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Pauls, J. L.

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Evacuation and Other Fire Safety Measures In High-Rise Buildings

by
J. L. Pauls

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L'EVACUATION ET AUTRES MESURES DE SECURITE INCENDIE DANS LES GRANDS IMMEUBLES

SOMMAIRE

Les mesures d'évacuation et le comportement des occupants d'un édifice en cas d'incendie ne sont pas aussi bien connus que d'autres aspects de la conception de plus en plus systématique et technologique de la sécurité incendie dans les edifices. La situation évolue toutefois. Des recherches récentes et en cours au Canada, dans le Royaume-Uni et aux Etats-Unis comportent l'étude des méthodes d'évacuation des tours de bureaux, et aussi des temps d'évacuation, du mouvement des personnes, des aspects physiques et humains de la sécurité des escaliers, de l'organisation de la sécurité incendie, des alertes et des communications, et du comportement humain dans des incendies réels. Il en résultera peut-être une révision de certaines dispositions des codes du bâtiment et des codes de prévention des incendies. Le degré de sécurité incendie de nos édifices complexes augmente la responsabilité juridique établie dans les codes et exige une conscience et une compétence accrues des architectes, des experts consiels, des propriétaires, des cadres, du personnel d'exploitation, des services d'incendie et, dans une certaine mesure, de tous les utilisateurs.

EVACUATION AND OTHER FIRE SAFETY MEASURES IN HIGH-RISE BUILDINGS

J.L. PAULS

Since the late 1960's the problem of fire in high-rise buildings has received a great deal of attention in popular and technical literature, and this is now increasingly reflected in safety regulations (1-6). In the last few years, concern for fire safety, particularly in high-rise buildings, has led to the installation of sometimes complex systems of fire detection and extinguishment, smoke control, and communication. In addition, systematic approaches to designing for fire safety are being developed (7, 8).

Evacuation in the various forms it might take in high-rise buildings as a result of these developments is less understood than many other aspects of such systems approaches to fire safety. Generally, knowledge about the behavior of building occupants during emergencies is poorly developed, although there has been recent progress in Canada, the United Kingdom, and the United States (9-11). Preliminary results of studies carried out in Canada provide better information than has been available to date about building population and other factors relevant to practicable total evacuation. They also raise questions about the validity of some traditionally accepted concepts and formulas for exit design.

A few comments about terminology and scope may be required. In this paper the term "evacuation" is used in a broad sense to describe the movement of some or all building occupants to a place of acceptable safety in the event of fire. "Total evacuation" means the conventional, simultaneous movement of all occupants to the building exterior at ground level. Other terms such as "phased evacuation" and "partial evacuation" describe the more controlled and usually more limited movement of occupants necessitated by insufficient exit capacity or made possible by fire and smoke control measures.

The evacuation procedures and study findings now described pertain to office buildings. Mass evacuation is less likely in large residential buildings because the high degree of compartmentation provided limits fire and smoke hazards. Occupancy conditions in residential buildings also make organized evacuation movement much less likely. By way of contrast, hospitals and similar institutions have a high degree of operational organization, as well as extensive compartmentation, and contain sophisticated fire safety systems. This permits minimal evacuation of occupants, a procedure that will be used increasingly in new office buildings but is unfortunately not appropriate for fire emergencies in many existing office buildings.

This paper describes the evacuation of high-rise office buildings taking place predominantly on exit stairs. Other evacuation, escape, or rescue facilities, such as elevators, ladders, ropes, and helicopters, have been instrumental in saving lives in high-rise fires; but with the possible exception of certain specially protected elevators these other facilities have inherent limitations, and dependence on their use for evacuation in properly equipped high-rise buildings is undesirable and unnecessary.

It should be noted that a small number (about 3%) of the people normally 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

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J.L. Pauls is Research Officer, Division of Building Research, National Research Council of Canada, Ottawa.

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.

RECENT CANADIAN STUDIES OF BUILDING EVACUATION

Predictions of times required for the total evacuation of high-rise office buildings were presented in 1969 by Galbreath (12), and these figures have been widely quoted during the last 5 years. Since that time more detailed studies, including field observations, have been conducted by the author (9), beginning with observations of a major evacuation drill in Vancouver's 22-story B.C. Hydro Building (13). Subsequently, observations have been made in cooperation with the Dominion Fire Commissioner of nearly 40 evacuation drills in Ottawa in high-rise office buildings ranging from 8 to 29 storys. The buildings were occupied mainly by Canadian Federal Government employees, many of whom were accustomed to taking part in evacuation drills. Requirements for such drills and for related building fire emergency organization, facilities, and activities have been established by the Dominion Fire Commissioner (14). Total, phased, and partial evacuation procedures were used, depending on each building's size, population, and communication facilities.

The observations of the Ottawa evacuation drills were conducted by teams of up to 15 observers whose duties included moving with evacuees down exit stairs or making flow counts at fixed locations. All observations were recorded (during the evacuations) on continuously running portable cassette recorders; and emergency building communication systems, when used, were recorded as well. Photographic and video-tape cameras also provided useful records. Extensive questionnaires, answered by samples of evacuees immediately following evacuation of two buildings, provided additional information that included insight into evacuees' interpretations of one particularly excited and ambiguous announcement, made over a public address system, suggesting a real fire requiring rapid evacuation.

Although neither the Ottawa evacuation studies nor previous ones included detailed observations of evacuation in cases of actual fire, it seems reasonable (and indeed is necessary) to use detailed data from evacuation drill observations in developing design and operational measures for use in actual high-rise fires. It seems particularly appropriate for the Ottawa evacuation observations because, in contrast with previous studies of movement down stairways, they were conducted in the context of modern high-rise office buildings. Furthermore, some of the observed evacuees are known to have interpreted the drills as actual fire emergencies.

Total Evacuation

An important factor in total evacuations, where all building occupants attempt to evacuate simultaneously, is the density of evacuees on stairs. Density is influenced by individual psychological desire for space and interpersonal separation (15). In the observed total-evacuation drills most evacuees chose to occupy a space requiring an average of about 2 stair treads of a typical 44-in. (1.12 m) wide exit stair. Based on the very limited behavioral information available, it is predicted that individuals perceiving an immediate threat to their safety might desire more space in which to move, thus producing lower densities on stairs; alternately, if more space were not available, they might experience additional anxiety.

Observed descent speeds, which varied according to density (Fig. 1), ranged from about 8 storys per minute for widely separated individuals to 0 for crowd densities equivalent to 3 evacuees on every two 44-in. (1.12 m) wide stair treads. At the apparently comfortable density of 1 evacuee to every 2 treads, the descent speed was about 4 storys per minute, the equivalent of about 100 ft/min (30 m/min) along the slope of the stairs.

Fig. 2 shows how flows on stairs, or number of people per minute passing a fixed point, also varied according to density, with the highest observed mean flow being about 30 persons per minute per 22 in. (0.56 m) of stair width. This occurred at an average density about 50% greater than the apparently confortable density described above. During a total evacuation in midwinter, when evacuees wore bulky outdoor clothing, mean flows were about 20 persons per minute per 22 in. (0.56 m) of stair width. The mean flows in all other observed drills averaged only 24 persons per minute per 22 in. (0.56 m) of stair width. These flows are much lower than that of 45 persons per minute per 22 in. (0.56 m) of stair width frequently mentioned in the literature and assumed by building codes.

Fig. 3 shows how observed crowd evacuation flows increase in proportion to stair width, according to a ramp function rather than the step function (with 22-in. and 12-in. increments of stair width) assumed in building codes. (The traditional 22-in. "unit of exit width" concept is described in the NFPA Life Safety Code (16)). The traditional assumption is that crowd movement is most effective with a shoulder to shoulder arrangement of people on stairs (i.e., 2 files on a 44-in. stair). Observations indicate not only that such highly organized arrangements are rare and almost impossible to maintain but also that freer, less-organized arrangements lead to effective flows on a range of stair widths. In recognition of both this crowd movement phenomenon and the mean flows described above, it is recommended that, with conversion to metric, codes adopt a stair design formula that assumes flows of 4 or 5 persons per minute per 0.10 m (4 in.) of stair width.

It should be noted that a minor constriction in the width of the egress path does not significantly reduce egress flow. For example, a crowd descending a 48-in. (1.22 m) stair can move through a 36-in. (0.91 m) doorway without reducing flow below the 50 to 60 persons per minute sustained on the stair alone.

Based on empirically derived density, speed, and flow relations, Fig. 4 shows how the time required to complete total evacuation is mainly dependent on actual building population and available stair width. By comparing predictions given by Fig. 4 with actual total evacuation times measured in 56 exit stairs used in nonwinter total-evacuation drills in Ottawa, it is estimated that predictions made for nonwinter total evacuation will be accurate to within plus or minus 20% for 90% of evacuations. Evacuations in which evacuees wear or carry bulky outdoor clothing could take up to 50% longer than is shown in Fig. 4. The lack of precision in predicting total evacuation times for office buildings reflects the limited knowledge available about a number of factors, including evacuees' experience with previous drills and normal stair use and the organizational or management aspects of high-rise evacuations.

These predictions are based on recent evacuation data and suggest that total evacuation will require up to twice the length of time suggested in previously published predictions, based largely on nonevacuation data (12). It should be noted that actual populations of general-purpose office buildings appear to be typically less than half the number assumed in building codes, and this may offset previous over-optimism in predicting evacuation flows and times.

An improved ability to predict total evacuation times is somewhat academic unless other factors affecting 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 (17) and for what period of time can exit stairs be used by crowds of evacuees before smoke becomes psychologically or physiologically unacceptable? Will the use of an exit stair for fire department access and fire-fighting operations rule out the use by evacuees of one or more exit stairs after 5, 10, or 15 min? Traditionally, 7 to 10 min has been considered acceptable as a workable total evacuation time, but this criterion, like many others, is in need of re-examination. Also to be considered are evacuation possibilities entailing more selective use of exit stairways.

Phased and Partial Evacuation

In phased and partial evacuation, exit stairs are generally reserved for people on the fire floor and adjacent floors. The phased evacuation drills observed in high-rise office buildings in Ottawa included sequential evacuation of occupants on some or all of the other floors, starting from the top, which could be made untenable by smoke moved upwards as a result of stack effect (17). Phasing or sequencing of evacuation usually resulted in much lower evacuee densities and flows but higher descent speeds than was the case in total evacuation.

Aside from the technological difficulties of providing working systems for fire and smoke control and for communication, both of which make the more selective approaches to evacuation possible, there are psychological, economic, legal, and other difficulties not yet resolved. For example, selective approaches to high-rise evacuation are heavily dependent on the judicious use of communication systems by trained and experienced personnel from the building fire emergency organization or the fire department that takes charge on arrival. Pre-programmed, recorded public address announcements have some advantages over live announcements (18), but they may cause difficulties if activated by false alarms or by legitimate alarms registered on a floor other than the fire floor. There is thus still a need for competent personnel to operate communication equipment (to override automatic systems), and their training poses one of several new challenges in operating large high-rise buildings (19).

It is increasingly apparent that fire safety in large buildings requires competency, not only in design and construction, but also in ongoing operation, including education of building users. This is reflected in revisions of major fire codes, such as New York City's fire code revision, Local Law No. 5. This Law applies to about 800 high-rise buildings and requires design and operating measures, including management training and certification (6).

There is an urgent need to evaluate such new measures in actual conditions. Various types of field studies, in many buildings, are needed if fire safety is to develop in a rational, cost-effective manner. The Ottawa evacuation-drill observations are an example of such evaluations. The need for further research is underlined by the fact that the findings described above raise questions about long-held, fire safety opinions and exit-design practices. To some extent, research on the behavior of people in fires also raises questions about the validity of assumptions underlying present fire safety practices.

BEHAVIOR OF PEOPLE IN FIRES

Scientific documentation of occupant behavior in building fires has been rare (20). Two recent reports from the U.K. and the U.S. address themselves to the problem (10, 11). Both point out the inadequacy of existing knowledge, describe work in related areas such as disaster studies and experimental psychology, and provide some guidance for more extensive study (now under way in both countries).

The report published by the U.K. Fire Research Station is specially valuable because questionnaire results were used to help describe the behavior of over 2,000 people involved in nearly 1,000 fires attended by fire brigades. The various actions taken by these people were cross-tabulated with personal, building, and fire variables. Evacuation of the buildings and movement through smoke were two important areas of interest, and many findings of a descriptive nature are listed in the report. It states, "In general terms the majority of people appeared to have behaved in what might be considered an appropriate fashion, although some 5% of the people did something which was judged to 'increase the risk'" (10).

"Panic" and other terms suggesting hysterical, nonadaptive, or antisocial behavior are often inappropriately used in both nontechnical and technical discussions of human behavior in fire emergencies and disasters. Limited research on behavior in fires and more extensive research on large-scale disaster behavior suggest that many common views of emergency behavior are unjustified and that they may lead to errors in measures designed to cope with emergencies (21). Within the specific context of high-rise building fires, more behavioral studies are needed to establish how best to utilize the predominantly adaptive and manageable behavior of people in emergencies.

CONCLUDING REMARKS

In view of the difficulties of studying human behavior, especially in actual emergency situations, it is not surprising that conventional opinion has played a very large role in setting out and implementing fire safety measures. Some opinions about high-rise fire safety have changed during the last 5 years and others may soon change, partly as a result of recent research.

Opinion may be divided regarding the validity of predictions for actual fire evacuations based on information derived from evacuation drills, especially in government office buildings. There appears to be a growing belief that emergency behavior and nonemergency behavior need not be too dissimilar if the design and operation of buildings are based on available technology. There is also a trend, increasingly promoted by legal and other pressures, for building fire emergency organizations and procedures to be set up in nongovernment occupancies.

Acceptance is growing of fire emergency procedures that do not involve total evacuation, and this is reflected in the increasing provision of special communication and control systems in high-rise buildings. The actual application of such procedures and systems raises difficulties, however, particularly for existing high-rise buildings. For example, code writers, enforcement officials, designers, and consultants do not deal simply with rules; they face new approaches to design, involving new performance standards and new equipment. Building owners and managers are increasingly encouraged, or required, to set up fire emergency organizations and procedures without having detailed guidelines and perhaps without the cooperation of some tenants. Fire safety measures must also be reconciled with rapidly changing measures for security. Operating personnel are faced with new equipment systems, some of which will be rarely needed but must be maintained to meet performance requirements that may tax the knowledge even of professional engineers.

Those who may have been complacent about safety in high-rise buildings have recently been disturbed (to a largely unknown extent) by popular-media accounts of high-rise firetraps. Now, another psychological adjustment may be required to make the high-rise refuge concept work. This situation is further complicated by the fact that people visit, reside, and work in different buildings, each with a different fire emergency procedure.

The task of achieving high-rise fire safety is complex. It entails cooperation and complementary measures in all areas of building design and construction, building management, occupant behavior, and fire department operation. As part of a systematic approach to fire safety, improved knowledge of the human factors involved in evacuation should lead to better decisions about fire safety options and improved awareness of the conditions and consequences associated with these options.

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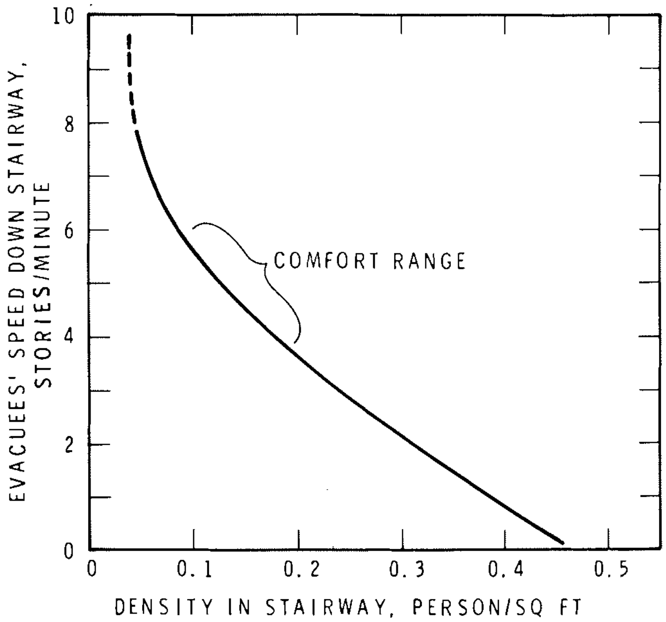

Fig. 1

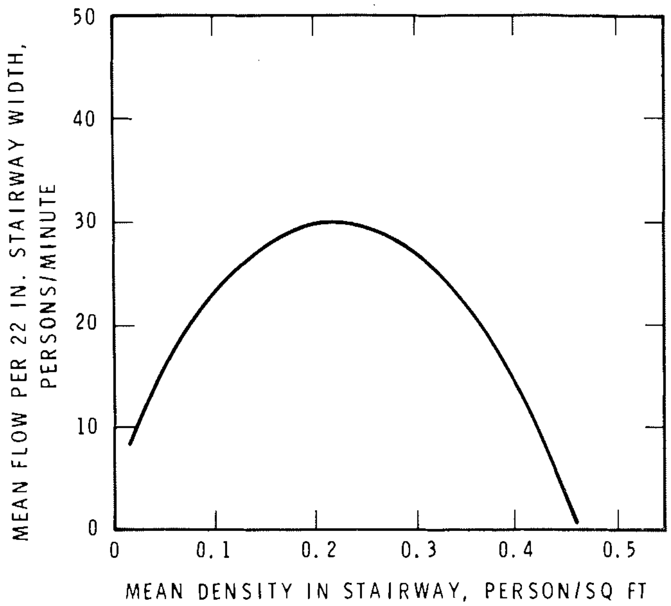

Fig. 2

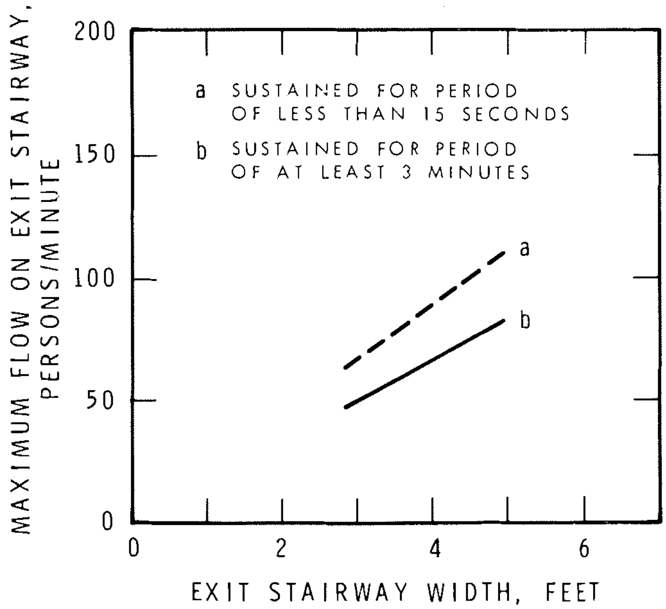

Fig. 3

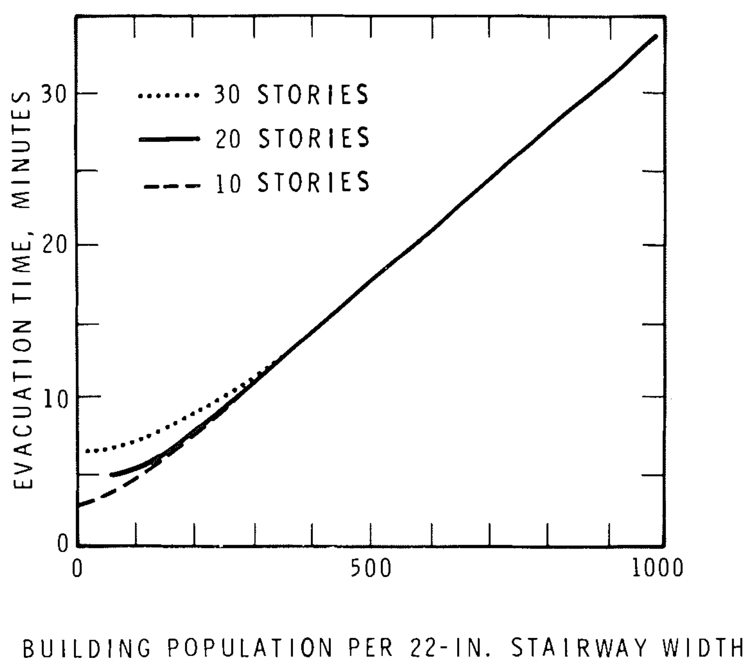

Fig. 4

DISCUSSION

CLEMENT G. STEWART (F.H. Siegfried Co., Springfield VA): With regard to fire department personnel using stairs to reach fire location, has there been any effect on evacuation when smoke and/or heat enters the stairs (and when standpipes are used with lines charged, taking up stair space and with possible water leakage)?

J.L. PAULS: The downward flow of evacuees in drills was not significantly affected in those few cases where several fire department personnel used the exit stairs to reach hypothetical fire floors. The other conditions (i.e., smoke, heat, charged hoses) did not occur in the evacuation study. Some information about the movement of evacuees through smoke in actual fires was obtained in a recent British study (Ref 10 in the paper). Quoting from the report of the study, "In incidents where smoke was present, 60% of the people attempted to move through it. Nearly 50% of these people moved 10 yards or more". The report also notes "A surprisingly large percentage of people move through smoke, an action which we were led to believe was fairly rare....There is certainly room for further research into the reasons for and the conditions under which people move into smoke." A laboratory study by Kelly et al., "Collective behaviour in a simulated panic situation" (<u>Journal of Experimental Social Psychology</u>, 1965, <u>1</u>, p. 20-54) describes social factors influencing individual behavior when threatened by smoke. More information about responses to environmental conditions in egress (and also refuge) is needed.