

# Human Behavior in the World Trade Center Evacuation

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## ABSTRACT

An explosion below the World Trade Center plaza in New York City on February 26, 1993, killed six workers, and resulted in injuries to over 1,000 occupants as they made their way out of the affected buildings. The explosion and subsequent fire caused extensive structural damage on several basement levels, interfered with the operation of the fire protection and other emergency systems and resulted in the evacuation of tens of thousands of occupants of the complex.

The National Fire Protection Association (NFPA) and the National Research Council of Canada (NRC) undertook a research project, funded by the National Institute of Standards and Technology, the General Services Administration, NFPA and NRC, to study the behavior of building occupants in this incident and to document, to the extent possible, those engineering details such as building design, fire safety features, training, and smoke spread, that effected behavior.

Over 400 occupants of the two 110-story office towers responded to a survey sent to the approximately 1,600 employees and tenants who were members of the fire safety team. This paper summarizes their responses, compares the responses between the two towers, and summarizes data on response times and initial actions.

**KEYWORDS:** Human behavior, high-rise buildings, evacuation, response times.

## INTRODUCTION

Six people were killed when a bomb exploded in an underground parking garage at the World

Trade Center plaza in New York City shortly after noon on February 26, 1993. Although the resulting fire was confined to the garage, involving 25 to 30 vehicles parked in the vicinity of the bomb, the explosion and fire caused extensive structural damage on several basement levels, interfered with the operation of the fire protection and other emergency systems and resulted in the evacuation of tens of thousands of occupants of the complex.

Smoke from the fire and the bomb as well as structural dust spread up the elevator shafts and migrated to upper floors of the buildings on the plaza. Over 1,000 people were treated for injuries suffered in the explosion and evacuation.

The World Trade Center is a complex of seven buildings, six of them situated on the plaza. The key features of the World Trade Center are the twin 110-story office buildings. They are joined at sidewalk level with a 22-story hotel. The other three buildings on the plaza are six and eight stories tall. (The seventh building, located across the street, was not involved in the explosion damage or the smoke spread.) There are approximately 40,000 people employed in each tower and an estimated 50,000 visitors are in the two towers during the course of a normal business day. Both towers as well as the other buildings on the plaza were evacuated.

The Port Authority of New York and New Jersey has made a longstanding commitment to fire safety in their management of the complex. Every tenant is required to conduct at least two fire drills a year. Every tenant has a fire warden trained in building evacuation. Any tenant holding space on more than one floor has a fire warden for each floor. In addition to the fire wardens, there are 25 fire safety directors who coordinate the activities of the fire wardens. These directors are in turn supervised by two Port Authority employees. A significant part of the fire safety plan for the fire wardens consisted of training them to alert the employees in their area and have everyone assemble at a point in the center core of the towers where they would receive additional information from the emergency control center in the basement. Due to the damage to the emergency system in the explosion, the fire alarms in the building did not sound and no communication was possible between the center, which was destroyed in the blast, and the employees in the towers.

## **STUDY DESIGN AND OBJECTIVES**

The National Fire Protection Association (NFPA) and the National Research Council of Canada (NRC) undertook a research project funded by the National Institute of Standards and Technology, the General Services Administration, NFPA and NRC to study the behavior of building occupants in this incident and to document, to the extent possible, engineering details such as building design, fire safety features, and smoke spread, that effected behavior.

The purpose of the project was to collect and preserve human behavior data. The data gathered will aid in understanding what people do in fires and why and how those actions may conform to or differ from the assumptions used in designing and planning for life safety in such a large building. Results will help improve fire safety in similar occupancies and enhance the knowledge needed in the development and use of fire evacuation models.

The specific objective of this study was to document the actions of the occupants of the World Trade Center Complex in order to see what effect training had on their decisions, to

gain an understanding of what decisions they made and why, to assess the effectiveness of their decisions and actions and reasons for successes and problems, and to learn of any information or experience gained by the evacuees that they feel might be of value to others in similar situations. It also provided the opportunity to collect information on delay times before responding to fire cues. In addition to this human behavior study, NFPA conducted a technical investigation of the incident that also will contribute to the body of knowledge being used throughout the world for the modeling of evacuation of high-rise buildings.<sup>1</sup>

Since there were 1,200 tenants in the complex, surveying only fire wardens gave us a sample covering every floor and was of a manageable size, a total of 1,598 people. Although they represented less than one person in 50 of those in the building, their special training was believed to have given them a context in which to describe what happened that could provide a comprehensive and valid basis of analysis.

This study was based on a design originally developed by Dr. John Bryan of the University of Maryland and in use since Project People in the 1970s. The design has been enhanced and applied by the NFPA in several fire incident studies over the years, in particular the Beverly Hills Supper Club, MGM Grand Hotel and Westchase Hilton Hotel fire investigations. NFPA's most recent previous use of this method involved the Westin Hotel fire in Boston on January 2, 1984. Similar studies have since been completed by the authors -- one a fatal high-rise apartment building fire in Ontario and the other a successful evacuation of a college dormitory in Massachusetts.

This study used a structured questionnaire mailed to the 1,598 fire wardens, assistant fire wardens and designated searchers and rescuers identified by the Port Authority of New York and New Jersey. To encourage cooperation of individuals involved in the fire, identities have been kept strictly confidential.

## **SURVEY RESULTS**

A total of 419 surveys were returned, 406 of which were usable (25.4%). (The other 13 surveys were returned by people who were away on vacation, on maternity leave, out of the building for lunch, or otherwise not present at the World Trade Center at the time of the incident.) The respondents ranged in age from 22 through 70 years of age and included 199 women and 197 men. The 406 respondents included 229 occupants of Tower 1, 163 occupants of Tower 2, seven on concourse levels, one each at the Vista Hotel, at 5 World Trade Center and the World Financial Center, and four who did not report their locations. Four of the occupants of Tower 1 and six of the occupants of Tower 2 were at subgrade, concourse or lobby levels in the buildings or in an elevator. Of most interest for this study were the 382 occupants of the two towers (23.9% of surveys sent).

This paper includes analyses of the behavior of the tower occupants only, that is, those who were on Floors 11 and above at the time of the incident. There were 225 such respondents from Tower 1 and 157 from Tower 2. The bomb was placed closer to Tower 1 than Tower 2 and responses to many of the questions differed significantly between occupants of the two towers.

## Occupant Reactions

Initial Awareness of the Incident. Occupants were asked how they first became aware that something unusual was occurring. Respondents mentioned the following cues, either singly or in combination, as the indication that something was occurring: hearing or feeling the explosion, loss or flickering of lights or telephones, smoke or dust, sirens and alarms, information from others, and people movement.

Of the respondents in Tower 1, 84% reported that the explosion, with or without another cue, was what alerted them, compared to 74% of the respondents in Tower 2. Looking at the responses in another way, 53% of the respondents in Tower 2 reported loss of power (lights, telephone), with or without another cue, as what alerted them, compared to 40% of the occupants of Tower 1. (These responses are not mutually exclusive since the explosion and loss of power were mentioned in combination by many of the respondents -- 35% in Tower 1 and 38% in Tower 2.) Both these differences were found to be significantly different.

Occupants were asked how they realized that what was occurring was a fire or explosion. Responses were similar to those listed for the previous question, again either singly or in combination, but the predominant responses included the explosion and smoke. Of the respondents in Tower 1, 69% reported that the explosion and smoke were what made them aware that a fire or explosion had occurred, compared to 57% of the respondents in Tower 2. This difference was found to be statistically significant.

Perception of Seriousness. The occupants of Tower 1 appeared to be more likely to consider the incident very serious than the occupants of Tower 2. In order to test this, a  $\chi^2$  test was performed which showed the responses were significantly different, that is, the occupants of Tower 1 were more likely to believe that the situation was very serious than the occupants in Tower 2. In order to test the hypothesis that differences in the distribution of occupants by age or sex between the two buildings might explain these differences, those distributions were also tested and not found to be significantly different. In fact, there was no significant difference in perception of seriousness between the different age groups or between men and women. Perception of severity also did not differ significantly by location (floor) within the towers.

Within each tower, responses were checked to see if the perception of severity differed significantly depending on how people became aware of the situation. For Tower 1, respondents' perception of severity did not differ significantly regardless of whether or not it was the explosion or power loss that alerted them to an unusual situation. By contrast, Tower 2 respondents were significantly more likely to believe the situation was extremely serious if they became aware of the situation as a result of the explosion rather than the loss of power.

Reporting the Incident or Notifying Others. Only a small proportion of occupants in either tower reported attempts to contact the fire department directly or to operate the manual pull stations. Of the 27 respondents from Tower 1 who called or tried to call the fire department, 14 made comments, including: the telephones were down (seven people); there was no answer (three people); the fire department already knew (one person); the alarm had been pulled (one person); there was no power at the box (one person); and the emergency phone in

the stairs was locked (one person). Of the 195 people who reported that they did not call the fire department, 21 gave reasons, including: the telephone system was down (six people); someone else called, would have called or should have called (six people); the fire department already knew or were already there (three people); they didn't know what was happening (three people); they were in contact with Port Authority personnel, who knew (two people); and his primary concern was the employees (one person).

Of the 33 respondents from Tower 2 who called or tried to call the fire department, 11 had comments, including: there was no answer (four people); the lines were busy (four people); the telephones were down (two people); and they wanted to let the fire department know where they were (one person). Of the 123 people who did not call the fire department, 31 gave reasons, including: the fire department already knew (nine people); someone else did (eight people); the telephone system was down (five people); they were in contact with Port Authority personnel (three people); there was no telephone in the area (two people); they did not know what was happening (two people); the alarm had been pulled (one person); and they had been instructed not to (one person).

Respondents were asked if they operated or attempted to operate a manual pull station. Of the 222 respondents from Tower 1 who answered the question, 185 (83%) did not and 37 did (17%). Of the 185 who did not pull or attempt to pull a manual pull station, 14 gave reasons, including: someone else already had or should have (five people); they didn't know where it was or couldn't see it (two people); everyone already knew (two people); they didn't know what was happening (two people); there was no power and it didn't work (one person); the fire department was already there (one person); and they just thought to get out (one person). Of the 37 who did or tried to operate the pull station, 15 said there was no power and it didn't work, six said there was no answer, one did it after and while attempting to contact the Port Authority, one did it shortly after smoke was visible, and one said she didn't expect it to work but no one else had tried.

Of the 152 respondents from Tower 2 who answered the question, 116 (76%) did not and 36 did (24%). Of the 116 who did not pull or attempt to pull a manual pull station, 16 gave reasons, including: someone else already had or should have (five people); the fire department was already there (five people); there was no power and it didn't work (two people); everyone already knew (two people); they didn't know what was happening (one person); and this would have caused a panic (one person). Of the 36 who did or tried to operate the pull station, six said there was no power, five said there was no answer and one said there was no tool to break the glass.

A higher percentage of respondents from Tower 2 called friends or family than respondents in Tower 1, possibly a reflection of the less clear fire cues received in that building as well as the long delays in beginning evacuation that occurred in Tower 2.

**Movement Through Smoke.** Respondents were asked if they moved through smoke and if they did, how far did they move, how far could they see and did they turn back. The responses to the distance questions were very subjective and it often was not clear if the respondent was referring to horizontal travel distance on the office floor or vertical distance in the stairs. For the question about how far could they see, the responses often had as much to do with the darkness they faced as with the smoke.

Almost all the respondents in Tower 1 (94%) and over two thirds of the respondents in Tower 2 (70%) reported that they tried to move through smoke. This difference is statistically significant. Almost half of the respondents in each tower who said they moved through smoke said they moved through smoke all the way out of the building. The proportion who did so is probably even higher since those who specified a distance or a number of floors may have been describing their entire travel path out of the building.

Over three quarters of those who moved through smoke turned back at some point. The difference between the two towers was not statistically significant. The most frequent reason given for turning back by those who did so was the smoke. Other reasons given included crowdedness, locked doors, difficulty breathing, not being able to see and being afraid.

Seeking Refuge. Respondents were asked if they sought refuge in another office or on another floor and, if so, why. Over half of the respondents in Tower 1 and over two thirds of the respondents in Tower 2 did not report seeking refuge. This difference is statistically significant. The way the question was answered suggests that people meant seeking refuge *after* starting their evacuation rather than seeking refuge *instead* of evacuating. The major reason given for seeking refuge was smoke. Other reasons frequently reported were to breathe or rest, being told to or directed to and the crowdedness of the stairs.

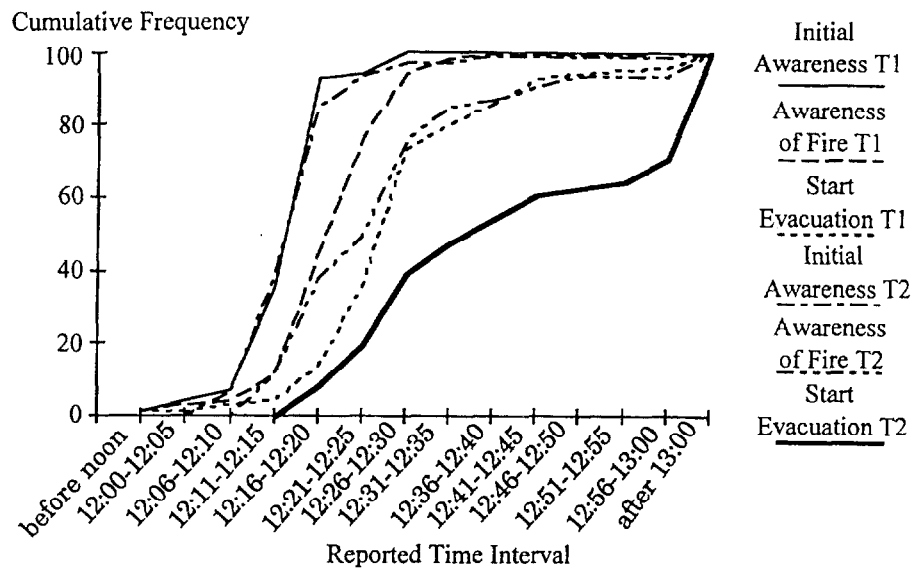
Beginning Evacuation. Two thirds of the respondents in Tower 1 and almost half of the respondents in Tower 2 left without being told to do so by someone in authority. A small proportion of others attempted to leave but were unable to do so. The difference in responses between the two towers was statistically significant.

The reasons people gave for not leaving voluntarily included 1) waiting for information or instructions, 2) felt it was better to wait or they were told to wait, 3) they didn't know there was a problem, 4) they were making sure others left, 5) health reasons, 6) too much smoke, 7) waiting for better conditions, and 8) waiting for the fire department as requested.

For Tower 1, the time from awareness of a fire or explosion to leaving ranged from 0 to 4 hrs 5 min with a mean time of 11.3 minutes and a median time of 5 minutes. For Tower 2, the times ranged from 0 to 3 hrs 5 min with a mean time of 25.4 minutes and a median of 10 minutes. This difference was statistically significant.

For those who attempted to leave the building, the differences in times from awareness of something unusual to the time of attempting to leave were statistically significant. For Tower 1, the times ranged from 2 to 30 minutes with a mean time of 8.9 minutes and a median time of 8 minutes. For Tower 2, the time ranged from 10 minutes to 4 hrs 14 minutes, with a mean time of 39.9 minutes and a median time of 25 minutes.

Figure 1 shows the differences between the two towers in terms of when occupants became aware that something unusual was happening, then realizing that what was happening was a fire or explosion and then in beginning to evacuate. The responses included in this figure are those for occupants who reported times for all three events. As shown, occupants of the two towers became aware that something unusual was happening at about the same time, although Tower 2 occupants were a little later. Due to the ambiguous cues present for many of the occupants of Tower 2, the times at which they realized that there had been an explosion or



**FIGURE 1. Comparison of Times of Becoming Aware of the Situation and Start Times for Tower 1 (T1) and Tower 2 (T2)**

fire are clearly later than the reported times for Tower 1 occupants. And, due to both the delays in finding out what had happened and to decisions to remain in the building until told by firefighters to leave, the time to begin evacuation is much later than for Tower 1 occupants.

How Long Did It Take to Leave the Building. Respondents were asked how long it took them to leave the building. The purpose of the question was to obtain evacuation times that could be used to test or validate evacuation models. Unfortunately, many of the respondents apparently interpreted the question to mean how much time passed between when they started to leave and when they reached the exit, including any time they may have spent resting or waiting in areas of refuge. An attempt was made to count only reported travel times. Over 70% of the respondents in Tower 2 said they left the building in an hour or less, compared to 40% of the respondents in Tower 1. Fifty-two percent of the respondents in Tower 1 reported that it took them one to three hours to leave the building. A significantly higher percentage of respondents in Tower 2 evacuated in less time than respondents from Tower 1 because many delayed their evacuation until told to leave by the fire department, when conditions in the stairs had improved, more lighting was provided and stairway travel was easier and more rapid.

**Prior Experiences**

Prior Fire Alarms. Respondents were asked if they were aware of previous fire alarms in the building and if they were, did they evacuate the building or move to another floor. Many of

the respondents who said they had been aware of prior fire alarms in the building specified that the alarms were fire drills. Other who simply checked off "yes" may have meant the same thing. Since occupants' actions should have been the same whether the alarm was due to an actual incident or a drill, those responses can be looked at together. Most of the respondents in both towers never left the building or the floor when alarms went off or drills were held. Over 90% of the respondents in Tower 2 never evacuated the building and never moved to another floor. In Tower 1, 79% of the respondents never moved to another floor and 88% never evacuated. These results help explain the unfamiliarity with the stairs that many respondents reported, in spite of the fact that most of the occupants who responded to the survey were fire wardens.

Previous Training. Respondents were asked if they had received training prior to the February 26, 1993, incident on actions to take in that building. Since the survey questionnaires were sent to members of the towers' fire safety team, we expected a very high percentage of respondents saying that they had received training. Surprisingly, approximately a quarter of the respondents from each building reported that they had not been trained. Some of this can be explained by the fact that we asked recipients of the survey to pass it on to a colleague if they were not themselves in the building at the time of the incident. Since we did not ask specifically if respondents were in fact members of the fire safety team, we cannot tell how many of the respondents were not members of the fire safety team and how many were members of the team who were saying they had not been trained. (One respondent did report that he was a new member of the team and had not yet been trained.)

People who had been trained were asked what type of training they received and did the training help. Most of the training reported consisted of drills. Simulations and "briefings at call stations" might also have meant drills. Most of the people whose responses are grouped under "Other" seem to be describing the Port Authority's fire safety plan.

Over half of the respondents said that the training did not help in this incident, with over half of them explaining that the drills had left them expecting that information and directions would be given in the event of an incident, but in this case no information was ever received. Others claimed that the fire safety team or system broke down in this incident. The majority of people who said the training helped said that they knew what to do and knew where the stairs were and not to use the elevator or go to the roof. The general positive comments made included those from one respondent who felt that the evacuation was sped up because he was able to direct people to exits, one who observed that people seemed disciplined and prepared by the training they had received and one who said the drills made her realize how serious a high-rise fire could be so she paid close attention to the training.

Prior Fire Safety Information. Respondents were asked if they had received fire safety information prior to the incident from radio, television, publications or other sources and if so, did it help in that incident. The intent of the question was to find out if people had fire safety information beyond the training provided by the Port Authority but we were apparently not clear on that. Four out of five respondents had received fire safety information, but many were referring to the World Trade Center's fire evacuation plan. Some of the people who said they received their information from publications or drills may also have been referring to materials provided by the Port Authority.



The largest number of people who said the information helped them said that they knew what to do and mentioned specific actions such as breathing through a wet cloth, staying low, staying calm, keeping doors closed and stuffing towels or other material under them, using stairs and avoiding elevators, feeling doors for heat before opening them, getting information or waiting for instructions, taking a flashlight and not breaking windows. (Another respondent said that if the situation had been serious he would have broken a window for fresh air and stayed there indefinitely with the fresh air supply. He was on the 36th floor.)

People who said that the other fire safety information they had received did not help generally mentioned again that they were trained to wait for instructions and none were received.

### **Analysis of First Five Actions**

One question on the survey asked respondents to describe what they did once they realized there was a fire or had been an explosion. The question specifically asks for their first five actions in exact sequence. Many people used the available lines to write a narrative account of their actions, while many others listed less than five actions.

Most respondents gave some answer to this question, but it would be a mistake to interpret their responses as literally describing what they did. Later in the questionnaire there are some questions about specific actions. Often a person would answer a later question in such a way as to indicate that a particular action had been taken, but would not have mentioned that action in response to the earlier question. For example, some people gave "left the building" as their first or second action and left the rest of the question blank. But in response to a later question they reported that they called or attempted to call the fire department or family members, or that they sought refuge during their evacuation attempt.

It is also important to remember that there is no time scale in this question. The actions listed by a person could have occurred over a span of minutes or hours.

In previous human behavior studies that asked this question, the responses were analyzed at face value. That is, all "first" actions were analyzed, with comparisons by gender for example, then all "second" actions were analyzed. In this study, for the reasons described above, the responses to this question are not interpreted that literally but are used to see who indicated that they engaged in any of several broad categories of actions.

The categories of action defined for this analysis are:

- investigate,
- seek information,
- prepare to evacuate,
- evacuate,
- alert others or report incident,
- assist others,
- seek refuge, and
- wait.

If any of the up to five actions given by a respondent fell into one of those categories, that category was checked off. Therefore, it didn't matter if, for example, alerting coworkers to the situation was the first action a person listed or the fifth, these categories capture the fact that the action was reported.

The only actions that provide meaningful information were: investigate, seek information, alert others or report incident, assist others, seek refuge, and wait. (Prepare to evacuate and evacuate are not analyzed since all respondents eventually left the building and obviously had to do some preparation before doing so.) The variation in responses between the two towers and between male and female respondents in each tower were analyzed.

Comparison of Actions Between the Two Towers. The actions of the occupants of the two towers are shown in Table 1. In each tower, individuals averaged 1.6 actions, so overall differences in reporting actions were not a factor in the differences by specific actions. The differences that were statistically significant are highlighted. These are seek information, alert others or report the situation, and wait. Significantly larger proportions of respondents in Tower 2 sought information and waited. This makes sense considering the cues they received were not as clear-cut as those received in Tower 1 and that so many occupants waited in the building through the emergency. In Tower 1, a significantly higher proportion of respondents alerted others or reported the incident, probably because they were more aware that an explosion had occurred and felt more threatened by the spreading smoke.

Comparison of Actions of Male and Female Respondents. Tables 2 and 3 compare the actions of male and female respondents in each tower. Again, the significant differences are highlighted. The only significant difference found was in Tower 1 where a significantly higher proportion of men than women reported that they investigated the situation. Other studies have shown that women seem more concerned with the safety of people, themselves and others, and were more likely to warn others and evacuate, while men were more likely to engage in fire fighting.<sup>2</sup>

TABLE 1. Comparison of Actions between the Two Towers

Actions	Tower 1	Percent	Tower 2	Percent
Investigate	25	11	12	8
<b>Seek information</b>	<b>122</b>	<b>54</b>	<b>107</b>	<b>68</b>
<b>Alert or report</b>	<b>88</b>	<b>39</b>	<b>39</b>	<b>25</b>
Assist others	24	11	18	11
Seek refuge	74	33	42	27
<b>Wait</b>	<b>24</b>	<b>11</b>	<b>36</b>	<b>23</b>
<b>Total</b>	<b>225</b>		<b>157</b>	
Tests of significance involving differences of proportions, .05 significance.				

**TABLE 2. Comparison of Actions of Male and Female Respondents in Tower 1**

Actions	Men	Percent	Women	Percent
Investigate	17	16	8	7
Seek information	59	56	60	52
Alert or report	46	44	41	36
Assist others	15	14	9	8
Seek refuge	29	28	43	37
Wait	10	10	13	11
<b>Total Respondents</b>	105		115	

Tests of significance involving differences of proportions, .05 significance.

**TABLE 3. Comparison of Actions of Male and Female Respondents in Tower 2**

Actions	Men	Percent	Women	Percent
Investigate	8	10	4	5
Seek information	57	72	48	64
Alert or report	23	29	13	17
Assist others	11	14	7	9
Seek refuge	21	27	21	28
Wait	21	27	15	20
<b>Total Respondents</b>	79		75	

Tests of significance involving differences of proportions, .05 significance.

### SUMMARY

Building occupants who are trained to expect instructions during an emergency need to be prepared to cope on their own should the necessary equipment be damaged or malfunction during an incident. In the World Trade Center explosion and fire, we were able to study such a population to learn about their actions and reactions to such a situation.

This incident demonstrated that, in an emergency, floor wardens need enough information to be able to make safe decisions when the power shuts down and no information is forthcoming from authorities. But training should not be limited to members of the fire safety team. Many fire wardens were not in their areas when the incident occurred. This is always a possibility, due not only to vacations, lunch breaks, and other regular leaves, but also to meetings that take place off-site or in other parts of the building.

All occupants need some level of training or education if they are going to react safely to a fire in a high-rise building. They should understand smoke movement in high-rises, stack effect, and the dangers of falling glass to people below. If fire wardens are properly trained, occupants should look to them in fire emergencies. In some cases, fire wardens reported that they were overruled by their managers, even though the managers may not have had better or additional training.

Recent human behavior studies have shown that people will move through smoke, but this incident demonstrated that people will keep moving, even as conditions worsen. Many evacuees believed they were heading straight into the fire, but they kept going down, through increasingly thick smoke.

People also need to understand how emergency workers operate. Many who waited for hours on upper floors in Tower 2 complained about the time it took fire fighters to reach them. They need to understand that when power to a building is off, people on upper floors of high-rise buildings who are in no danger can expect fire fighters to take several hours to reach them.

This study provided important data on delay times before people begin evacuation and provided further evidence that multiple cues are often necessary before people will decide that they should leave. The mean delay times between realizing that the explosion and fire had occurred and beginning to leave were 11.3 minutes in Tower 1, where most respondents reported feeling or hearing the explosion, and 39.9 minutes in Tower 2, where the cues available for many of the respondents were more ambiguous, with median delay times of 5 and 10 minutes, respectively.

This study also provided supporting evidence of one of the differences in the way men and women respond to fire incidents. A significantly higher percentage of men than women in Tower 1 reported activities interpreted as investigating the situation. This has frequently been reported in home fires. In this case, although men were more likely than women to investigate the situation, it was only reported by 16 percent of the men and is an action not as likely to occur in an office building as in a home fire.

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