Chapter 8
Methodology for the Evaluation of Fire Safety in Existing Urban Residential Areas in Spain:
The Case of Social Housing in Pamplona (1940–80)

María Fernández-Vigil
Universidad de Navarra, Spain

Carmen Corrales
Universidad de Navarra, Spain

Raquel Garin
Universidad de Navarra, Spain

Juan Bautista Echeverría
https://orcid.org/0000-0002-4438-6449
Universidad de Navarra, Spain

ABSTRACT

Residential buildings are the most common scenario of fatal fires in Spain, and over the past decade, there has been no significant decrease of fatalities in this kind of accident, even a slight increase in recent years. In this context, a systematic methodology to evaluate the risk level of residential buildings, previously grouped into building typologies, is presented. Its application to different housing typologies allows covering large urban ensembles, providing an important information to regulators and fire services. The factors that most increase the level of fire risk are identified, analyzing them both by their construction stage and by their morphology.

DOI: 10.4018/978-1-6684-4030-8.ch008

Copyright © 2022, IGI Global. Copying or distributing in print or electronic forms without written permission of IGI Global is prohibited.

INTRODUCTION

Between 2010 and 2017, there were 1359 fatal victims in fires in Spain (Fundación Mapfre & APTB, 2010, 2011, 2014, 2015, 2016, 2017, 2018), that is, an average of about 170 people per year. During this period, deaths in residential buildings represented 77% of casualties, meaning that houses are the most common scenario for this kind of fatal fires. 60.1% of these victims were more than 65 years old, this value contrasting with the percentage of people over this age in Spain, 18.3% (Instituto Nacional de Estadística, 2011). In other words, the risk of dying in a domestic fire is multiplied by 3.3 for the elderly people.

This is particularly relevant attending to demographic forecast for the coming decades: in 2064 people over 65 will be 38.7% of the entire Spanish population, which means that the elderly will account for more than the third part of the society (Instituto Nacional de Estadística, 2014). By the same date, life expectancy will be 95 years for women and 91 years for men; and the largest population group will be those between 85 and 89 years old (Instituto Nacional de Estadística, 2014).

The situation is therefore critical since, as the number of elderly people increases, it is expected that the number of deaths in residential fires will also increase. In fact, the downward trend that could be appreciated in the reduction of fatalities in domestic fires had a turning point in 2013, and it is still growing (Fundación Mapfre & APTB, 2018).

The main objective of this research is the creation of a systematic and regular methodology to evaluate and quantify the fire safety of a large number of residential buildings, and the identification of the most dangerous elements. Safety in these blocks built in the second half of the 20th century is often critical. For this reason, the conclusions of this assessment should be taken into account when considering the unavoidable urban regeneration that many Spanish cities will undergo. This renovation will be a great opportunity to solve the safety problem.

BACKGROUND

The first challenge when addressing fire safety in residential buildings in Spain is the lack of official data, what makes impossible to know what the risk factors behind fire events are and, therefore, design the more efficient measures to fight against them. At the present time, there is no nation-wide, systematic approach to collecting, analyzing and presenting fire loss data in Spain, in spite of being an essential tool for fighting against those accidents (Fernández-Vigil & Echeverría, 2019). The statistic treatment of the fire departments interventions in Spain is poorly regulated, and it does not have homogeneity. In 1985, the Spanish Royal Decree 1053/1985 about the statistical treatment in the Fire and Rescue Services was published ("Real Decreto 1053/1985, de 25 de Mayo, Sobre Ordenación de La Estadísticas de Las Actuaciones de Los Servicios Contra Incendios y de Salvamento," 1985). However, since 1994, official statistics have not been published. Every Fire Service has its own system for fire data collection, according to its resources and the regulation established in each community, region or municipality, as appropriate (Fernández-Vigil & Echeverría, 2019).

There are only few documents elaborated by MAPFRE Foundation in collaboration with APTB (Professional Association of Firefighters, *Asociación Profesional de Técnicos de Bomberos* in Spanish) collecting data on fatal victims since 2010 (Fundación Mapfre & APTB, 2010, 2011, 2014, 2015, 2016, 2017, 2018). Despite the utility of these documents, the information they present is limited and only allows us to draw a very general panorama of the problem. Recently, the University of Navarra built a database based on news, collecting all the incidents and victims, injured and casualties, of residential fires in 2016 (Fernández-Vigil & Echeverría, 2019). The research concluded that the advanced age, living in old housing units and having a low-income profile are important factors increasing the risk of dying in a domestic fire.

In this context, and for the analysis, social housing blocks in Pamplona´s suburban neighborhoods built between 1940 and 1980 were selected. These case studies were chosen due to several reasons: On the one hand, nearly 50% of the total housing stock was built in these decades (Table 1). In the case of Pamplona, 42% of these buildings are social housing, a consequence of the processes of generation of the city: large residential neighborhoods were created in order to give immediate response to the needs of the large masses of immigrant population displaced by the incipient industrial development. This process started on the 1950s, was consolidated in the 1960s and it lasted until the end of the 1970s (SAVIArquitectura, 2016). In addition, the considered blocks were built before current building regulations and, especially, any fire protection requirement, with criteria in which quantity prevailed over quality (SAVIArquitectura, 2016). Therefore, their safety conditions are usually far below what is required.

Table 1. Dwellings in Spain, Navarre and Pamplona according to year of construction. (Instituto Nacional de Estadística, 2011)

Year of construction	Number of dwellings in Spain	Number of dwellings in Navarre	Number of dwellings in Pamplona
Before 1940	2387395 (9.5%)	43445 (14.1%)	8375 (9.3%)
1940-1980	11249500 (44.6%)	123465 (40.0%)	48045 (53.3%)
After 1981	10882810 (43.2%)	136265 (44.2%)	32335 (35.9%)
Unknown	688915 (2.7%)	5435 (1.8%)	1415 (1.6%)
Total	25208620 (100%)	308610 (100%)	90170 (100%)

On the other hand, nearly 60% of fatalities in residential buildings between 2010 and 2016 lived in blocks, against a 40% of fatal victims who lived in single-family houses (Fundación Mapfre & APTB, 2010, 2011, 2014, 2015, 2016, 2017). This is reasonable considering that only 21% of the Spanish population lives in semi-detached houses and only 12.7% in detached houses (Eurostat, n.d.).

In addition, as it was mentioned above, the age of the dwellings, the age of the occupants and the socioeconomic profile are risk factors in case of fire. For that reason, buildings located in suburban neighborhoods have been selected as case studies and blocks of similar characteristics in central areas of the city have been excluded, since they are highly revalued due to their location. The selected dwellings have suffered a gradual physical decay, together with their occupation by low-income sectors of the population due to their low prices (SAVIArquitectura, 2016).

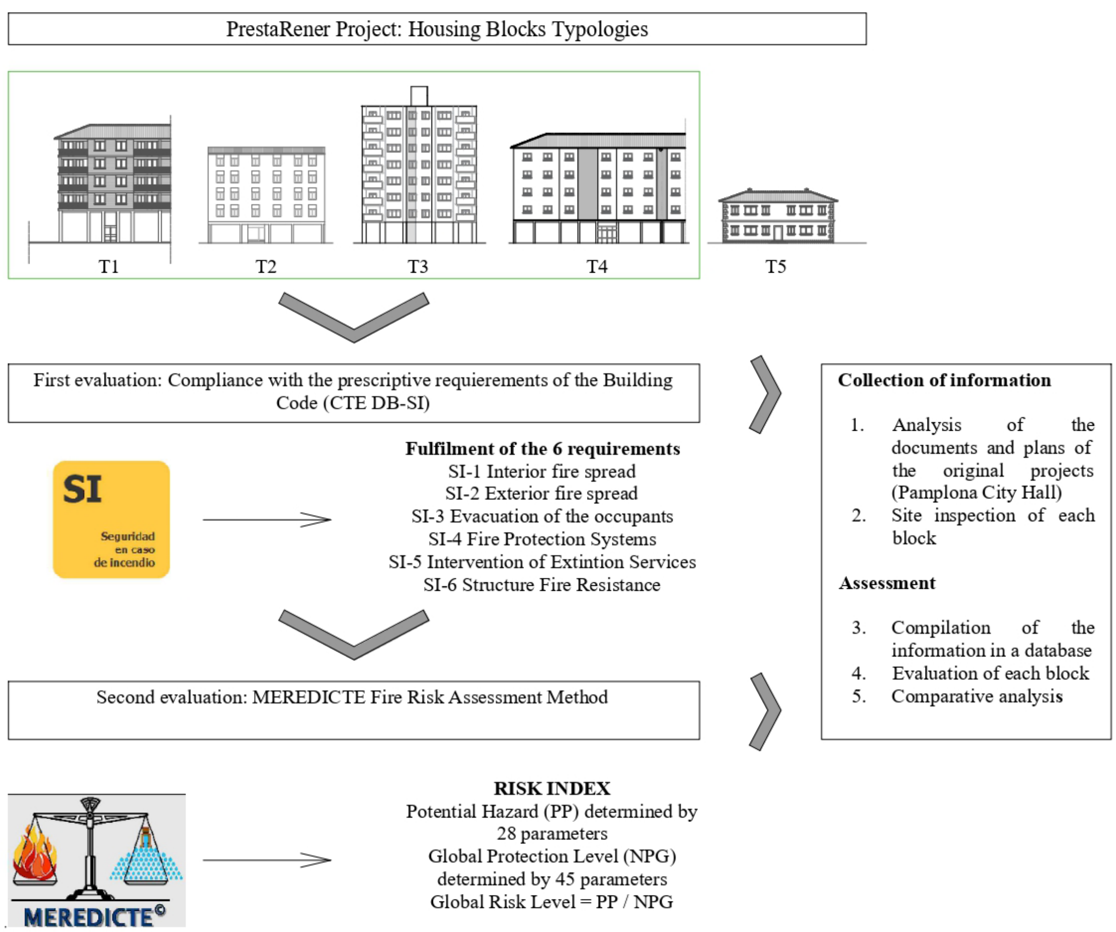
The present analysis allows us to identify which typologies and elements pose a higher fire risk. The conclusions drawn should be taken into account when addressing the urban regeneration of social neighborhoods, not only from an energy perspective, but also focused on safety.

METHODOLOGY

For this research, first of all a series of housing blocks grouped by typologies has been selected. Then, their fire risk level has been evaluated, comparing their current performance with the one required by the Fire Document, “DB-SI”, in the Spanish Building Code, “CTE” (Ministerio de Fomento, 2019b). Finally, the case studies were assessed with the Fire Risk Assessment Method MEREDICTE © (Pérez-Martín, 2014), in order to verify the consistency of the results. The different stages of the research are explained below and are shown in Figure 1.

Throughout this chapter, several references to different regulations, abbreviations and codes for the typologies are used. For that reason, a collection of all these abbreviations is presented in Table 8, Appendix 1.

Figure 1. Diagram of the methodology used in the research



Identification of the Typologies: PrestaRener Project

To carry out the analysis in an efficient way, grouping the blocks in typologies becomes a key factor. This allows covering a bigger number of buildings, identifying those with the same problems and improvement needs, and generating comparably results. The systematic analysis based on a classification by typologies has proved successful in building research (Domínguez Arribas et al., 2015; Ortega Madrigal et al., 2013; Rubio del Val, 2011; SAVIArquitectura, 2016).

In this case, the typologies identified in the prestaRener project, which was funded by the Ministry of Economy and Competitivity in Spain, have been used (SAVIArquitectura & Worcester Polythecnic Institute, 2016).

In that research, the blocks in Pamplona have been grouped by typologies according to the construction date, their morphology and height, and in sub-typologies according to the construction characterization of their components (SAVIArquitectura, 2016), all of them key factors for fire risk analysis. The repetitiveness of the identified typologies allows to simplify the risk characterization.

Table 2 shows the division in typologies and sub-typologies. The sample size has been calculated assuming a confidence level of 90%, a sample error of 5% and a variability of 0.5. The final number of blocks to be studied is shown in the last column of the table.

The initial research also included the typology number T5, single-family house, which was divided in two sub-typologies: single-family house with ground floor (T5.1), and single-family house with ground floor plus one (T5.2). However, it was discarded in this analysis since, as it was already mentioned, most of residential fires happen in blocks, which have the additional risk of the evacuation through the stairs when there are several stories.

Table 2. Total number of dwellings and sample size according to the PrestaRener typologies (SAVIArquitectura, 2016)

Typology	Sub-typology	Number of dwellings	Percentage	Sample Size
T1 Linear Block	T1.1 Linear block with nearby building environment	432	16.8%	41
	T1.2 Non-clustered linear block	576	22.4%	55
	T1.3 Linear block with one orientation	33	1.3%	3
	T1.4 Linear block with minimum courtyard	60	2.3%	6
T2 H Block	T2.1 H-block	202	7.9%	19
	T2.2 H-block, height above Ground + 4	59	2.3%	6
	T2.3 H-block with minimum courtyard	60	2.3%	6
T3 Tower	T3.1 H-tower	99	3.9%	9
	T3.3 Cross Tower	6	0.2%	1
T4 T Block	T4.1 T-block, 3 dwellings per floor	28	1.1%	3
	T4.2 T-block, 2 dwellings per floor	69	2.7%	7
T5 Single-family houses (excluded in the analysis)	T5.1 Single-family house, ground floor	78	3.0%	7
	T5.2 Single-family house, ground floor + 1	868	33.8%	82
Total		2570	100%	244

Figure 2 shows a typical floor of each typology, and Table 3 shows the main characteristics of each sub-typology.

Figure 2. Typical floor of the typologies analyzed in the study

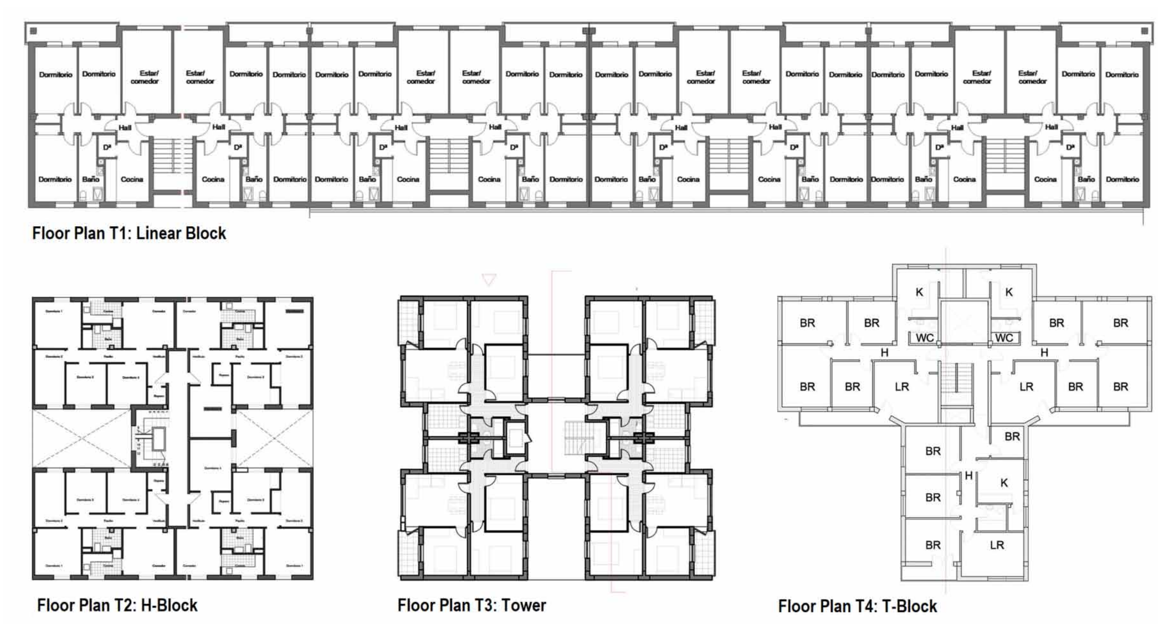


Table 3. Main characteristics of each sub-typology of the PrestaRener Project (SAVIArquitectura, 2016)

Typology	Sub-typology	Year of construction	Minimum Height	Maximum Height	Dwellings per floor	Residential use on the ground floor	Average surface area of the dwellings (m^2)
T1	T1.1	1940-1979	Ground+1	Ground+5	2	Some cases	80
	T1.2	1940-1978	Ground+1	Ground+11	2	Some cases	80
	T1.3	1950-1971	Ground+3	Ground+10	4	Some cases	85
	T1.4	1962-1979	Ground+4	Ground+6	2	Some cases	95
T2	T2.1	1959-1978	Ground+4	Ground+4	4	No	70
	T2.2	1959-1978	Ground+5	Ground+11	4	No	85
	T2.3	1954-1979	Ground+4	Ground+8	4	No	75
T3	T3.1	1961-1975	Ground+4	Ground+10	4	Some cases	80
	T3.2	1966	Ground+10	Ground+10	4	No	80
T4	T4.1	1964-1978	Ground+3	Ground+7	3	No	80
	T4.2	1963-1973	Ground+4	Ground+8	2	No	100

At the end of this section, it will be presented which typologies and which characteristics imply a higher risk of fire.

Fire Risk Assessment

The Building Code (CTE) establishes basic requirements to satisfy the objectives of habitability and safety of the buildings. According to Article 5.1, Part I, of the CTE (Ministerio de Fomento, 2019c), the designer has two options for justifying that a building complies with these requirements: either to adopt the solutions set out in the Basic Documents (prescriptive design), or to propose alternative measures whose performance is at least equivalent to those indicated in the Basic Documents (performance-based design).

In the case of Fire Safety, the objective consists in reducing to acceptable limits the risk that the building users suffer damage from an accidental fire. The Basic Document about Fire Safety, henceforth DB-SI, specifies objective parameters and procedures whose fulfillment ensures the satisfaction of the basic requirements (Ministerio de Fomento, 2019c).

For all these reasons, in order to evaluate the fire risk level in the selected buildings, the degree of fulfilment of the six requirements has been studied. If they do, it can be assumed that their risk level is acceptable. Each of the six sections refers to a basic requirement, namely: SI-1, limitation of the interior fire spread; SI-2, limitation of the exterior fire spread; SI-3, provision of adequate means of escape to ensure that the occupants evacuate the building safely; SI-4, provision of adequate fire protection systems: detection, control, extinction and alarm transmission; SI-5, means to allow the intervention of rescue and extinction services; SI-6, design of the load-bearing structure with the necessary fire resistance.

Working Method

Once the number of case studies was calculated, the working method consisted in selecting a representative sample of buildings that have been inspected, finding a coherent distribution of the affected neighborhoods for each sub-typology.

To proceed to the comparative analysis between the building characteristics and the prescriptions in the code an inspection document was elaborated. The document is divided into seven sections: On the one hand, general data, which includes basic information such as the address, typology, year of construction, number of stories, number of dwellings and areas, among others. On the other hand, the construction characteristics, where the materials of the structure, facade, roof, floor slabs, and interior partitions are described. The remaining five sections refer to the basic requirements SI-1 to SI-5. The analysis of the requirement SI-6, structural fire resistance, is a really difficult task, so it was approached with a different method, as it will be explained in the "Results" Section.

The collection of all the required information is a complex process, especially for dwellings built more than 40 years ago. To guarantee the reliability of the introduced data, the inspection had two stages.

The first one consisted in the analysis of the plans and written documentation of the original projects, in the Pamplona City Hall Archives. The review of the technical reports, as well as the economic budget and the graphic information, made it possible to extract data about the type of structure, materials, surface areas, uses and distribution of the dwellings.

However, the age of the documents made it necessary to carry out a second stage of data collection, which consisted of a site inspection of each selected block. This second phase has three objectives: to collect the information which was not provided by the original plans (especially necessary in older projects); to verify the information shown in the plans; and finally, to check whether there have been subsequent interventions. In that case, it is possible that the building has been adapted to the current fire regulations (for example, with the installation of fire protection systems) or that there have been changes which affect the behavior of the building in case of fire (such as a retrofitting of the envelope, with its consequent change of materials).

Once all the buildings were inspected, the information was compiled in an Excel data base. Then, the evaluation of the risk level of every block was completed, through the analysis of the compliance with the basic requirements. Finally, a comparative analysis by typologies and construction date completed the work.

MEREDICTE © Method

The case studies were assessed in a second evaluation, in order to verify the obtained results. For this purpose, they were analyzed with the Fire Risk Assessment Method MEREDICTE©. This method was part of the CTE between 2014 and 2020. The Royal Decree 732/2019, of December 20, incorporated modifications to the DB-SI. For that reason, the MEREDICTE© is no longer considered applicable to the current version of the DB-SI (Ministerio de transportes movilidad y agenda urbana, 2020). However, it is still an interesting risk analysis to study the adequacy of the constructed buildings to the requirements of the Spanish regulations.

MEREDICTE© is a Risk Index that aims to objectively quantify the level of danger and protection of buildings in case of fire. It assumes that a building will always have an acceptable level of risk if the fire hazard is compensated by the means of protection available [1].

$$Global\,Risk\,Level\left(NRG\right) = Potential\,Hazard\ /\ Level\,of\,Global\,Protection \quad [1]$$

It is considered that the risk is acceptable when the result is under 1. The level of Potential Hazard (PP) [2] is determined from 28 parameters, including the sector capacity (AS), parameters related to the fire tetrahedron (T), occupant characteristics (CO) and architectural characteristics (CA).

$$Potential\,Hazard\left(PP\right) = AS \times \left(0,4 \times T + 0,3 \times CO + 0,3 \times CA\right) \quad [2]$$

The level of Global Protection (NPG) [3] is determined from 45 parameters, including the presence of a self-protection plan (NPA), the fire resistance of the structure (RFE), the interior and exterior fire spread (P), the evacuation of the occupants (EO), the fire protection systems (IPCI) and the intervention of the fire services (IB).

$$NPG = NPA \times \left[RFE \times \left(0,24 \times P + 0,4 \times EO + 0,24 \times IPCI + 0,12 \times IB\right)\right] \quad [3]$$

The components of these equations are also weighted with several coefficients that allow to quantify the level of danger and protection, as well as to know the relative importance of each of the hazards and safety measures (Pérez-Martín et al., 2010).

The risk level calculated by MEREDICTE© always refers to the safety of the building users, and never to the integrity of the building.

Once the first analysis was conducted, the second assessment using the MEREDICTE© Method was performed. For this purpose, the coefficients were introduced in a new Excel spreadsheet and the coherence between both results was verified.

RESULTS AND DISCUSSION

Before showing the obtained results, some clarifications are needed.

In some cases, the original projects covered several blocks at the same time. As it is quite difficult to give a definition of what a single building is, for the purpose, every housing part with a single entrance hall has been considered as a unit.

On the other hand, as the project is focused on housing the other establishments (commercial or others) integrated in the buildings have not been considered. Only the exterior spread requirements have been checked for compliance.

Interior Spread

The first requirement of the Fire Safety Document, DB-SI-1, establishes that buildings must be divided in fire compartments, according to variable maximum surface areas depending on the use. In the case of residential buildings, the fire compartments cannot exceed 2500 m^2.

88% of the analyzed blocks does not exceed 2500 m^2 of floor area, therefore, they do not need to be divided into compartments. However, the remaining 12%, which exceeds the surface limit, does not comply with the requirements: all of them have an open staircase that connects the stories of the block, creating a single fire compartment. The blocks that are not correctly compartmentalized are high-rise buildings, between 7 and 12 stories, mostly belonging to typology T2.1 (H-block, height above Ground + 4) or T3 (Tower), and they were built along the decade of 1970s.

In order to limit the fire spread between dwellings, the DB-SI document indicates that the separating elements must have at least 60 minutes of fire resistance (EI-60). This requirement is met in every analyzed block, since in all cases the interior partitions are made of variable thickness brick, with plaster in both sides. The construction solutions used to separate dwellings can be divided into five types: double-air brick wall (7 cm), double-air brick wall (12 cm), double wall of single-air brick (5+5 cm), with or without air chamber, and double wall of double-air brick (7+7 cm). According to the DB-SI document, the fire resistance of all these brick elements varies between 90 and 240 minutes.

However, in most cases the project documentation does not contain detailed information on the floor slabs. For this reason, it is not possible to guarantee that their fire resistance meets the requirements.

Regarding the special risk locals of the case studies, it can be appreciated that the blocks built in the 1940s only have electricity meter rooms. Later, spaces for the elevator machinery, storage rooms, cleaning and waste storage rooms, and boiler rooms also appear. In 28% of the cases, this special risk areas are not correctly compartmentalized. Sometimes, a low special risk area does not have a fire-resistant door, and sometimes a medium special risk area does not have an independent vestibule.

According to the section 4 of the DB-SI-1 document, the construction elements used in walls and ceilings in the occupied areas must have a fire reaction equal or greater than C-s2, d0, and floors must be E_{FL}. The requirement excludes the interior of the dwellings; therefore, the materials of the vertical and horizontal elements of the hallways and common areas were analyzed, only if they exceed 5% of the total surface of the enclosure.

All the studied blocks have a plaster finish on walls and ceilings of the staircases area, whose fire reaction class is A1, without the need for testing ("Real Decreto 842/2013, de 31 de Octubre, Por El Que Se Aprueba La Clasificación de Los Productos de Construcción y de Los Elementos Constructivos En Función de Sus Propiedades de Reacción y de Resistencia Frente Al Fuego," 2013). The cladding used in floors are hydraulic tiles, granite, or terrazzo, which are also class $A1_{FL}$ without the need for testing. Therefore, in all the cases, the materials used in the communication areas comply with the regulations.

There are a greater variety of finishes in the doorways, for instance, ceramic or marble coatings, used in both vertical and horizontal surfaces. These materials are also class A1 or $A1_{FL}$. In 16 buildings, the doorway walls were covered with wood. Seven of these cases are renovations made after 2006, when the current regulation was approved, so it can be assumed that the wood has been adequately treated in order to comply with the requirement. The remaining nine cases have not been modified after the construction, so they do not comply with the regulation, since the reaction to fire of the wood is class D-s2, d0.

The DB-SI document also establishes that the coverings used on walls of non-watertight concealed spaces, except those located inside dwellings, must be at least class B-s3, d0; B_{FL}-s2 for floors. In this regard, a conflictive area may be the space between the top floor slab and the roof. Table 4 shows the construction solutions for roofs according to the decade of construction.

In construction solutions C5, C7 and C8, the roof is directly supported by the top floor slab. However, in the remaining solutions a non-watertight concealed space is created, where a fire could start. Therefore, these areas must have the required fire reaction class, B-s3,d0.

Table 4. Percentage of buildings using different roof construction solutions, by decade of construction

Roof Construction Solution	Percentage of blocks			
	1940	1950	1960	1970
C1: Wooden substructure + shingle board + curved ceramic roof tile	100%			
C2: Wooden substructure + ceramic board + curved ceramic roof tile		39%		
C3: Supporting brick partitions + ceramic board + Concrete compression layer + curved ceramic roof tile		61%	92%	27%
C4: Supporting brick partitions + ceramic and concrete board + Concrete compression layer + curved ceramic roof tile			5%	21%
C5: Reinforced concrete floor slab + sloped concrete + fiber cement panel			3%	
C6: Supporting brick partitions + ceramic board + fiber cement panel				30%
C7: Reinforced concrete floor slab + sloped concrete + asphalt cloth + EPS insulation (3 cm) + Gravel				12%
C8: Reinforced concrete floor slab + sloped concrete + asphalt cloth + EPS insulation (3 cm) + XPS (7 cm) + Gravel				9%

Solution C3, C4 and C6 are made of double air brick walls, where a shingle board is sustained, with or without concrete, and a ceramic tile or a fiber cement panel as exterior cover. The fired clay pieces belong to a fire reaction class A1, without the need for testing, so they comply with the requirement.

By contrast, in solutions C1 and C2, which are present in 48 buildings of the sample, the roof is supported by a wooden substructure and a ceramic or shingle board. They do not comply with the requirement, since wood without fireproofing treatment belongs, at best, to class D-s2,d0. As it can be seen in Table 4 this solution is used in every block built in the 1940s, it loses prominence along the 1950s in favor of the roof supported by brick partitions, and it completely disappeared in later buildings.

75% of the blocks with solutions C1 and C2 belongs to the typology T1.2 (non-clustered linear block). These solutions also are present in the typologies T1.1 (Linear block with nearby building environment), T2.1 (H-Block) and T4 (T-Block).

Exterior Spread

The second section of the DB-SI document establishes that the vertical walls between buildings must have a fire resistance equal to or greater than 120 minutes. As it was explained before, every block with a single entrance hall has been considered as a unit. In order to evaluate compliance with this requirement, the construction solutions used in the party walls were analyzed.

The party walls are made in all the cases by air brick of variable thickness, with plaster in both faces. 85.5% of those walls have a thickness greater than 8 cm, therefore, their fire resistance is at least 180 minutes. The remaining 14.5% are made by a double-air brick (7 cm), with plaster in both sides. According to the regulation, these walls have a fire resistance of 90 minutes, so they do not comply with the requirement. There is no pattern in the distribution by typology or construction period of the buildings with this kind of party walls.

Table 5. Fire reaction of the facade construction solutions of the case studies

Facade Construction Solution	Reaction to Fire
F1: Perforated or Solid Brick Wall (24 cm) + Plaster	A1
F2: Brick cladding or cement mortar + Double-air brick wall (24 cm) + plaster	A1
F3: Double-air brick wall (12 cm) + Air chamber + Single-air brick partition + plaster	A1
F4: Perforated or solid brick wall (12 cm) + air chamber + single-air brick partition + plaster	A1
F5: Brick cladding or cement mortar + double-air brick wall (12 cm) + Air chamber + single-air brick partition + plaster	A1
F6: Brick cladding or cement mortar + double-air brick wall (24 cm) + Air chamber + single-air brick partition + plaster	A1
F7: Perforated or Solid Brick Wall (12 cm) + mortar + fiberglass insulation (4 cm) + double-air brick partition (10 cm) + Plaster	A1
F8: "Granulite" type Cladding + Cement mortar + double-air brick wall (12 cm) + Air chamber + single-air brick partition + plaster	A2-s1.do
F9: "Granulite" type Cladding + Cement mortar + double-air brick wall (12 cm) + plaster	A2-s1.do
F10: Ventilated façade (Ceramic panel + Mineral wool + Metal Framing) + Cement mortar + double-air brick wal (12 cm) + Air chamber + single-air brick partition + Plaster	A1
F11: Ventilated facade, no data	Test Needed

Table 6. Percentage of blocks that comply with the required number of floor exit, by typology

The block complies with the number of floor exits		Percentage of blocks									
		T1.1	**T1.2**	**T1.3**	**T1.4**	**T2.1**	**T2.2**	**T2.3**	**T3**	**T4**	**Total**
Yes:	The floor exit can be and is a non-protected stair	78%	86%	67%	23%	100%		29%		10%	65%
No	The stair should be protected. The evacuation route is longer than allowed.	22%	12%		62%			29%	70%	50%	22%
	The stair should be especially protected. There should be more floor exits		2%	33%	15%		100%		30%	20%	10%
	The hole of the non-protected stair is > 1.30 m^2. It is not a floor exit; the evacuation route is longer than allowed							43%		20%	3%

All blocks comply with the requirements for distances between elements with a fire resistance lower than 60 minutes, for the limitation of the horizontal and vertical spread through the facade.

Regarding the reaction to fire, the facade construction systems are shown in Table 5. Solutions F1 to F6 are different variations of a brick facade, which is always made of materials that belong to class A1. Solution F7, present in a block built in 1976, is the first with thermal insulation: 4 centimeters of fiberglass, covered on both sides by layers with a fire resistance higher than 30 minutes.

Facades F8 and F9 have a synthetic-mineral coating, composed of marble granules and acrylic resins. They are present in 6 grouped linear blocks, built in the 60s, and 2 towers built in the 70s. Similar materials used today belong to class A2-s1,d0; but in order to accurately determine their reaction to fire, it would be necessary to perform the necessary test.

Facades F10 and F11 are the result of later interventions to improve the quality of the thermal envelope of the building. In both cases, exterior thermal insulation has been added, through the installation of a ventilated facade over the exiting one. Data about F10 was obtained from the plans of three T3 blocks, built in the 1970s. However, it was not possible in the case of the six blocks with a facade F11: Ventilated facade, no data. The modification introduced in the last version of the DB-SI document alludes specifically to the insulation placed inside ventilated chambers. F10 complies with the regulation since mineral wool is class A1. For facades F11 it would be necessary to obtain detailed data to know if they meet the current standard.

The requirements for the limitation of the exterior spread through the roof are met in all the cases, and the covering materials -ceramic tile, fiber cement and gravel- always belong to class B_{ROOF} (Table 5).

Evacuation of Occupants

The most conflicting element when assessing the adequacy of the case studies to the regulation about the occupant evacuation is the type of staircase. As mentioned above, all blocks have a single open staircase. Therefore, those that exceed 28 meters of descending evacuation height will not comply with the regulations because they require more than one floor exit. On the other hand, blocks exceeding 14 meters of evacuation height should have a protected staircase to be considered as a floor exit. If this

Table 7. Percentage of blocks that comply with the number of required floor exits, by construction period

The block complies with the number of floor exits		Percentage of blocks				
		1940	1950	1960	1970	Total
Yes	The floor exit can be and is a non-protected stair	88%	53%	77%	15%	65%
No	The stair should be protected. The evacuation route is longer than allowed.	12%	37%	15%	42%	22%
	The stair should be especially protected. There should be more floor exits		11%	7%	30%	10%
	The hole of the non-protected stair is > 1.30 m2. It is not a floor exit; the evacuation route is longer than allowed			1%	12%	3%

is not the case, the evacuation route extends from the door of the dwelling to the exit of the building, exceeding the maximum permitted length (25 m). The same occurs in those buildings lower than 14 meters, in which the floor area of the staircase hole is greater than 1.30 m^2.

35% of case studies do not comply with the number of floor exits and type of stair (Tables 6 and 7). In order to verify whether the width of the means of escape was adequate, the occupancy of each block has been calculated. Then, the formulas contained in DB-SI-3 for the dimensioning of the evacuation elements were used. For non-protected descending stairs, the formula is $A \geq P/160$, being A the element width (in meters) and P the total number of persons whose passage is expected. In the case of dimensioning doors and passages, the formula is $A \geq P/200 \geq 1.00$ m.

10 buildings have a stair narrower than 1.00 m (between 0.75 and 0.90 meters), so they do not reach the minimum dimension established in the Basic Document “Safety of Use and Accessibility”, DB-SUA (Ministerio de Fomento, 2019a). 7 of them belonging to the H-Block typology (T2), and the remaining three to the T-Block typology (T4). In addition, eleven blocks do not have the appropriate dimension according to the formula. All of these are high-rise buildings, so they have high occupancies. Nine of them, built in the 70s, do not comply with the minimum width of the main door.

In all the cases, the building exit doors are hinged with a vertical rotation axis by means of an easy and quick opening locking system. In “Housing” use, the exit doors must open in the direction of evacuation if the occupancy exceeds 200 people. This condition occurs in nine blocks analyzed, of which only three meet the requirement.

Those residential buildings that exceed 28 meters height must dispose means for the evacuation of occupants with disabilities, that may be: a pass to an alternative fire compartment through an accessible floor exit, or a refuge area where they can wait safely to the rescue services. None of the studied blocks, of which 16 are higher than 28 meters, had any of these means. This is an important issue, since data shows that the elderly and people with mobility impairments are the most common fatal victims in fires in Spain (Fernández-Vigil & Echeverría, 2019).

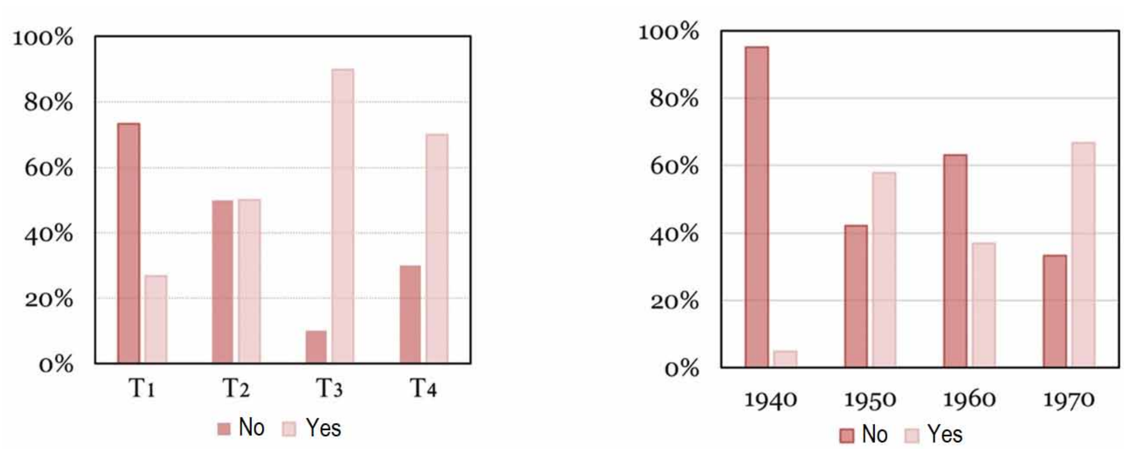
Fire Protection Systems

The analyzed residential buildings must dispose the following fire protection systems: portable extinguishers of 21A-113 effectiveness, located at less than 15 meters of any point of the evacuation route (excluding the interior of the dwelling), and in the special risk zones; exterior hydrants when the descendent evacuation height exceeds 28 meters, and dry column when it exceeds 24 meters. None of the analyzed blocks is higher than 33 meters, so the detection and alarm systems and automatic extinguisher systems are not compulsory for any building.

It should be noted that 63% of the case studies do not have any fire protection system. As it can be seen in Figure 3, the linear typology and those blocks built in the 40s are those with the highest percentage of buildings without protection systems. 54.8% of the blocks that exceeds 24 meters have a dry column, and only 12.5% of those higher than 28 m have an exterior hydrant.

The Section 4 of the DB-SI document also states that the manual fire protection systems must be correctly signaled, according to the Standard "Fire Protection Systems Regulation", RIPCI, published in 2017 ("Real Decreto 513/2017, de 22 de Mayo, Por El Que Se Aprueba El Reglamento de Instalaciones de Protección Contra Incendios.," 2017). However, 34.5% of the buildings that have these systems lack signage.

Figure 3. Percentage of blocks with fire protection systems, by typology and decade of construction



Fire Department Operation

When the descendant evacuation height exceeds 9 meters, it is necessary to have a maneuvering space that allows for the adequate intervention of the rescue services in case of fire. The conditions of such space are included in Section 5 of the DB-SI document, and they refer to the width, height, slope and resistance to puncturing of the operating space, the separation of the vehicle to the facade and accesses; and the width, height and bearing capacity of the approach roads.

45% of the case studies infringe some of the described conditions. There is not a pattern in the distribution of the cases that comply with the requirements and those that do not by typology or construction period, but it depends on the urban location of the block. On the other hand, the accessibility conditions of the facade to allow the access of the fire department are guaranteed in all the case studies.

Structure Fire Resistance

The analysis of the fire resistance of structural elements is a very complex task since most of the projects lack structural drawings. Those that do have these plans, do not provide enough information to estimate the fire resistance. This would imply to analyze element by element of each building in order to provide reliable results, which is an unfeasible task in a study of these characteristics.

All the buildings have a structure made of reinforced concrete columns and beams, in some cases with load-bearing brick walls. The first Instruction for the Design and Execution of Concrete Projects was approved in 1939 (Ministerio de Obras Públicas, 1939), and it required a minimum steel reinforcement cover of "more than one diameter and more than one centimeter". This standard underwent a constant process of review and modifications along the period under study. The last modification was in 1973, with the publication of the Instruction EH-73 ("Real Decreto 3062/1973, de 19 de Octubre, Por El Que Se Aprueba La Instrucción Para El Proyecto y La Ejecución de Obras de Hormigón En Masa o Armado," 1973). This regulation maintains the same minimum coverings.

The first mandatory fire protection regulation in Spain (although it was later declared voluntary) is the Basic Standard of Fire Protection, NBE-CPI-81, approved in 1981, which is a date after the period covered by this research. This standard establishes that the steel reinforcements of the concrete structures should have a minimum cover of 2 centimeters, in order to ensure a fire resistance of 60 minutes ("Real Decreto 2059/1981 Por El Que Se Aprueba La Norma Básica de La Edificación," 1981).

Therefore, it is not possible to guarantee the structure fire resistance of the case studies, since the reinforced concrete regulations applicable at the period when they were built required minimum coverings lower than those stated in the fire protection regulation.

Table 8. Percentage of blocks that comply with the prescription of the DB-SI document, by typology

Number of requirements met	Percentage of blocks				
	T1	T2	T3	T4	Total
Less than 6	3%	27%	30%	60%	13%
7 – 8	77%	40%	70%	30%	67%
9 – 10	20%	33%	0%	10%	20%

Overall Assessment of the Case Studies

Once each of the sections of the DB-SI document had been analyzed, an overall rating was performed to identify which morphologies and construction periods have the highest level of risk. In order to carry out this assessment, the number of requirements -10 in total- met by each block was quantified as follows:

Interior Spread (3): adequate compartmentalization in fire sectors, adequate compartmentalization of special risk locals and adequate reaction to fire of the materials.

Exterior Spread (2): The exterior spread is properly limited through dividing walls and facades, and through roofs.

Evacuation of Occupants (3): The building has the necessary number of floor exits, adequate dimensions and opening of the means of evacuation, there are means for the evacuation of occupants with disabilities in buildings over 28 m high.

Fire Protection Systems (1): The building has all the fire protection systems required by the regulation, according to its characteristics.

Fire Department Operation (1): The approach conditions and the environment of the building comply with the requirements of the regulation.

The typologies that comply less with the prescriptions of the Building Code, and therefore they have the highest level of risk, are T3 Tower, and T4 T-block (Table 8). When the comparison is made according to the construction decade, the buildings with the highest level of risk are those built between 1970 and 1979 (Table 9).

Table 9. Percentage of blocks that comply with the prescription of the DB-SI document, by construction decade

Number of requirements met	Percentage of blocks				
	1940	1950	1960	1970	Total
Less than 6	10%	6%	5%	36%	13%
7 – 8	90%	72%	58%	55%	67%
9 – 10		22%	36%	9%	20%

As it was detailed in the previous sections, this is since most of the high-rise buildings belong to these typologies and decade. The building height is one of the most determining factors when applying the prescriptions of the DB-SI document, since it affects several parameters: the requirements for the interior spread (the necessity for compartmentalization for large surface areas), exterior spread (it is needed a better reaction to fire of facade material at higher height), evacuation of occupants (number of floor exits, protection of the stairs) and fire protection systems (the necessity of a dry column, external hydrant…).

On the other hand, T1 buildings, linear block, and those built in the 40s, are the cases that must comply with the less demanding prescriptions: their small size and low height imply that it is not necessary to divide the building into fire sectors, nor to dispose more than one floor exit or protected evacuation routes, nor sophisticated fire protection systems. However, the fact that they meet many requirements of the regulation and that they do not have the hazards associated with high-rise buildings, does not mean that they are exempt of risks. Fire statistics show that older residential buildings have more fatal fires (Fernández-Vigil & Echeverría, 2019). This may be due to the poor condition of the electrical installation in many cases, which is the second most frequent cause of this type of accidents. Or this may be due to the fact that the low quality of the thermal envelope causes many occupants use portable heating devices, the leading cause of fatal fires (Fernández-Vigil & Echeverría, 2019).

In addition, none of the analyzed buildings had a detection and alarm system. However, several international studies confirm the effectiveness of smoke detectors in the reduction of mortality and morbidity rates from domestic fires (Bruck, 2001; Marshall et al., 1998; Stevenson & Lee, 2003; Warda et al., 1999) and they even conclude that these systems reduce the probability of death in a fire by about half (Ahrens, 2019; Echeverría Trueba et al., 2020; Rohde et al., 2016). A study conducted in the University of Navarra revealed that 96% of fatal victims in residential fires between 2014 and 2016 died inside their dwelling (Fernández-Vigil & Echeverría, 2019). This does not mean that the safety of the evacuation routes should be underestimated, and even less in high-rise buildings. But it does mean that focus should be placed on the protection measures that can be implemented inside dwellings, which are currently almost non-existent.

It is necessary to consider these circumstances when assessing the fire risk level of the building stock, as well as other factors such as the age of the occupants, the presence of people with disabilities or mobility impairments… All of them are elements that increase the risk of fire in residential buildings. It would be desirable to enforce risk evaluation methods that allow a more accurate study of fire safety in residential buildings (Echeverría Trueba et al., 2020).

50% of building stock in Spain is previous to the first mandatory fire regulation. The urgent need in this country to refurbish residential buildings in order to comply with the energy efficiency standards are a great opportunity to also improve their fire safety. In those cases when it is not possible to meet the prescriptions of the regulation, the performance-based design is the appropriate tool to reduce the level of risk, relying on active protection systems (Echeverría Trueba et al., 2020).

Results Obtained after Application of the MEREDICTE© Method

All the cases studies were assessed with the MEREDICTE© Method (Pérez-Martín, 2014). The results show that none of the building have a Global Risk Level below 1. In other words, all the residential buildings have an unacceptable fire risk, according to MEREDICTE©. Within the "unacceptable risk" group, the method presents 5 categories: high ($1 < NRG \leq 1.5$), very high ($1.5 < NRG \leq 2$), severe ($2 < NRG \leq 5$), very severe ($5 < NRG \leq 10$) or catastrophic ($NRG > 10$).

Figure 4. Global risk level of the analyzed buildings

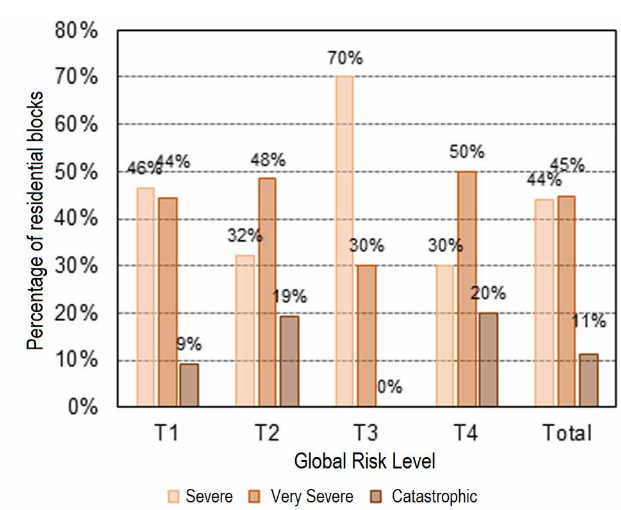
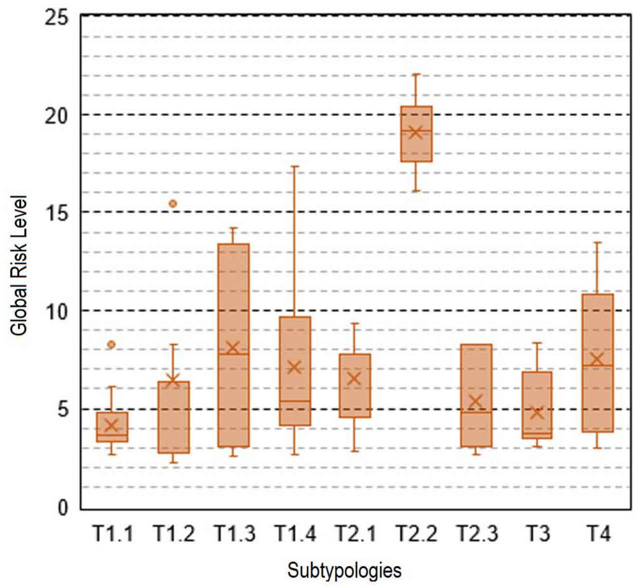


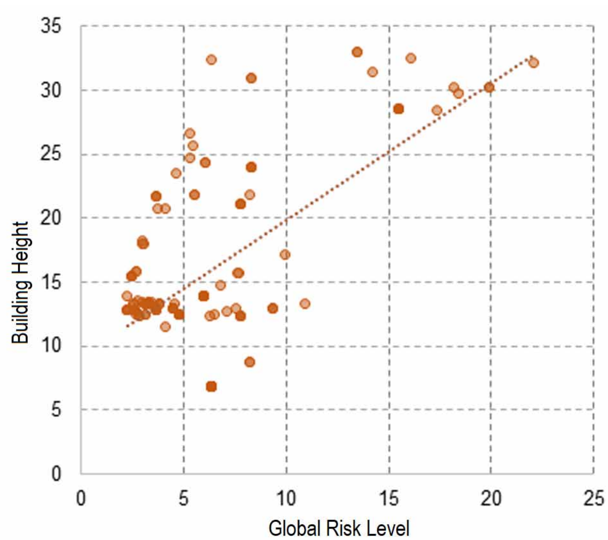
Figure 5. Global risk level, by sub-typology



The average Global Risk Level obtained in the case studies was 6.43, very severe risk. The lowest average Global Risk Level was obtained in typology T1.1, linear block with nearby building environment, and the highest in typology T2.2, H-block, height above Ground + 4. Table 11 shows a summary of the results (see Appendix 2).

All the blocks have a risk over 2, that is, all of them have at least a sever fire risk. 11% of the buildings had a catastrophic Global Risk Level (Figure 4). Figure 5 shows the Global Risk Level in a boxplot, by sub-typology.

Figure 6. Relation between building height and global risk level



The results confirm that the high-rise buildings have the highest fire risk, and that buildings belonging to T1 typology have the lowest fire risk. As it was detailed in the previous sections, this is due to all the requirements that must be complied by the highest buildings, according to the Spanish regulations.

In fact, there is a positive moderate correlation between the building height and their global risk level, with a Pearson correlation coefficient of 0.62 (Figure 6).

One of the great challenges of urban sustainability in Spain is the regeneration of social neighborhoods built in the second half of the 20th century. There is a consensus on the importance of their energy restoration, but less importance has been given to other aspects, such as fire safety. This chapter discusses which factors and typologies increase the risk of fire and shows how safety is currently very weak. In addition, the social and demographic characteristics of the occupants further increase the risk of fire. For this reason, safety should be considered when addressing the regeneration of these neighborhoods.

CONCLUSION

- The systematic study of the buildings fire risk by typologies allows affording big urban ensembles. The results can be of interest for regulators and fire fighters. The first can inform their future decisions and the latter can develop risk maps to optimize their action. The methodology created for this analysis can be easily replicated in any other city to obtain an approach to the fire risk level of its residential buildings.
- To evaluate the level of risk, it is taken as a model of "safe building" that which complies with all the requirements of the CTE DB-SI. It would be interesting to implement a specific fire risk assessment method to analyze dwellings, which would allow a more precise study of specific factors of this type of buildings.
- The results for Pamplona show that the highest blocks built before the implementation of fire regulations present the highest risk level. The systematic application of the MEREDICTE© Method confirms this result.
- Some of the conflictive elements in the analyzed buildings are: the non-watertight concealed spaces generated under the roof, when it rests on a wooden substructure; the open staircases in high-rise buildings, the absence of fire protection systems and the presence of unprotected special risk locals.
- Unless some of the studied buildings have been renovated, none of them has had an intervention in the evacuation routes. The most significative improvements consisted in the installation of extinguishers, lighting and signing.
- As part of urban sustainability, it is necessary to address the regeneration of social neighborhoods built in the second half of the 20th century. This regeneration must be comprehensive, and it must include the aspect of fire safety.
- The future architectural interventions that may be performed in these buildings are a great opportunity to increase their fire safety. In those cases where it is not possible to comply with the prescriptions of the regulation, the performance-based design is the appropriate tool to reduce the level of risk, based on a correct evaluation of each case study.

REFERENCES

Ahrens, M. (2019). *Smoke Alarms in U.S. Home Fire*. https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Detection-and-signaling/ossmokealarms.pdf

Bruck, D. (2001). The who, what, where and why of waking to fire alarms: A review. *Fire Safety Journal*, *36*(7), 623–639. doi:10.1016/S0379-7112(01)00025-X

Domínguez Arribas, L. E., Serrano Lanzarote, B., García-Prieto Ruiz, A., Ortega Madrigal, L., & Soto Francés, L. (2015). *Estudio del Potencial de ahorro energético y reducción de emisiones de CO2 en la Comunitat Valenciana*. www.five.es

Echeverría Trueba, J. B., Rubio Poves, N., Rodríguez Oyarbide, I., Jönsson, J., Vigne, G., & Sánchez Peña, J. (2020). Retos de la seguridad en caso de incendio de levantes en edificios de vivienda existentes. *Informes de la Construcción*, *559*.

Eurostat. (n.d.). *Housing statistics*. Retrieved December 18, 2019, from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Housing_statistics#Type_of_dwelling

Fernández-Vigil, M., & Echeverría, J. B. (2019). Elderly at Home: A Case for the Systematic Collection and Analysis of Fire Statistics in Spain. *Fire Technology*, *55*(6), 2215–2244. doi:10.100710694-019-00852-6

Fundación Mapfre & APTB. (2017). *Víctimas de Incendios en España en 2016*. doi:10.2865/5721

Fundación Mapfre & APTB. (2010). *Víctimas de incendios en España 2010*. https://www.fundacionmapfre.org/fundacion/es_es/images/informe-victimas-incendios-en-espana-2010-actualizado_tcm1069-211526.pdf

Fundación Mapfre & APTB. (2011). *Víctimas de Incendios en España 2011*. https://www.fundacionmapfre.org/fundacion/es_es/images/informe-victimas-incendios-en-espana-2011_tcm1069-211527.pdf

Fundación Mapfre & APTB. (2014). *Víctimas de incendios en España 2012 y 2013*. https://www.fundacionmapfre.org/fundacion/es_es/images/informe-victimas-incendios-en-espana-2012-2013_tcm1069-211528.pdf

Fundación Mapfre & APTB. (2015). *Víctimas de incendios en España en 2014*. https://www.fundacionmapfre.org/fundacion/es_es/images/informe-victimas-incendios-en-espana-2014_tcm1069-211529.pdf

Fundación Mapfre & APTB. (2016). *Víctimas de incendios en españa en 2015*. https://www.fundacionmapfre.org/fundacion/es_es/images/informe-victimas-incendios-espana-2015_tcm1069-388743.pdf

Fundación Mapfre & APTB. (2018). *Estudio de víctimas de incendios en España en 2017*. https://www.fundacionmapfre.org/fundacion/es_es/images/informe-victimas-incendios-espana-2017_tcm1069-522308.pdf

Instituto Nacional de Estadística. (2011). *Censos de Población y Viviendas 2011*. Cifras de Población y Censos Demográficos. https://www.ine.es/censos2011_datos/cen11_datos_inicio.htm

Instituto Nacional de Estadística. (2014). *Proyección de la Población de España 2014–2064*. Author.

Marshall, S. W., Runyan, C. W., Bangdiwala, S. I., Linzer, M. A., Sacks, J. J., & Butts, J. D. (1998). Fatal Residential Fires: Who dies and who survives? *Journal of the American Medical Association*, *279*(20), 1633–1637. doi:10.1001/jama.279.20.1633 PMID:9613913

Ministerio de Fomento. (2019a). *Código Técnico de la Edificación: Documento Básico de Seguridad de utilización y accesibilidad*. https://www.codigotecnico.org/pdf/Documentos/SUA/DBSUA.pdf

Ministerio de Fomento. (2019b). *Código Técnico de la Edificación: Documento Básico de Seguridad en caso de incendio*. https://www.codigotecnico.org/images/stories/pdf/seguridadIncendio/DccSI.pdf

Ministerio de Fomento. (2019c). *Código Técnico de la Edificación. Parte I*. https://www.codigotecnico.org/pdf/Documentos/Parte1/Parte_I_20dic2019.pdf

Ministerio de Obras Públicas. (1939). *Instrucción para el Proyecto y Ejecución de Obras de Hormigón*.

Ministerio de transportes movilidad y agenda urbana. (2020). *Nota sobre el Documento Reconocido CTE-DR/048/14*. https://www.mitma.es/carreteras/trafico-velocidades-y-accidentes-mapa-estimacion-y-evolucion/mapas-de-trafico/2019

Ortega Madrigal, L., García-Prieto Ruiz, A., & Serrano Lanzarote, B. (2013). *Catálogo de tipología edificatoria residencial.* Ámbito. https://episcope.eu/fileadmin/tabula/public/docs/brochure/ES_TABULA_TypologyBrochure_IVE.pdf

Pérez-Martín, J. C. (2014). *MEREDICTE Método de evaluación de riesgo en caso de incendio en el marco del Código Técnico de la Edificación*. Academic Press.

Pérez-Martín, J. C., Díaz-Díaz, R., & Santos García, R. (2010). Método de evaluación del riesgo de incendio en el marco del Código Técnico de la Edificación. *DYNA Ingeniería e Industria*, *85*(4), 303–314. doi:10.6036/3437

Real Decreto 1053/1985, de 25 de mayo, sobre ordenación de la estadísticas de las actuaciones de los Servicios contra Incendios y de Salvamento. (1985). In *Boletín Oficial del Estado* (Vol. 158, Issue 12771, pp. 20843–20844).

Real Decreto 2059/1981 por el que se aprueba la Norma Básica de la Edificación. (1981). In *Boletín Oficial del Estado* (Vol. 224, pp. 21707–21727).

Real Decreto 3062/1973, de 19 de octubre, por el que se aprueba la instrucción para el proyecto y la ejecución de obras de hormigón en masa o armado. (1973). In *Boletín Oficial del Estado* (Vol. 2993, pp. 23701–24204). https://www.boe.es/boe/dias/1973/12/07/pdfs/R23701-24204.pdf

Real Decreto 513/2017, de 22 de mayo, por el que se aprueba el Reglamento de instalaciones de protección contra incendios. (2017). In *Boletín Oficial del Estado* (Vol. 139, Issue I, pp. 48349–48386). http://www.boe.es

Real Decreto 842/2013, de 31 de octubre, por el que se aprueba la clasificación de los productos de construcción y de los elementos constructivos en función de sus propiedades de reacción y de resistencia frente al fuego. (2013). In *Boletín Oficial del Estado* (Vol. 281, Issue I, pp. 93493–93527).

Rohde, D., Corcoran, J., Sydes, M., & Higginson, A. (2016). The association between smoke alarm presence and injury and death rates: A systematic review and meta-analysis. *Fire Safety Journal*, *81*, 58–63. doi:10.1016/j.firesaf.2016.01.008

Rubio del Val, J. (2011). Rehabilitación Urbana en España (1989-2010). Barreras actuales y sugerencias para su eliminación. *Informes de La Construccion, 63*, 5–20. doi:10.3989/ic.11.060

SAVIArquitectura. (2016). *Proyecto prestaRener. Capítulo 3: Tipologías*. Author.

SAVIArquitectura & Worcester Polythecnic Institute. (2016). *Proyecto prestaRener: Protocolo de Actuación en la Rehabilitación de la Envolvente de Edificios basado en el Diseño Prestacional*. Author.

Stevenson, M. R., & Lee, A. H. (2003). Smoke alarms and residential fire mortality in the United States: An ecologic study. *Fire Safety Journal*, *38*(1), 43–52. doi:10.1016/S0379-7112(02)00048-6

Warda, L., Tenenbein, M., & Moffatt, M. E. K. (1999). House fire injury prevention update. Part II. A review of the efectiveness of preventive interventions. *Injury Prevention*, *5*(3), 217–225. doi:10.1136/ip.5.3.217 PMID:10518271

KEY TERMS AND DEFINITIONS

Combustion: Exothermic reaction of a combustible substance with an oxidizer.

Compartmentation: The technique of dividing a building into a number of compartments.

Escape: The fire safety tactic of ensuring that the occupants of the building are able to move to places of safety before they are threatened by heat and smoke.

Fire Engineering: Design which considers the building as a complex system, and fire safety as one of the many interrelated subsystems which can be achieved through a variety of equivalent strategies.

Fire Resistance: The properties that establish the maintenance of the capacity of sustenance of the work for a determined time in case of fire.

Fire Risk: The product of 1) probability of occurrence of a fire to be expected in a given state, 2) consequence or extent of damage to be expected on occurrence of a fire.

Reaction to Fire: The properties that limit the initiation and propagation of the fire and the smoke inside the work.

APPENDIX 1

Table 10. List of codes and abbreviations used

Abbreviation	Spanish Meaning	English Meaning
STANDARDS AND CODES		
CTE	Código Técnico de la Edificación	Spanish Building Code
DB-SI	Documento Básico: Seguridad en caso de Incendio	Basic Document: Fire Safety
DB-SI-1	Documento Básico: Seguridad en caso de Incendio – Propagación interior	Basic Document: Fire Safety – Interior Fire Spread
DB-SI-2	Documento Básico: Seguridad en caso de Incendio – Propagación exterior	Basic Document: Fire Safety – Exterior Fire Spread
DB-SI-3	Documento Básico: Seguridad en caso de Incendio – Evacuación de ocupantes	Basic Document: Fire Safety – Evacuation of occupants
DB-SI-4	Documento Básico: Seguridad en caso de Incendio – Instalaciones de protección contra incendios	Basic Document: Fire Safety – Fire protection Systems
DB-SI-5	Documento Básico: Seguridad en caso de Incendio – Intervención de bomberos	Basic Document: Fire Safety – Intervention of extinction services
DB-SI-6	Documento Básico: Seguridad en caso de Incendio – Resistencia al fuego de la estructura	Basic Document: Fire Safety – Fire resistance of the load-bearing structure
DB-SUA	Documento Básico: Seguridad de utilización y accesibilidad	Basic Document: Safety of Use and Accesibility
RIPCI	Reglamento de Instalaciones de Protección contra Incendios	Fire Protection Systems Regulation
-	Instrucción para el Proyecto y Ejecución de Obras de Hormigón (1939)	Instruction for the Design and Execution of Concrete Projects (1939)
EH-73	Instrucción para el Proyecto y la ejecución de obras de hormigón en masa o armado (1973)	Instruction for the Design and Execution of Concrete Projects (1973)
NBE-CPI-81	Norma Básica de la Edificación - Condiciones de protección contra incendio en los edificios (1981)	Basic Standard of Fire Protection
BUILDING TYPOLOGIES		
T1	Bloque lineal	Linear block
T1.1	Bloque lineal en manzana	Linear block with nearby building environment
T1.2	Bloque lineal no agrupado	Non-clustered linear block
T1.3	Bloque lineal con una orientación	Linear block with one orientation
T1.4	Bloque lineal con patio mínimo	Linear block with minimum courtyard
T2	Bloque en H	H-Block
T2.1	Bloque en H	H-block
T2.2	Bloque en H, altura mayor que B+A	H-block, height above Ground + 4
T2.3	Bloque en H con patio mínimo	H-block with minimum courtyard
T3	Torre	Tower
T3.1	Torre en H	H-tower
T3.2	Torre en cruz	Cross Tower
T4	Bloque en T	T-Block
T4.1	Bloque en T, 3 viviendas por planta	T-block, 3 dwellings per floor
T4.2	Bloque en T, 2 viviendas por planta	T-block, 2 dwellings per floor
T5	Unifamiliar	Single-family houses
T5.1	Unifamiliar, Planta baja	Single-family house, ground floor
T5.2	Unifamiliar, Baja + 1	Single-family house, ground floor + 1
MEREDICTE		
NRG	Nivel de Riesgo Global	Global Risk Level
PP	Peligro Potencial	Potential Hazard
AS	Aforo del sector	Sector Capacity
T	Tetraedro del fuego	Fire tetrahedron
CO	Características de los ocupantes	Occupants Characteristics
CA	Características arquitectónicas	Architectural characteristics
NPG	Nivel de protección global	Level pf Global Protection
NPA	Plan de Autoprotección	Self-protection Plan
RFE	Resistencia al fuego de la estructura	Fire Resistance of the structure
P	Propagación interior y exterior	Interior and exterior fire spread
EO	Evacuación de ocupantes	Evacuation of the occupants
IPCI	Instalaciones de protección contra incendios	Fire Protection Systems
IB	Intervención de bomberos	Intervention of the fire services

APPENDIX 2

Table 11. Global risk level, potential hazard and global protection level obtained in the case studies, by sub-typology

Typology	Global Risk Level			Potential Hazard Average	Global Protection Level Average
	Average	Minimum	Maximum		
T1.1	4.14	2.63	8.25	2.3	0.56
T1.2	6.44	2.26	15.48	4.1	0.68
T1.3	8.07	2.53	14.20	4.7	0.62
T1.4	7.09	2.68	17.38	3.7	0.54
T1	5.75	2.26	17.38	3.5	0.63
T2.1	6.55	2.78	9.34	4.3	0.65
T2.2	19.07	16.08	22.06	8.6	0.45
T2.3	5.34	2.68	8.27	3.6	0.68
T2	8.74	2.68	22.06	5.0	0.62
T3	4.79	3.04	8.32	3.4	0.73
T4	7.55	3.01	13.44	5.5	0.73
Total	6.43	2.26	22.06	3.9	0.64