NBS BUILDING SCIENCE SERIES 115

# Fire Safety for High-Rise Buildings: Role of Communications



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# ABSTRACT

This literature survey reviews the communications requirements for fire safety in buildings from the standpoint of the building occupant and the control operator. It traces the development of the problem of communications in buildings and the specialized needs that exist today.

An examination is made of the purposes of a communications system in buildings as well as some of the psychological design requirements necessary for such a system.

The communications requirements of the building occupants are also covered, with emphasis on the types of information communicated by signals and the integration of those signals into an overall system design.

Personnel requirements for staffing a control center are also discussed, along with common problems in several operational communications systems.

Detailed examples of communications systems are provided. Portions of several model codes which cover communications systems are presented. Suggested areas for future research on fire safety in buildings are identified.

Key words: Buildings; communications system; fire safety; high-rise; model codes; people movement; systems design.

# CONTENTS

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# 1. THE NATURE OF THE PROBLEM

The problem of occupant fire safety in buildings has received considerable, albeit belated, attention in recent years. The publication of "America Burning" by the National Commission on Fire Prevention and Control in 1973 provided an extensive overview of the "fire problem" and indicated the following:

- The United States leads all the major industrialized nations in per capita deaths as well as property loss from fire. The total cost of destructive fire is estimated to be $11.0 billion per year. These estimates are thought to be *conservative* by some experts.
- Almost 12,000 persons have been killed in fires in each of the past 6 years in the United States. Only motor vehicle accidents and falls rank higher among the causes of accidental deaths.

Further documentation of losses attributed to fires is given by Ahern and Morgan (1973).

- The death rate attributed to fires on a per capita basis in the United States is twice that of Canada, four times that of the United Kingdom, and 6-1/2 times that of Japan.

- As a nation, the United States spent about $5.5 billion in 1971 on fire-related activities: $2.7 billion on fire protection, $2.8 billion due to property losses.

As evidence of the concern for fire safety in buildings, a substantial number and variety of activities have been undertaken in recent years by the United States and other national governments, by local and state governments, as well as by fire professionals and technical organizations. Legislation and standards work are very much in evidence, as are innovative ideas suggested by many individuals and organizations concerned about this matter.

A focal point for much of this activity in the United States has been the General Services Administration (GSA). More specifically, the problems were highlighted by the convening of two conferences on "Fire Safety in High-Rise Buildings" (April 1971 and October 1971). These conferences brought together fire safety experts from many countries, who not only pinpointed major problem areas but suggested approaches to overcome the problems identified. The findings resulting from these conferences were used as the starting point for this investigation.

In the later chapters of this report, we will explore in more detail both the identification of needs for effective communication in building-fire emergencies, and the systems advocated for meeting this need. For the time being, we will simply assert that the problem has been recognized by many fire experts as being extremely important if buildings are to be safe for occupants.

## 1.1 COMMUNICATIONS—HIGH-RISE AND OTHER BUILDINGS

Our discussion is limited to communications in high-rise buildings. There is, however, little reason to believe that the basic fire safety communication requirements would be different for buildings which are classified as high-rise than for other structures.

We emphasize the word "basic" because by "communicate" is meant the need to transmit necessary information in a timely and effective manner. We assume that the message transmitted is designed to be received *directly* by the individual (e.g., the person hearing an alarm) rather than through an intermediary (e.g., someone else hearing an alarm, and then informing the individual about the alarm). Under these circumstances, the major differences among communications requirements in various building types have to do with the means of transmitting messages and the context and complexity of the messages.

Naturally, it is to be expected that, as the number of variables is increased, there is a greater likelihood that messages would be complex. These complexities may relate to the nature of the activities performed, to the building and/or site, or to the building occupants. Consider table 1, which illustrates some of the pertinent variables.

**Table 1. CHARACTERISTICS WHICH AFFECT COMMUNICATIONS**

| Building | Occupant |
|---|---|
| Height | Number |
| Volume | Health |
| Variety of activities | Age distribution |
| Type of building | Degree of self-sufficiency |
| Location | Transient, permanent |
| Fire safety features | Training |
| Materials | Experience |
| Contents | |
| Areas of refuge | |

High-rise buildings can then be explored as a "worst case" example of communications problems likely to occur in buildings. It is especially important to consider this building type because of the sophisticated approaches and technologies which are now being employed in them in the form of control centers. The concept of a control center for fire safety communications is a direct outgrowth of experiences in civil defense, military command and control systems, NASA-based activities and more recently police and fire departments.

Nevertheless, we should be alert to the differences between the historical applications of these systems as indicated above and their general application to high-rise building needs. Perhaps one of the most fundamental differences concerns the characteristics of the people both at the sending and receiving end of communications.

In most present applications of these systems, the communicators and receivers of messages are highly trained individuals, prepared to act in one of a limited number of ways, depending on the nature of the message. The person sending the message and the one receiving it share common training, and specialized language (jargon) all of which are major factors in communicating effectively and appropriately. The similarity of backgrounds between participants at both ends of a communications link tends to reduce the chances of misunderstandings and errors during transmission of a message.

In contrast, the communications systems designed for high-rise public buildings often do not have people with common backgrounds and experience at both ends of the communications link. On the contrary, in many instances the people receiving fire emergency messages are unprepared for such communications, are not likely to know what actions should be taken, and therefore need instructions as to what to do.

When we recall that the concept of total building evacuation in high-rise structures is no longer thought to be feasible, then a general alarm (of any type) is not likely to serve as anything but an alerting signal. This signal must be augmented by specific messages to occupants, depending upon the respective locations of the fire, the occupants, areas of refuge, exit pathways, etc. The requirement of a communications system to deal with this multitude of variables has led many experts to conclude that voice communication to building occupants is an essential feature of a fire safety control system

## 1.2 STUDIES OF FIRE SAFETY COMMUNICATIONS FOR BUILDINGS

In an earlier study conducted at the National Bureau of Standards (Rubin and Cohen, 1973), the authors noted the dearth of directly applicable information on the topic of occupant fire safety in buildings. The same is true for the subject of the present study which is really a subset of the problem addressed in the earlier investigation. There are several reasons for the difficulty in obtaining useful data, some of which will be discussed in some detail in later parts of the present study. These reasons include:

- The impracticality of conducting carefully controlled research studies under real emergency conditions. (For legal and ethical reasons).
- An incomplete understanding of the dimensions and parameters of the problem.
- The absence of appropriate tested methodologies and approaches to obtain required information.
- The unreliability of popular (news media) accounts of activities which occur during emergencies.
- The emphasis by those who collect "fire data" on other aspects of building fire losses, while neglecting occupant safety needs.

## 1.3 VISUAL COMMUNICATIONS AND FIRE SAFETY

A cursory review of the literature dealing with fire safety communications can be very misleading. The discussions of fire safety experts about proposed system designs deal extensively with sophisticated computerized techniques, control consoles, auditory alarms and voice communications. It would be easy to conclude that "communications requirements" refers exclusively to auditory means of transfering information. If, however, we view the fire safety requirements of building occupants in a systems context (how people fit into the overall plan), it is evident that a good deal of visual information must also be provided. Exit and direction signs, visible paths to safe areas, doors to the outside, stairway and hallway lighting, all of these necessary means of reaching safe areas must be seen by building occupants.

A viable fire safety communications plan therefore must consist not only of the sounding of an alarm, possibly followed by verbal instructions, but also must include informational cues (visual and other) which aid the movement to safety. Redundant auditory and visual systems would probably be more effective than either system acting independently. Also, the possibility of providing information by tactual or other means should not be overlooked when safety systems are designed. Tactual cues can be important for the visually handicapped, and in smoke-filled environments, where everyone is visually handicapped.

Although we have indicated the need to consider *new* auditory and visual means of communication, our literature review deals with this subject only tangentially, since we were unsuccessful in our search for information dealing directly with this problem. This experience has strengthened our belief expressed in a previous paper (Rubin and Cohen, 1973) that the topic is neglected, but has not altered our conviction that the subject is a vital one in occupant fire safety.

## 1.4 REPORT OBJECTIVES AND APPROACH

The objectives of this report are:

- To describe the state-of-the-art of occupant communications systems in buildings.
- To provide an overview of subjects which are directly related to such systems.
- To critique systems in current use.
- To point a direction for research by identifying problem areas.

In defining the state-of-the-art, we have conducted an extensive literature search of hardware and software approaches, with special emphasis on attempting to identify systems in actual use as well as proposed design recommendations. The review, which covers a variety of building types, can by no means be considered an exhaustive treatment of this vast topic. The subject of occupant fire safety does not have a solid research foundation and therefore only a limited number of investigations was available for examination. These studies and evaluations, as well as particular designs by fire safety experts, have been documented by relying extensively on direct quotations from the authors of the works. This course was adopted in order to document a variety of approaches in detail, with the aim of enabling the reader to make independent evaluations.

Finally, the communications requirements contained in several recent building fire safety codes have been cited as a guide for readers concerned with this topic. This information appears in Appendix A.

Communications requirements for fire safety in buildings touch on several subject areas—each of which deserves detailed attention. Topics such as communication system design, informational requirements, alarm signals and human behavior under emergency conditions have all been examined by investigators, leading to a sizable literature for each. This wealth of information is such that it could not possibly be summarized or even extensively dealt with in the context of this report. Thus, these problem areas will not be dealt with extensively; neither will they be ignored. Rather, they will be touched upon whenever they are relevant to the discussion.

Readers often expect certain information in a report and then are disappointed when that information is not included in the document. One way of avoiding this problem is to list topics close to those included in the study, but which are *not* dealt with. Among these subjects are:

- Communications by professional fire fighters.
- Communications to and within communities.
- Comparisons of requirements by building types.*
- Design recommendations.*

Although it would be premature to attempt to provide many of the answers to the problems of communications, it is possible to identify major subject areas where more and better information is needed. The authors made judgments based upon written material (literature search), personal communications, conversations with fire safety experts, and attendance at a number of meetings dealing with this topic.

*These subject areas will require extensive investigations before information summaries can be given.

# 2. SAFETY IN HIGH-RISE BUILDINGS

## 2.1 BACKGROUND

Concern for fire safety in high-rise buildings is relatively recent. In South America, from July 1973 to February 1974, there were 3 major high-rise building fires that resulted in 183 fatalities and $9 million in damages (Sharry, 1974). None of these buildings followed the NFPA #101 Life Safety Code. Even with such a code, the potential for disaster in U.S. high-rise buildings still exists. In this country, a major fire at One New York Plaza, New York City, extensively damaged three floors of the 50-story building and resulted in 2 deaths and 30 injuries. This fire served to focus attention on the problems of high-rise fire safety. If the building had been fully occupied or the fire had occurred during working hours, the life loss might have been much higher.

What problems are associated with occupant safety in high-rise buildings? What are the relationships between communications requirements and some of the latest life safety systems developed especially for high-rise buildings? What design changes in such systems can we expect in the future?

Prior to World War II, skyscrapers were built of structural steel and concrete. They generally had openable windows, since air conditioning was rare. Most of the problem buildings were erected during the office building boom of the 1960's and early 1970's, when for economic reasons the trend was to build taller and taller buildings. In New York City alone, according to Powers (1973), there are 77 buildings taller than 500 feet (152 meters) including the 2 World Trade Center Buildings at 1350 feet (411 meters) and the Empire State Building at 1250 feet (381 meters). Of these, the newest buildings present special fire safety problems because of design innovations such as open air spaces, moveable walls, modern plastic furnishings, and sealed windows to make central air conditioning more effective. All of these design features contribute to the rapid build-up of heat, and spread of a fire once it has started. In addition to the fire hazard, central air conditioning ducts provide a potential pathway for smoke.

Many of the larger high-rise buildings have thousands of occupants dispersed throughout many offices and engaged in a variety of activities. Each building is likely to constitute a rather complex community, or even a series of communities, including a population consisting of young and aged, healthy and handicapped, skilled and unskilled, etc. The importance of this heterogeneity of people, spaces, furnishings and activities becomes evident now that experts seem to oppose total evacuation of such buildings in the event of fire. Instead of a single, standard action to be performed by building occupants (total evacuation), a number of alternative procedures has been developed. Thus, depending on the situation, a fire safety plan for occupants may call for one group to stay in place, another one to move horizontally to a refuge area, a third to move vertically and/or evacuate the building. Under these conditions, accurate communications become crucial!

Several factors appear to have influenced the conclusions expressed by Sampson (1971), Stevens (1971) and others concerned with problems of fire safety in high-rise buildings. There has been a number of fires in recent years with very high death tolls especially in South America and South Korea. After a long time during which the height of high-rise buildings was limited (for some 40 years none competed with the Empire State Building in New York) structures of monumental size such as the World Trade Center and the Sears Tower have been built.

John Sharry (1974), described a fire which occurred in the 25-story Joelma Building in Sao Paulo, Brazil on February 1, 1974. This fire resulted in 179 deaths and 300 injuries. Ironically, the 31-story Andraus Building in the same city was the scene of a similar catastrophe two years before, when 16 people were killed and more than 375 injured. A. E. Willey (1972) notes that in the Andraus building fire, 500 people escaped the fire by moving to safe areas in the building employed as unplanned "refuge" locations.

Willey and Sharry concluded that the main factors contributing to loss of life and injuries in these fires were:

- The absence of illuminated emergency exit signs.
- The lack of emergency illumination.
- The absence of manual alarms and automatic detection or extinguishing systems.
- The absence of procedures to deal with fire emergencies

## 2.2. BEHAVIORAL STUDIES—PEOPLE MOVEMENT

The Division of Building Research (DBR) of the National Research Council, Ottawa, Canada, has documented the actual movements of large numbers of people in high-rise buildings and other structures containing large populations. Jake Pauls of DBR has been a leader in these activities since 1968, developing an impressive set of empirical findings based on evacuation drills.

His first study was in the 22-story Hydro Building in Vancouver, British Columbia. In describing the background for this study, Pauls indicated that over the last few years interest in emergency evacuation of buildings had grown considerably, as a result of fire incidents in tall buildings and intensive study of the movement and control of smoke. As part of a total approach to life safety in buildings, a need existed, he said, for information describing the context, procedure, and efficacy of building evacuation. He continues (Pauls, 1971):

> During the first two minutes of the drill, a prearranged procedure was followed to check the source of the alarm and organize key evacuation personnel. When total evacuation was ordered over the building's public address system, the floor warden supervised the clearing and checking of each floor before reporting to a central control center, using an emergency telephone system. It took twelve minutes to clear the building once the evacuation was announced. Of a total of 945 people from floors above the mezzanine level, 910 left by two 47-inch exit stairways and 35 used a supervised elevator.
>
> They (the exit stairways) have a width of 47 in. at shoulder height, and each stairway has an area of 155 sq. ft. per story, of which about 140 sq. ft. is the effective area taken up by a 47-in.-wide stream of people. The length of the travel path per floor is 40

ft. measured along the centerline of a 47-in. path down the stairs and landings.

> Evacuation procedures for the B. C. Hydro Head Office building are designed to be simple to follow while permitting flexible control by key evacuation personnel. Total evacuation, for example, is initiated by means of a siren signal and an announcement, both transmitted over the building's public address system. (The building is *not* equipped with a general fire gong system.) Evacuation of each floor occurs under the direction of a floor warden or his alternate; people line up in the corridor area at the designated exit and proceed down the exit stairway as the warden directs.

As for communications, Pauls quotes evacuation personnel and observers after the evacuation drill as saying that with a few exceptions, the siren and the initial announcement, both transmitted over the public address system, were clearly heard everywhere in the floor areas. With no speakers in the exit stairways, however, there was reportedly some confusion when some of the wardens stationed at the emergency telephones in the stairways failed to hear subsequent announcements.

In terms of their initial interpretation of the public address announcements, Pauls cites all the evacuation personnel, and presumably most of the other occupants, as being sure it was an exercise rather than a real emergency.

This report (Pauls, 1971) 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 stories in height. The chief goal of 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 supervisors. Large-scale data collection was often necessary because of numerous variables that could not be controlled experimentally.

Observation techniques included equipping 2 to 15 observers with portable cassette recorders to register all observations and background sounds. These observations, tape recordings of any communications used in the evacuations, and 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 rerun for purposes of detailed analysis. For example, in one 21-story 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 2,000 people. Observers moving with evacuees from floor areas to the outside of the building were able to record data for a wide range of behavioral variables, often without the knowledge of evacuees only a few feet away.

In terms of method and the quantity and quality of data, these observations appear to have no precedent in the literature.

These and other studies provided a background of experience for the Canadians in establishing a national building code.

E. S. Hornby, Assistant Dominion Fire Commissioner (1974) described in a talk the experience of the Canadian Government in dealing with fire safety problems in high-rise buildings. He said that in the 1960's the rapid increase in high-rise construction focused attention on the importance of fire fighting and rescue activities. Such fire fighting activities must now be largely carried out inside buildings, since most floors in high-rise structures are out of the reach of effective external operations.

Paralleling the development of the modern high-rise building Hornby cited new innovations in fire detection and fire control equipment: flame detectors, heat detector thermostats, rate-of-rise detectors, combination heat detectors, smoke detectors and products-of-combustion detectors, in addition to more sophisticated alarm circuitry. All have been installed in high-rise buildings to a greater or lesser degree.

Hornby points out that current emergency procedures employ the principle of "phased evacuation."

Phased evacuation is usually used in apartment buildings, but in office buildings it is employed only when the building is fully occupied.

Hornby stresses two requirements to successfully manage a phased evacuation: an effective integrated fire alarm and voice communications system; and the presence of competent personnel to operate the system in accordance with a predetermined fire safety plan.

Another authority, Ralph Ehlers of the Building Industry Consulting Service (BICS) made the following points on the topic of emergency communications for building occupants (1972):

> One of the most important factors in a high-rise emergency is control of the occupants. Not only from a life safety standpoint, but their undirected movement can hinder fire department personnel in the performance of their job.
>
> In those buildings where total evacuation is not feasible, occupants must receive verbal instructions and status information if they are to remain calm. This is especially true if smoke is present. Studies show that, under these conditions, most people

(even those in relatively safe areas) will try to leave the building, which may seriously congest the exits.

Therefore, where total evacuation is not contemplated, alarms alone should not be used because they convey no instructions. A selective alerting and voice communication system seems necessary. Such a system should meet the following basic criteria:

The system should be operated from the Communication and Control Center by fire or other authorized personnel.

It should have an emergency power supply in the event of commercial power failure.

It must be able to alert and communicate with a large number of stations at one time.

The alerting signal must be distinctive.

The system must be able to select predetermined zones, probably consisting of one or two floors of the building.

It must, by necessity, be a one-way communication system, arranged so the stations can receive only. This is simply because a large number of transmitting devices on line at the same time would make noise levels intolerable and transmission impossible. [This judgment is not universally accepted, as noted below.—Authors]

It should probably have the capacity not only for direct voice, but also for a continuous tape recorded message input from the controls.

Smoke refuge zones, if provided, should also be included as stations on this system so the occupants could be advised as required.

Babcock (1971) and Jensen (1972) dealt with this same subject and drew conclusions similar to those already noted.

One of the very few systematic studies of actual fires designed to better understand occupant requirements was summarized by D. C. Grupp at the Eighth Systems Building Seminar (1972). This investigation was designed to "study the various facets of the high-rise fire problem and, more importantly, to develop possible approaches to solving this problem, which could then be subsequently translated into new code regulations."

The study was divided into six phases: literature search, a code comparison study, fire investigations, systems analysis of problems, a brain-storming phase and development of solutions.

The study of actual fire incidents by Grupp is of special interest. A total of 51 high-rise fires was investigated—half of them by experts who were on the scene within 24 hours of the fire. Grupp says:

Available reports from other sources on the remaining fires varies from good to poor, with the main problem being one of the investigator having placed insufficient emphasis on life safety factors such as smoke spread, occupant reactions, evacuation modes and times, etc. Occupant evacuation problems quite clearly arose from the basic necessity to at least partially evacuate occupants in all of various cases, in order to remove them from the effects of smoke or fire. In about one-fourth of the instances, only the fire floor had to be evacuated. However, the remainder also involved the evacuation of several other floors with about 15% of these requiring complete evacuation of all floors above the fire.

Grupp noted that in a significant number of cases, evacuation times were quite long because of smoke along exit routes and in stairwells. He also cited inadequacies in evacuation alarm systems in a high number of instances, ranging from alarm systems that were inoperative, or ineffective to those that were non-existent. He continues:

Occupant safety considerations, involve a wide variety of factors which come into play during a high-rise fire. However, the results of our three background studies clearly indicate that the elements of alarm transmission and evacuation directions, tenability of exit routes and the adequacy of egress facilities are of primary importance. In the absence of alarm notification and/or an inability to provide selective instructions to occupants, evacuation of areas exposed to the fire or its combustion products are significantly delayed, panic conditions can develop and the occupants are subjected to an undue level of danger. This problem is accentuated by the tendency for egress routes to become blocked by smoke relatively early in the fire and by the inability of stairways to handle a mass evacuation.

This latter factor is of key importance in the design of any set of fire safety countermeasures. Utilizing an assumed five minute evacuation time, we found that the present exit capacity requirements are generally sufficient to serve only buildings not exceeding 6 stories in height. Furthermore, our analysis indicated that 25 stories probably represents the maximum height at which total evacuation can be achieved in 5 minutes regardless of the number of stairways provided. Thus, it is quite obvious that a safe total evacuation is out of the question for many of our high-rise buildings and that some other life safety concepts need to be developed.

Summarizing his conclusions, Grupp pointed out:

In all cases, with both new and existing buildings, there is a definite need to provide for occupant/fire department emergency communications and to provide the fire department with some definite means to ventilate fires in high-rise buildings. In structures less than 25 stories high, where the exit capacity is found adequate to contemplate complete evacuation, a general manual alarm system can be provided and arranged to sound bells, horns or some similar devices. However, where only partial evacuation is feasible and designed for, a suitable voice signal system with selective floor capabilities is definitely needed. In existing buildings, the most practical solution in many cases appears to be a group alerting system involving a piggy-backing on the intercom or the basic telephone service provided within the building.

Grupp said he still found significant knowledge gaps which made it difficult at this time to develop a completely rational and scientific approach to solving this problem.

## 2.3 ENGINEERING STUDIES

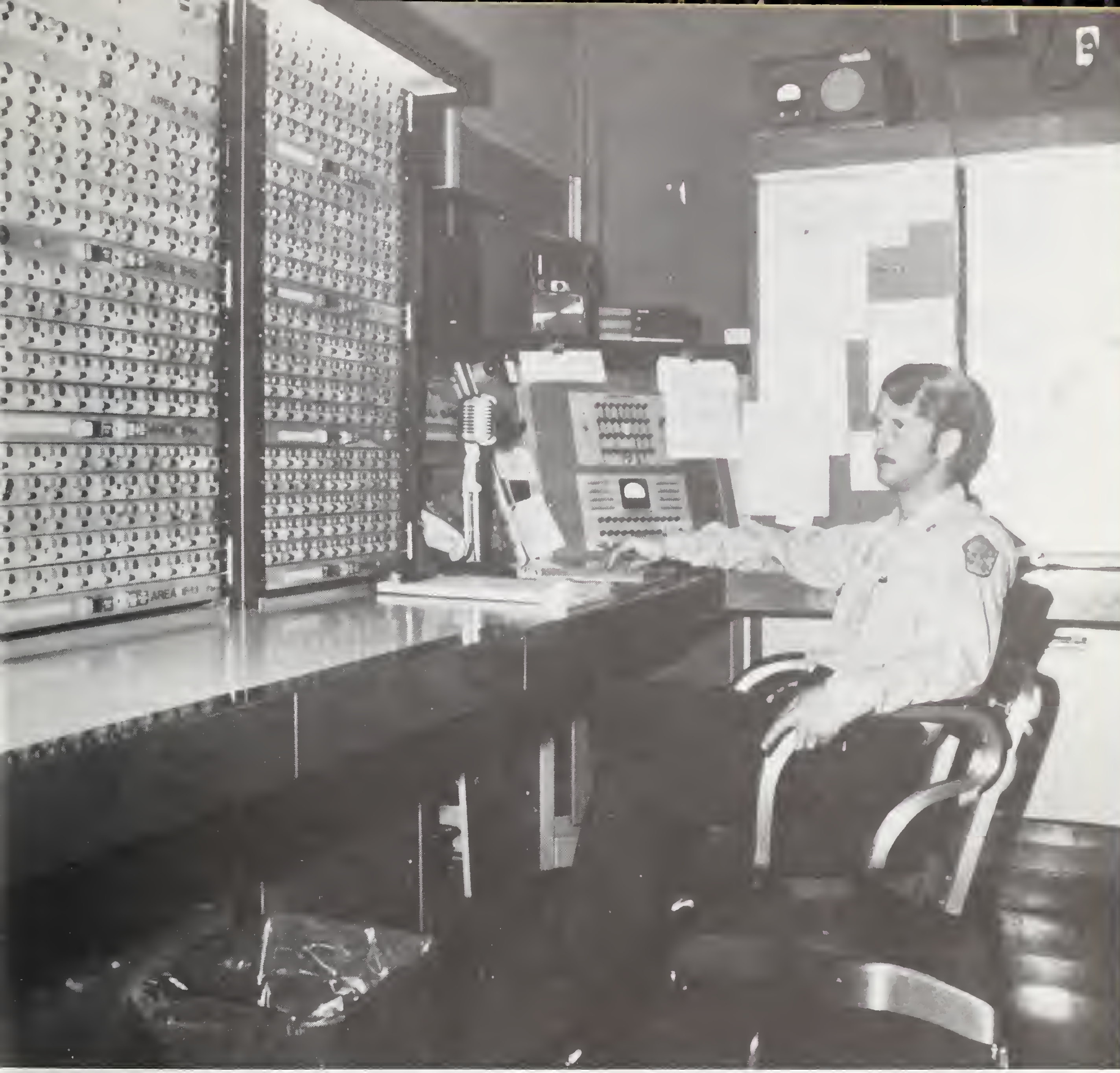
It is important to make a distinction between a communications system designed to be monitored by an operator as a means of obtaining information only, and a command and control system, only *one* function of which is the display of information. The military and, more recently, NASA have advocated these complex systems, which were designed to integrate closely interacting "human" and "hardware" subsystem components. Such a control system is needed for high-rise safety because the solution of such problems is inherently complex. For example, fully automatic sensing and sprinkling devices do not provide a complete solution to the problem of fire safety, any more than building evacuation or formal communications networks do. Instead, an effective system depends on the integration of the many automatic, semi-automatic and manually based components associated with the various aspects of fire safety.

Above all, a control center is designed to inform the person responsible for making decisions as to his options as he performs his fire safety functions.

This view of the importance of a control center is echoed by others who have been intimately involved in fire safety for high-rise buildings.

The location of the central control station is of major concern. Some codes prefer a control center on the ground floor, which is fire-safe in itself, and which can communicate with the occupants by both voice and visual devices (such as flashing signs, directional signals, even television) to advise them of the emergency, and to issue warnings and directions if necessary.

The types of alarm systems are not specified in all codes: for instance the British code is silent on this point in the case of dwellings—and one can wonder in fact about the necessity of expensive systems. On the contrary, the BOCA International (U.S.A.) Basic Building Code requires a fire alarm system for many occupancies and, in the case of hotels, for all buildings higher than one story. Once more, it is difficult to set general rules. The National Building Code (Canada) requires an approved voice communication system in all buildings that are over twelve stories in building height.



## 3. VOICE COMMUNICATIONS SYSTEMS

Within the past few years, there has been an increased emphasis on the need to augment traditional emergency systems with voice communications systems. The concept of using a public address system for fire emergency warnings is largely traceable to the Reconvened International Conference on Fire Safety in High-Rise Buildings in 1971 (GSA, 1971). It emerged in response to the idea that people needed to be reassured during an emergency in order to prevent undesirable irrational behavior such as panic.

However, if one examines the literature carefully and consults with those who have studied human behavior in disasters, one finds many myths. Dr. Quarantelli, from Ohio State University's Disaster Research Unit, reports that people do not panic and do not act irrationally. From his research (on human behavior in mass disasters) Quarantelli (1973, p. 70) concludes that: "Human behavior as such does not appear to be a major problem at times of disaster."

These communications systems serve to keep the occupants informed and also presumably help people to find the safer areas of the building. Unfortunately, while these objectives appear to be reasonable, the specifics of how such systems should work have yet to be thoroughly investigated from the standpoint of the needs of building occupants.

## 3.1 PURPOSES OF COMMUNICATIONS SYSTEMS

Voice communications systems can be designed to serve several purposes; consequently, a number of alternate approaches is possible:

- Communication can be one-way from control center to building occupants; or a two-way system can be designed to serve the same function.
- Verbal communication may take the form of either pre-recorded messages to occupants or live messages; systems may operate both ways.
- Communications may be directed toward a fire safety staff (wardens) or to occupants.

These are only a few of the possible system variations.

R. Stevens (1971), in an editorial for the *Fire Journal,* discusses the function of an alarm system in high-rise buildings. He notes that such a system should notify the fire department and the building manager. A communications system is also necessary to maintain contact with building occupants. Mr. Stevens feels people are more likely to perform required actions if given appropriate information. A voice communications system between the person(s) responsible for carrying out fire emergency procedures and building occupants is essential to people who must remain in a building during a fire emergency. It would also serve to keep the person in charge informed of the situation as it changes. This two-way voice communications system allows occupants and people with fire safety responsibilities to make intelligent decisions concerning the actions to be taken by those affected by the fire emergency.

The importance of a voice communications system was noted at the GSA Reconvened International Conference on Fire Safety in High-Rise Buildings (1971b, p. 4–10). In an analysis of "Public Confidence Systems" the following statement was made:

> If a building occupant is able to call some central point for instructions or is reassured and informed by public address system or other means, he is far less likely to become excited or apprehensive.
>
> If he is periodically made aware of fire prevention and fire control programs and equipment that are available; of safety areas and alternate escape routes that are open to him; and of the fact that the building is designed to defend him against a fire, he will be more likely to go about his business and to accept further guidance.

At the same conference (GSA 1971b), John Degenkolb suggested that voice communications could be made through radios or TV's in a hotel or apartment, or through the background music system in lobbies. An alternative idea would be to use the telephone system with special speakers attached. The main point to keep in mind is that the messages should be available and easily understandable.

## 3.2 VARIABLES TO CONSIDER IN DESIGNING COMMUNICATIONS SYSTEMS

We noted earlier that many variables must be considered when designing fire safety communications systems—some related to building characteristics (previously mentioned), others tied to the abilities and limitations of people. One method of attacking the people problem is to develop one or more classifications.

Anne Phillips (GSA, 1971, p. A-25) suggested that the population can be divided into: normal adults, subnormal adults, and children, all of whom may be affected by products of combustion (smoke, gases, etc.). These groups in turn can be divided into subgroups based on special requirements of each group. The following is a listing of those groups:

A. Normal Adults
   1. Leaders, trained or emergent
   2. Persons transiently confused but responsive to directions
   3. Persons making delayed or inadequate response
   4. Persons withdrawing from reality
      a. Those behaving irrationally
      b. Those becoming completely inert

B. Subnormal Adults
   1. Physically handicapped
      a. Those equipped to move unaided
      b. Those unable to move without help
   2. Mentally handicapped
      a. Those requiring direction
      b. Those requiring coercion

C. Children
   1. Able to move unaided when directed
   2. Unable to move unaided (infants, toddlers, sick, or handicapped)
   3. Like adults some children will react rationally and a smaller number will react irrationally or become helpless

Furthermore, assistance or directions may be necessary for that part of the population which, after inhaling products of combustion, have difficulty coordinating or thinking clearly. Also some elements of the population may become completely uncoordinated or irrational and must be bodily carried out.

G. Claiborne (GSA, 1971, p. A-24) relates people classifications to mental capabilities and physical capabilities. The following scale shows the extremes of capabilities of people:

**MENTAL CAPABILITY**

| 0 | 100 |
|---|---|
| Irrational | Rational |
| Asleep (semiconscious) | (Conscious) awake |
| Child/aged mentality | Adult mentality |
| Transient (knowledge) | Non-transient (knowledge) |
| Apathetic | Non apathetic |
| Excitable | Cool headed |

**PHYSICAL CAPABILITY**

| 0 | | 100 |
|---|---|---|
| Non-ambulatory | Semi ambulatory | Ambulatory |
| | Ambulatory with much assistance | |
| | Ambulatory with minimum assistance | |
| Restrained | | Unrestrained |
| Child/aged | | Adult |
| Sleeping | | Awake |

Thus, we can see that careful attention must be paid to the physical abilities and limitations of the building occupants, when designing a communications system that is to be responsive to the needs of the occupants in times of emergency.

## 3.3 CHARACTERISTICS OF THE MESSAGE IN VOICE COMMUNICATIONS SYSTEMS

In developing a communications system for high-rise buildings, the characteristics of the message become an important variable. Care must be taken to insure that the message transmitted is tailored to the conditions in the building. For example, different types of messages would be required for open area offices as opposed to compartmentalized offices.

Local fire departments who have jurisdiction over the high-rise building should be consulted in developing the message as some may require the floor on fire, as well as the one above, to be evacuated, while other fire departments may also require the floor below to be evacuated.

The message should warn occupants to use the stairwells, rather than the elevators (except in special cases determined by the fire department). Depending on the building's characteristics, occupants might be told to go up or down two floors from the fire floor and await further instructions.

If the message is to be heard in an apartment building, then it should also have a distinctive sound preceding it, so as to wake any sleeping tenants, or to otherwise get their attention.

Loftus and Keating (1974) described how a number of the GSA Conference suggestions were incorporated into the design of a voice communications system for the Seattle building. They said the objective of their investigation was as follows:

> The communications hardware system that has been installed in the Seattle Federal Building allows for the optimal implementation of the recommendations derived from the International Conferences on Fire Safety in High-Rise Buildings. The recommendations in this report deal with issues such as "What words would best communicate to the building occupants the facts of the situation, and the instructions they should follow? Should a warning signal alert the occupants to the beginning of the message? Should the message be spoken by a male or a female?" The recommendations for these aspects of the system are culled from the best available data from human factors engineering and social psychology.

To illustrate the approach suggested by Loftus and Keating, here is the message directed to the fire floor, along with its rationale:

> Message to the affected area. When a fire is reported on any floor, once the elevator message has been sent, several other messages need to be transmitted. The occupants of the fire floor, most importantly, need to be told the facts and instructed where to go. The adjacent floors need to be cleared, and thus their occupants also must be given instructions. And, finally, a message must go to the "receiving" floors, the floors to which these occupants will be sent. For illustrative purposes, we describe the messages that are sent when a fire is reported on the 12th floor.
>
> The messages—Message to fire floor and floor below (12th and 11th)
>
> Alert tone—"May I have your attention please. May I have your attention please. There has been a fire reported on the 12th floor. While this report is being verified, the building manager would like you to proceed to the stairways and walk down to the 10th floor. Wait on the 10th floor for further instructions. Please do not use the elevators, as they may be needed. Please do not use the elevators, as they may be needed. Please do not use the elevators, but proceed to the stairways."
>
> Message to fire floor. The message tells the occupants (1) what has happened, (2) what they are to do, and (3) why they should not use the elevators. Some important aspects of the message are the following:
>
> (1) As stated in the rationale for the elevator message, "May I have your attention please" is

used instead of "Your attention please" because it sounds less panicked.

(2) All essential instructions are repeated twice: two times it is pointed out that the occupants should proceed to the stairways, that the 10th floor is the place to go, and that the elevators should not be used.

(3) Relatively common words are used. Research has shown that high frequency words, or words that are used commonly, are more easily understood, and this empirical finding has found its way into the Human Engineering Guide to Equipment Design (1972) which states: "Other things being equal the more frequently a word occurs in everyday usage, the more readily it is correctly identified when transmitted over a speech communication system"; and later recommends: "use familiar words rather than unfamiliar ones."

(4) The word "evacuate" is never used, since it may mean to some of the occupants "leave the building." Occupants of the fire floor, most importantly, need to be told the facts and instructed where to go. The adjacent floors need to be cleared, and thus their occupants also must be given instructions. And, finally, a message must go to the "receiving" floors, the floors to which these occupants will be sent.

(5) A rationale is given for why the elevators should not be used, making it less likely that occupants will attempt to use them. Loftus and Keating also take up the qualities of the voices to be used in emergency communications, as follows:

*The recommendation.* It is recommended that the emergency announcement be introduced by a female voice and that the instructions themselves be delivered by a trained male voice which is authoritative, calming, and not concentrated in the bass range.

*The rationale.* Psychological research suggests that switching from a female to a male voice will be noticed even when people are not really paying attention. Such a switch will get through the "attentional barrier" of occupants who may be absorbed in their work, in conversation, etc. The introduction of a female voice after the signal is dramatically different from the male voice that typically announces the warning. In our opinion, this difference would eliminate even the small possibility of such "false-alarm behavior" particularly since the signal is only used to tune people in to the information that follows the signal. The instructions that are delivered should be clear, instill confidence that the communicator knows the situation and knows what should be done, and that the directions will be followed. At this stage in our society males are stereotypically looked to as the ones who take charge in an emergency. Using this stereotype, a male voice was recommended for the bulk of instructional delivery. The voice should be trained, exercised in the use of clear diction so that the information will be received clearly. The voice should be calming since in most situations the avoidance of panic will be at least as important as the rapid dispersion of occupants from troubled floors.

A higher range male voice is recommended since the majority of the message delivered by such a voice will reside in the 1000+ Hz range; this range is considered to be a more easily understood range of voice delivery.

These recommendations should be regarded as tentative. Much more research needs to be done on the psychological aspects of voice instructions as given to groups of people under emergency conditions.

## 3.4 REPRESENTATIVE COMMUNICATIONS SYSTEM FOR BUILDINGS

In order to fully understand the overall functioning of a communications system we will examine a representative voice communications system which incorporates many of the just mentioned characteristics. A system which incorporates these concepts is the Seattle Federal Building in Seattle, Washington.

The Seattle Federal Building control room was designed to handle routine building management security and fire emergencies, using a Honeywell Alpha 3000 system. At the first indication of fire the system has several automatic responses:

a. A message is sent to the fire department.

b. A silhouette of the building lights up, pinpointing the exact origin of the alarm by device type and location.

c. A tape is automatically queued up and played which announces instructions over the public address system, directing occupants away from the fire area to safety havens.

The system also is able to:

- Capture all elevators in the building and play a tape telling passengers that the car is being returned to the main floor for possible fire department use;
- Automatically control the air handler system by shutting it off in the fire zone, increasing the pressure on other floors and stairwells for effective smoke control and flooding other floors with fresh air;

- Sound the alarm in the control room, print out alarm information (by device type and location), queue up and display a slide of the floor layout and other emergency instructional information;
- Record all emergency conversations for future reference;
- Provide a written record of the alarm by printer (all fire information is printed in red to distinguish it from routine maintenance information);
- Display the status of all mechanical fan systems;
- Provide redundant digital display of alarm point and condition.

In addition the system acts as a communications center, allowing a man at the console to confer with personnel at the fire and at emergency stations on each floor. Each time a station is activated its coded identifying number is flashed on a panel and the communications operator establishes his link with the station by dialing the coded number. In addition, there are telephone jacks at each floor in the exit stairwell so that fire department personnel can contact one another via hand telephone.

The main features of this audio communications system include:

- A constant voice link between emergency call stations and the central console for fire and other emergencies;
- Public address capability between central control console and speakers in the building;
- Automatic electronic testing of all speakers and manual and automatic announcement amplifiers at predetermined times.

Automatic responses in audio communication include: a status display annunciator of the prerecorded announcement system indicating the message being queued for playing, the main message played, the secondary message played, and requeuing for a repeat announcement.

The system also triggers special automatic recording equipment which keeps a permanent record of all communications both to and from the control center.

In addition, there are several manual responses to the audio communication system signal which the central operator may perform. He may communicate with building personnel by calling any reporting station. He may also select and monitor any of the announcement channels and make manual announcements on a microphone at the console to any floor, elevator group or the entire building. Through the control center operator, trained fire fighters can join with the building occupants and be in constant communication with all areas of the building during the emergency.

In the Seattle Federal Building, a special room is devoted to the command center. The communications system extends 25 feet and includes 7 major panels of information, 2 teleprinters and a cathode ray tube/keyboard display for master control. Not including all of the dials and gauges, there are 12 visual display panels, all with separate information. The center is manned 24 hours per day, but only by one operator per 8-hour shift. Although much of the system is automatic, in times of severe emergency (such as a major building fire), manning the control center would take more than one operator.

In the next chapter, we will examine some of the physical design problems encountered in a voice communications system such as the one described.

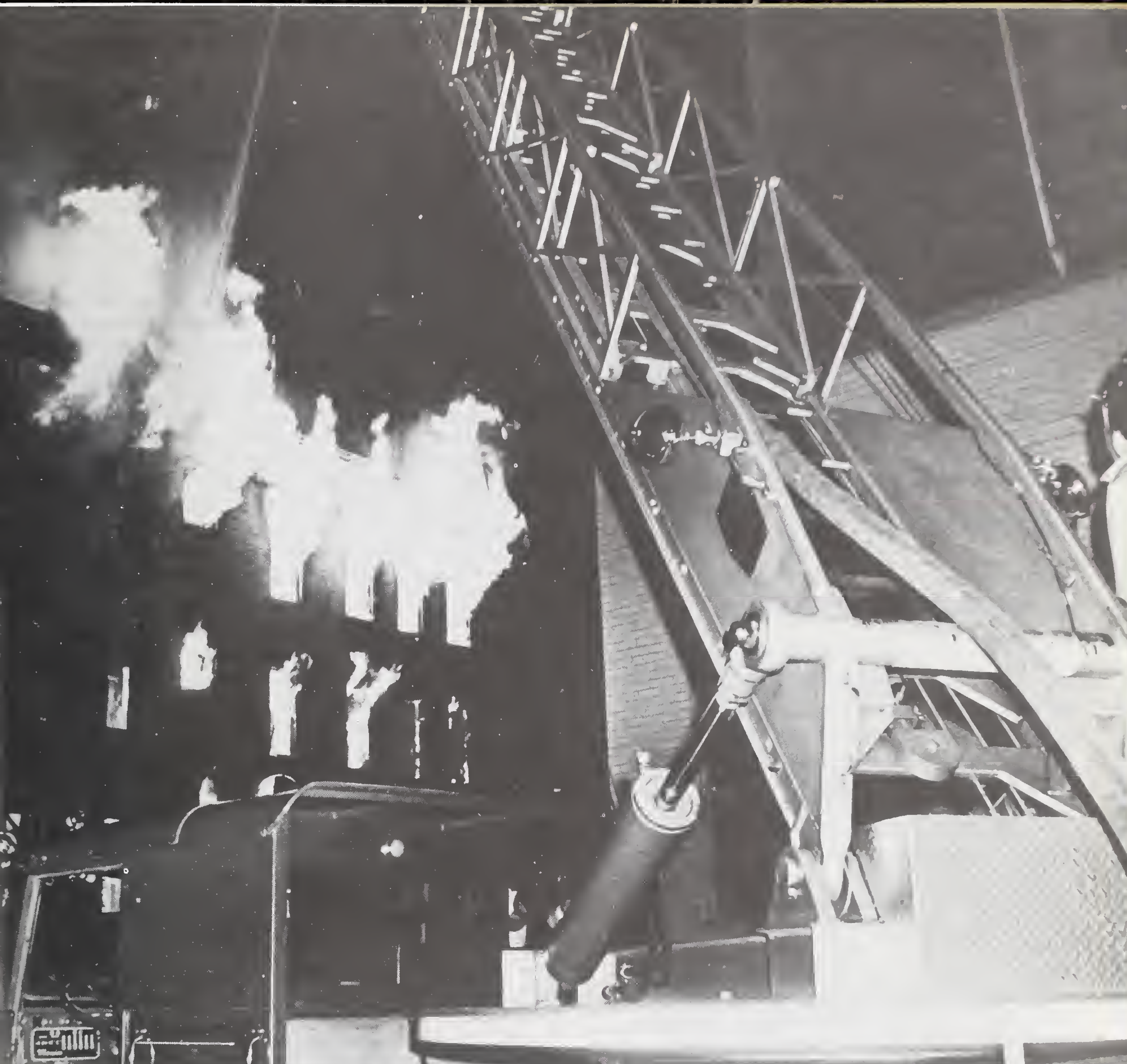
## 3.5 CONCLUSION

We have examined a variety of purposes of voice communications and have seen that in general:

- Communications can be one-way from the control center to the building occupants
- Communications can be two-way between the building occupants and the control center
- Messages may be live or recorded.

In summary, the voice communications requirements of the messages are:

1. The messages should be tailored to the particular requirements of the building.
2. The messages should be developed jointly with the building manager, building staff, and the local fire department.
3. The messages should be pre-recorded for all anticipated emergencies.
4. The messages should be automatically triggered by any of the automatic or manual fire alarms.
5. The messages should be audible above building "background" noise.
6. The messages should have a distinctive tone to get people's attention.
7. The messages should use common words which are easily understandable.
8. The messages should be informative to the occupants in the emergency so as to reassure them and prevent them from getting overly excited.
9. The messages should warn building occupants to use stairwells rather than elevators.
10. Control operator should have the ability to override all automatic conditions.



# 4. COMMUNICATIONS REQUIREMENTS

Any communications designed for fire safety must be in accord with a systems framework to be effective.

By "systems framework" or "systems approach" we mean that the design of the communications system must be integrated into the functioning of the whole building. In the past equipment designers followed a piecemeal design approach in which each functional element (subsystem) of equipment was designed separately, with little regard for the inter-relationships with the other subsystems. The systems approach is the designing of a *total* system that creates a complete design all at once, with an attempt to anticipate all functions that the system might be called upon to perform, and allows for all necessary inter-connections between the subsystems for carrying out the more complex functions.

This chapter elaborates further on this approach, using as a vehicle a number of highlights from studies directly relevant to the issues considered here.

The earliest extensive use of the systems approach began with the planning and operations of the military after World War II, and has continued to the present. The space programs have also been identified with use of similar procedures since the establishment of NASA. More recently, law enforcement as well as fire protection agencies have made increasing use of systems procedures developed and refined by the other organizations.

The most common image that comes to mind when thinking of a system is a command and control center containing an abundance of communications devices—visual and auditory "black boxes" and sophisticated control panels. Such centers have been widely employed by the military and have had widespread exposure on television during the various space missions—especially the lunar exploration program. It is these that are now employed in high-rise buildings.

## 4.1 HUMAN FACTORS—SYSTEMS ANALYSIS

The authors have indicated in this paper the importance of formulating a systematic approach to our problem. In an earlier study (Rubin and Cohen, 1973) it was noted that human factor investigations provide a model that could be applied to fire safety problems. Also, a number of suggestions were formulated concerning the topics that should be pursued.

The first stressed that the occupant needs to be considered as a component in a safety system, not merely a passive observer. The roles of the occupant, as well as of others engaged in fire safety, such as managers, police, and fire fighters, should be explored. Parameters such as building type, size and location need to be examined as they relate to the design of safety systems. Individual characteristics such as age, health, sex as well as social and institutional roles should be investigated. As progress occurs in this long-range investigation, we will be better able to pinpoint the needs for additional information.

Finally, by employing a systems analytic viewpoint at the outset, we established as an early goal the development of a comprehensive viewpoint which is in itself of major importance in the formulation of an integrated program—especially one that is just beginning. This framework can then be continuously revised while more information is developed during the program. There will be a constant awareness of the need for maintaining an overview of the occupant safety research being performed in order to establish meaningful research priorities.

In the past few years considerable attention has been devoted to fire problems in high-rise structures. There is a growing consensus among designers and operators that total evacuation of such buildings is not feasible and that, therefore, alternative safety approaches must be developed. These approaches, especially when combined with partial evacuation, have highlighted the importance of effective communications in building safety. Buildings are being conceived of as being complex systems requiring communications networks to ensure the safety of occupants. During fires, instead of general alarms (which transmit essentially the same message to all), many different types of signals could be employed, each consisting of a unique set of instructions to a particular group of people. The military has used command and control systems for many years, and it appears that high-rise buildings should be serviced in the same way. GSA has employed this concept in new buildings in Seattle and Atlanta. However, these buildings can at best employ the current state-of-the-art with respect both to hardware technology and to what is known about how people respond to signals during emergencies. Unfortunately, the available information is not particularly good and, in many instances, its applicability to fire safety problems is questionable.

The adequacy of any communications system is based on several factors, among them:

- The availability of hardware to transmit (and sometimes receive) messages.
- Information concerning *which* messages should be transmitted.
- Information concerning *how* best to transmit the messages.
- Information about the ability of the "audience" to correctly interpret and respond to the messages.

In designing a system to be used to transmit information *within* a building, we must first know what the requirements are. We recently completed a multi-year project on signalling systems and have become aware of the absence of good data on these parameters. It is our judgment that the state-of-the-art must be advanced in order to develop reasonable guidelines for designing systems of communications for building emergencies. We do not know what tradeoffs are feasible and must consider alternative visual systems, exploring such variables as color, intensity, flash rate (if any), and the interactions of visual and auditory systems. On the auditory side, we must examine voice and non-voice auditory signalling, various alternatives of wording messages, alerting signals (alarms) and complex messages. In addition, we must explore both feedback requirements, internal (within building) and external (to fire safety professionals). In short, there are far too many unknowns to be able to satisfactorily develop even rather simple systems, much less to take on the design of complex communications networks consisting of combinations of these systems.

## 4.2 MODES OF COMMUNICATING INFORMATION

There are several possible ways of communicating information. Each day our sensory systems are bombarded with an overabundance of information—so much so, in fact, that we must selectively filter through and select only that deemed most important. We continually receive information from our sensory world in the form of tastes, smells, touches, sounds and light. Of these, taste and smell play a smaller role than other senses in our everyday life. In a building, tastes and smells of smoke and the actual sighting of flames may sometimes provide the first alert to the presence of fire. In most instances, however, such information is transmitted indirectly by means of a warning signal, such as the sounding of an alarm. The most common warning signals (and by far the most important means of conveying information) are based on the visual and auditory capabilities of people.

As a result of the ways that the "eye" and the "ear" function (including their neural paths to and from the brain), there are advantages and disadvantages associated with each of these means of receiving and processing information (McCormick, 1957, p. 427 and 1976, p. 43). A number of these characteristics are listed below:

1. Stimuli may be either temporal or spatial in nature, or both. Thus, the information from the stimuli may be extended through time (temporal) or have a location in space (spatial). Some sensory stimuli can be constantly presented to an observer so that he can refer back to them if necessary. An example here would be an EXIT SIGN in a building.
2. The way that sensory stimuli reach an individual can be through sequential presentation (speech is an example) or simultaneous presentation (several stimuli presented at the same time).
3. Some stimuli have relatively greater flexibility in communicating information. Speech (auditory stimuli), for example, may contain information associated with emotions, e.g., fear, conveyed by the manner in which words are spoken.
4. Stimuli may also offer advantages in the rate of transmission of information to an observer. For example speech is limited to a "speaking rate" whereas visual information is much less limited, and can be readily coded as described later.
5. Certain stimuli, notably auditory and tactile (touch), are multi-directional and are therefore more easily able to break in on one's attention. Typical visual stimuli cannot easily break in on attention unless one's eyes happen to be open and looking in the appropriate direction.
6. Some sensory stimuli are less resistant to fatigue than others. Examples of this may be found in *visual* stimuli, where eyes become tired when engaged in a demanding task, or in *tactile* stimuli, where one is not generally aware of constant pressure—i.e., you normally aren't aware of your clothes once you've put them on.

Information provided by signals** may be classified by three separate problems:

a. Detection Problem—"Is something there?" or "Is something not there?"
b. Recognition Problem—"If something is there, what is it?"
c. Discrimination Problem—"Now that I know what it is, is it different from something else?"

This model can be applied in a similar way to building occupants and their detection of a signal:

**Detection Problem:**

Occupants must be alerted as to the presence of an emergency. The signal transmitted must be noticed by building occupants. ("Is something there?" or "Is something not there?"—the Detection Problem). People in buildings are engaged in many activities and surrounded by sights and sounds of all types. A warning signal must attract sufficient attention even though individuals may be focusing their attention elsewhere.

The signal must first be sensed. People are aware of only a portion of the total amount of signal energy present in the environment. (Among the waves normally present, but not sensed by humans, are infrared, ultra-violet, electric, magnetic, ultra-sonic, radio and x-rays.) In order to perceive, or sense energy, two conditions are necessary. (1) We must have a sense organ which is capable of detecting the *form* of energy transmitted, including the particular *frequency* of the energy, if it is in the form of a wave. (2) The energy must be of sufficient intensity so our sense organs are sensitive enough to perceive it. For example, for a sound to be audible, it must not only transmit an adequate amount of acoustic energy, but must contain frequencies roughly between 20 and 20,000 Hz (hertz=cycles per second), because the human ear does not respond to sounds outside this range.

**Note: For a more detailed discussion of information provided by signals, the reader is referred to Rubin and Howett (1978).

Similarly, a visible light must not only transmit an adequate level of radiant energy, but must also contain wavelengths roughly between 400 and 700 nanometers ($10^{-9}$ meter), because the average human eye responds only slightly to light waves outside this range.

To determine how much intensity a signal must provide in order to be detected, it is necessary not only to take account of the preceding considerations, but also to examine the conditions under which the signal is normally used. For example, in a very quiet building an alarm can be heard at great distances. If the same alarm were employed in the daytime in an industrial situation, many workers would probably have difficulty hearing it. Engineers sometimes use the concept of signal-to-noise ratio in explaining this type of situation. That is, the strength of the "signal" provides only part of the information necessary to predict effectiveness; it is also necessary to account for the level of "noise" where the signal is going to be used. "Noise" in this sense may mean background sound or it can refer to so called "visual noise"—the color, intensity and other characteristics of lights which make it difficult to distinguish signal lights from the other sources of illumination present.

In the instances of both lights and sound, when the intensity of the "noise" (background) is much greater than that of the signal, it is very difficult to detect the signal. The other critical factor in detection is the degree of similarity between the signal and the background. The more alike the signal and background are, the more difficult it is to detect the signal.

The signal must be noticed. The primary function of a warning signal is to interrupt the normal routine by attracting the attention of a person whose attention may well be focused elsewhere. It takes a signal of unusual impact to be successful under these circumstances.

Even if a signal is designed so it can be detected by building occupants, there is no assurance that it will be noticed. It is important to realize that in any large, relatively unselected group, such as building occupants, abilities vary over a considerable range. Some have permanently impaired senses due to age, eye or ear disorders, or brain damage. There are others who cannot be expected to respond appropriately because of temporary circumstances such as sleepiness, inattention, emotional state, intoxication, or influence of drugs. In the case of both the permanent and temporary conditions, people sometimes fail to see even the most obvious objects in front of them. We must therefore expect that *any* warning system that can be designed will fall short of 100% effectiveness.

**Recognition Problem:**

The signal must be correctly interpreted. Even after a signal has been noticed, the occupant must determine its meaning. ("If something is there, what is it?"—the Recognition Problem.)

Interpretation of the signal. Even after a person has noticed the presence of a warning signal, the job of communicating has just begun. The meaning of the signal must then be determined. Based on training, past experience and reasoning, the purpose of the signal will be judged and an attempt to anticipate the appropriate action will be made. The ability to interpret a signal correctly is based upon several factors. Perhaps the most important ones are the "message set" (the number of possible messages and their meanings) and the number of possible interpretations (degree of ambiguity). The more messages and interpretations possible, the longer it takes to react to a signal and the greater the likelihood of error. As an illustration, a driver has a simple task when he sees a traffic light and must respond appropriately. For the most part, the same signals are used throughout the country and they always have the same meaning. A driver does not have to spend time determining the meaning of a red or green light. The message set is usually limited to three at most—red, yellow and green—and the signals are free of ambiguity.

Contrast the traffic-light example with the fire warning-signal situation that currently prevails. As noted previously, there are no nationally "standardized" signals and consequently a signal is subject to a number of interpretations, depending largely on the personal experience of the individual. Little systematic work concerned specifically with the design of warning systems for any specific purpose has been performed, and therefore a builder has been largely free of restraints (except for code provisions, where they exist).

In the case of fire alarm signals, of special importance is the history or experience of occupants with past alarms that were "fire drills" as against real emergencies. Those that had experience only with fire drills are likely to assume that the alarm they hear is signalling "just another drill" and may not make the appropriate responses. Those people with previous experience in real emergency situations may be more likely to make the required appropriate response.

**Discrimination Problem:**

Deciding what to do and when to do it. Once the signal has been detected and recognized as a signal, the Discrimination Problem comes into play—"Now that I know what it is [e.g., a signal on a loud-speaker], is it different from something else [e.g., a fire emergency message as opposed to some other message]?" Once the signal is correctly interpreted, one must still determine proper response.

A number of alternative actions is likely to be open to the occupant, some of which may lead to safety and others may be harmful. Characteristics of the building (location of stairways) and clues associated with the emergency (presence of smoke) will naturally shape the decision. Additionally, people's previous experience will influence their decision.

Performing the action. Finally, the communications system is designed to have the occupant do something. The ultimate success of the system is largely measured by the behavior of building occupants attributed to the effectiveness of the messages transmitted by the system.

## 4.3 SYSTEM DESIGN

In designing a system to be used to transmit information within a building, careful attention should be placed on the coding of signals. The following section presents general information on the coding of signals. This information can be used to help design effective communications systems, both from the standpoint of the occupant (the "receiver") and the fire safety control operator (the "sender"). The information presented in this section comes directly from the Human Engineering Guide to Equipment Design, edited by Van Cott and Kinkade, 1972. The reader is directed to this excellent work for more detailed work on the coding of signals and the design of equipment such as a communications system.

### 4.3.1 Visual Coding

Inside and outside of buildings, man uses visual codes which warn him of danger or which convey information. Spots of color, numbers, letters, lines, arrows, lights, as well as color codes for wires and electrical resistors are used for these purposes. Most codes are symbolic and must be learned, but, once mastered, they can be an effective way of conveying information. On the other hand, poorly designed codes can cause confusion and accidents.

In general, visual coding can be accomplished by the use of: a) color; b) shape; and c) magnitude (Grether and Baker, 1972).

#### 4.3.1.1 The Use of Color

The total number of distinguishable colors is very large, but the number of different colors that can be used in any particular coding system is rather small, because people's memory for individual colors is vastly inferior to their ability to see differences between 2 simultaneously viewed colors. In general, the actual number of colors available depends on whether colored lights or colored surfaces are used. More saturated colors can be obtained with lights, but more coding steps can be obtained with surface colors (pigments or reflected colors). Surface colors are subject to serious perceptual distortion under certain types of illumination, whereas colored lights are not as easily affected.

In signals, the number of easily identifiable spectral colors depends on luminance, size (in visual angle) and color temperature of the lights.

Colored lights are often used in long distance signalling. In general, the longer wavelengths (perceptually appearing as whites, greens, yellows and reds) are used for long distance signalling because much of the visible light energy in tungsten lamps is in the longer wavelengths. The shorter wavelengths (which perceptually appear as blues or violets) are not used generally for signalling because the required filters transmit only a small percentage of the visible light in tungsten lamps. There are also special problems with using purples, which are mixtures of short (blue) and long (red) wavelengths.

For a more detailed explanation of the use of colored lights as signals, see U.S. Department of Commerce, National Bureau of Standards, Monograph 75: *Colors of Signal Lights; Their Selection, Definition, Measurement, Production and Use,* F. C. Breckenridge, 1967.

#### 4.3.1.2 The Use of Shape

Shapes can be used for coding information both for the occupant of a building and for the design of effective control panels for communications systems. There are, of course, an unlimited number of possible shapes, but in tests of geometric form learning and retention, the number of shapes is usually limited to a set of 15 (Grether and Baker, 1972).

Detailed information on shape coding including the use of numbers, letters and graphics can be found in Van Cott and Kinkade's Human Engineering Guide to Equipment Design, 1972.

#### 4.3.1.3 The Use of Magnitude

Information can also be coded by symbol magnitude (area or linear extent), luminance, and/or frequency by correlating it with some quantitative characteristic of the target.

The use of magnitude coding is fully described in Grether and Baker (1972).

An important use of signals and of some codes is to get the operator's attention so that he may make the appropriate decisions. There has been much work on vigilance which shows that alertness on a job tends to lessen as time passes during the work period. This problem is worse for low-probability signals and most warning signals have a low frequency of occurrence. To get an operator's attention, signals of high attention value are needed. This value increases with size, brightness, loudness or motion of a signal. Of course, a signal should not be so intense as to handicap the operator (i.e., through temporary blindness, etc.)

### 4.3.2 Requirements for Warning Devices—Visual

A good warning device should meet the following requirements (Grether and Baker, 1972, pp. 77–79):

1. It attracts the attention of a busy or bored operator.
2. It quickly tells him what is wrong or what action to take.
3. It does not prevent his continued attention to other duties.
4. It should not be likely to fail or to give false warnings. Failures of the warning device should be easily detected (such as by a press-to-test button).

   a. Group of Signals

   By grouping signal lights or mechanical "flags" in appropriate patterns the designer can help the operator to learn what is wrong. Such patterns make a different signal easy to detect. A pictorial pattern can be of even more help to the operator. By showing him the positions of switches, valves, etc., as part of a diagram, the effects of their operation are easy to see.

   b. Selecting Signals

   In selecting a warning signal for a particular application, the designer should consider the urgency of the message, the other duties of the operator, and the other warning devices in the station. Unimportant warnings make operators neglect critical ones; too many of the same type are confusing.

   Auditory signals should be used only for a few of the most urgent warnings. Such warnings, while attention getting and independent of visual control, can interfere with speech communication and may be less suitable for indicating what is wrong or what to do.

   Signal lights can tell the operator what to do by their location, labeling, color or other coding, but he must be looking in their general direction to notice them. Other visual signals, such as mechanical flags, have low attention values. They are practical for giving "on-off" types of information.

   c. Lights for Warning Signals

   A warning light signals a dangerous condition requiring prompt action by the operator. Such lights normally should be red because red means danger to most people. Other signal lights in the operator's vicinity should be of other colors. In addition, the location, luminance, and attention value of lights for warnings should be considered.

   d. Location and Identification

   Because warning lights become less effective as they are moved out of the center of the field of vision, urgent warnings should always be within 30 degrees of the operator's normal line of sight.

   Sometimes many warning or caution signals must be used in a single operator station. This situation not only adds to the operator's identification problem, but it also creates the problem of finding panel space near the operator's normal line of sight. The master light can be located near the operator's line of sight on the instrument panel, and the specific warning panel can be located where space is more readily available. Any time the master light comes on, the operator checks the specific warning panel. For very urgent warnings the master warning light may be supplemented by an auditory warning (Siegel and Crain, 1960). This is particularly advisable if the operator's visual duties could cause him to miss the master light.

   Because warning lights call for fast corrective action, their identification must be simple and positive. Ideally, each light should have a unique location and be easily distinguishable from other lights. As a further aid, the warning light may be near or built into the associated corrective control device.

   e. Intensity

   Warning lights should be bright enough to stand out clearly against the paneling on which they appear under all expected lighting conditions, but they should not be so bright as to blind the operator. In work stations that are darkened at night, provision should be included for dimming the warning lights when other lights are dimmed; this can be accomplished by "tying in" warning lights with the same control used to dim panel or general station lights. In this way, the proper level is provided automatically.

In the design of a communications system control panel care should be taken to follow the above recommendations. For more detailed information on such design parameters as the: lighting of words, size of lettering, attention value and general design recommendations, the reader is referred to Van Cott and Kinkade, Human Engineering Guide to Equipment Design, 1972.

#### 4.3.3 Requirements for Warning Devices—Auditory

The preceding discussion on visual devices centered on the control module and the operator. However, from the occupant standpoint auditory signals are often used as alarms and warning devices to call attention to an urgent situation. Deatherage (1972, p. 125) has suggested design recommendations for alarm and warning systems:

> For the selection and design of signals for alarm and warning, the following principles should be observed . . .:
>
> 1. Use sounds having frequencies between 200 and 5,000 cps, and, if possible, between 500 and 3,000 cps, because the human ear is most sensitive to this middle range.
> 2. Use sounds having frequencies below 1,000 cps when signals must travel long distances (over 1,000 ft.) because high frequencies are absorbed in their passage through the air and hence cannot travel as far.
> 3. Use frequencies below 500 cps when signals must bend around obstacles or pass through partitions. High frequencies cannot pass around or through solid objects as well as can low ones.
> 4. In a noisy environment, use signal frequencies as different as possible from the most intense frequencies of the noise. In this way, the masking of the signal by the noise is reduced to a minimum.
> 5. To demand attention, use a modulated signal, such as intermittent beeps repeated at rates of 1 to 8 beeps per second, or warbling sounds that rise and fall in pitch. Such signals are seldom encountered in a normal environment and are different enough to get immediate attention. If important speech communications are likely to be necessary during the alarm, use an intermittent, pure-tone signal of relatively high frequency.
> 6. Use complex tones rather than pure sinusoidal waves, if possible, because relatively few pure tones can be positively identified, whereas there are a very large number of complex sounds that can be identified because each such sound is noticeably different from the other sounds.

### 4.4 PERSONNEL REQUIREMENTS FOR OPERATING THE CONTROL CENTER

Due to the highly sophisticated nature of manning a control center, a new problem has arisen concerning the training of operators. No longer can a semi-retired night watchman be relied upon to maintain such a system. Instead, these systems require well-trained and well-paid operators, since ultimately the system is only as good as the decisions of the console operator. Thus, it should be realized that the job of console operator is a highly technical and skilled position, only the most competent operators should be selected, and they should be reimbursed accordingly.

Kryter (1972) has done extensive work on personnel selection and training for communications systems.

Kryter (1972, p. 219) suggests that:

> A combination of heavy information loads and poorly trained personnel can be as hard on system performance as are noise and distortion. Successful communication depends on vocabulary, message set size, and degree of standardization, as well as familiarity with message and equipment. These factors in turn depend on selection and training of operators. Large differences in fundamental intelligibility among individual talkers and listeners tend to persist even through practice and training, although proper training can improve performance.
>
> Personnel working in high noise fields, or with communications equipment that itself adds noise, are apparently able to hear and understand messages the novice finds completely unintelligible. They have learned to identify the slight differences that exist between speech and noise. The same applies to persons using speech compression systems where certain distortions are introduced into the speech signal.
>
> ...It is not wise to rely only upon training as a method for improvement unless there are severe cost, channel capacity, or time constraints. Not only may relatively untrained users be required to operate the communications systems from time to time, but the "margin of safety" for satisfactory communications on the part of trained observers becomes dangerously small.

### 4.5 OPERATION OF THE SYSTEM

#### Automatic vs. Manual

A major problem in selecting or designing present communication systems is identification of the proper "mix" between manual and automatic modes of operation. Due to the variety of tasks an operator must perform at the critical time of an emergency, he may be overwhelmed with too many tasks, especially if he is also to act as a link between the building communications system and the fire department. At the other extreme, many communications-fire safety systems rely on what has been termed an "automatic first-mode condition." That means that whenever a fire emergency exists, the computer automatically performs several functions, such as sounding alarms and bringing elevators to the lobby floor. In some existing and proposed systems this automatic mode includes the cueing of pre-recorded messages to be played on selected floors, the message transmitted depending on the location of the fire.

While automatic playing of messages was designed to save lives, it may in fact cost more lives than it saves. Consider the following hypothetical situation: a fire has started on the 10th floor of a building, but because of the building design and placement of the smoke detectors, the smoke has drifted up the ventilation system and triggered a detector on the 12th floor. The system "perceives" a fire on the 12th floor, and automatically directs the occupants of the 12th and 11th floors to evacuate down to the 10th floor. There is now a situation where the wrong instructions have been given and the people on 2 floors will actually be moving into the fire, rather than away from it to safety.

Perhaps a better design would include a period of delay of a few seconds operator to determine at least whether any other warning devices on other floors are triggered before he decides on appropriate actions. Enabling an operator to override any automatic system is essential if his role as a decision maker is to be effective. Regardless of the amount of planning that precedes the design and installation of automatic communications systems, it is not possible to predict all possibilities. As a result, provision must be made for emergencies which were not anticipated. Past experience, such as that gained during the NASA program, demonstrates that a well-trained person permitted to make a decision and act on it provides this critical safeguard.

#### Separate or Combined Systems?

Should a fire communications system be maintained as a separate system, or combined with existing public address systems? Table 2 summarizes the advantages and disadvantages of each approach:

**Table 2. ADVANTAGES AND DISADVANTAGES OF SEPARATE VERSUS COMBINED SYSTEMS**

| | Advantages | Disadvantages |
|---|---|---|
| SEPARATE SYSTEM: | Easily monitored<br>Easily maintained | More expensive |
| COMBINED SYSTEM: | Less expensive | Speakers may be inadvertently turned off<br>Complexity |

Although a combined system is less expensive to install and operate, it has the distinct disadvantage of also being more complex and hence more difficult to service. A combined system also allows the possibility that some building tenants may turn off their speakers because they don't want to hear the background music. Depending on specific requirements, either approach offers an increased level of life safety over the traditional fire-bell approach.

### 4.6 PERFORMANCE CRITERIA

Ehlers (1972, p. 23) drew the following conclusions from his investigation of the problem of fire safety communications:

> The communications systems we have discussed require no major departure from techniques currently available today, but, rather, only specific applications. The major problem lies in a definition of performance and operating criteria. What you must decide, like any other use of communication, is what features are needed to do the job. Then, I think, you will find the communications industry ready, willing, and able to provide system applications.

He said criteria to be specified should be on a performance basis, rather than trying to choose the medium of transmission and type of hardware. With the state-of-the-art in the communications industry changing so rapidly, Ehlers continued, hardware oriented specifications would require constant updating to take advantage of technical advances. He added that some systems not practical today might well be the most economical tomorrow.

He also pointed out:

> There has been much concern about the ability of these systems to self-detect line faults as to assure working order when required. Fault detection, either by scanning or constant monitoring is available, but don't forget that they check the transmission media only. The only true test is an actual operating test that also checks the end equipment where most troubles occur.

Few major cities in the United State require any type of tenant alerting system for high-rise buildings. But Ehlers cautioned, even though the existing systems might not be ideal, where building codes required such communications—there only did they in fact exist. Also, authorities in the major cities did not necessarily agree on the parameters for these systems. Therefore, he said, there had been little incentive for the communications industry to develop a system which might not be acceptable in the next municipality. Ehlers concluded that "to assure significant and continuing involvement of the industry, we must look toward not only local solutions, but some reasonably well-defined nationwide standards in the area of communications."

## 4.7 PHYSICAL DESIGN PROBLEMS

### 4.7.1 Transfire Capabilities

One of the major physical problems of emergency communications systems is that the control center is typically tied to all sensing and communications devices via hard wire cables. Many of these cables do not have transfire capabilities, that is, they do not function properly when crossing through parts of the building that are on fire. Thus, if a fire takes place at mid-height of a building, communications must remain open to those people in refuge areas above the fire.

Methods exist to solve this problem. Redundant communications lines could be placed in separate locations in buildings as was done in the new GSA Seattle Federal Building. Unfortunately, this system is still vulnerable in a severe fire, and the duplicate wiring greatly adds to the cost. One alternative design is a wireless system using radios.

Of course, there would be many additional problems imposed by use of such a system. For example, due to the density of building materials, antennae would have to be placed throughout the building. Other difficulties might be encountered. If there were several buildings in close proximity, radio signals from one system could be picked up in another building.

An alternative to a wireless system is a telephone system with fire resistant transmission lines separated from the regular communications conduits. Clearly, more research is necessary before any such system becomes viable.

Another equipment problem centers around the use of tape recorders for sending automatic messages to building occupants. In the Seattle Federal Building the tape machine automatically queues the appropriate messages, and plays them. Unfortunately, the selector unit is quite complex and prone to breakdowns. Most control centers do not have backup tape decks.

Also, if the unit does fail (in the Seattle building), the control operator would know only after a minute or two because there is no warning or trouble signal for the tape unit on the control panel. There is, instead, a series of five buttons; each lights up in turn indicating the message being played (i.e., message to fire floor, message to receiving floor, etc.); if the tape recorder malfunctions, the light remains lit in lieu of turning on the next light. Thus, in an emergency, the control operator is under severe pressure and perhaps too busy to notice that one of the many panel lights was on too long.

To overcome this problem in part, the messages are purposely shortened to no more than 90 seconds. The control operator can, at his option, patch in and listen to the message as it is played. An important remaining difficulty is that he is able to listen only directly through the tape unit and, thus, has no assurance that the message is being played over the appropriate floor intercoms. This problem was further compounded in the GSA Portland, Oregon Building, where a four-channel system was selected, so that four messages could go out at the same time. Now the control operator cannot listen to all the messages since they are being played simultaneously.

### 4.7.2 Equipment Malfunctions

Elaborate communications systems presently rely heavily on the use of slide projectors and tape recorders. Slide projectors often serve to continuously display floor plans. Most have only a standard projection bulb which may burn out. Certainly, one margin of safety in this regard would be to have a "hard copy" of all slides available in the control center for easy access. Similarly, backup provision for the various tape recorded messages should also be made, in case the primary tape recorder malfunctions. There is also the possibility that the wrong tape may be selected and played automatically. In most systems, at present, the control operator does not know that the correct message was received on the appropriate floor, since he can only monitor the tape playback in the control center, rather than the speakers on the affected floor.

### 4.7.3 Psychological Aspects

Other problems dealing with verbal messages are related to their psychological aspects.

One issue is: How loudly should the message be broadcast? In view of the lack of research into this area, it was arbitrarily decided in the Seattle Federal Building to make the message at least 25 dBA above ambient room noises. At present the ambient room noises are estimated to be about 65 dBA; yet these measures may be totally inaccurate. Assuming them to be reasonable, the speakers should be broadcasting at approximately 90 dBA. This means that the level is the same everywhere in the building, including maintenance rooms where heavy machinery might be operating, so that 90 dBA might be totally inadequate for the perception of speech, or even for awareness that a message was being broadcast.

In the Seattle communications system there is only one volume control knob for the entire building. A single knob for volume control allows for the possibility of human error. If someone accidentally turns the volume sharply down (located on the console), without the control center operator being aware of it, he might notice that the tape recorder is working and following the appropriate sequence; yet no message will be heard on any of the appropriate floors, and great loss of life could ensue, all due to a single, inadvertantly turned down knob. In addition, since the knob is not calibrated, it is unlikely that the knob was in the same place and that the actual voice level was still set at 90 dBA a year later.

As noted earlier, when a fire alarm sounds, the elevators are automatically captured and brought to the ground floor for fire department use. In the Seattle building, this means capturing 22 elevators and returning all of them to the ground floor. Under the present plan, if a fire breaks out on one floor, the floor above is evacuated and the occupants of that floor move up another floor. The rest of the building is undisturbed, unless, of course, the fire becomes more severe. However, all occupants of the building would be affected as soon as they tried to use elevators that did not respond. Undue anxiety would arise, since the individuals involved would realize there was a fire emergency, but not know where. In such a situation it is possible that one person tells a few fellow workers, who might then head for the nearest stairwell, creating problems should they accidentally choose the wrong exit pathway. Since this system was originally designed to prevent mass egress and the confusion associated with it, warning messages should sound on all floors near the elevators, explaining that the elevators are in a fire mode. In some buildings, all floor fire wardens are notified in emergencies and are supposed to station themselves in the elevator lobbies to discourage use. This procedure has obvious limitations, since now the occupants will be extremely alarmed, but helpless to deal with the situation.

## 4.8 CONCLUSIONS

In the design of any Vocal Alarm System it is especially important to consider the "systems approach" since the system must be integrated into the functioning of the entire building.

The specific needs and abilities of building occupants in times of emergency must be carefully considered. Attention must be paid to the specifics of coding signals, and the appropriateness of the code to the detection of the signals.

A designer of a vocal alarm system must consider the proper "mix" between manual and automatic vocal alarm systems. The training of systems operators also becomes important.

Decisions about separate "dedicated" vocal alarm systems versus combined systems which combine general public address or background music and emergency systems, must be made with care.

The physical design of a vocal alarm system should also be carefully planned to avoid some of the problems outlined in this chapter.

In this chapter, we have briefly touched on many elements which should be considered in the design of emergency command and control systems. The review is strictly a cursory one. Those actually designing their own system should refer to the Human Engineering Guide to Equipment Design (Van Cott and Kinkade, 1972), for a detailed explanation of any of the topics mentioned in this chapter.

# 5. STUDIES OF FIRE SAFETY: THREE EXAMPLES

We indicated earlier that good information on fire emergency communications is difficult to find. One source of such information consists of investigation reports by the Fire Analysis Department of the National Fire Protection Association (NFPA). One report reviewed in this chapter deals with a fire in the World Trade Center, New York, in 1975 and is of special relevance in the present study. The fire occurred in a modern high-rise building equipped with a state-of-the-art control center. The investigation highlighted a number of problems involving effective communications in building fire emergencies. Also, the procedures employed to document the emergency offer insights into some of the difficulties encountered when seeking viable information on fire communications.

A second example is a study conducted by Pauls (1974) to obtain quantitative information regarding the time required to evacuate buildings. The study was carried out as a fire drill and was used to elicit questions about the relation of simulated emergency behavior to actual emergency conditions.

A third example we will examine is a study designed to explore the use of visual signals (signs) as a means for directing people to safety during fire emergencies.

## 5.1 WORLD TRADE CENTER FIRE

The World Trade Center has two 110-story buildings. A fire occurred in one of the buildings April 17, 1975 causing some smoke on floors 9–22. The fire was quickly contained and the occupants were in no danger. However, many saw the smoke and ignored repeated requests over the loudspeaker systems to return to their offices. Finally, due to the resulting confusion, floors 9–22 were evacuated.

From the experience of this fire emergency it is evident that the sophisticated communications network did not accomplish the purpose for which it was designed. People did not behave in accordance with the fire safety plan; they did not respond appropriately to the messages which were sent to them.

Why not?

There are plausible reasons, although without a systematic study it is not possible to give any assurance that they are correct.

The communication system in the building provided only one source of information to the occupants—a "formal" or official one. However, the occupants of the building also received information in another, and much more direct form—namely the appearance of smoke in many lobbies. It is reasonable to infer that there were also conversations among building occupants concerning the two sources of information: discrepant announcements to "return to your office," accompanied by the presence of smoke. Such verbal exchanges of interpretations are also likely to be an important influence on behavior. Under these circumstances, it would be no surprise if many occupants were in conflict, seeking to determine whether their actions should be governed by the official announcements or by the evidence of their own senses. Since part of the folklore experience may be summarized in the cliche, "where there is smoke there is fire," this "message" no doubt had more impact than the verbal instructions which constituted the formal communication.

Unfortunately, these issues were not addressed in the follow-up investigation conducted by the NFPA after the incident. Let us consider a number of generally recognized problems associated with field investigations of emergencies and disasters.

Killian and Turner (1957) note that when significant psychological and sociological variables are analyzed for their effect on behavior during and immediately after a disaster, special methodological difficulties arise.

The first and most important constraint facing the researcher is his lack of control over the situation that he is studying. The fact that the research is *post hoc* rather than a result of careful preparation makes the timing of of data collection critical. The investigator must be on the scene as soon as possible if he is to obtain valid first hand impressions of what happened during the disaster. Two factors often seriously impair the validity of findings obtained long after the event. The first is the general tendency of memories of events to become less clear with the passage of time. The other is the tendency of people experiencing the same major event or disaster to compare impressions until there is a general consensus as to "what really happened." This process introduces biases because of the dominance of some people and the susceptibility of others to such influence, i.e., reluctance to express a minority viewpoint.

Also, in a *post hoc* disaster study, the population is not in, and probably will never quite return to, its normal pre-disaster state. Any analysis of the sociological and psychological characteristics of the population *before* the disaster must be made now in retrospect. That those who did not survive, cannot tell their stories, can create a wide gap in the data on survival behavior.

In a report entitled "The Occasion Instant," Baker and Mack (1960) explored behavior during situations where unanticipated air raid warning signals were sounded. They found "false alarm behavior" among people in situations where the signals were real ones. They concluded that hearing the warning signal alone is totally inadequate to stimulate people to immediate protective action. Most people sought additional information to validate or refute the meaning of the original signal. The sources of verification were usually informal and unofficial. Baker and Mack imply that the signal may well need to be interpreted during the event to guide people to an appropriate response. They note further that the organizational context is the most important factor in eliciting the correct response. That is, if the boss issues an official directive in a place of business to perform an action, then people act despite their attitudes, for fear of sanctions.

In summarizing their findings, they note that in an emergency a series of factors must be considered. The receipt of a warning message is treated in the context of the overall situation as evaluated by each person. Objective reality is but one factor in this evaluation, past experience with the same signal must also be considered. The interpretation also depends largely on observing how others in the environment behave. The response of people in positions of authority is another strong factor. The type of group present at the onset of the signal is important. Being with one's family adds to the likelihood of taking a signal seriously. A person's educational status has also been found relevant. Those with middle level educations are more likely to respond appropriately than people with low or high level schooling experience.

The nature of the organization is another important factor. Signals received in a large and complex organization are more likely to be believed than those occurring in a smaller institution. Finally, those who perceive the specific environment as a threat are more likely to believe a warning signal than are others.

**Follow-Up Activities**

What follow-up activities occurred at the Twin Towers fire? In order to determine the conditions on the individual floors, a survey form was given to all involved fire safety team members at their next meeting.

The method used to collect this additional information, the particular questions asked and, more importantly, those not asked, provide some insight into the weakness of the data base concerned with occupant safety and communications in building fire emergencies.

The questionnaire was administered "at their next meeting," rather than at the conclusion of the emergency, and so the results were affected by the time elapsed. (This procedure indicated little or no awareness of the factors mentioned by Killian and Turner.)

The information was developed exclusively by means of input from the fire safety team members. Individuals affected by the fire, but not associated with the team, were not questioned. As a result, a major potential source of information was ignored.

The questions do not directly address the problems found in the investigation report. There was no attempt to identify most of the actions of people nor the nature of the communications received, how they were interpreted, and the reasons why the people acted as they did.

Because of the follow-up procedure, it is difficult to determine how similar problems might be avoided in the future. *The nature of the problem(s) is still not understood.* Perhaps one solution would be the development of a "universal" fire emergency questionnaire which could be administered at the conclusion of an emergency. Similar and more elaborate suggestions have been made by Glass and Rubin (1978b).

## 5.2 FIRE DRILLS AS A SOURCE OF DATA

One can never be certain that a situation is truly stressful for the subjects because this evaluation is highly subjective. Stress research in most instances has been performed in university or governmental laboratories using rather sophisticated volunteer subjects. Under these circumstances an awareness exists that a situation which appears to be dangerous is actually simulated.

The relationship of behavior in fire drill situations to real emergencies has been discussed by several investigators and views differ as to the degree of "carry-over" from one to the other. These investigators especially cite case studies concerning the usefulness of drills in school situations. Evidently, there is no simple way of assessing such practices—they depend on the circumstances, the people involved and many other factors. J. Pauls, as stated earlier, has investigated the problem of building evacuation since 1968, by means of a number of carefully conducted investigations. His work, although in the nature of simulated emergencies rather than actual fire situations, has contributed data which have important implications for fire safety design. Pauls' findings have seriously questioned the design criteria for exit stairwells by documenting how they are actually used by people, as against assumptions based on data from related situations.

In one study, Pauls examined the use of a modern voice communications system in a rather complex movement of people. He describes this study as follows:

> 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 29-story office building in which the 3rd floor was considered to be the fire floor. The evacuation sequence was to be 3rd floor, 4th floor, 2nd floor, 21st floor, 20th floor and so on down to the 5th 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 2,100 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 3rd 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. This 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 2,100 evacuees as well as information about their behavior during the exercise. For example, 17 percent reported interpreting the situation as a genuine fire emergency when they first heard the fire alarm; but after the ambiguous public address announcement 42 percent 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 3rd 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 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.

If Pauls' suggestions are adopted, significant human behavioral information could be derived from each such emergency, so as to better protect ourselves in the future by avoiding mistakes in the past.

## 5.3 VISUAL COMMUNICATIONS AND SYSTEMS

Our third example of a fire safety study concerns another aspect of communication—namely a visual "signal" or sign.

J. L. Bryan conducted a study designed to investigate a fire at the Arundel Park Hall in Brooklyn, Maryland, in January 1956. The fire occurred during an annual oyster roast, with an estimated 1,100 to 1,200 persons occupying the hall. As a result of the fire, 11 persons were killed and 250 injured. The investigation (Bryan, 1956) which consisted of interviews of people present at the fire, included a question posed to 38 people: "Did you notice if any of the doors had exit lights over them?" Bryan determined that: "Only 1 person stated that he knew the exit lights were on... 2 persons did not know, and 2 persons thought the lights were on, while 33 people said they never noticed"—including the 8 firemen or policemen questioned.

It is easy to fall into the trap of equating communications requirements in building fire emergencies with auditory signals; and in more recent times to sophisticated control centers. "Communications" in the present paper is, however, defined broadly as methods which are (or could be) used to provide information to building occupants which enable them to avoid injury in fire emergencies. As stated by Bryan (1956), some information should be conveyed by exit signs—perhaps the most widespread method of conveying safety related instructions in buildings. Signal lights, signs, alarms, voice communications systems, and verbal instructions by wardens constitute only some of the methods usable in devising a safety plan for building occupants.

It is especially important to consider communications in terms of the *overall objective*—the safety of building occupants in fire emergencies. This is best accomplished by means of a systems analysis perspective. The systems analysis approach has been explored in some depth by the General Services Administration (GSA)—and includes many aspects of fire safety, some of which directly concern the occupant. This overall approach does include many engineering and design issues which are beyond the scope of the present paper. The system of concern here is one which may be defined by the informational needs of occupants when faced with a building fire emergency. These requirements largely cover the subjects of:

- What to do (or not to do).
- How to do it.
- Providing assistance to accomplish the required actions.

For example, in the event of a fire, verbal instructions may indicate that people on the fire floor are to proceed to the exits, go down stairs to the floor below and await further instructions. In this illustration, occupants are told *what to do* but may need guidance in carrying out the required actions i.e., additional information may be required. The solution to the problem may be lighted signs or lights to communicate this information. Such signals could be placed near the floor rather than near the ceiling where they are more likely to be obscured by smoke. Another possibility is tactual signals, with indentations or raised surfaces on walls which indicate the path to the stairway. It may be even better to have redundant systems—auditory, visual and tactual.

In any event, the design of the comunication *system* should have as its goal the safety of a person. It would likely include an alarm of some kind and information which enables a person to move from danger to safety without harm. The scope of the system therefore comes to an end whenever the goal is achieved (i.e., the person is at a safe location) not with the issuance of "what to do" instructions.

# 6. CONCLUSIONS AND RESEARCH RECOMMENDATIONS

Stress as a research area is almost unique in that it is associated with a range of difficulties that involve not only technical and administrative judgments but moral ones too (e.g., to what extent should people remain detached in an actual emergency situation even with the best of intentions, such as the collection of objective data).

If planned field disaster research is to have the same control benefits as laboratory investigations, several flexible research designs must be developed for specific types of emergencies. These designs or models should be supplemented by the creation of basic interview and questionnaire formats, a set of questions for which both statistical reliability and validity have been demonstrated, and observational methods of data collection. In addition, when a permanent staff is available, trained observers with pre-assigned tasks would considerably shorten the required lead time in responding to emergencies. Since disasters of differing types and magnitudes have already been studied, research designs and findings from these experiences should provide a satisfactory point of departure for this kind of planning.

It is also desirable to explore other research techniques. At a conference entitled "Human Behavior in Fire Emergencies" (Glass and Rubin, 1978), a frequent suggestion was to have a trained observer work as a member of the staff in the work environment being examined. For example, in a health care facility, a researcher could gain an insight into communications patterns during normal work situations as well as during emergencies—whether related to fire incidents or not. Such first hand exposure to the activities which occur in buildings, and the actions of staff personnel, would provide valuable insights to help in defining the problems—and to point the way to possible solutions. Another source of potentially valuable information identified at the meeting was the monitoring (by tape recordings) of messages at switchboards during times of emergencies. This monitoring would provide first hand data on what occurred, when, and the sequence of actions.

It is important to consider the mundane as well as the exotic. That is, it is important to consider the characteristics of good exit signs as well as defining the requirements for command and control centers. A person faced with an emergency in a building needs all the help that can be provided, in several forms, if possible, if injury is to be avoided. Visual signs and signals are a component of safety systems in virtually all buildings; the practices followed today, on the other hand, are those specified many years ago—and they are without a solid research foundation.

Fire safety for building occupants must be seen as a problem which can be dealt with only by means of a systems orientation. Analytic procedures must be employed which accomplish the following:

1. *Define an overall objective* in terms that are readily agreed upon and capable of analysis (e.g., enabling people to avoid injury or death in building fires).
2. *Analyze the overall objective* into major subareas (subsystems, tasks) which are capable of being clearly defined (e.g., communications requirements for the transmission of information among all people and/or organizations affected by fire emergencies).
3. *Specify procedures* (and other means) which are designed to meet the system requirement by responding to the task and subsystem requirements (e.g., signs, voice communication systems, etc., having specified capabilities). These subsystem requirements should preferably be written in performance language to the degree feasible.

In the context of the above framework, the problem area addressed in the present report (communications requirements for building occupants in fire emergencies) clearly comprises only one subsystem in a fire safety system.

The problem of fire safety in buildings has been addressed by the authors of the present report on several occasions (Rubin and Cohen, 1973), (Glass and Rubin, 1977, 1978) and has been explored by Wood (1971), Pauls (1971, 1974), Canter (1975), Bryan (1971), Quarantelli (1972, 1974), and other investigators. There is a general consensus among those who have worked on this subject that a great deal of work remains to be done to define the nature and scope of the problem. The subject area has been virtually neglected by those responsible for fire safety design in buildings. Valid information concerning the following topics is lacking:

- How people typically behave in fire emergencies.
- The effect of training on fire safety performance.
- The relationship of fire drills to injuries and deaths in fires.
- The relationship of building type, activity, characteristics of people, etc. to fire safety requirements.

Since little is known about how people have behaved in past fire emergencies, and only speculation is now possible concerning what actions *should* be performed by occupants in such cases, the task of defining communications requirements becomes very difficult. It is not, however, impossible if a distinction is made between *what* is transmitted and *how* information is sent.

Our lack of empirical data about actual behavior in fire emergencies (and, hence, suggested courses of action) makes it difficult to specify the *particular* messages which should be transmitted to building occupants. Not enough is currently known to make suggestions based on research data—obviously fire safety systems must continue to be designed on the basis of the existing state-of-the-art. Furthermore, it will take a major research effort and considerable time to develop the information required to make such recommendations.

However, one need not determine *what* information should be transmitted in order to explore *how* such messages might be sent. The design of systems to transmit information to building occupants is largely dependent on the physiological, psychological and perceptual abilities of people (as noted earlier in the section on human factors). A great deal of information is already available concerning these factors—in contrast to the lack of information on behavior in fires. What is needed is to explore conditions, such as smoke, which alter the basic capabilities and limitations of people in ways that are likely to affect their behaviors in fires.

Another subject in need of exploration is the right "mix" of visual, auditory (and possibly other) systems, and the cost/benefits of having redundant systems to transmit information.

Among the research questions requiring answers are:

- How do we determine the optimal characteristics for exit signs?
- How can the attention of occupants best be attracted?
- What kind of information should be transmitted by visual signals, auditory signals and other modes (e.g., touch)?
- How long should messages be?
- How often should messages be repeated?
- What should the signal-to-noise ratio be for auditory and visual messages? (What characteristics should the messages have to ensure that occupants are aware of them regardless of where they are?)
- What kind of messages should be transmitted and under what conditions?
- Which types of messages should be prerecorded; which should be transmitted "live"?
- What system is needed for two-way communications?
- What backup systems are needed for manual override or to substitute for automatic systems?

The authors of this report recommend that several research programs be set up and funded by the Federal government in order to begin answering some of the posed questions. The area of occupant fire safety behavior is an important one and has been largely neglected. A number of research approaches should be pursued in parallel. If only systematic parametric work is performed, it will take decades to produce the findings. Only after the proper data base has been developed, can we expect to meaningfully design effective communications systems for building occupants.

# APPENDIX A

## MODEL BUILDING CODES

In order to see differences in the model codes with respect to voice alarms signalling in high-rise buildings, the following table is presented (Cellantani, 1975). The codes covered here are the: Building Officials and Code Administrators (UBC); and the Southern Building Code Congress (SBCC). The authors thank Mr. Eugene N. Cellantani, Vice President & General Manager of Federal Signal Corporation, Autocall Division, for permission to reproduce this article in its entirety. This section was prepared by Mr. Cellantani as a speech to the National Bureau of Standards in March 1975, during a conference on voice alarm systems in high-rise buildings.

VOICE ALARM SIGNALING, HIGH-RISE

| | Model building codes | | | State codes | | | | City codes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FUNCTION | BOCA | SBCC | UBC | (UBC) Calif. | (BOCA) Mass. | (UBC) Minn. | (UBC) Nev. | (BOCA) (State) Boston | (BOCA) Detroit | (UBC) Los Angeles | New York City |
| Voice communication—one way | X | X | X | X | X | X | X | X | X | X | X |
| Alerting tone | - | X 2 | - | X 2 | - | X | X | - | - | X | X 2 |
| Fire tone | - | - | - | - | - | - | - | - | X | - | X |
| Pre-determined message | - | X | - | - | - | X | - | - | - | - | - |
| Pre-recorded message | X | - | - | - | X | - | - | X 5 | - | - | - |
| Live voice | X | X | X | X | X | - | X | X | X | X | X |
| Selective alarm | X | X | X | X | X | X | X | X | X | X | X |
| General alarm | X | X | X | X | X | X | X | X | X | X | X |
| Speaker locations | | | | | | | | | | | |
| Elevators | X | X | X | X | X | X | X | X | X | X | X |
| Elevator lobbies | X | X | X | X | X | X | X | X | X | X | X |
| Exit corridors | X | X | X | X | X | X | X | X | X | X | X |
| Exit stairwells | X | X | X | X | X | X | X | X | X | X | X |
| Apartments | X | X | X | X | X | X | X | - | X | X | - |
| Guest rooms | X | X | X | X | X | X | X | - | X | X | - |
| Offices (over 1000 sq. ft.) | X | X | X | - | X | X | X | X | X | X | - |
| Room occupancy load (over 50) | - | - | - | X | - | - | - | - | - | - | - |
| Sound output | | | | | | | | | | | |
| dBA references | - | - | - | X 3 | - | - | X 3 | - | - | - | - |
| "Shall be clearly heard" | - | X | X | - | - | X | - | - | - | X | X |
| No reference | X | - | - | - | X | - | - | X | X | - | - |
| Voice communications—two way | X | X | X | X | X | X | X | X | X | X | X |
| Elevators | X | X | X | X | X | X | X | X | X | X | X |
| Elevator lobbies | X | X | X | X | X | X | X | X | X | X | X |
| Exit corridors | X | X | X | X | X | - | X | X | X | X | X |
| Exit stairwells | X | X | X | X | X | X | X | X | X | X | X |
| Apartments | - | - | X 6 | - | - | - | X 6 | - | - | - | - |
| Guest rooms | - | - | X 6 | - | - | - | X 6 | - | - | - | - |
| Offices (over 1000 sq. ft.) | - | - | X 6 | - | - | - | X 6 | - | - | - | - |
| Room occupancy load (over 50) | - | - | - | - | - | - | - | - | - | - | - |
| Electrical supervision, NFPA-72A | - | - | - | - | - | - | X | - | - | - | - |
| Electrical supervision, other | X | X 1 | X | X 1 | X | X | X | X | X | X 1 | - 1 |
| Combination systems OK | X | X | X | X | X | X | X | X | X | X 7 | X 7 |
| Approvals, UL | - | - | - | - | - | - | X 4 | - | X 4 | - | - |
| Approvals, other | X | X | X | X | X | X | X | X | X | X | X |
| Test to NFPA standards | - | - | - | - | - | - | X | - | X | - | - |

Notes of explanation for numbers in the table are found in the accompanying text.

## NOTE #1—ELECTRICAL SUPERVISION

If you will note from the chart, almost all of the code authorities require supervision. The only building code authority that gives an explanation of supervision is the Southern Building Code Congress, Section 518:

Paragraph (d)1. "The system shall be continuously electrically supervised against component failure of the audio path including amplifiers, speaker wiring, switches and electrical contacts and shall detect opens and shorts which might impair the function of the system."

The State of California has adopted a basic UBC Code, however, their interpretation of electrical supervision goes beyond the normal NFPA Pamphlet 72A interpretation.

Pamphlet 72A, Article 240, entitled "Electrical Supervision" subparagraph 2410 entitled "General" subparagraph 2411 states as follows:

"Except as otherwise indicated in this standard all fire alarm and process monitoring alarm systems shall be electrically supervised so that the occurrence of a break or a ground fault condition of its installation wiring ciruits which prevents the required operation of the system or failure of its main power supply source will be indicated by a distinctive trouble signal."

The State of California in an explanatory letter to me indicated that "by policy the fire alarm systems for high-rise buildings shall be electrically supervised to the extent that all equipment and devices (circuits, etc.) necessary to the transmission of a fire alarm signal are included for detection of open, ground, or short. This also includes the speakers."

New York City does not require the speaker circuits to be supervised, however, they do require the speaker circuits to be wired alternately on two or more circuits on a floor or in a zone.

They will accept supervised systems in lieu of the alternate wiring pattern.

Again, this is not defined in New York City's Class E Fire Code, but is interpreted by the local authority having jurisdiction.

In the area of supervision there are several questions that need to be clarified. For example, do you supervise the motor of the tape deck? Do you supervise the tape itself? Do you have redundant tape decks so that if one fails the other one will take over in lieu of supervision? Do you have a separate fire tone signal that is transmitted prior to the taped message to alert people of the coming message, then repeat this sequence of tone/message as many times as the local authority having jurisdiction requires? Do we apply the same type of supervision as now required by NFPA 72A?

The above is a major area that needs clarification.

## NOTE #2—ALERTING TONE

The State of California has amended UBC Section 1807, Paragraph (b)1 as follows:

"In lieu of a voice alarm signal when approved by the fire authority having jurisdiction, the local alarm system may employ any sounding device or devices which are approved and listed by the State Fire Marshall. The sounding device of such alternate systems shall have a distinctive tone and shall be arranged to emit intermittent, prolonged or continuous sound signals for a full period of 10 seconds before the signal is repeated. Such signal shall continue to sound until manually terminated at the building control station but in no case shall such manual operation be arranged to cause termination in less than three minutes."

The City of Los Angeles states, "Staff alerting type systems may be acceptable depending upon special occupancy requirements."

The City of New York requires sounding the alarm on the floor of incidents and the floor above, as well as other specifically mentioned areas. In addition, they require that a different alerting tone be sounded to notify the floor wardens that a fire has been reported in the building. These two tones, the fire tone and the warden alerting tone, are to be sounded simultaneously.

Out of the three major model code groups, Southern Building Code Congress is the only one that makes specific reference to an alerting tone to be followed by a pre-determined message.

The alerting tone is rather clear. This would be a tone preceding the message, however, "pre-determined message" is now different from their original text which said "pre-recorded." The latest revision would seem to allow an option of either a pre-determined message that was pre-recorded or a message transmitted by live voice communication.

Other code authorities have allowed the use of alerting tones such as the GSA in their building in Seattle.

This is another area that needs clarification and uniformity.

## NOTE #3—SOUND OUTPUT

The State of California has modified UBC Section 1807, Paragraph 6.2 as follows:

**Speakers or Signaling Devices**

"Speakers or signaling devices used to sound the voice or fire alarm shall be so located as to be clearly heard on the floor where activated, except as may be otherwise found necessary or acceptable by the enforcing authority, a minimum of 85 dBA or 10 dBA over ambient noise levels measured 4 feet above the floor shall be provided."

The State of Nevada in their code Paragraph 2000 states as follows:

"Design criteria minimum decibel coverage for loud speakers. Areas to be protected by paging alarm systems shall be covered with sufficient loud speakers to achieve 6 dB above ambient noise level or not less than 84 dB plus or minus 6 dB at 4 feet above the floor."

The State of California and the State of Nevada are the only two authorities that have specified dB output and loudness. Other code authorities state that the signal shall be "clearly heard" and many make no reference to any sound output in their codes.

This area certainly needs clarification and some sort of standardization among the code writing authorities.

## NOTE #4—APPROVALS

The State of Nevada, as well as the city of Detroit, are the only two codes that make specific reference to NFPA and UL as far as standards are concerned or listed equipment is concerned.

All of the other code writing groups make reference to approve systems but do not clarify the term "approved."

This area certainly could be strengthened if specific references were made to standards such as NFPA and/or approving authorities like UL, PM and other recognized testing laboratories.

## NOTE #5—PRE-RECORDED MESSAGES

You will note that many of the code authorities require a pre-recorded message, however, to the best of our knowledge no one really defines what the message is to contain. They usually say it is up to local authorities having jurisdiction.

The City of Boston has interpreted the pre-recorded message to be a fire tone followed by a live voice communication.

St. Paul, Minnesota (not charted) has suggested the pre-recorded message be preceded by an alerting tone interrupted by the following message. The message is as follows:

"This is a fire emergency. Listen to the following instructions carefully. Do not enter the hallway until you have checked the upper portion of the door for heat. If it is cool, open door carefully and close immediately if there is smoke in the hall.

If the hallway is clear of smoke, proceed to the nearest stairwell. Do not use the elevator.

If there is smoke in the hallway, remain in your room. You are reasonably safe where you are. The Fire Department has been notified." Repeat the above message.

The area of pre-recorded messages has to be carefully looked at from all sides, the psychological effect of receiving a pre-recorded message and how we will respond to such a message. The exact wording of the message has to be considered so that you don't alarm people but you motivate them to respond.

This entire area needs careful study and review to determine: (1) if this is a practical application for a pre-recorded message, and (2) if it is a practical application, how shall the message be worded.

## NOTE #6—TWO-WAY SYSTEMS

In the area of two-way communication systems there seems to be quite a bit of agreement in reference to location of the two-way communication stations, telephones, etc. Except in the UBC Code and the State of Nevada (modified UBC Code) they clearly show that the two-way communication devices are to be also placed in apartments, guest rooms, and office areas over 1,000 square feet. None of the other model building codes or none of the other state codes or city codes that we have reviewed to date have required this application.

This would bear some interpretation on the part of the UBC and perhaps a modification to their code, because as we understand it the two-way communication system is intended for fire department use.

## NOTE #7—COMBINATION SYSTEMS

Most of the model code writing groups have stated that combination of two-way and one-way is acceptable. The question arises as to what is meant by this statement.

We don't believe that in "H" type occupancies where you are putting a speaker in every room or apartment that you will be able to have a two-way conversation between the central control point and the room. This would be similar to a nurses call system which allows a conversation between patient and nurse.

In this day and age where eavesdropping, bugging and Watergate are foremost in everbody's mind, we feel the liability of putting in a system of this nature may border on the lines of being illegal. This point would have to be clarified by all authorities using the phrase "Combination System" in their codes.

The City of Los Angeles goes on to say that combination systems are acceptable but priority for all functions is given to the central control station.

This probably was meant to clarify the combination system but it still leaves many questions unanswered in our minds.

The City of New York Class E Fire Alarm Code states that the fire command station (which is the central console) may permit floor warden stations to make announcements over the loudspeaker system.

Their combination system permits the central console operator to patch in a floor so the fire warden of that floor can make an announcement to all of the floor and/or building occupants.

This is another interpretation of a combination system.

This area also needs clarification in reference to what is truly meant by combination systems in these various codes.

In summation, I would like to say that a great deal of work has been put into the writing of these codes by the various model code groups, states, municipalities, etc. As a result of their effort (and evidently close cooperation and coordination between each other) there is a great deal of similarity and uniformity between all of these codes.

Some questionable areas have been raised. We realize that these points will need further clarification before a standard code could be developed.

The problem as we see it today is that we are leaving most of the questionable areas in these codes up to "the local authority having jurisdiction." In the absence of a definitive standard, such as NFPA or listing authority like UL and PM, a broad interpretation by the local authority having jurisdiction is not only a likelihood but a probability.

The model code groups should continue to work together to clarify sections of the code which are open to interpretation. This will help eliminate the necessity of each state or municipality providing their own interpretive amendments to the model codes. For example, if electrical supervision had been clearly defined we would not have the diversity of interpretations as we now have between New York, California and Nevada.

In addition to the previous comparison of the model codes' requirements for high-rise buildings, the following is a proposed new fire-alarm signal standard which might ultimately be used in all buildings in the United States.

## A PROPOSED STANDARD FIRE-ALARM SIGNAL (NATIONAL ACADEMY OF SCIENCES, 1974):

The standard fire-alarm signal, when detected by the occupant of any building should indicate imminent danger from fire and signify unambiguously that action is necessary. This action might consist of immediate evacuation of the building or withdrawal to certain safe areas within the building, for example, to a designated area within a multistoried building. The signal should be specific and simple so that it would be universally recognized by by all people and easily distinguished from other alarm signals.

In any particular location, the standard fire signal might be supplemented by auxiliary instructions; that is, other signals might follow the standard alarm signal and indicate the most appropriate action in that particular environment.

In designing such a signal a variety of criteria might be considered. We considered the following. First, the signal must be evident and easily detected by the occupants of the building. Thus, the signal must be noticeable and easily detected above whatever background noise is present. Secondly, the signal must be distinctive and clearly different from a variety of other alarm systems. There must be no confusion on the part of the recipient as to what alarm signal is being sounded and whether or not this is the standard fire-alarm signal. Thirdly, we took into account the problem of adapting existing fire-alarm systems to the present proposed signal; this criterion was considered to be less important than the other two.

In connection with the first criterion, the Working Group reviewed information on the ambient spectra present in a variety of buildings such as apartments, schools, hospitals, offices, and theaters. As one might expect, the ambient spectra are varied and the character of the temporal fluctuations in these different environments is similarly heterogeneous. In addition, existing or proposed signaling systems displayed a variety of power spectra, temporal profiles, and modulation characteristics.

Based on the above information and the following considerations, the Working Group unanimously recommended adoption of a standard temporal profile for the fire-alarm signal rather than any special signaling device or standard spectrum to signify fire danger.

The main advantage to be gained from adopting a standard temporal profile for the fire-alarm signal is that the heterogeneity of both signal and background spectra of each location can be evaluated and a particular signal system selected to penetrate that background. This point seemed particularly important since in the opinion of the group an extreme variety and range of background noise level can be found to exist where fire alarms are needed. Indeed, in the opinion of the Working Group, given any alarm signal one could find somewhere a background noise spectrum that would mask it. Thus, the particular system can be designed to optimize the detectability of that signal in that particular location. In addition, a standard temporal profile would allow for either visual or tactile systems to be used as alternative or supplementary means of communicating the signal. The need for nonauditory signals is obviously important for deaf people. Tactile or visual systems could be used in deaf schools or special systems could be made available to deaf lodgers of apartments or hotels. In addition, the employment of a standard temporal profile for the fire-alarm signal would allow other emergency vehicles such as police cars or ambulances to direct this signal to people within a building. For example, a fire engine, once it reaches the site of the fire, would begin to broadcast the standard alarm signal both to warn occupants of the building and to alert the neighborhood of potential danger. A final argument in favor of using a standard temporal profile is that it would reduce the problem of refitting existing systems, because practically all alarm systems could be adapted to generate the standard temporal profile.

The standard fire alarm should, therefore, consist of a particular alternation of nominal "on" and nominal "off" states, presented repetitively. The Working Group suggests that the basic temporal pattern should consist of two "shorts" and a "long" repeated regularly. Specifically, if the on-segment is denoted by an underlined number and the off-segment is not underlined, then the basic pattern would be:

$$\underline{1}\ 1\ \underline{1}\ 1\ \underline{2}\ 4.$$

If the nominal duration for a segment were 1/2 second, then the standard signal would be "on" a 1/2-second, "off" a 1/2-second, "on" a 1/2-second, "off" a 1/2-second, "on" 1 second, "off" 2 seconds, and repeat. We would suggest that the nominal on-segment be between 0.4 and 0.6 seconds, and that the nominal off-segments be between 0.3 and 0.6 seconds.

The definition of the nominal "on" and "off" state for the signal is a standardization problem. We recommend that once the signal is nominally "on" it should achieve some level and fluctuate less than 2 dB from that sound level.[1] Once the "on" state is terminated, the level of the signal should fall at least 10 dB within 0.1 seconds, and stay below that nominal "off" level until it resumes the "on" state. The transition from "off" to "on" should occur within 0.1 seconds. These measurements could be made in a free field, because while the numerical values of "on" and "off" would be influenced by peculiarities of the acoustic environment (e.g., the local reverberation), the informative value of the signal would probably still be preserved.

Automatically, the standard fire-alarm signal should be clearly audible and distinguishable from potential background interference. To accomplish this objective, we recommend that the signal be loud enough to produce a sound level in the "on" state that exceeds by 15 dB the prevailing equivalent sound level[2] at the potential listener's ear or exceeds by 5 dB any maximum sound level having a duration greater than 30 seconds, whichever is greater. Equivalent sound level is the level of a constant sound, which, in a given situation and time period (for our purposes, 24 hours), has the same sound energy as does the existing time-varying sound. Technically, equivalent sound level is the level of the mean-square A-weighted sound pressure, measured over a 24-hour period. The 24-hour equivalent sound level is selected because a fire might occur at any time. A signal sufficiently intense in its "on" state to exceed the equivalent sound level by 15 dB should be easily detectable. Many acoustic environments show considerable fluctuation in sound level over time. If equivalent sound level needed to achieve the 15 dB increase is greater than 130 dB, further consultation with local health authorities is recommended because of possible risk of hearing damage, especially if the alarm signal is frequently presented for drills or rehearsals.

Compliance with the preceding considerations should lead to an alarm signal that is both detectable everywhere and distinguishable from a variety of presently existing alarm signals. Probably the largest single source of confusion between a fire signal and other warning signals currently in use, is the similarity of the fire signal to signals originating from emergency vehicles. In order to eliminate this confusion, the Working Group recommends that all moving emergency vehicles (including fire engines) employ a single alarm system; we recommend the high-low or "continental" alarm as the most appropriate outdoor signal for moving vehicles.

To review briefly the advantages of the proposed standard fire-alarm signal are: (1) the signal could be

[1]For the purposes of this report decibel (dB) is the quantity measured by a sound-level meter satisfying the requirements of American National Standards Specification for Sound Level Meters S1.4-1971. Sound level is the frequency-weighted sound-pressure level obtained with standardized fast dynamic characteristics and an A frequency weighting.

[2]The 24-hour equivalent sound level is analogous to specifying the electrical energy used in a household over a 24-hour period in terms of the wattage of a single light bulb that one would burn for a 24-hour period to consume the same amount of energy.

designed to take advantage of practically any acoustic environment by matching the signal to the existing background noise to optimize detectability; (2) because of its distinctive time course, it would be less easily confused with the variety of existing systems, especially those emanating from outside buildings; (3) because of its distinctive temporal pattern, it could be easily adapted to vision and touch; and (4) it would minimize the problem of adapting existing systems because it would usually involve less time and money to insert a temporal interruptor into an existing circuit than to replace the entire alarm system. In addition, some acoustic criteria are suggested to insure that the signal would be easily detected and noticed in practically any acoustic environment.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This literature survey reviews the communications requirements for fire safety in buildings from the standpoint of the building occupant and the control operator. It traces the development of the problem of communications in buildings and the specialized needs that exist today.

An examination is made of the purposes of a communications system in buildings as well as some of the psychological design requirements necessary for such a system.

The communications requirements of the building occupants are also covered, with emphasis on the types of information communicated by signals and the integration of those signals into an overall system design.

Personnel requirements for staffing a control center are also discussed, along with common problems in several operational communications systems.

Detailed examples of communications systems are provided. Portions of several model codes which cover communications systems are presented. Suggested areas for future research on fire safety in buildings are identified.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Buildings; communications systems; fire safety; high-rise; model codes; people movement; systems design.

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