Building evacuation and other fire-safety measures: some research results and their application to building design, operation, and regulation

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BUILDING EVACUATION AND OTHER FIRE-SAFETY MEASURES: SOME RESEARCH RESULTS AND THEIR APPLICATION TO BUILDING DESIGN, OPERATION, AND REGULATION

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L'évacuation des édifices et autres mesures de sécurité incendie: Quelques résultats de recherche et leur application à la conception, l'exploitation et la réglementation des édifices

SOMMAIRE

On a beaucoup écrit sur les menaces à la vie que représentent les incendies dans les tours de bureaux. Plusieurs aspects du problème ont été étudiés au Canada et les résultats appliqués à la conception, l'exploitation et la réglementation des édifices. Le comportement des êtres humains en cas d'incendie est à l'étude à la Division des recherches en bâtiment, où l'on a observé avec soin 40 exercices d'évacuation dans des tours de bureaux. Des methodes d'observation ont été mises au point et l'utilité des questionnaires a été mise à l'essai. Des renseignements préliminaires décrivent la nature du mouvement d'évacuation dans les escaliers de sortie, les comportements en cas d'incendie et l'utilisation normale des escaliers de sortie. Certains résultats montrent le besoin de changements précis des exigences des codes du bâtiment et d'autres aspects de conception et d'exploitation.

BUILDING EVACUATION AND OTHER FIRE-SAFETY MEASURES: SOME RESEARCH RESULTS AND THEIR APPLICATION TO BUILDING DESIGN, OPERATION, AND REGULATION

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The hazard to life safety from fire in high-rise buildings has been widely publicized. In Canada, several aspects of the problem have been studied and results applied to building design, operation, and regulations. One aspect, that of human behavior in fire emergencies, is under study at the Division of Building Research where detailed observations of 40 evacuation exercises in high-rise office buildings have been made. Observation techniques have been developed and the usefulness of questionnaires has been tested. Preliminary information describes the nature of evacuation movement on exit stairways, behavior in fire emergencies, and the use of exit stairways in the normal building occupancy. Some results suggest the need for specific changes in building code requirements and other design and operational considerations.

During the last five years the problem of life safety for occupants of high-rise buildings under fire conditions has received a great deal of attention, both in new safety regulations and in the popular and technical literature. Key elements include the difficulties of controlling smoke movement and of moving endangered occupants to areas of safety (Hutcheon and Shorter, 1968; Wilson and Shorter, 1970; National Fire Protection Association, 1972).

Control of smoke movement in high-rise buildings is relatively manageable because there exists a fairly good theoretical basis for devising control systems, and because the practical implementation of such smoke systems is within the area of competence of engineering consultants (Tamura and McGuire, 1971; ASHRAE, 1973; Associate Committee on the National Building Code, 1973). Greater difficulties are posed by occupant movement to areas of safety or by general behavior in a fire situation. Neither the theoretical basis for predicting human behavior nor the means of controlling it is available to any great extent. This paper will describe current research focused on evacuation movement from high-rise office buildings but touching other aspects of the life safety problem in buildings. Preliminary results are reported and a description given of their potential as well as actual application to building design, management, and regulations in Canada.

The Canadian context for research and application of results relating to building fire safety is somewhat unusual and warrants a brief description. There exists a fortunate relation between the Division of Building Research of the National Research Council and the committees that prepare the model codes known as the National Building Code of Canada and the National Fire Code of Canada. The National Building Code has already been widely adopted throughout Canada and its use is increasing on a provincial basis so that uniformity across the country is progressing rapidly. One aspect of this close relation between research and codes preparation is that research officers from the Division of Building Research are technical advisers to code committees composed of individuals drawn from all sectors of the building industry. This facilitates a two-way exchange so that up-to-date information is made available to committees and new areas for research are identified. This exchange has been particularly significant for the Division's Building Use Section, which has a major goal of developing information on the human requirements in buildings, particularly requirements relating to safety. The research staff of the Building Use Section are in close contact with other research sections of the Division responsible for much of the present technology regarding smoke control in high-rise buildings. This has had a major influence in recent revisions of the National Building Code of Canada (Associate Committee on the National Building Code, 1970, 1973; Hebert, 1973). Such close contact is most desirable in view of the growing opinion that implementation of solutions to the high-rise fire problem will involve manipulation of physical form and forces and will require, moreover, judicious human behavior before and during fire emergencies (Schaffner, 1973).

It should be noted that this Canadian research is not determined by or applied to building and fire regulations alone. The Division often assists designers and others with particular problems not covered by existing professional design expertise. The most favoured mechanism for applying research is through education rather than imposition of regulations. Greater expertise on the part of building owners, designers, consultants and others concerned with building is actively promoted by the Division of Building Research through an extensive publications program as well as through more direct contact with the public in seminar/workshops and meetings. The study, which is described below in preliminary form, is taking place within this context of research and application.

STUDY DESCRIPTION

The author's study began in 1968 with a survey of potentially relevant literature. The amount of potentially relevant literature has grown not only as new knowledge has been published but also as the problem of human response to fire at both the individual and the social level has been redefined in a more comprehensive manner. Pertinent literature may be considered to fall into several broad areas.

The most obvious, that of reports of human behavior in fire incidents, is extremely limited if the many journalistic accounts and poorly-researched reports of particular fires are not included. Such reports of fire incidents too often describe human behavior in a stereotyped manner based more on preconception than fact. On the other hand, one recent study based on questionnaires administered by fire department personnel at the scene of nearly 1000 fires in Great Britain appears to be very useful (Wood, 1972).

Disaster research is relatively well established and many publications date back nearly 20 years. Studies of human behavior in large-scale disasters, usually natural disasters, have not advanced far beyond the descriptive stage. Hypotheses regarding behavior during various stages of large scale disaster have been proposed and some might be applicable to the smaller-scale and shorter-duration emergencies in building fires. Resulting from the multi-disciplinary work of sociologists, psychologists, anthropologists, geographers, and others, these hypotheses deal with such factors as effect of warning, prior exposure to hazard, communication, decision-making, leadership, and social organization. The testing of these hypotheses, even in large-scale disasters, has not advanced very far. Similar hypothesis formation, hypothesis testing, and theory building in relation to building fires is needed if technology is to replace unorganized experience as the main basis for building and fire regulations. Numerous reports of the National Academy of Sciences - National Research Council (U.S.), Disaster Research Group, of some two decades ago, have been published and there is a very useful book based largely on the Committee's work (Disaster Research Group, 1961, Baker and

Chapman, 1962). Recently, disaster studies have been coordinated by the Natural Hazards Research Group based at the University of Colorado.

Smaller scale studies of human behavior under simulated emergency conditions, examining phenomena such as panic and decision-making under conditions of stress and uncertainty, are reported in sociological and psychological journals. No attempt has been made by DBR/NRC to survey this area, partly because of the questionable validity of applying results from laboratory conditions and student subjects to actual fire behavior (Wood, 1972).

Although not yet represented to any great extent in the literature, there are a number of fire safety studies apparently being conducted at U.S. universities. These include the Center for Architectural Research at Rensselaer Polytechnic Institute, the School of Architecture at the State University of New York, Buffalo, the Center for Urban Environmental Studies at the Polytechnic Institute of Brooklyn, the Fire Protection Curriculum at the University of Maryland, and the Graduate School at the University of California. In addition, a widely-publicized systems approach to fire safety in buildings is under way in the General Services Administration, Washington (General Services Administration, 1971).

The literature relating specifically to human movement in and around buildings stems largely from studies with a traffic engineering orientation. A detailed examination of the available literature suggests that many building codes have exit stairway requirements that are partly based on poorly-interpreted test situations, inadequate observations, and inappropriate extrapolations.

The literature about movement on stairways, which has had the greatest influence on building code requirements for means of egress, is too heavily dependent on observation of movement in non-evacuation contexts such as in subway and railway stations (National Bureau of Standards, 1935; London Transport Board, 1958; Galbreath, 1969; Stevens, 1969).

Evacuation Observations

Some five years ago there appeared to be a definite need of studies of what actually happens when building occupants are subjected to actual fire emergencies, or even to simulated emergencies in which some of their behavior will be similar to their expected behavior in real fire emergencies.

In 1969 observations were conducted in the test evacuation of Vancouver's 22-storey B.C. Hydro Office building. A report describing observations by a team of observers, including an analysis of evacuation movement down exit stairways, was subsequently prepared (Pauls, 1971). This report describes observation techniques and results not previously reported in the literature. It led to an invitation by Canada's Dominion Fire Commissioner to conduct observations of a variety of evacuation exercises in Federal Government-occupied buildings in Ottawa.

Between 1970 and 1972, nearly 40 test evacuations involving about 20,000 evacuees were observed in office buildings ranging between 8 and 29 storeys in height. The chief goal in these observations was to collect data describing the nature of evacuation movement, any influences on such movement and other relevant behavior of individuals and groups, including those having supervisory responsibilities. Large-scale data collection was often necessary because variables were numerous and could not be controlled experimentally.

Observation techniques included equipping between 2 and 15 observers with portable cassette recorders to register all observations and background sounds. These observations plus tape recordings of any communications 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. In effect, the evacuation could be re-run for purposes of detailed analysis. For example, in one 21-storey office building nearly 20 channels of audio recordings were made at both fixed and moving observation positions throughout the 30-minute period of a phased total evacuation exercise involving over 2000 people. Observers moving with evacuees from floor areas to the building exterior were able to record data for a wide variety of behavioral variables, often without the knowledge of evacuees only a few feet away.

In terms of the methods used and the quantity and quality of data, these evacuation observations appear to have no precedent in the literature. If further work of this nature is to be carried out, some of the techniques being developed in other studies of the man-environment interaction should prove very useful (Davis and Ayers, 1973).

Immediately following two evacuation exercises in office buildings questionnaires were given to about 10 per cent of each building's population. There was nearly a 90 per cent mail return rate. Results suggested that some evacuees interpreted these surprise test evacuations as genuine emergencies. Other results, reported below, suggest that such questionnaires provide useful data.

It is noteworthy that some of the observation techniques developed for studying building evacuation can be used by non-research personnel. For example, building management and fire safety personnel in Ottawa began to use the recording techniques to help in assessing evacuations for their own purposes. This type of evaluation effort by people directly responsible for fire safety practices should be encouraged, particularly in view of the cost of evacuation exercises.

PRELIMINARY RESULTS

Preliminary results already raise questions regarding the validity of existing data and formulae for evacuation movement and the design of exit stairways. They must, however, be applied with caution. Analyses of observation data are still incomplete, but there are certain indications regarding the influence of stairway geometry and population size on density, speed, flow and evacuation time for high-rise evacuation using both conventional rapid total egress procedures and newer, more sophisticated, phased evacuation procedures. These findings are relatively easy to interpret and apply in revising exit stairway requirements in building codes.

In the course of analysing results, an attempt is also being made to learn more about other, less quantifiable variables. These come under such headings as the total physical setting for evacuation, communications, social organizations, learning and prior practice, fire safety attitudes, nature of perceived hazards (if any), urgency factors, population descriptions, personal space, and decision-making under conditions of stress and uncertainty. Many of these variables relate to operational aspects of building safety and, as information grows, may influence fire codes and building management procedures. In addition, some of the assumptions implicit in building design and regulation may be checked for validity. At present, very little is known about the man-environment aspects of building fire safety and it is hoped that other researchers will become more involved in studies that can have application to building design and operation.

Reaction and Attitude to Evacuation

Before describing evacuee movement down stairways more general comments are in order. To some people involved with buildings and fire safety the most noteworthy feature of the observed high-rise evacuation exercises are that they are conducted at all and that they have been well received by building occupants. Contrary to popular opinion, panic or non-rational, non-adaptive, non-social behavior is rare, even where people perceive a situation as actually or potentially hazardous. In a recently published study of the behavior of over 2000 people in nearly 1000 fires, it was considered that only about 5 per cent did something that was judged "to increase the risk," and this was rarely panic (Wood, 1972). It is unfortunate that accounts of building fires or, in some cases, evacuations of buildings where there are no fires often use the term "panic" to describe rational, adaptive behavior that might more aptly be described by terms such as "reflective fear," "anxiety," or "discomfort."

Following one surprise evacuation drill in a 21- storey Ottawa office building in 1971, the building occupants answering a questionnaire responded four to one in favour of such exercises. This attitude is particularly noteworthy because the questionnaire results predate many serious high-rise fires in the U.S. and other countries that were widely publicized. During the last few years public attitudes towards high-rise fire safety appear to have changed, although this has not been documented.

Movement Down Exit Stairways

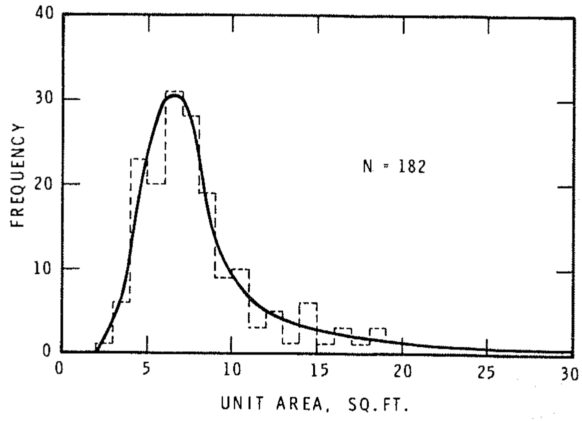
Movement down stairways has traditionally been, and continues to be, the chief physical activity in fire emergency procedures in buildings. The collection of data for variables such as spacing, density, speed, flow, queuing, and evacuation time was the most important aspect of the 40 high-rise evacuations observed in Ottawa office buildings.

The results of this study seem to confirm that some long standing misconceptions have greatly influenced building code exit stairway requirements. The misconceptions relate to the 22-inch unit exit width used to determine exit widths and to the flow that can be accommodated on various stair widths. The Ottawa observations indicate that the 22-inch unit exit width concept cannot be justified on the basis of fairly discrete lanes of movement, as previously believed. In addition, the conventionally-accepted flow of 45 persons per minute per 22 inches of stairway width appears to be over-optimistic by 50 to 100 per cent or more, expecially for mid-winter total evacuations in cold climates.

Personal Space. In describing evacuation movement characteristics one might consider first the personal space that each evacuee tries to maintain while evacuating. Although based on a very incomplete

Figure 1

Frequency Distribution of Unit Area (stairway area per person) in 17 Stairways during Evacuations of High Office Buildings.



analysis of early data, Figure 1 shows a frequency distribution of unit area (or stairway area per evacuee actually moving on the stairs and landings in total evacuations) peaking at a mode of about 6.5 square feet and having a median of about 7.4 square feet. The distribution would probably have a more pronounced peak if the population waiting to enter the stairway and other factors were similar in each evacuation. This suggests that each evacuee regards a certain space as comfortable under the circumstances. This space is influenced by factors such as the evacuee's clothing, cultural background, sex, relation to people close by, and emotional state (Horowitz, et al, 1970; Evans, 1973). The limited information available about the personal space regarded as comfortable suggests that in real emergencies a larger personal space would be desired. This could lead to lower densities on stairways.

Unit Exit Width. Observations of evacuation flow down various widths of exit stairway indicate that evacuees usually locate themselves on the stairs so as to maximize their spacing or "body buffer zone." Shoulder to shoulder movement is rare unless stairways are at least 48 inches wide, and even then it occurs mainly with people who are trying to talk with one another while evacuating. Thus, the traditional assumption about 22-inch-wide lanes of movement, or units of exit width, seems incorrect. An area per person or personal space model for sizing exit widths thus appears more realistic than the artificial anthropometric model now implicitly accepted in building code exit width requirements. This was presumably based on shoulder widths for some large percentile of typical building populations. Further evidence undermining the 22-inch unit exit width concept is described below where it is pointed out that flows down many widths of exit stairway are generally in proportion to width. Thus, flow plotted against stair width is a ramp function, not a step function as assumed in building codes.

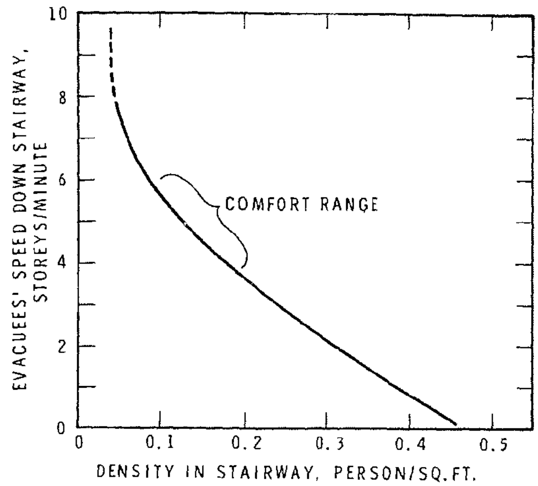


Figure 2

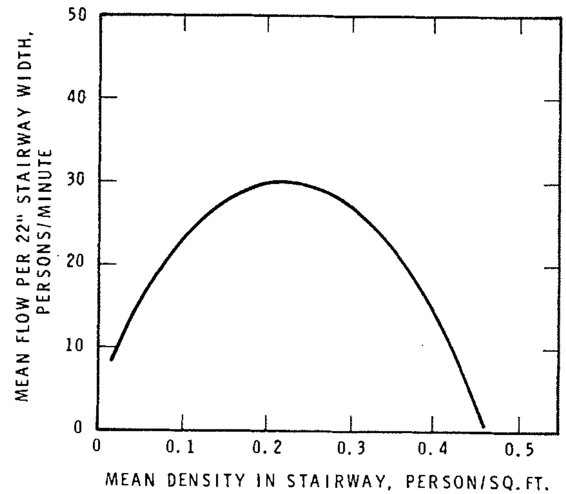
Effect of Density on Speed Down Exit Stairways in Evacuations of High Office Buildings.

Evacuation Speeds. For much of the following discussion the variable, density, or inverse of unit area will be used. Figure 2, for example, shows that mean speeds of descent down exit stairways in evacuation exercises decrease as density increases. This occurs as a result of increasing psychological interference and greater chance of physical contact. There appears to be a comfort range for evacuation movement of 4 to 6 storeys per minute at a density of 0.1 to 0.2 persons per square foot. For the typical office building stairway 44 inches wide, this condition permits each evacuee to occupy an average of about two stair treads of area. When densities on the stairs increase to about 0.45 persons per square foot, comfortable movement down stairways becomes almost impossible.

Evacuation Flows. The mean flow of evacuees down stairways is described as a function of density in Figure 3. Flow, or persons per minute descending stairs, is obtained by multiplying the speed by the density. The graph for flow as a function of density peaks at a density of about 0.2 persons per square foot, a density slightly greater than that apparently regarded as comfortable. The peak or optimum mean flow is described in terms of the 22-inch unit width simply because this width is familiar to designers and others who must work with existing building codes. The optimum mean flow observed in evacuation exercises was 30 persons per minute per 22 inches of stairway width. In most total evacuations observed, mean flows were less than this figure, and for a mid-winter evacuation where evacuees wore heavy winter coats the mean flow was about 20 persons per minute.

Figure 3

Effect of Density on Flow Down Exit Stairways in Evacuations of High Office Buildings.



Existing literature on evacuation flow down exit stairways suggests mean design flows of up to 45 persons per minute per 22 inches of stairway width (National Bureau of Standards, 1935; Joint Committee on Fire Grading of Buildings, 1952; Galbreath 1969). Careful examination of the studies that originally suggested this flow indicates that such high flows occurred only in experimental situations involving people who were specially instructed, motivated, and perhaps experienced in regimented movement at high densities. An experiment by the author with a small group of selected individuals produced similarly high flow rates. The conventional flow assumption of 45 persons per minute should not be used for estimating realistic evacuation flows for typical building populations.

Another factor to be recognized is the period over which flow down stairways is averaged (Figure 4). This figure also shows that flow is proportional to stair width over the range of widths studied in Ottawa evacuation exercises (36 to 60 inches). It should be pointed out that very localized constrictions in the width of stairways or passageways apparently do not reduce flow. For example, a 36-inch wide doorway does not reduce the flow from wider stairways. Although Figure 4 is based on a preliminary analysis of data, it appears to be a better basis for stairway sizing than that now recommended in the literature, where the unit width concept and an artificially high flow of 45 persons per minute per 22 inches of stairway width are promoted.

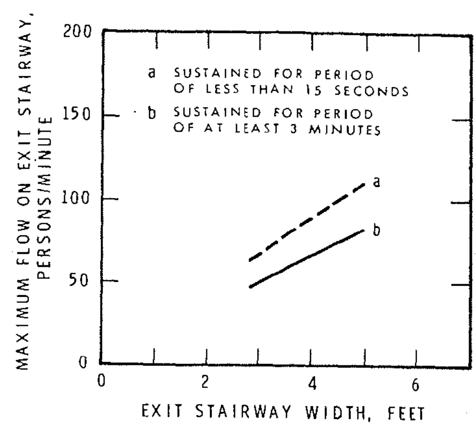


Figure 4

Effect of Exit Stairway Width on Flows in Evacuations of High Office Buildings.

Evacuation Time. Predictions of evacuation time for total evacuation of large office buildings during non-winter conditions can be made by dividing the actual building population by the flow suggested in Figure 3. An extra minute or so (during which time flow is established) should be added to give a reasonable total evacuation time for untrained, able-bodied adults who use stairs to full advantage. The term "able-bodied" here includes about 97 per cent of typical office populations. Figure 5 shows that evacuation times are dependent on the actual

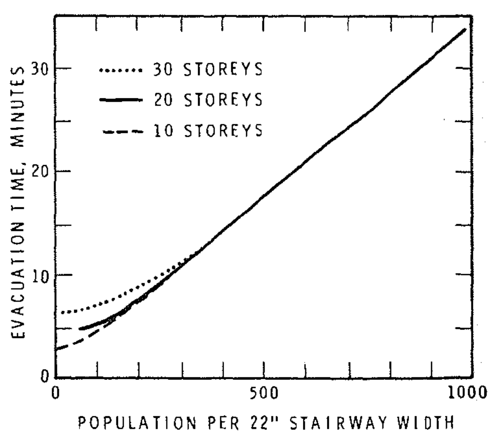


Figure 5

Predicted Total Evacuation Times of Tall Office Buildings Using Exit Stairways.

evacuation population and that building height affects time only in buildings with very small populations per floor.

The evacuation times predicted by Figure 5 may be modified by about 20 per cent either way for cases of better or poorer evacuation organization, depending on factors such as evacuee training and supervision.

These predictions of evacuation time are about 50 to 100 per cent higher than predictions reported in the literature (Galbreath, 1969).

It should also be recognized, however, that actual populations of office buildings tend to be only about half as great as is often assumed, so that this tends to offset previous errors in predicting total evacuation times of large office buildings. For example, the National Building Code usually assumes that each occupant of an office building will have a minimum of about 100 square feet of gross rentable floor area, but studies by the author of actual office building populations suggest that typical office occupants may often average over 200 square feet of gross rentable area.

These descriptions of evacuation movement down exit stairways apply mainly to conventional total evacuations in which all occupants begin their egress simultaneously. Stairways are thus used to capacity and some control in addition to the density-controlling influence of personal space may have to be exercised in order to make sure that stairways are not occupied by too many people. As shown in Figure 3, the flow by typical evacuees down stairs will be reduced if densities rise above about 0.2 persons per square foot. On the other hand, very low densities and thus low flows often occur in drills where entry of evacuees to the exit stairway is controlled, as in phased or sequential evacuations. In these evacuations, people from the fire floor, the floor above, and afterwards the floor below are evacuated in sequence to lower floors or to the building exterior. Other floors may then be evacuated, depending on the severity of the fire and smoke problem, the rule being that egress routes are essentially reserved for the most endangered occupants. (The safety of people on upper floors would be of particular concern for fires occurring during cold weather, since stack effect promotes smoke movement from lower to upper floors, largely by way of stairs, elevator, and service shafts.) For these types of phased evacuation, flows down exit stairways may be some fraction of those normally observed in total evacuations; use of exit stairways, however, might still be considered efficient in terms of actually achieving safety in buildings too large and too populated for unorganized total evacuation to work.

Communications During Evacuations

Public address or two-way communication systems were used during observations of phased or sequential procedures adopted for evacuating high-rise office buildings in Ottawa. They were operated by building safety personnel at an entrance lobby control console and at various locations throughout the building. Recordings of these systems in use during evacuation drills have proved to be very useful, especially when observers were simultaneously collecting data about evacuation movement. For example, the time taken for safety staff to reach their communications stations, make decisions regarding evacuation procedures, wait for feedback about the completion of evacuation of particular areas, etc., was often the biggest single factor in the total time taken to select and evacuate areas considered to be in danger.

Selective, highly-controlled approaches to high-rise evacuation are heavily dependent on skilled use of communications systems by trained and experienced personnel. There was considerable evidence of this in a major, surprise evacuation exercise during 1971 of a 21-storey office building in which the third floor was considered to be the fire floor. The evacuation sequence was to be third floor, fourth floor, second floor, 21st floor, 20th floor and so on down to the fifth floor until the building was completely cleared of occupants. The exercise started with a general sounding of fire alarm bells throughout the building to alert the building's 2100 occupants to move to core areas on each floor and await instructions to be given over the building's public address system. After about 2 minutes a somewhat excited voice was heard over the loudspeakers with the following message: "Ladies and gentlemen. We have to evacuate the building. The alarm has been set on the third floor. Please evacuate. Other floors stand by."

Use of the public address system in this excited and ambiguous fashion resulted in a great deal of confusion in what should have been a highly-controlled evacuation. It was well documented, with observations collected by a team of 15 observers located throughout the building. In addition, a detailed questionnaire distributed to 200 evacuees immediately following evacuation provided background information about 176 of the 2100 evacuees as well as information about their behavior during the exercise. For example, 17 per cent reported interpreting the situation as a genuine fire emergency when they first heard the fire alarm; but after the ambiguous public address announcement 42 per cent of the respondents reported interpreting it as a real fire emergency. Many respondents even reported that in the announcement they thought they heard "a fire has been reported on the third floor." This example underlines the importance of judicious use of public address systems, which increasingly are being installed in high-rise buildings for use in fire emergencies.

On the subject of communication systems in high-rise buildings, it appears highly desirable for audio recording equipment to be permanently installed in control consoles. If such recorders were to be programmed for continuous recording of all uses of public address and two-way communications systems whenever a fire alarm is activated, they could serve a useful function similar to that of aircraft flight recorders in providing otherwise unavailable information about emergency situations. Very useful data about occupant behavior, fire development, and smoke movement could be made available to researchers in this way.

USEFULNESS OF QUESTIONNAIRES

Useful information about evacuee response to fire alarms and other communcations was developed from the questionnaire results reported above. Returned by a fairly random sample of 176 people who had just taken part in a large-scale evacuation exercise, the questionnaire also provided information relating to normal and emergency use of exit stairways in high-rise office buildings. For example, some of the 40 items in the questionnaire were intended to check the degree of correspondence between observational data and occupants' interpretation of their experiences during the evacuation. There was good correspondence between objective measurements and reported subjective responses for such things as descent speeds. On the other hand, there was less correspondence between objective measures of density and perceived experiences of crowding discomfort, where individual personality factors in the experience of crowding may be more important than actual density conditions.

In addition to reactions to the evacuation, the questionnaire checked attitudes towards fire safety practices in high-rise office buildings and asked respondents to describe the nature, extent, reasons for, and capability of normal exit stairway use. The results have potential implications for setting up fire safety measures and for design of exit stairways as a building amenity.

The questionnaire results suggested that 3 per cent of the building's population could not or should not attempt to evacuate by stairway while the stairs are occupied by evacuees. This figure was true of other evacuation drills observed in Canadian office buildings as well (Pauls, 1971). Of the 176 respondents to the questionnaire, 97 per cent felt capable of descending at least three storeys of stairs and 64 per cent felt capable of descending at least 20 storeys "without stopping, at a normal speed, and without assistance from others." It should be noted that typical descent speeds during total evacuation drills were usually about half the six to eight storeys per minute that physically-fit adults can comfortably achieve for non-emergency movement down uncrowded stairways. The group of questionnaire respondents from this particular 21-storey office building who felt capable of descending at least 20 storeys comprised 76 per cent of the men and 45 per cent of the women in the sample 176 respondents, 79 per cent of those aged under 40 and 52 per cent of those aged 40 or older. By way of contrast, 90 per cent of the men under 40 and 28 per cent of the women over 40 felt capable of at least 20 storeys. Only 27 per cent of the respondents reported ever having descended at least 20 storeys at one time before the evacuation exercise.

In terms of normal use of exit stairways, about half the respondents (72 per cent of those from the lower half of the 21-storey building and 30 per cent from the upper half) reported using the stairways at least once a day. The building had only three government departments on the 20 office floors, which were separated into two zones for high-rise and low-rise elevators, and interfloor stair travel was heavy. Nearly 60 per cent of the men and 40 per cent of the women reported such normal usage. Nearly 20 per cent reported using the stairs in the mornings to reach their work floor, and 31 per cent reported using stairs at the end of the work day to leave the building. This level of use was not checked by observations of normal stairway use.

Results such as these are useful in indicating the value of exit stairways as a building amenity. In addition, evacuees have been observed to adapt well to exit stairways that appeared somewhat dangerous from a design point of view, and this was most pronounced in buildings in which normal use of exit stairways was very great. In general, it appears that non-emergency use of stairs not only prepares evacuees for overcoming deficiencies in stairs that have received inadequate attention in design, construction and maintenance but also encourages greater care in design, construction, and maintenance. The sometimes conflicting amenity, safety, and security demands on exit stairways must be resolved through more judicious building design and operation.

GENERAL APPLICATIONS OF RESEARCH RESULTS

Throughout, this paper has suggested the application of research to building and fire regulations. For example, rules for exit stairway sizing appear to be in need of change as a result of recent observations of evacuation flow. Potential revisions include wider stairways in buildings where rapid total evacuation is regarded as a necessary life-safety procedure. In other buildings specially designed to reduce fire and smoke hazards a more flexible approach to exit width seems to be appropriate.

Although not discussed in this paper, a large number of stairway detail-related factors are yet to be analysed, using the large body of data amassed in several years of evacuation observations. Keeping in mind the degree of adaptability that people tend to show to stairway deficiencies, one can speculate on the importance of stair landing sizes and door swings, the provision of windows in stair entrance doors, different stair configurations (including scissors stairs), the direction of stair turn, handrail sections and locations, tread finishes, stairwell wall textures and colors, and so forth. Such features have been noted in the wide variety of stairs observed in use, and design recommendations may be forthcoming.

In terms of building management or operation, the necessity for judicious use of communications systems in evacuations has been illustrated. Building management personnel must also devote more care to the problems posed by selective and sophisticated evacuation procedures and refuge options in large buildings increasingly equipped with complex security, energy control, and fire protection systems. With greater technological sophistication in building design, there is greater need for more highly trained supervisory personnel. Not only must they keep the building operating, they may also have to undertake the training of building occupants so that their behavior during fire emergencies will enable them to take full advantage of the building's bult-in safety features.

The application of the data and techniques developed as a result of evacuation research is increasingly important for normal, non-emergency occupancy conditions in buildings. For example, when analysed in greater detail the data concerning crowd movements in exit stairways may be relevant to the normal access and egress movement in assembly occupancies such as theatres, arenas, and stadia. Pilot observations were begun during 1973 of crowd movements in such assembly occupancy contexts and will probably be extended in 1974. Aisle-seating layouts and design considerations for stairs, ramps, and vomitories may eventually be widely influenced by such work.

SPECIFIC APPLICATIONS OF THE EVACUATION RESEARCH

As preliminary results of evacuation observations have become available in the last few years, there has been increasing contact with building designers, building management personnel, and committees responsible for life safety requirements in the National Building Code of Canada and the National Fire Code of Canada. For example, meetings between research staff of DBR/NRC and designers from private practice have often dealt with large unusual building projects in which the problems of fire protection and occupant evacuation procedures were better solved by return to fundamental principles rather than use of existing code requirements. In one case the means of egress for a large grandstand was approached from a principles or performance point of view with the result that significant savings have been achieved.

Work on evacuation movement in buildings is also being presented extensively during 1974 in seminar/workshops for Canadian designers, consultants, fire officials, and building managers and in smaller meetings with Canadian and U.S. fire regulation and research personnel. Discussions during these meetings deal extensively with re-definition of the fire safety problem in buildings. In high-rise buildings, for example, fire and smoke control systems are under development that will permit greater design freedom but at the same time require greater design and operational expertise (Associate Committee on the National Building Code, 1973). The systems are closely related to non-traditional evacuation and refuge options for occupants who do not wish to be disturbed by minor fire occurrences in increasingly large and complex buildings.

SUMMARY

Although many of the findings of a preliminary analysis of evacuation observations of high-rise buildings apply to increasingly obsolete total evacuation procedures, such studies have recently broadened their emphasis to include the total problem of life safety from fire in buildings of many occupancy types. The application of this work is becoming wider, encompassing not only building codes but also other regulations and standards affecting life safety. The work has been, to a large extent, justified on the basis of improving safety regulations, but it should be noted that knowledge of safety-related matters can often be more suitably applied when safety is part of design competance rather than controlled by regulations too often applied as complete solutions to particular design problems. As this paper has suggested, safety features in buildings must be considered in terms of other factors such as amenity and security.

Hopefully, as research continues in organizations such as Canada's Divison of Building Research and in consulting firms and universities, many traditional rules and approaches will be re-examined, in some cases by observation of people's actual behavior in buildings. This paper has tried to show that traditional rules and approaches relating

to building evacuation during fire are in need of re-examination and that some rather simple study procedures can be used to produce readily applicable results. Areas for further research may be suggested to those reading this paper. The author would particularly like to hear from readers who are involved in such work or anticipate work that can be applied to the problem areas suggested in this paper.

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