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Comparative full-scale fire performance testing of ETICS systems

Authors:

Prof. Dubravka Bjegović
dubravka@grad.hr

Prof. Ivana Banjad Pečur
banjadi@grad.hr

Bojan Milovanović, PhD CE
bmilovanovic@grad.hr

Marija Jelčić Rukavina, PhD CE
jmarija@grad.hr

Marina Bagarić, MCE
mbagaric@grad.hr

University of Zagreb
Faculty of Civil Engineering
Department of Materials

Original scientific paper

Dubravka Bjegović, Ivana Banjad Pečur, Bojan Milovanović, Marija Jelčić Rukavina, Marina Bagarić

Comparative full-scale fire performance testing of ETICS systems

A full-scale test has been performed to determine fire performance of different ETICS systems (combustible insulation, combustible insulation with fire barrier, non-combustible insulation). Test specimens were constructed and tested according to BS 8414-1:2002, while additional measurements were also conducted to obtain valuable information for better understanding of fire performance of systems used.

Key words:
ETICS, combustible insulation, non-combustible insulation, fire barrier, fire spread, fire performance

Izvorni znanstveni rad

Dubravka Bjegović, Ivana Banjad Pečur, Bojan Milovanović, Marija Jelčić Rukavina, Marina Bagarić

Usporedba ponašanja različitih ETICS sustava u uvjetima požara ispitivanjem u stvarnoj veličini

U ovom radu prikazano je ispitivanje fasadnih sustava u stvarnoj veličini. Ispitivanje je provedeno s ciljem usporedbe ponašanja ETICS sustava s različitim toplinsko izolacijskim slojem (goriva izolacija, goriva izolacija s protupožarnom barijerom od negorivog materijala, negoriva izolacija) u uvjetima požara. Uzorci su izrađeni i ispitani u skladu s normom BS 8414-1:2002, a provedena su i dodatna mjerenja kako bi se dobili bitni podaci koji omogućuju bolje razumijevanje ponašanja ETICS sustava u požaru.

Ključne riječi:
ETICS, goriva izolacija, negoriva izolacija, protupožarna barijera, ponašanje u požaru

Wissenschaftlicher Originalbeitrag

Dubravka Bjegović, Ivana Banjad Pečur, Bojan Milovanović, Marija Jelčić Rukavina, Marina Bagarić

Vergleich des Brandverhaltens von WDVS im Originalmaßstab

In dieser Arbeit werden Versuche an Fassadensystemen im Originalmaßstab dargestellt, die durchgeführt wurden, um das Brandverhalten von WDVS mit verschiedenen Wärmedämmungen (brennbare Dämmung, brennbare Dämmung mit Sturzschutz, nicht brennbare Dämmung) zu vergleichen. Die Versuchsproben wurden gemäß Norm BS-8414-1 erstellt und geprüft. Außerdem wurden zusätzliche Messungen durchgeführt, die aufgrund der wichtigen aufgenommenen Daten ein besseres Verständnis des Brandverhaltens von WDVS ermöglichen.

Schlüsselwörter:
WDVS, brennbare Dämmung, nicht brennbare Dämmung, Brandverhalten

1. Introduction

The European Union (EU) has defined its energy policy for overall energy efficiency and has harmonised this policy with the Energy Saving Legislation and other Instruments, all of which is aimed at reviving European economy [1]. The overall energy efficiency implies reduction of energy consumption in buildings, since buildings account for 40 % of the EU energy use and 36 % of its overall CO_2 emissions [2]. The energy performance of buildings can primarily be improved through implementation of thermally enhanced building envelopes. Among several possible technologies to thermally enhance building envelopes, *External Thermal Insulation Composite Systems* (ETICS) (Figure 1) are the most commonly used façade systems in Europe.

Thermal insulation materials used in ETICS systems can be either non-combustible or combustible. When applied on building facades, combustible thermal insulation materials, e.g. expanded polystyrene (EPS), can significantly increase fire load and risk of fire spread in buildings, because of reaction to fire of such materials. It has become obvious that fire safety and energy efficiency of buildings are not mutually exclusive, and so stricter requirements for energy performance of buildings have to be applied, together with stricter requirements for fire performance of buildings. Thermal insulation materials are currently classified according to their reaction to fire, as shown in Table 1.

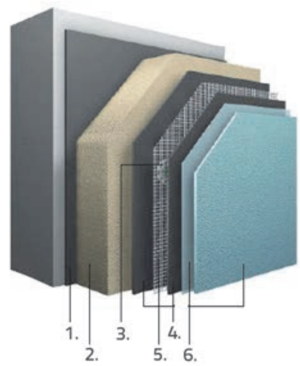

Figure 1. ETICS systems components [3, 4]

It should be emphasized that fire performance of a building façade, e.g. cladding system with ETICS, cannot be described solely on the basis of reaction of individual materials to fire, which is determined according to the fire classification system presented in Table 1. The fire classification system is based on the end-use conditions, while test methods are mainly based on the reference scenario, which is the Room Corner test, i.e. a room fire. Thus, this classification

Table 1. Reaction to fire of construction products excluding floorings - Euroclass system [5, 6]

Class	Test methods	Additional classification	Examples of products
A1	HRN EN ISO 1182 *and*	-	Products made of natural stone, concrete, brick, ceramics, glass, and large number of metal products
	HRN EN ISO 1716		
A2	HRN EN ISO 1182 *or*	Smoke production *and* Flaming droplets / particles	Products as in class A1 but with small quantities of organic material
	HRN EN ISO 1716 *and*		
	HRN EN 13823 (SBI)		
B	HRN EN 13823 (SBI) *and*	Smoke production *and* Flaming droplets / particles	Plasterboards with different (thin) coverings Wood based fire retardants
	EN ISO 11925-2: *Exposure = 30 s*		
C	HRN EN 13823 (SBI) *and*	Smoke production *and* Flaming droplets / particles	Phenolic foams, plasterboards with different coverings (thinner than those in class B)
	EN ISO 11925-2: *Exposure = 30 s*		
D	HRN EN 13823 (SBI) *and*	Smoke production *and* Flaming droplets / particles	Wooden products with thickness greater than 10 mm and density greater than 400 kg/m^3 (depending on end-use of the product)
	EN ISO 11925-2: *Exposure = 30 s*		
E	EN ISO 11925-2: *Exposure = 15 s*	Flaming droplets / particles	Different type of fiber boards, insulation products and products from plastics
F	No performance determined		Products that are not tested on fire (no requirements for reaction to fire properties)

system is very far from the façade fire scenario and, therefore, the methods cannot be applied for determining fire performance of facades. Reaction to fire of the individual materials of the system greatly affects the fire performance of a facade as a whole. Because of that, facades can be truly assessed only on the full-scale level, and taking into consideration detailing such as windows, penetrations, and other details that may have a great impact on fire performance. Fire performance characteristics include fire spread, contribution to fire, maximum dimensions of flame spread, temperature/time characteristics, continuous smouldering and glowing combustion, mechanical performance including falling of burning droplets/particles, collapse of cladding system, as well as areas damaged by fire in all layers assessed by post-test analysis. A full-scale test must be conducted in order to obtain all these characteristics. Kotthoff [7] suggested that a medium or large scale test should be performed depending on the building type and building height, as shown in Figure 2. Kotthoff based his proposal on two standards, DIN E 4102-20 (medium scale test) and BS 8414-1 (large scale test). These standards could be used as a possible basis for developing new harmonized methods. They should not be used as default methods, i.e. as given, for medium and large scale testing, respectively, since there is a substantial difference in their fire exposure (fire exposure is almost ten times higher in BS 8414-1 compared to DIN E 4102-20), which is not proportional to their height difference. Nevertheless, such approach would allow choosing appropriate test method for fire performance of façade systems depending on the building type (i.e. type of activity in the building), its height, and fire scenario.

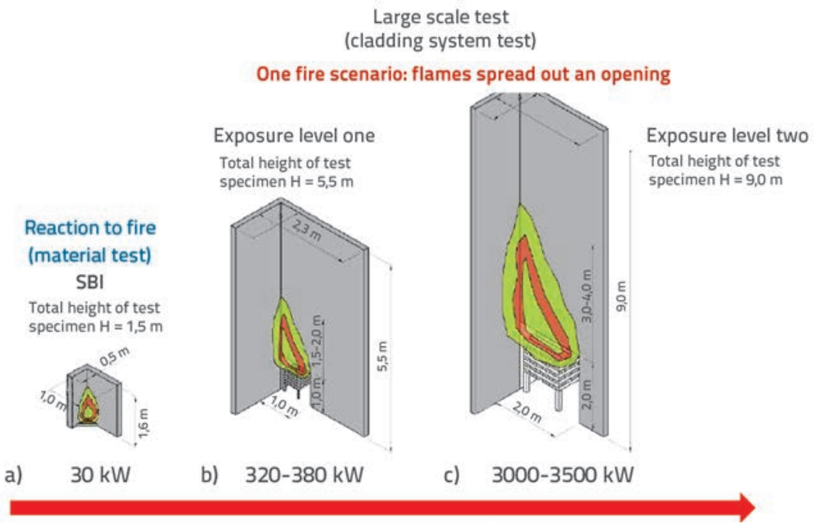

Figure 2. Kotthoff's proposal for large scale fire performance testing of external wall cladding systems [7]

As shown in Figure 2, SBI testing [8] is proposed only for the material level, since the SBI does not reflect the end-use conditions and is therefore not applicable for facades. For a building regarded as a whole Kotthoff proposed two different test methods, one for medium-rise buildings (exposure level one) and another for high-rise buildings (exposure level two). The exposure level two is characterized by a severe full-fire and its application is beyond the high-rise level, e.g. beyond 22 or 18 m depending on national building codes. This proposal was made by Kotthoff within the framework of EOTA's work, and it is currently being discussed. A multitude of various national test methods means high costs for industry, and it limits the flow of façade systems across the whole of Europe, thus suppressing a single market for façade systems. Besides, interpretation of test results, i.e. determination of fire performance, is influenced by different national building codes. Relying on the only currently existing harmonized European fire test, the SBI test [8], and the corresponding classification scheme [5], has the potential of enabling the use of systems that will perform poorly in a real fire conditions, and will thereby increase the risk to occupants and firefighters [9]. The main aim of this study is to support these findings.

Fire and fire spread in buildings can be caused by fire in neighbouring structures (burning droplets or radiated heat from fire in an adjacent building), fire from the outside (fire source in close proximity of a building, e.g. burning waste container or burning vehicle) or fire inside a building (rooms). This paper will focus on the most common cause of fire, when the fire occurs inside of a building and spreads to the façade due to venting through an opening, as shown in Figure 3.a. An approximate time of floor to floor fire spread in this fire scenario, and in case ETICS is used as cladding, is shown in Figure 3.b.

This paper discusses results obtained by the full scale test performed on three façade test specimens based on ETICS systems with different type of thermal insulation material, i.e. ETICS system with combustible insulation, ETICS system with combustible insulation and fire barrier from non-combustible insulation, and ETICS system with non-combustible insulation. The testing was conducted according to British Standard BS 8414-1:2002 [12], which is applicable for high-rise buildings, since fire safety issues of facades have become one of a major problem in high-rise buildings [13]. Also, this standard is one of proposed test methods for future harmonized European procedures for testing fire performance of buildings, and it has been proposed to the European Organisation for Technical Assessment (EOTA).

The main parameter observed during the testing was temperature development at certain points of test specimens during exposure to fire. In addition to standardised

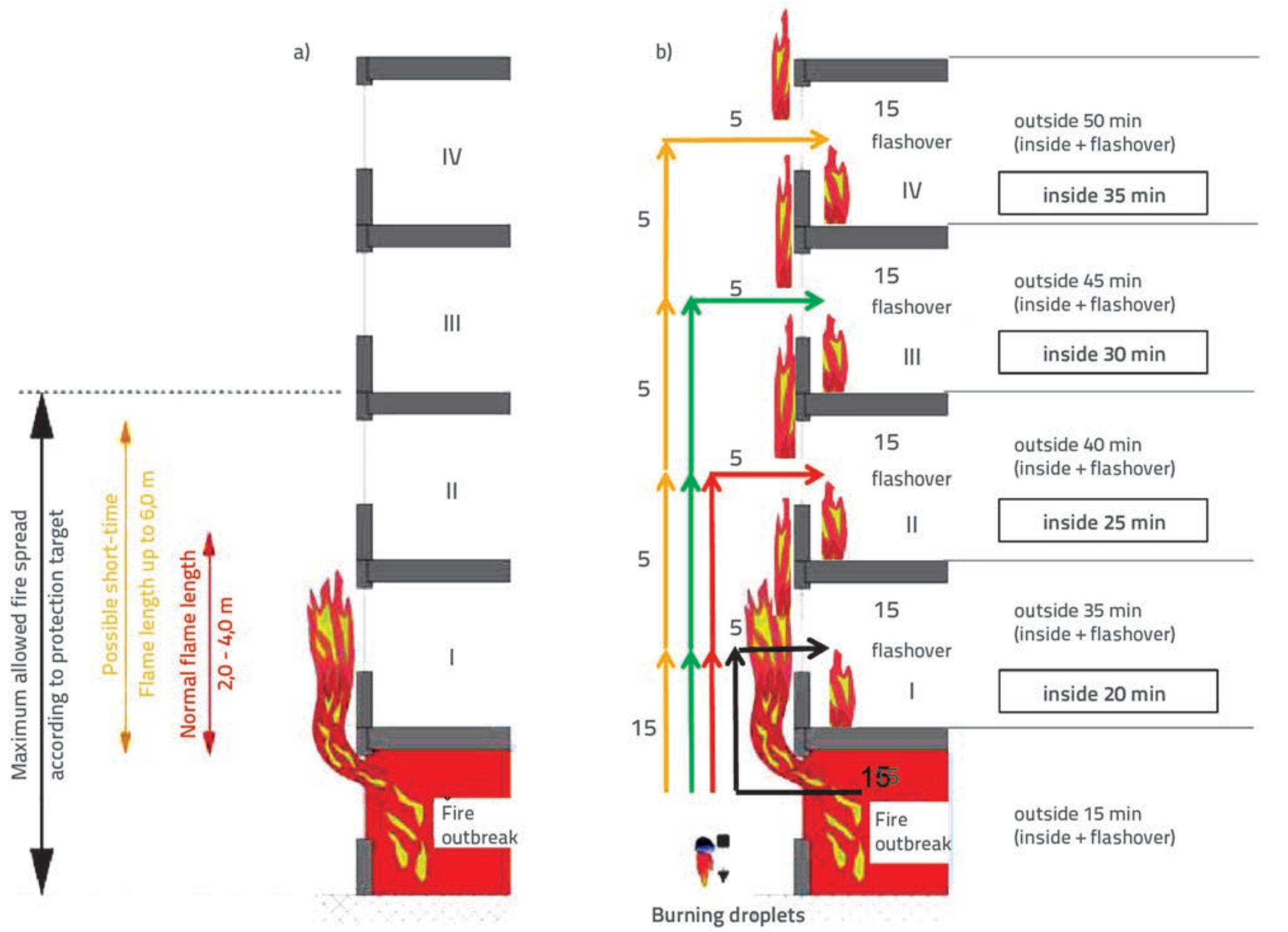

Figure 3. a) Fire spread via building façade when fire source is placed inside the building [10]; b) Approximate time of fire spread from floor to floor in case of facade with ETICS system [11]

measurements required by BS 8414-1 [12], additional measurements were also performed in terms of temperature monitoring with additional thermocouples, i.e. temperature monitoring with plate thermometers, determination of heat flux intensity and weight loss rate of the wood crib during the test. Based on the results, the fire performance of three mentioned ETICS systems is presented.

It must be emphasized that the literature review shows a lack of results on fire performance of ETICS systems obtained during full scale tests, and thus situation is similar with interpretation of these results, specifically according to the standard used in this paper [12]. Although full scale tests are more demanding and expensive than smaller scale tests, they give more reliable results about the overall fire performance of a system as a whole. The testing presented in this paper was performed in May 2014 in Croatia and it constitutes a significant contribution to further research and better understanding of fire performance of facades made of ETICS systems, with various thermal insulation materials. Better understanding of fire performance of facades with various ETICS systems will ensure their appropriate application in terms of building type and building height, and it will therefore increase fire safety of buildings.

2. Methodology

In the absence of national Croatian standards, the fire performance of three different types of ETICS systems was tested according to the BS 8414-1:2002 test method, as mentioned above [12]. This standard describes a method for assessing behaviour of non-loadbearing external cladding systems, the rain screen over the cladding systems, and external wall insulation systems when applied to the face of a masonry building exposed to external fire under controlled conditions. The fire exposure is representative of an external fire source or a fully-developed (post flashover) fire in a room, venting through an opening such as a window aperture that exposes the cladding to the effects of external flames [12]. It should be noted that BS 8414-1:2002 was used only as a "guide" for preparing and conducting this test, since the main objective was to gain new knowledge about complex fire performance of various ETICS systems, at the level of a building, in the same fire scenario, i.e. in the same fire conditions. In addition to the study of their individual fire performance results, the testing was also aimed at comparing fire performance of specimens relative to each other.

Table 2. Description of test specimens

TEST SPECIMEN	Thermal insulation material and thickness	Render	Fixing method	Reaction to fire classification
E_1	Expanded polystyrene (EPS) – 150 mm	Basic render reinforced with glass fibre mesh and final organic (acrylic) render – 5 mm	Bonded and mechanically fixed	B-s2,d0
EM_2	Expanded polystyrene (EPS) – 150 mm + fire barrier 150 mm thick and 200 mm high; directly above combustion chamber			B-s2,d0 (A2-s1,d0 barrier)
M_3	Mineral stone wool (MW) – 150 mm			A2-s1,d0

2.1. Experimental set-up

All three test specimens were L-shaped, 8 m high, with one leg forming the main test wall (main face) 2.6 m in length, and the other leg forming the return wall (wing) 1.5 m in length, as shown in Figure 4. The L-shape of the specimens represents a corner of a building. The only difference between test specimens was the type of thermal insulation material used in the ETICS system erected on the brick wall, i.e. combustible expanded polystyrene (EPS) and non-combustible mineral wool (MW) thermal insulation. The composition of all three test specimens and their classification according to the reaction to fire as declared by the manufacturer [4, 5] is shown in Table 2.

Figure 4. Test specimens before testing

It should be emphasized that the declared reaction to fire class of the test specimen EM_2 (B-s2,d0) is related to the layer of the ETICS façade system in which the EPS is used as the thermal insulation material, while the fire barrier reaction class was A2-s1,d0.

In the test specimen EM_2 the fire barrier was positioned right above the combustion chamber, which simulated an opening in a building, Figure 5a). The scheme of lintel protection constructed above the opening according to relevant rules of practice, as applied on test specimen EM_2, is shown in Figure 5.b) and Figure 5.c). According to [11], this is one of possible constructive ''fire protection'' solutions, i.e. it is a passive fire protection in ETICS systems with EPS. Another possible solution is to place fire barrier along the entire perimeter of the building after every second storey [14]. Fire barriers could limit the risk of fire spreading through the combustible thermal insulation layer.

The heat source placed in the combustion chamber at the base of the main vertical test wall was a timber crib nominally measuring 1500 mm x 1000 mm in plane, and 1000 mm in height, constructed using softwood sticks nominally measuring 50 mm x 50 mm in cross-section, and 1500 mm and 1000 mm in length. This heat source releases a nominal total heat output of 4500 MJ over 30 min at the peak rate of (3 ± 0.5) MW. It should be noted that the density of softwood varies considerably and, therefore, the timber crib mass amounted to 445 kg, 437 kg and 395 kg for test specimens E_1, EM_2 and M_3, respectively.

The combustion chamber represents the room inside the building where the ignition starts.

All test specimens were constructed in accordance with relevant rules of practice and according to manufacturers' specifications [15, 16], where a special attention was given to details.

Standard temperature measurements defined in BS 8414-1 were conducted [12]. Also, additional measurements with other types of thermocouples and temperature-measurement devices were made, as described further on in this section.

Type K (Chromel/Alumel) mineral-insulated 1.5-mm (nominal) diameter thermocouples with insulated junctions were used for standard temperature measurements, based on

Figure 5. Fire barrier: a) Applied on test specimen EM_2; b) General scheme - cross-section [14]; c) General scheme – front view [14]

the relevant BS standard. The arrangement of external and internal thermocouples across the façade wall cross-section is shown in Figure 6. Internal thermocouples were drilled through the brick wall and the thermal insulation layer, while external thermocouples were mounted on a girder placed 10 cm away from the surface of the façade, as shown in Figure 4. The front view of the thermocouples is shown in Figure 7.a.

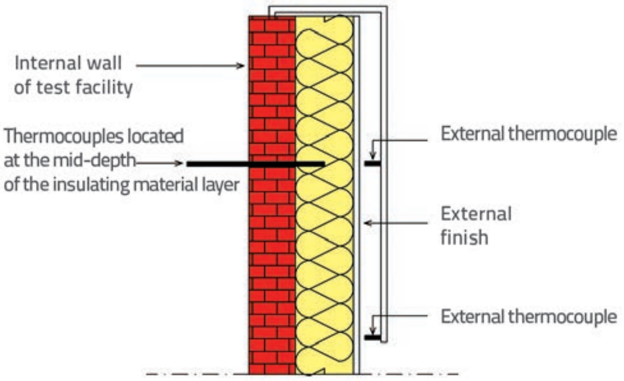

Figure 6. Position of external and internal thermocouples in test specimen cross-section

Standard external thermocouples were positioned at the main face of the façade (five locations) and at the wing (three locations), both at Level 1 and Level 2 (Figure 7.a). Standard internal thermocouples were positioned at Level 2 only, at the main face of the façade (five locations) and at the wing (three locations).

The behaviour of test specimens during fire exposure was recorded with a video camera as required by the standard used [12]. This video information was used to help interpret test results, i.e. temperature profiles, and to observe the timeline of specific appearances on test specimens.

Additional thermocouples (1.0, 1.5, and 3.0 mm in nominal diameter, respectively), plate thermometers and load cells, marked red and blue in Figures 7.b and 7.c, were mounted on test specimens.

Additional measurements, also analysed in this paper, are described in Table 3. Results of other additional measurements mentioned previously, will be published elsewhere.

Table 3. Description of additional measurements analysed in this paper

Measuring instrument	Purpose	Number and position
Additional internal thermocouples (In TCadd) 1.5 mm	Measuring temperature distribution in thermal insulation layer	10 thermocouples per test specimen (7 at the main face and 3 at the wing)
Load cell under the support platform legs (LC)	Measuring weight loss rate of the wood crib during the test; i.e. burning rate of fire source	Placed below each leg of platform onto which the wood crib was placed

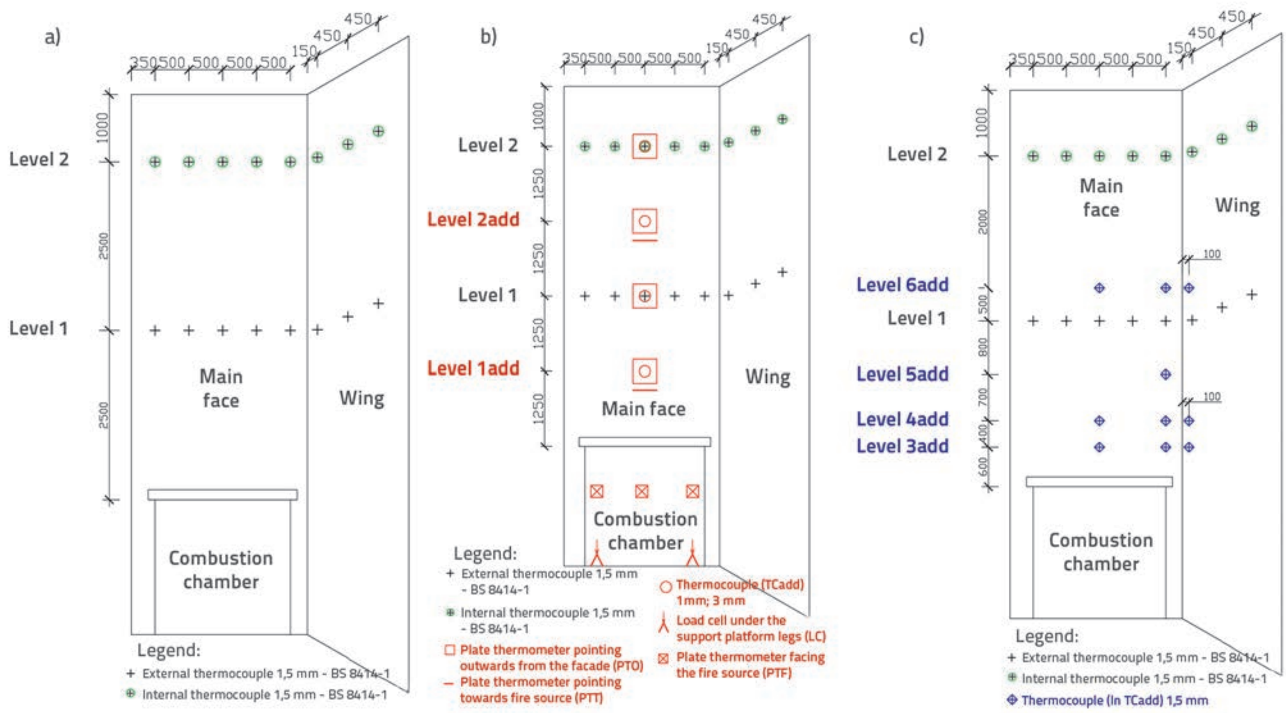

Figure 7. Front view of: a) thermocouples required by BS 8414-1:2002 [12]; b) additional external thermocouples, plate thermometers, load cells; c) additional internal thermocouples

For all three test specimens, i.e. E_1, EM_2, and M_3, the wood crib was ignited at the same time so as to enable visual comparison of fire development and fire spread for all three test specimens. The wood crib ignition time is used as the start time in the following analysis of results.

3. Experimental results

As described previously, this paper will focus only on measurements according to BS 8414-1:2002 [12] and additional measurements as shown in Table 3.
Since the test was performed outside, relevant weather conditions, i.e. wind speed, wind direction, and air temperature were monitored during the test. Air temperature during the test was within the range of 20.5 – 22.2 °C and the air velocity was within the range of 2.2 – 4.5 m/s in the N, N-W direction. The north direction is shown in Figure 4.
Results obtained during the test can be classified into three different groups: Timeline of events for test specimens, Temperature profiles, and Mass loss.

3.1. Timeline of events for test specimens

Timeline of specific appearances on test specimens, in relation to surface temperatures at Level 1 on the main face, is shown in Figure 8.

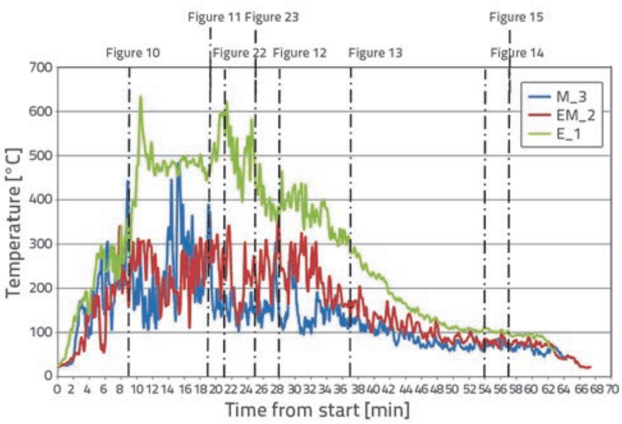

Figure 8. Timeline of specific appearances on test specimens in relation to surface temperature profiles

The development and fire spread at all three specimens, and fire performance of these specimens, are presented in Figures 9 to 18. Visual observation during the test revealed that the fastest fire spread, both vertically and horizontally, was registered at test specimen E_1 and was accompanied with significantly greater smoke production compared to other specimens, Figure 11 and Figure 12. The fire spread at test specimen EM_2 was mitigated due to presence of fire barrier above the combustion chamber. Hence, the average surface temperature (Figure 8), and average temperatures within the thermal insulation layer (Figure 21) of this test specimen, were significantly lower compared to the temperatures registered at test specimen E_1. Despite the lower temperatures, after some time, fire propagated over the fire barrier and continued to spread on the test specimen. It resulted in delayed smoke production due to melted thermal insulation, compared to test specimen E_1 and burning droplets. The main risk with burning droplets is that they can spread the fire downwards, cause the fire to spread to a nearby building, and can also endanger firefighters in case of real fire. Test specimen EM_2 smouldered after the wood crib had burned up, i.e. after the fire source was extinguished. At the same time, smoke production was negligible at test specimen M_3.
Average surface temperatures at test specimen EM_2 and test specimen M_3 are quite comparable, although slightly lower average surface temperatures were registered at test specimen M_3, Figure 8. The analysis of average temperatures within the thermal insulation layer shows that temperatures at test specimen M_3 are considerably lower compared to those registered at test specimen EM_2 and test specimen E_1, Figure 21. This will be analysed in detail in next chapter.
More than 60 minutes from the start, firefighters hosed down fire sources and all test specimens for safety reasons. Only the glass fibre mesh and finishing render was left of test specimen E_1, while the entire thermal insulation burned up in less than 40 min after the start of fire. At test specimen EM_2, once the fire propagated over the fire barrier above the combustion chamber, the thermal insulation started to melt and burning droplets fell down. The thermal insulation melted only partially at this test specimen. At test specimen M_3, only a few cracks were detected above the combustion chamber after watering by firefighters, and only organic render finishing was burned out. The thermal insulation at test specimen M_3 was not significantly damaged.

Figure 9. Ignition of wood crib – start time

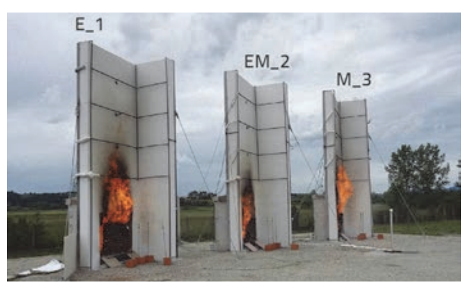

Figure 10. 9 min from the start

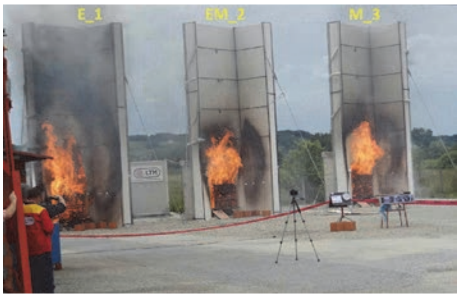

Figure 11. 19 min from the start

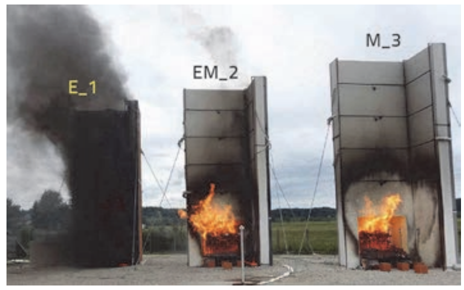

Figure 12. 28 min from the start

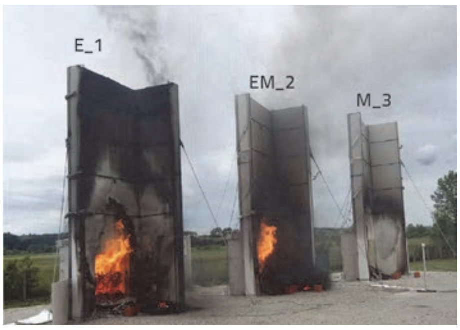

Figure 13. 37 min from the start

Figure 14. 54 min from the start – smouldering at test specimen EM_2

Figure 15. 57 min from the start – wood crib has burned up

Figure 16. 64 min from the start – firefighters watering M_3 for safety reasons

Figure 17. 66 min from the start - firefighters watering EM_2 for safety reasons

Figure 18. 67 min from the start - firefighters watering E_1 for safety reasons

3.2. Temperature profiles

All temperature measurement results will be presented in this section as average temperatures. An average temperature implies an average value of several thermocouples positioned at the same level.

Average temperatures measured with external thermocouples on test specimens at Level 1 and Level 2 according to the relevant standard are presented in Figure 19 and Figure 20, respectively. Figure 21 presents average temperatures measured with internal thermocouples, according to the relevant standard,

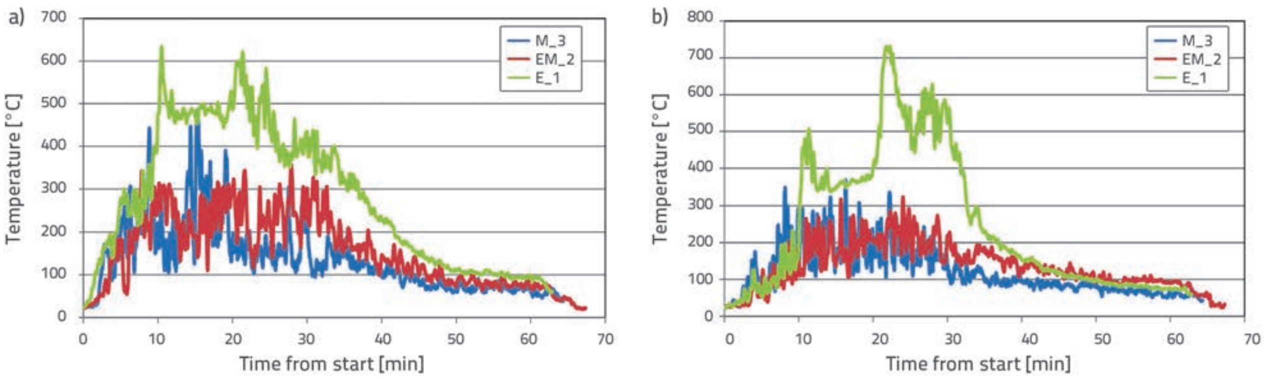

Figure 19. Average surface temperatures at Level 1: a) Main face; b) Wing

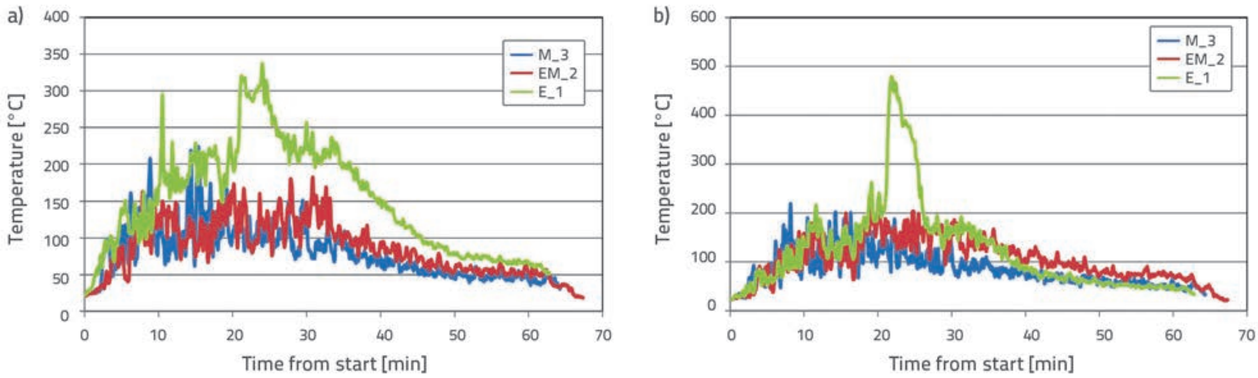

Figure 20. Average surface temperatures at Level 2: a) Main face; b) Wing

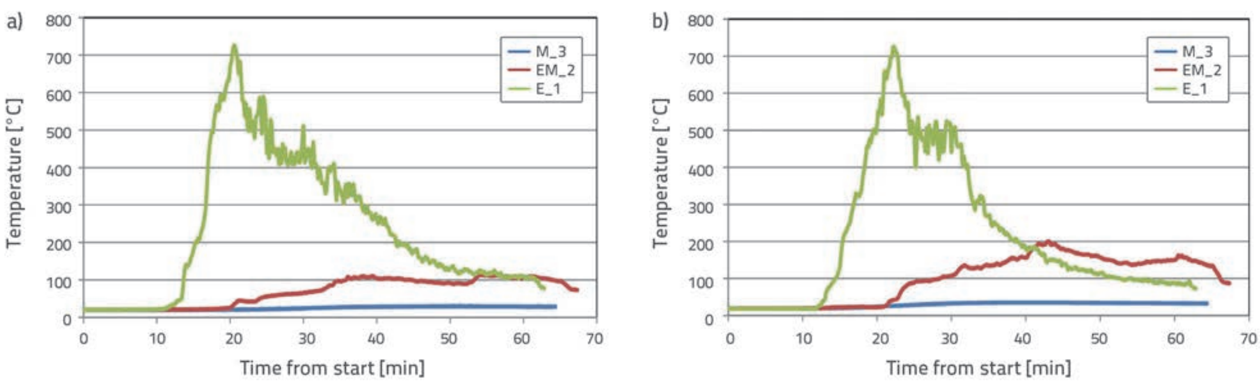

Figure 21. Average temperatures within thermal insulation layer at Level 2: a) Main face; b) Wing

within the thermal insulation layer at Level 2 for all three specimens.

Temperature development at test specimen E_1 is quite interesting due to the temperature peaks registered at that specimen. Surface peaks and internal peaks are induced by specific occurrences registered at test specimen E_1. Specific occurrences observed during the test, and their corresponding peaks are chronologically presented in Table 4.

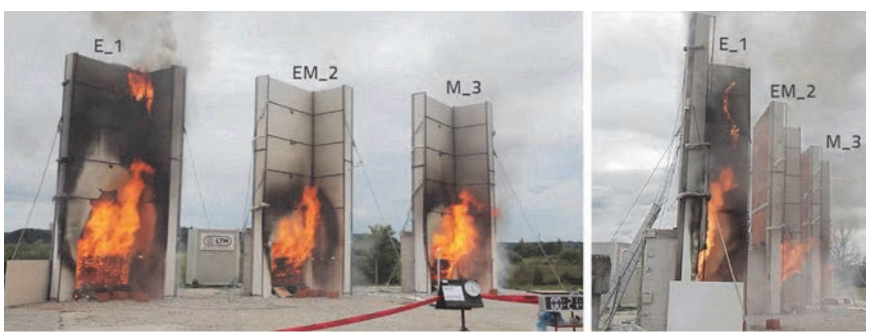

Figure 22. Fire outbreak at Level 2 (specimen E_1): 21 min from start

Table 4. Chronological order of peaks in temperature profile of test specimen E_1

Test specimen E_1 Main façade					
Time from start	**Temperature profile**	**Temperature**	**Position**	**Shown in Figure**	**Occurrences at test specimen that induced peaks in temperature profile**
10 min	First surface peak	Over 600 °C	Level 1	19.a	Burning render – at Level 1add render was caught by fire and fire started to spread upwards to Level 1. As shown in Fig 19a) and Fig 20a), specimen E_1 has greater average surface temperatures compared to specimens EM_2 and M_1, which implies that EPS started to burn underneath the rendering.
		Gotovo 300 °C	Level 2	20.a	
10 – 20 min	Plateau	Over 450 °C	Level 1	19.a	EPS burning underneath the rendering, followed by great smoke production. 15 min from start, the rendering opened thus providing extra air supply that boosted the stack effect. It was visually confirmed through this opening of render that EPS was burning
		Oscilira između 170 i 230 °C	Level 2	20.a	
Around 20 min	First internal peak	Over 700 °C	Level 2	21.a, 22	Second surface peaks were induced by fire breaking out through the render. Temperature and time shift is present when comparing the first internal peak and the second surface peak. Significant temperature difference inside the thermal insulation layer and on the surface at the same level is a strong confirmation that thermal insulation, i.e. EPS, was burning and render was separating it from the outside air. Render caused significant temperature difference and time delay of surface temperature peak compared to the temperature peak within the thermal insulation layer. It can be concluded that EPS burning underneath the rendering induced the first internal peak; while burning EPS breaking out through the rendering induced the second surface peak.
21 min	Second surface peak	Over 600 °C	Level 1	19.a	
		Over 300 °C	Level 2	20.a, 22	
25 min	Third surface peak	Over 550°C	Level 1	19.a, 23	Burning droplets on the ground, followed by great smoke production.
		Over 300°C	Level 2	20.a, 23	
25 – 60 min	Decay stage of fire development curve	Temperatures are decreasing	Level 1	19.a	EPS was completely burned up.
			Level 2	20.a	

The described peaks and plateau occurred also at specimens' wing, Figure 19.b), within the same time frame albeit at different temperatures. As expected, average surface temperatures are higher at Level 1 compared to Level 2, which is due to the fact that Level 1 is closer to the fire source. Fire source together with the burning render caused higher temperature values. The greater the distance from fire source, the less significant is the influence of fire source on an average surface temperature.

When analysing temperature development within the thermal insulation layer at Level 2 of the test specimen EM_2 and test specimen M_3, as shown in Figure 21, it can be seen that the test specimen EM_2 and test specimen M_3 have practically the same constant temperature in the first 20 minutes from the start. After 20 minutes from the start, the temperature within the thermal insulation layer at the main face of the test

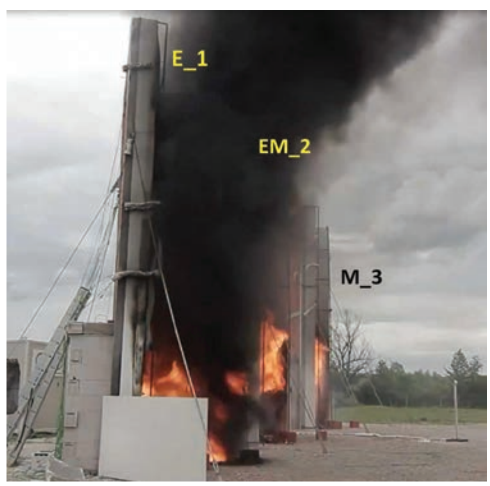

Figure 23. Great smoke production and droplets burning on the ground (specimen E_1): 25 min from start

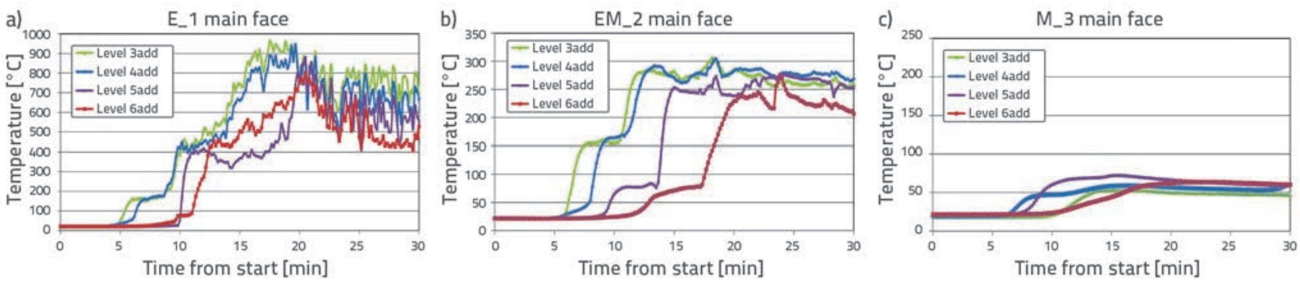

Figure 24. Fire spread within thermal insulation layer: a) Specimen E_1; b) Specimen EM_2; c) Specimen M_3

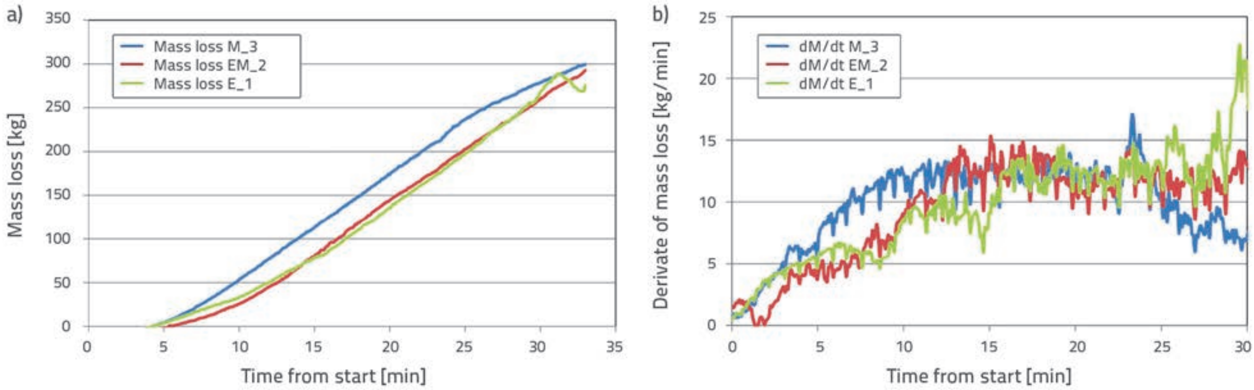

Figure 25. a) Measured mass loss of fire sources during the test; b) Derivative of measured mass loss of fire sources during the test

specimen EM_ 2 started to rise and oscillate around 100°C, until render above the fire barrier cracked and fire penetrated into thermal insulation layer, i.e. EPS, which was melting. At test specimen M_3, temperatures within the thermal insulation layer at the main face remained the same, and reached the maximum of around 30°C. Temperature profiles of the test specimens EM_2 and M_3 show no peaks. The only specific occurrence at test specimen EM_2 was EPS that melted above the fire barrier and started to burn when it fell to the ground, generating smoke. Test specimen EM_2 produced less smoke compared to test specimen E_1.

Vertical fire spread within the thermal insulation is presented in Figure 24 for each test specimen. The presented fire spread within insulation is characterized by average temperatures measured with additional internal thermocouples, as shown in Figure 7.c. The highest and fastest average temperature development occurs at test specimen E_1, while the smallest and slowest average temperature development occurs at test specimen M_3. The highest and fastest average temperature development within the thermal insulation of test specimen E_1 is due to the greatest rate of fire spread compared to other test specimens. In test specimen E_1 at Level 4add an average temperature within the thermal insulation exceeds 400°C in the first 10 minutes from the start and reaches maximum at above 800°C in the first 15 minutes from the start. This is significant since, according to literature, EPS starts to melt at temperatures beyond 80°C [18], thus accelerating fire spread due to occurred stack effect. EPS ignites with external flame at around 480°C and self-ignites (without external flame) beyond 575°C [10], which confirms that EPS burned up within specimen E_1. Regarding test specimen EM_2, during the entire testing, average temperatures within the thermal insulation were under 300 °C at the Levels 3add and 4add, which indicates that EPS melted, but did not burn up at this test specimen. During the entire testing, average temperatures within the thermal insulation layer of test specimen M_3 were below 100°C. This means that the thermal insulation at specimen M_3 preserved its integrity, i.e. its mechanical properties, which is due to the fact that organic binder in mineral wool melts at temperatures beyond 200°C.

3.3. Mass loss

The mass of the fire source was measured during the test by applying load cells below each leg of the table onto which the wood crib was placed. When observing the mass loss, Figure 25a), it can be seen that the mass loss generally decreases with the combustibility of the facade system, i.e. that the facade with non-combustible insulation exhibits a faster mass loss compared to other facades, and that the slowest mass loss is exhibited by the facade with combustible insulation without barrier. This interesting occurrence was also noted in full scale testing (same test specimens, same standard) performed in March 2014 [17]. Figure 25.b shows the derivative of the mass loss which is the same for test specimens M_3 and E_1 in the early phase of the test, while test specimen EM_2 differs considerably. This could be due to the effects of the wind.

4. Conclusion

Current environmental concerns urge designers to conceive buildings capable of meeting energy efficiency requirements by their form and performance. In parallel, fire safety of buildings implies compliance with a number of various standards imposed by regulations. In that context, fundamental changes and significant improvements should be achieved, i.e. an integrated design procedure should include both thermal comfort (energy efficiency) and fire safety requirements. A considerable future research is needed in both areas to establish such an approach in design practice.

This paper presents results and findings on fire performance of the ETICS systems with different types of thermal insulation material, i.e. combustible, combustible with fire barrier, and non-combustible, tested in the scope of the full scale test in May 2014 in Croatia. It is shown that façades can greatly affect fire spread in buildings, i.e. contribute to or retard the fire spread. The type of façade, i.e. the type of an ETICS system, determines fire performance of buildings. Fire performance of buildings can be defined as a time history of complex behaviour of buildings exposed to fire. Smoke production, fire/flame spread, smouldering, mechanical performance such as falling and/or burning droplets, collapse of the cladding system, and areas damaged by fire in all layers assessed by post-test analysis, should be included in the determination of fire performance of building facades. Future harmonized European full scale test method should take into account all these characteristics. Findings based on tests performed according to BS 8414-1 will hopefully contribute to the development of a future harmonized method that should bring considerable improvements compared to national test methods that are currently in use. According to the authors' insight in the current situation, the size of test specimens in future harmonized method would most probably be similar to the size of the test specimen defined in BS 8414-1. The main conclusion of the testing conducted in this paper is that the fire barrier made of non-combustible material (i.e. mineral wool), even in a relatively small height of 20 cm above the opening, can significantly mitigate fire spread and vertical development of temperatures along the façade, and its performance is therefore better compared to ETICS with EPS only. However, burning droplets, delayed smoke production, and smouldering, were present at the ETICS with EPS and fire barrier, which endangered firefighters and increased the possibility of fire transmission to a nearby building. As expected, the most favourable overall fire performance was demonstrated by ETICS with MW.

According to the SBI test, the ETICS system with the EPS and fire barrier has the B-s2,d0 reaction to fire class, which implies no appearance of burning droplets. However, this paper reveals that burning droplets occurred at the ETICS system with the EPS and fire barrier, which means that the SBI test is not suitable for large scale specimens, i.e. full scale systems. The SBI test does not represent and cannot fully describe real fire performance of a full scale system, i.e. the entire building and its façade.

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