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SPECIAL ISSUE PAPER

Analysis of response behavior of people in fire incidents where residential fire alarms successfully worked

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SUMMARY

All residential homes in Japan have been required to install residential fire alarms since 2006. According to a survey by Tokyo Fire Department in 2011, the installation rate of residential fire alarms per household within the jurisdiction of the Tokyo Fire Department is 80.6%. The authors carried out an analysis of reports of cases, where residential fire alarms successfully worked. The information in these real fire incident reports is very useful for us to understand the actual circumstances as well as the behavior of the people involved in and nearby a fire incident. In many cases of successful activation of fire alarms for fires originating in a living room and bedroom, the occupants were likely to be in sleeping in the room of fire origin and did not become aware of the fire alarm, even if it sounded. By contrast, other family members and/or neighbors outside the room of fire origin were more likely to hear the sound and initiated the response activity to the fire incident. This indicates the potential for persons in the room of fire origin at the time of fire to be saved by others nearby because of the activation of residential fire alarms, even if they are sleeping and do not respond by themselves to the alarm sound. Copyright © 2017 John Wiley & Sons, Ltd.

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1. INTRODUCTION

The installation of residential fire alarms is one of the key fire protection measures for reducing fire deaths and injuries in residential homes. Therefore, in the past few decades, smoke alarms have been popularized in many countries. The main concerns in this study are firstly to know what kind of actions are taken by the people in the vicinity of a fire after a fire alarm activation and secondly to review the potential role of residential fire alarms in reducing fire deaths and injuries of especially mobility-impaired people such as the aged.

The previous studies related to the main targets of our study can be divided into three groups such as (1) statistical analysis on response behavior and the effects of existence of working smoke detectors on casualties reduction [1–4], (2) specific descriptive studies of human behavior in case of fire based on interviews and the like with persons who survived the fire [5–8], and (3) experimental studies and literature review of related papers on the relation between sound of residential fire alarm and arousal of persons [9, 10]. Furthermore, the fire statistics reports of each country [11, 12] are also considered as those in the group (1).

As a representative one of the studies in the first group, David Rohde *et al*. [1] collected a number of past studies that contain statistical analysis on the relationship between the presence of residential fire

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alarms and the occurrence of casualties. They examined the many facets by meta-analysis based on the documents, especially the data by Marty Ahrens [2] and the unpublished raw data on fire incidents by the Queensland Fire and Emergency Service in Australia. From the results, they pointed out that the existence of working smoke detectors has an effect in reducing the probability of fire deaths roughly by half. In the meantime, Amy Harpur *et al*. [4] presented an analysis of the circumstances surrounding elderly dwelling fire fatalities based on coronial reports. They pointed that the elderly people are more likely to be killed by fire even with the existence of working fire alarms compared with other adults, but this is often relating to their poor mobility and illness condition in the event of a fire. In the conclusions, they made a very important reference to the concern of a greater social issue of how elderly persons are cared for within an aging society even though the intervention strategies to reduce this risk are complicated. This issue is quite very common in many countries including Japan.

As a good example study of the second group, Lin Xiong *et al*. [5] investigated into the response behavior of people at a fire through the interviews with 182 fire survivors who had no serious injuries. Regarding the purpose and analysis, their study has a commonality to some extent to our study [6, 7], in which the response behavior of people at a fire were analyzed using the data of successful activation cases of residential fire alarms. From the results of the analysis by Lin Xiong *et al*., two-thirds of people among those who took part in the interview survey did not immediately evacuate, but took proactive behaviors such as initial fire-fighting, alerting others/neighbors, or taking out belongings, and so on. In general, people who have little fire prevention knowledge or only basic knowledge tend to take proactive actions, but many of them have confirmed safety before taking action, so they are understandable. Lin Xiong *et al*. raised the question whether or not we should evacuate immediately rather than doing firefighting and/or rescuing activity after a fire alarm, which is not recommended by conventional fire prevention instruction.

As one of the third group of studies, Ian Thomas *et al*. [9] compared the effectiveness of smoke alarms in hallways of dwellings with the same alarms in rooms but interconnected each other using full-scale models of four houses and the smoke from a variety of burning materials in a large test facility. From the results, they concluded that if there were the interconnected smoke alarms in every room in a dwelling, the probability of an occupant being killed in the event of a fire would be much lower than in the same dwelling with only hallway smoke alarms. The paper by Dorothy Bruck [10] is the literature review that discussed the influence of various factors such as age, signal frequency, background noise, hearing loss, alcohol, and many other things to arouse sleeping people by fire alarms. As a result, she recommended that smoke detector alarms are to be installed in the bedrooms so that the signal intensity is approximately 90 dBA at the maximum level.

From the review of the existing literature, we found there is a question and discussion on how and to what extent residential fire alarms work for reducing fire casualty especially of the elderly. In this regard, we should examine the potential of effectiveness of residential fire alarms from the viewpoint of reducing fire risk in both property loss and life loss especially for mobility-impaired people.

By the way, through the revision of the Fire Service Law in Japan as of 2004, all residential homes are required to install residential fire alarms. This revision made the installation obligatory in all new residential homes from 2006 and in existing homes by June 1, 2011. As seen in Figure 1, the

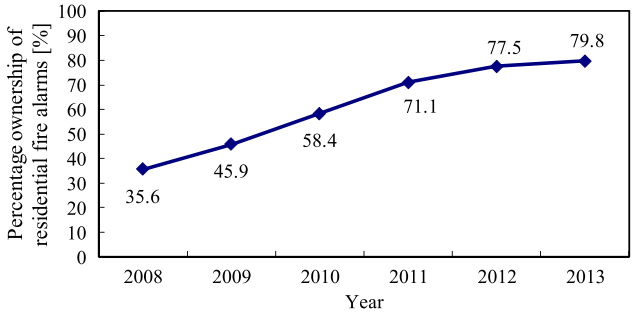

Figure 1. Yearly percentage ownership [%] of residential fire alarms in Japan [13]. [Colour figure can be viewed at wileyonlinelibrary.com]

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percentage ownership of residential fire alarms in Japan has been drastically increasing since 2008 and has almost stabilized recently [13]. During the same period for 2008 to 2013, the number of fire deaths has been slightly declining, but it is not so obvious whether or not this reduction trend has been brought by the increase in fire alarm ownership in Japanese homes at present.

According to the survey by the Tokyo Fire Department in 2011 [14], the installation ratio of residential fire alarms per household within their jurisdiction was 80.6%. For a number of years, the Tokyo Fire Department has been collecting reports of cases involving the successful activation of residential fire alarms. In these cases, they identify the effectiveness of fire alarms' activation in reducing the consequences of the fire incident. Alongside the popularization of residential fire alarms, the cases, where residential fire alarms successfully work for saving life and property loss, have been increasing year by year, for example, 253 cases in 2009 and 459 cases in 2010.

The authors think these successful activation cases include valuable information that indicates not only the effect of residential fire alarms but also response behavior of people at the very beginning of fire. With the cooperation of the Tokyo Fire Department, the authors have carried out the analysis using the data of the cases where residential fire alarms successfully worked. In this paper, the results of the analysis are presented; this includes information on the circumstances of the fires, along with analysis of the response behavior of people nearby the location of fire origin at the activation of residential fire alarms.

2. DATA USED FOR THE ANALYSIS

The data of cases of successful activation of residential fire alarms used in the analysis are derived from 660 reports collected by the Tokyo Fire Department in 2009 and 2010; those call outs that did not lead to fires and arson fires are excluded. Here, in order to adequately estimate the effectiveness of the presence of residential fire alarms, the arson fires were excluded because these fires tend to quickly grow, as they are intentionally set and hence may reduce the response time of residents as is normally expected.

Of these, 535 reports relate to cases where the residential fire alarms worked successfully for kitchen fires and 125 reports are the cases where they worked successfully for fires in a living room or a bedroom. Each report contains a detailed commentary regarding how people found and reported a fire and how they carried out fire-suppression activities in addition to coded records of fire cause and the attributes of persons related to a fire incident.

Table I compares the causes of fire in living rooms and bedrooms in Tokyo in 2009 and 2010 for the cases of successful activation of residential fire alarms and all residential fires, respectively. Because the percentages of major items of cause of fire for the cases of successful activation of residential fire alarms are similar to those of all residential fires, the analysis of human behavior description obtained by the cases of successful activation must be useful for us to understand the actual situation of fires as well as human behavior of the people related to and nearby real fire incidents.

An example of a successful activation cases is shown in Table II and Figure 2. The report of successful activation cases includes the items and the contents indicated in Table II. As shown, it is very interesting and informative because the cause and location of the fire, the person who found and reported the fire to the fire station, who carried out an initial fire suppression, and so forth (hereinafter these people are to be collectively called 'persons concerned') are recorded in a descriptive format. In this paper, the authors have analyzed these successful activation cases of residential fire alarms from the following two viewpoints.

Firstly, the locations of residential fire alarms and persons concerned at the fire together with the room of fire origin were analyzed. Secondly, in order to examine how fire casualties are mitigated by the activation of the residential fire alarm, the authors determined the location of the persons concerned, their age, and whether they were sleeping or not. The persons concerned in the aforementioned cases naturally include persons involved in the fire ignition, those who discovered the fire, those who reported a fire to the fire station, and those who attempted extinguishment and/or rescuing. Here, it should be noted that these categories are not mutually exclusive, that is, they could have been the same person.

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Table I. Breakdown by cause of fire of successful activation cases of fire alarms and all residential fires in living rooms and bedrooms in 2009 and 2010 in Tokyo.

Cause of fire		The cases of successful activation of fire alarms		All residential fires	
Major item	Subsection	Number of the cases	Composition ratio (%)	Number of the cases	Composition ratio (%)
Cigarette		42	33.6	365	30.3
Electrical appliances		28	22.4	295	24.5
	Electrical appliances	14		69	
	Wiring accessories	14		141	
	Others	0		85	
Naked flame		19	15.2	137	11.3
	Candle	16		29	
	Incense stick	3		25	
	Others	0		83	
Space heater		17	13.6	139	11.6
	Oil heater	5		28	
	Electrical heater	12		111	
	Others	0		0	
Cooking stove		5	4.0	28	2.3
Play with fire		3	2.4	28	2.3
Others		2	1.6	82	6.8
Unknown		9	7.2	129	10.7
Total		125	100.0	1203	100.0

Table II. Example of recorded information in a successful activation of a residential fire alarm case.

No.	Items recorded	Contents
1	Type of use	Residential use (one-family and two-family homes)
2	Type of construction for fire protection	Fire-proof construction
3	Extent of fire damage	Small fire confined to a fire origin
4	Number of fatality	0
5	Number of injured	1
6	Room of fire origin	Kitchen
7	Type of detector	Smoke detector
8	Location of the activated fire alarm	Kitchen
9	Cause and process of fire	A resident, female (84 years old), put a fry pan on a gas cooking stove in a kitchen and moved to the adjoining room leaving the pan. As she slept, the pan burned off and generated smoke.
10	Discovery, notification and fire extinguishing	After a short sleep, the aforementioned resident heard the sound of a fire alarm and went to the kitchen and turned off the gas cooking stove. A woman (35 years old) happened to pass outside nearby the house of fire origin and heard the sound of the fire alarm. She then made an emergency call 119 to a fire station with her mobile phone.

3. CASES WHERE A FIRE ALARM SUCCESSFULLY WORKED FOR KITCHEN FIRES

In the jurisdiction of the Tokyo Fire Department, the number of successful activation cases of residential fire alarms for fires originating in a kitchen in 2009 and 2010 was 535. The results of an analysis of the positional relationship between the room of fire origin, the location of the first activated residential fire alarm, and persons concerned are shown in Table III and Figure 3.

In Table III, the breakdown by dwelling types in numbers is given by apartments (Top), one-family and two-family homes (Middle), and for the sum of these (Bottom) in each cell. It should be noted that the same individual could be involved in different response behaviors associated with the fire. The category of locations in the leftmost column in Table III shows the places of fire alarms or the

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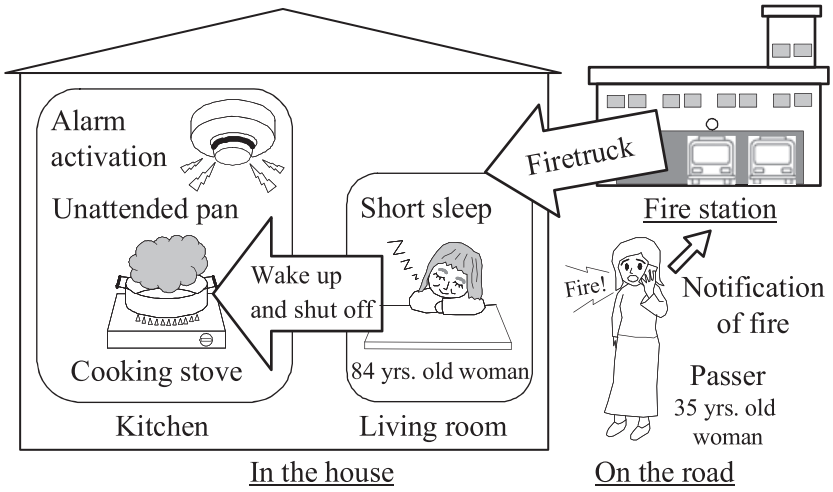

Figure 2. Illustration that shows an example of a case of a successful activation of the residential fire alarm.

Table III. Positions of key persons concerned with the fire relative to the room of fire origin in the successful activation cases for kitchen fires.

	Activated fire alarm and category of person concerned				
Category of locations	Number of activated fire alarm	Person related to ignition	Person who heard the fire alarm	Person who reported a fire to fire station	Person who tried to extinguish and/or rescue
Room of fire origin	271	64	29	18	15
	134	14	10	7	5
	405	78	39	25	20
Same building but another home	2	1	167	169	24
	0	0	0	0	0
	2	1	167	169	24
Outside the building concerned	0	101	68	95	51
	0	47	75	97	31
	0	148	143	192	82
Others	0	2	0	1	9
	0	2	4	8	6
	0	4	4	9	15
Unknown	6	32	3	21	176
	1	16	4	13	69
	7	48	7	34	245
Total	368	368	368	368	368
	167	167	167	167	167
	535	535	535	535	535

Top: apartments; middle: one-family and two-family homes; bottom: total of them in each cell.

persons involved in a fire incident when fire alarms activated. And each column from second to sixth in Table III shows the number of activated smoke alarms and the numbers of concerned persons in each category that was counted as each one per fire incident. In fact, for example, there may be plural people who heard the fire alarm, but the recorded person in a report was the first person to hear the alarm.

From Table III, it is evident that residential fire alarms installed in a kitchen comprised 76% (n = 405) of the 535 successful activation cases. Further analysis revealed that persons related to ignition were in the room of fire origin in only 15% (n = 78 cases) of all cases, that is, in the other 76% (n = 404 cases), persons related to ignition were in other rooms in the same building or outside the building at the time of fire. Those who discovered the fire by hearing the alarm were located elsewhere other than the kitchen at a fire in many cases that counted in 93% (496 cases) out of 535

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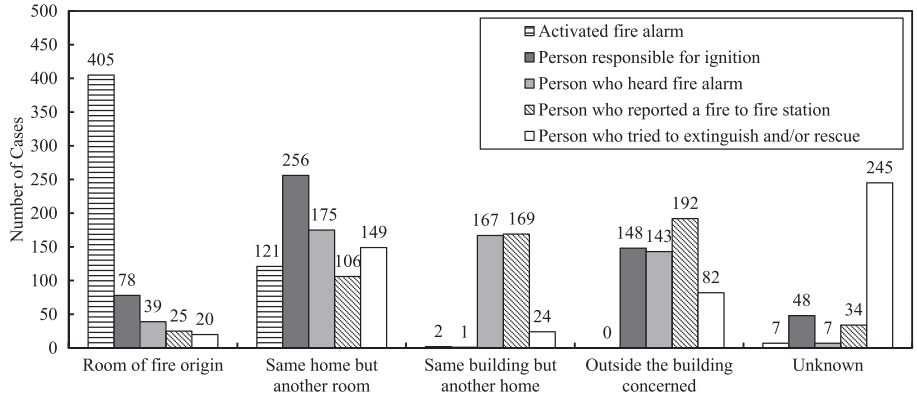

Figure 3. Positional relationship of the room of fire origin, the activated fire alarm and persons concerned in the successful activation cases for kitchen fires.

cases. This high percentage can be explained by the fact that a typical kitchen fire occurs when a cooking fire is left unattended.

From the data for 'one-family and two-family homes', it is interesting to see that quite a large number of persons who heard the fire alarm and reported a fire to a fire station were outside the building concerned, which is roughly half of the total. These results suggest that a typical successful activation case in kitchen fires may be the one in which the fire breaks out in a kitchen where nobody is present, while the residential fire alarm detects the fire and persons who are located elsewhere other than the kitchen hear the fire alarm, investigates, and discovers the fire. A more detailed analysis confirmed that pans or frying pans on cooking stoves in the kitchen were unattended in 85% (n = 457 cases) out of 535 cases.

In addition, 15 cases among these 457 cases were prevented automatically because of the overheating prevention system of a pan bottom that is mandatorily equipped with all gas cooking stoves in Japan. With this system, the stove is automatically turned on to the low heat condition if the temperature of the pan bottom exceeds 250°C. And if the time elapses in 30 min, then the stove is turned off automatically. Because the installation of an overheating prevention system has been obligatory for all new cooking stoves in Japan since 2008, it is expected that in the future, cooking stove fires that occur by being set and left unattended will reduce in number as this type of gas stove becomes more prevalent.

On the other hand, residential fire alarms in rooms other than a kitchen were activated in 23.0% (n = 123 cases) out of 535 cases in Table III. Interestingly, among them, in 12 cases, a smoke detector alarm in a living room started to sound earlier than the heat detector alarm in the kitchen.

We compared the percentages of locations of the 'Person who heard the fire alarm first' and the 'person who reported a fire to fire station' between one-family and two-family homes and apartments based on the data in Table III. There is quite a noticeable difference in the 'person who heard the fire alarm' in Figure 4 and the 'person who reported a fire to a fire station' in Figure 5 in different dwelling types.

From Figure 4, the persons who heard the fire alarm were more likely to be in the building of fire origin but in another home for the cases of apartments. By contrast, for the cases of one-family and two-family homes, those people are more in the same home of fire origin but in another room or outside the building of fire origin. And Figure 5 shows that persons who reported fires to a fire station were more likely to be in the building of fire origin but in another home for the cases of apartments, while these people are mostly outside the building of fire origin for the cases of one-family and two-family homes.

This result tells us that the warning sound of fire alarms was heard quite well by the people outside the home of fire origin regardless whether or not they are within the building of fire origin in either case of different dwelling types. Although this may be derived from the fact that Japanese houses are relatively smaller and are less compartmentalized than the European or the North American houses,

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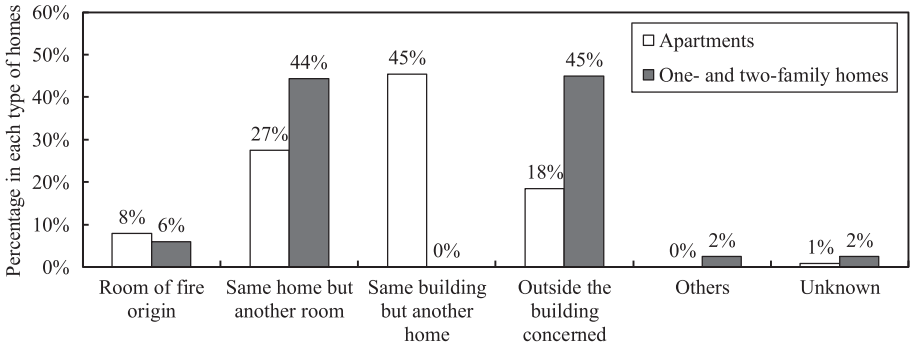

Figure 4. Comparison in locations of the 'person who heard the fire alarm first' between one-family and two-family homes and apartments in the successful activation cases for kitchen fires.

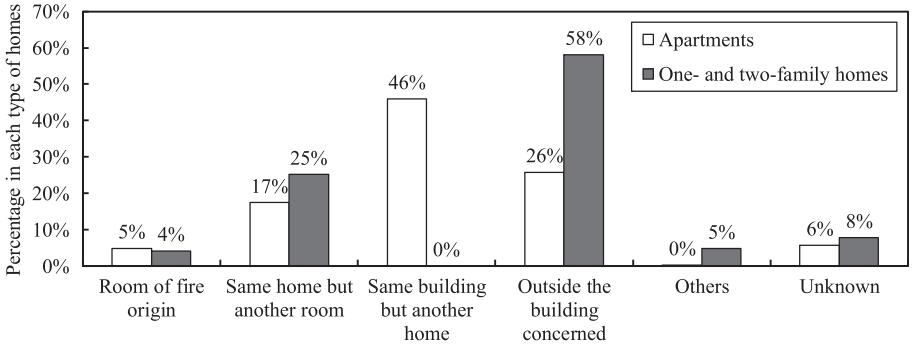

Figure 5. Comparison in locations of the 'person who reported a fire to fire station' between one-family and two-family homes and apartments in the successful activation cases for kitchen fires.

there is a considerable chance of proactive behaviors by other family members and/or neighbors such as fire-fighting and rescue activities triggered by a fire alarm.

4. CASES WHERE A FIRE ALARM SUCCESSFULLY WORKED FOR FIRES IN A LIVING ROOM OR A BEDROOM

In 2009 and 2010, there were 125 cases in which the fire occurred in a living room or a bedroom with successful activation of the residential fire alarms excluding false alarms and deliberate fires. Among these cases, four examples of typical cases, that is, two cases where the person related to ignition was in the room of fire origin and another two cases where the person was away from home, were chosen for discussion and are introduced in Table IV for reference. In every case introduced here, while the person related to fire ignition was sleeping or out the room of fire origin, other family members or neighbors noticed the sound of fire alarm and started the responsive actions to the fire.

4.1. Positional relationship of the room of fire origin, the activated fire alarm, and the persons concerned

The positional relationship of the room of fire origin, the activated residential fire alarm, and the persons concerned are shown in Table V and graphically displayed in Figure 6. In 101 cases (81%) out of a total of 125 successful activation cases for the fires in living rooms and bedrooms, the residential fire alarms were in the room of fire origin. In addition, in 51 cases (41%) out of the total, the more persons related to ignition were in the room of fire origin compared with the percentage for kitchen fires (15%). This means the delay of the detection of a fire may cause larger exposure to fire and smoke resulting in the possibility of human damage in the fires in living rooms and bedrooms.

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Table IV. Examples of successful activation cases for the fires in a living room or a bedroom.

No.	Cause of fire	Discovery, notification, and fire extinguishing
1	A halogen heater that was being used in a bedroom came into contact with bedding (futon) and ignited the bedding over time. ● A case in which a person related to fire ignition was in the room of fire origin and was sleeping. He was finally saved.	A resident, woman (71 years old), went to her husband's (76 years old) bedroom because a fire alarm installed in husband's bedroom (he was sleeping) sounded. On investigation, she found that the futon was burning. She alerted a man (79 years old) who lived in another apartment unit on the 3rd floor (Room#301). Immediately, they cooperated together to fill the washing-up bowl with tap water, pour three bowls of water on the futon and extinguish a fire. The president of a residents' association in the same apartments got a sign of the fire and reported it.
2	While watching television, a man (61 years old) was smoking. The cigarette fell on the futon and it started to smoke, so he tried to extinguish the fire with a bottle of water and is believed to have been temporarily successful. However, it was insufficient and the source of fire remained. The flameless combustion continued until flaming eventually occurred. ● The case in which person related to ignition was in the room of fire origin and was sleeping. He was finally saved.	One neighbor, a woman (57 years old), became aware of the warning sound of the fire alarm, and came down on the ground of the outside, checked the side of the veranda and noticed white smoke coming from the fourth floor. Another neighbor, a man (72 years old), who also noticed the fire made his daughter (42 years old) call 119 to report it from the telephone in his house. The man in the room of fire origin was awakened by a knock by someone at the door and poured water from a plastic bottle on the fire but he could not extinguish a fire.
3	Before going out, a resident, a woman (25 years old), smoked a cigarette, which happened to fall on the clothes. But she did not notice it and went out. Sometime later the cigarette ignited the clothes, and the fire spread to the other clothes around and the fire broke out. ● The case where the person related to the ignition was out of the house.	A man (21 years old), who lived in the same apartments, was watching television at home and he heard the sound of the alarm. He opened the front door and looked around to see what was wrong. He heard the sounding of the fire alarm in a stair on the second floor, and he saw white smoke floating from a gap in the front door of room 205. He called 119 and reported it with his mobile phone. The resident was absent when the fire broke out. The fire was suppressed by the fire brigade.
4	An electric space heater, which was kept switched on, was overturned (cause unknown) and a fire broke out. ● The case where a person in the room of fire origin was out.	The female office worker (47 years old) who lived immediately above the room of fire origin heard a warning sound in the external staircase in the same apartments on her way home. Additionally, she observed white smoke coming from a ventilation opening near the front door in the room of fire origin. She called 119 and reported it with her mobile phone. A man who lived in the neighborhood heard a warning sound, and came into the room of fire origin. He confirmed the flame around the fallen electric heater, so he trampled out the burning point under his shoe.

On the other hand, it is interesting to note that the people outside the room of fire origin such as in the same home but another room ($n = 41$, 33%) and/or in the same building but another home ($n = 44$, 35%) were more likely to hear the alarm sound first and discover the fire than the persons in the room of fire origin ($n = 18$, 14%), while this was despite the activated residential fire alarms and persons related to ignition being in the room of fire origin in many cases.

Further analysis of the circumstances of these fires suggests that people related to fire ignition were often sleeping in the room of fire origin (living room or bedroom) and did not become aware of the fire alarm in many cases of fires. By contrast, other family members or the neighborhood outside the room

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Table V. Positional relationship of the room of fire origin, activated residential fire alarms, and persons concerned in successful activation cases for the fires in a living room or a bedroom.

	Activated fire alarm and category of persons concerned				
Category of locations	Activated fire alarm	Person related to ignition	Person who heard the fire alarm	Person who reported a fire to fire station	Person who tried to extinguish and/or rescue
Room of fire origin	101	51	18	13	18
Same home but another room	23	21	41	25	25
Same building but another home	1	2	44	44	16
Outside the building concerned	0	29	21	35	8
Others	0	14	1	1	12
Unknown	0	8	0	7	46
Total	125	125	125	125	125

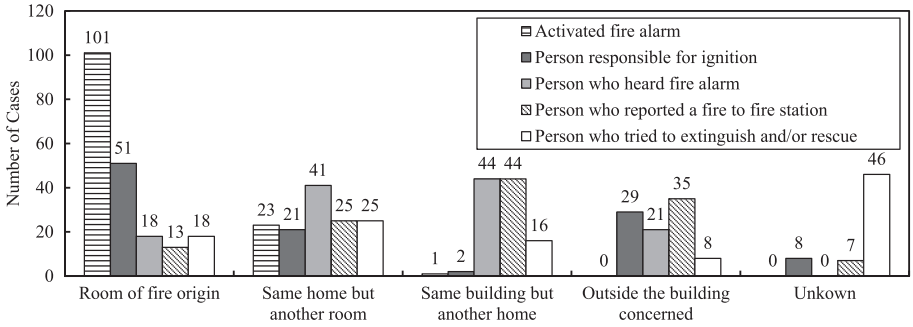

Figure 6. Positional relationship of the room of fire origin, activated residential fire alarms, and the persons concerned in the successful activation cases for the fires in a living room or a bedroom.

of fire origin were more likely to hear the alarm sound and realize the fire incident. The same thing can also be said about those who reported the fire to a fire station, that is, they were also more likely to be outside the room of fire origin than inside.

Although it used to be considered hard to rescue the persons related to ignition who are deeply sleeping and/or heavily drunk in the room of fire origin, the existence of a residential fire alarm may enable them to be rescued in the early stages of a fire by the people outside the room of fire origin who hear the sound of fire alarm.

4.2. Location of persons concerned and whether they were sleeping or not at the time of fire

Figure 7 shows the location of persons involved with the fire along with whether they were sleeping or not when the fire broke out in a living room or a bedroom. When the fire incident fell into a successful activation case of a residential fire alarm, non-sleeping cases (n = 184 people) are three times as many as sleeping cases (49 people) concerning the persons who were related to the fire incident.

This figure also shows that of the 48 people who were asleep 65% (n = 32) were in the room of fire origin, while 90% (n = 168) of those who were awake were out of the room of fire origin. This result shows that even if people were out of the room of fire origin but within the same building, the sound of a residential fire alarm was successful in notifying them of the sign of a fire quickly and made them start actions of reporting a fire to a fire station, saving a person in need, and attempting an early stage fire suppression.

4.3. Location and age of persons related to fire incident in conjunction with whether they were sleeping or not at the time of fire

Physical conditions such as an emergency reaction capability naturally deteriorate as the people age. For example, the fire deaths ratio per capita for the aged 65 and over is five times as much as that

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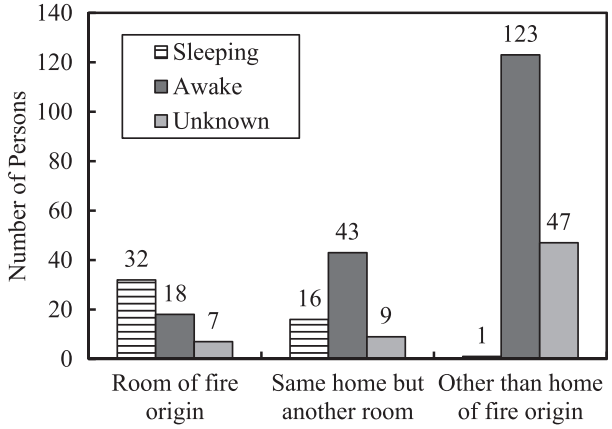

Figure 7. Relationship between the location of the individuals at the time of ignition and their situation (sleeping or awake).

for the aged 64 and under in Japan as the average of 10 years of 2000 to 2009 based on the analysis using the data from the National Fire Incident Database compiled by the Fire and Disaster Management Agency. Therefore, we took age as one of key risk factors regarding residential fires while looking at the location and sleep/awake condition at a fire.

Figure 8 shows the location of people related to the fire incident in conjunction with whether they were sleeping or not at fire ignition and also whether they were over 65 years old or not. About 24% of those aged 65 and over were sleeping compared with 19% of those aged 64 and under. Particularly with those aged 64 and under, 61% out of the total were in the same building but another home (43 people) or in the neighborhood (45 people) and most of them were non-sleeping. It was found that they heard the sound of the residential fire alarm from the outside and came to rescue the people and/or suppress the fire.

From these successful activation cases of fire alarms, it is obvious that the existence of residential fire alarms plays an important role of warning not only the residents in the room of fire origin but also the people outside the room of fire origin as well as neighbors around. As seen in this light, the results re-enforce how the relationship with one's neighbors and the mutual help in the course of a normal day are important.

5. EFFECT FOR FIRE DEATH REDUCTION BY RESIDENTIAL FIRE ALARMS

As the installation of residential fire alarms has been popularized in Japanese homes in recent years, it has become possible to estimate the reduction effect of fire damage by residential fire alarms based on

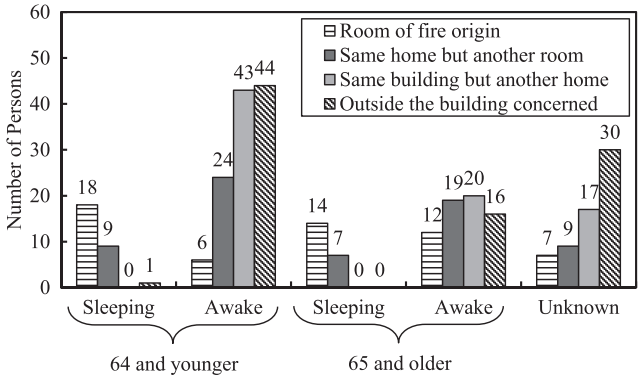

Figure 8. Relationship between the location of the individuals who stayed at the time of ignition, the age, and the situation (sleeping or awake).

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the analysis using the fire statistics in Japan. In this section, the authors investigated into the effectiveness in reducing property loss and human loss by the activation of residential fire alarms in wooden one-family and two-family homes using the data for 2009 from the National Fire Incident Database compiled by the Fire and Disaster Management Agency. In order to adequately estimate the effectiveness of the presence of residential fire alarms, the arson fires were excluded because these fires tend to quickly grow, as they are intentionally set and hence may reduce the response time of residents as is normally expected.

In Figure 9, the authors compared the property loss in terms of area of fire damage (m^2) in wooden houses. In fires where residential fire alarms were installed and activated, the area of fire damage on average was 30.8 m^2, which is 38% smaller than in those fires where residential fire alarms were absent (49.9 m^2). It is somewhat confusing that the average floor area of fire damage, where installed fire alarms did not work, is smaller than that in the cases where fire alarms were not present at all. Although this reason cannot be figured out clearly, we assume there may be the cases where the residents realize a fire cue earlier than fire alarms activate or where a fire is too small to activate fire alarms when it is found. But this intuitively strange result should be further examined in the future study.

Figure 10 shows the reduction effect of the occurrence rate of fatal fires (percentage of fires, which involves fire deaths out of the total number of fires) for both fires originating in the kitchen and fires originating in the living room/bedroom. In the cases where there was a residential fire alarm and it activated, the occurrence rate of fatal fires was 35% less for fires in living rooms and bedrooms and 59% less for kitchen fires compared with the cases where no alarm was installed. Not surprisingly

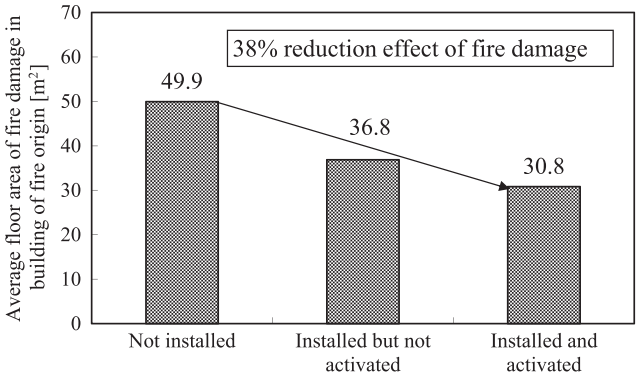

Figure 9. Reduction effect on floor area of fire damage by operation of residential fire alarms for fires in wooden houses in 2009.

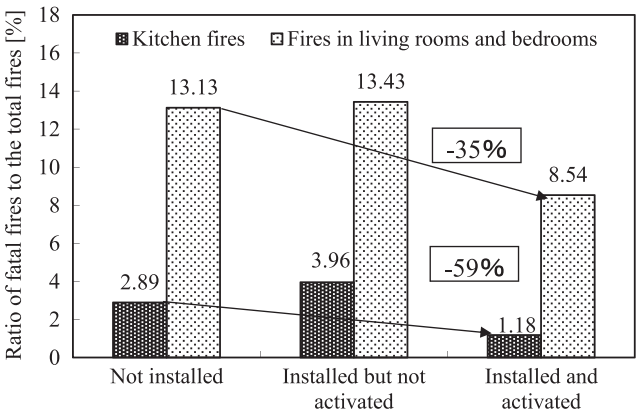

Figure 10. Reduction effect in the ratio of fatal fires to the total fires by residential fire alarms for the fires in wooden houses in 2009.

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perhaps, Figure 10 also shows that the occurrence rate of fatal fires remains much the same in those cases where residential fire alarms were installed but did not operate despite the installation.

The decreasing effect in the number of fire fatalities by residential fire alarms can be referred to be roughly half as noted by David Rohde *et al*. [1], introduced in the previous section. In addition, if the aforementioned data for fires in living rooms and bedrooms and fires in kitchens are aggregated, the occurrence rate of fatal fires to the total was 47.5% smaller in the cases where there was a residential fire alarm and it activated compared with the cases of no installation of residential fire alarms. It is worth noting that this reduction of rate of fatal fires in Japan is quite similar to the reduction of rate of fatal fires reported in the National Fire Protection Association report [2] in the USA, which shows that the death rate in fires with working smoke alarms is 45.3% smaller than the risk of deaths from fires with no smoke alarms at all.

6. DISCUSSION AND CONCLUSIONS

The installation of residential fire alarms is one of key fire protection measures for reducing fire deaths and injuries as well as property loss in residential homes. In this study, the authors analyzed the responsive behaviors of people at a fire incident in its early stage by using the data of successful activation cases of fire alarms in Tokyo in Japan. The main concern in the study was firstly to know what kind of actions are taken by the people in the vicinity of a fire after a fire alarm activation. Secondly, the authors reviewed the potential role of residential fire alarms in reducing fire deaths and injuries of especially mobility-impaired people such as the aged by the activation of residential fire alarms.

In the past, it was told that even if a residential fire alarm sounds, mobility-impaired people such as the elderly may not be saved because they have difficulty in self-evacuation. Also, if these people are in the room of fire origin and the residential fire alarm there sounds, the rumbling sound is hard to reach other rooms when the partitions of each room is solid. By these widespread impressions, it is likely to be thought that the residential fire alarm has little effect on these people. However, as Lin Xiong *et al*. [5] raised the question whether or not we should focus on evacuating immediately rather than doing active behaviors like firefighting and rescuing after a fire alarm, which are not recommended by conventional fire prevention instruction. Therefore, we should examine the potential of the effectiveness of residential fire alarms in terms of reducing casualties especially for mobility-impaired people.

In this paper, the authors analyzed the behavior of people related to and near by a fire incident together with the circumstances surrounding the successful activation cases of residential fire alarms in fires originating in kitchens, living rooms, and bedrooms in 2009 and 2010 in Tokyo. The important findings from the results are summarized as follows.

1. The reports of successful activation cases of residential fire alarms are very useful for us to understand the circumstances as well as the behavior of the people related to and near by a fire incident, because the data include very valuable information such as the locations and behaviors of people who were involved in a fire, heard the sound of the fire alarm, and did active response behaviors.
2. A typical successful activation case for kitchen fires is that a fire breaks out in a kitchen when nobody is present while the residential fire alarm detects a fire and persons who are located elsewhere other than the kitchen hear the fire alarm and discover the fire. It was confirmed that the pans or frying pans on cooking stoves in the kitchen were unattended in 457 cases (85%) out of 535 cases when the fire occurred.
3. In many cases of successful activation of fire alarms for fires originating in a living room or a bedroom, the people related to fire ignition were in sleeping in the room of fire origin and did not become aware of the fire alarm even if a residential fire alarm sounded. By contrast, other family members and/or neighbors outside the room of fire origin were more likely to hear the sound and start the active behaviors including fire suppression and rescuing.

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4. Residential fire alarms play a very important role of giving a warning not only to persons in a room of fire origin, but also to residents in the same building and/or in the neighborhood.

The aforementioned analysis shows that even when a fire breaks out while the persons, who relate to ignition such as the elderly are sleeping in a room of fire origin, other family members, or neighbors notice the sound of residential fire alarms and rush to save these people in a quite many cases. Therefore, the authors would like to make a point of showing that there will be more potential to save mobility-impaired people like the elderly by the presence and its activation of residential fire alarms. This will be realized if we shift our conventional fire safety instruction in fire such as evacuating immediately to a more proactive one such as trying to do initial firefighting, saving people who need help, reporting a fire, and so forth as far as they can confirm the safety of their behavior. And the authors think it has been already realized to some extent in Japan.

Behind this, we assume there is the influence of difference in fire protection education to public between Japan and other countries. In Japan, by a regular fire protection education, the people are taught to do proactive actions as usual such as an initial fire suppression, rescuing persons in need, getting out, and then reporting to a fire station after they find a fire. This tradition in Japan must be due to the fact that we have so many fire prone districts consisting of very packed wood house where a small fire is easily to grow to be an urban fire unless the people try to control it by themselves.

Also in connection with the previous discussion, popularizing the interconnected type of residential fire alarms, which are now moderate in price, is very expected and important because a fire alarm is perceived much earlier by persons in other rooms than a single station type as suggested by Ian Thomas [9]. This gives us more safety margin to do the aforementioned active behaviors. We should also make much more efforts to educate the public about the accurate knowledge of a fire as well as safety actions and operations to a fire.

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