Movement of people in building evacuations
Pauls, J. L.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40000448
Research Paper (National Research Council of Canada. Division of Building Research), 1977

National Research Council Canada
Conseil national de recherches Canada

MOVEMENT OF PEOPLE IN BUILDING EVACUATIONS

by J.L. Pauls

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Human Response to Tall Buildings
Chapter 21, p. 281 - 292
D.J. Conway, ed., Dowden, Hutchinson and Ross
Stroudsburg, Pa.
Community Development Series, Vol. 34, 1977

DBR Paper No. 736
Division of Building Research

Price 25 cents OTTAWA NRCC 16253

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Le mouvement des personnes dans les escaliers de sortie et autres issues a été étudié dans des exercises d'évacuation des tours de bureaux et au cours de sorties normales dans d'autres édifices. L'auteur décrit le nombre de personnes, les vitesses et les mouvements. Les résultats soulèvent des questions quant aux idées et aux règles de calcul pré-
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Movement of People in Building Evacuations

J. L. Pauls
National Research Council of Canada

INTRODUCTION AND OBJECTIVES

Facilities for the movement of people are a major concern in building and fire codes, particularly in situations where rapid egress is required for occupant safety in emergencies. Fire is usually considered the most probable reason for rapid evacuation of all or part of a building; however, other emergency conditions, such as bomb threats, tornadoes, or loss of electric power might lead to evacuation in certain types of buildings.

The problem of fire in high-rise buildings has received much attention recently in the popular and technical literature, including building and fire codes [1-9]. Although difficulties in evacuation in high-rise fires are frequently mentioned (along with problems of smoke movement and fire department access), little original research has been done on this subject [10-15]. The limited recorded rationale for present-day exit requirements in codes is often based on a few, very limited and dated studies of movement in buildings[16-22].

The literature on evacuation is largely based on studies of the movement of people in contexts not perceived as genuine fire emergencies. Information, especially quantitative information, about how people move in buildings during actual fires is difficult to obtain. A few researchers have examined in detail the behavior of persons in fires; a much larger research effort, however, has been on their behavior in large-scale emergency situations, e.g., natural disasters [23-27]. (A paper in press reviews these areas in slightly more detail[28].) Such studies indicate that, contrary to popular belief, panic is relatively rare in these situations; in general, people cope remarkably well not only with fire emergencies but also with a wide variety of disaster situations.

Research on behavior in a range of circumstances should assist greatly in the transition from findings about movement in nonemergency or drill situations

This chapter is a contribution of the Division of Building Research, National Research Council of Canada, and is published with the approval of the director of the division.

to hypotheses about evacuation in cases of actual fire in buildings. It should be noted that communication systems, increasingly being provided in high-rise buildings for use in fire emergencies, have a considerable influence on how people perceive an emergency or a drill situation. This is one of the factors that may influence people to construe a drill situation as an actual emergency or conversely an actual emergency as a drill[14]. Therefore it seems reasonable to assume that the findings reported below, although based on observations of drills and normal egress, are generally applicable to many evacuation situations.

These introductory comments indicate not only the need for more detailed information about occupant movement in high-rise building fires but also the potential validity of developing such information in nonfire situations, such as drills. Studies of crowd egress in high-rise office buildings and in buildings with public assembly occupancies have been conducted during the last six years in Canada. The objective of these studies of movement of people was to develop largely empirical information which would contribute to improved design and operation of buildings, both through direct communication with designers and others in practice and through the medium of building codes[14,29].

STUDY METHODS

In 1969 the author was invited to take part in observations of a test evacuation of Vancouver's twenty-two story B. C. Hydro office building. Working with a team of seventeen observers, an attempt was made to record key events and conditions during the phased evacuation of about 1,000 people (with a fire floor and lower floors cleared first). The report[12] based on these observations describes the building and its occupancy; evacuation planning, organization, and procedure; key events during the drill (shown on a time scale); the speeds, flows, and densities of people on the exit stairs; environmental conditions in the stairs; and some findings of a questionnaire given to evacuation-control personnel in the building.

As a result of this study the author was invited by Canada's Dominion Fire Commissioner to conduct observations of a variety of evacuation exercises usually held in buildings occupied by the federal government in Ottawa. Between 1970 and 1974 some forty test evacuations were observed in office buildings ranging between eight and twenty-nine stories in height.

The majority of these evacuations were total evacuations (in which all occupants attempt to leave the building more or less simultaneously by way of exit stairs). The chief goal in observations of such total evacuations was the collection of data describing crowd movement down exit stairs.

Other observed evacuations in the larger buildings used more selective procedures in which particular floors of buildings were cleared in a predetermined sequence (floors in the assumed fire areas, then the top floors, and then perhaps the other floors in descending order). In addition to documenting crowd movement down stairs, observations were made of the use of communication systems and the supervision of evacuation by fire wardens.

Observation techniques included equipping between two and fifteen observers with portable cassette recorders operating continuously to register all observations and background sounds. These observations, plus tape recordings of communication systems used in the evacuations, supplemented by visual records provided by slide photography and video tape recording, could all be played back in the correct time scale. For example, the time at which each photograph was taken was readily recorded by attaching a cassette recorder microphone directly to each camera so that the shutter operation, the camera operator's comments, and the background soundtrack were recorded automatically.

Using these techniques, each evacuation drill could be rerun for detailed analysis. Such a large amount of raw data was produced in some drill observations that the processing is not yet complete. A good example of how extensive such observations could be occurred in a twenty-one-story office building from which over 2,000 people were evacuated without prior warning according to a phased procedure requiring nearly thirty minutes to complete. Nearly twenty channels of audio recording were made at both fixed and moving observation positions. As in other drills, observers moving with the evacuees from floor areas to the building exterior were able to record information about many behavioral variables, often without attracting the attention of people only a few feet away.

Questionnaires were distributed to about 10 percent of the population of two buildings immediately following evacuation drills. Results revealed that some evacuees interpreted these surprise evacuation drills as genuine emergencies. Other results described the evacuees' normal use of exit stairs, their capability with stairs, their perceived speeds and densities during the evacuation, etc. The questionnaire included nearly forty items, many of which provided insights not otherwise quickly obtainable.

Aside from the challenges of recording human behavior under field conditions, it is difficult to manipulate and display data so as to provide useful information about the complex phenomena being studied. These difficulties are made more acute by the almost total lack of precedents for movement studies, either in high-rise office buildings or in public-assembly buildings. For this reason, charts such as shown in Figures 21-1 and 21-2 require more than a quick glance to appreciate their meaning and potential usefulness. (Similar charts have been used by Predtetschenski and Milinski[20].)

Figures 21-1 and 21-2 show, in graphical form, two basic procedures that can be used to evacuate some or all occupants from a high-rise building in case of fire. In both charts the vertical scale is a spatial dimension, effectively the egress path provided by the exit stairs serving each story of a building. The horizontal scale is time, measured from the initiation of a fire alarm which begins the evacuation. Each line on the chart is a movement trace indicating where a particular evacuee is in the exit stair at a particular time. Such traces usually record the observers' movement down the stairs with evacuees. The slopes of the lines indicate speeds of movement.

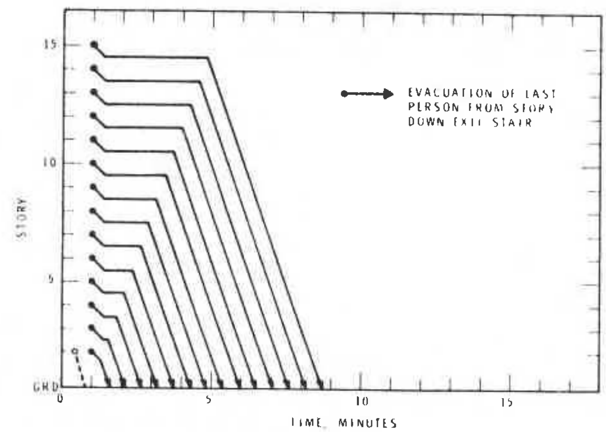

Figure 21-1
Total evacuation of fifteen-story office building.

Figure 21-1 displays movement traces characteristic of total evacuations, the conventional procedure where all building occupants attempt to leave the building at the same time. Illustrated is the total evacuation of a fifteen-story office building with with two 44-in. (1.12 m) wide exit stairs. Each story is assumed to contain seventy persons at the time the evacuation begins. Applying somewhat optimistic but still realistic evacuation-initiation and flow asssump-

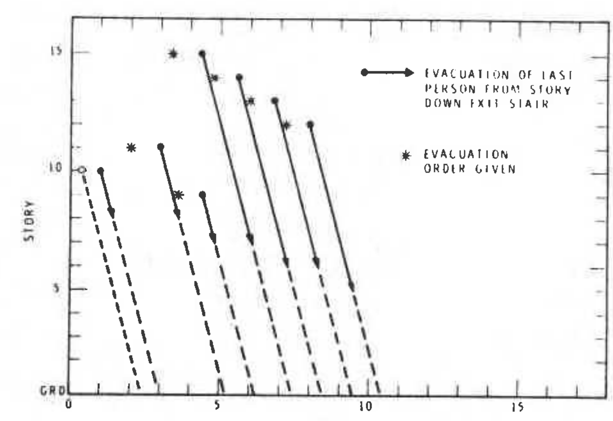

Figure 21-2
Phased, partial evacuation of fifteen-story office building.

tions, it can be predicted that such a building will be cleared of all people, by means of the stairs, in just under nine minutes.

Figure 21-2 shows movement traces characteristic of phased, partial evacuations in which both the need to evacuate particular floors and the priority of such evacuations are determined by trained staff in the building or by fire department personnel. Communication systems are used to help make decisions and give directions regarding such an evacuation. In Figure 21-2 the fifteen-story building is assumed to have a fire on the tenth story. Only the top half of the building is evacuated and people from the upper floors may be directed to seek refuge on certain lower floors or they may be moved to the building exterior at ground level. In any event, because of the time required to control an evacuation using a phased procedure, nearly nine minutes are required merely to move half the building population to below the fire area.

Charts such as shown in Figures 21-1 and 21-2 can be used to illustrate a variety of procedures as well as particular events (e.g., movement up stairs by fire department personnel, and smoke contamination of portions of exits). Graphical simulations using such formats are also very useful. Rather than describing this in detail, a report will be given of some study findings that must be understood to give such charts proper dimensions and make reasonable quantitative predictions about crowd movement on stairs.

FINDINGS PERTAINING TO TOTAL EVACUATIONS

Observations of thirty total evacuation drills dealt almost entirely with movement of crowds down exit stairs. The observations were made in office buldings ranging between eight and twenty stories in height with evacuation populations ranging between 130 and 1,500 persons. Elevators and voice communication systems were not used in these evacuations. Important variables and factors such as density, personal space, crowd configuration, speed, flow, and evacuation time are described below with a brief report of preliminary findings.

Density and personal space

Density, or number of persons occupying a certain space, is influenced not only by the number of persons who must use the stairs during an evacuation but also by individual psychological desire for space and interpersonal separation. In the total evacuation drills most evacuees chose to occupy a space requiring an average of about two stair treads of a typical 44-in. (1.12-m) wide exit stair (Figure 21-3). In terms of density, the inverse of unit area, the average density in total evacuations was about 0.14 persons per square foot (1.5 persons per square meter). Further discussion of density and movement, not necessarily in evacuation situations, is given by Fruin in his book on pedestrian planning[21]).

The space that evacuees regard as acceptable while they are in the exit depends on many factors including speed of movement, type of clothing worn, relationship to people sharing the exit space, and individual emotional state. The limited information about the space a person tries to maintain around himself suggests that in situations perceived as real emergencies a larger personal space is desired[30]. This could lead to lower densities in exits or, alternatively, if more space were not available, to increased discomfort, perhaps even extreme anxiety regarding personal safety.

Crowd configurations

Evacuees did not walk in a highly regimented fashion, shoulder to shoulder, or even in regular staggered files. Side-to-side body sway, individual concern for interpersonal separation, varying needs for handrail support, and concern about not rubbing against sometimes rough walls, all influence the configuration of evacuees on exit stairs. Thus the traditional assump-

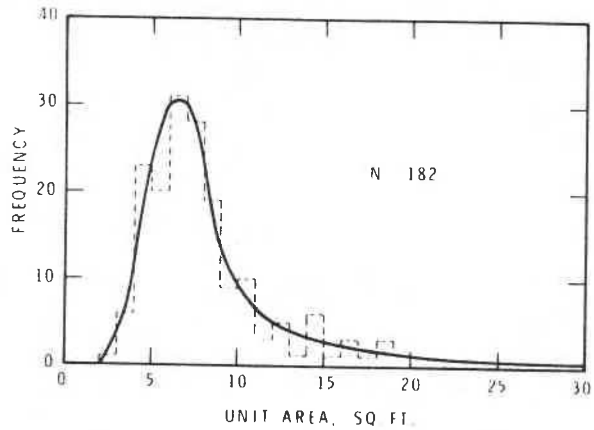

Figure 21-3
Frequency distribution of unit area (stairway area per person) in seventeen stairways during evacuations of high office buildings.

tion about units of exit width or regular lanes of egress movement[16,22] is to be questioned. Further discussion of the questionable validity of the traditional unit of exit width concept is given below in discussing flow rates.

Speed of descent

Speeds of descent on exit stairs varied according to density (Figure 21-4). Widely separated individuals could move at speeds up to about eight stories per minute. At the apparently comfortable density of about one evacuee on every two treads of a typical 44-in. (1.12-m) wide stair, the descent speed was about four stories per minute, the equivalent of about 100 ft. per minute (30 m per minute) along the slope of the stairs. With three evacuees on every two treads, the descent speed approached zero.

Flow

Flow on stairs, or number of people per minute passing a fixed point, also depends on density. Figure 21-5 shows this relation, calculated using the equation for flow as the product of density, speed, and stair width.

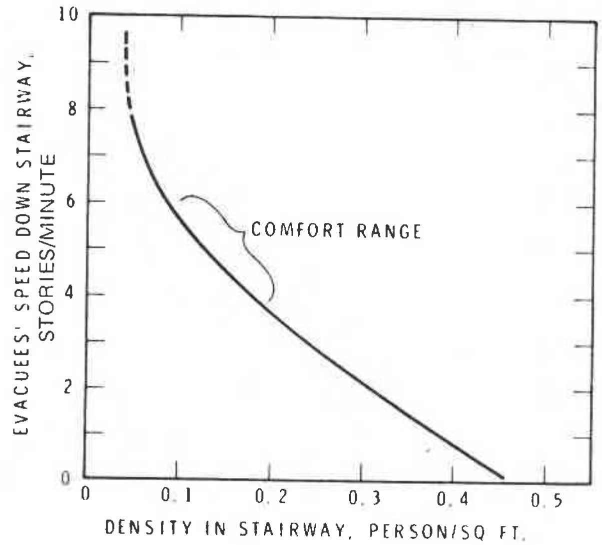

Figure 21-4
Effect of density on speed down exit stairways in evacuations of high office buildings.

Several things should be noted in Figure 21-5. First, the mean flow is stated in terms of 22 in. (0.56 m) of stairway width simply to make the graph more easily understood by designers and officials who normally work with this unit of exit width concept. Second, the mean flows actually measured in total evacuation drills almost invariably fell below the curve plotted in this figure. Thus, this curve should be used only to make the most optimistic predictions of mean flows to be expected in total evacuations. It can be reported that, in general, the mean flows for all observed total evacuations averaged only twenty-four persons per minute per 22 in. (0.56 m) of stair width. During a total evacuation in mid-winter, when evacuees wore bulky clothing, mean flows were only about twenty persons per minute per 22 in. (0.56 m) of stair width. Third, the peak mean flow occurs when the density of evacuees on the exit stairs is

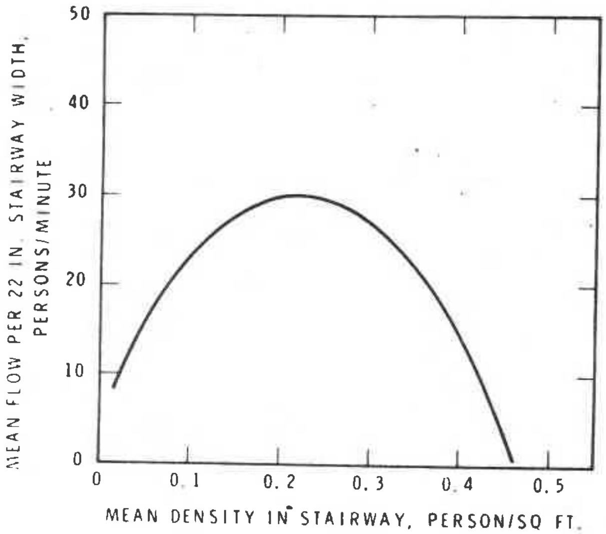

Figure 21-5
Effect of density on flow down exit stairways in evacuations of high office buildings.

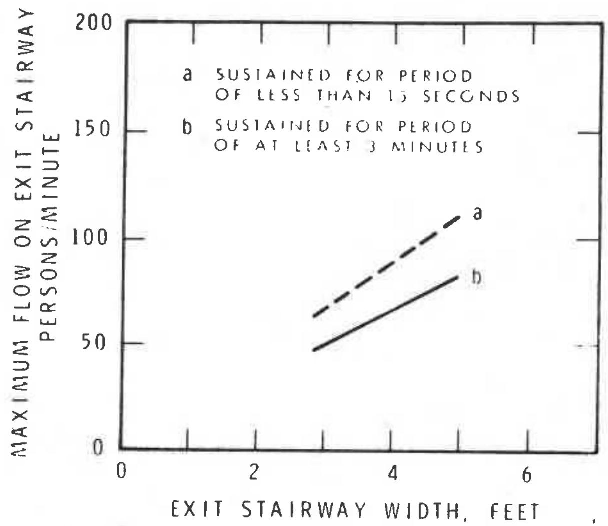

Figure 21-6
Effect of exit stairway width on flows in evacuations of high office buildings.

somewhat greater than the density that evacuees may regard as most acceptable in terms of comfort.

Possibly the most striking feature of such flows is that they are much lower than the conventionally assumed flow figure of forty-five persons per minute per 22 in. (0.56 m) of stair width. This figure is often assumed in exit design regulations[22]. An examination of highly influential reports such as that published in 1935[16] suggests that a figure of forty-five persons per minute is based on somewhat artificial test results that are not good indicators of what can be achieved by typical building occupants in a total evacuation. Tests performed by the author as well as other earlier tests reported in the literature[17] confirm that very high flows down stairs can be achieved only in very contrived situations involving specially motivated groups of individuals who temporarily disregard the normal need for personal space. Figure 21-6 shows that higher flows, even in total evacuations, are only sustained for very brief periods of time and should not be used in predicting mean flows in total evacuations.

Figure 21-6 also shows that, when other factors affecting flow are controlled, flows on stairs are proportional to stair width, at least in the range of stair widths observed. Counts of flows on stairs having widths of 36, 42, 44, 45, 47, 48, 56 and 60 in. (0.91 m to 1.52 m) suggest that the conventional unit of exit width concept, which recognizes only 22-in. and 12-in. (0.56-m and 0.31-m) increments in crediting exit width, is unreasonable. In other words, flow plotted against stair width is a ramp function rather than a step function, as assumed in building codes [22]. With increasing use of performance requirements and also with the impending conversion to metric, use of an exit-design formula based on a mean flow of about four to five persons per minute per 0.10 m (4 in.) of stair width appears more realistic and flexible than the traditional 22-in. (0.56-m) unit of exit width formula.

A minor constriction in the width of the egress path does not significantly reduce egress flow. For example, a crowd descending a stair 48 in. (1.22 m) wide can move through a 36-in. (0.91-m) doorway without reducing the flow below the fifty to sixty persons per minute sustained on the stair alone. Ob-

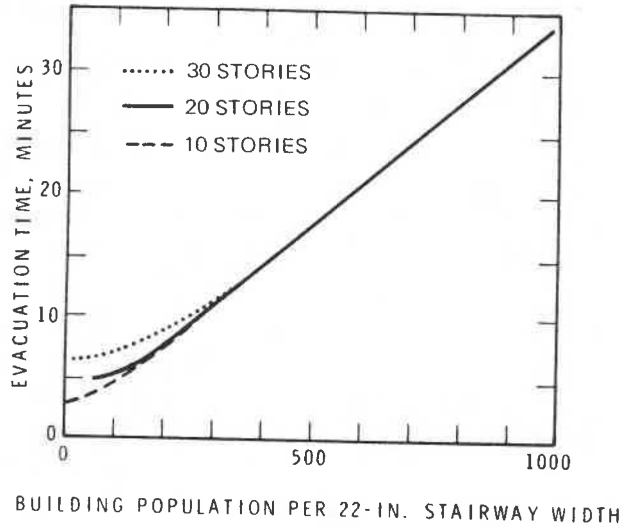

Figure 21-7
Predicted total evacuation times of tall office buildings using exit stairways.

servations also indicate that crowd flow is not greatly affected by minor constrictions caused by an occasional person stopping at one side on the stair nor by having a few fire fighters walk up the stairs against the descending flow of evacuees.

Evacuation time

Based on empirically derived density, speed, and flow relations and partially validated by observed total evacuation times, Figure 21-7 shows that the time required to complete the total evacuation of an office building is mainly dependent on actual building population and available stair width. Buildings with small populations will have reduced densities and flows in the exit stairs, and thus the graph is nonlinear at the left. At the extreme left side of Figure 21-7 the predicted evacuation time is the time taken by a single individual to react to an alarm and descend the stairs. Thus, for this condition, evacuation time is almost entirely determined by building height.

In predicting evacuation times in office buildings with a variety of occupancy conditions, one should be aware that some simplifying assumptions have been made in developing Figure 21-7. For example, it is assumed that evacuees take with them only the clothing normally worn at their work place. If clothing intended for protection from rain or moderately cool outdoor conditions is worn or carried, evacuation time will probably be increased by roughly 15 percent. If, for mid-winter cold weather conditions, evacuees prepare for more than a few minutes of outdoor exposure by putting on or carrying bulky outdoor clothing, the evacuation time will be increased by roughly 25 percent.

The information in Figure 21-7 is based on the following assumptions: (1) the evacuees are typical office workers with some previous experience of total evacuation drills in high-rise office buildings, (2) the evacuees will not be aware of the reason for evacuation, although most may believe that the alarm has not been activated by a serious emergency, (3) there is some trained supervision on each office floor, i.e., evacuation of confused or reluctant occupants will begin within a minute or two of the alarm's being sounded.

Even in situations where these assumptions are true, there will be a range of actual evacuation times. For the particular conditions described, perhaps 90 percent of the actual evacuation times will be within ± 20 percent of the times predicted. During those evacuation drills in office buildings in Ottawa, which were held under fair weather conditions (i.e., no special outdoor clothing requirements), the actual evacuation times for thirty-eight exit stairs were, overall, only about 3 percent longer than the time predicted in Figure 21-7. (Almost all these buildings had fewer than 200 evacuees per 22 in. of exit stair width.)

The total evacuation times predicted in Figure 21-7 are about 50 percent longer than the times suggested in previously published predictions[11]. Total evacuations in mid-winter could take twice the time suggested in previously published predictions.

Typical populations of general-purpose office buildings appear to be about half as great as is often assumed in building codes (i.e., one person for every 100 sq. ft. of gross rentable area). Thus, errors caused by previous optimistic predictions of evacuation flows and times may fortunately be offset by the use of very conservative population assumptions. Now that a better appreciation of evacuation flow is available, it is important that factors, in addition to population, be more carefully examined so that evacuation time predictions and other expectations will have greater validity. Such factors include normal stair use, evacuee experience with previous drills, the management aspects of high-rise evacuations, and evacuees' physical abilities (discussed below).

An improved ability to predict total evacuation times is somewhat academic unless the factors that affect the acceptability of the times are considered. For example, when a serious fire occurs, how much time is available before floor areas become smoke logged[1,5] and for what period of time can exit stairs be used by crowds of evacuees before smoke becomes psychologically or physiologically unacceptable [25,31]? Will the use of an exit stair for fire department access and firefighting operations rule out the use by evacuees of one or more exit stairs after five, ten, or fifteen minutes? Traditionally, seven to ten minutes has been considered acceptable as a workable total evacuation time, but this criterion, like many others, is now in need of reexamination. At some set of building and occupancy conditions (height, number of stories, construction, population, occupant characteristics, etc.) other approaches to coping with life safety in high-rise fires become more appropriate. Figures 21-1 and 21-2 give some indication of the limiting conditions that might be considered in choosing between the total evacuations already described and the selective, phased, partial evacuations now to be described.

FINDINGS PERTAINING TO SELECTIVE EVACUATIONS

In phased evacuations, exit stairs are generally reserved during initial stages of evacuation for people on the fire floor and adjacent floors (Figure 21-2). The ten-phased evacuation drills observed in high-rise buildings in Ottawa included sequential evacuation of occupants on some or all of the other floors, starting from the top. The upper floors could become untenable before most of the lower floors because of smoke movement due to stack effect during cold weather[1,5]. In buildings having zoned air-handling systems for groups of floors, th priority with which floors are to be evacuated could differ.

Movement characteristics

In the drills observed in Ottawa the phasing or sequencing of evacuation usually resulted in much lower overall evacuee densities and flows but higher descent speeds than was the case with total evacuations. The following example illustrates these and other features of the observed nontraditional, evacuation procedures.

In a phased, partial evacuation of a twenty-two-story office building 195 people from floors 14, 15, 13, and 22 walked, in that sequence to the ground floor, following instructions communicated on the building's public address system. The average flows on the two 38-in. (0.97-m) exit stairs, from the time the first evacuee reached the ground to some nine minutes later when the last evacuee reached the ground, were about twelve persons per minute or about seven persons per minute per 22 in. (0.56 m) of stair width. Flows were somewhat intermittent; peak flows, sustained for periods of at least 15 seconds, reached forty-eight persons per minute or twenty-eight persons per minute per 22 in. (0.56 m) of stair width. This compares with average peak flows of thirty-two persons per minute per 22 in. (0.56 m) of stair width in total evacuations. Even during peak flows the density on the stairs only reached 0.17 person per square foot (1.8 persons per square meter) or approximately two stair treads per evacuee. On the average, each evacuee occupied nearly four stair treads of area. Speeds of descent ranged from 3-1/2 to 6 stories per minute.

This example is typical of phased, partial evacuation drills observed in Ottawa office buildings. By comparison, the hypothetical phased, partial evacuation of 490 people illustrated in Figure 21-2 assumes similar density and speed conditions; however the flow is assumed to be less intermittent (with the mean flow assumed to be twice as great as described in the example above).

Time required

Optimistic, perhaps unrealistic, assumptions are made in Figure 21-2 regarding the time required for the building's fire-emergency personnel to ascertain the fire location and severity, make decisions about needed evacuation, and direct occupants with appropriate public address announcements. In the above example of the phased evacuation of a twenty-two-story building, about five minutes of the twelve minutes elapsing between the initial alarm and the arrival of the last evacuee at the ground floor was taken up with such management aspects of the selective evacuation procedure. In other words, the efficient use of exit facilities is not only dependent on the evacuee's movement down stairs but is also greatly influenced by management of the evacuation, either by building fire-emergency personnel or by fire department personnel.

Communications

Selective evacuation procedures require that public address and telephone systems be provided and maintained, and that trained, experienced persons are present to supervise the evacuation. The training of personnel to operate fire emergency communication systems before fire department personnel arrive or, under fire department supervision, after their arrival is a major concern of the Dominion fire commissioner in Canada. In has been found, for example, that many people selected from among those working in a building cannot cope with the stress and responsibility of operating communication systems even in a training and practice context where a variety of emergencies are merely simulated[32,33].

Preprogrammed, recorded public address announcements, although they have some advantages over live announcements[2,34], may cause difficulties when activated by false alarms or by legitimate alarms registered on a floor above or below the fire floor. There is thus still a need for competent personnel to operate communication equipment to override, on occasion, automatic systems.

Refuge behavior

Selective approaches to high-rise evacuation are made possible by the provision and proper operation of systems for fire and smoke control and for communication. Aside from the problems of making such systems work, there are a number of other difficulties, including occupant-behavior, that are not yet resolved. For example, it is not clear whether people who are aware of a fire in a high-rise building will tolerate remaining in probably safe refuge areas, located perhaps above the fire floor. In addition to asking the question "Are refuge areas safe?" one must also ask "Are refuge areas perceived to be safe by those who have to use them?"

Information on the behavior of people in fires is extremely limited. What information we do have indicates that people cope remarkably well in fire emergencies[25]. Behavior that may appear to be excited and disorganized is often quite reasonable. Unfortunately, the information that does exist on this subject pertains almost entirely to situations where people have the opportunity of evacuating or escaping to the perceived safety of the outdoors relatively easily (in contrast to what might be the case in a large high-rise building). To accomplish this, people will even move considerable distances through smoke-contaminated spaces[25]. What is needed now is information on such factors as how people will behave in a perceived refuge situation, what messages should be directed to them, what supervision should be provided, and what activities they should undertake to reduce anxiety and the desire to escape.

It is not surprising, therefore, that many large high-rise buildings are being designed and operated in a far more sophisticated manner than was the case even a decade ago. If these measures prove reliable, fire in a high-rise office building will be far less disruptive, with occupants carrying on their normal activities, perhaps oblivious of the fire. This seems to be common in high-rise apartment buildings. Unfortunately, it will be some time before this is generally the case in office buildings and thus the ability of building occupants to move quickly in case of fire is still important.

MOVEMENT ABILITY AND SAFETY

Brief mention should be made of the capability of typical office workers to evacuate to refuge spaces or to the outdoors by means of stairs. If the office workers observed in the Canadian office building evacuations are representative, as they appear to be, it is estimated that about 3 percent of the persons usually present in high-rise office buildings cannot or should not attempt to evacuate by means of crowded stairs. In addition to those with obvious physical disabilities, this minority includes people with heart disorders and convalescents from recent illness, surgery or accident. Movement of these individuals to a place of safety will require additional planning and assistance from other occupants. This could include their descending the stairs behind able-bodied occupants, being carried by others down the stairs, or having elevators, operated by fire department personnel, take them to safety.

Evacuees who responded to a questionnaire after the complete evacuation of a twenty-one-story office building judged their capabilities of descending stairs "without stopping, at a normal speed, and without assistance from others" as follows: 97 percent felt capable of at least three stories of stairs and 64 percent felt capable of descending at least twenty stories. Only 27 percent reported ever having descended twenty stories at one time before the evacuation was held[14]. Nine percent, mostly from the upper half of the building, did not feel capable of descending all the stairs from their normal work floor. (The questionnaire also dealt with normal use of the exit stairs. Currently, the Division of Building Research at the National Research Council of Canada is attempting, through field observations in Ottawa office buildings, to document such normal use which, aside from having economic implications, is relevant to people's ability to use those stairs in emergencies.)

Although people's beliefs about their stair movement capability are important, their actual performance is a more immediate concern in a fire-emergency evacuation. Observing crowds move down stairs, both in office building evacuations and in other situations, one is often impressed by how well people manage, including people with obvious disabilities. It is noteworthy, in this regard, that no injury-causing accidents were reported in the observed evacuation drills in Ottawa, even with observed total stair use exceeding 75,000 person-stories.

Equally noteworthy are some preliminary findings from current Canadian studies of crowd egress from grandstands and other buildings with public assembly occupancies[35]. In the case of a new 17,000 seat triple-tier grandstand in Calgary, the people using the building's 200 flights of stairs had a greater variety of ages and abilities than normally found in office buildings. Even though totally unfamiliar with the building, they used the stairs effectively (a mean flow of twenty-three persons per minute per 22 in. of stair width) and surprisingly safely, particularly in situations where stairs were crowded.

Although these studies suggest a degree of stair safety, they must be regarded with caution. More detailed observations of egress flow by crowds on stairs are needed to assess risk of accident properly and to understand better the factors that cause accidents. In addition to the on-going crowd egress studies by the

Division of Building Research, stair design and safety studies recently done in the United States are proving very useful and should be considered in the design, regulation, and operation of buildings[36-38].

CONCLUDING REMARKS

As the studies reported here deal largely with crowd movement in buildings, the information gained is particularly applicable to traditional total evacuation procedures and facilities. Findings provide an improved basis for making predictions of total evacuation time of tall office buildings and for designing the exit stairs used for total evacuations. This information comes at a time when, increasingly, high-rise buildings are being designed in a more sophisticated manner to reduce the hazards of fire and obviate the need for total evacuation in case of fire. Nontraditional evacuation procedures, some using facilities other than stairs, are being proposed and in some cases adopted[4,13,27,39]. Their testing under field conditions is, however, very limited. Thus, as was the case with total evacuation procedures, overoptimistic assumptions may be made, leading to a false sense of security about their efficacy. For example, the reported observations of evacuation drills using nontraditional procedures indicate that effective fire-emergency organizations, occupant training, and communications are needed to carry out selective evacuation. Currently, aside from government- and institution-occupied buildings, most tall buildings do not have fire-emergency organizations[40] and their occupants are largely unaware of fire-safety facilities and their use in emergencies. Some emergency communication systems, now being installed without adequate standards for either design or maintenance, may fail to function as expected even if trained personnel are available to use them.

In general, neither basic knowledge regarding fire emergency measures, including evacuation, nor related building design and operating practices have kept pace with society's propensity and ability to construct large buildings. More research is needed and the preliminary studies of evacuation reported herein should only be considered part of an initial phase of such research.

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