Passive fire protection requirements achieved by fixed firefighting systems in external façades

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Abstract: Due to recent fires in high-rise buildings, fire propagation through exterior façades has become a critical focus for fire safety engineers and regulatory frameworks. Older cladding systems often do not meet current standards and present significant fire risks. Furthermore, replacing these systems can be hindered by high cost, technical issues or heritage preservation regulations. Fixed firefighting systems (FFFS) offer an effective solution to complement passive fire protection by helping to meet façade fire propagation and structural fire resistance requirements.

This study conducts CFD simulations on two façade configurations: a façade with a combustible cladding and another with an external steel structure. The fire performance of these systems is modeled based on the BS 8414-1 standard. Results show FFFS significantly reduces flame propagation on combustible claddings and protect steel from thermal radiation. The study highlights that FFFS are an effective tool to address deficiencies in passive protection and optimize design. It also presents a testing and evaluation protocol to assess their effectiveness as façade fire protection systems.

Keywords: Fixed firefighting system (FFFS), passive fire protection, external façade, combustible cladding, external steel structure, ad-hoc fire testing.

1. Introduction

The risk associated to combustible façade claddings has become a growing concern due to the recent fires that occurred in high-rise buildings. Fire propagation through the exterior façade is a key area of research for fire safety engineers and building codes regulators [1- 3]. In most cases, fire is localized inside the building until it reaches the exterior through a window. Next, combustible materials on the façade cladding in combination with wind and temperature conditions boost fire propagation through the façade and could affect egress and tenability conditions, building fire compartmentation and structural fire resistance when an external structure is also on the façade [4].

There is no harmonized standard or a common European regulatory framework related to fire protection of façades. Currently, a novel full-scale fire-performance test standard for external cladding systems is under development. Meanwhile, some states incorporate their own national regulations. Older constructions did not comply with fire regulations or requirements that ensure a minimum level of fire protection on façades, nor do they restrict the use of combustible cladding to prevent fire propagation.

Tall buildings constructed under older regulations with combustible cladding materials on the façade present significant risks to occupants and firefighters that must be addressed. Replacement of these claddings incurs high costs, faces technical restrictions, or may conflict with other regulations, such as those related to heritage preservation. In example, the case of an historic building protected under heritage laws that often have strict restrictions on external modifications. There is limited capacity to replace current cladding systems or add new fire-resistant materials because it would change its original appearance or structural configuration. Another example is the case of steel exoskeleton structure with a degraded fire protection, such as an intumescent coating that requires replacement. If not replaced, the fire resistance of the steel could be compromised. The old coating must be completely removed before the new one can be applied. In both cases, and in general for existing buildings, an alternative needs to be found in order to improve the fire protection of the façade while keeping system changes to the minimum. This study proposes an alternative to the use of passive protection fire solutions to fulfil façade fire protection requirements achieved by the addition of Fixed Firefighting Systems (FFFS).

In recent years, fire laboratories have received numerous requests to test and evaluate alternative fire protection solutions, such as FFFS, for existing façades to ensure compliance with current fire protection regulations. In this context, this study evaluates the feasibility and effectiveness of FFFS as a façade fire protection system and proposes a test protocol for assessing the effectiveness of specific FFFS designs. By the use of Computational Fluid Dynamics (CFD) simulations this research establishes the testing methodology and boundary parameters required to conduct this assessment effectively. Two different cases are studied here with the aim of developing the required protocol for testing this type of fire protection solution on façades.

1) An exterior façade with a combustible cladding i.e. of an historic building protected under heritage laws.
2) A steel exoskeleton structure in exterior façade spaced 1 m from the building, i.e. with a degraded intumescent coating protection that needs to be replaced.

2. Methodology

The setup and conditions of a fire performance test of external cladding systems based on the BS 8414-1:2020 standard [5] are modelled in the CFD software Fire Dynamics Simulator (FDS) [6]. FDS is developed by the National Institute of Standards and Technology of the US specifically designed for modelling fire-driven fluid flow and heat transfer phenomena. The software uses large eddy simulation techniques to solve numerically the Navier-Stokes equations.

In all cases, cell size is 0,1 m throughout the entire simulation domain. Characteristic diameter is calculated according to the characteristic fire diameter expression:

$$D^* = \left(\frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{g}}\right)^{\frac{2}{5}} = 1.46$$

Where $\dot{Q}$ is the total heat release rate of the fire, ρ_∞ the air density, c_p is the specific heat of the air, T_∞ its temperature, and g gravity. Therefore, using $\partial x = 0.1$ m the ratio $D^*/\partial x$ equals 14.6, which indicates a fine mesh for the design fire used.

Two different FFFS are used: low-pressure conventional sprinkler and low-pressure water mist nozzle. Technical characteristics are extracted from commercial literature and are defined in Table 1:

Table 1: Technical characteristics of the FFFS used in the CFD simulation.

	Sprinkler	**Water mist**
Droplet diameter, [μm]	2000	200
Activation temperature, [°C]	68	68
Response Time Index, [$(\mathrm{m}\cdot\mathrm{s})^{1/2}$]	50	50
C-factor, [$(\mathrm{m}\cdot\mathrm{s})^{1/2}$]	0.7	0.7
K-factor,[$\mathrm{L}/(\mathrm{min}\cdot\mathrm{bar})^{1/2}$]	80.5	25.5
Pressure, [bar]	1	16
Spray angle, [°]	80	80
Particle velocity, [m/s]	5	5
Pattern shape	Uniform	Uniform

Water mist and sprinkler systems represent two different approaches to fire suppression. Water mist systems use very fine water droplets (less than 1000 μm in diameter) discharged at high pressure. It creates a fog-like spray that provides superior heat absorption and thermal radiation attenuation compared to sprinklers. On the other hand, sprinklers operate at lower pressures and use a larger droplet diameter [7]. They work by controlling or extinguishing the fire by cooling and wetting the fire surfaces and the air around them. All parameters are kept the same for both systems exception of the droplet diameter, k-factor and operating pressure which are the main source of operation differences between both.

The design of FFFS has a significant influence on achieving passive fire protection requirements. Parameters such as nozzle or sprinkler type and coverage, their distribution, as well as activation method and timing, must be defined. This study considers only a few simplified FFFS configurations and designs in order to evaluate the feasibility of FFFS as a façade fire protection system.

2.1. Combustible cladding

The test setup is specified in the input file of the simulation based on BS 8414-1:2020 test scenario. The façade is 9.7 m tall; the return wing and the main face have a width of 1.5 m and 2.6 m respectively (**Figure *1*** a). In the case where horizontal propagation is evaluated and in the case with the external steel structure the main face is extended to 5.9 m width (**Figure *1*** b and Figure 6). The opening of the combustion chamber is located on the main façade, with a height of 2 m plus a 0.2 m concrete lintel, and a width of 2 m. The chamber has a depth of 1.1 m. The fire generated by the timber crib is placed on a 1x1 m surface at mid-height of the crib, elevated 0.9 m from the floor to account for the effect of the timber consumption during fire. The design fire is characterised by the Heat Release Rate (HRR) curve shown in Figure 2. It has a fast growth with a heat output of 4500 MJ over 30 minutes and a peak HRR of 3 ± 0.5 MW, as specified for the test.

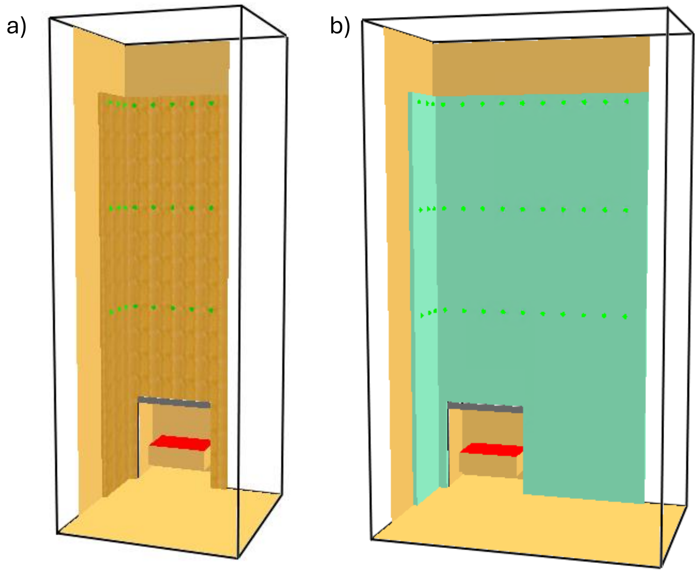

Figure 1: Geometry of the CFD model used for the test of a) timber cladding and b) polyurethane cladding.

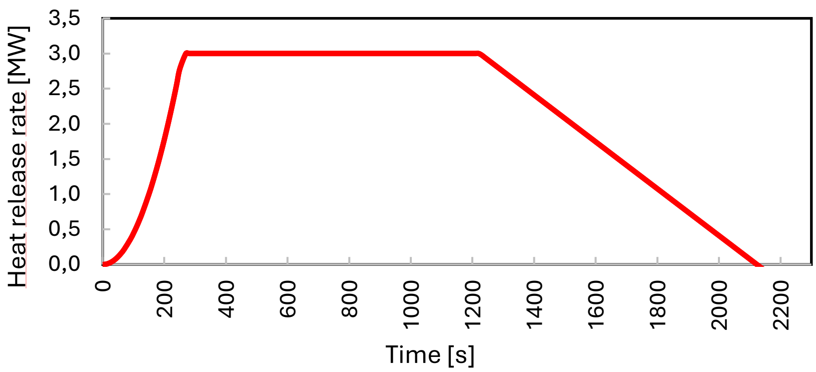

Figure 2: HRR of the design fire used in the computational simulation.

Two combustible cladding materials are used in the study: one considered to pose a high fire risk and another with a medium fire risk, based on their combustibility. The façade claddings considered are:

- Non-fireproof polyurethane foam to analyse vertical and horizontal fire propagation.
- Timber cladding to analyse vertical propagation.

Polyurethane foam exhibits a high peak HRR and has a fast fire propagation. In contrast, timber cladding shows a moderate peak HRR but releases more total energy over time (Figure 3). The HRR per unit area is measured with a cone calorimeter in [8] and [9] with an input heat flux of 50 kW/m^2. The thermal parameters are based on those from [10] (Table 2).

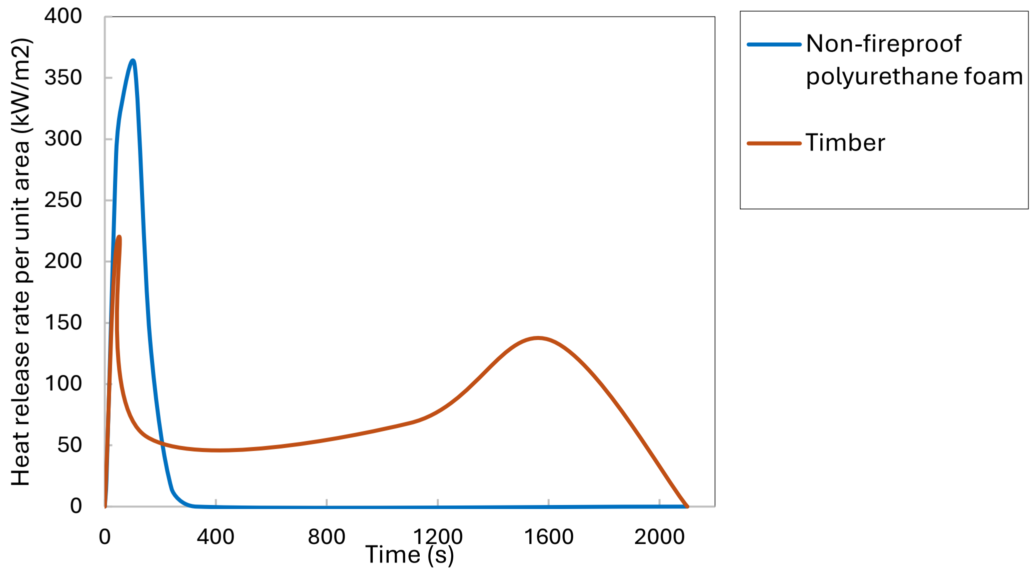

Figure 3: HRR of the cladding materials measured in refs. [8] and [9].

Table 2: Combustion properties of the cladding materials.

	Polyurethane foam	Timber
Thermal conductivity, *k*, [W/(m℃)]	0.025	0.12
Specific heat, c_p, [J/(kg ℃)	1.4	1.53
Density, ρ, [kg/m3]	40	550
Ignition temperature, T_{ig}, [℃]	350	350

In the model, three levels of thermocouples are located as it is required in the BS 8414-1:2020 standard. Level 1 (L1) is placed at 2.5 m from the top of the combustion chamber, level 2 (L2) at 5 m and level 3 (L3) at 7.5 m. On each level, they are placed laterally with a spacing of 0.5 m on the main face, and between 0.1 m and 0.5 m on the wing, as shown by the green dots in Figure 1. Wall-temperature devices are oriented perpendicular to the wall placed at the exact location of the thermocouples in the test. The nomenclature for referring to the thermocouples on the model of the combustible cladding is defined by two numbers followed by M or R. Where the first number is the level where the thermocouple is located and the second number the position in the horizontal axis starting from the corner between both walls. M/R is defined depending on whether the thermocouple is placed on the main wall (M) or the return wall (R). Failure criteria is based on BR-135 [11]. The start time, ts, for fire propagation is initiated when the temperature at any detector on level 1 equals or exceeds 200 °C rise above the start temperature, Ts, and remains above this temperature increment for at least 30 s. Failure due to fire propagation occurs if i) the temperature rise above Ts on any of the external thermocouples at level 2 exceeds 600 °C for a period of at least 30 s, within 15 min of the start time, ts. And if ii) the temperature rise above Ts of any of the external thermocouples at level 3 exceeds 200 °C for a period of at least 30 s, which means that the fire has propagated up to the top level of the cladding.

Two different configurations of devices are studied. The first FFFS configuration case consists on a single device (sprinkler or water mist nozzle) placed at different height or z-axis (4.5 m or 7 m) but with the same location and orientation that describes the scheme of x-y plane in Figure 4. This means four different simulations, accounting for both height and device type.

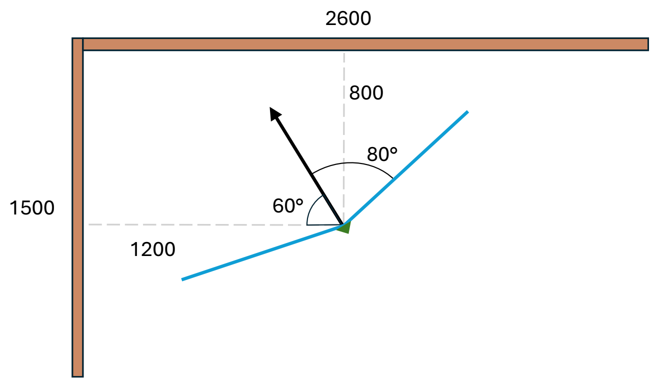

Figure 4: Schematic representation of the nozzle / sprinkler head location and orientation in the first FFFS configuration case. Dimensions are in mm.

The second FFFS configuration case is designed to increase the effect of the suppression system on the polyurethane cladding since this one has a higher combustibility. It consists of a temperature detector and 4 nozzle / sprinkler heads and the same distribution, shown in Figure 5. The detector is placed on top of the opening of the combustion chamber. When the detector reaches 68 °C all four devices are activated simultaneously. The first device column has the same orientation as in Figure 4, and the second column is completely oriented towards the façade wall. This means two different simulations accounting for the different device type.

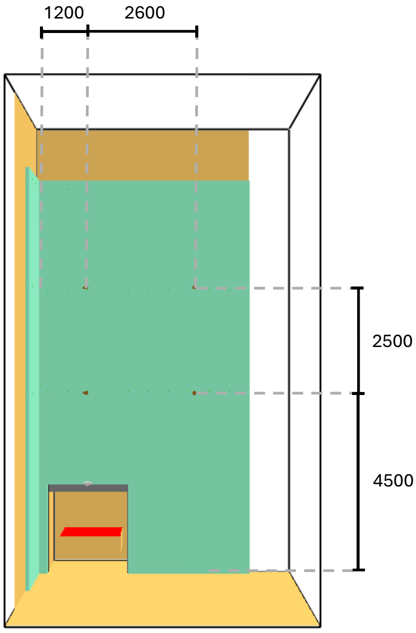

Figure 5: Nozzle / sprinkler head distribution in the second FFFS configuration case. Dimensions are in mm.

2.2.External steel structure

The same fire scenario defined in BS 8414-1 is also considered for the case with the external structure but with the addition of thin I-section profiles (Figure 6). The horizontal beams are spaced 1.2 m apart in height, and the first vertical beam is spaced 2 m apart from the return wall. The structure is spaced 1 m from the façade and the opening of the combustion chamber. (Figure 6).

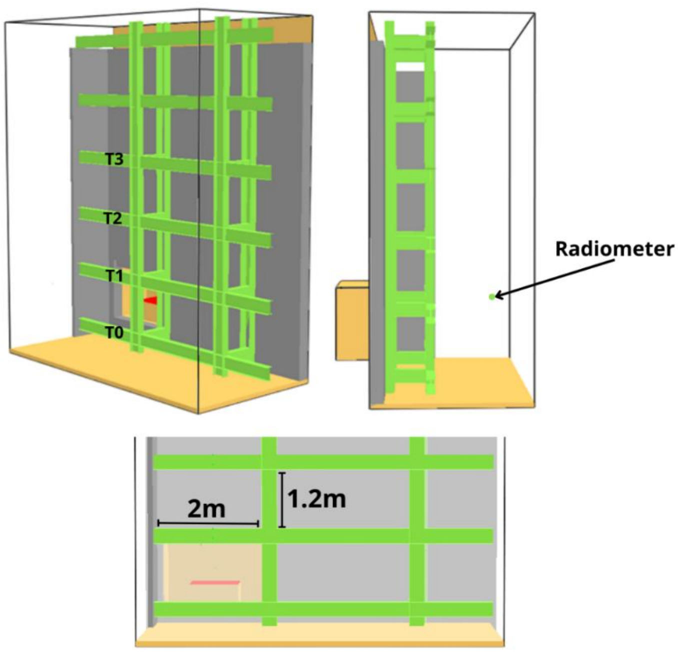

Figure 6: Geometry of the CFD model used for the façade test with external steel structure.

The Eurocode temperature-dependence of the steel for the thermal conductivity and specific heat are introduced in the model.

Thermocouples are distributed along the beams surface, specifically on the inner face exposed to the flames, to identify the critical areas that need to be protected. In addition, a radiometer is placed two meters away from the façade to assess the effect of the FFFS in mitigating the fire radiation.

The FFFS devices are arranged in order to generate a curtain that would protect the external structure from the heat of the combustion chamber. The most affected area is identified, as it defines the zone that needs to be protected and determines the position of the FFFS. Thereafter, three cases are established to study the FFFS and evaluate its performance.

In the first case, the device is placed on the structure, creating a water curtain that covers the identified critical section, as it is shown in Figure 7.

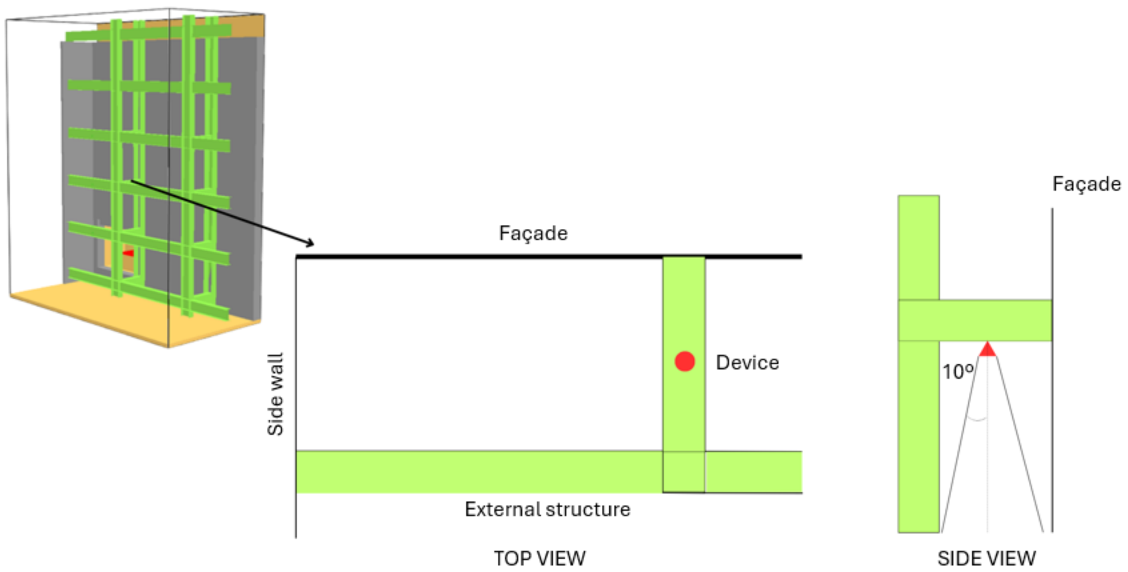

Figure 7: Schematic representation of the first case with the sprinkler head / nozzle located on the external steel structure.

In the second case, the device is placed on the façade, on top of the opening of combustion chamber as it is presented in Figure 8. This modification is used to analyse the impact of the device position on the test performance.

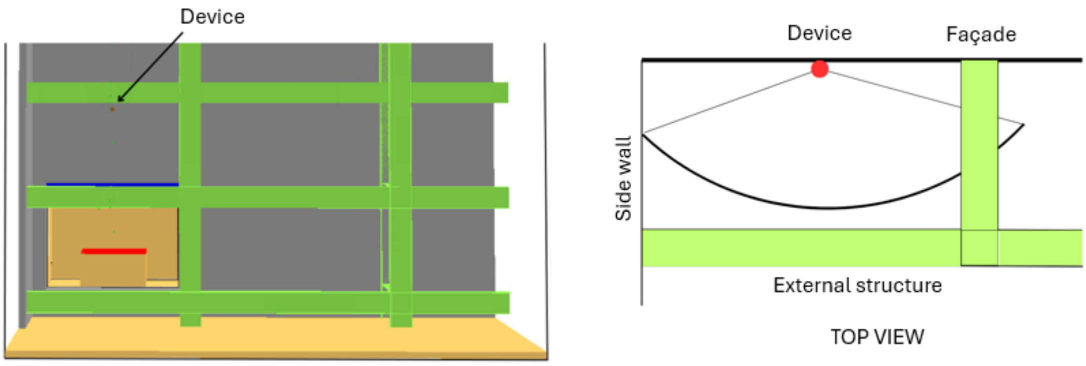

Figure 8: Schematic representation of the second case with the nozzle located on the façade

Finally, the third case consists of two water mist devices placed on the steel structure as in Figure 7 but positioned at two different heights (Figure 9). This setup is going to show the influence of a second device on the temperature and radiative flux.

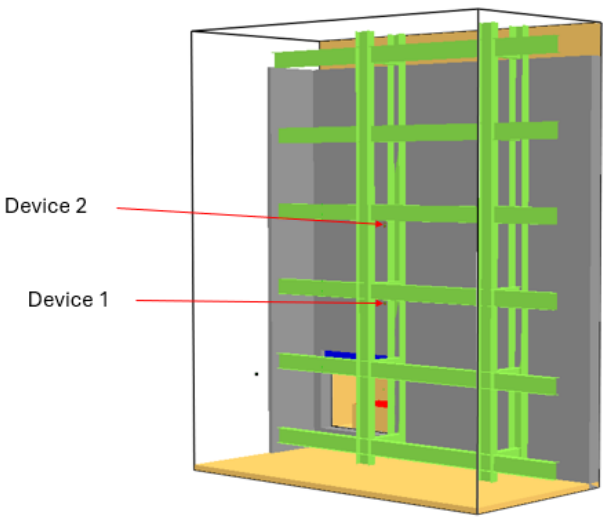

Figure 9: Schematic representation of the third case with two nozzles at different heights.

3. Results and discussion

3.1. Combustible cladding

The simulation with the timber cladding is performed without any FFFS. The most critical temperature of each level is graphed in Figure 10. 600 °C limit criteria for level 2 and propagation temperature 200 °C for level 3 are also marked.

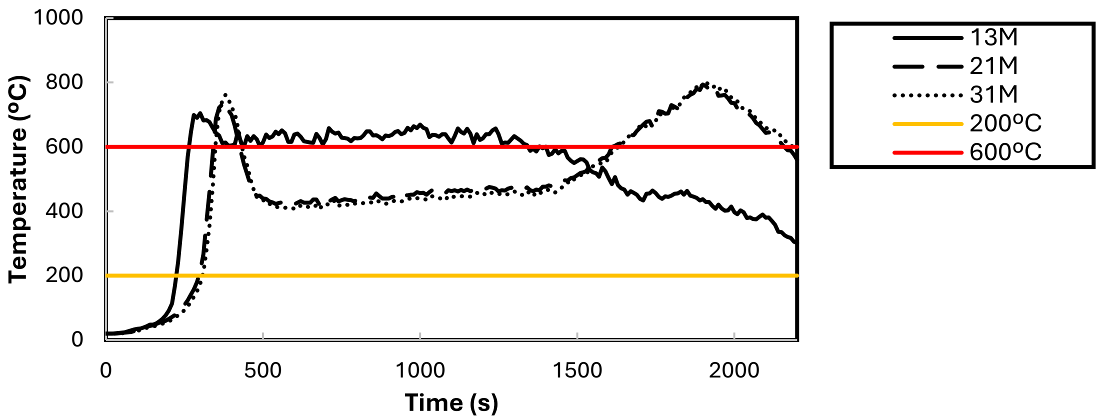

Figure 10: Temperature variation on the most critical external thermocouple on each level of the timber cladding simulation.

The results with the incorporation of the FFFS are shown in Figure 11. When the nozzle or sprinkler is introduced at 4.5 m height, both systems are able to supress the fire propagation on the critical thermocouple locations. In all of them, temperature is kept blow 200 °C. When the device is located at 4.5 m height, water mist system has a major influence since it is able to keep temperature below 100 °C in all of the levels. When the device is placed at 7 meters, both systems are able to meet the failure criteria. However, the water mist has a minor impact on the temperature curve of the critical thermocouple temperature of level 1. As seen in Figure 12, at 7 m height adiabatic surface temperature on level 1 is not being affected by water droplets coming from the water mist. In this case, droplets are being evaporated or dragged upwards due to the fire plume. The sprinkler droplets are ten times larger, allowing them to reach level 1 before evaporating. Due to their greater mass, they are not carried upward by the air flow. At level 2, the temperature is reduced in both cases, but sprinkler has a higher cooling effect on the surface. At level 3, the water mist system performs better than the sprinkler system because the smaller droplets are carried upward by the air flow, cooling the fire plume at this level.

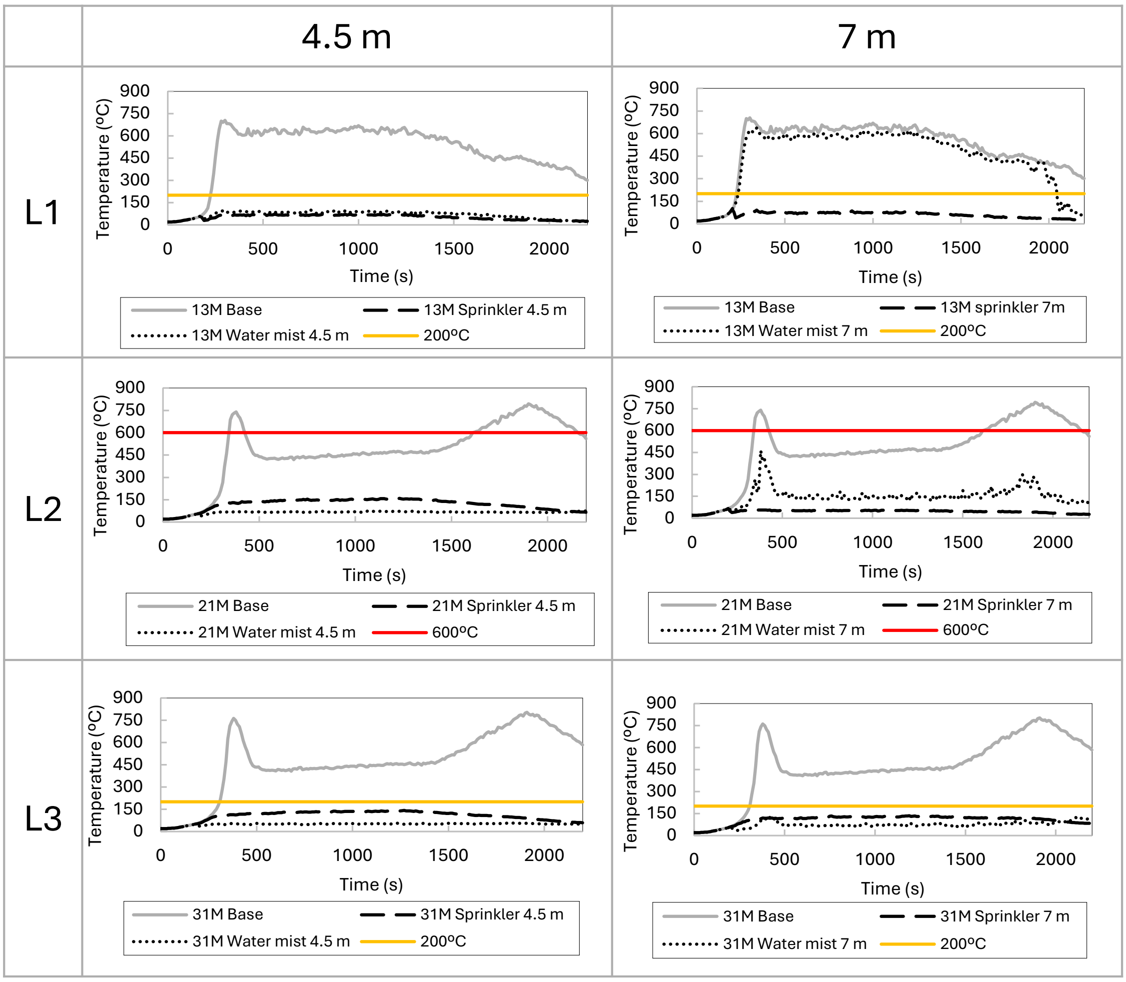

Figure 11: Vertical fire propagation on the timber cladding. Temperature variation of the most critical thermocouple temperature on each level with the sprinkler and water mist placed at heights 4.5 m and 7 m.

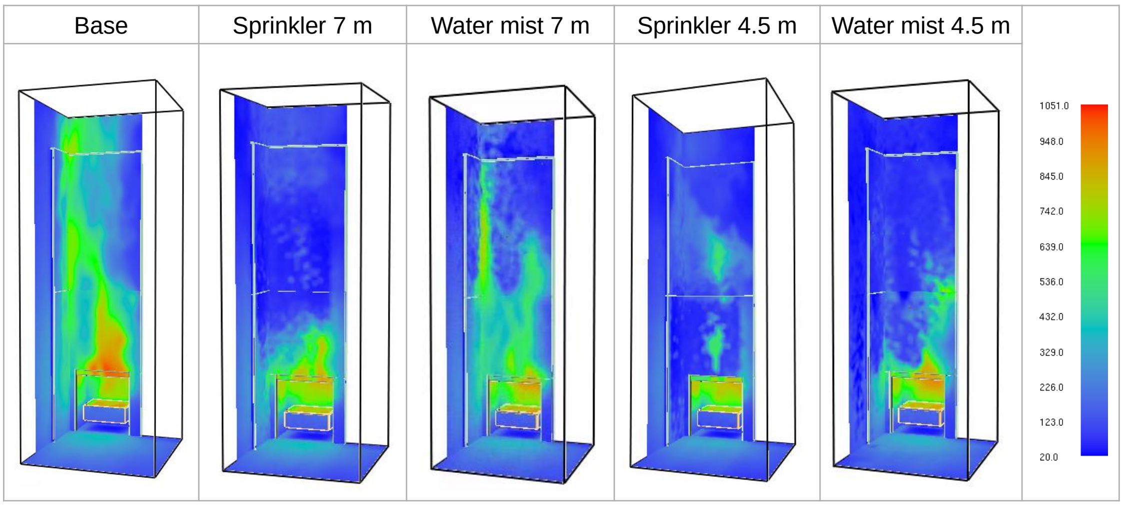

Figure 12: Adiabatic surface temperature distribution in each case for the vertical propagation on timber cladding at 410 s.

The same procedure is applied to the polyurethane cladding with the horizontally extended main wall. To evaluate the vertical propagation, the most critical thermocouple temperatures on each level are compared with and without FFFS in Figure 13. In this case, any of the FFFS is able to reduce temperature curves enough to be below the temperature increase criteria. This is due to the high peak HRR of the polyurethane, and its fast fire propagation rate. The sprinkler system is able to reduce the temperature at level 1, and at level 2 when it is located at 7 m. Small changes compared to the base curve are observed in the other cases.

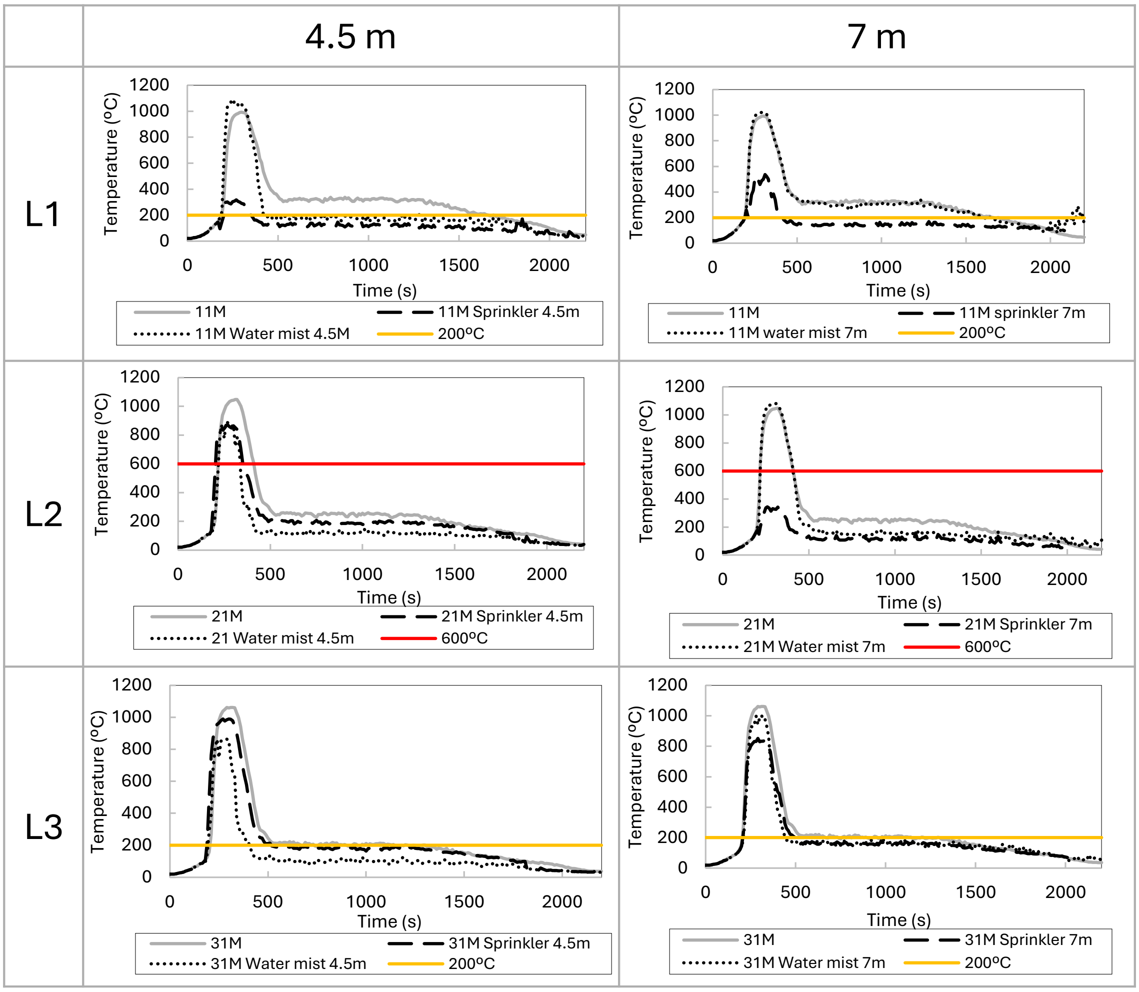

Figure 13: Vertical fire propagation on the polyurethane cladding. Temperature variation of the most critical thermocouple temperature on each level with the sprinkler and water mist systems placed at heights 4.5 m and 7 m.

To evaluate the horizontal fire propagation Figure 14 shows the temperature variation at the first thermocouple located after the 2.6 m width mark (the x6M thermocouple). This is the first added thermocouple on this extended test that receives the highest temperature due to the horizontal propagation. The result also exhibits almost no differences with and without FFFS.

Figure 15 shows the adiabatic surface temperature at the same time-step for the different cases. It is possible to see how the fire propagates horizontally even with the use of the FFFS. As previously explained, the differences between water mist and sprinkler systems become evident when observing the wetting pattern on the façade near the combustion chamber opening.

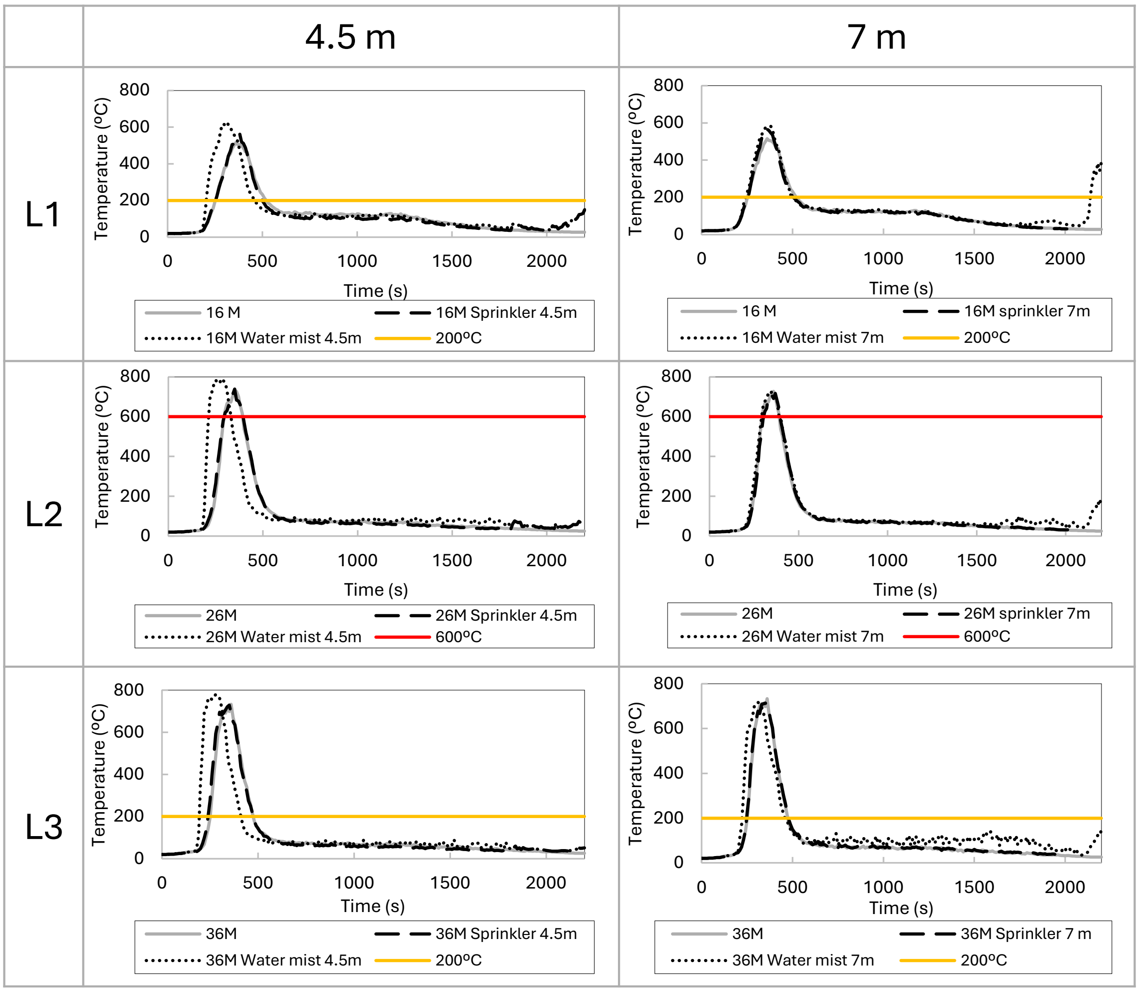

Figure 14: Horizontal fire propagation on the polyurethane cladding. Temperature variation of the most critical thermocouple temperature on each level with the sprinkler and water mist systems placed at heights 4.5 m and 7 m.

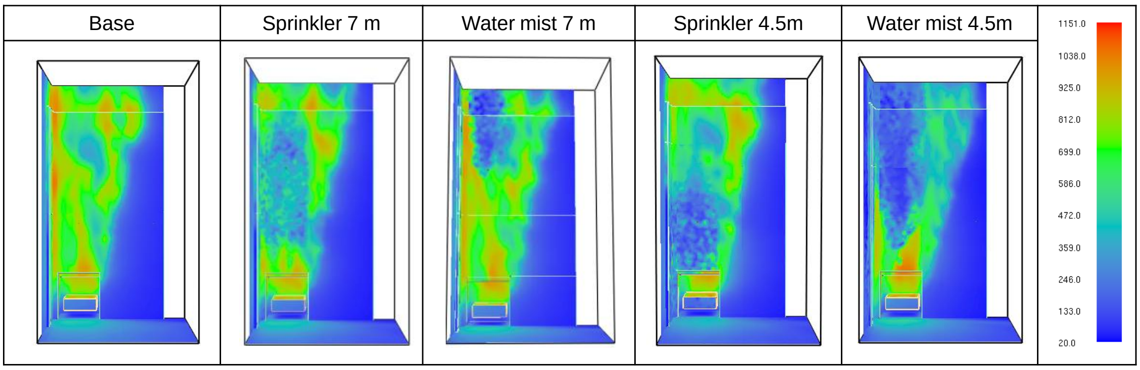

Figure 15: Adiabatic surface temperature distribution in each case for the horizontal propagation on polyurethane cladding at 350 s.

Since the effect of the FFFS is not able to reduce any of both vertical and horizontal fire propagation on the polyurethane cladding, the second FFFS configuration case is performed. Results of the temperature variation on the most critical thermocouple for the vertical propagation and on the x6M thermocouple for the horizontal propagation are shown in Figure 16. Both systems are able to reduce temperature increase on level 2 and level 3. However, the use of this system increases the temperature peak at level 1 and also accelerates fire propagation in all cases, which is evidenced by the earlier rise in temperature. The heat released by the combustion of the façade cladding material may be intensified due to altered airflow patterns caused by the water spray. This can potentially increase flame propagation and temperature rise in some parts of the wall, amplified by thermal buoyancy and increased oxygen flow. Understanding these interactions is critical for optimizing sprinkler design and placement to achieve effective façade fire suppression.

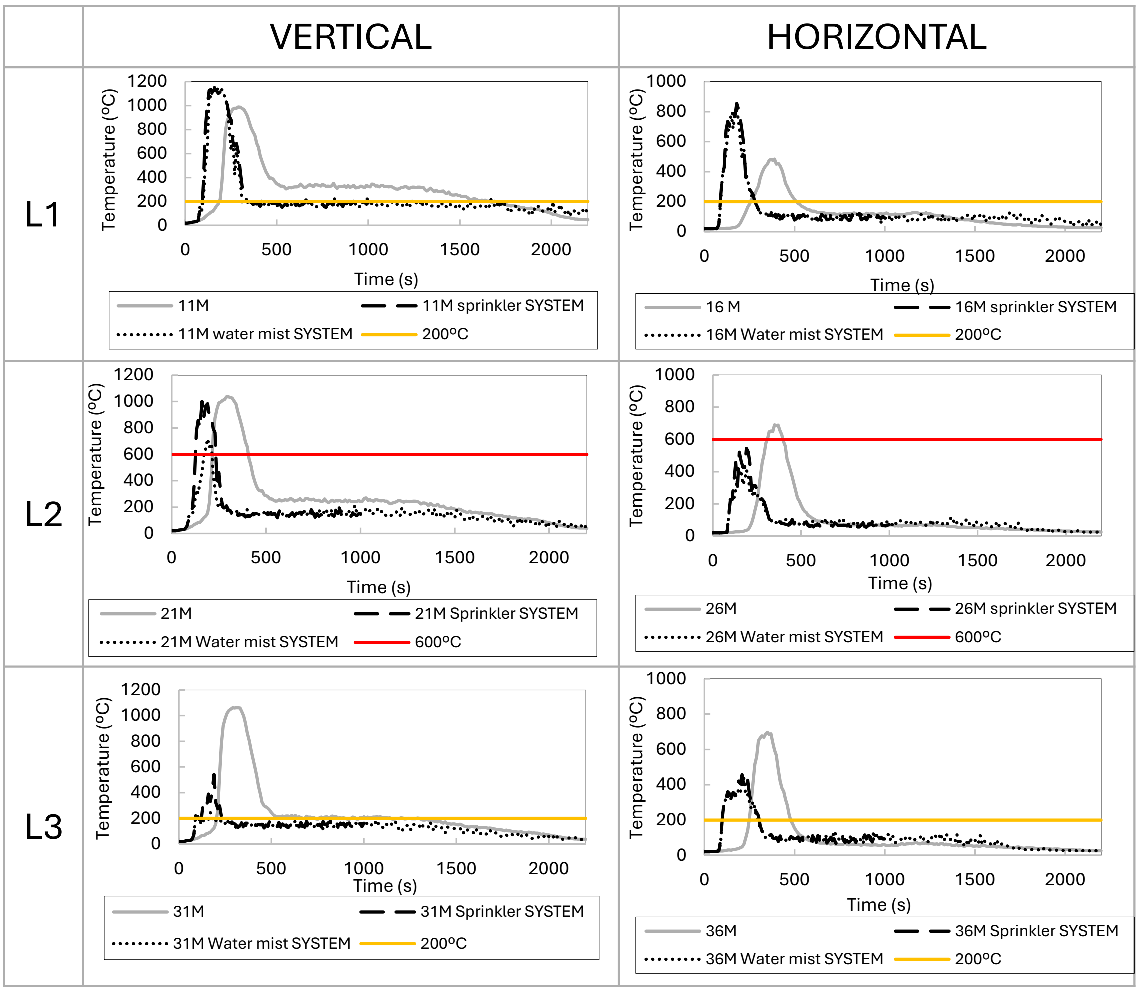

Figure 16: Vertical and horizontal fire propagation on the polyurethane cladding in the systems with four nozzles / sprinkler heads. Temperature variations of the most critical thermocouple temperature for vertical and horizontal propagation of the sprinkler and water mist systems.

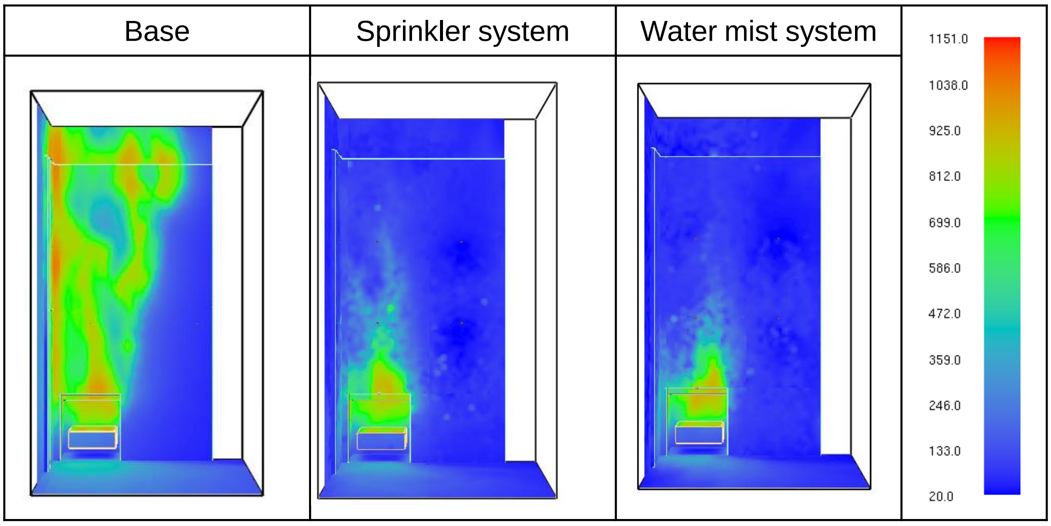

Figure 17: Adiabatic surface temperature distribution in each case for the systems with four nozzles / sprinkler heads in the polyurethane cladding at 350 s.

3.2. External steel structure

In the case with the external steel structure spaced 1 m from the façade, the objective of the FFFS is to prevent the structure to reach the limit temperature of the steel. In this case, a temperature limit of 400 °C is defined to prevent plastic deformation or other inelastic behaviour in the steel that could compromise structural integrity.

The inner face of the second beam, at position T1, in Figure 18 is identified as the most critical point since it exceeds the temperature limit. The third beam (T2) is observed to be close to the temperature limit. Therefore, T2 is also taken as reference to evaluate the performance of the FFFS.

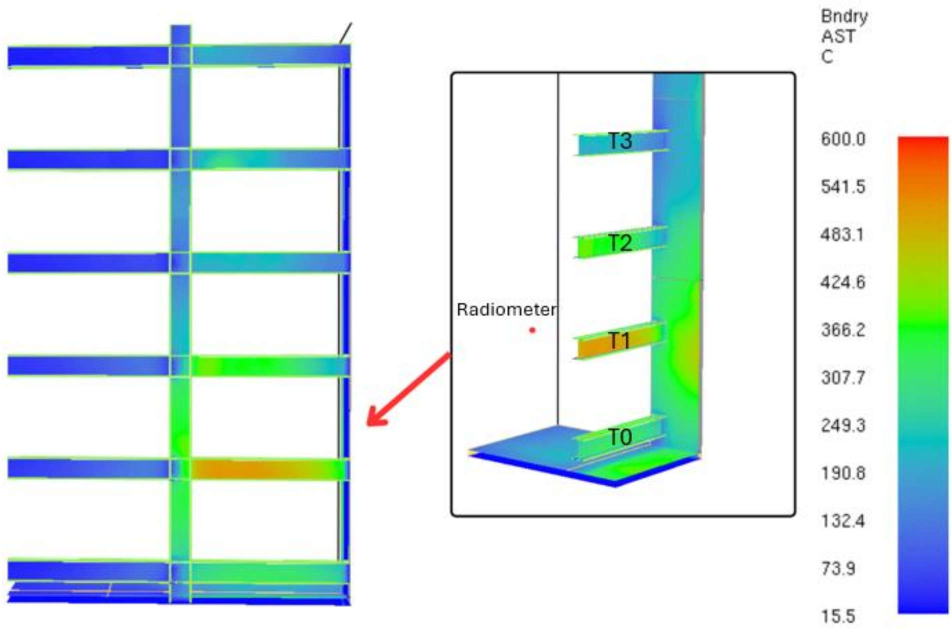

Figure 18: Adiabatic surface temperature on the inner face of the structure without FFFS.

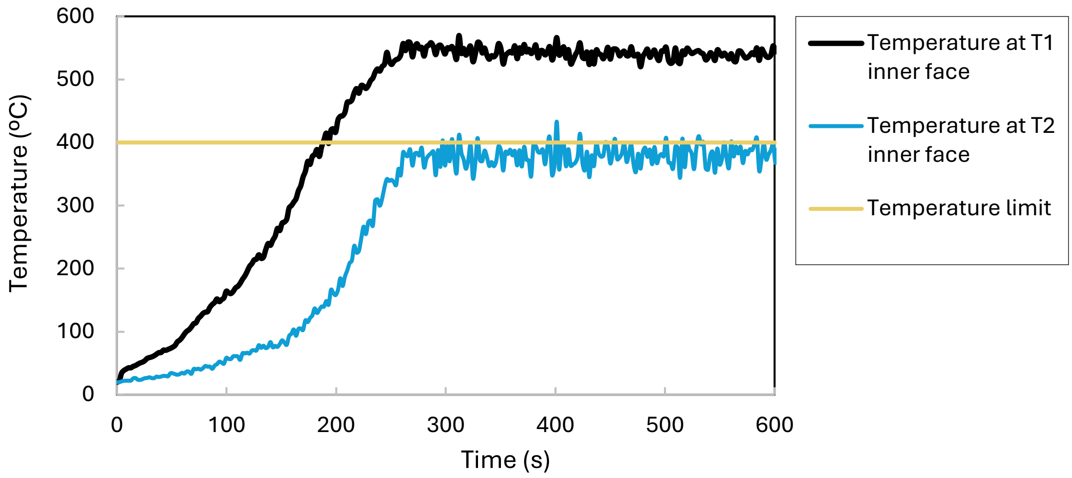

Figure 19: Temperature evolution of T1 and T2 without FFFS protecting the structure.

In the first case with the configuration shown in the Figure 7, FFFS are located on the beam. Temperature variations on T1 using both sprinkler and water mist are presented in Figure 20. Only the water mist placed on the structure is able to reduce the temperature at T1 below the defined limit.

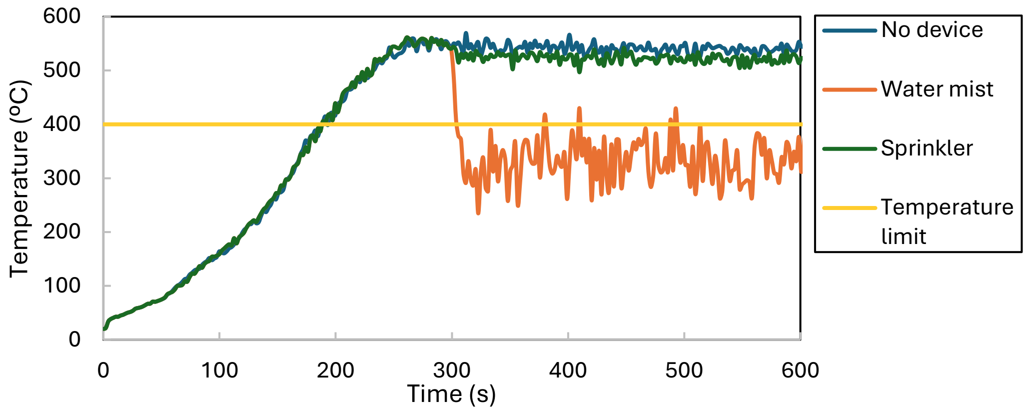

Figure 20: Temperature evolution at T1 using different FFFS.

The results of radiative flux on the radiometer located two meters away from the façade are shown in Figure 21.

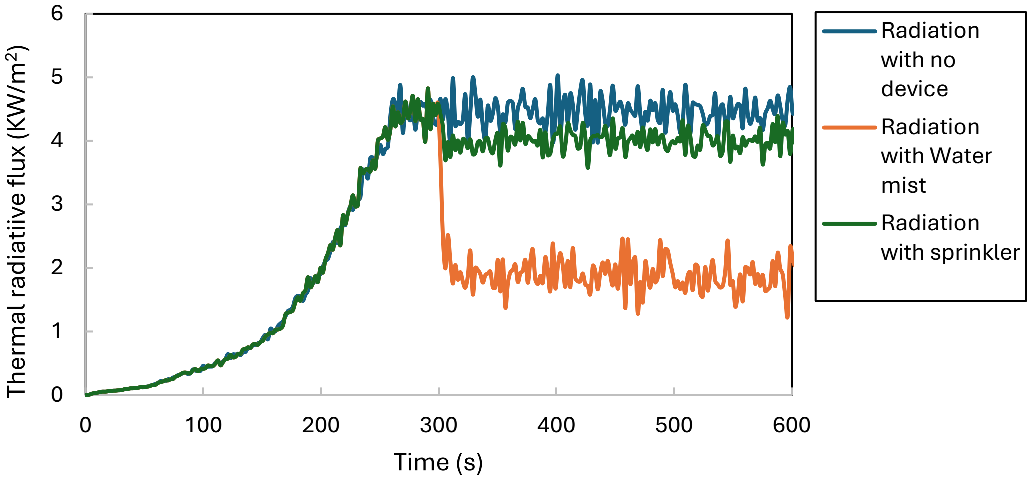

Figure 21: Thermal radiative flux variation using different FFFS.

Both results show that the created water curtain is effective to reduce both the radiative heat flux and the temperature reached by the structure using the water mist system. The smaller water droplets produced by the water mist system create a uniform barrier that enhances the attenuation of the thermal radiation and improves cooling of the surroundings, thereby increasing the protection of the external structure. However, the defined temperature limit is exceeded before the activation of the FFFS.

In the second case scenario, the device is placed on the façade, on top the combustion chamber opening as it is presented in Figure 8. Results of the temperature variation and radiative flux are also compared with the previous case with the water mist on the structure and are shown in Figure 22 and Figure 23.

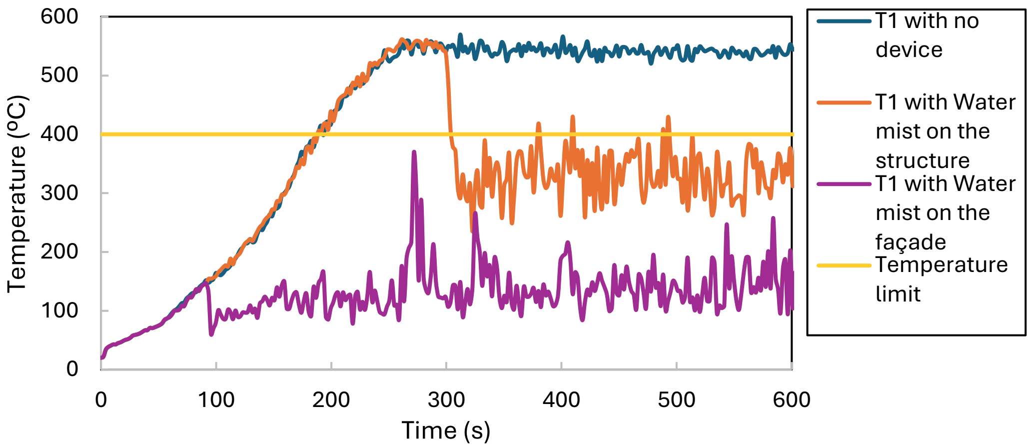

Figure 22: Temperature evolution at T1 when the nozzle is placed on the structure (first case) and on the façade (second case).

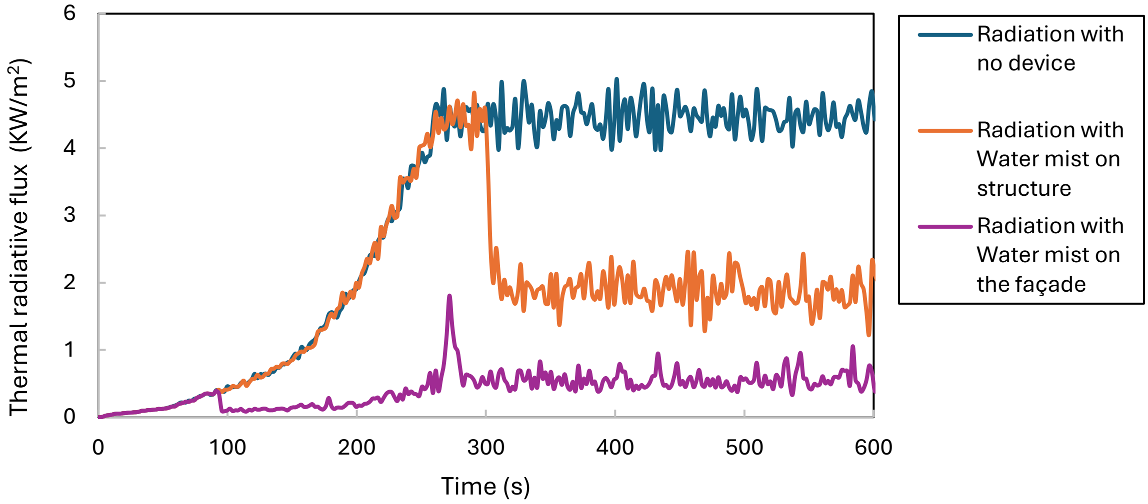

Figure 23: Evolution of the radiative flux when the nozzle is placed on the structure (first case) and on the façade (second case).

In the second case, with the water mist on the façade, the activation time of the FFFS is reduced, thereby preventing the temperature from reaching the defined limit. Moreover, it reduces significantly both thermal radiation and temperature variation on T1. The effect of the different configurations is shown in Figure 24, comparing the adiabatic surface temperature at the inner face of the external structure for both water mist and sprinkler on the structure (first case) and with the water mist nozzle on top of the combustion chamber (second case).

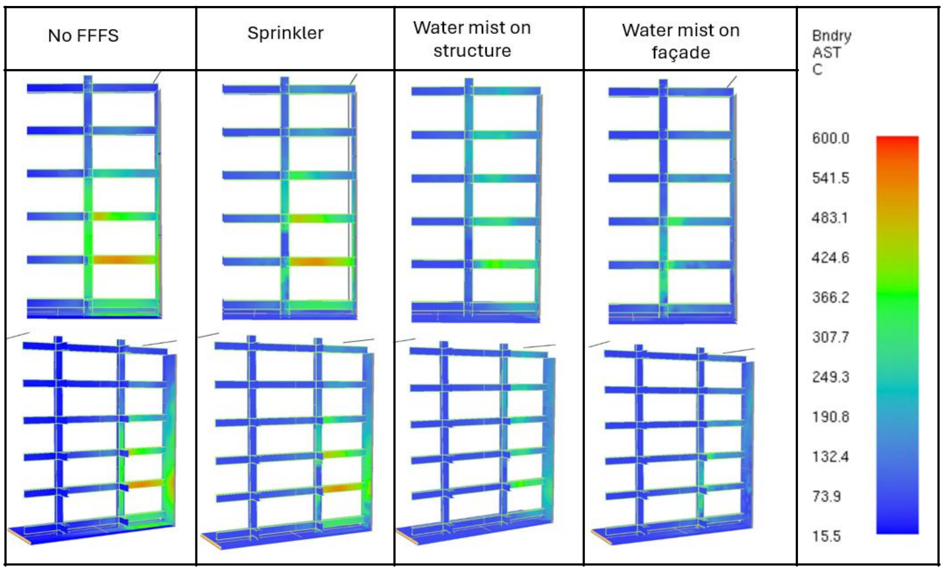

Figure 24: Adiabatic surface temperature on the inner face of the structure for different case configurations at 350s.

FFFS based on water mist effectively reduces the structure temperature on the structure and its surroundings. Furthermore, the positioning of the device plays a key role in its performance. It reduces the activation time and improves the cooling of the structure.

In the third case (Figure 9) a second nozzle is positioned in the structure to see the effect on the temperature variation on T1 and in the radiative flux. Results are shown in Figure 25 and Figure 26.

As expected, there is a delay between the activation of the water mist nozzles and the second nozzle is activated later since it is placed farther. It is concluded that the incorporation of the second nozzle has no effect on the steel temperature or the radiative flux.

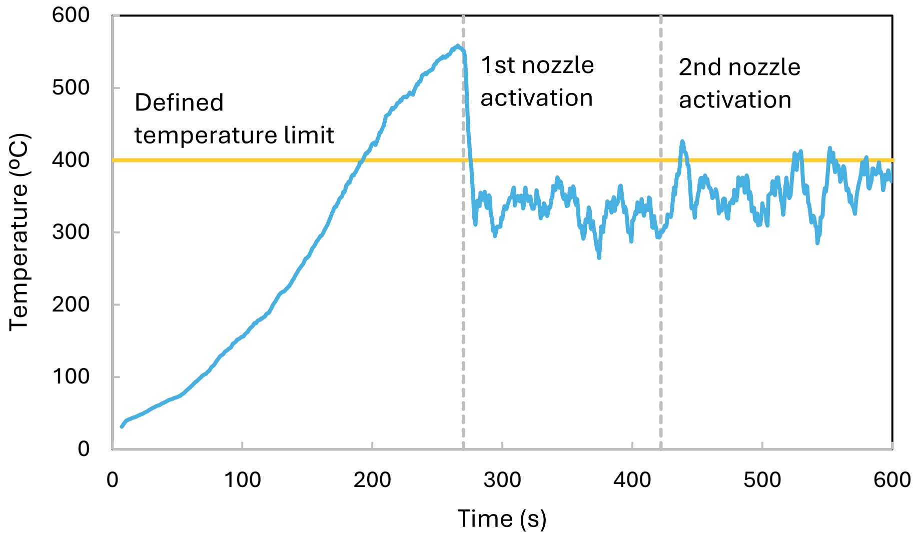

Figure 25: Temperature variation in T1 of the third case with the two nozzles configuration.

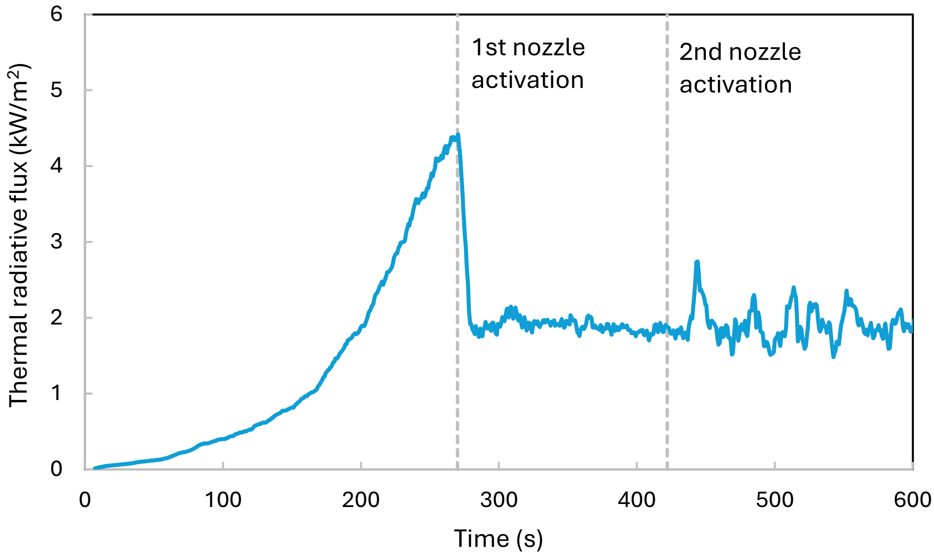

Figure 26: Radiative flux evolution of the third case with the two nozzles configuration.

4. TEST PROTOCOL for the fire performance of external wall systems with FSSS protection

Based on reference standards and the CFD study presented above, the following fire test protocol *Fixed firefighting systems – Test protocol for external façade systems* is presented. The objective is to evaluate the effectiveness of Fixed Firefighting Systems (FFFS) as a fire protection system on combustible façade cladding.

I. Scope

This document specifies the evaluation of the fire performance of FFFS for the fire protection of:

- Façade systems with FFFS independent of the façade cladding solution.
- Façade system with FFFS integrated into the façade cladding system such as ventilated façades.
- External steel structure separated from the façade.

This fire test protocol is applicable to automatic and non-automatic nozzles.

The components of FFFS shall be tested according to their reference standard.

II. Normative references

The following documents are considered.

- BS 8414-1:2020 Fire performance of external cladding systems. Test method for non-loadbearing external cladding systems fixed to, and supported by, a masonry substrate
- BS 8414-2:2020 Fire performance of external cladding systems. Test method for non-loadbearing external cladding systems fixed to, and supported by, a structural steel frame
- EN 13501-1:2018 Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests
- EN 13501-2:2023 Fire classification of construction products and building elements - Part 2: Classification using data from fire resistance tests, excluding ventilation services
- EN 12259-1 Fixed firefighting systems - Components for sprinkler and water spray systems - Part 1: Sprinklers
- EN 12845 Fixed firefighting systems - Automatic sprinkler systems - Design, installation and maintenance
- EN 17450 (all parts) Fixed firefighting systems - Water mist components
- EN 14972-1:2020 Fixed firefighting systems - Water mist systems - Part 1: Design, installation, inspection and maintenance
- EN 14972-6:2023: Test protocol for false floors and false ceilings for automatic nozzle systems
- EN 14972-10:2022: Test protocol for atrium protection with sidewall nozzles for open nozzle systems

III. Objectives

This test method aims to assess the fire performance of FFFS integrated within an external façade system or solution when exposed to fire. It is combined with a façade cladding or external structure.

The use of FFFS is applied to fulfil the fire safety performance of the entire façade. It is installed on a vertical surface to prevent fire propagation and attenuate fire development and thermal radiation.

IV. Test apparatus

The tests apparatus consists of a vertical wall comprising a main wall, and a return wall at 90 ^{o} from the main wall. Main wall shall extend 7700 mm above the top of the combustion chamber opening, and at least 5200 mm wide. The return wall shall be the same height as the main wall and at least 1500 mm wide.

The combustion chamber shall have an opening of 2000 x 2000 mm, and a depth of 1100 mm.

V. Heat source

A timber crib heat source is designed to accomplish a fire of a nominal total heat output of 4 500 MJ over 30 min at a peak rate of (3 ±0.5) MW.

VI. Façade cladding

The façade has to incorporate a combustible cladding to be able to evaluate the effectiveness of FFFS to avoid façade fire propagation.

VII. Fixed Firefighting System

The installation of the FFFS is performed to mock the real installation of the system when applied in service conditions. Exposed parts of the system, operating pressure, water flow and coverage pattern shall resemble as closely as possible to the real application to be able to ensure its extrapolation and correct evaluation.

VIII. Measurements

a) Temperature

As in BS 8414-1:2020, thermocouples at levels 1, 2 and 3 shall be positioned at ten locations in each of the levels on the main wall face. They are positioned at the different levels spaced 500 mm between them, and the first one at 100 mm from the intersection with the return wall.

On the return wall the front of the wing thermocouples shall be positioned in front of the return wall face at three locations from the corner with the main wall. At 150 mm, 600 mm and 1050 mm.

In the event a steel structure is present on the façade acting as a structural support, such as an exoskeleton of the building, the variation in the load-bearing capacity of the structure with temperature must be calculated according to the rules specified in Eurocode 3 for steel. Therefore, it will be necessary to place thermocouples in the steel beams and columns oriented towards the façade. For the beams coming out perpendicular to the facade, the thermocouple shall be located at a distance of 100 mm from the façade cladding external surface.

b) Fire propagation

In the case of there is a combustible cladding, vertical and horizontal flame propagation are monitored by infrared cameras and temperatures are recorded using the thermocouples mentioned above.

c) Structural façade integrity

Visual and dimensional assessment of panel joints and connections, and anchorage fixings.

d) FFFS performance

Technical specifications and parameters of the FFFS shall be are characterized. The following measurements must be performed:

- **Activation monitoring:** Temperature at each nozzle location at the time of activation must be recorded. Also, the activation time on each nozzle from the detection to the water expulsion.
  In case of activation based on detection system, the detection time must be recorded. Also, the delay time on each nozzle from the detection to the water expulsion has to be monitored.
- **Water flow and pressure:** System flow and pressure shall be monitored during the entire test. The number of activated nozzles and total water consumption shall be determined.
- **Water distribution:** The coverage pattern of the sprinklers must be monitored by imaging analysis to confirm the covering angle specified on the technical specifications. Other methods might also be accepted.

IX. Performance Criteria

a) Fire propagation

Start time, ts, is defined when any level 1 thermocouple exceeds 200 °C for a period of at least 30 s.

- **Vertical fire propagation:** Failure criteria due to external wall temperature on the vertical direction takes place when any of the thermocouples of levels 2 and 3 fulfils the following:

	Criterion
Level 2	T > 600°C for 30s in t < ts+15min
Level 3	T > 200°C for 30s

This applies to the thermocouples that are placed within the firsts 2.6 m width on the main face from the corner with the return face or on the return face.

- **Horizontal fire propagation**: The system shall prevent the horizontal propagation of the fire.

	Criterion
Level 1	T>200°C for 30s
Level 2	T>200°C for 30s
Level 3	T>200°C for 30s

This applies to the thermocouples that are placed beyond 2.6 m on the main face from the corner with the return face.

b) Structural façade integrity

Visual inspection of the integrity of the façade system, deformations, panel joints, anchors.

c) Load-bearing capacity

- **External steel structure:** In the case of structural elements on the external façade, Eurocode 3 must be used taking into account the temperature dependent capacity of the steel member or the whole structure.

Others evaluation test criteria could be applied depending on the requirements of the authority having jurisdiction and/or national building and fire code regulation.

VI. Field of application

Test results will be directly applicable to external façades taking into account the following considerations:

- The same façade cladding material than tested.
- Façades geometry similar to that tested, fully vertical without obstruction.
- External steel structure at equal or higher distance than the tested distance between the structure and top centre of the opening of the combustion chamber.
- External steel structure different than the tested structure if the section factor of the structural elements is equal or lower than the of the tested

- Same FFFS design and parameters than the tested (nozzle model, coverage pattern, water and flow conditions).
  Distance between nozzles shall be equal or less than that tested.
  In case that just one nozzle is to be tested, FFFS shall comply:
    - In height, the maximum distance between nozzles shall be equal or less than the tested distance between the nozzle and the centre of the opening of the combustion chamber.
    - In wide, the maximum distance between nozzles shall be equal or less than 2600 mm.

Others façade cladding materials are allowed if they have a better fire reaction performance than the tested. Additional small-scale or mid-scale fire tests could be required to verify fire reaction performance of the material (combustibility, ignition temperature and fire propagation).

FFFS on ventilated façades can be tested according to this test protocol as a component of the ventilated façade system and considering FFFS as a part of the façade system. Test results are applicable to the same ventilated façade system. Direct extrapolation of the test results is not permitted.

To extrapolate the tests results for singular façade cladding materials, external steel structure geometries or configurations, it is necessary a performance-based design using a CFD simulation. This method requires that the numerical model has to be previously validated against the experimental data. From the validated model, one parameter defining a characteristic of the system can be changed at each time and the result has to prove an equal or a better performance than the tested solution in terms of the monitored variables.

5. Conclusions

In existing buildings with combustible façades claddings or exterior steel structures such as a steel exoskeleton of a building, FFFS can be a realistic and valid solution to achieve passive fire protection requirements.

- When combined with combustible façade claddings, FFFS contributes to preventing vertical and horizontal fire propagation.
- With an existing external steel structure, FFFS has been proven to be an effective solution for reducing both radiation and steel temperature by creating a water curtain between the structure and the façade.

- However, system design characteristics such as the position of the nozzle or sprinkler relative to the fire are identified as critical, as they can significantly influence overall system performance. Therefore, there is no generic solution, and a specific FFFS solution must be designed and tested.
- The presented test protocol based on BS 8414-1:2020 fire test is useful to test and evaluate the effectiveness of FFFS to achieve fire protection requirements for façades.
- Computational CFD simulation is an effective tool for a preliminary FFFS design and for the extrapolation of test results to specific building geometry and configuration, provided it is based on a validated numerical model.

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