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AUDIBILITY PROBLEMS WITH FIRE ALARMS IN APARTMENT BUILDINGS

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A previous study of apartment building evacuation drills showed that as many as 25% of the occupants mentioned not hearing the fire alarm from inside their apartments. A new experiment was developed to observe evacuation drills and to measure the sound level of the fire alarms in three high-rise apartment buildings. These buildings, built during the 1980's, met the local building regulations regarding the provision of fire alarms at the time of construction. Each building contained approximately 200 apartments, with 1 to 4 persons per apartment. For each building, the printed fire safety procedures stated that all occupants should leave the building or move to an area of refuge, upon hearing the building fire alarm.

During each evacuation drill, video cameras, were located in corridors and staircases, to record the movement time and behaviour of occupants. Using a digital audio tape recorder, precise sound samples of the fire alarm and background noise were taken from different locations in the buildings. Analyses of the alarm sound spectrum and levels were performed. Results confirm the subjective assessment of occupants who mentioned not hearing the fire alarm in specific locations of the building. It was also found that, in some other areas, the alarm was overpowering. The impact of alarm audibility on fire safety is discussed.

INTRODUCTION

A series of field studies was developed to collect real data on occupant response and evacuation times during fire drills in apartment buildings. This information will support the development of realistic computer models on human factors during building evacuations, as part of the overall fire risk and cost assessment computer model called FiRECAM, at the National Research Council of Canada (Yung & Hadjisophocleous, 1993). The results of such field studies are being used to bridge the gap between common assumptions and actual human response during building evacuations. The buildings chosen for the field studies were located in different Canadian cities to take into account a variety of locally-employed evacuation strategies.

In the first study (1993-94), four evacuation drills were carried out in mid-rise apartment buildings. Each building, of 6-7 storeys, contained approximately 100 apartments and 200 occupants (Proulx et al., 1994; Proulx & McQueen, 1994). In a second study (1994-95), three evacuation drills were carried out in high-rise apartment buildings. These three buildings were 12-15 storeys high and contained over 200 apartments with 2 to 4 persons per apartment. The occupants in both studies included adults, teenagers and children, as well as seniors and people with disabilities. The buildings in both studies had been built between 1975 and 1985 and met the local building codes at the time of construction. These buildings received annual fire safety inspections. In each building, the printed fire safety procedures stated that all occupants should leave the building or move to an area of refuge when hearing the building fire alarm.

The evacuation drills in both studies used the same methodology. The drills were recorded by video cameras located in the corridors, staircases and exits of the buildings. The videotapes showed the actions of every occupant from the time at which they left their unit to the moment that they reached safety. After the drills, a questionnaire was distributed to each unit asking occupants if they had heard the fire alarm and to list the chronology of their actions after hearing the fire alarm. On average, 45% of the questionnaires were returned.

Each drill was planned and carried out with the full participation of the local fire department. To start a drill, a resident on the 4th floor was asked to pull the fire alarm. In all buildings, the alarm-bells started ringing immediately.

OCCUPANT TIME DELAY TO START EVACUATION

The results of the first study showed that the time at which occupants left their apartments and started their evacuations varied enormously among the buildings (Proulx, 1994). Building 1 had the shortest average time delay to start to evacuate of 2:30. It is important to note that this building was the only one in the study equipped with a fire alarm speaker in the bedroom of each unit. The post-evacuation questionnaires showed that all the occupants heard the fire alarm. The other three buildings had fire alarm systems with alarm-bells located only in corridors and staircases. The post-evacuation questionnaires showed that 25% of the occupants of Building 2, and 23% in Building 3 did not hear the alarm-bells from inside their apartments. The average time delays to start evacuating for these two buildings were 8:22 and 9:42. Many occupants of these buildings had to be notified of the

evacuation by neighbours or firefighters who arrived 5 to 8 min after the fire alarm. Some occupants reported that they learned the drill was going on when they heard the siren of the fire trucks arriving at the building. Some people in these two buildings took as long as 25 min before starting to evacuate. In Building 4, the average time delay was 3:08. The post-evacuation questionnaires showed that 17% did not hear the alarm but, since these occupants were located on the lower floors, they started their evacuation fairly early when they saw movement of other evacuees at the front of the building.

It was expected, in this first study, to observe that people take some time before starting to evacuate. This time delay is the time needed for occupants to get dressed, gather valuables and to find pets and children. It was not expected, however, that the alarm-bells would not be heard by some occupants, thus considerably delaying their time to start.

This finding brought out unexpected questions regarding the audibility of building fire alarms. Considering that in the post-evacuation questionnaire a significant proportion of occupants mentioned not hearing the alarm, could it be explained by some hearing limitation or was the alarm not audible in their apartments due to sound attenuation? (Sultan & Halliwell, 1990) To determine the problem, it was decided to precisely measure the sound of the fire alarm in a second series of field studies.

HIGH-RISE APARTMENT EVACUATIONS

Three high-rise buildings (Buildings 5, 6, 7) were studied using the same methodology as the first study. The buildings, built between 1975 and 1982, had 12 to 15 storeys and contained approximately 300 occupants each. The three buildings were rectangular in shape with a central corridor, two elevators located approximately at the centre of the building and a staircase at both ends of the central corridor. The building fire alarm was equipped with alarm-bells located exclusively on one of the walls of the central corridor on each floor.

Building 5 had 2 alarm-bells, one of 15 cm and one of 25 cm diameter, on each floor area of 2500 m². During the evacuation drill in this building, the fire alarm malfunctioned

and shut off after 5:18. The few occupants who had time to start their evacuation had an average time delay to start of 1:30. The post-evacuation questionnaires showed that 19% of the building occupants did not hear the fire alarm. Building 6 had 2 alarm bells, each of 15 cm diameter, for each floor area of 725 m². The average time delay to start evacuating was 2:48 and 12% mentioned not hearing the alarm. Finally, Building 7 had 5 alarm-bells, each of 15 cm diameter, on each floor area of 1300 m². The average time delay to start evacuating was 5:43 and 21% mentioned not hearing the alarm in the questionnaires.

ALARM SOUND MEASUREMENTS

The sound of the fire alarm was measured during the fire drills in the three high-rise buildings. The first series of measurements was carried out one hour before the drill to measure the ambient sound. The measurements were taken using a type 1 microphone (Cirrus MK 224) plugged into a digital audio tape recorder (TEAC DAP-20). Different samples of approximately 15 to 20 seconds duration were recorded in different rooms of different units as shown in Figure 1. In the units the sound measurements were taken from the center of the room with the bedroom door open and closed, the window open and closed and the air conditioning on and off. During the drill, a second series of measurements was taken in the same rooms. The rooms were selected in order to give a good representation of the different apartment locations in the buildings. Some rooms were close to an alarm bell while others were far from the alarm bell.

Data gathered were analyzed using a Toshiba T-5200 computer equipped with a digital-to-analog board and two specialized software packages. The first software package, dBFEFE, gives the 1/3 octave band levels (80-8000 Hz) and the overall level in dBA of each sample. The second software package, Detectsound™, was used to analyze the audibility and recognition of the alarm for different background noises recorded in the different apartments. The audibility was assessed taking into account the hearing status of hypothetical persons; for example a group of 55 year old men with normal

Figure 1: Building 6, floor plan and locations of sound samples taken

Table 1: Overall sound pressures without and with the alarm in different rooms of different apartments of Building 6

Apartment	Room	Overall sound pressure	
		without alarm dBA	with alarm dBA
508	bedroom, door closed	55	55
506	bathroom, fan on	55	53
	bedroom, door closed	40	40
	living room	36	51
505	bathroom, fan on	57	56
	bedroom, door closed	38	44
	living room, TV on	52	56
501	bathroom, fan on	65	63
	bedroom, door closed	42	44
	living room	41	50
Staircase	5th floor	37	68
Corridor	1 m from the 15 cm bell	44	94

hearing according to age and a group of 55 year old men with a mild to severe hearing loss.

The results presented in Table 1 were obtained using the dBFE software. This table shows the overall levels in dBA for Building 6 when the alarm was turned off and on in different rooms of different apartments, with the main door closed as well as in the staircase and the corridor.

Table 1, clearly shows that, with or without the alarm, the overall sound pressure levels were almost identical in some units. In the bathrooms, these results can be explained by the fact that a fan came on automatically with the light, causing the overall sound levels to be dominated by the fan noise. In the bedrooms and the living rooms, the alarm was sometimes loud enough to be heard but it seemed doubtful that this sound level could attract attention and be recognized as being a fire alarm, especially at night when people are sleeping. The sound pressure in all bedrooms was too low when compared to the ISO 8201 standard, which stipulates that *"...the signal shall be 75 dB at the bedhead with all doors closed."* (p.2) (ISO, 1987). The sound of the alarm was very high, however, in the corridors reaching levels of 94 dBA which can cause temporary hearing loss and can be very annoying to evacuating occupants since it makes communication difficult. To further assess the audibility of the fire alarm, Detectsound™, a software package for alarm analysis, was used.

ALARM AUDIBILITY

Detectsound™ is a software package developed by the University of Montreal Groupe d'Acoustique to evaluate and help in the selection of warning sounds (Laroche et al. 1991, 1993). The software analyzes the audibility and recognition of the alarm considering the background noise, the hearing status of the receivers, and if appropriate, the use of hearing protectors. Different algorithms, based on scientific literature and experimental studies, are included in the software. They allow comparisons to be made between: a) the spectral content of an alarm measured at a specific location and b) the audibility "design window" calculated according to the background characteristics and the hearing status of the receivers, which refers to the hearing thresholds and the frequency selectivity of the ear. Hearing thresholds in noise are computed for each 1/3 octave band and 10 to 25 dB are added to these values in order to ensure that the alarm will not only be detected but also attract attention and be recognized. The design window goes from 125 to 3000 Hz in a way to take into account that spectral elements over 3000 Hz can be missed by people suffering from different kinds of hearing losses, for example, older people or workers exposed to noise.

Figures 2 to 5 illustrate some of the results obtained with Detectsound™ for the fire alarm analysis of Building 6. In

Figure 2: Audibility Design Window for a 55 year old man with normal hearing - Living Room of Unit 506

these figures, the x-axis represents the frequency content in hertz (Hz). The y-axis gives the sound pressure level (dB SPL). Measurements of the spectral content of the background noise is represented by the horizontal continuous line and the alarm level by the vertical lines for each 1/3 octave band. For the buildings studied, the alarm is often lost in the background noise making it difficult to extract its exact spectral content. The diagonal hatched area represents the audibility design window into which the alarm should have a minimum of three spectral elements in order to meet the requirements of audibility. The spectral elements reaching the audibility design window are represented with a thicker line.

In the living room of unit 506, only two spectral components reach the audibility design window for a 55 year old man with normal hearing, as shown in Figure 2. These two spectral elements might be loud enough for normal hearing subjects but would be missed by people with mild to severe hearing loss (from 1 to 8 kHz) as shown in Figure 3. It should be noted that in Figures 2 and 3, the background noise level and the alarm level are the same, the only difference is

the hearing status of the receivers. The hearing status of the receivers changes the shape of the design window which becomes an important factor in an alarm audibility analysis. Figure 4 shows that in the bedroom of unit 506 with the door closed, the alarm is completely lost in the background noise, except for a few 1/3 octave bands which do not reach the design window. Without paying attention and being awake, it is almost impossible for an occupant to hear the fire alarm under such circumstances.

Figure 5 shows that the alarm met the audibility requirements in the corridor with four spectral elements reaching the audibility design window. There is, however, eleven spectral elements exceeding the design window and a series of high level/high frequency elements, confirming the intense sound pressure at that location.

The overall results for the three high-rise apartment buildings in the second study show that, in many rooms of different units, the fire alarm had a low audibility while in the corridors the sound pressure was very high.

Figure 3: Audibility Design Window for a 55 year old man with mild to severe hearing loss - Living Room of Unit 506

Figure 4: Audibility Design Window for a 55 year old man with normal hearing - Bedroom of Unit 506

Figure 5: Audibility Design Window - Corridor of Building 6

CONCLUSIONS

From the analysis, it appears that not only the overall sound pressure level but also the sound spectrum and the location of alarm-bells, have a major impact on the audibility of the fire alarm throughout the building. Locating the alarm-bells in the corridors or staircases does not ensure that occupants will hear the alarm from inside their units even if the sound pressure is set at a very high level. More importantly, locating alarm-bells in corridors seems counter-productive because once the occupants have left their units to evacuate, they no longer need the sound of the alarm to be alerted of the danger. In the buildings studied, the sound of the alarm in the corridors was so loud, that exchange of verbal information became impossible and occupants could not discuss a plan of action. Furthermore, the mobility-impaired people, who had been moved to a safe area on the same floor, had to suffer the deafening sound of the alarm for over 15 min. Alarm-bells with a lower sound level in every apartment appear to be a more efficient means of alerting occupants of a possible fire. It could be suggested that alarm-bells may not be needed in the corridors and staircases of apartment buildings. Nevertheless if alarm-bells appear needed, then they should have a low sound pressure to allow people to exchange information.

It is important to remember that fire alarms are installed to alert occupants that an emergency exists. If the occupants cannot hear and recognize the alarm, it entirely defeats the purpose of having fire alarms. Since fire departments prefer to have occupants reach ground level, or an area of refuge, by the time they arrive at a building, it is essential that everyone hear the fire alarm immediately when activated to start their evacuation with a minimal delay. The 1995 National Building Code of Canada will have provision for an alarm-bell in every suite of new apartment buildings which, hopefully, will solve the problem in the future. Meanwhile, however, there is a very large existing building stock where alarms may not be audible by all occupants.

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