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A new test method to determine the fire behavior of façades with etic system

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Summary

New building high-energy efficiency requirements have introduced a significant utilization of combustible materials as thermal insulation in building envelopes and especially in façades. The damage occurring in case of fire can thus become considerable, due to greater fire spread. Risks for building occupants and unsafety for rescue team are added to social, economic, and environmental consequences. Despite the fire behavior of the single thermal insulation materials is known, the fire performance of the finished façade system is not yet predictable.This paper describes a proposal of a new medium-scale test method to evaluate the fire behavior for façades with external thermal insulation composite system (ETICS). The project aimed to identify a test protocol conceived to be repeatable, versatile, and able to provide the relevant evaluation fire hazard quantities required for performing a fire risk assessment. Furthermore, the fire hazardous quantities collected during the test could also be useful for a fire performance-based design using fire safety engineering to define building fire safety requirements, occupant evacuation systems, the safety of rescue teams intervention and for estimating residual damage on the building and the adjacent ones after the outbreak of a fire.

1 | INTRODUCTION

Traditionally, the design of building façades was principally driven by architectural or aesthetic features, considering also building weather protective issues. The most recent building façade surfaces are covered by extensive paneling fitted with insulating plastic-based materials or by wide glass surfaces, capable of carrying out the most diverse purposes including energy reduction, climate comfort, recovery of electricity through photovoltaic panels, large space for advertising purpose, just to name a few. Moreover, building high-energy efficiency requirements have introduced a significant utilization of combustible materials as thermal insulation in building envelopes and especially in façades. The damage caused in case of fire can thus become considerable, due to greater fire spread, with additional risks for building occupants and endangering rescue team safety, including social, economic, and environmental consequences.[1-3] Several fires involving external thermal insulation composite systems (ETICS) with polystyrene foam expanded polystyrene (EPS) insulation in Germany led to an extensive discussion and German building authorities called for tests in a fire scenario representing a burning waste container. As these tests revealed weaknesses, measures were introduced to enhance the systems. The topic has been studied by A. Hofmann and others, and the appropriateness of German test standard DIN 4102-20 to take these changes and other relevant factors into account is discussed.[4] Moreover, J. Zehfuß[5] and others have discussed the experimental setup, procedure, and results of different large-scale fire tests carried out on a flat façade with ETICS based on polystyrene. The tests were scientifically monitored to be used as a base for systematic investigations to study the fire phenomena of façades.

Nonetheless, a good fire safety design of the building must be based on a holistic approach, considering the façade performances in case of fire within a fire risk assessment process taking into account the overall fire safety provisions of the building: compartmentation, passive fire measures, fire detection and fire suppression systems, fire safety management, and so on.[6,7]

Fire testing can be a good instrument to forecast the fire performance of the façade system but the specific test method should be able to guarantee the repeatability of conditions and results in order to have an accurate classification structure for the comparison among systems, as it happens nowadays in Europe for the construction products. The construction products for building in Europe have to fulfill the legal requirements stated in the Regulation of Construction Products (CPR n. 305/2011).[8] The basic requirement n. 2 of the CPR - safety in case of fire - claims that construction work must be designed and built in such a way that in the event of an outbreak of a fire:

- The load-bearing capacity of the construction can be assumed for a specific time.
- The generation and spread of fire and smoke within the construction works are limited.
- The spread of fire to neighboring construction work is limited.
- Occupants can leave the construction work or be rescued by other means.
- The safety of rescue teams is taken into consideration.

Therefore, the European harmonized standardization, that has been developed to fulfill the basic safety requirements of construction products classifies the fire performance of construction products and is based on relevant classification parameters. For instance, the reaction to fire of construction products is classified according to the standard[9] EN 13501-1, assuming class A products as noncombustible, class B is the best achievable class for combustible materials, while classes C, D, and E are less performing reaction to fire classes and class F is for products that do not satisfy the flammable test required for E classification.

The data provided by tests can be considered as hazardous parameters and applied during the risk assessment process to be aware of the aggravation of the fire spread risk, associated to the presence of combustible façades, in order to fulfill the above-mentioned holistic approach fire safety design of buildings and activities. Furthermore, the impact of different passive protective measures against external fire spread can be investigated using fire dynamics simulator based on tests data. Examples of validation studies conducted using experimental results from SP FIRE 105 have been discussed by M. Nilsson and others.[10] The final aim of SP FIRE 105 is to guarantee the fire safety of buildings to decide case by case if the use of combustible insulation materials in building façades could be allowed, totally avoided, or kept under control enhancing the most vulnerable parts of the façade. For example, B. Zhou and others,[11] have discussed the optimal opening edge treatment and EPS thickness effects on EPS ETICS reaction-to-fire performance, and façade fire tests were carried out by testing a series of specimens varying EPS thickness, and opening edge treatment methods, etc.

The European Commission has already examined all relevant regulatory data and experiences of all EU/EFTA (European Free Trade Association) Member States, which have developed regulations on the assessment of construction products used to build up façades. The objective of the project was to address a request from the Standing Committee of Construction works to provide EU Member State regulators with a standard tool for regulating the fire performance of façade systems based on a unique European assessment approach.[12]

An outline of some test methods used in different countries is provided in the report of this project and summarized in Table 1, adding also the most relevant North American test methods. It is important to highlight that not all the mentioned test methods have been developed with the same scope, as well as the fact that for many façade systems different from ETICS the fire spread cannot be accurately studied with an intermediate-scale test.

To know the differences and the reliability of the different test methods, a comparative simulation study on three large-scale facade testing methods, namely, the SP Fire 105, BS 8414-1, and the ISO 13785-2 methods, has been conducted by J. Anderson and others.[13] Furthermore, the authors have compared SP Fire 105 and BS 8414-1 regarding repeatability and the use of modeling to discern changes in the test rig setups. For example, two test series according to BS 8414-1 were repeated outside using the same façade systems on two different days, and the results show that the wind around the test setup may have a significant impact on the test results.[14]

This paper aims to describe a new test method specifically designed to evaluate the fire behavior for façades with ETICS. The behavior of this system can be described using medium-scale tests, ensuring the economic advantages if compared with the proposed large-scale test methods listed in Table 1.

2 | NEW TEST METHOD DESCRIPTION

The Italian National Fire Rescue and Service subscribed on July 22, 2014 a research agreement for the evaluation of fire performances of ETICS for building façade systems. The partners of the research project are the Central Directorate for Fire Prevention and Technical safety of the Italian National Fire Rescue and Service, the notified body laboratory L.S. Fire testing institute and two Italian insulating systems manufacturers. The project was finalized to define a test method able to describe the fire spread on building facades with ETICS, for the certification of their fire-related performances. Thanks to the peculiarity of this façade system (unlike other systems as ventilated façades that need a large-scale test method) it has been possible to reduce the study at a single storey height module, cheaper than the large-scale existing methods in international standards and optimal to allow laboratory measurements for collecting hazardous parameters.

Therefore, the aim of the research agreement is double: give to Italian economic operators a test method with a limited economic impact and to study ETICS fire behavior associated to representative fire scenarios with ETICS end use conditions, also through the experimental execution of tests according to the protocol scheme developed during the research agreement implementation phase. The first part of the research program has been focused on developing a test

TABLE 1 Outline of some test methods used in different countries

Test method	Countries using the test method	Type of fuel	Scale	Configuration
DIN 4102–20	Switzerland, Germany	Wood cribs / gas burner	Medium	Two wings (ie, corner)
BS 8414 series	UK, Republic of Ireland	Wood cribs	Large	Right angle, return wall
PN-B-02867	Poland	Wood cribs	Medium	A single vertical wall without openings
Engineering guidance 16	Finland	Timber cribs and timber boards	Large	Single vertical wall
ISO 13785-1	Czech Republic	Gas burner	Medium	Right angle, return wall
ISO 13785-2	Slovakia	propane / liquid (eg, heptane) / wooden cribs	Large	Right angle, return wall
LEPIR 2	France	Wood cribs	Large	Single vertical wall
MSZ 14800-6	Hungary	Wood cribs	Large	Single vertical wall with two openings
Prüfbestimmung für Aussenwandbe-kleidungssysteme	Switzerland, Lichtenstein	Wood cribs	Large	Single vertical wall, no wings
SP Fire 105	Sweden, Norway, Denmark	Heptane	Large	Single vertical wall
Technical regulation A 2.2.1.5	Germany	Wood cribs	Large	Two wings (ie, corner)
ÖNORM B 3800-5	Switzerland, Austria	Wood cribs	Medium	Vertical wall and a right angle wing
NFPA 285	USA	Room gas burner and window gas burner	Large	Two storey wall assembly, window in the lower floor
CAN/ULC-S134	Canada	Propane burner	Large	Exterior wall facility
FM 4880	USA	Wood pallets	Large	High corner test

method referring to ETICS kit with plaster and considering these two fire scenarios:

- Construction work fire scenario: mounting face fire scenario in which only the uncoated insulation element of the system is exposed to an ignition source.
- Finished work fire scenario: fire scenario in which the ETICS system in its end use condition is exposed to an ignition source.

The first part of the research program has issued the Internal note of the Italian Ministry of Interior called "281 Procedure."[15] The 281 Procedure consists of a facade ETICS test sample of the dimension of 2950 mm× 2950 mm hit by a premixed flame of a 30 kW linear burner for the unfinished system, representing the construction work scenario. For the finished work scenario, the same sample is hit by a 300 kW linear burner. In both cases, a room corner test equipment (ISO 9705) is used to collect the products of combustion and to record the total heat release (THR), heat release rate (HRR) and smoke obscuration quantities as hazardous parameters. Additional criteria are the measure of the flame spread and the recording of burning droplets. In general, the problems that arise when deciding to define a method for assessing the fire behavior of a product or material are various. They depend on the use of the materials, on the necessity (and possibility) of representing it during the test, the identification of the parameters that must be measured and recorded (not simply observed), the overall evaluation of the data collected during the performance of the tests for any classification to be used in the required fire behavior assessments.

In this phase, concentration between the regulators and the organizations that must carry out the research and the documentation that collect the data regarding, for example, the fire pattern,which must always reproduce the same thermal attack on the surfaces under test to classify them is needed. In 2018, the autonomous province of Bolzano, in collaboration with the polytechnic of Milan, became both partners of the research program, also contributing to the tests with insulating materials of particular interest to Alto Adige (insulating walls and wood-based panels). The new objective was to identify a test protocol conceived to be repeatable, versatile, and able to provide the relevant evaluation parameters required for a fire risk assessment. Furthermore, test fire hazardous quantities could be also useful for a performance-based design making use of fire safety engineering to define occupant evacuation, the safety of rescue team intervention and for estimating residual damage on the building and the adjacent ones after the outbreak of a fire.

Since the scope of the proposed fire hazard assessment test is the fire behavior of ETICS facades, the following step was the identification of the scenarios of interest. The most significant fire scenario is represented by a flame and other fire effluents exiting from a window where a flashover has been reached that hit the façade. The flame height and temperature coming out from a window of a building room fire are a function of the room geometry, room openings (both size and shape of the openings) and the HRR of the fire, as reported, for example, in Annex B of Eurocode 1, part 1-2 titled: "Thermal actions for external members - Simplified calculation method."[16]

According to Fang et al[17] the flame ejected from an opening has a flame temperature of about 550°C at the height of about 1.2 m, using a 30 kg of wood crib as fuel. To describe the facade flame height, authors usually use the mean flame height as a parameter that occurs where the intermittency assumes the value of 50% above the neutral plane of the opening. A classical model on facade flame height has been proposed by Delichatsios et al[18,19] where façade flame can be physically regarded as generated by a rectangular fire source at the neutral plane of the opening. Moreover, the actual environment of facade fires is usually complex involving wind, pressure, building façade structure and so on. To investigate the fire phenomenon under these conditions, several pieces of research have been done. For the effect of sidewalls, results show that facade flame is stretched to a high level and flame height increases with decreasing the separation distance between the two sidewalls.[20] For the condition of ambient wind, facade flame is compressed with its height decreasing.

Facade flame height ejected from an opening of a fire compartment under external wind has been studied by L. Hu et al[21] and has been observed that the flame height decreases significantly with the increase of external wind speed.[22] In one of the quantitative papers of façade flame heights parameters, Lee[23] proposes the following experimental correlation:

$$\frac{W_{f,max}}{Z_f} = \text{func}\left(\frac{l_1}{Z_f}\right) \quad (1)$$

where $W_{f,\ max}$ is the maximum width of the flame (m), Z_f is the flame height (m) and $l_1 = \left(A \cdot \sqrt{H}\right)^{\frac{2}{5}}$ is the characteristics length scale representing the exit condition at the opening (m). The opening considered in the test presented in this paper, is characterized by a width of 1000 mm and a height of 1250 mm, having width over height ratio W/H = 0,8. Analyzing the paper "Window ejected flame width and depth evolution along façade from under-ventilated enclosure fires" of L. Hu et al[21] it is possible to observe that Lee's correlation can be approximately true also for openings with ($\ell_1/Z_f > 0{,}33$). Assuming the same size for the opening of the lower floor from which the flame comes out, it is possible to predict the flame height Z_f according to Lee's correlation:

$$\frac{W_{f,max}}{Z_f} = \frac{l_1}{Z_f} + 0.12 \quad (2)$$

The maximum flame widths are generally larger than the maximum flame depth and they both grow with HRR increasing. For a square opening, it is found that the maximum flame width is larger than the area opening. Considering that the maximum flame width (m) is approximately equal to the width of the opening (m) increased by a factor of 1.4, it is possible to determine the flame height Z_f for the opening considered in the proposed test:

$$Z_f = \frac{W_{f,max} - l_1}{0.12} = 2.14\, m \quad (3)$$

Figure 1 illustrates the section and the front view of the flame ejecting from an opening of a flashover room. The ratio of flame base height to the opening height is nearly constant ($H_E \approx 0.28$ H) for different openings, therefore in our proposed setup:

$$H_E \approx 0.28\, H = 0.28 \cdot 1.25 = 0.35\, m. \quad (4)$$

and the flame height that should start from the top of the lower floor opening is:

$$Z_{f,top} = Z_f - (H - H_E) = 2.14 - (1.25 - 0.35) = 1.24\, m. \quad (5)$$

Therefore, a gas burner (1250 mm × 240 mm × 125 mm, see Figure 2) has been selected as the most representative fire scenario, with a power of 500 kW, giving a thermal attack of 20 minutes on the façade, with a constant flame dimension of about 1250 mm × 1200 mm. This fire attack represents a flame ejecting from an opening of a flashover room.

The test configuration requires the gas burner to be positioned 50 mm under the lower surface of the sample to attack the lower surface of the base of the artifact to take into account all the effects of the coming out mechanism of a flame from an opening (a window) involving the external building façade. The propane burners then always apply the same thermal attack, the same radiation, always produce the same amount of smoke to be subtracted then to the total smoke measured in the test and therefore they allow to verify the damages caused to the facade under test with very good reproducibility.

At the end of 2016, some comments from other European fire laboratories were collected and some of them produced modifications and improvements in the test procedure after changing the shape of the facades under test: instead of using a sample composed by a flat surface of three meters by three, with a window in the middle, it was decided to modify the artifact under test by adding a wall of 1 m, orthogonal, to produce a dihedral, which is supposed to better represent a real building configuration.

The sample has been shaped with a single angle and with a central window opening of 100 mm × 125 mm in size, placed at 170 mm from the base and with 57 thermocouples arranged to measure the temperature increase upwards and sideways, at different depths (see Figure 3). Figure 4 shows the section view of the sample highlighting the three levels of thermocouple positions in the facade under test. The first level of thermocouples has been placed immediately inside the coating plaster (see Figure 3A). The second level, at 50% of the thickness of the insulating product (see Figure 3B).

The third and last deepened level sees the thermocouples positioned exactly at the height of the surface of the building wall surface, masonry, or wood depending on the nature of the test sample, thus measuring the temperature on the surface of the wall that has to be thermally insulated in normal end use conditions (see Figure 3C).

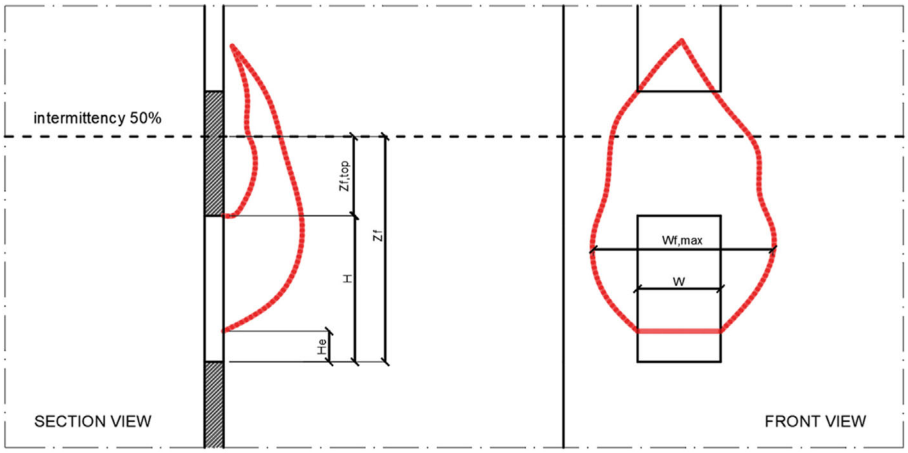


FIGURE 1 Section and the front view of the flame ejecting from an opening [Colour figure can be viewed at wileyonlinelibrary.com]

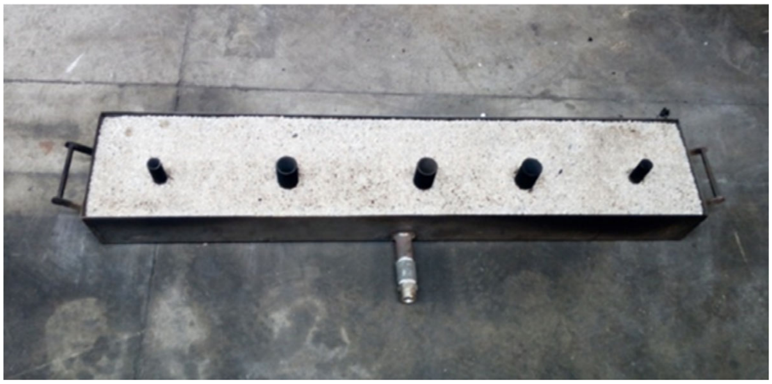


FIGURE 2 View of the gas burner [Colour figure can be viewed at wileyonlinelibrary.com]

The measurement included the recording of the temperature trend with 57 K type thermocouples; the aim is to obtain the trend of the penetration of the energy imposed by the fire model inside the façade sample under test during the time of the test itself. Three additional thermocouples directly exposed to the flame from the burner (see Figure 3D), have been placed around the opening.

Besides, five water-cooled heat flux sensors have been placed inside the window opening, and externally on the side, as shown in Figure 5. These instruments are used for collecting valuable information to be used in performance-based approaches (fire safety engineering) such as the minimum critical flux for ignition or pyrolysis and the time to ignition.[24] The scope of the heat flux sensors behind the window is to determine the indoor heat flux to know if the fire could spread inside the building through the opening and if the mechanism could be repeated on building stories above. The lateral heat flux sensors have been used to determine the effect on a hypothetical adjacent façade.

Figure 6 shows how the product sample is positioned below the hood of the Room Corner Test to allow the flue gases to be conveyed into the exhaust duct. The system for collecting the products of combustion of the ISO 9705 is designed in order to make airflow and effluents generated by the fire sucked at different velocities for mixing them inside the duct allowing the examination thanks to the analysers[25]. The room corner test has been developed as a practical testing protocol for the flammability of interior finish materials[26] and is one of the well-recognized experimental technologies for determining the rate of heat release (RHR) applying calorimetry theory at an intermediate scale level. The sampling line is made of inert material that does not influence in any way the concentration of the gases to be analyzed, in particular, oxygen, and carbon dioxide contained in the combustion products (smoke and particles). The paramagnetic oxygen analyzer and the data acquisition system record the variation of the gas concentration: according to the principle of oxygen consumption, the heat release measurement provides an evaluation of the growth of the fire based on the calculation of the oxygen consumption itself. Thanks to this system it is, therefore, possible to evaluate the RHR and the THR.

Regarding the smoke, the hazard given by the reduction in visibility is estimated measuring the light obscuration and optical density. Obscuration and optical smoke density are measured in a system consisting of an incandescent filament lamp, parallel-aligned lenses and a photocell able to intercept the light beam and the decrease in its intensity to provide information on the parameters of transmittance and total smoke production (TPS). Eventually, a thermal imaging camera has been used for recording the dynamic trend of temperatures on the surface of the wall throughout the test time.

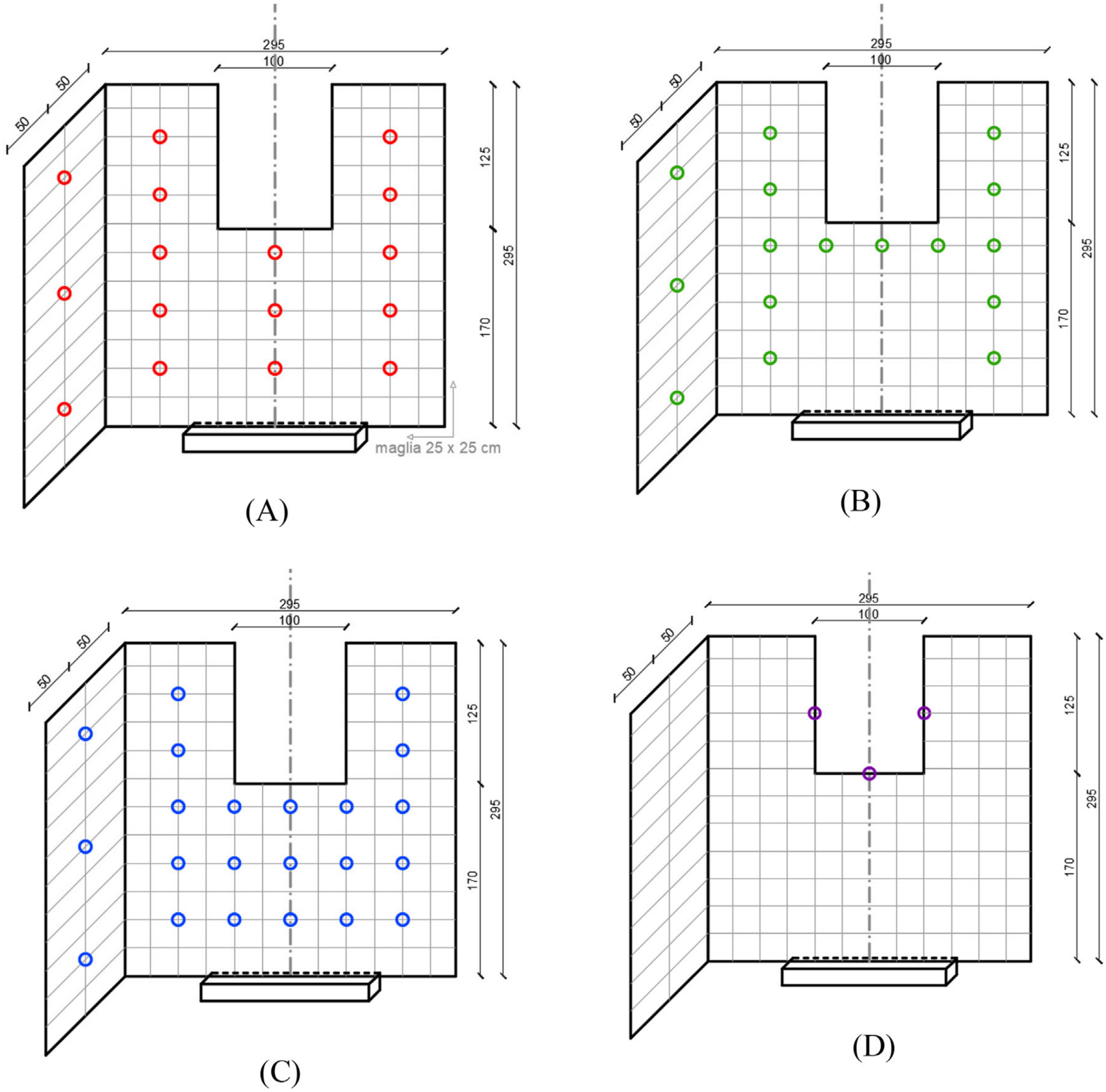


FIGURE 3 Shape of the sample and thermocouple positions under the plaster [Colour figure can be viewed at wileyonlinelibrary.com]

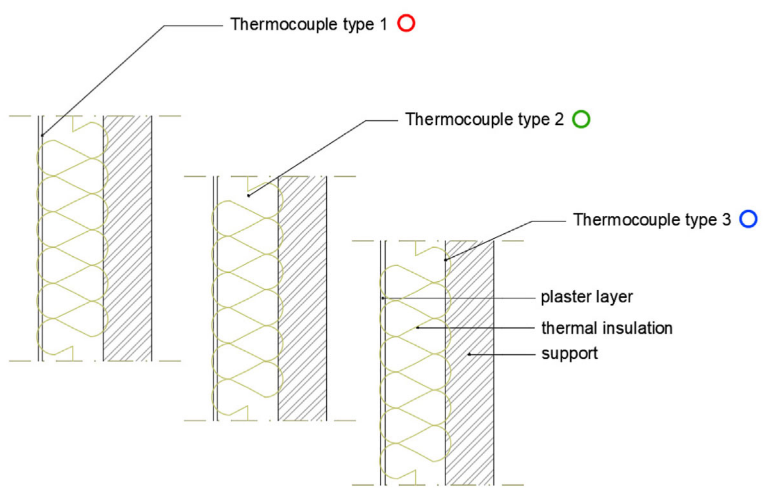


FIGURE 4 The three-level of thermocouple positions [Colour figure can be viewed at wileyonlinelibrary.com]

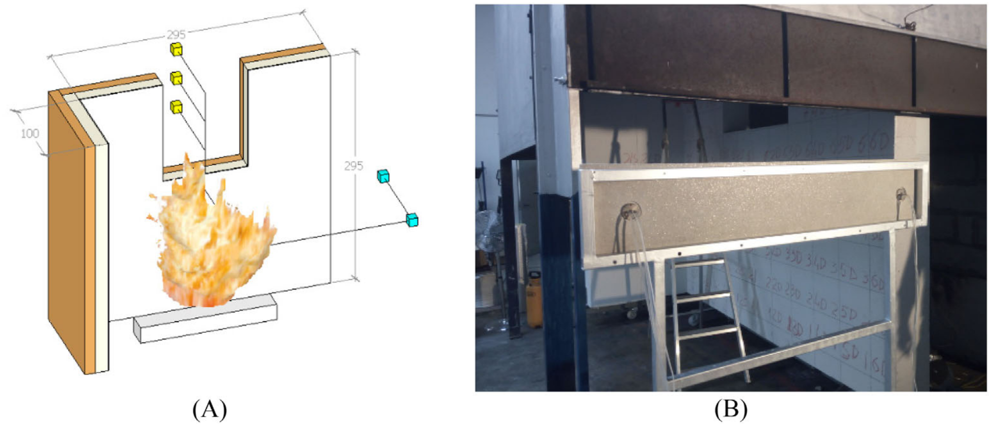


FIGURE 5 A, Positions of the five water-cooled heat flux sensors and B, Actual view of the two laterals heat flux sensors [Colour figure can be viewed at wileyonlinelibrary.com]

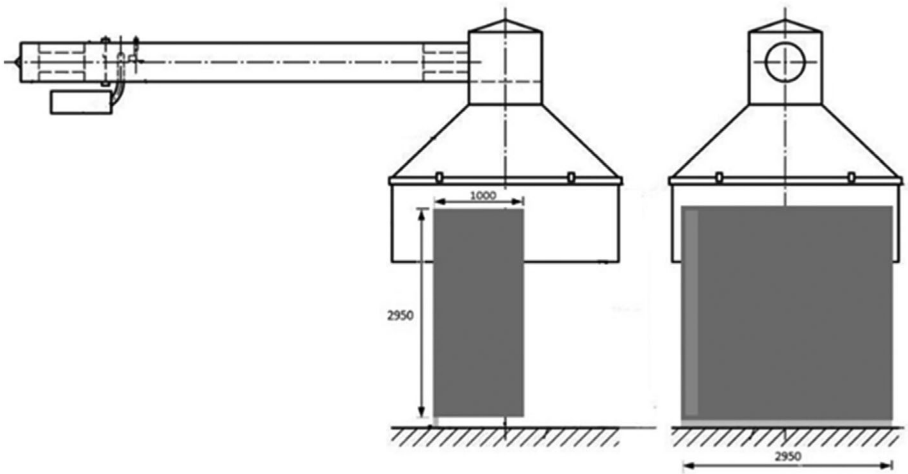


FIGURE 6 Side and front view of the system (dimensions in millimeters)

3 | TEST METHOD PROCEDURE

The preparation of the samples is done as indicated in the European guideline for the application of the coating system, created by EAE (European Association for ETICS).[27] It is fully adopted in Italy with references to the technical and application in the manual for the application of the coat system CORTEXA (consortium for the culture of the cladding system).[28] These application guidelines relate to systems that use insulating materials such as sinteredEPS and mineral wool. However, for the preparation of these test samples, it has been extended to all the materials considered in the test campaign.

The support frames identified for the structure are of two kinds: masonry composed of autoclaved aerated concrete bricks (AAC) and a cross laminated timber (CLT/X-LAM) wall. The 12 cm thick bricks are positioned from the bottom upwards, staggered one on top of the other and completely placed together on a mobile sheet metal platform and the cement used is left to dry for 30 days. The CLT support is composed of planed wooden boards, joined with a comb joint, crossed, and glued together. The panels of insulating material are laid on the support with the so-called bead/spot method that consists of a border of adhesive around the circumferences (bead) and three spots of the same material in the center, without allowing any air passage, uniformly to the surface of the support to avoid the occurrence of the pillow effect or mattress effect. The wood fibers panels are anchored with five anchors per panel while the panels in and EPS are anchored according to the so-called *T* scheme for which a piece is placed in the center and the remaining four are positioned at each intersection of the joints; the polyurethane (PIR/PUR) insulation panels are not anchored. After 24 hours the base coat/glue is extended employing a 14 mm notched trowel and then a 150 g/m^2 fiber glass mesh is laid and lightly pressed. After a further 24 hours, the second coat of base coat/glue is extended to fill the net and evenly fill any unevenness or cavities.

A period of about 30 days is necessary for drying and hardening the base coat/glue, at the end of which a layer of water-based primer is applied. After the latter has dried, the finish coating with 1.2 mm grain is laid. The finishing plaster is applied by hand, using a spatula, along the entire perimeter of the structure, including the window profile. The completed samples are stored in a closed environment, inside the laboratory to allow their complete drying; from this moment, the samples are ready to be subjected to drilling for the insertion of type *K* thermocouples at the depths described in Figure 3 and thereafter to

FIGURE 7 Samples preparation in early phases [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 8 Samples during and after the test [Colour figure can be viewed at wileyonlinelibrary.com]

be tested. Figure 7 reports the early preparation phases of a test sample.

First, the environmental conditions are verified to determine the feasibility of the test during the pre-established day: the temperature in the test area must be 20 ± 10°C, the relative humidity 55 ± 15% and the atmospheric pressure is also recorded. The sample is pushed thanks to the platform equipped with wheels below the hood of the Room Corner Test, where it is positioned at the center of the square that it represents. The heat flux sensors are placed at the predetermined distances as shown in Figure 4A,B and the thermocouples are connected to the data acquisition system. The last step of the test rig setup is the burner (Figure 2) placed in correspondence of the opening that represents the window, 50 mm in depth below the insulation, in such a way as to represent the flame coming out from the window of the below floor, where a flashover is occurring. Once all the elements have been positioned, including two video cameras and a thermal camera at a distance of about 4 m from the sample, the volume flow of the exhaust system is set to 2.6 m^3/seconds and all the measuring instruments are switched on to allow the acquisition of a baseline for at least 2 minutes. The test steps are done as follows:

- *t* = 0 seconds starting of the chronometer and automatic recording of data.
- *t* = 100 seconds ignition of the pilot flame (candle) that will ignite the burner.
- *t* = 120 seconds ignition of the burner at 500 kW with the pilot flame (candle).
- *t* = 1320s switch-off of the burner stopping the propane supply.

The burner is, therefore, able to supply a constant 500 kW power to attack the façade sample under test both frontally and in its depth from below, with a constant flame height of about 1.2 m. Figure 8 shows a sample during and after the fire test.

During the period in which the burner is lit, any falling parts and dripping are observed. Once the burner is switched off, elements such as flame retention or self-ignition are continuously observed and recorded for a further 40 minutes. At the end of the observation period, the sample is left to cool down and the damaged area is evaluated at different depth levels: at the superficial level then, by cutting the artifact, at the level of the insulation and finally at the level of the incombustible support, to evaluate the total sample consumption. To calibrate the instrumentation these supports have been initially tested with incombustible insulation, using a mineral insulation board on the AAC blocks and using rock wool on the wooden support.

Then, different types of insulation have been tested, referring to the most widespread materials used in Italy for ETIC systems. Table 2 lists the executed tests specifying the support frame nature, the

TABLE 2 Executed tests

Test number	Support frame	Insulating material	plaster layer thickness	Reaction to fire insulation material
1	Autoclaved aerated concrete blocks	Mineral insulation boards	7 mm	A1
2	Cross laminated timber	Rock wool	7 mm	A1
3	Autoclaved aerated concrete blocks	Wood fibres	7 mm	E
4	Cross laminated timber	Wood fibres	7 mm	E
5	Autoclaved aerated concrete blocks	EPS	7 mm	E
6	Cross laminated timber	EPS	7 mm	E
7	Concrete blocks	EPS with graphite	20 mm	E
8	Autoclaved aerated concrete blocks	PIR (low performance)	7 mm	N.A.
9	Cross laminated timber	PIR (high performance)	7 mm	N.A.
10	Cross laminated timber	PUR (generic)	7 mm	F
11	Autoclaved aerated concrete blocks	PIR (for ETICS)	7 mm	E
12	Cross laminated timber	PIR (for ETICS)	7 mm	E

Abbreviations: EPS, expanded polystyrene; ETICS, external thermal insulation composite system; PIR/PUR, polyurethane.

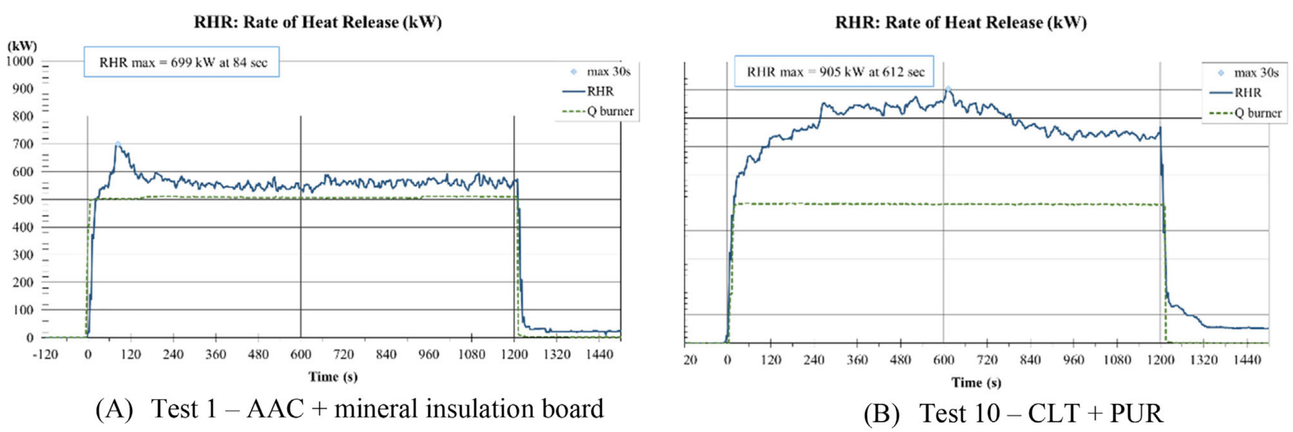


FIGURE 9 RHR curve A, test on AAC support with mineral insulation board and B, test on CLT support with PUR insulation. AAC, aerated concrete bricks; CLT, cross laminated timber; PUR, polyurethane; RHR, rate of heat release [Colour figure can be viewed at wileyonlinelibrary.com]

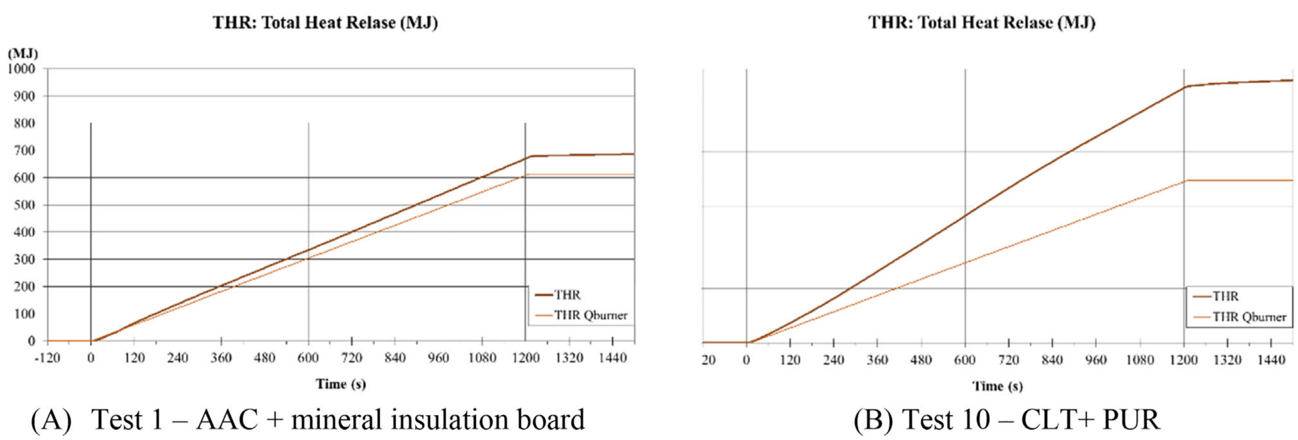
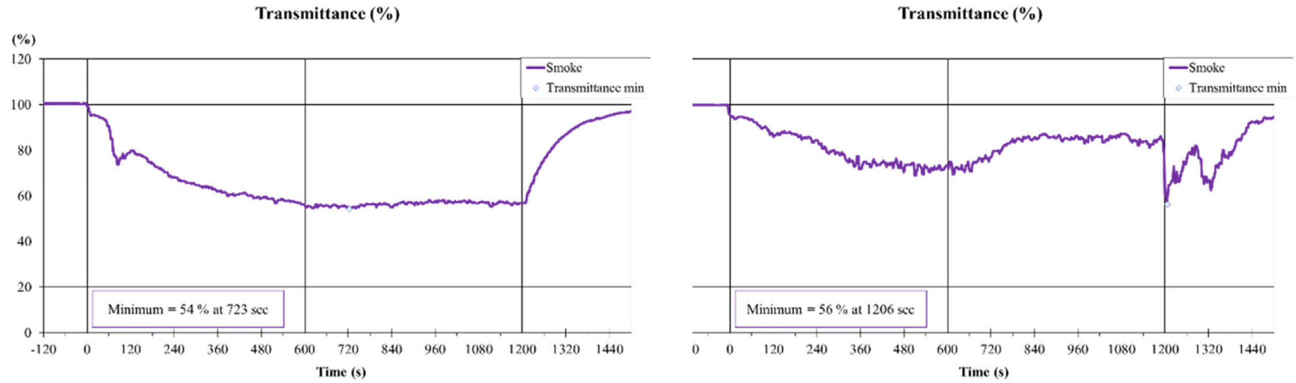


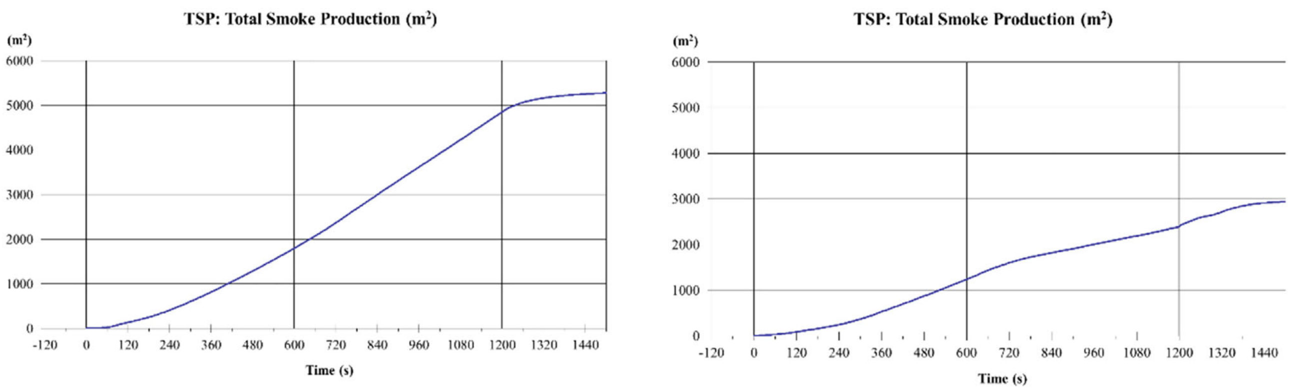
FIGURE 10 THR curve A, test on AAC support with mineral insulation board; B, test on CLT support with PUR insulation. AAC, aerated concrete bricks; CLT, cross laminated timber; PUR, polyurethane [Colour figure can be viewed at wileyonlinelibrary.com]



(A) Test 1 – AAC + mineral insulation board

(B) Test 10 – CLT+ PUR

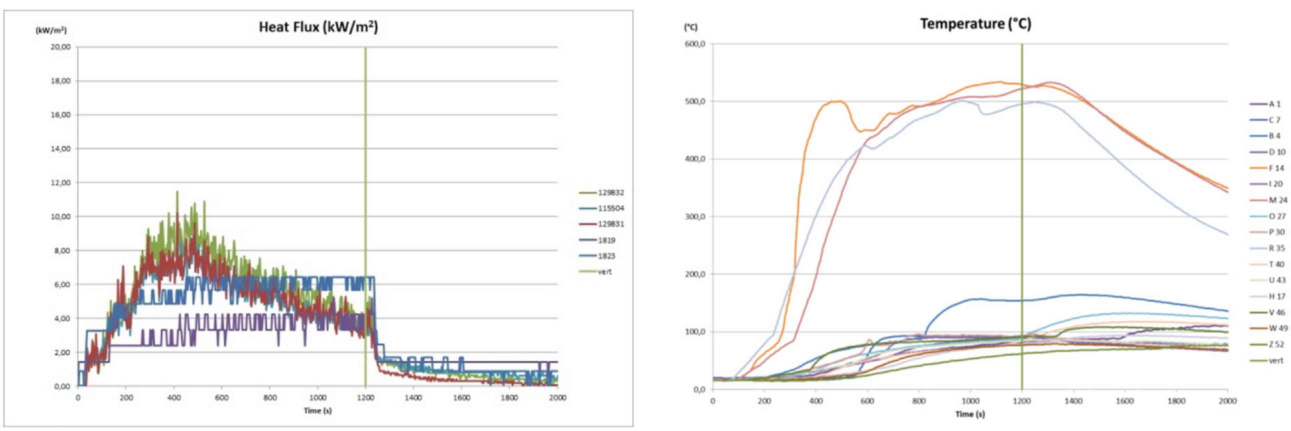
FIGURE 11 Transmittance (%) A, test on AAC support with mineral insulation board and B, test on CLT support with PUR insulation. AAC, aerated concrete bricks; CLT, cross laminated timber; PUR, polyurethane [Colour figure can be viewed at wileyonlinelibrary.com]



(A) Test 1 – AAC + mineral insulation board

(B) Test 10588 – CLT + PUR

FIGURE 12 Total smoke production (m^2) A, test on AAC support with mineral insulation board B, test on CLT support with PUR insulation. AAC, aerated concrete bricks; CLT, cross laminated timber; PUR, polyurethane [Colour figure can be viewed at wileyonlinelibrary.com]

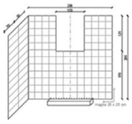
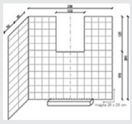
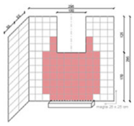
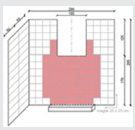
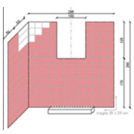
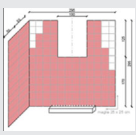
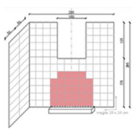
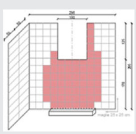
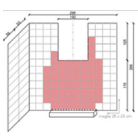
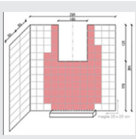
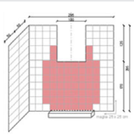
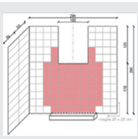


(A)

(B)

FIGURE 13 A, Example of the measured heat flux and B, example of the temperature evolution during the test measured with the thermocouples [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 3 Measured and observed parameters [Colour table can be viewed at wileyonlinelibrary.com]

Test number	ΔRHR Maximum value	ΔRHR Average value	ΔTHR	Transmittance (%)	TSP (m2)	Interested area	Additional notes
1	199	50	70	54	4850		No post-combustion
2	175	80	70	51	5000		No post-combustion
3	150	100	110	57	4600		Protract post-combustion, difficulty in extinguishing
4	175	100	130	54	4850		Protract post-combustion, difficulty in extinguishing, damage to the support
5	190	110	110	36	5800		Important post-combustion, sudden re-ignition, falling of flaming droplets
6	208	90	110	48	5000		Important post-combustion, falling of flaming droplets
7	245	90	100	56	4500		Very limited post-combustion, cracks in the plaster
8	359	250	300	59	3000		Post-combustion, explosion of small portions of the plaster
9	337	200	235	76	1750		Post-combustion, explosion of small portions of the plaster
10	405	260	330	56	2400		Post-combustion, explosion of small portions of the plaster
11	210	105	130	82	1650		Post-combustion, explosion of small portions of the plaster
12	160	100	100	83	1400		Post-combustion, explosion of small portions of the plaster

Abbreviations: RHR, rate of heat release.

(A) (B)

FIGURE 14 A, Investigation to determine the carbonized area and B, determination of the penetration of the combustion [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 15 Sudden reignition phenomena occurred on the specimen with EPS insulation (test 5 of Tables 2 and 3). EPS, expanded polystyrene [Colour figure can be viewed at wileyonlinelibrary.com]

sample insulating material, the plaster layer thickness and the European reaction to fire of the insulation material. The European reaction to fire classification contained in the standard EN 13501-1 is mainly based on the single burning item test that uses a reduced hood set compared the one proposed in the room corner test (ISO 9705-1), as described in the standard EN 13823.[30]

4 | RESULTS AND DISCUSSION

During each test, the measured parameters have been:

- The HRR (kW).
- The THR (MJ).
- The transmittance (%).
- The TSP (m^2).
- The heat flux (kW/m^2).
- The temperature evolution at three different deepen levels (°C).

In Figure 9 the HRR curves of a façade with both incombustible insulation and support and a façade with combustible insulation and support are compared. It is possible to observe the participation at the combustion of the combustible materials that have increased the heat power provided by the burner (500 kW) to a maximum of 905 kW at the time of about 10 minutes. The THR, expressed in MJ, provides another view of the increase of the two tests from the heat released by the burner that was about 600 MJ (see Figure 10). Examples of the measurement of transmittance and the TPS are showed in Figure 11 and Figure 12. In Figure 13A is reported an example of heat flux measured with the five water-cooled heat flux sensors. The evolution of the temperatures measured with the thermocouples can be observed in Figure 13B.

Besides, visive analysis with the support of a thermal camera has been made, to observe the evolution of the temperature under the plaster layer. This information has been useful to know where, when and how was possible to remove the plaster layer for the final investigation to determine the residual damage on the specimens.

The damaged areas are compared in the graphic schemes of Table 3, as well as the other measured parameters. Furthermore, the investigation has allowed to know the depth of the combustion and to verify the residual damage on the support (when combustible). Examples of the executed investigation are reported in Figure 14.

Table 3 resumes the main data collected during the test of the 12 façade samples. In Table 3 are also highlighted additional notes describing other detailed phenomena observed on the specimens during the tests. Sudden reignition, falling of flaming droplets are an example of what has been observed on the specimens with EPS insulation (see Figure 15).

The specimen with graphite-enhanced EPS insulation and with a two centimeters plaster layer has demonstrated a better behavior, with a reduced combusted area and without reignition phenomena, confirming the importance of the plaster that is the first barrier that protects from fire. The specimens with the wood fibers have demonstrated an initial good behavior, with a slow progression of the combustion, so it is possible to imagine, in case of fire on the façade, an intervention of the fire brigades without all the aggravation connected to sudden flames, especially as it happens for EPS when lesions on the plaster entail the entering of oxygen and the exit of still unburned gases. At the same time, the difficulty in extinguishing could entail damages at the support (when combustible) with risks connected to the stability of the structure.

On the specimens with PUR has been observed a better behavior if compared with EPS, and it is possible to observe (referring to Table 3) the importance of using materials appositely developed to be used on ETICS (test 12 in Table 2) rather than generic PUR (test 10 in Table 2). On the specimens with PUR have been also observed more or less pronounced phenomena of the explosion of some portions of the plaster but without dangerous consequences, except the aggravation connected to the direct exposition of the material to fire.

All the collected data, including those associated with the produced smokes characteristics, will be analyzed to associate to the ETIC system a comprehensive level of performance.

In the new test method presented in this paper, the three water-cooled heat flux sensors behind the window have been positioned at 2000 mm, 2375 mm, and 2750 mm from the base (floor) of the test rig, and the two lateral ones at 1500 mm from the base. Considering the full-scale experiments reported by I. Oleszkiewicz[29]carried out to study the impact of HRR, in conjunction with window opening dimensions on heat transfer to an exterior wall, the heat fluxes recorded during the test (see Figure 13A) agree with the data collected by Oleszkiewicz.

5 | CONCLUSION

Test results show that there is a sensible difference among the insulation materials, depending on the plaster thickness and on the supporting material, highlighting the importance of evaluating the fire behavior of cladding façade system as a kit in the real finished application conditions, where it is not uncommon, for example, to find ETICS with a plaster thickness of just about 4 mm to 5 mm. The proposed medium-scale test method highlights how the different insulation materials used inside ETIC systems require specific intervention methodologies for the rescue teams, due to the different behavior in case of an outbreak of a façade fire. The novel test protocol can be thus a good instrument to compare the performance of different ETIC systems and to obtain fire spread assessment on the façade. The proposed method is also flexible, less expensive if compared to façade larger scale tests (such as BS 8414 and DIN 4102-20) and repeatable in the same conditions thanks to the gas burner that can guarantee a constant flame power unlike other types of fuel as wood cribs.

Also the measured parameters like HRR, TSP, smoke characteristics or heat flux can provide relevant experimental data. To validate the proposed test method a comparison experimental campaign to other full-scale test methods has been planned and will be carried. Furthermore, the development of façade product classification is also required. The novel classification systems will be developed on the interpretation of test results, specifying the procedure to be used in calculating the overall fire hazard comparison among ETICS façade products. The average value of the ΔRHR could be expressed, for example, per unit of mass, obtaining a parameterized value that could be used for classification as well as a quantitative data for performance-based design in the fire safety engineering methodology.

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REFERENCES

1. Lamberto M, Cancelliere P. The Italian National guidelines for the Fire Safety of Facades. *MATEC Web of Conferences 11*. 2013;9:01005. https://doi.org/10.1051/matecconf/20130901005.
2. Mazziotti L, Cancelliere P, Paduano G, Setti P, Sassi S. Fire Risk Related to the Use of PV Systems in Building Facades. *MATEC Web of Conferences*. 2016;46:05001. https://doi.org/10.1051/matecconf/20164605001.
3. Sassi S, Setti P, Amaro G, et al. Fire Safety Engineering Applied to High-Rise Building Facades. *MATEC Web of Conferences*. 2016;46:04002. https://doi.org/10.1051/matecconf/20164604002.
4. Hofmann A, Kaudelka S, Hauswaldt S. Fire Safety of FAÇADES with Polystyrene Foam Insulation, 2018;466-474. https://doi.org/10.1002/fam.2662
5. Zehfuß J, Northe C, Riese O. An Investigation of the Fire Behavior of ETICS Facades with Polystyrene under Fire Loads of Different Size and Location. *Fire and Materials*. 2018;42(5):508-516. https://doi.org/10.1002/fam.2499.
6. Piergiacomo Cancelliere, Mara Lombardi, Luca Ponticelli, Emanule Gissi, Giordana Gai, Mauro Caciolai: Italian hybrid fire prevention code. Paper presented at: SAFE 2017 7th International Conference on Safety and Security Engineering, Rome University La Sapienza, 2017. https://doi.org/10.2495/SAFE170101

7. Paolo Setti, Lamberto Mazziotti, Piergiacomo Cancelliere, Samuele Sassi, Mauro Madeddu, Mehmet Yenisan: Performance-based approach for complex structure design. Paper presented at: ifiress 2017–2nd International Fire Safety Symposium, Naples, Italy, June 2017
8. REGULATION (EU) No 305/2011 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL. Laying down harmonised conditions for the marketing of construction products and repealing council directive 89/106/EEC. *Official Journal of the European Union*. 2011; 54:L88/5.
9. EN 13501–1:2018 Fire classification of construction products and building elements–Part 1: Classification using data from reaction to fire tests.
10. Nilsson M, Husted B, Mossberg A, Anderson J, McNamee RJ. A Numerical Comparison of Protective Measures against External Fire Spread. *Fire and Materials*. 2018;42(5):493-507. https://doi.org/10.1002/fam.2527.
11. Zhou B, Yoshioka H, Noguchi T, Ando T. Effects of opening edge treatment and EPS thickness on eps external thermal insulation composite systems (ETICS) façade reaction-to-fire performance based on JIS A1310 standard façade fire test method. *Fire and Materials*. 2018; 42(5):537-548.
12. Lars Boström, Anja Hofmann-Böllinghaus, Sarah Colwell, Roman Chiva, Péter Tóth, Istvan Moder Johan Sjöström, Johan Anderson, David Lange, 2018, Development of a European approach to assess the fire performance of facades
13. Anderson J, Boström L, Jansson McNamee R, Milovanović B. Modeling of fire exposure in facade fire testing. *Fire and Materials*. 2017;42: 475-483. https://doi.org/10.1002/fam.2485.
14. Anderson J, Boström L, Jansson R, Milovanović MNB. Experimental comparisons in façade fire testing considering SP fire 105 and the BS 8414–1. *Fire and Materials*. 2018;42(5):484-492. https://doi.org/10.1002/fam.2517.
15. *The 281 Procedure, Ministry of Interior Italian National Fire Rescue and Service (CNVVF), Central Directorate for Fire Prevention and Technical Safety*. Italy; 2015.
16. EN -1-2:2002 Eurocode 1: Actions on structures - Part 1–2: General actions - Actions on structures exposed to fire.
17. Fang X, Ren F, Zhang X, Sun X, Yang Y, Hu L. Facade flame height ejected from opening of a compartment under the coupling effect of side walls and ambient wind. *Fire Saf J*. 2020;112:102966.
18. Coutin M, Most JM, Delichatsios MA, Delichatsios MM. Flame heights in wall fires: effects of width, confinement and pyrolysis length. *Fire Saf Sci*. 2000;6:729-740.
19. Lee YP, Delichatsios MA, Silcock GWH. Heat fluxes and flame heights in facades from fires in enclosures of varying geometry. *Proc Combust Inst*. 2007;31(2):2521-2528.
20. Ohmiya Y, Kang S, Noaki M, Delichatsios MA. Effects of opening aspect ratio on facade gas temperatures with and without sidewalls for underventilated conditions. *Fire Saf J*. 2019;113:102944.
21. Hu L, Qiu Z, Lu K, Tang F. Window ejected flame width and depth evolution along façade from under-ventilated enclosure fires. *Fire Saf J*. 2015;76:44-53.
22. Hu L, Hu K, Ren F, Facade X. Flame height ejected from an opening of fire compartment under external wind. *Fire Saf J*. 2017;92: 151-158.
23. Lee YP. *Heat Fluxes and Flame Heights in External Façade Fires*. University of Ulster, FireSERT, UK; 2006.
24. Delichatsios MA, Panagiotou T, Kiley F. The use of time to ignition data for characterizing the thermal inertia and the minimum (critical) heat flux for ignition or pyrolysis. *Combust Flame*. 1991;84(3–4): 323-332.
25. ISO 9705-1:2016 Reaction to fire tests–Room corner test for wall and ceiling lining products–Part 1: Test method for a small room configuration
26. Quintiere JG. A simulation model for fire growth on materials subject to a room-corner test. *Fire Saf J*. 1993;20:313-339.
27. EAE European guideline for the Application of ETICS, https://www.ea-etics.eu/files/dokumente-eae/5_Publications/Brochures/ETICS_brochure_application_guidelines.pdf
28. CORTEXA Coating Application Manual (in Italian) http://www.cortexa.it/index.php/it/informazione-specialisti/manuale-di-applicazione/manuale-per-applicazione-del-sistema-a-cappotto.html
29. I. Oleszkiewicz, Heat transfer from a window fire plume to a building façade, paper of the national research council of Canada. Institute for Research in construction no. IRC-P-1662 (1998).
30. EN 13823:2010+A1:2014 Reaction to fire tests for building products–Building products excluding floorings exposed to the thermal attack by a single burning item

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