasonable safety to the exterior of the building. An exit may comprise vertical and horizontal means of travel, such as exterior doors, protected stairways, ramps, and exit passageways.
3. *Exit discharge.* Portion of a means of egress between the termination of the exit and a public way.

Figure 4.3.6 illustrates the relationship among these three parts of an exit in a building.

The Exit Access

The exit access may be a corridor, aisle, balcony, gallery, room, porch, or roof. The length of the exit access establishes the travel distance to an exit, an extremely important feature of a means of egress, since an occupant might be exposed to fire or smoke during the time it takes to reach an exit. The average recommended maximum travel distance is 200 ft (61 m), but this distance varies with the occupancy, depending upon the fire hazard and the physical ability and alertness of the occupants (Table 4.3.2). The travel distance must be measured from the most remote point in a room or floor area to an exit.

In most cases, the travel distance can be increased up to 50 percent if the building is completely protected with a standard supervised automatic sprinkler system.

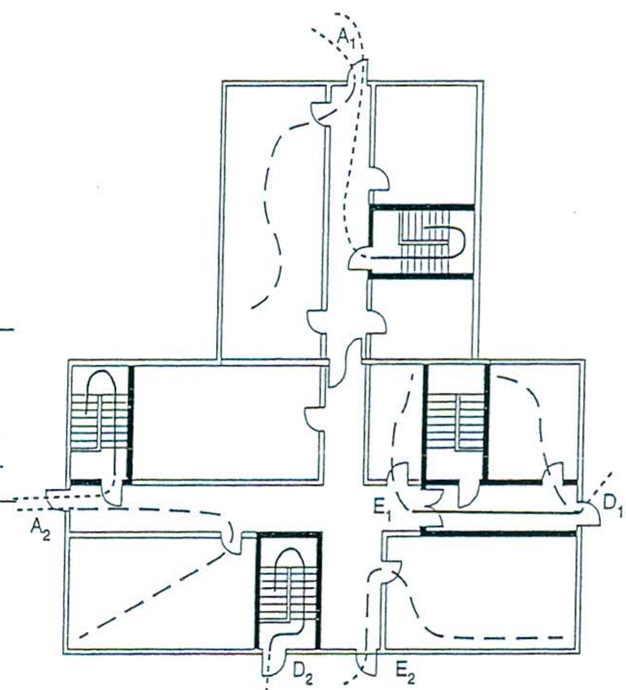


FIGURE 4.3.6 *Examples of Exit Access, Exit, and Exit Discharge. To the occupant of the building at the discharge level, the doors at A_1, A_2, E_1, and E_2 are exits, and the path denoted by dashes is the exit access. To the person emerging from the exit enclosures or from doors A_1, A_2, or E_2 the paths denoted by dotted lines are the exit discharge. Doors D_1 and D_2 are exit discharge doors. Solid lines are within the exit.*

TABLE 4.3.2 *Common Path, Dead-End, and Travel Distance Limits (by occupancy)*

Type of Occupancy	Common Path Limit		Dead-End Limit		Travel Distance Limit	
	Unsprinklered [ft (m)]	Sprinklered [ft (m)]	Unsprinklered [ft (m)]	Sprinklered [ft (m)]	Unsprinklered [ft (m)]	Sprinklered [ft (m)]
Assembly						
New	20/75 (6.1/23)[a,b]	20/75 (6.1/23)[a,b]	0/20 (0/6.1)[b]	0/20 (0/6.1)[b]	150 (45)[c]	200 (60)[c]
Existing	20/75 (6.1/23)[a,b]	20/75 (6.1/23)[a,b]	0/20 (0/6.1)[b]	0/20 (0/6.1)[b]	150 (45)[c]	200 (60)[c]
Educational						
New	75 (23)	100 (30)	20 (6.1)	50 (15)	150 (45)	200 (60)
Existing	75 (23)	100 (30)	20 (6.1)	50 (15)	150 (45)	200 (60)
Daycare						
New	75 (23)	100 (30)	20 (6.1)	50 (15)	150 (45)[d]	200 (60)[d]
Existing	75 (23)	100 (30)	20 (6.1)	50 (15)	150 (45)[d]	200 (60)[d]
Healthcare						
New	NR	NR	30 (9.1)	30 (9.1)	NA	200 (60)[d]
Existing	NR	NR	NR	NR	150 (45)[d]	200 (60)[d]
Ambulatory healthcare						
New	75 (23)[e]	100 (30)[e]	20 (6.1)	50 (15)	150 (45)[d]	200 (60)[d]
Existing	75 (23)[e]	200 (30)[e]	50 (15)	50 (15)	150 (45)[d]	200 (60)[d]
Detention and correctional						
New—Use conditions II, III, IV	50 (15)	100 (30)	50 (15)	50 (15)	150 (45)[d]	200 (60)[d]
New—Use conditions V	50 (15)	100 (30)	20 (6.1)	20 (6.1)	150 (45)[d]	200 (60)[d]
Existing—Use conditions II, III, IV, V	50 (15)[f]	100 (30)[f]	NR	NR	150 (45)[d]	200 (60)[d]
Residential						
One- and two-family dwellings	NR	NR	NR	NR	NR	NR
Lodging or rooming houses	NR	NR	NR	NR	NR	NR
Hotels and dormitories						
New	35 (10.7)[g,i]	50 (15)[g,i]	35 (10.7)[i]	50 (15)	175 (53)[d,h]	325 (99)[d,h]
Existing	35 (10.7)[g]	50 (15)[g]	50 (15)	50 (15)	175 (53)[d,h]	325 (99)[d,h]
Apartments						
New	35 (10.7)[g]	50 (15)[g]	35 (10.7)	50 (15)	175 (53)[d,h]	325 (99)[d,h]
Existing	35 (10.7)[g]	50 (15)[g]	50 (15)	50 (15)	175 (53)[d,h]	325 (99)[d,h]
Board and care						
Small, new and existing	NR	NR	NR	NR	NR	NR
Large, new	NR	125 (38)[i]	NA	50 (15)	NA	325 (99)[d,h]
Large, existing	110 (33)	160 (49)	50 (15)	50 (15)	175 (53)[d,h]	325 (99)[d,h]
Mercantile						
Class A, B, C						
New	75 (23)	100 (30)	20 (6.1)	50 (15)	100 (30)	200 (60)
Existing	75 (23)	100 (30)	50 (15)	50 (15)	150 (45)	200 (60)
Open air	NR	NR	0 (0)	0 (0)	NR	NR
Covered mall						
New	75 (23)	100 (30)	20 (6.1)	50 (15)	100 (30)	400 (120)[j]
Existing	75 (23)	100 (30)	50 (15)	50 (15)	150 (45)	400 (120)[j]

TABLE 4.3.2 *Continued*

Type of Occupancy	Common Path Limit		Dead-End Limit		Travel Distance Limit	
	Unsprinklered [ft (m)]	Sprinklered [ft (m)]	Unsprinklered [ft (m)]	Sprinklered [ft (m)]	Unsprinklered [ft (m)]	Sprinklered [ft (m)]
Business						
New	75 (23)[k]	100 (30)[k]	20 (6.1)	50 (15)	200 (60)	300 (91)
Existing	75 (23)[k]	100 (30)[k]	50 (15)	50 (15)	200 (60)	300 (91)
Industrial						
General	50 (15)	100 (30)	50 (15)	50 (15)	200 (60)[n]	250 (75)[l]
Special purpose	50 (15)	100 (30)	50 (15)	50 (15)	300 (91)	400 (122)
High hazard	0 (0)	0 (0)	0 (0)	0 (0)	75 (23)	75 (23)
Aircraft servicing hangars, ground floor	50 (15)[m]	50 (15)[m]	50 (15)[m]	50 (15)[m]	note *n*	note *n*
Aircraft servicing hangars, mezzanine floor	50 (15)[m]	50 (15)[m]	50 (15)[m]	50 (15)[m]	75 (23)	75 (23)
Storage						
Low hazard	NR	NR	NR	NR	NR	NR
Ordinary hazard	50 (15)	100 (30)	50 (15)	100 (30)	200 (60)	400 (122)
High hazard	0 (0)	0 (0)	0 (0)	0 (0)	75 (23)	100 (30)
Parking garages, open	50 (15)	50 (15)	50 (15)	50 (15)	300 (91)	400 (122)
Parking garages, enclosed	50 (15)	50 (15)	50 (15)	50 (15)	150 (45)	200 (60)
Aircraft storage hangars, ground floor	50 (15)[m]	100 (30)[m]	50 (15)[m]	50 (15)[m]	note *n*	note *n*
Aircraft storage hangars, mezzanine floor	50 (15)[m]	75 (23)[m]	50 (15)[m]	50 (15)[m]	75 (23)	75 (23)
Underground spaces in grain elevators	50 (15)[m]	100 (30)[m]	50 (15)[m]	100 (30)[m]	200 (60)	400 (122)

NA: Not applicable.
NR: No requirement.
[a]20 ft (6.1 m) for common path serving >50 persons: 75 ft (23 m) for common path serving ≤ 50 persons.
[b]Dead-end corridors not permitted: 20 ft (6.1 m) dead-end aisled permitted.
[c]See Chapters 12 and 13 for special considerations for smoke-protected assembly seating in arenas and stadia.
[d]This dimension is for the total travel distance, assuming incremental portions have fully utilized their permitted maximums. For travel distance within the room, and from the room exit access door to the exit, see the appropriate occupancy chapter.
[e]See business occupancies Chapters 38 and 39.
[f]See Chapter 23 for special considerations for existing common paths.
[g]This dimension is from the room/corridor or suite/corridor exit access door to the exit; thus, is applies to corridor common path.
[h]See appropriate occupancy chapter for special travel distance considerations for exterior ways of exit access.
[i]See appropriate occupancy chapter for requirement for second exit access based on room area.
[j]See Sections 36.4 and 37.4 for special travel distance considerations in covered malls considered pedestrian ways.
[k]See Chapters 38 and 39 for special common path considerations for single tenant spaces.
[l]See Chapter 40 for industrial occupancy special travel distance considerations.
[m]See Chapters 40 and 423 for special requirements if high hazard.
[n]See Chapters 40 and 423 for special requirements on spacing of doors in aircraft hangars.
Source: NFPA *101*®, *Life Safety Code*®, 2000, pp. 101–296 and 101–297.

A dead end is an extension of a corridor beyond an exit or an access to exits that forms a pocket in which occupants may be trapped. Since there is only one direction of travel to an exit from a dead end, a fire in a dead end between the exit and an occupant prevents the occupant from reaching the exit. Another problem with dead ends is that while traveling toward an exit in a smoky atmosphere, an occupant may pass by the exit and walk into the dead end. This requires return travel, which adds distance, and therefore time, to reach the exit. In good egress designs, dead-end corridors are not used. However, NFPA *101* permits dead ends in most occupancies, within reasonable limits (see Table 4.3.2). Two dead-end corridors are illustrated in Figure 4.3.7.

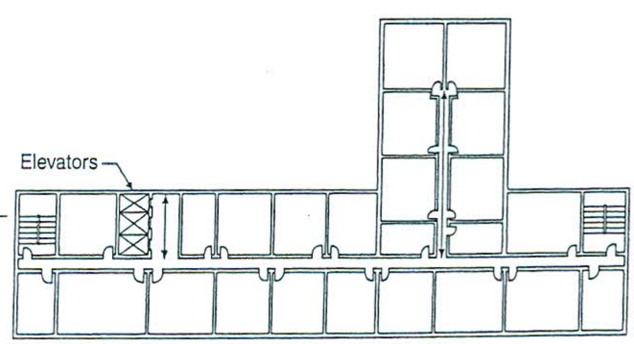


FIGURE 4.3.7 *Two Types of Dead-End Corridors*

The width of an exit access should be at least sufficient for the number of persons it must accommodate. In some occupancies, the width of the access is governed by the character of activity in the occupancy. One example is a new hospital, where patients may be moved in beds or in gurneys. The corridors in the patient areas of the hospital must be 8 ft (2.4 m) wide to allow for a bed to be wheeled out of a room and turned 90°.

A fundamental principle of exit access is the provision of a free and unobstructed way to the exits. If the access passes through a room that can be locked or through an area containing a fire hazard more severe than is typical of the occupancy, the principles of free and unobstructed exit access are violated.

The floor of an exit access should be level. If this is not possible, small differences in elevation may be overcome by a ramp and large differences by stairs. Where only one or two steps are necessary to overcome differences in level in an exit access, a ramp is preferred, because people may trip in a crowded corridor and fall on the stairs if they do not see the steps or notice that those in front of them have stepped up.

The Exit

The types of permissible exits are doors leading directly outside at ground level or through a protected passageway to the outside at ground level, smokeproof towers, protected interior and outside stairs, exit passageways, enclosed ramps, and enclosed escalators or moving walkways in existing buildings. Elevators are not accepted as exits; however, they can be used to provide a way of removing mobility impaired individuals from areas of refuge. NFPA *101* also recognizes elevators for very limited use as a second exit for limited access towers such as FAA control towers. See Figures 4.3.8 and 4.3.9 for illustrations of some common types of exit arrangements.

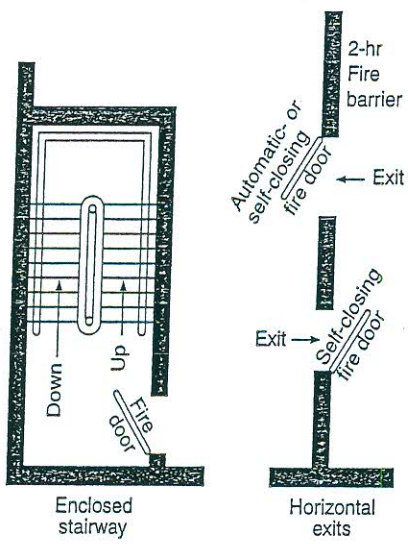


FIGURE 4.3.8 *Plan Views of Types of Exits. Stair enclosure prevents a fire on any floor from trapping the persons above. A smokeproof tower is better, as it opens to the air at each floor, largely preventing the chance of smoke in the stairway. A horizontal exit provides a quick refuge and lessens the need for a hasty flight down stairs. Fire-rated doors must be arranged to be self-closing or automatic-closing by smoke detection.*

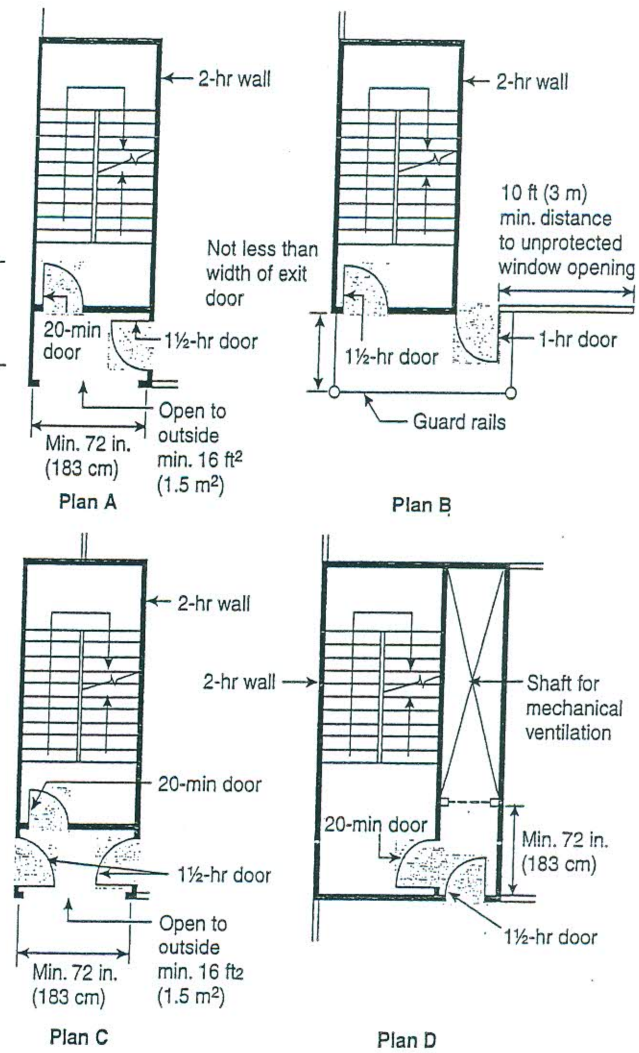


FIGURE 4.3.9 *Four Variations of Smokeproof Towers. Plan A has a vestibule opening from a corridor. Plan B shows an entrance by way of an outside balcony. Plan C could provide a stair tower entrance common to two areas. In Plan D, smoke and gases entering the vestibule would be exhausted by a natural or induced draft in the open air shaft. In each case, a double entrance to the stair tower with at least one side open or vented is characteristic of this type of construction. Pressurization of the stair tower in the event of fire provides an attracted alternate for tall buildings and is a means of eliminating the entrance vestibule.*

The specific placement of exits is a matter of design judgment, given the specifications of travel distance, allowable dead ends, common path of travel, and exit capacity. NFPA *101* states that exits must be remote from each other, thus providing two separate means of egress so located that occupants can travel in either of two opposite directions to reach an exit. This concept is important when it is necessary for occupants to leave a fire or smoke-contaminated area and move toward an exit. If occupants have no choice but to enter the fire area to reach an exit, it is doubtful whether they will be able or willing to do so.

The Exit Discharge

Ideally, all exits in a building should discharge directly to the outside or through a fire-resistance-rated passageway to the outside of the building. NFPA *101* permits a maximum of 50 percent of the exit stairs to discharge onto the street floor. The obvious disadvantage of this arrangement is that if a fire occurs on the street-level floor, it is possible for people using the exit stairs discharging to that floor to be discharged into the fire area. If any exits discharge to the street floor, NFPA *101* therefore requires that such exits discharge to a free and unobstructed way to the outside of the building, that the street floor be protected by automatic sprinklers, and that the street floor be separated from any floors below by construction having a 2-hr fire resistance rating.

Discharging an exit to the outside is not necessarily discharging to a safe place. If the exit discharges into a courtyard, an exit passageway must be provided from the courtyard through the building so that the occupants can get away from the building. If the exit discharges into a fenced yard, the occupants must be able to get out of the yard to get away from the building. If the exit discharges into an alley, the alley must be of sufficient width to accommodate the capacity of all the exits discharging into it, and any openings in the building walls bordering the alley should be protected to prevent fire exposure to the occupants proceeding through the alley.

When exit stairs from floors above the street floor continue on to floors below the street floor, occupants evacuating the building may miss the exit discharge door to the street level, continue down the stairway, and enter a floor below the level of exit discharge. Therefore, NFPA *101* requires a physical barrier or other effective means at the street floor landing to prevent evacuees from passing the level of exit discharge.

CAPACITY OF EXITS

The capacity of exits is calculated using a capacity factor provided in NFPA *101*. This capacity factor is given as in./person and varies with the occupancy (Table 4.3.3). The total exit capacity for each component of the means of egress, such as doors, stairs, ramps, corridors, and so on, is calculated based on its clear width. For example, one 34-in. clear-width door in an office occupancy would have an exit capacity of 170 persons (34 in. ÷ 0.2 in./person 170 persons [86 cm ÷ 0.5 cm/person 172 persons]). The reason for these variations in exit capacity factors is to establish a consistent total evacuation time in different occupancies, based on the physical ability, mental alertness, age, and sociological roles of the occupants. In occupancies where people are housed for care, the time taken to reach exits will be greater than in some other occupancies, and so the exits must be sufficiently wide to allow nonambulatory occupants to egress and to prevent any waiting to get into the exit.

The capacity of exits was traditionally used to establish a consistency of evacuation time on the basis of the rate of travel through a door of 60 persons/min and down a stairway of 45 persons/min/22 in. (558.8 mm) of exit width, respectively. These figures were established by evacuation counts conducted primarily in federal office buildings.[26] More recent studies of evacuations in high-rise office buildings indicate peak flows of 30 persons/min and mean flows of 24 persons/min/22 in. (558.8 mm) of exit width down stairways.[5,16,17]

Occupant Load

Occupant load, or the number of people to be expected in a building or an area within a building at any time for whom exits must be provided, is determined by the actual anticipated occupant load but not less than that number obtained by dividing the gross area of the building or the net area of a specific portion of the building by the area in sq ft (m^2) projected for each person. The amount of floor area projected for each person varies with the occupancy (Table 4.3.4). These figures are based on actual counts of people in buildings and on reviews of architectural plans. In some situations, the maximum number of people in a building above the calculated occupant load can be determined at the design stage, in which case this number should be used in the design of the exits. A typical example is an assembly occupancy in which fixed seating is installed. Counting the number of seats provided, and calculating the standing or waiting areas by the occupant load factor, would obviously give a more accurate figure than multiplying a sq ft (m^2)/person figure by the net floor area.

Computing Required Egress Width

To compute the minimum required egress widths from the individual floors of a building, it is necessary to

1. Calculate the floor area, either net or gross, whichever is applicable
2. Determine from NFPA *101* the estimated number of sq ft (m^2)/person, or occupant load factor
3. Divide the number of sq ft (m^2)/person (occupant load factor) into the floor area to determine the minimum number of people for whom exits must be provided for that floor
4. Measure the clear width of each component in the means of egress
5. Determine the capacity factor from NFPA *101* for each exit component for the appropriate occupancy
6. Divide the clear width of each exit component by the capacity factor to determine the exit capacity for each component
7. Determine the most restrictive component in each egress system
8. Determine the total egress capacity for the floor
9. Ensure that the total egress capacity equals or exceeds the total occupant load.

In multistory buildings, the exit capacity for each floor is calculated separately. In other words, the capacity of the stairs need only be wide enough to serve each floor, but it must not be less than the minimum width required by NFPA *101*. It must also be noted that the required egress capacity cannot be decreased in the direction of egress travel.

Street-floor exits may require special treatment, depending upon the occupancy. Some occupancies require that street-floor exits be sized to handle not only the occupant load of the street floor but also the occupant load of the exits discharging to the

TABLE 4.3.3 *Occupant Load Factor*

Use	ft^{2a} (per person)	m^{2a} (per person)
Assembly Use		
Concentrated use, without fixed seating	7 net	0.65 net
Less concentrated use, without fixed seating	15 net	1.4 net
Bench-type seating	1 person/18 linear in.	1 person/45.7 linear cm
Fixed seating	Number of fixed seats	Number of fixed seats
Waiting spaces	*See 12.1.7.2 and 13.1.7.2*	*See 12.1.7.2 and 13.1.7.2*
Kitchens	100	9.3
Library stack areas	100	9.3
Library reading rooms	50 net	4.6 net
Swimming pools	50—of water surface	4.6—of water surface
Swimming pool decks	30	2.8
Exercise rooms with equipment	50	4.6
Exercise rooms without equipment	15	1.4
Stages	15 net	1.4 net
Lighting and access catwalks, galleries, gridirons	100 net	9.3 net
Casinos and similar gaming areas	11	1
Skating rinks	50	4.6
Educational Use		
Classrooms	20 net	1.9 net
Shops, laboratories, vocational rooms	50 net	4.6 net
Daycare Use	35 net	3.3 net
Healthcare Use		
Inpatient treatment departments	240	22.3
Sleeping departments	120	11.1
Detention and Correctional Use	120	11.1
Residential Use		
Hotels and dormitories	200	18.6
Apartment buildings	200	18.6
Board and care, large	200	18.6
Industrial Use		
General and high hazard industrial	100	9.3
Special purpose industrial	NA[b]	NA[b]
Business Use	100	9.3
Storage Use (other than mercantile storerooms)	NA[b]	NA[b]
Mercantile Use		
Sales area on street floor[c,d]	30	2.8
Sales area on two or more street floors[d]	40	3.7
Sales area on floor below street floor[d]	30	2.8
Sales area on floor above street floor[d]	60	5.6
Floors or portions of floors used only for offices	*See business use.*	*See business use.*
Floors or portions of floors used only for storage, receiving, and shipping, and not open to general public	300	27.9
Covered mall buildings	Per factors applicable to use of space[e]	Per factors applicable to use of space[e]

[a]All factors expressed in gross area unless marked "net."

[b]Not applicable. The occupant load shall not be less than the maximum probable number of occupants present at any time.

[c]For the purpose of determining occupant load in mercantile occupancies where, due to differences in grade of streets on different sides, two or more floors directly accessible from streets (not including alleys or similar back streets) exist, each such floor shall be considered a street floor. The occupant load factor shall be one person for each 40 ft^2 (3.7 m^2) of gross floor area of sales space.

[d]In mercantile occupancies with no street floor, as defined in 3.3.196, but with access directly from the street by stairs or escalators, the principal floor at the point of entrance to the mercantile occupancy shall be considered the street floor.

[e]The portions of the covered mall, where considered a pedestrian way and not used as a gross leasable area, shall not be assessed an occupant load based on this table. However, means of egress from a covered mall pedestrian way shall be provided for an occupant load determined by dividing the gross leasable area of the covered mall building (not including anchor stores) by the appropriate lowest whole number occupant load factor from Figure 7.3.1.2 of NFPA *101*.

Each individual tenant space shall have means of egress to the outside or to the covered mall based on occupant loads figured by using the appropriate occupant load factor from this table.

Each individual anchor store shall have means of egress independent of the covered mall.

TABLE 4.3.4 *Summary of NFPA 101®, Life Safety Code®, Provisions for Occupant Load and Exit Capacity*

Occupancy	Occupant Load sq ft (m^2) per person	Level Components (Doors, Corridors, Horizontal Exits, Ramps)		Stairs	
Assembly					
Less concentrated use without fixed seating	15 net (1.4)	0.2		0.3	
Concentrated use without fixed seating	7 Net (.65)	0.2		0.3	
Fixed seating	Actual number of seats	0.2		0.3	
Educational					
Classrooms	20 Net (1.9)	0.2		0.3	
Shops and vocational	50 Net (4.6)	0.2		0.3	
Care centers	35 Net (3.3)	0.2		0.3	
Healthcare		NAS	AS	NAS	AS
Sleeping departments	120 Gross (11.1)	0.5	0.1	0.6	0.3
Treatment departments	240 Gross (22.3)	0.5	0.2	0.6	0.3
Residential	200 Gross (18.6)	0.2		0.3	
Board and care	200 Gross (18.6)	0.2		0.4	
Mercantile					
Street floor and sales basement	30 Gross (3.7)	0.2		0.3	
Multiple street floors—each	40 Gross (3.7)	0.2		0.3	
Other floors	60 Gross (5.6)	0.2		0.3	
Storage—shipping	300 Gross (27.9)	0.2		0.3	
Malls	See Code	0.2		0.3	
Business	100 Gross (9.3)	0.2		0.3	
Industrial	100 Gross (9.3)	0.2		0.3	
Detention and correctional	120 Gross (11.1)	0.2		0.3	

Note: NAS = nonsprinklered; AS = sprinklered.
See NFPA *101* for additional Occupant Load factors.

street floor from floors above and below. In addition, in those occupancies where floors above and/or below the street floor are permitted to have unenclosed stairs and escalators connecting them with the street floor, the exits must be sufficient to provide simultaneously for all the occupants of all communicating levels and areas. In other words, all communicating levels in the same fire area are considered a single floor area for the purposes of determining the required exit capacity. This identical, single fire area factor can have a considerable effect on the sizing of the street-floor exits.

Should two or more exits converge into a common exit, the common exit should never be narrower than the sum of the width of the exits converging into it.

Generally, the minimum number of exits is two. In certain limited situations, however, one exit may be permitted in some occupancies if there is a very low occupant load, low fire hazard, and a limited travel distance.

EXIT FACILITIES AND ARRANGEMENTS

The following exit facilities are covered in NFPA *101*.

Doors

Doors should be side-hinged or pivoted swinging type and should swing in the direction of exit travel, except in small rooms. Horizontal sliding, vertical, or rolling doors are recognized for use as means of egress in some occupancies. In assembly occupancies and in schools, panic hardware should be installed on all egress doors equipped with latches that serve rooms with an occupant load of 100 or more.

Where doors protect exit facilities, as in stairway enclosures and horizontal exits, they normally must be kept closed to limit the spread of smoke. If open, they must be closed immediately in case of fire. Although ordinary, fusible-link-operated devices to close doors in case of fire are designed to close in time to stop the spread of fire, they do not operate soon enough to stop the spread of smoke and are not permitted by NFPA *101*. At relatively low temperatures, smoke accumulation could continue and could reach untenable levels long before the fusible link melts, allowing the door to close.

Sometimes, people keep self-closing doors open with hooks or with wedges under the door. Doors also can be blocked open to provide ventilation, for the convenience of building maintenance personnel, or to avoid the accident hazard of swinging doors. The following measures have been provided in the NFPA *101* to alleviate this undesirable situation:

1. Doors that are normally kept open can be equipped with door closers and automatic hold-open devices that release the door and allow them to close when an automatic sprinkler system, the fire alarm system, an automatic fire detection system, and smoke or other products of combustion detection devices operate.
2. Doors that are normally closed can be equipped to open electrically or pneumatically when a person approaches the door, as long as precautions are used to prevent the door from automatically opening when there is smoke in the area.
3. Doors that normally are closed can be opened and held open manually by monitors, as in schools.
4. Use of smokeproof towers that protect against smoke, even if the doors are open.

Qualifications and limitations are applicable to each of these measures. One is that, in the event of electrical failure, the door must close and remain closed unless it is opened manually for egress purposes.

Another major maintenance difficulty with exit doors is the exterior door that is locked to prevent unauthorized access or for other reasons. NFPA *101* specifies that when the building is occupied, all doors must be kept unlocked from the side from which egress is made.

NFPA *101* allows a delayed releasing device on some egress doors, provided this is permitted by the requirements of the occupancy in question. Where the devices are allowed, the following provisions apply:

1. The building must be protected throughout by an approved and supervised automatic fire detection system or automatic sprinkler system.
2. The release devices are installed only in low- or ordinary-hazard areas.
3. The devices must unlock when the fire detection system or automatic sprinkler system operates.
4. The devices must unlock upon loss of power.
5. The devices must initiate an irreversible process that v free the latch within 15 sec whenever a force of not m than 15 lb (6.8 kg) is applied to the releasing device, and t door must not relock automatically. Operation of the leasing device must actuate a signal near the door.
6. A sign must be placed adjacent to the door that reac PUSH UNTIL ALARM SOUNDS. DOOR CAN E OPENED IN 15 SECONDS!
7. Emergency lighting must be provided at the door.

NFPA *101* also provides "Access Controlled Egress Door The code spells out several limitations for these. One of the li itations included is that when an occupant approaches the doo a sensor must unlock it.

Locks on a door that let people exit but not enter are sati factory, but even this type of lock may not be satisfactory for s curity purposes. Possible measures to prevent unauthorized us of exit doors include

1. An automatic alarm that rings when the door is opened
2. Visual supervision such as wired-glass panels, closed circuit television, and mirrors, which may be used whe appropriate
3. Automatic photographic devices to provide pictures of users

So-called exit locks, with a break-glass unit actuated b striking a handle with the hand, are not permitted by NFPA *101* unless installed in conjunction with panic bars. Otherwise, the do not comply with the NFPA *101* provision that reads: "A latc or other fastening device on a door shall be provided with a releasing device having an obvious method of operation and that is readily operated under all lighting conditions."

Other types of break-glass locks and electrical controls fo releasing exits from a central point are not permitted by NFPA *101*. The exception is an occupancy where controls may b necessary, as in healthcare, and detention and correctiona occupancies.

A single door in a doorway should not be less than 32 in (813 mm) wide in new buildings and 28 in. (711 mm) in existin buildings. To prevent tripping, the floor on both sides of the door should have the same elevation for the full swing of the door.

Panic Hardware

Egress doors in assembly and educational occupancies, such as schools or movie theaters, normally are equipped with panic hardware. Basically, panic hardware devices are designed to facilitate the release of the latching device on the door when a pressure not to exceed 15 lb (6.8 kg) is applied in the direction of exit travel. Such releasing devices are bars or panels extending not less than one-half of the width of the door and placed at a height not less than 30 in. (762 mm) or more than 44 in. (1.1 m) above the floor.

Panic hardware that has been tested and listed for use on fire-protection-rated doors is termed "fire exit hardware." If panic hardware is needed on fire-protection-rated doors, only fire exit hardware is to be used.

Panic hardware is available for use on single and double doors, with variations for rim-mounted hardware and mortise or vertical rod devices.

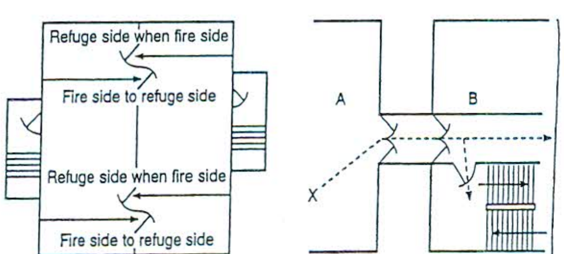
Horizontal Exits

A horizontal exit is a means of egress from one building to an area of refuge in another building on approximately the same level, or a means of egress through a 2-hr fire barrier to an area of refuge at approximately the same level in the same building that affords safety from fire and smoke. With a horizontal exit, it is obvious that space must be provided in the area or building of refuge for the people entering the refuge area. NFPA *101* recommends 3 sq ft (0.28 m^2) of space per person, with the exception of healthcare and detention and correctional occupancies, where 6 to 30 sq ft (0.56 to 2.79 m^2) of space is recommended. Horizontal exits cannot comprise more than one-half the total required exit capacity, except in healthcare facilities, where horizontal exits may comprise two-thirds of the total required exit capacity, and in detention and correctional facilities, where horizontal exits can comprise 100 percent of the total exit capacity. Horizontal exits have been applied universally in healthcare facilities where the evacuation of patients over stairs is slower and more difficult than taking them through a horizontal exit to a safe area of refuge. A horizontal exit arrangement within a single building and between two buildings is illustrated in Figure 4.3.10.

A swinging door in a fire wall provides a horizontal exit in one direction only. Two openings, each with a door swinging in the direction of exit travel, are needed to provide horizontal exits from both sides of the wall. Where property protection requires fire doors on both sides of the wall, a normally open, automatic, fusible-link-operated, horizontally sliding fire door may be used on one side, with a swinging fire door on the other.

Stairs

Exit stairs are arranged to minimize the danger of falling, because one person falling on a stairway may result in the complete blockage of an exit. Stairs must be wide enough for two persons to descend side by side, thus maintaining a reasonable rate of evacuation, even though aged or infirm persons may slow the travel on one side. There must be no decrease in the width of the stair along the path of travel, since this may create congestion.



Two-way horizontal exit in an open-plan building. Self-closing fire doors required in fire separation.

One-way horizontal exit from building A to building B. Self-closing or automatic-closing fire doors and protected passage required.

FIGURE 4.3.10 *Types of Horizontal Exits*

Steep stairs are dangerous. Stair treads must be deep enough to give good footing. NFPA *101* specifies a minimum 11 in. (279 mm) tread and a maximum 7 in. (178 mm) riser for new stairs. Landings should be provided to break up any excessively long individual flight. Continuous railings are now recommended for new stairs. New stairs more than 60 in. (1.5 m) wide should have one or more center rails.

Two classes of stairs are permitted in NFPA *101* for existing buildings, with a single class of stairs for new stairs. There are Class A and Class B stairs for existing buildings. The requirements for each class are given in Table 4.3.5.

Stairs can serve as exit access, exit, or exit discharge. When used as an exit, they must be in an enclosure that meets exit enclosure requirements or outside the building and properly protected. Exit access stairs that connect two or more stairs are vertical openings and must be protected as a vertical opening.

Stairways may be inside the building where the NFPA *101* generally specifies protective enclosures. They also may be outside if they comply with the requirements for exterior stairs and are arranged so that persons who fear heights will not be reluctant to use them, are not exposed to fire conditions originating in the building, and, where necessary, are shielded from snow and ice. Exterior stairs should not be confused with fire escape stairs (Figure 4.3.11). This method has application in many types of occupancies, such as schools, motels, small professional buildings, and so on. Note that there are two means of egress, remote from each other, from the second-story balcony.

Construction details of stair enclosures involve the principles of limiting fire and smoke spread. Doors on openings from each story are essential to prevent the stairway from serving as a flue. In general, stairway enclosures should include not only the stairs, but also the path of travel from the bottom of the stairs to the exit discharge, so that occupants have a protected, enclosed passageway all the way out of the building. The stair enclosure should be of 1-hr construction when connecting three or fewer floors and of 2-hr construction when connecting four or more floors.

Smokeproof Towers

Smokeproof towers provide the highest protected type of stair enclosure recommended by NFPA *101*. Access to the stair tower is only by balconies open to the outside air, vented vestibules, or mechanically pressurized vestibules, so that smoke, heat, and flame will not spread readily into the tower even if the doors are accidentally left open (see Figure 4.3.9).

Ramps

Ramps, enclosed and otherwise arranged like stairways, are sometimes used instead of stairways where there are large crowds and to provide both access and egress for nonambulatory persons. To be considered safe, exits ramps must have a very gradual slope.

Exit Passageways

A hallway, corridor, passage, tunnel, or underfloor or overhead passageway may be designated an exit passageway, providing it

TABLE 4.3.5 *Requirements for New and Existing Building Stairs*

	New Stairs	Existing Stairs Class A	Existing Stairs Class B
Minimum width clear of all obstructions except projections not exceeding 3½ in. (0.89 mm) at and below handrail height on each side	44 in. (1.12 m) 36 in. (0.91 m) where total occupant load of all floors served by stairways is less than 50.	44 in. (1.12 m) 36 in. (0.91 m) where total occupant load of all floors served by stairways is less than 50.	44 in. (1.12 m) 36 in. (0.91 m)
Maximum height of risers	7 in. (178 mm)	7½ in. (191 mm)	8 in. (203 mm)
Minimum height of risers	4 in. (102 mm)	—	—
Minimum tread depth	11 in. (279 mm)	10 in. (244 mm)	9 in. (229 mm)
Minimum headroom	6 ft 8 in. (2.03 m)	6 ft 8 in. (2.03 m)	6 ft 8 in. (2.03 m)
Maximum height between landings	12 ft (3.7 m)	12 ft (3.7 m)	12 ft (3.7 m)
Minimum dimension of landings in direction of travel	Stairways and intermediate landings shall continue with no decrease in width along the direction of exit travel. In new buildings every landing shall have a dimension, measured in direction of travel, equal to the width of the stair. Such dimension need not exceed 4 ft (1.22 m) when the stair has a straight run.		
Doors opening immediately on stairs, without landing at least width of door	No	No	No

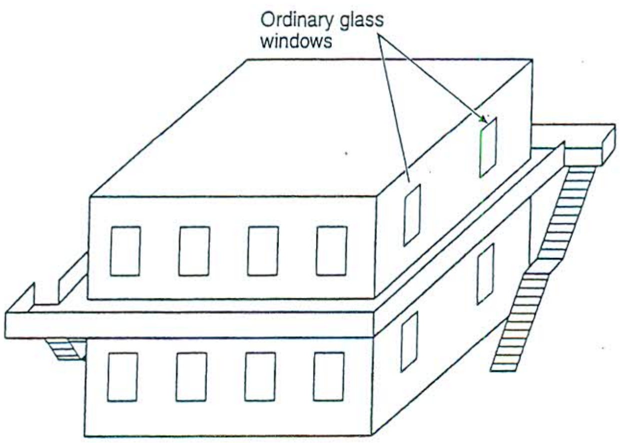


FIGURE 4.3.11 *Outside Stairs Providing Direct Exits to the Outside for All Rooms in a Multistory Building. There are no interior corridors through which smoke and flame could spread.*

is separated and arranged according to the requirements for exits.

The use of a hallway or corridor as an exit passageway introduces some unique considerations. The use of these spaces for purposes other than exiting may violate fundamental design considerations. In an industrial situation, for example, the use of a gasoline-powered forklift in a corridor designated as an exit passageway would violate the principles of exit design. NFPA *101* specifies that an exit enclosure should not be used for any purpose that could interfere with its value as an exit and is strictly limited by the code. Furthermore, penetration of the enclosure by ducts and other utilities may violate the protective enclosure.

Each opening in an exit enclosure introduces a point of weakness that could allow fire contaminants to spread into the exit and prevent its use. The typical corridor used as an exit with numerous door openings could result in fire contamination of the enclosure if a door fails to close and latch. The door openings in exit enclosures should be limited to those necessary for access to the enclosure from normally occupied spaces. Therefore, doors and other openings to spaces such as boiler rooms, storage spaces, trash rooms, and maintenance closets are not allowed into an exit passageway.

An exit passageway should not be confused with an exit access corridor. Exit access corridors do not have as stringent construction protection requirements as do exit passageways, since they provide access to an exit rather than being an extension and component of the exit. In Figure 4.3.6 the passage between E and D is an exit passageway.

Fire Escape Stairs

Fire escapes should be stairs, not ladders. Fire escapes are, at best, a poor substitute for standard interior or exterior stairs. NFPA *101* only permits existing fire escapes in existing buildings.

The same principles of design apply to fire escapes that apply to interior stairs, though requirements for width, pitch, and other dimensions are generally less strict. NFPA *101* gives the following criteria for fire escape stair design.

Fire escape stairs ideally extend to the street or to ground level. When sidewalks would be obstructed by permanent stairs, swinging stair sections designed to swing down under the weight of a person may be used for the lowest flight of the fire escape stairs. The area below the swinging section must be kept unobstructed so the swinging section can reach the ground. A counterweight of the type that balances on a pivot should be provided for swinging stairs; cables should not be used. Fire escapes that end on balconies above the ground level and provide no way to reach the ground, except by portable ladders or jumping, are unsafe.

Many persons who fear heights are reluctant to use fire escapes. As far as possible, design should provide a sense of security, as well as suitable railings and other details actually needed for safety. Fire escapes must be well anchored to building walls and kept painted to prevent rust.

Preferred access to fire escapes is through doors leading from the main building area or from corridors, never through rooms that may have locked doors except where every room or apartment has separate access to a fire escape. Although preferred access to fire escapes is by doors, windows may be used, in which case sills should not be too high above the floor. Windows should be of ample size, and, if insect screens are installed, they should be of a type that can be opened or removed quickly and easily. Decorative grilles or security bars should not be installed over windows that provide access to fire escapes.

Fire escapes can create a severe fire exposure to people if flames come out windows beneath them (Figure 4.3.12). The best location for fire escapes is on exterior masonry walls without exposing windows, with access to fire escape balconies by exterior fire doors. Where window openings expose fire escapes, fixed wired-glass in metal sashes should be used. Where there is a complete standard automatic sprinkler system in the building, the fire exposure hazard to personnel on fire escapes is minimized.

In northern climates, outside fire escapes may be obstructed by snow and ice.

Escalators, Moving Walkways, and Elevators

In some occupancies, escalators may be recognized as exits in existing buildings if they have enclosures similar to exit stairs and meet the requirements for stairs as to tread width and riser height. However, they are seldom installed in such a way that

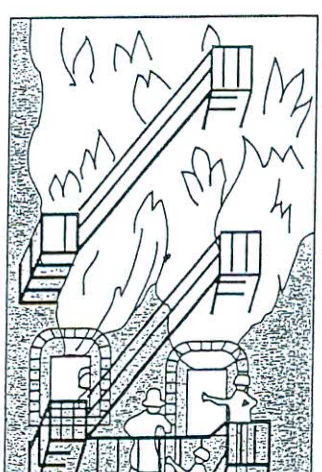


FIGURE 4.3.12 *The Makeshift, Often Dangerous Aspect of Fire Escapes. Fire may make fire escapes useless as this picture, drawn from a photograph of an actual fire, shows.*

they would qualify as exits, and it is common to find escalator installations with unprotected floor openings. Escalators are not recognized as an acceptable component in a means of egress in new construction.

Moving walkways also may be used as means of egress if they conform to the general requirements for ramps, if inclined, and for passageways, if level.

Elevators are not recognized as exits. However, elevators are permitted to be used, under limited conditions, to serve areas of refuge for the mobility impaired. The *Life Safety Code* also recognizes elevators, under very limited conditions, as the second exit from limited access towers such as FAA control towers.

Areas of Refuge

Since 1991, NFPA *101* has listed "areas of refuge" as a specific means of egress element. Although they are beneficial to all people, their primary purpose is for people with difficulty using stairs. All new buildings must address the issue of "accessible means of egress." In most new nonsprinklered multistory buildings, this will require some form of area of refuge. Figures 4.3.13 and 4.3.14 illustrate two methods for providing areas of refuge in non-sprinklered buildings.

Ropes and Ladders

Ropes and ladders generally are not recognized in codes as a substitute for standard exits from a building. This is proper since there is no excuse for permitting their use except possibly in

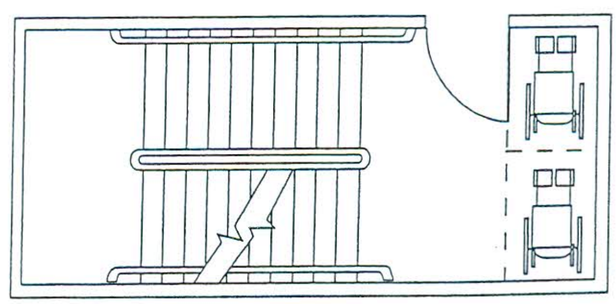


FIGURE 4.3.13 *Exit Stair Used as an Area of Refuge*

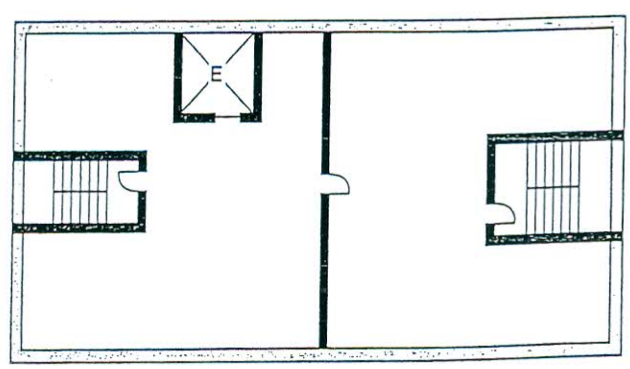


FIGURE 4.3.14 *Areas of Refuge in Nonsprinklered New Construction*

existing one- and two-family dwellings where it is economically impractical to add a secondary means of escape. In this case, a suitable rope or chain ladder or a folding metal ladder may be suitable. However, the homeowner should recognize that aged, infirm, very young, and physically handicapped persons cannot use ladders and that, if the ladder passes near or over a window in a lower floor, flames from the window can prevent the use of the ladder.

Windows

Windows are not exits. They may be used as access to fire escapes in existing buildings if they meet certain criteria concerning the size of window opening and the height of the sill from the floor. Windows may be considered a means of escape from certain residential occupancies.

Windows are required in school rooms subject to student occupancy, unless the building is equipped with a standard automatic sprinkler system, and in bedrooms in one- and two-family dwellings that do not have two separate means of escape. These windows are for rescue and ventilation and must meet the criteria for size of opening, method of operation, and height from the floor.

EXIT LIGHTING AND SIGNS

Exit Lighting

In buildings where artificial lighting is provided for normal use, the illumination of the means of egress is required to ensure that occupants can evacuate the building quickly. The intensity of the illumination of the means of egress should be not less than 1 footcandle (10.77 lu/m^2) measured at the floor. It is desirable that such floor illumination be provided by lights recessed in the wall and located approximately 1 ft (30.5 cm) above the floor because such lights are then unlikely to be obscured by the smoke that might occur during a fire. In auditoriums and other places of public assembly where movies or other projections are shown, NFPA *101* permits a reduction in this illumination for the period of the projection to values of not less than ⅕ footcandle (2.2 lu/m^2).

Emergency Lighting

NFPA *101* requires emergency power for illuminating the means of egress in many occupancies. For example, emergency lighting is required in assembly occupancies; in most educational buildings; in healthcare facilities; in detention and correctional facilities; most hotels and apartment buildings; in Class A and B mercantiles; in business buildings based on occupant load and number of stories; in most industrial and storage buildings; and in underground or windowless structures subject to occupancy by more than 100 persons.

Well-designed emergency lighting using a source of power independent from the normal building service automatically provides the necessary illumination in the event of an interruption of power to normal lighting. The failure of the public utility or other outside electric power supply, the opening of a circuit breaker or fuse, or any manual act, including accidental opening of a switch controlling normal lighting facilities, should result the automatic operation of the emergency lighting system.

Reliability of the exit illumination is most important. NFI 70, *National Electrical Code®*, details requirements for the i stallation of emergency lighting equipment. Battery-operat electric lights and portable lights normally are not used for pi mary exit illumination, but they may be used as an emergen source under the restrictions imposed by NFPA *101*. Lumine cent, fluorescent, or other reflective materials are not a substitu for required illumination, since they are not normally sufi ciently intense to justify recognition as exit floor illumination.

Where electric battery-operated emergency lights are use suitable facilities are needed to keep the batteries proper charged. Automobile-type lead storage batteries are not suitabl because of their relatively short life when not subject to freque recharge. Likewise, dry batteries have a limited life, and there is danger that they may not be replaced when they have deteriorated

If normal building lighting fails, well-arranged emergenc lighting provides necessary floor illumination automaticall with no appreciable interruption of illumination during the changeover. Where a generator is provided, a delay of up to 1(seconds is considered tolerable. The normal procedure is to prc vide such emergency lighting for a minimum period of 1½ h. Most healthcare occupancies have self-contained electric generating plants for emergency power supplies, not only for exi lighting but also for use in the event of failure of the public util ity. Where such emergency electric facilities are provided, they may supply power for emergency exit lighting, as well as othe critical areas of such buildings.

Exit Signs

All required exits and access ways must be identified by readily visible signs where the exit or the way to reach it is not immediately visible to the occupants. Directional "EXIT" signs are required in locations where the direction of travel to the nearest exit is not immediately apparent. The character of the occupancy will determine the actual need for such signs. In assembly occupancies, hotels, department stores, and other buildings with transient populations, the need for signs will be greater than in a building with permanent or semi-permanent populations. Even in permanent residential-occupancy buildings, signs are needed to identify exit facilities, such as stairs, that are not used regularly during the normal occupancy of the building. It is just as important that doors, passageways, or stairs that are not exits but are so located or arranged that they may be mistaken for exits be identified by signs with the words "NO EXIT."

Signs should be so located and of such size, color, and design as to be readily visible. Care should be taken not to locate decorations, furnishings, or other building equipment so as to obscure the visibility of these signs. NFPA *101* does not make any specific requirement for sign color but requires that signs be of a distinctive color. Some local codes do specify exit sign color. NFPA *101* specifies the size of the sign, the dimensions of the letters, and the levels of illumination for both externally and internally illuminated signs.

Improvement in the physical marking of exits in an office occupancy with point-source, red or green strobe lights has been suggested. Placing corridor illumination on the walls close to the floor to provide effective illumination under smoke conditions, as is the practice in Japan, is a technique worthy of research.[27]

ALARM SYSTEMS

Fire alarm systems to alert occupants to leave the building are normally operated manually. The alarm-sounding devices themselves should be distinctive in pitch and tone quality from all other sounding devices, and the use of these devices should be restricted to evacuation notification. Vocal alarm systems have been developed and installed in many high-rise buildings.[14] NFPA *101* mandates voice alarm and communication systems in high-rise buildings. It is, of course, very important that all alarm system devices be distributed throughout a building so as to be heard effectively in every room above all other sounds. Visible, as well as audible, alarm devices are sometimes used in buildings. NFPA *101* permits flashing the exit signs with the activation of the fire alarm system. In new construction, visible alarms must be provided in addition to audible alarms in most instances.

The proper maintenance of alarm systems is most important. Alarm systems should be supervised by a responsible person who will make the proper tests at specified intervals and will take charge of all alterations and additions to the systems.

EMERGENCY EGRESS AND RELOCATION DRILLS

Emergency exit and relocation drills are essential in schools and are desirable in every type of occupancy to ensure familiarity with the exits and their operation. In occupancies such as hospitals, nursing homes, hotels, and department stores, drills are usually limited to employee participation, without alarming patients, guests, or customers. Drills should be planned to get everyone out of the building or to an area of refuge in an orderly manner, as promptly as possible. Fire fighting is always secondary to life safety, and, in general, fire-fighting operations should not be started until the evacuation is completed, except in cases where trained fire departments conduct rescue and fire-fighting operations simultaneously.

Drills should be held at least once a month or more often, but not at regularly scheduled periods. Drills should occur on all shifts in an occupancy operated 24 hours a day. They should simulate typical fire conditions for the occupancy. Drills, both with and without warning, are beneficial.

School emergency egress and relocation drills are an exercise in discipline, not speed, though reasonably prompt evacuation of a building is important. Students and staff should not be permitted to stop to put on coats. No individuals should be permitted to remain in the building, and no one should be excused from participating in the drill. The drill should include a roll call by class at designated assembly areas outside the building to make sure that no one has been left behind.

There also should be an established routine for a complete check of the entire building, including toilets, to make sure that no one has been left behind. All exits should be used in drills, but routes should be varied from drill to drill. Occasional drills should be held that simulate conditions of an exit blocked by fire or smoke. All drills should simulate the fire department notification procedure. For a more detailed discussion of fire exit drills, see Chapter 1 of this section.

MAINTENANCE OF THE MEANS OF EGRESS

The provision of a standard means of egress with adequate capacity does not guarantee the safety of the occupants in the event of an evacuation of any building. Means of egress that are not properly maintained can mean loss of life in a fire. Property managers usually assign definite responsibility for maintenance of mechanical and electrical equipment but may fail to do the same for the means of egress. As a result inspection authorities may find otherwise safe stairways used as storage for materials during peak sales or manufacturing periods. In apartment buildings, rubbish, baby carriages, and other obstructions are often found in stairway enclosures. Exit doors may be found locked or hardware in need of repair. Doors blocked open or removed from openings into stairway enclosures may permit rapid spread of smoke or hot gases throughout the building. Loose handrails and loose or slippery stair treads offer the dangerous probability that persons evacuating a building will fall in the path of others seeking escape. Maintaining the means of egress in safe operating condition at all times is as important to the prevention of loss of life as the proper construction of the building and the elimination of fire hazards.

SUMMARY

Providing adequate means of egress is a key fire safety issue in both new buildings and in existing facilities. NFPA *101* provides in-depth coverage for providing adequate means of egress. For new construction, many of the issues are also covered in building codes, including the new *NFPA 5000*. This chapter only introduces the subject. To more completely understand the subject, both the NFPA *Life Safety Code*® *Handbook* and the *SFPE Handbook of Fire Protection Engineering* should be consulted.

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NFPA Codes, Standards, and Recommended Practices

Reference to the following NFPA codes, standards, and recommended practices will provide further information on concepts of egress design discussed in this chapter. (See the latest version of The NFPA Catalog *for availability of current editions of the following documents.)*

NFPA 13, *Standard for Installation of Sprinkler Systems*
NFPA 70, *National Electrical Code®*
NFPA *101®*, *Life Safety Code®*
NFPA 101A, *Guide on Alternative Approaches to Life Safety*
NFPA 253, *Standard Method of Test for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source*
NFPA 255, *Standard Method of Test of Surface Burning Characteristics of Building Materials*
NFPA 260, *Standard Method of Tests and Classification System for Cigarette Ignition Resistance of Components of Upholstered Furniture*
NFPA 261, *Standard Method for Determining Resistance of Mock-Up Upholstered Furniture Material Assemblies to Ignition by Smoldering Cigarettes*
NFPA 267, *Standard Method of Test for Fire Characteristics of Mattresses and Bedding Assemblies Exposed to Flaming Ignition Source*
NFPA 286, *Standard Methods of Fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth*
NFPA 5000™, Building Construction and Safety Code™

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SELECTION 4

Occupant Response to Fire Alarm Signals

Guylène Proulx

This selection, originally published in NFPA's 2002 edition of the National Fire Alarm Code Handbook, *provides information on how people react when a fire alarm sounds and they're faced with a potential emergency situation. All internal cross references, figure numbers, and table numbers remain unchanged and refer to the original published material.*

Source: Supplement 4, *National Fire Alarm Code Handbook,* 2002 Edition.

Supplement 4

Occupant Response to Fire Alarm Signals

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Editor's Note: The National Fire Alarm Code is based on the premise that fire alarm systems will detect and signal the presence of fire or other products of combustion and that building occupants will respond to alarm signals.

INTRODUCTION

Fire alarms go off from time to time in most buildings. Users of *NFPA 72, National Fire Alarm Code®* expect that the fire alarm system will improve the level of fire safety. It is generally assumed that the signal transmitted by the fire alarm system notifying occupants about a fire requires their immediate action. The most common action expected of building occupants upon hearing a fire alarm is that they will immediately start to evacuate the building. However, it has been observed that occupants are slow in taking action when hearing a fire alarm, especially in deciding to evacuate. In fact, research shows that in some buildings, occupants tend to completely ignore the fire alarm signal. Supplement 4 will attempt to explain such situations and identify the means to change occupants' indifference.

FIRE ALARM SYSTEMS OBJECTIVES

Questioning the intentions behind the installation of fire alarm systems in buildings that are required by NFPA *101®, Life Safety Code®,* and many other codes is a good beginning. Why install fire alarm notification appliances that will transmit a signal to the building occupants? This question may appear strange but is worthwhile asking to demystify occupants' reactions. According to the Code, an *alarm* is defined as a warning of fire danger. The first objective of a fire alarm signal is to notify occupants of a fire. Another objective is implicit in the definition of the *alarm signal*: a signal indicating an emergency requiring immediate action. The second objective for installing fire alarms is the expectation that occupants will immediately react to the alarm signal. It is usually expected that the

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fire alarm signal will be understood by occupants as the *evacuation signal*, which is defined as a distinctive signal intended to be recognized by the occupants as requiring evacuation of the building. The third objective of fire alarms is that, upon hearing its signal, occupants will start evacuation. A final objective is that the fire alarm activation will allow sufficient time for the occupants to escape.

In summary, there are four occupant behavior objectives intended to result from the activation of the fire alarm signal:

1. Warn occupants of a fire
2. Prompt immediate action
3. Initiate evacuation movement
4. Allow sufficient time to escape

Are these rather demanding objectives met when the fire alarm signal is activated? In some buildings, they are met, but in some others, they are not. For example, when the fire alarm goes off in elementary schools, all pupils leave in ranks with their teachers and gather on the playground. In such situations, it is concluded that the four objectives of the fire alarm signal are met. In comparison, when a fire alarm goes off in a shopping center or a high-rise office building, fire fighters often observe upon arriving on location that most, if not all, occupants are still in the building continuing their activities and ignoring the fire alarm. In such cases, the objectives of the fire alarm signal are not met. This lack of occupant response could have tragic consequences in the event of an actual fire.

THE MEANING OF THE FIRE ALARM SIGNAL

One explanation for the occupants' lack of reaction to the fire alarm signal is the occupants' failure to recognize the signal as the fire alarm signal. Fire alarm signals can be delivered through appliances such as bells, horns, chimes, or electronic appliances. In turn, these appliances can emit either a continuous, pulsating, slow whoop, or voice instruction. This situation means that a large variety of sounds can be used as a fire alarm signal. Furthermore, there are other types of alarms that can be activated in buildings, such as burglar alarms, elevator fault alarms, security door alarms, and so forth. Consequently, the public may have difficulty recognizing the sound of the fire alarm signal. This problem in identifying the fire alarm signal could explain, in part, the public's indifference when a fire alarm actuates.

The need to identify a unique fire alarm signal that could become universal was acknowledged a long time ago. Since the 1970s, numerous discussions to develop a standard fire alarm signal have taken place [Mande, 1975; CHABA, 1975]. Experts finally agreed not to limit the fire alarm signal to any one sound, but instead to support universal identification through the use of a consistent sound pattern. The temporal three pattern, described in ISO 8201, *Acoustics — Audible Emergency Evacuation Signal*, is expected to become the standard fire alarm signal to be used everywhere to warn occupants of a fire danger. The temporal three signal has been required by NFPA 72 since 1996 and, in Canada since 1995 in the *National Building Code* of Canada [NBC, 1995]. (See Exhibit S4.1.)

It is expected that it may take 15 years to 20 years before most buildings in Canada and the United States have the temporal three fire alarm signal installed. With time, it is hoped that more countries around the world will adopt this standard signal. The objective of the implementation of the temporal three alarm signal is to facilitate occupants' recognition of the fire alarm signal by using a standardized sound pattern. This sound pattern allows for cultural and language differences, and it can also facilitate perception by people with minor hearing limitations.

The introduction of the temporal three alarm signal is aimed at meeting the first objective of the fire alarm, which is to warn occupants of a fire. The question remains, however, whether the implementation of the new temporal three alarm signal will solve the problem of occupants ignoring

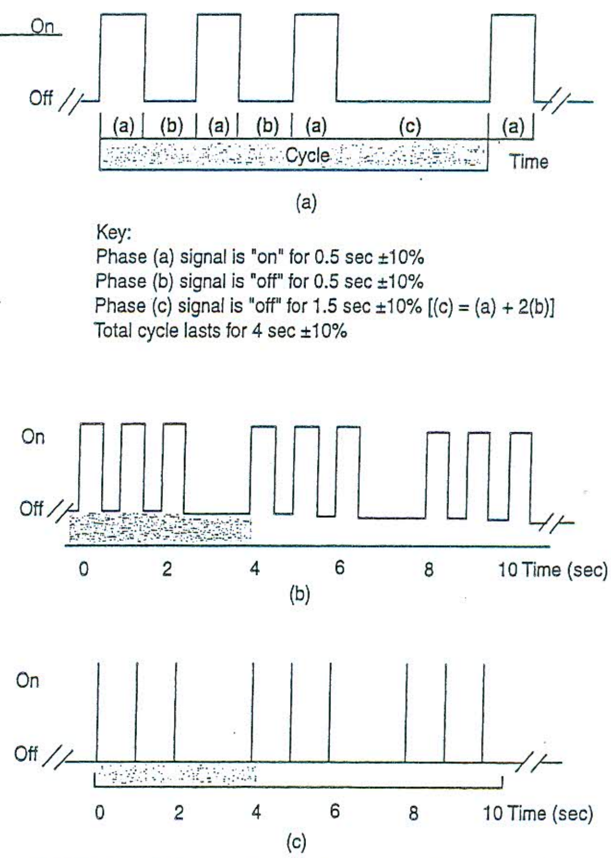

EXHIBIT S4.1 Temporal Three Pattern for Fire Alarm Signal. (Source: Life Safety Code Handbook, 8th ed., National Fire Protection Association, Quincy, MA) the fire alarm. It is one thing to recognize a signal, it is another thing to act upon perceiving a signal.

Assuming that the fire alarm signal is recognized by occupants, is this signal sufficient to trigger evacuation movement? After studying numerous actual fires, false alarms, and evacuation drills, it appears that a fire alarm signal alone is often not sufficient to prompt all occupants to leave a building. The intention behind the installation of the temporal three signal is that occupants will recognize this signal and will know that they should immediately evacuate the building. Will the new temporal three alarm signal, by itself, meet this intention? Probably not. For the temporal three signal to be understood by occupants as a signal indicating that they should immediately evacuate the building would require considerable public education and occupant training in each specific building. The implementation of the temporal three alarm signal is a big step in the right direction but it cannot solve all the problems. In the long run, it should solve the problem of recognition but, to ensure occupant safety, the problem of proper response must also be handled. Proper response can be achieved by means complementary to the fire alarm signal. Meanwhile, fire alarm devices emitting the temporal three-pattern signal should become the universal means to notify occupants of a fire, no matter what behavior is expected from the occupants.

THE TENDENCY TO IGNORE FIRE ALARMS

A first element of the explanation as to why occupants tend to ignore fire alarms was previously discussed: the occupants do not recognize the meaning of the fire alarm signal. But there is more. It seems that the large number of false alarms, test alarms, and drills can also explain the fact that occupants are reluctant to act when the fire alarm sounds. The problem with nuisance or false alarms is that, after a time, occupants lose confidence in the system, assuming that when the fire alarm goes off it is only another false alarm. The number of nuisance alarms and their deterring effects have to be studied over a period of time. Three nuisance alarms in the course of the same week will not have the same impact as three nuisance alarms over a year. The time of occurrence and the type of building might also play an important role in the impact of such nuisance alarms. If the nuisance alarm occurs in the middle of the night in a high-rise residential building, it may have a more negative lasting effect on occupants than a nuisance alarm happening in an office building on a nice, sunny day.

How many nuisance alarms are too many? How many will make people lose faith in this signal? Over the period of a year, are three, five, or 10 nuisance alarms the maximum? No research data has been found on that question. What is known, though, is that nuisance alarms tend to wear out the meaning of danger or urgency that should be associated with the fire alarm signal. It has been documented by the NFPA that, in households, 25 percent of single-station smoke alarms failed to activate when tested because the power source had been removed or disconnected. When asked why the power source was missing, one-third of the respondents cited too many nuisance alarms [Smith et al., 1997].

Confronted with many nuisance alarms, people are likely to ignore the signal or attempt to disconnect the system if they can. This type of behavior is similar to that shown in the great movie with Audrey Hepburn and Peter O'Toole, entitled "How to Steal a Million" in which the couple wants to steal a statue in a Paris museum. The statue is surrounded by a sophisticated burglar alarm, and the couple manage to trigger the alarm from a distance with a boomerang. After the alarm has been triggered twice in the middle of the night for no apparent reason, the chief guard, who has become annoyed with the alarm system, disconnects it. Thus the thieves are able to run away with the statue without a problem.

One way to mitigate the impact of nuisance alarms is to reduce them to a minimum. Reducing nuisance alarms is not easy in some buildings where the fire alarm system is antiquated, receives poor maintenance, or is badly installed. Nonetheless, it is necessary to investigate each nuisance alarm to try to solve the problem. A Code-compliant fire alarm system will produce fewer false alarms.

The public often assumes that false alarms are due to teenagers' mischief. Teenagers are blamed for many things. However, it was observed on surveillance cameras that pranksters could be teenagers, but were also children, adults, or even elderly people. Further, the assumption that nuisance alarms are usually prank alarms is not founded. In fact, most nuisance alarms are usually due to system malfunctions. In 1997, fire departments in the United States received close to 2 million false alarm calls. As presented in Table S4.1 [Karter, 1998], 45 percent of these calls were system malfunctions, 27 percent were well-intentioned calls that turned out not to be fires, 16 percent were mischievous false calls, and 12 percent were other types of false alarms (such as bomb scares).

The important thing to remember is to attempt to reduce the number of nuisance alarms to a minimum. If nuisance alarms still occur, it is essential to inform occupants of the situation. After a nuisance alarm, occupants should be informed of the cause of the problem so that they will know that the building owners and managers are aware of the situation and are doing something about it. Informing the occupants will help maintain a certain level of confidence about the fire alarm system and the building management.

Due to the deterring effect of actuating the alarm for

TABLE S4.1 Estimated False Alarms Received by U.S. Fire Departments in 1997

Reasons for Alarm	*Estimated Number*	*Percent (%)*
System malfunctions	816,500	45.0
Unintentional calls	490,000	27.0
Malicious, mischievous false calls	286,500	15.8
Other false alarms (bomb scares, etc.)	221,500	12.2
Total	1,814,500	100

non-fire reasons, should conducting system tests and evacuation drills with occupants in the building be avoided? Yes and no. System tests should be conducted when there is a limited number of occupants in the building, because the objective of such tests is to assess whether the system is functioning properly or not. Walkthrough tests conducted on the input side without any output are not sufficient. Test of the notification appliances must be conducted by actuating the devices. If such tests are conducted when occupants are in the building, it is important to inform the occupants before the fire alarm activation that a test will be conducted, and after the test, that the test is completed. Silent, walkthrough tests are frequently conducted on the input side (i.e., for pull boxes and smoke/heat detectors) without any output. This test procedure minimizes the disturbance. Tests of the notification appliances must be done by actuating the devices.

EVACUATION DRILLS

Evacuation drills are a different issue. There is some discussion in the field whether or not building management should tell occupants when drills are expected, so they are not perceived as nuisance alarms. Often if occupants are told in advance, they tend not to participate or avoid being in the building during a drill. After the drill, however, occupants should be told that "this was a drill," that "the drill was conducted to improve safety," and "if you have comments or concerns, please contact so and so."

Exercises or drills are held to assess if staff and occupants can apply the fire safety plan and if the evacuation procedure is appropriate. Consequently, evacuation drills should be conducted at least annually in all buildings (regardless of occupancy), with the full participation of every occupant. Each drill may add to the number of perceived nuisance alarms, but drills are essential. It is the best way to train occupants. During a drill, occupants learn to recognize the sound of the fire alarm signal; they also learn and practice the actions expected from them. Usually, drills are the only opportunity for occupants to experience alternative ways out, such as stairwells and emergency exits not usually used or even prohibited from normal use. A drill allows management to assess the evacuation procedure that is in place but, more importantly, it allows occupants to become familiar with the procedure. Through a drill, occupants can assess their own capacity in carrying out the evacuation procedure. For instance, it might be the only opportunity for an occupant to evaluate how long it takes to evacuate the building using the stairwell from the 45th floor. Drill participation allows an occupant to confirm that the stairwell is accessible, that the door at the bottom is indeed unlocked, and that the exit leads to a safe outside area. A person who has never experienced a route is very unlikely to give it a first try during an emergency. People tend to go toward the familiar [Sime, 1980]. Gaining experience with a nonfamiliar route to evacuate a building is the best way to ensure that occupants are likely to use this means of egress during an actual fire.

AUDIBILITY OF FIRE ALARM SIGNALS

The problem of recognition of the fire alarm signal and the number of nuisance alarms are two phenomena that can explain occupants' tendency to ignore fire alarm signals. A third explanation is also possible: the audibility problem of the fire alarm signal. Studies in mid-rise and high-rise residential buildings have shown that, in some buildings, occupants could not hear the fire alarm signal from inside their apartments [Proulx et al., 1995a]. This audibility problem was typically observed in apartment buildings where the fire alarm appliances were located in the common corridors. Even though the fire alarm signal was very loud in the corridor, sound attenuation was such that the signal was not audible inside dwelling units, especially in rooms located farthest from the corridor. Ambient sound created by television, radio, air conditioning, or human activities can easily mask the sound of the fire alarm signal.

The audibility problem is very important because people cannot be expected to do the right things if they are not notified of the fire in the first place. To ensure alarm audibility, Chapter 4 of the Code requires certain sound pressure levels. In most multi-dwelling buildings, the required levels can be met only by locating the appliance inside the dwelling unit. In fact, locating a notification appliance in each unit is probably the best way to ensure alarm audibility.

The traditional location of fire alarm appliances in corridors and stairwells can create areas where the alarm is not audible. Further, locating appliances in common areas can be counterproductive. It was observed during evacuation drills, and was reported after fires, that once occupants were notified of the fire and decided to leave their unit, they often went to their neighbors or discussed the best course of action with others in the corridor. Communication among members of a group from the same dwelling or with neighbors becomes paramount to ensure that everybody is accounted for, to decide what to do, where to go, to confirm decisions with others, and so forth. Very loud alarm signals in corridors and stairwells can prevent these essential exchanges among people. Once in the corridor or stairwell, occupants no longer need to be notified of the fire; what they need is the opportunity to obtain and exchange information. Corridors and stairwells are also locations where occupants might receive instructions from wardens, staff, or fire fighters, so the volume of the fire alarm should be low enough to allow for efficient communication in these locations. Designers, installers, and authorities having jurisdiction should consider these human reactions when locating, installing, or inspecting the notification appliances in corridors and stairwells.

Despite the fact that the volume of the fire alarm signal should be low enough to allow verbal exchanges, it should not be so low that occupants might think that the signal has been switched off. During an evacuation study, the fire alarm signal was turned off after 5 minutes to facilitate walkie-talkie communication among fire fighters [Proulx et al., 1995b]. It was observed, on camera, that most occupants who had started to evacuate stopped and returned home when the alarm signal was deactivated. Because the fire alarm was switched off, occupants assumed the emergency was over and they could return home. This reaction from the occupants explains why it is very important to maintain the actuation of the alarm signal as long as the situation is not totally resolved. For the occupants, interruption of the fire alarm signal is the sign that the situation is over. As long as there are occupants in the building, the fire alarm signal should be functioning to maintain awareness of the state of emergency.

THE BUILDING, THE OCCUPANT, AND THE FIRE

When a fire alarm actuates in a building, what occupants will do about it — assuming they heard the signal, recognized it as the fire alarm, and have not been completely desensitized by too many nuisance alarms — depends on a number of complex factors. These complex factors can be organized around three major headings: the building characteristics, the occupant characteristics, and the fire characteristics.

There are a number of characteristics that simultaneously could have an impact on occupant behavior during a fire. The characteristics to be presented are not an exhaustive list. Furthermore, some characteristics can have a greater impact than others.

Among the building characteristics, a few types of occupancies can be identified to illustrate the importance of looking at the essence of each building and building area. The traditional way to approach occupancy classification is sometimes too broad to support predictions relative to occupant behavior in fire. For example, it cannot be expected that occupants in a church, a cinema, or a skating rink will react the same way in the event of a fire even though these buildings are all assembly-type occupancies. Each of these locations presents a specific challenge. The architecture of the space is another important building characteristic. If the space is complex, it can have a major impact on occupant movement and on the possibility of finding an alternative way out if the familiar route is blocked. At the time of the fire, the activities happening in the protected premises will have a major impact on occupants' response and reaction time. For example, in a hotel, whether the guests are located in their rooms, at the swimming pool, or on the casino floor will have an impact on their reactions. Finally, the building fire safety features will also play a key role in informing the occupants of the situation.

The following represents a partial list of building characteristics that can impact occupants' response and reaction time to a fire alarm signal.

1. *Type of occupancy.*
   a. Residential (low-rise, mid-rise, high-rise)
   b. Office
   c. Factory
   d. Hospital
   e. Hotel
   f. Cinema
   g. College and university
   h. Shopping center
2. *Architecture.*
   a. Number of floors
   b. Floor area
   c. Location of exits
   d. Location of stairwells
   e. Complexity of space
   f. Building shape
   g. Visual access
3. *Activities in the building.*
   a. Working
   b. Sleeping
   c. Eating
   d. Shopping
   e. Watching a show, a play, a film, etc.
4. *Fire safety features.*
   a. Fire alarm signal (type, audibility, location, number of nuisance alarms)
   b. Voice communication system

c. Fire safety plan
d. Trained staff
e. Refuge area

The occupant characteristics will be paramount in explaining and predicting potential occupant behavior. Occupant characteristics include the occupants' profile, which represents a grouping of important parameters that can be influential in predicting occupants' response to a fire such as the occupants' age and mobility. Occupants' knowledge and experience are also important factors, because occupants who have, or do not have, training can react very differently. The condition of the occupants at the time of the event can also determine their potential to react promptly and appropriately. Personality and decision-making styles of each occupant can be influential; some occupants copy the reactions of others, whereas other occupants are prepared to take on a leadership role. Finally, the occupant's role in the building can explain different responses, for example, in a restaurant, the owner might be more likely than a client to fight a kitchen fire.

The following represents a partial list of occupant characteristics that can impact occupants' response and reaction time to a fire alarm signal.

1. Profile.
   a. Gender
   b. Age
   c. Ability
   d. Limitation
2. Knowledge and experience.
   a. Familiarity with the building
   b. Past fire experience
   c. Fire safety training
   d. Other emergency training
3. Condition at the time of event.
   a. Alone vs. with others
   b. Active vs. passive
   c. Alert
   d. Under influence of drug, alcohol, medication
4. Personality.
   a. Influenced by others
   b. Leadership qualities
   c. Attitude toward authority
   d. Anxiety level
5. Role.
   a. Visitor
   b. Employee
   c. Owner

Fire characteristics also can play an important role in the occupant response. During a fire, people perceive different cues from the fire and their interpretation of the situation changes rapidly, influencing their behavior. Perceiving a smell of smoke initiates a different response from directly seeing the fire.

The following represents a partial list of fire characteristics that can impact occupants' response and reaction time to a fire alarm signal.

1. Visual cues.
   a. Flame
   b. Smoke (color, thickness)
   c. Deflection of wall, ceiling, floor
2. Olfactory cues.
   a. Burn smell
   b. Acrid smell
3. Audible cues.
   a. Cracking
   b. Broken glass
   c. Object falling
4. Other cues.
   a. Heat
   b. Air draft

The difficulty with attempting to predict the occupants' behavior is that a number of the characteristics previously listed are mixed in different patterns according to each situation. There are a few concepts that can help explain and predict some of the occupant behavior, however. The concept of commitment is one of them. For example, imagine occupants of a cinema watching a suspense movie. The fire alarm signal sounds, the sound level of the alarm is audible above the sound track, and occupants recognize the signal. According to the objectives of the fire alarm system, the signal should prompt immediate action and initiate evacuation movement. Unfortunately, these reactions are unlikely to happen. It should be expected that most occupants will stay in their seat hoping that the alarm signal will shut up soon. Such a response could be explained using the concept of commitment. Occupants who have paid good money to watch a movie are not prepared to leave while they are engrossed in the story. They are committed to the activity of watching this movie, and the fire alarm signal by itself is probably insufficient to make them leave. Being committed to an activity, such as eating a meal, waiting in line for a ticket, or watching a show, is very powerful. People have a decision plan to carry out a specific activity and are reluctant to switch their attention to something unrelated.

As another example, the concept of role can explain the lack of response of some occupants in public buildings. In a museum or a department store, most occupants play the role of visitors and, as such, they expect to be taken care of. When the fire alarm signal is actuated, there are social interactions taking place: people will be looking at what others are doing. Therefore, if others are not paying attention to the fire alarm signal, occupants become reluctant to take any action that would make them appear to be out of place or overreacting to an insignificant situation. The role of visitors is usually to conform to the general behavior of others. Furthermore, visitors feel that it is their role to wait for instructions, even if they have recognized the signal as a fire alarm signal. They expect that someone will tell them what to do if something serious is really happening.

Despite constant efforts to educate the public as to the meaning of the fire alarm signal, that is, "that a fire alarm signal means leave immediately," this association is not automatic for every situation. For instance, in most public buildings, such as airports, occupants' interpretation of the fire alarm signal is that something is happening that is unlikely to be a fire, so they should stay put and wait to see what happens.

FIRE SAFETY PLAN

It is reasonable to expect occupants to be warned of a fire by the alarm signal, but the related response expected from the occupants may not be known by them unless it is detailed in a document such as the fire safety plan. Different names are used such as "fire safety information," "emergency instructions," or "escape plan," but these are all fire safety plans. Every building should have a fire safety plan from the single family home, to airports, shopping centers, hospitals, and warehouses. A fire safety plan should contain all the fire safety features of the building (including how the fire department is called), instructions regarding the actions expected by the occupants (whether they are staff or visitors, and including people with disabilities), number and frequency of drills, and so forth. This fire safety plan should be available to everybody; it should be posted in the building, updated regularly, and used during training and drills.

In more and more large buildings, the fire alarm signal does not indicate that occupants should evacuate the building. Instead, occupants are expected to remain on location, move to another area, move to an area of refuge, or implement any other plan of action that is the most appropriate for the building or some specific locations of a building. A massive evacuation movement could bring tragic outcomes in many large buildings. In some cases, such as high-rise hotels protected by a complete automatic sprinkler system, it might be safer for occupants to stay in their rooms and start protect-in-place activities such as sealing doors and cracks to prevent smoke from entering, waiting for the situation to be controlled, or waiting to be rescued.

The fire safety plan is an essential tool to ensure occupant fire safety. The fire alarm signal may not make occupants start to move, but if the intention and occupant response expected are stated clearly in the fire safety plan, and this plan is known and available, it might help to make occupants respond the way it has been planned.

CHANGE THE ENVIRONMENT

Once occupants have been warned of the fire danger through the fire alarm signal, the second step is to initiate action. Because it cannot be expected that the alarm signal, by itself, will initiate action, some other means must come into play. In many buildings, what is needed to make occupants move is to stop the current activities and change the environment.

In a shopping center, such change of the environment would be turning off the music; in a cinema, the movie should be stopped and the lights should be turned on as soon as the fire alarm actuates. In a discotheque or restaurant, the music should be stopped and full lighting should flood the space. Initial protestation from the crowd will diminish as occupants perceive new information. This kind of atmosphere change will help occupants to understand that something is going on and will facilitate the shift of occupants' attention from their current activities to the emergency situation.

This ambiance change is essential to ensure that occupants pay attention to the fire alarm signal and the emergency situation. Occupants are usually committed to specific activities such as eating, shopping, watching a show, or participating in a sporting event. As long as the show continues, people focus their attention on this activity and are very reluctant to shift their attention to an unexpected or ambiguous event. It is, therefore, critical to have a sharp change in the environment to alter the behavior of occupants.

After the fire alarm signal actuation to warn occupants, additional means to convey information will help initiate evacuation movement, such as using a voice communication system.

USE OF A VOICE COMMUNICATION SYSTEM

Most modern buildings are equipped with a voice communication system that is used to broadcast music and specific messages directed to the occupants or the staff on location. In the past, this means was rarely used to provide information to the occupants during fire emergencies. This is unfortunate because a voice communication system is probably one of the best ways to provide essential information to the occupants.

The reluctance to use the voice communication system to provide information was mainly due to the false idea that occupants will panic if they are told that there is a fire [Sime, 1980; Keating, 1982]. In fact, being told the truth is more likely to trigger the appropriate reaction than to trigger dysfunctional behavior. Research and actual fires demonstrate that receiving information through a voice communication system is one of the best ways to ensure that occupants will react immediately. Telling occupants that "there is a fire on the 3rd floor, please leave immediately" makes it easier for occupants to decide what to do. Contrary to some beliefs, occupants tend to immediately obey instructions given through the voice communication system [Proulx and Sime, 1991; Proulx, 1998].

As soon as the situation has been assessed as a fire emergency, there should be no delay in using the voice communication system to deliver messages to occupants. Voice messages will confirm the meaning of the fire alarm signal and instruct occupants on the best course of action. On-site management should be prepared to rapidly make the decision to evacuate the building or to direct occupants to a safe location in accordance with the fire safety plan. Waiting for the arrival of the fire department and for their assessment of the situation to deliver messages could be counterproductive. In fact, the fire department's first priority upon arrival at a fire scene is the location of occupants. This important activity occurs more quickly if occupants have gathered in a meeting place. Furthermore, when the fire department arrives on location, 5 minutes to 10 minutes, if not more, have passed since the fire was first detected. By that time, the situation could be lethal in some locations; if occupants are required to evacuate at that time, they may have to move through smoke-filled areas to reach the outside [Proulx, 1998].

Some buildings are equipped with an emergency voice alarm communication system that delivers prerecorded messages. Although such a system saves staff time, the use of prerecorded messages has proven ineffective and even dangerous in some situations. A field study demonstrated that a prerecorded message could not be precise enough to help occupants locate the nearest exit. During the evacuation of an underground station where the main escalator was blocked, occupants did not know where to go because the prerecorded message could not provide information as to the location of an alternative way out [Proulx and Sime, 1991].

The information content of a prerecorded message is always limited because it needs to be general enough to cover all situations of an alarm actuation. There are some new systems that can deliver different messages according to the location of the actuated detectors, but this technology has not yet proven totally efficient. During the Düsseldorf Airport fire in 1996, prerecorded messages in different languages were transmitted; unfortunately, the information delivered during the initial 10 minutes was erroneous, directing passengers toward the most dangerous areas of the airport [NFPA, 1998].

On two recent transatlantic British Airways' flights, a prerecorded emergency evacuation message was broadcast mistakenly. The crew could not stop the messages for approximately 30 minutes. During that time, passengers were crying, praying, and putting on life safety vests for emergency landing at sea. The distressful moments these passengers experienced were terrible. Issuing a prerecorded evacuation message by mistake is similar to a false alarm, in that it discredits a means of providing emergency information.

Evidently, the best approach is to broadcast live messages. Live messages allow the flexibility of altering the messages as new information is relayed to the person delivering the information. The tone of live messages can convey the urgency and importance of the information. Occupants are more receptive to live messages because they consider this information more likely to be genuine.

Messages delivered to the public during a fire emergency should contain three essential types of information:

1. Identification of the problem
2. Location of the problem
3. Instructions

If occupants are expected to react correctly, it is imperative for them to understand the situation. Attempting to minimize the danger or using technical jargon to disguise the real situation could confuse occupants and prevent them from reacting appropriately. Instead, it is important to identify the problem in common terms such as "we suspect a fire" or "there is a fire." The second important type of information is the location of the problem. The occupants will want to know if they are at immediate risk; knowing the location of the problem will help them in their decision-making process. Finally, the message should clearly explain what is expected from the occupants. In some cases, it might be best for the occupants to remain where they are when the alarm sounds; in others, they can be directed through a specific route and to a specific exit with the aid of live messages.

The availability of closed-circuit televisions (CCTVs) to broadcast useful and precise messages becomes a must for the person issuing messages. Because many buildings are now equipped with CCTVs for security purposes, these tools are an incomparable source of information to deliver the most precise messages during an emergency. Strategically placed CCTVs allow the person behind the microphone an overview of conditions in different areas of the premises. Messages can then be tailored to the crowd movement and the developing situation.

WELL-TRAINED OCCUPANTS

If the occupants are expected to do the right things during a fire emergency, the best way to meet this intention is to train them. The public, in general, does not have the knowledge of those who deal with fire safety issues day after day. Occupants' knowledge and assumptions regarding the development of a fire are often wrong. The literature is full of anecdotes reporting about people not doing what they were expected to do or, worse, doing things that endangered their lives. For example, occupants broke windows during the World Trade Center fire to vent the smoke, which made the situation worse, as fire professionals would predict [Fahy and Proulx, 1995]. In a high-rise residential fire, occupants did not close the main door upon leaving, judging that a wood door would burn right through [Proulx, 1996]. Some people poured water on burning oil (read in the newspaper); other people have attempted to hold their breath moving long distances through smoke [Proulx, 1998]; and some people entered a subway station and went down an escalator next to the fire, focused on their journey back home [Donald and Canter, 1990]. More horror stories are not needed.

The public, in general, should be educated about fire, how it can start, how it develops, and what impact it has on people. Most fire safety education programs are targeted toward children, which is excellent and should continue, but other groups are at risk and need to be educated as well. Everybody needs general education about fire safety. Further, occupants need to be trained in the fire safety plan for buildings they are visiting. This is easier for buildings that people visit frequently, such as a place of work, or where they stay for a period of time, such as a cinema or theater, where a short message could inform occupants of the fire safety plan for that location before the performance. But there are other types of buildings, such as airports or sport centers, where training occupants is not practical. In such locations, a large part of the responsibility for occupants' safety rests with staff. Consequently, staff training is paramount.

In public buildings, occupants are unlikely to initiate evacuation movement on hearing the fire alarm alone, but they are very likely to respond to members of staff. Staff members are regarded as knowledgeable; they are expected to know what is going on, what is the best course of action, and where the closest exit is. In uniform or wearing a name tag, staff are likely to be listened to. Evacuations of Marks & Spencer's department stores in the United Kingdom demonstrated that customers, even though the fire alarm had been ringing for some time, were prompted to evacuate only when requested to do so by the staff; then they complied right away with instructions [Shields et al., 1998]. In another situation, during an evacuation drill in an underground subway station, passengers waited three minutes on the platform under the ringing fire alarm signal. They complied immediately with the instruction to reboard the train when the uniformed guard arrived.

Proper staff training should include regular classroom training sessions as well as evacuation drills. An evacuation drill is a valuable occasion for staff to put into practice ideas learned in the training class, and for management to assess the application of the fire safety plan. Changes and other adjustments might be required after an evacuation drill; feedback from staff can help to identify areas for improvement. An assessment is also advisable after false alarms or actual fires in order to improve the fire safety plan.

If staff are expected to play an important role during the evacuation of the public, it becomes essential to train them. Each staff member, whether part-time or permanent, should be educated about the content of the fire safety plan. Staff should not be allowed to begin work before having received proper fire safety training. The lives of hundreds of people could be in the hands of a few staff members. Employees need to be made aware of the importance of their role and of their responsibility to look after the public in case of an emergency.

When dealing with large spaces or with large crowds, it is not practical to rely entirely on staff to direct occupants to safety, as the number of employees required might be very large. For such situations, it is more efficient to rely on a few well-trained staff members, the emergency voice alarm communication system, and CCTVs. With CCTVs, the person issuing information will have an overview of the situation that will contribute to the delivery of precise messages. Staff on location will then be able to assist with the evacuation in conjunction with the instructions being delivered through the voice communication system.

TIME TO ESCAPE

When the fire alarm is actuated, it should provide enough time for occupants to move to a safe location before conditions become dangerous. However, if the occupants do not start to move immediately after perceiving the fire alarm signal, the time available for safe escape becomes shorter. In an effort to reduce the delay between the time of alarm activation and the time at which people start to move, information should be provided to the occupants to prompt their movement. Movement can be prompted through a dramatic change in the environment (people are dancing the night away and suddenly the music stops and full lighting floods the space; a scary but effective way to make people pay attention), voice communication messages, staff instructions, and so forth. These means to inform occupants of the emergency should come into play as soon as possible after the alarm actuation to provide sufficient time for occupants to leave safely.

In residential evacuations, the delay time to start evacuation after hearing the fire alarm signal was three-fourths of the whole evacuation time [Proulx et al., 1995b]. In other words, if the total evacuation time was 4 minutes, 3 minutes were spent in delay time (investigating the situation, gathering family members and pets, finding wallet and keys, etc.), then 1 minute was used to move to safety. The initial delay time could be dramatically shortened if additional means to inform occupants were used. In an underground station, not all occupants managed to be evacuated; 15 minutes after the fire alarm signal activation, some passengers were still patiently waiting for their train, reading their newspaper. When the fire alarm signal was paired with emergency voice alarm communication messages or staff, the space was cleared in just over 5 minutes [Proulx and Sime, 1991].

Consequently, even a good fire alarm system that can issue early warnings to occupants might not ensure that occupants have sufficient time to escape safely if they do not respond to the alarm rapidly. Complementary means to provide information to occupants will help shorten the delay in response, providing enough time for occupants to reach safety.

CONCLUSION

It was demonstrated that it might be overly optimistic to expect that the fire alarm signal alone will warn occupants, prompt immediate action, initiate evacuation movement, and allow sufficient time to escape safely. A fire alarm signal emitting the temporal three pattern should be excellent at warning occupants of a fire danger. To meet the other objectives of the fire alarm signal regarding rapid appropriate response from occupants, other means to convey information are required.

The actuation of a fire alarm signal is unlikely to trigger a massive evacuation movement. This observation does not imply that fire alarms should be removed, because fire alarms are indispensable in warning occupants of an imminent danger. Occupants want and need to be warned of an occurring fire. With the recognizable temporal three pattern, good audibility, and minimum nuisance alarms, warning occupants of a fire danger with the fire alarm signal is a realistic objective. Obtaining a specific occupant response can be achieved through complementary means including voice communication messages, staff–warden instruction, training, drills and a well-devised fire safety plan. It is the combination of the fire alarm signal with other means to convey information that will ensure occupants' safety.

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