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Fire Safety Strategies to Reduce Mortality in Dwellings Occupied by Elderly People: The Spanish Case

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Abstract. 77% of fatal fires in Spain take place in residential buildings, and more than 60% of deaths are people over 65 years old. The collection of fire loss data in Spain is poorly regulated and it does not have homogeneity. This makes it extremely difficult to study the fire problem and the effectiveness of different safety strategies in general, and more specifically with relation to vulnerable groups, such as the elderly. As first step to assess the measures aimed to reduce mortality in residential buildings, a methodology for collecting fire data has been developed, based on information extracted from the media. Information on 289 fatal dwelling fires has been systematically analyzed in order to identify the prevention and protection strategies more effective to prevent fire deaths. Among the identified measures, they stand out the installation of fire detection and alarm systems in residential buildings, which is not required by law at the present time, and the installation of automatic extinguishing systems, such as household sprinklers. The use of safe heating systems, avoiding old and bad-maintained portable heaters, is a particularly useful prevention strategy for the elderly people.

Keywords: Fire safety strategies, Elderly people, Residential buildings, Spain

1. Introduction

Between 2010 and 2017 there have been 1359 fatalities in fires in Spain [1–7], that is, an average of almost 170 deaths per year. In that period, fatal victims in residential fires were 77% of the total deaths in this type of accidents, which means that dwellings are the most common place where fatal fires occur, far away from the next one, exterior fires, which account for 12% of deaths [1–6].

As it happens in Spain, residential fires are the main scenario where casualties occur, accounting for closely three out four fatal fires in the United States and the United Kingdom [8, 9]. The pattern is similar in other countries, such as in New Zealand (65%), China (69.6%) or Sweden (80–90%) [10–15].

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Over the last years, significant efforts have been made to reduce the number of fire causalities with successful results, as it is evidenced in the US, where the rate of deaths per million of inhabitants has decreased by 64% between 1979 and 2007; or in the UK, with a reduction of 68% [16].

However, there are certain population groups which still have a relative risk of dying in a fire considerably higher than the general population. This is, for example, the case of the elderly people, who are known to be one of the most vulnerable groups in case of fire [8, 11, 17–30]. Despite along the last decade great advances have been made in lowering fire death rates in other population groups, such as children, fewer gains have been realized among the oldest age groups [17].

This poses a challenge for the current society, where the ageing of the population is already a reality that will be intensified over the coming years. The Spanish case is truly alarming: Despite the fire death rate per million inhabitants in Spain is considerably lower than in other countries, the percentage of fatal victims over 65 years old is one of the highest. In Spain there are 5.2 fire deaths per million population, compared to 7.6 in the UK, 8.3 in New Zealand, 12.4 in the US or 16 in Japan [16] (Fig. 1).

However, the analysis of the fatalities shows that 60.1% of fatal victims in residential fires in Spain are people over 65 years old, which contrasts with the percentage of population over the age of 65: 18.3% [31]. This means that the relative risk of dying in a residential fire is multiplied by 3.3 for the elderly people.

Other countries, which have higher fire mortality rates for the general population than Spain, have lower rates for the elderly people: the relative risk for the elderly is 2.69 in the US (35% of fire deaths, 13% of the total population). In Japan, it is 2.4 (60% of fatal fire victims compared to 25% of total population) [28, 29].

The situation, which is already critical, is exacerbated by the demographic previsions for the next decades: By 2064 adults age 65 or over will comprise 38.7% of Spain, that is, they will be more than the third part of the Spanish population.

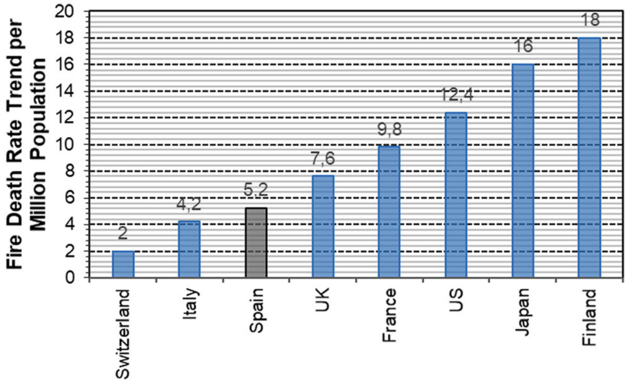

Figure 1. Fire death rate trend per million population by country *Source*: Fire death rate trends: An International Perspective (2011) United States Fire Administration [16].

By that date, life expectancy will reach 95 years old for women, and it will be 91 years old for men, and the largest population group will be people between 85 and 89 years old [32].

Consequently, knowing the demographic evolution and the profile of the fatal fire victims, the study and proposal of safety measures aimed to reduce the fire mortality rate in Spain is urgent. In fact, the downward trend in the reduction of fire fatalities in this country has a turning point in 2013, when it started growing and continues today [7].

Despite the facts mentioned above, there is not any official research which describes the characteristics of elderly people involved in residential fires. Moreover, there is no nation-wide, systematic approach to collecting fire data in Spain, although there is a law that requires it [33]. Since 1994, official statistics have not been published [1–7]. A survey was sent to all the Fire Departments in Spain, with questions about the methodology used to collect fire data. The answers indicated that the main reason that there are not official statistics is the lack of specialized staff to perform the data collection task. This action is performed in most cases, especially in small fire stations, by the same firefighters who carried out the suppression. Over time, each service has developed its own data collection system. Many Fire Departments answered that their data have been used only internally for many years, and they are not sent to Civil Protection, which is the body supposedly responsible for producing national statistics. Nowadays, the only existent documents about fire victims are those published by private entities, such as Mapfre Foundation.

The lack of fire data makes it very difficult to know which prevention measures should be applied. The identification of the risk profiles should be complemented with the identification of the appropriate safety strategies for those profiles. Therefore, a systematic assessment of the potential effectiveness of different measures should be performed, in order to develop useful safety strategies especially focused on the most vulnerable people, such as the elderly.

The aim of the present research is the analysis of real lethal fires, in order to detect which barriers could have prevented that outcome, from the beginning of the event until the death of the victim.

For the development of the study, residential fires have been chosen since they are the most common, as mentioned above. Arson fires have been discarded, as they have a casuistry that is difficult to extrapolate to an accidental fire. A total of 289 cases of fatal fires in dwellings in Spain between 2014 and 2016 have been analyzed.

2. Methodology

The methodology used in this paper is based on the research conducted by Runfors, Johansson and Van Hees in 2016, who analyzed the measures that could have prevented 144 fatal residential fires in Sweden, between 2011 and 2014 [14]. Since the aim of that study is the same that the one proposed in this research, the methodology was considered to be the appropriate for the qualitative analysis of the household fires in Spain. In turn, this methodology is based on the event analysis developed by Rollenhagen in cooperation with the Swedish nuclear industry. It consists on an event chain together with the barriers that could have stopped the progression between events.

For the study of fires in Spain, the same adaptation of the Rollenhagen methodology developed by Runefors et al. has been used, and it consists of a simplification of the event chain, whose original form is very detailed and therefore it varies from accident to accident. The new simplified event chain is more generic, and it can be adapted to any residential fire. The resulting standardized event chain is composed by 5 steps: heat source, ignition of first object, fire growth, evacuation initiated, evacuation completed (Fig. 2a).

In the steps one to three, the barriers that could have stopped the negative progression of the event are analyzed. In the steps four and five the measures that could have facilitated the positive progression of the event are studied, that is, those strategies that could have favored the successful evacuation of the occupants (Fig. 2b).

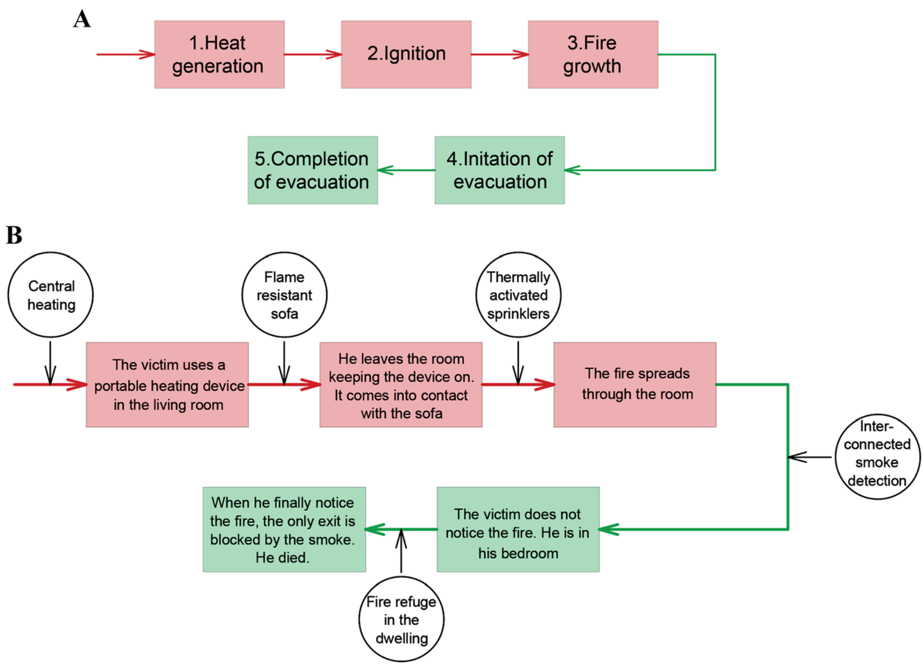

Figure 2. a The five steps of the event chain. b An example of an event chain, and possible strategies. For steps one to three, measures that could have prevented the negative progression are analyzed. For steps four and five, measures that could have favored the positive progression are analyzed.

2.1. Data

The performance of such a study in Spain is a great challenge, since, as it was mentioned before, there are not official data. However, the urgency of proposing safety measures aimed to reduce the mortality rate among the elderly in residential fires has led us to develop a methodology that tries to overcome the lack of a national fire-incident database.

The statistic treatment of the fire departments interventions in Spain is poorly regulated. In 1985 the Spanish Royal Decree 1053/1985 was promoted [33], which established the need of collecting fire data and the procedure to do it, through the use of a standard document. However, since 1994, official statistics have not been published. Most of the Fire Departments have their own resources for collecting data, but the lack of a uniform and standardized system makes the task of statistical analysis extremely difficult. In order to verify whether it was possible to extract the data from the reports developed by the Fire Services, all of them were contacted by email and they were required to answer a survey about the methodology used for the collection of data after each intervention. When the survey was designed, there were 134 fire departments in Spain, composed by 714 fire stations. 53 fire departments responses were obtained (39.6%), composed by 430 fire stations (60.2%). 41.9% of the stations that responded the survey do not collect the data about the age of the victim in their internal data-bases. In addition, each station has its own methodology for producing intervention reports, according to its resources. Only 34.8% of the fire stations that answered the survey use the official document to collect the information after an incident. For this reason, the reports made by the Fire Departments were discarded as the source of data for this research.

Currently in Spain, the only existent documents about fire victims are those annually published by Mapfre Foundation in collaboration with ‘‘Asociación Profesional de Técnicos de Bomberos’’[1] (APTB). APTB is an association which brings together most of the chiefs and technicians of the Spanish Fire Services, who lead many training and fire prevention activities. On the other hand, Mapfre Foundation is a non-profit institution created by Mapfre, a Spanish insurance company. The activities that they develop are divided in five areas: Social Actions, Culture, Health Promotion, Social Welfare and Prevention and Road Safety. This latter area is the framework for the development of the fire reports. These reports (henceforth Mapfre Reports) collect some information about fatal victims in structural fires: fatal victims by month, day of the week, community, sex and age or leading causes of fatal fires. Since 2012, the reports include a section about fatal victims in residential fires specifically [1–7]. Mapfre Reports are developed from data detailed by fire departments. They voluntarily fill out a form answering some questions related to those fires which produce fatal victims. However, the original database used in its reports is not accessible for researchers, and the data collected in their template is limited and it does not have the necessary format for the development of this study.

[1] Asociación Profesional de Técnicos de Bomberos, APTB, could be translated as ‘‘Professional Association of Firefighters’’.

Previously to the development of this research, the University of Navarra developed its own fire database, which tried to collect the data concerning all residential fires, fatal and non-fatal victims in Spain during 2016 [34]. The study confirmed that the elderly population are the most vulnerable group in case of fire in this country. The present research intends now to delve into the strategies that will allow to reduce the mortality for those risk profiles.

A methodology for collecting fire data, based on information extracted from the media, was developed, similar to the one used in the 2016 database [34]. Following personal interviews with Emergency Services workers and international experts in fire data processing, it was determined that it was the best option to conduct the research. This approach is modeled in part on the Fire Incident Data Organization (FIDO) system from the National Fire Protection Association (NFPA) in the United States, which identifies significant fires through a clipping service, the Internet and other sources.

For the extraction of the information, the tool MyNews Hemeroteca was used [35], a Spanish online newspaper archive which includes more than 1400 sources. Information about fatal fires that happened in dwellings in Spain between 2014 and 2016 was collected, in order to obtain a sample size large enough.

Mapfre Reports for these years indicate that there had been a total of 373 deaths in domestic fires, of which 322 (86.3%) were located in the media. Of these, 15 cases were discarded since further investigations revealed that they had been caused by arson fires, suicides, home violence cases… and therefore, they did not comply with the purpose of this study.

In addition, 28 fatal victims that did not appear at Mapfre Reports were found in the media. This may be since these reports are carried out with the collaboration of the Fire Departments, which voluntarily fill out a form answering some questions related to those fatal fires that have occurred at their area of operation. However, every year there are some Fire Departments that do not send their data.

The tracking system was as follows: a first search with the keywords “fire, dwelling” was carried out in the MyNews Hemeroteca browser, using a 2-day temporary filter. Once a fatal fire was located, that incident was traced with especial emphasis on local press, since it usually includes more detailed information. In this second search, the time filters were removed in order to find out whether an extension of the information was provided along the months following the accident.

The information provided in the newspapers usually included, in addition to the description of the accident, interviews with relatives, neighbors or the rescue services. Moreover, each fire appeared in several media and frequently, since there were fatalities, the incident was tracked over time. All this information was collected, and an individual document was created for each fatal fire. The information was then organized, and the facts were described chronologically.

At the end, a narrative of the incident was created, instead of a simple extraction of data. This allowed not to lose relevant information that may be ignored when extracting variables.

Then, these narrations were transformed into an event chain, in order to answer the five questions: What was the heat source? How did the ignition occur? How did the fire grow? Why did not the victim initiate the evacuation? Why did not the victim complete the evacuation?

46 of the 355 collected cases (13.7%) had to be discarded because the information obtained was very scarce and it prevented the development of the event chain (Table 1).

In addition to the incident narration, several variables are collected, in order to identify the risk profiles and to study whether the safety measures to be applied should be different for different profiles. These variables include information regarding the general context and more detailed data concerning the fatal victim (Table 2).

Two additional variables are also collected: whether the victim was in the room of fire origin or not, and whether the victim was involved in the ignition or not; since many of the potential safety strategies will not have effect if the victim is intimately related to the fire.

The last stage consists in inductively identifying the potential barriers that could have prevented the progress of the event chain from the ignition to the victim death. For that purpose, it is first described each of the events we intend to avoid

Table 1
Included and Discarded Cases in the Present Research and in Mapfre Reports

	Total	No located	Arson fires	Too short	Included in the research
Mapfre Reports	373	51	15	40	267
Only at the media	28	0	0	6	22
Total	401	51	15	46	**289**

Number of cases is highlighted in bold

Table 2
Variables Collected in the Research

General context	Type of housing
	Block of flats
	Single-family house
	Detached house
	Poor-quality house
	Number of stories of the building
	Fire floor
	Room where the fire started
	Starting time
	Number of occupants who were at the dwelling when the fire started
	Number of fatal victims
Fatal victim	Sex
	Age
	Previous diseases
	Was the victim asleep when the fire started?
	Nationality

(heat source, ignition, fire growth) or facilitate (start of evacuation and end of evacuation). Then, it is established which strategy would stop the development of the event chain, and they are introduced in an excel sheet.

It is important to highlight that the agent involved in the application of the safety measures will be different for each case. Some of the proposed strategies depend on the building designer or the development of technologies and fire safety engineering. Some measures must be enforced by the administration and policy-makers. And in many situations, the measures must be applied by the occupants of the building, or they depend on their education on fire safety [36, 37].

3. Results and Discussion

This section shows the results obtained after the analysis of the barriers proposed in order to stop the event chain which starts with the generation of heat and ends with the death of the victim.

First, the results of the analysis of the variables related to the context where the fire occurred are presented which allow to draw the risk profiles. Then, the potential barriers identified are shown, comparing their effectiveness for the general population and for the elderly people.

3.1. Demographic Data

3.1.1. Age and Gender Table 3 shows the distribution of fatal victims by their age and gender. 61.2% (n = 177) of reported fatal home fire victims in Spain between

Table 3
Spanish Fire Deaths in Home Structure Fires, by Age Group and Gender, from 2014 to 2016

Age	Gender			Total
	Males	Females	Unknown	
Under 5	8 (5.3%)	2 (1.5%)	2 (66.7%)	12 (4.2%)
5–9	5 (3.3%)	2 (1.5%)	0 (0.0%)	7 (2.4%)
10–14	3 (2.0%)	0 (0.0%)	0 (0.0%)	3 (1.0%)
15–19	1 (0.7%)	2 (1.5%)	0 (0.0%)	3 (1.0%)
20–34	6 (4.0%)	4 (3.0%)	0 (0.0%)	10 (3.5%)
35–49	15 (9.9%)	10 (7.4%)	0 (0.0%)	25 (8.7%)
50–64	28 (18.5%)	20 (14.8%)	0 (0.0%)	48 (16.6%)
65–74	24 (15.9%)	21 (15.6%)	0 (0.0%)	45 (15.6%)
75–84	30 (19.9%)	42 (31.1%)	0 (0.0%)	72 (24.9%)
85 and over	29 (19.2%)	31 (23.0%)	0 (0.0%)	60 (20.8%)
Unknown	2 (1.3%)	1 (0.7%)	1 (33.3%)	4 (1.4%)
Total	151 (100%)	135 (100%)	3 (100%)	289 (100%)
Selected age groups				
14 and under	16 (10.6%)	4 (3.0%)	2 (66.6%)	22 (7.6%)
65 and over	83 (55.0%)	94 (69.6%)	0 (0.0%)	177 (61.2%)

2014 and 2016 were over 65 years old. 52.2% of victims in the sample (n = 151) were male. It can be appreciated that most fatal victims in the 75 and older age groups were female. This is due in part to the fact that life expectancy is higher for women than for men [31], so it is reasonable that at higher age the proportion of female victims increases.

3.1.2. Previous Disabilities At least 90 victims (31.1% of the sample) suffered some type of mental or physical disability, that is, almost one out of three deaths. This percentage could be even higher, since a missing data does not mean that the victim was healthy, but that there is not information available. 69.8% of these 90 disabled victims (n = 65) were over 65 years old.

Table 4 shows the distribution of victims according to their disability and divided into two age groups: elderly and non-elderly. The percentage of people in each group over the total sample (n = 289) is shown in brackets. As it can be appreciated, the most frequent disability is low-mobility, accounting for 73.3% (n = 66) of disabled victims, and 22.8% of total fatal victims in residential fires between 2014 and 2016.

3.2. Safety Strategies Identified

The potential effectiveness of each barrier is defined as the percentage of deaths that could have been prevented if that barrier would had been in place (for steps 1–3). For steps 4 and 5, the potential effectiveness is the percentage of deaths that could have been prevented if the progression of the event chain had been allowed

Table 4
Fatal Victims in Residential Fires in Spain, from 2014 to 2016, According to Their Previous Disability and Age

	Age		
Disease	0–64	Over 65	Total
Reduced mobility (unspecified)	5 (1.7%)	28 (9.7%)	33 (11.4%)
Reduced mobility (cane, crutches, walking aid)	1 (0.3%)	11 (3.8%)	12 (4.2%)
Reduced mobility (Bedridden)	0 (0.0%)	6 (2.1%)	6 (2.1%)
Reduced mobility (Wheelchair)	4 (1.4%)	11 (3.8%)	15 (5.2%)
Total reduced mobility	10 (3.5%)	56 (19.4%)	66 (22.8%)
Alcoholism	3 (1.0%)	1 (0.3%)	4 (1.4%)
Dementia	0 (0.0%)	1 (0.3%)	1 (0.3%)
Mental disability	4 (1.4%)	0 (0.0%)	4 (1.4%)
Epilepsy	0 (0.0%)	1 (0.3%)	1 (0.3%)
Cerebral palsy	1 (0.3%)	0 (0.0%)	1 (0.3%)
Health problems (unspecified)	2 (0.7%)	1 (0.3%)	3 (1.0%)
Respiratory disease	1 (0.3%)	2 (0.7%)	3 (1.0%)
Diogenes syndrome	3 (1.0%)	2 (0.7%)	6 (2.1%)
Deafness	0 (0.0%)	1 (0.3%)	1 (0.3%)
Total	24 (8.3%)	65 (22.5%)	90 (31.1%)

(e.g. through the installation of smoke detectors that alert the fire and allow the occupants to start the evacuation).

The present study aims to extract general safety strategies, therefore, not all the identified barriers are discussed in this paper. Those that affect a low number of cases have been removed, since they are linked to a very specific type of fire and then their potential effectiveness is quite limited. Only those barriers whose effectiveness is higher than 7% have been included (that is, they could have prevented 20 deaths for the general population or 12 deaths for the people aged 65 and older).

The results are presented below for all type of fires and victims and specifically for the elderly population. The strategies shown in the following tables are not mutually exclusive, but several measures could be useful for the same fire. Therefore, percentages may add up to more than 100. In addition, the results of proportions for the general population and for the elderly people specifically will be compared, in order to find out whether any of the strategies is more effective for this group. For that purpose, the statistical significance of proportions is analyzed by Chi square testing, with a p value of < 0.05 defined as significant.

3.2.1. Strategies that Could Have Prevented the Heat Generation Table 5 shows the strategies that could have prevented the unwanted heat generation, and the number of victims that could potentially had been saved. Results are shown for the general population and for those victims over 65 years old. Between brackets, the percentage of avoided victims is presented for the total sample of elderly (n = 177) and for the total sample (n = 289).

34.3% of victims died in a fire ignited by a portable heating device, chimney or other unsafe system used to heat the dwelling. That is, 99 fatal victims would not have been exposed to a heat source if they had used a central and safe heating

Table 5
Measures for the Prevention of Heat Generation, for People Over 65 and for the General Population

	Deaths that could have been avoided	
Measures for the prevention of heat generation	Over 65	Total
Use of approved and well-maintained portable heating devices	30 (17.0%)	47 (16.3%)
Turn off heating devices before going to sleep	26 (14.8%)	41 (14.2%)
Do not use braziers (*braseros*)	31 (17.6%)	43 (14.9%)
Use central heating/safe heating systems	71 (40.3%)**	99 (34.3%)
Do not smoke in bed or sleepy	13 (7.4%)	23 (7.9%)
Put out the butts	10 (5.7%)	22 (7.6%)
Well-maintained electrical distribution	30 (17.0%)	45 (15.6%)
Use of approved and well-maintained electrical devices	23 (13.1%)	33 (11.4%)
Do not overload sockets	11 (6.3%)	22 (7.6%)
Total fatal victims	177 (100%)	289 (100%)

**p value < 0.01

system, either by water, air or electrical. 71 of these 99 people were over 65 years old. In particular, 41 victims, 26 of them elderly people, died after leaving the space heater on when going to sleep.

Pearson Chi squared test showed that the use of central heating or safe heating systems presents a significant variation in its utility for the elderly and for the general population ($\chi^2 = 6.95$, $df = 1$, p value < 0.01). In other words, this strategy proves to be more useful for the elderly than for people under 65, while the other proposed measures seem to have similar utility in both population groups.

One of the heating devices that has proven to be more dangerous is the one called "brazier". It is a widely used system in Spain, especially in the southern part of the country. Coals were traditionally used, but nowadays the use of electrical braziers is quite common. The main issue lies in their way of employment: they are placed on the floor, usually under a round table (stretcher table) and covered by a tablecloth or other fabric, and people sit around it. On many occasions, they fall asleep or they leave the room keeping the device on, then the tissue comes into contact with the brazier. At least 43 people (14.9% of the sample) died in fires ignited by a brazier between 2014 and 2016. 31 of those victims were aged 65 and older. The use of braziers is quite common among the elderly population, since it is a traditional heating system.

While in the US, Sweden, Australia, or the UK the first cause are smoking materials [8, 15, 18, 19, 24, 28, 30, 38, 39], according to both Mapfre Reports [1–6] and the research carried out by the University of Navarra [34] the first cause in Spain is heating equipment. The great percentage of people affected in this kind of fires can be explained by several common social factors in Spain. One of them is the increase of fire risk among people with low incomes, as it was confirmed in previous researches [8, 11, 17–21, 28, 34, 39–41]. The antiquity of the building was also identified as a factor that increases the risk of death in case of fire in Spain [34].

The combination of both factors—low income and an old dwelling—creates a typical scenario of fatal home fires in Spain. The central heating source of the dwelling does not work properly, or the occupants cannot afford the cost of it, or even it is not installed in the dwelling (a very usual situation in some Spanish locations, especially in the south, where up to 48% of households does not have central heating due to warm weather during most of the year [42]). Then, people use to rely on temporary sources of heat, such as portable space heaters or fireplaces, to keep their homes warm. Frequently, these devices are old and cannot be replaced, introducing a higher risk of home fire [11, 20]. The risk is particularly high for the elderly, who usually live on fixed low incomes, but on the other hand they often need higher temperatures to maintain an adequate level of thermal comfort [8].

Poorer households in Spain are generally associated with lower temperatures in winter [43], which lead to the use of portable heating appliances; and faulty electrical installations [17, 44].

The solution is therefore complex, as frequently the most vulnerable groups do not have access to safe heating systems. The development of prevention and awareness campaigns aimed at the review of portable heaters may be a first step to address the problem, emphasizing the replacement of bad-maintained, old or dangerous devices, particularly braziers, with safer appliances, such as oil radiators.

On the other hand, 15.6% of fires (n = 45) were caused by a malfunction of the electrical system. Sometimes due to failures in the fixed electrical distribution, sometimes due to failures in the electrical devices. And sometimes fires are caused by a misuse of the products, for example, when several appliances are connected to the same socket through multiple connectors and consequently, they cause an overload in the installation.

A study previously performed in Spain [44] suggested regular and detailed maintenance work in the electrical installations of those building older than 15 years in order to avoid this unwanted heat source, since they can go wrong over time. This research also affirmed that the most common source of electrical fire is indoor electric sockets, due to a faulty connection, material fatigue or overloading. Some studies in the US confirm that those electrical systems which have not been well-maintained can be compromised, since they are often outdated, inadequate or not operational. The result of that is a higher likelihood of fires caused by fraying electrical wiring, faulty heating and worn-out household appliances [17].

Consequently, education campaigns should be aimed at the regular inspection of the electrical installation, particularly for those buildings older than 15 years, and they should also focus on the correct use of the electrical appliances, avoiding the overloading of sockets, and always using approved devices which complain with the quality standards [7].

3.2.2. Strategies that Could Have Prevented the Ignition Since portable space heaters are the leading cause of residential fires, it is not surprising that several measures aimed to prevent the unwanted ignition are related to the use of these devices. As it is shown in Table 6, 40 fatal victims (13.8%)—30 of them over 65 years old (16.9%)—died in fires caused due to placing the room heater too

Table 6
Measures for the Prevention of Ignition, for People Over 65 and for the General Population

	Deaths that could have been avoided	
Measures for the prevention of ignition	Over 65	Total
Heating devices away from combustible items	30 (16.9%)	40 (13.8%)
Stove Guard	15 (8.5%)	19 (6.6%)
Ignition-proof cigarettes	19 (10.7%)	31 (10.7%)
Flame resistant mattress and bedclothes	20 (11.3%)	30 (10.4%)
Flame resistant sofa	15 (8.5%)	20 (6.9%)
Flame resistant fabrics (curtains, tablecloths)	22 (12.4%)**	25 (8.7%)
Total fatal victims	177 (100%)	289 (100%)

**p value < 0.01

close to a combustible item: the victim puts the device near to the bed and it ignites the blankets, or he/she leaves clothes drying on the heater, or, as it was mentioned before, the tablecloth comes into contact with the brazier. Placing this portable space heaters away from items that may ignite is one of the strategies that could have prevented a higher number of fatalities. In at least 19 fires (6.6%) these devices did not have a stove guard, therefore the incandescent resistors or the open flame were exposed. It is important to make the consumer aware about the importance of buying safe heating appliances, which at least have a guard to avoid the contact with combustible items.

Again, the application of these measures depends solely on the user, on the appropriate and safe use of the space heaters. Therefore, they do not depend on changes in the legislation or on the building design. However, it is important to improve the fire safety knowledge of the user, since several accidents result from errors or omissions due to a lack of fire safety education. Several fire safety education programs have demonstrated to be effective, increasing the knowledge about fire prevention strategies, although it is important to adapt them to the targeted population group, for example, the elderly [45].

Fire risk of upholstered furniture is widely known. 20 victims (6.9%) died in a fire where the first object ignited was a sofa, usually due to a space heater (30%) or a cigarette (20%). 25 people died when a fabric came into contact with the heat source, commonly the tablecloth of the stretcher table (68%). The incorporation of ignition protectors to these materials is a prevention strategy particularly useful for the elderly people, according to Pearson Chi square test ($\chi^2 = 8.25$, $df = 1$, p value < 0.05). More than 12% of fatal accidents among people over 65 years old could have been prevented with this measure.

It is usually assumed that the protection against ignition of those materials needs the addition of flame retardants. However, there are some studies which call their effectiveness into question, as the risks that the increased use of chemicals poses to health or the environment may be greater than the potential benefits they bring [14, 46]. For that reason, different alternatives are being studied, such as the addition of barrier fabrics between the exterior surface and the flammable interior foam. These barriers have demonstrated to reduce the heat release, and that their effectiveness is higher for the denser fabrics. This also applies to smoke production [46].

It was also analyzed the simple substitution of the type of fabric used. The varying flammability of fabrics have been studied since the 1940s, and now fabrics made of synthetic fibers, such as polyester, are known to be less flammable than cotton [37]. The risk of ignition is significantly lower for synthetic fabrics since they tend to melt away from the flame instead of igniting. The substitution of cotton fabrics for synthetic materials has demonstrated to reduce the risk of ignition from a cigarette from 43–86% to 2–5% [14]. The possible risk of this solution is that, in case of a flaming ignition, the consequences of the fire could be increased by this substitution as the fabric would retract from the heat, exposing the interior foam [14]. This change of materials could be justified for those fabrics which are not covering other materials, like curtains or tablecloths, even when the source of ignition is an open flame. In fact, this measure proved to be useful in the past, when the US regulated the materials used for children's sleepwear. Although the type of fabric was not specified, the law established that sleepwear garments must pass a test before being marketed. The test consisted in applying a small open flame to the garment for 3 s. After that time, the garment is removed from the exposure, and it must stop burning. In general, clothing made of untreated cotton will not pass the test, while those made of synthetic fabrics, such as polyester, will pass. The decrease of childhood deaths caused by these accidents was dramatic. This legislation minimizes not only the risk of ignition, but also the severity of the injuries, by reducing the propagation speed of the fire. The World Health Organization has included the substitution of cotton by synthetic fabrics as an accepted injury prevention strategy [37].

Not-extinguished cigarettes, or smoking materials that fall on combustible elements were the cause of 31 fire deaths (10.7%). An alternative to providing ignition protection of the fuel, is to modify the cigarette to prevent it from being a potential ignition source [14].

Several countries have investigated this path following the New York initiative in 2004, which established that all cigarettes sold must be self-extinguishing [11]. This is the case of the European Union nations, which approved a Commission in 2007 requiring the use of fire-retardant paper in all cigarettes [8]; or the private Bill recently considered by the New Zealand Parliament, which promotes the development of mandatory regulations to ensure that discarded cigarettes cannot ignite flammable materials [11]. Legislation requiring cigarettes to be self-extinguishing is also in place in Canada [8].

Many efforts have been made in research on this topic. NIST conducted tests to determine whether a cigarette made with a slower-burning paper would reduce the risk that such a cigarette, if dropped or discarded, would start a fire. They compared conventional and modified cigarettes by measuring the ignition propensities of the two type of cigarettes. The analyses showed that the modified cigarette has a lower ignition propensity than the conventional one [47]. The Cigarette Safety Act of 1984 showed that several factors influence the likelihood that a cigarette will continue burning and ignite other materials: cigarette circumference, tobacco packing density and paper properties such as permeability and the use of chemical additives. All these factors can be adjusted [37, 47].

3.2.3. Strategies that Could Have Prevented the Fire Growth Thermally activated fire suppression systems, such as sprinklers, could have prevented the death of 70 people (Table 7). This barrier was considered to be effective only when the victim was not involved in the ignition, nor in the room of fire origin; since in those cases the fire probably will be too large when the sprinkler activates, even for quick response sprinklers. In fact, the objective of the NFPA Life Safety Code is to protect occupants who are not intimate with the initial fire development, and only to improve the survivability of those who are intimate with the ignition source [48].

For those situations when the victim is not involved in the ignition, but in the room of fire origin, a more suitable option would be a detector-activated fire suppression system. This strategy could have prevented 95 fatalities (32.8%), of which

Table 7
Measures for the Prevention of Fire Growth, for People Over 65 and for the General Population

	Deaths that could have been avoided	
Measures for the prevention of fire growth	Over 65	Total
Fire extinguisher inside the dwelling	13 (7.4%)	23 (8.0%)
Detector activated fire suppression system in the bedroom	30 (17.0%)	49 (17.0%)
Detector activated fire suppression system in the living room	23 (13.1%)	30 (10.4%)
Thermally activated fire suppression system in the living room	44 (25.0%)	70 (24.2%)
Total fatal victims	177 (100%)	289 (100%)

49 were in the living room and 30 in the bedroom. Among the different type of suppression systems available, the most appropriate would be a water mist system, since it would minimize the material damage caused by the water in case of false alarm, maintaining a low cost [49]. Its effectiveness will depend on the degree of involvement of the victim with the burning object.

An international literature review confirmed that sprinkler systems are one of the most effective measures for the reduction of home fire deaths. For example, a study developed by NFPA in the US says that the death rate per 1000 reported fires was 81% lower in homes with sprinklers than in homes with no automatic extinguishing systems [50]. A study conducted in New Zealand states that the installation of a sprinkler system in the dwelling reduces the number of injuries by approximately 55% and the number of fatalities by 72% [51]. Both studies indicate that the combination of sprinklers and hardwired smoke alarms is the most successful at reducing the number of fatal victims in residential fires: the death rate was 90% lower in homes with both systems installed.

Another possible strategy for the prevention of the fire growth is to have a fire extinguisher inside the dwelling. In the present research, the measure was only considered to be effective if there was a person able to handle the extinguisher. Most of the 23 victims who could have been saved with this simple measure could not use the extinguisher themselves, but they were accompanied by a person who had the ability to put out the fire if he had the necessary resources. However, this strategy requires the installation of a detection system in order to be truly effective, since in almost all fires which could have been fought with an extinguisher, the enabled person was aware of the fire too late. The Spanish Building Code requires the installation of portable extinguishers at less than 15 m of any point of evacuation rout. This excludes the installation inside the dwellings, since they do not count as part of the route [52].

3.2.4. Strategies that Could Have Favored the Initiation of Evacuation The main strategy that could have favored the initiation of evacuation is the installation of smoke detection and alarm systems. However, it had not been effective for all situations: when the victims are not able to evacuate due to a disability or if they are involved in the ignition.

Even so, as it is shown in Table 8, it is one of the most useful strategies identified: 53.3% (n = 154) of fatal victims did not evacuate because they did not receive an early warning, therefore they died before being aware of the fire. Sometimes the victims tried to evacuate, but the fire was too developed, causing them death before they managed to leave their home. In most cases (33.2%, 96 people) the fatal victim was not at the room of fire origin, so an interconnected smoke detection and alarm system would be the most appropriate in order to ensure that the occupant is aware of the fire, even when he is not close to the fire origin. In 19 and 32 cases (6.6% and 11.1%) the victims were in the living room or in the bedroom respectively, these rooms being the origin of the fire. However, they did not realize what was happening since they were asleep.

At least 22 people (7.6%) tried to evacuate. That is, they did realize that there was a fire in the dwelling, but when they detected it, smoke and flames were too large that they were not able to reach the exit, and they were trapped and fatally intoxicated. Probably, a smoke detection system would have given instant notification, increasing the time available for escape.

39 people (23 of them aged over 65 years) died in a fire inside their dwelling, where there was a family member or a caregiver able to assist them during the evacuation, which could not be performed by themselves due to having a physical or cognitive disability. However, when they were aware of the fire it was too late, since they did not have smoke alarms installed.

The installation of smoke detectors in residential buildings in Spain is only required for those buildings which are over 50 m high [52]. However, 100% of fatal residential fires in Spain between 2014 and 2016 for which the building height data was available occurred in blocks of flats less than 50 m (n = 203, 70,2%). Only 0.37% of residential buildings in Spain have more than 10 floors

Table 8
Measures to Favor the Initiation of Evacuation, for People Over 65 and for the General Population

Measures to favor the initiation of evacuation	Deaths that could have been avoided	
	Over 65	Total
Smoke detection (total)	91 (51.4%)	154 (53.3%)
Interconnected smoke detection	56 (31.6%)	96 (33.2%)
Smoke detection (vulnerable victim, relative's alert)	23 (13.0%)	39 (13.5%)
Smoke detection (vulnerable victim, neighbor's alert)	33 (18.6%)	43 (14.9%)
Smoke detection installed in the bedroom	16 (9.0%)	32 (11.1%)
Smoke detection installed in the living room	16 (9.0%)*	19 (6.6%)
Telecare medallion	25 (14.1%)**	29 (10.0%)
Telecare medallion (prior detection)	45 (25.4%)**	47 (16.3%)
Total fatal victims	177 (100%)	289 (100%)

*p value < 0.05; **p value < 0.01

above ground [31]. None of the households where fatalities occurred between 2014 and 2016 had a detection system.

Several developed countries, such as the US, made the installation of smoke detectors compulsory years ago [48]. They are also required in countries such as Australia, UK or France, among others, where smoke detectors are mandatory in all new residential buildings [53–55]; or as in Japan, where the installation is also compulsory in old residential buildings since 2011 [25].

Different studies confirm the effectiveness of smoke detectors in reducing residential fire-related mortality and morbidity [22, 56–58], and they even affirm that smoke alarms reduce the probability of home fire death to about half [59, 60], or that fatal fires are over three times more likely to occur in a home without a functioning smoke detector, compared with non-fatal fires [11].

However, according to international studies, the installation of domestic smoke detectors appears to be less effective when elderly people are involved, particularly during the sleeping hours, due to several factors. One reason is that elderly people seem less likely to check the functionality of their smoke detector with the required frequency, especially those living alone [53]. It was also studied the reduced effectiveness of smoke detectors associated with higher prevalence of low mobility or disease conditions among the elderly [30]; or the difficulty of waking an older person due to the possible hearing loss or the ingestion of sleep aid medication [61].

These results have led to conduct researches for the optimization of the smoke alarm signal in order to make these devices also useful for the elderly population. Experimental studies conclude that the reaction of asleep people when the alarm sounds varies with the age. They recommend the installation of smoke detectors inside bedrooms, with a maximum signal intensity of 90 dBA [56]. Interconnected smoke alarms in every room in the dwelling reduce the probability of an occupant being killed in a fire compared to the same dwelling with only hallway smoke alarms [62]. The placement of interconnected smoke detectors in every floor of the dwelling and inside the bedrooms could benefit not only vulnerable occupants: Those without hearing or ageing impairments will probably hear the alarm earlier if it sounds in their bedroom. The hearing-impaired and the elderly can link the smoke detectors to additional devices such as visual and tactile alarms [61].

The detection and alarm systems that are improved to wake all sleeping occupants with the above-mentioned strategies would reduce the risk to older adults by 27–32%, compared to traditional systems (those installed in the hallways and no interconnected) [61].

Since the installation of smoke alarms is not required in Spain, some municipalities have begun to carry out smoke alarms installation campaigns in dwellings occupied by vulnerable people. This kind of interventions and programs have demonstrated to be effective in several countries in reducing the incidence of injuries in residential fires in high-risk areas [58, 63, 64]. Knowing the profile of the vulnerable populations, as well as the most appropriate detection system depending on the characteristics of the occupant, is necessary for the success of these interventions. The collection of fire data is essential for the development of this task.

The installation of these systems, as it was mentioned before, is not always effective. For example, a smoke alarm does not ensure life safety for people who is alone and mobility impaired. Nevertheless, there are studies which affirms that, even in those cases, smoke alarms may be useful since other family members or neighbors outside the dwelling could hear the warning and initiate the response activity [25]. In the present research, 33 elderly people, 43 in total, could have been potentially saved by a neighbor.

The effectiveness of this measure is very difficult to predict, since it is first necessary that the alarm sound be listened by a neighbor and then, that the neighbor show a proactive behavior, such as putting out the fire or rescuing the victim. However, the installation of smoke alarms should not be dismissed in these situations since, although its effectiveness may be lower for vulnerable populations compared to the rest of the population, at least it is possible that the emergency services will be alerted earlier—both if the alarm is listened by the victim or by a neighbor—, and thus the chances of a successful rescue will increase.

In short, the potential effectiveness of residential smoke alarms should be studied in order to reduce casualties among vulnerable groups, such as the elderly or mobility-impaired people. Smoke alarms play an essential role, not only in alerting people in the room of fire origin, but the rest of occupants of the dwelling, block or neighborhood [25].

Some Spanish municipalities have begun to promote the use of telecare medallions. These devices are given to vulnerable people (mainly elderly and disabled people) and they allow to be in contact with the emergency services or a relative in a quick and simple way. They are usually placed on the neck or on the wrist of the user, who only needs to press a button to establish direct contact with the police or a responsible person previously designated.

This kind of devices could have provided an early warning in 29 accidents, 47 if there had also been a detection system. Thus, those victims who were not able to start the evacuation due to their physical disabilities would have given a quick alert. Despite they cannot ensure life safety since it is necessary that the rescue services arrive on time to take the victims out of the dwelling, these are available tools which in some cases could be the difference between life and death. An early warning also helps to prevent the fire spread to other dwellings, and to reduce material damage and life risk to other occupants of the building.

3.2.5. Strategies that Could Have Favored the Completion of Evacuation 94 victims collected in this study died in a different room from the one of fire origin: either he was already in another room or he tried to take refuge in another place in the dwelling after being aware of the fire. However, the victim could not evacuate because there were flames and smoke between him and the exit, or he had low mobility. For these situations, the activation of a refuge linked to smoke detection inside the household is proposed as a protection strategy. When the system detects the fire, the dwelling will be automatically divided in two fire compartments, and the occupant can wait inside one of them until the rescue service arrives. If the dwelling layout does not allow this division, the fire refuge can be created in one room of the home, where the victim can go if the exit is blocked by the fire. These compartments must withstand burnout of the fuel load and they must remain tenable as long as required in order to let emergency services to rescue occupants in safety conditions [65].

34 of those 94 victims (11.8%) sought refuge inside some room of the dwelling when they became aware of the fire, since smoke and flames had blocked their evacuation route. Nevertheless, they died inside that refuge because it was not prepared to prevent the smoke to penetrate. 66 fatal victims (22.8%) could have benefited from this measure if the refuge doors would have been linked to the detection system and if they would have been closed automatically, as they were asleep, or they were mobility impaired (Table 9).

In other countries, there are standards which do limit the length and layout of the evacuation routes inside the dwellings. For example, in UK, when the dwelling is more than 4.5 m above ground, the travel distance from the entrance door to any habitable room is limited to 9 m and the cooking facilities must be remote from the entrance door. As an alternative, it is allowed that the travel distance from the entrance door to the door of any habitable room is 9 m or less, if a protected entrance hall is provided, with fire doors and 30 min fire-resisting walls. If this is not possible, an alternative exit from the flat must be provided [54].

However, the Spanish Building Code considers that the evacuation origin in residential buildings is the door of the dwelling, and therefore, the code does not limit the length of the routes inside the dwelling, and it does not require any kind of interior compartmentation [52]. Since an alternative evacuation route is not possible in most cases due to the spatial layout of existing buildings, a possible strategy for existing residential buildings is the creation of fire compartments inside the dwelling, which allow defense-in-place strategies when the evacuation is not possible.

In most cases reported in this study, the victims died inside the dwelling where the fire started (n = 278, 96.2%). Eight of the eleven victims who did not died inside the dwelling of origin were neighbors, and three of them reached the stairs, but they died before arriving to a safe place.

These data pose the need to review the Spanish Building Code approach which does not include the interior of dwellings as part of the evacuation route. Even

Table 9
Measures to favor the Completion of Evacuation, for People Over 65 and for the General Population

	Deaths that could have been avoided	
Measures to favor the completion of evacuation	Over 65	Total
Fire refuge inside the dwelling	19 (10.8%)	34 (11.8%)
Fire refuge inside the dwelling, linked to smoke detection	40 (22.7%)	66 (22.8%)
Knowledge of defense-in-place protocols	12 (6.8%)	26 (9.0%)
Total fatal victims	177 (100%)	289 (100%)

more if it is considered that most of the victims are elderly or mobility-impaired people, who may be asleep or unready to initiate the evacuation, thus pre-movement times could be significantly long [66]. Requirements similar to those of the British Standards could have provided an opportunity for the 66 fatal victims who died since they could not leave their homes because the only evacuation route was blocked, and they did not have an alternative safe refuge area.

At least 26 people (9.0%) died waiting to be rescued, and maybe they could have been saved if they had known any defend-in-place strategy, such as closing the door of the room and placing sheets or wet towels to block up the slits. Although it is highly difficult to assess how many people could actually have been saved by this measure, the knowledge of action plans in case of fire will always be an advantage.

4. Limitations

The main limitation of this research is that the information was extracted from the media, so its reliability is not absolute: It can be affected by the presence of sensationalism, inconsistencies between sources or lack of detail.

However, despite the reliability of the information is lower than the one which could have been provided by official institutions, the event narrations provided in this type of news is highly valuable for the present study. When the reported incident is a fatal fire, the story usually includes interviews with the family of the victim, the neighbors, the survivors or the rescue service, who provide their perspective of the accident and give information which otherwise would be lost in the collection of an official document.

In many cases, the fire cause does not appear in the media, since it is not found out until a subsequent investigation carried out by the Forensic Science or the competent authority. However, many of the barriers analyzed in this study are not dependent on the cause of the fire but on its development. This is the case of the automatic suppression systems, which are not dependent on the origin of the fire, but on the victim's location in relation to where the fire started [14]. Therefore, the effectiveness of the potential barriers is not totally dependent on the fire cause, and the uncertainty about it does not condition the research.

Further research in fire safety is needed, since official data is not available in Spain. Nevertheless, this work is a first step in the process of determining which targeted measures would be effective for the most vulnerable groups, through the description of the most typical fatal residential fire scenarios. This study demonstrates the necessity of collecting and analyzing fire data, in order to identify the key risk factors and take the most appropriate actions. Despite its limitations, the study has identified potential strategies for the reduction of death rates in residential fires in Spain.

This research is part of a larger investigation about fire safety in dwelling occupied by elderly people. As part of the study, the first fire database in Spain was created, with data about deaths, injuries and fires without casualties. Some of the proposed measures, such as the suppression systems, smoke detectors and alarms and refuges or compartments inside the dwelling, are being analyzed through computational modeling, applied to the most common housing typologies in Spain.

5. Conclusions

Most fatal fires have their origin in residential buildings; with elderly people being the most vulnerable group. The number of fatalities among this age groups is increasing every year [1–6, 34]. Demographic previsions show an increase of elderly population over the coming years [31], so we can expect that the number of fires continue growing in Spain, as it has happened along last years [7].

The development of a fire safety strategy is a complex process which involves many agents in the society and depends on many factors. However, a regulated system for data collection is essential in order to understand the fire problem, and how to face it. The use of fire data from other countries for the development of standards could have really bad consequences, since the demographic and architectural characteristics in each country imply singularities that cannot be ignored. For that reason, the development of a common criterion for the fire data treatment in Spain is considered necessary. For this purpose, it is recommended that all the Fire Services use an official fire data document that updates the existing one [34]. The methodologies used in countries with a long tradition of fire statistics analysis, such as the US or the UK, could be used as a model for drawing up the new document [67, 68].

Once the most vulnerable groups have been identified, it is necessary to start the development of strategies for the reduction of deaths and injuries, as well as the economic losses that occur among these groups. On the other hand, different studies suggest that the preventive strategies for the elderly people require a different emphasis from those for the general population [24, 30, 69].

The best way to prevent fire victims is not the application of reactive measures aimed at minimizing the risk after ignition, but directly avoiding the ignition through preventive measures. This is particularly important for the elderly people, who usually have difficulty fighting the fire when it started, detecting it and evacuating.

Some of the proposed solutions have a difficult—but not impossible—application in existing buildings. However, other strategies are really simple to execute, and they can save many lives per year.

Among the preventive measures, the use of safe heating systems seems to be the most effective. Several lives could be saved each year if the population, especially the vulnerable groups, would be aware of the risk associated to the use of braziers and old, dangerous or bad-maintained heating devices. It is impossible to expect that accidents can be completely prevented by only relaying on people being cautious. However, the number of fatalities will decrease, if safety solutions are developed so that a human error does not lead to a fire. Therefore, the development of fire-safe appliances which are not affected by the user age or physical conditions should be a priority in order to prevent fires, as well as to improve the health and living environment for the elderly people [29].

Among the protection strategies identified in this study, it highlights the installation of detection and alarm systems in residential buildings. In particular, those systems which are appropriate for the elderly people, with the suitable frequency and intensity, interconnected detectors in every room of the dwelling, and additional alarm devices if necessary, such as visual or tactile alarms. Another of the most useful protection strategies is the installation of thermally activated suppression systems, such as residential sprinklers.

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