Construction techniques to protect houses from wildland fires

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Abstract

In Portugal, particularly in recent years, fires have had a major impact on forest areas, mainly due to climate change and the high combustibility of trees. Fires in these zones cause severe lasting damage or even the destruction of dwellings, due to wind effects and the excessive proximity to urban areas. The protection not only of the residents but also of the building structures poses a challenge that needs to be investigated in a sustainable manner.

The aim of this thesis is to analyse the general characteristics of the buildings affected by the major fires of 2017 (Pedrógão Grande and October 15) and the causes of ignition, in order to propose solutions to prevent future incidents. Since the houses in the affected rural regions are usually built with old materials, it stands to reason that their fire protection capacities are severely limited. For this reason, this study presents possibilities to use new construction techniques to protect existing houses located in highly endangered wildland fire areas. In this thesis, solutions are proposed to protect the roof and openings.

Furthermore, the focus is on new-build construction using state-of-the-art materials and methods to maintain the overall structure of the building for a longer time during an ongoing fire. Exterior walls, roofs and openings are the elements that serve as a link between exterior and interior, so their construction techniques must be examined in the overall context. Finally, the situation of isolated villages surrounded by vegetation is also investigated to protect the habitants.

Key-words: Wildland fires, Construction methods, Fire prevention, Protection of houses, Isolated villages.

1. Introduction

The risk of wildland fires in Portugal has increased in recent years due to climate change and the structure of forests (eucalyptus and pine). The forest area represents about two thirds of the national territory, a fact that justifies the great importance of its preservation. In 2017, there were two large fires that marked the history of Portugal - the fires of Pedrógão Grande and the fires in 15th of October. These had a major impact not only on forest areas, but also on communities.

To this end, it is essential to first study the characteristics of the affected houses by means of surveys sent to the affected municipalities. It was subsequently observed that the majority of the burnt houses were rebuilt with characteristics similar to the original ones, without new solutions being introduced after the accidents that occurred. Thus, protective measures were created in this study for houses located in high-risk areas, as well as in the case of new-build construction, where new techniques were implemented. Also, the formulation of new solutions to protect the inhabitants and animals in isolated villages was a study object in this dissertation.

One of the main objectives of this work is the creation of a barrier between fire and structures that hinders the propagation of smoke, combustion gases and flames into the interior. In the event of a building fire, there is a concern about the evacuation of residents. In the case of a fire in the wildland-urban interface, the objective is precisely the opposite, i.e., to ensure that people remain safe inside their homes for at least one hour. According to the conclusions of the study of Pedrógão Grande fires, it was found that the number of victims would have been lower if people had stayed at home while the fire was passing by their houses (Viegas *et al*., 2017). Therefore, it is important that people feel safe in their own houses as long as there is a fire nearby.

In order to implement the proposed fire protection measures, it was necessary to appeal to several companies and study their suggested techniques to ensure the best possible sealing.

2. Wild fires

Wildland fires occur when the fuel is natural component, i.e. the vegetation found in the forest areas. There are several causes of wildland fires, such as weather conditions, the use of fire, arson, accidental, structural, natural and undetermined causes (Lourenço *et al.*, 2012). The last ones were the most frequent in a study carried out between 1996 and 2010, corresponding to 50% of cases. The probability of fires occurring during dry periods and with a high density of vegetation is very high and may also depend on local topography. If the conditions show low humidity and high wind speed (Westhaver, 2016), the propagation speed is significantly higher.

2.1. Fire risk

The Canadian Fire Weather Index (FWI) system is used in Portugal to estimate the fire risk. The wildland fire risk index is determined by combining the FWI index, provided by the *Instituto Português do Mar e da Atmosfera (IPMA)*, with the cyclical risk index provided by the *Instituto da Conservação da Natureza e das Florestas (ICNF).* The wildland fire risk index is divided into five classes, for which IPMA publishes a risk value for each municipality on a daily basis.

2.2. Fires in the wildland-urban interface (WUI)

Wildland-urban interface fires is “any point where the fuel feeding a wildfire changes from natural (forest) fuel to man-made (urban) fuel" (Butler, 1974). The potential for a structure to initiate ignition depends on its materials and their respective vulnerability, as well as its exposure to the surrounding environment (Cohen, 2000). There are several possibilities for a wildland fire to reach structures: through the direct action of flames, by radiation or indirectly due to firebrands. The first two should not be taken into account as it is assumed that the forests around the structures are free of vegetation (Westhaver, 2016). Firebrands are produced through flames in the vegetation, with a maximum diameter of 3 cm, and placed in vulnerable areas of the structures. Firebrands projections are the main responsible of structures ignition, according to several studies like of Westhaver (2016).

2.3. Fires of 2017

In 2017, around 510 thousand hectares of Portuguese territory were burnt, of which 6 thousand hectares were urban areas. In this study, the fires of Pedrogão Grande and 15th October 2017 were selected not only because of their dimension, impact and complexity, but also because they were recent occurrences. In addition, it was subsequently observed that the houses were rebuilt with similar characteristics to the original ones, not carrying out interventions with new techniques in order to protect them.

- **Pedrógão Grande (17.06.2017 - 24.06.2017)**

These fires had a greater impact on many municipalities. It was considered one of the most serious accidents in Europe (Viegas *et al.*, 2017) with a total area of 45.328ha.

According to the study carried out by the University of Coimbra (Viegas *et al.*, 2017), it was found that 61% of the 1041 structures were damaged due to the projection of firebrands. Regarding the ignition site, about 62% occurred on the roof, not only due to the existence of vulnerable points, but also because of the wind (Viegas *et al*., 2017). This report concluded that about half of the fatalities lost their lives while trying to escape from their homes, and it was found that one third of the victims had no actual damage in their homes.

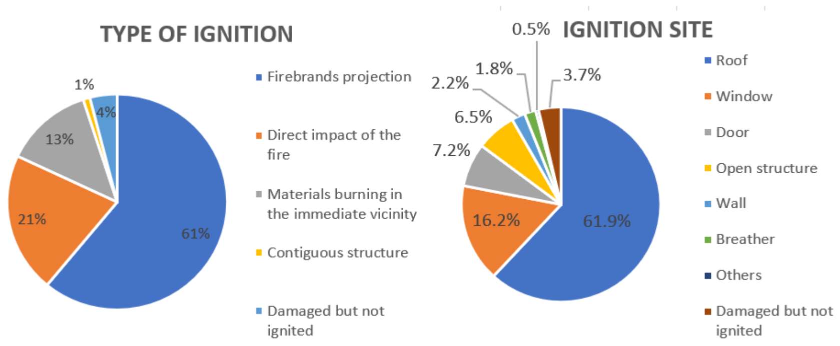


FIGURE 1 - GRAPHS WITH THE DAMAGED STRUCTURES DEPENDING ON THE TYPE OF IGNITION (LEFT) AND THE IGNITION SITE (RIGHT). ADAPTED FROM VIEGAS ET AL., 2017.

- **15TH OF OCTOBER 2017 (14.10.2017 - 16.10.2017)**

The geographical dispersion of these fires was much higher, with 241 thousand hectares of burnt area (Guerreiro *et al*., 2018). It was concluded that fuel treatment guidelines, which means that the forest around buildings is cleared of vegetation, would be ineffective in these extreme conditions of spread, since they were uncontrollable fires. There was also the propagation of firebrands more than 2 km between the forest and urban areas.

3. BUILDING FIRES

The fires inside the buildings were not the object of study, since the scope of the dissertation is the fires from outside to inside. However, it is important to highlight the behaviour of construction products against fire. The fire resistance of a construction product is estimated through tests. They are subjected to real conditions and temperatures and the time period in minutes is calculated from the thermal process to the moment when it no longer meets the functional requirements for which it was designed (Silva, 2010). For each class of fire resistance, there are associated nine categories that represents the required duration in minutes. The reaction to fire is associated with the ignition capacity of a given material and is evaluated according to standardized tests on materials, defining the combustibility, flammability, flame velocity, calorific value, opacity and propagation of gases and fumes (Brito *et al*., 2004). Euroclass A1 means that the material is 100% non-combustible, such as rock wool. Construction products increase the combustibility of Euroclass A2 to F according to EN 13501-1.

Regarding to construction materials, it was studied their respective behaviours in the structural context. The masonry structures were widely used in older houses. The ceramic brick normally has a function of filling walls and has high fire resistance. Stone has characteristics such as compressive strength, resistance to wear and fire action. Wood is an overly sensitive material to temperature and humidity. When exposed to fire, this material decreases its original section, creating an insulating carbonization surface with a lower thermal conductivity than wood. Concrete is a very recent construction product in the market (20th century) that consists of the mixture of water, aggregates and sand with a hydraulic binder (usually cement paste). Reinforced concrete is concrete that involves steel bars (reinforcements) thus ensuring the tensile and compressive strength of a given element. Concrete has excellent fire characteristics, to a certain extent in which it loses its properties, causing cracks, fissures and detachment of the material. Reinforced concrete steel is a metallic alloy composed of iron and carbon, with high thermal conductivity, which impairs its resistance when subjected to high temperatures. Metallic structures have a fire behaviour similar to that of reinforced concrete steel.

4. ANALYSIS OF THE SURVEYS

A questionnaire was elaborated and sent to all the municipalities affected by the two fires mentioned above, in order to reinforce the study and analyse the raised hypotheses. This questionnaire was sent out in November 2017 and was answered by the following municipalities: Sertã, Oleiros, Arganil, Penela, Pampilhosa da Serra, Mira, Figueiró dos Vinhos, Pedrógão Grande, Seia, Vale de Cambra, Monção and Vouzela. There was also the possibility of conducting an interview with Commander Carlos Pires of the

Aveiro Fire Department to understand some specific issues of the fight against flames and support the information collected previously.

All respondents stated that, in general, the houses heavily affected by the fires had stone masonry walls and a sloping roof made of ceramic tile, in which about 93% of the houses that burned completely had the same characteristics (Figure 2). However, there were also burnt houses built in concrete structure, although with a much smaller expression. An unusual situation arose in the municipality of Oleiros, where 49 houses consisting of concrete structure were completely burnt down. This situation can be justified due to the lack of maintenance of the structures and the consideration as "fully burnt houses", since there was a need to demolish some remaining houses for structural reasons. In addition, there was a traditional schist village, where the predominant building material in most of the houses is schist. One of the damages that can arise in the shale structures is the deterioration or detachment of the plaster (Barros, 2009), which can even result in cracks that allow the entry of firebrands, thus simplifying the spread of fire in the village.

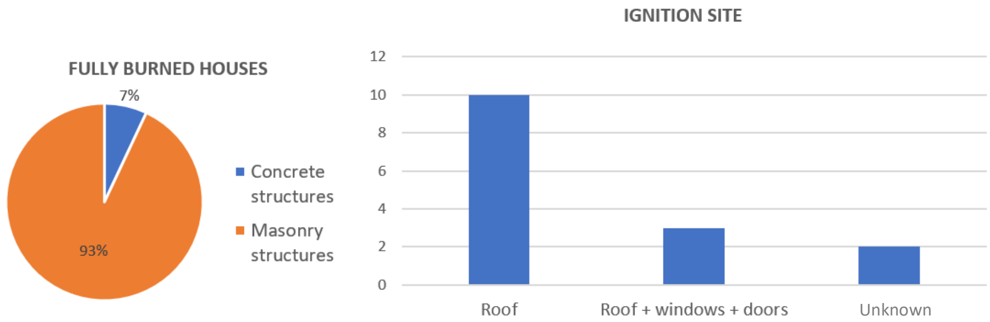


FIGURE 2 - GRAPHS WITH THE PERCENTAGE OF FULLY BURNT HOUSES DEPENDING ON THE TYPE OF STRUCTURE (LEFT) AND THE IGNITION SITE (RIGHT).

In most of the burnt houses the fire started in the roof. However, three of the twelve respondents, replied that the ignition also started at the windows and doors of the houses, as it is stated in Figure 2. It is possible to conclude that the ignition appeared on the roof in most of the houses affected by the two fires of 2017. This fact is justified by the propagation of firebrands along the urban-forestry interface, depositing them on the roofs at fragile points and thus initiating new ignitions, so called secondary fires. Around 84 % of the respondents answered that fires in structures started due to the propagation of firebrands.

The district of Aveiro was affected by the October fires, which had a major impact on the forest and urban areas. There were 64 occurrences on 15 October 2017 in this district. According to the information obtained by the Commander, firebrands were the main reason for urban fires, particularly intensified by the effects of wind. There were cases in this district where the firebrands were projected to more than 2400 m distance from the source, initiating new ignitions.

5. Protection of existing houses

This section covers constructive techniques of roofing and openings in the context of the protection and rehabilitation of houses. Since it is not possible to implement solutions where materials will not ignite at all when exposed to flames, it is the aim to minimize the likelihood of ignition and reduce the rate of growth of a fire.

This study includes the protection of a house with the characteristics analysed on the questionnaires. This house has 150 m^2 of gross floor area, two floors and a non-habitable attic. It makes a "fireproof" house, in which the entrance of firebrands is impossible or at least insignificant. The house in question shall be able to withstand fire after the suggested interventions so that its residents remain safe for at least one hour without being exposed to the risk of the structure igniting in a shorter period of time.

The studies presented here are based on solutions available from two companies that offer various fire prevention techniques using rock wool (Isover Saint-Gobain and FTB – Fábrica da Barca) as well as specific products for fire doors (Gosimat). Subsequently, it was made an analysis of the proposals of the companies in order to acquire a "fireproof" solution in the roofs, windows and doors.

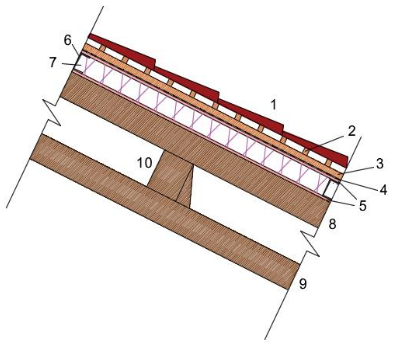
The rock wool consists of a thermal insulating material made from basalt rocks and other minerals, giving rise to a light, flexible and easy to install product (Isover - Catalogues). It is a product widely used in construction, giving high energy efficiency and good acoustic performance. It is incombustible, i.e. it does not propagate flames, and does not produce fumes or create flammable droplets. For that reason, its application has been studied to be placed in the previously mentioned elements of a house.

5.1. Roof

The implementation of the roof is defined by a traditional cover, with discontinuous wooden support structure and ceramic tile. It is assumed that the roof consists on a pyramid hip roof which has four intersecting sides. The tiles must rest on the lath and counter-lath, which in this case is also made of wood. Two intervention solutions are then presented for houses in zones of high wildland fire risk. Both solutions are techniques for the rehabilitation of a roof and it is necessary to remove the ceramic tiles to carry out the operations. This leads to increased labour costs. However, a large part of the houses in these villages do not have their maintenance up to date, so there are many roofs whose roof tiles are already in poor state of preservation. The fact of removing and replacing the tiles is an action of great importance for the conservation status of the roofs.

- **Solution nº1 – Roof made of gypsum plasterboard separated by profiles and mineral wool in the interior**

The first presented solution (Solution nº1), guided by Isover Saint-Gobain, is based on a simple technique as presented in Figure 3.



1 - Roof tile
2 - Counter-lath
3 - Lath
4 - Vapour permeability membrane
5 - PPF boards (13 mm)
6 - Profile
7 - Mineral wool
8 - Rods
9 – Triangular roof truss
10 – Binding joist

FIGURE 3 - CROSS SECTION OF THE ROOF (SOLUTION Nº1). DRAWING WITHOUT SCALE.

It consists of partition walls made of gypsum plasterboards (PPF boards) separated by metal profiles and mineral wool. This set ensures the fire resistance class EI60, which means the lower plate that is not exposed to fire, can resist up to one hour from the beginning of the fire resistance test up to at least 945 ºC.

The solution under study, consisting on two 13 mm boards separated by profiles and mineral wool inside, was tested for fire resistance with a normalized temperature increase curve and with the wall on a vertical position. The normalized curve will not be the same, because this system was tested for fire resistance in different situations. However, it is assumed that this curve is very similar. The fire resistance test of a vertical wall made of gypsum plasterboards is relatively different from a scenario in which it is arranged horizontally and inclined, so the mechanical stresses on the profiles are different. Thus, the profiles may suffer changes, that on the other hand do not affect the fire resistance for at least one hour, as the lower plate supported on the rods continues to function.

The metal profiles should have the same spacing as the rods, in order to reinforce the resistance in this area. The treatment of joints between panels is of great importance to ensure the tightness and integrity of the boards surface. The arrangement of the joints must be alternated in order not to match the joints of the lower and upper plates and to prevent the occurrence of cracks.

Rock wool is a thermal and acoustic insulation that must be applied between the panels and is a non-combustible material (Euroclass A1) that does not release toxic fumes. The increased thickness of the system allows to obtain excellent benefits in terms of fire resistance, never decreasing its EI classification. In the original dividing walls, the mineral wool has a thickness of about 50 mm, being insufficient for this purpose. Thus, it is essential to increase the thickness to 90 mm, thus reducing the thermal transmission coefficient and resisting more effectively to fire.

It is necessary to place a vapour permeable membrane screwed to the PPF board. This membrane, with reduced thickness, is normally used when it is important to protect the thermal insulator against atmospheric agents while letting the cover "breathe" being permeable to water vapour. Most of the membranes on the market are made of combustible materials which, despite their low thickness, contribute to the spread of a fire. Nevertheless, a fire-resistant membrane - Effisus FR class A2 - which is also permeable to water vapour, but impermeable to rainwater and windtight (Effisus) was recommended.

- **Solution №2 - Rock wool sandwich panel**

This solution, presented by the company FTB - Fábrica da Barca, is an existing technique made of rock wool and two metal boards, as represented in Figure 4. It is a technique to add a coating to the roof, which is widely used in industrial buildings and can also be adapted in residential complexes.

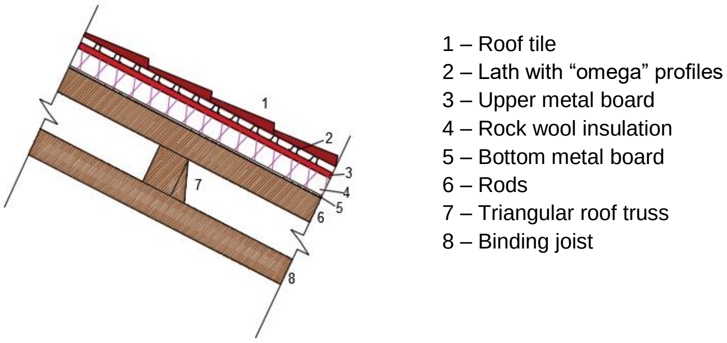


FIGURE 4 - CROSS SECTION OF THE ROOF (SOLUTION №2). DRAWING WITHOUT SCALE.

The thickness of the upper metal board can be 50 mm acquiring a fire resistance class EI 45, or a thickness of 75 mm with a class EI 120 (FTB - Catalogues). In this context, the second option is the most appropriate as it withstands fire for at least 120 minutes, and therefore more than one hour as indicated in the objectives of this study. The metal boards are exposed to a hot-dip galvanizing process before being applied. The thickness of the rock wool will be 75 mm. In this case the traditional lath will be replaced by metal profiles in the form of an "omega" and screwed to the upper metal board. Finally, a ceramic tile coating is placed above.

5.2. Openings

Openings, which are windows and doors, are located in the walls of buildings, and have various requirements such as ventilation, but at the same time weather protection. After evaluating the questionnaires, it can be concluded that windows and external doors are also significant ignition points. It is therefore important to propose solutions to protect these elements from incandescent firebrands in order to ensure indoor safety.

The normative requirements regarding window frames are, in fact, very weak in the context of wildland fires (minimum fire reaction: D-s3,d0). The use of window frames made of aluminium and a double glazing is a solution that may reduce the spread of a fire from outside. However, this solution is not sufficient, apart from the fact that aluminium frames are not thermally viable. It is also possible to use fire-resistant glass, which on the other hand has the disadvantages that it has a high thickness of about 25 mm, is expensive to produce and not suitable for the use in conventional houses. Therefore, techniques are proposed in the following, in order to protect the structure components and to maintain the existing openings without having to replace them.

- **Shutters and covers**

The roller blinds (shutters) made of aluminium were significant to prevent the entry of firebrands in the fires of Pedrógão Grande (Viegas *et al*., 2017). Thus, it is suggested to use them for the existing houses. Although they are primarily elements for controlling the lighting in a house, they represent a considerable added value in the context of fire protection. Shutters and covers can be installed as economical solutions outside of windows and also, as normally not done, in front of doors. The objective would then be that in case of an approaching wildland fire, the inhabitants could lower the shutters or close the covers to ensure safety in the house.

According to the technicians associated with this construction elements, it is not possible to place gypsum or rock wool inside blinds, due to the thickness requirements. These shutters (Persax) are made of heat-lacquered aluminium vertical sheets and polyurethane foam. Polyurethane is usually a flammable material, but it is possible to inject a foam called Den Braven B1 polyurethane, which retards the spread of flames, smoke and toxic gases. Another solution would be the implementation of aluminium covers, without the openings between the blades.

- **Fireproof doors**

The installation of a fireproof door that ensures safety against fire for at least one hour is a solution that, despite being more expensive than the application of shutters and covers, ends up being a viable and very effective hypothesis. There are more economical doors (about 300€) but visually less pleasant composed essentially of galvanized steel and rock wool insulation. There are also more aesthetically doors, which are much more expensive on the other hand (about 800€).

6. Protection of new houses

The new construction of a structure, in this case type I (housing), should protect the population in the interior for at least one hour. The materials and techniques to be used in structural and non-structural elements were evaluated in order to avoid the propagation of a wildland fire to the interior of a house. The following solutions show similarities to the already presented ones, thus they will not be discussed in detail. In this chapter, constructive methods of external non-load-bearing walls, roofs and openings are studied, since they are the constituent elements of a structure that most strongly influence its vulnerability to fire. The construction of exterior walls is covered since it is in contact with the exterior. Therefore, it is easier to implement a solution that resists fire because it is a construction from scratch. In this analysis it was considered a reinforced concrete frame structure.

6.1. Exterior walls

As already mentioned in the evaluation of the questionnaires, the walls were not the main elements to initiate ignition. However, most of the exterior area of a structure is the exterior walls, which form the bridge between the interior and the exterior and should therefore be constructed in such a way as to prevent the spread of a fire.

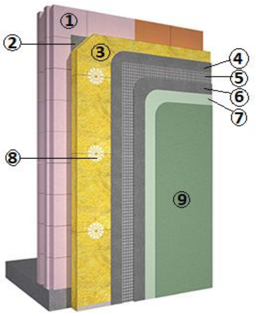
The solution involving masonry walls made of perforated ceramic bricks is nowadays the most frequently used in the construction industry. It is a cost-effective method having high fire resistance such as concrete blocks and is effective when performing on non-load-bearing exterior walls. They can be built simple, double or mixed (stone and brick), depending on the requirements of each building project. In this case, the application of a double-filled masonry wall with several non-combustible materials is the most appropriate solution, being one of the most fire-resistant techniques.

They consist of ceramic bricks of 30 x 20 x 11 cm size. Ceramic materials have a significant advantage over other materials, which lies in the fact that they are non-combustible, class A1, so when using 11 cm bricks it is guaranteed fire-resistance for about 90 min. In addition, the walls are composed of laying mortar, which makes the connection between bricks. Furthermore, there is the air cavity with 4 to 5 cm whose main function is to protect the wall from condensation and rainwater, allowing water runoff (Correia *et al*., 2003). It is concluded with insulation, which in this case will be placed outside correcting the thermal bridges and with a thickness of 6 to 8cm.

- **WEBER SOLUTION**

This solution called weber.therm Comfort System is a recent technique on the market that consists of placing glass wool plates as external thermal insulation, ensuring good acoustic insulation and fire resistance.

Figure 5 shows this technique divided into layers. The substrate must have a flat and dust-free surface, to subsequently place the mortar that connects the glass wool to the masonry. Glass wool is a material composed of fiberglass with reaction to fire class A2-s1, d0. The global system with all components was tested for fire-resistance and allows a reaction of B-s1,d0, that is slightly lower than the insulated glass wool due to the presence of coating mortars and the coating itself. The thickness of the glass wool is 80 mm.



1 - Masonry support;
2 - Adhesive mortar;
3 - Glass wool;
4 - Coating mortar;
5 - Reinforcement net;
6 - Coating mortar;
7 - Regularization primer;
8 - Mechanical fixing (bushing);
9 - Coating.

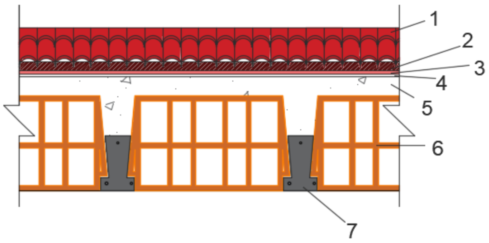
FIGURE 5 - EXTERIOR INSULATED WALL COMPONENTS (WEBER SOLUTION). ADAPTED FROM WEBER, 2018.

6.2. ROOF

Regarding the roof under construction from scratch, two construction techniques are presented in the following in order to protect houses against wildland fires. The first consists of a solution with a sloped roof and the second is based on a terrace roofing technique.

- **SLOPED**

The roof structure of this solution is basically a slab that, instead of being horizontal, is following the roof with slope. It is a non-traditional prefabricated structural solution consisting of vaults with hollowed ceramic blocks, C35/45 pre-stressed concrete joists, C20/25 supplementary concrete with reinforcement steel, Effisus FR fireproofing membrane as well as rock wool insulation. These elements are illustrated in Figure 6. It should be noted that the materials are highly resistant to fire, although the steel cables inside the joists have a strong possibility of losing their characteristics when meeting high temperatures, which is not advisable (Machado *et al*.). Thus, it is necessary to ensure a relatively high cover of the joists so that the reinforcement steel is not affected.



1 – Roof tile;
2 – Lath;
3 – Fireproofing membrane;
4 – Rock wool insulation;
5 – Supplementary concrete;
6 – Vaulted ceramics;
7 – Joists.

FIGURE 6 - CUT IN THE LONGITUDINAL DIRECTION OF THE SLOPING ROOF. DRAWING WITHOUT SCALE.

- **TERRACE**

A terrace roof should essentially guarantee water tightness, thermal comfort and safety. A slight slope is required to drain rainwater and washing water, with a minimum slope of 2%, according to *Laboratório Nacional de Engenharia Civil* (LNEC). The presented solution consists of implementing a roof terrace with a control system to release water when a button is pressed by inhabitants inside the house. In this case, the "horizontal" slab that constitutes the terrace will also be composed of joists, vaults and supplementary concrete and the roof is intended to be accessible and the attic should be habitable.

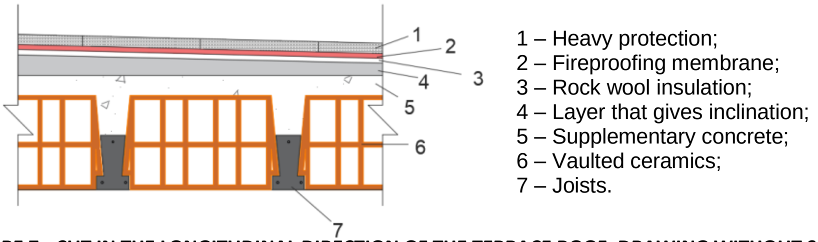


FIGURE 7 - CUT IN THE LONGITUDINAL DIRECTION OF THE TERRACE ROOF. DRAWING WITHOUT SCALE.

In Figure 7 is shown an inverted roof solution, where the thermal insulation is placed above the waterproofing coating, protecting it and avoiding thermal shock and its own degradation. As in any roof, it is important to provide a good drainage, avoiding that the water flows inside the building and does not cause overload of the roof. In this case, a terrace roof with two slopes will be considered, allowing the water to run off to two drains that lead to drop pipes inside the structure.

As it is shown in the left part of Figure 8, the system contains drains, a faucet, an overflow tube and a control button. Furthermore, Figure 8 intends to illustrate on the right side the sequence inherent to the control system process. The second step represents the moment when the process is started by pressing the control button to directly activating the faucet or interrupting the water circulation in the drains and overflow tube. Subsequently in step 3, the water is already on the terrace. The amount of water required for the firebrands not to ignite depends on the size of the terrace (considered area = 150m^2) and the permeability of the roof. It is assumed that a height of 2 cm of water is enough for the firebrands to rest on the water without damaging the roof structure. Thus, for a flow rate of for example 750 l/min, this corresponds to about 4 minutes to cover the entire 2 cm high terrace area. When the fire is extinguished, the control system (step 4 in Figure 8) can be switched off to drain the water.

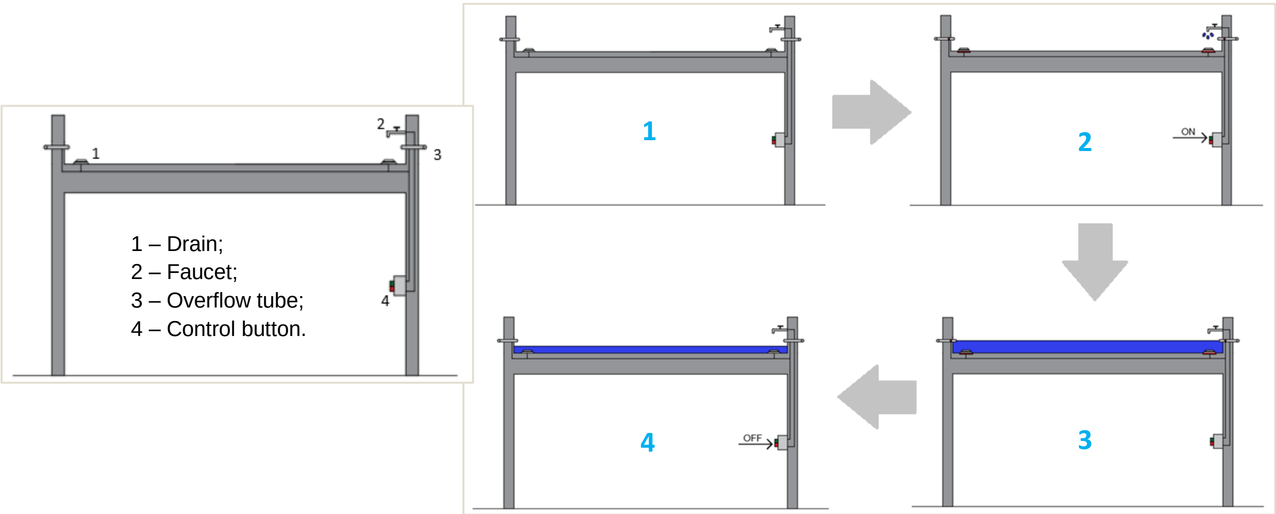


FIGURE 8 – LEGEND OF THE COMPONENTS (ON THE LEFT) AND PROCEDURE SEQUENCE OF THE PROPOSED CONTROL SYSTEM (ON THE RIGHT).

6.3. Openings

The openings solutions in new construction are the same as mentioned above, i.e. implementation of shutters, covers and fire doors. In order to reinforce the protection of the windows, aluminium frames with double glazing should be placed.

7. Protection of isolated villages

As previously mentioned, most of the fires occurred in houses located in isolated villages and surrounded by vegetation, and in some situations the fire was surrounding the village.

The first solution, already existing in some villages, is the introduction of a waist-high concrete tank for evacuation purposes. This tank may have a capacity for all inhabitants of a village or there may be several tanks at different places distributed over the area. It should include a structure attached to the roof consisting on a sandwich panel as mentioned in Solution nº2, to ensure that firebrands do not interfere with people. The tank needs to be filled completely with water.

Another solution is to build two similar structures for the protection of people and animals. The characteristics of the structure are the same as mentioned in the section about protection of new houses, but on a larger scale. It should be made of reinforced concrete structure, in which the openings can be avoided since it is a sensitive point to catch fire. However, not only the structure needs ventilation, but also one or two entry/exit points for people/animals. The doors should be fireproof with an opening for inside and anti-panic bar in order to guarantee easy and fast access. Regarding the ventilation inside, measures should be taken with the help of air conditioning equipment such as air handling units.

8. Conclusion

Forest areas represent two-third of the Portuguese territory, so conservation is a major issue. Wildland fires have been very frequent in Portugal during the dry season, causing enormous impacts not only on forest areas, but also on communities. The excessive proximity of urban areas to vegetation is an unresolved problem, as it is impossible to create barriers between them. However, it is pertinent to mention the importance of fuel treatment guidelines, in which it is mandatory by law until 15th of April of every year to create a 50 m cleared forest from the facade. However, it is not necessary to have direct structural ignition, since the propagation of firebrands with wind can be 2 km from flames to structures. This means that the problem is not only the proximity between forest and urban areas, but also the materials and the construction techniques used in the structures.

The huge wildland fires of Pedrógão Grande and 15 October marked the history of Portugal by the impacts they created. Therefore, this study analysed the main methods of protecting communities so that the impact of these events is reduced in the future. It should be noted that it is almost impossible to guarantee complete fire protection because situations and conditions vary, but the scope of this study covers the circumstances in which it is possible to significantly reduce the tragic impact, as was the case with the fires mentioned above.

This work differs from other studies carried out in the sense that the focus was set on fires from outdoor to the interior, so that the instruction aims to keep the residents in their homes for at least one hour (time of fire passing), rather than evacuating the structure. The protection of houses from wildland fire are defined for the areas with the highest fire risk, where this study was carried out with the focus on existing houses, construction from scratch and isolated villages. The method used was the study of burnt houses with the aid of reports, surveys and an interview, as well as the contact with several companies that provided information on their products. After analysing the feasibility of the solutions, the methods and instructions for the construction were proposed.

Finally, it should be noted that no economic analysis has been carried out in this work, which is one of the main limitations in building construction and rehabilitation. The work developed in this work is expected to contribute to a better understanding of the topic under study and to underline its importance. The recommendations made in the course of the work may serve as an indication for future projects, which deal in detail with the individual aspects.

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