Fire Safety of Façades in Croatia: Research and Experience from the University of Zagreb

Assist. Prof. Marija Jelčić Rukavina
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5. FAÇADE FIRE TESTS - towards a harmonized European test method
Introduction – paradox?

- **1666: Great Fire of London**
  - Fire in the entire London that lasted for 4 days
  - Displacement of 70,000 people (out of 80,000 of all population)
  - 6 verified deaths

- **2017: Fire in Grenfell Tower**
  - Fire in a single 24-storeys building
  - app. 80 deaths


351 years of improving fire safety engineering ???!!!!
Introduction – link between energy efficiency and fire safety

Comparison of 2020 and 2030 goals for set by EU for energy efficiency in buildings:

-20% lower emission of CO$_{2eq}$ gases
+20% higher use of renewable energy sources
-20% lower need for energy in buildings
-40% lower emission of CO$_{2eq}$ gases
+27% higher use of renewable energy sources
-27% lower need for energy in buildings

In order to satisfy above requirements, one of the modes is to thermally enhance building envelopes.

Most common system to thermally enhance the building envelope in EU is ETICS

1. adhesive mortar
2. thermal insulation material (combustible or non-combustible)
3. mechanical fixings
4. mortar for reinforcement layer
5. glass fibre mesh
6. finishing layer

If combustible insulation materials is used, it leads to increased risk of vertical fire spread across façades, especially in high-rise buildings.
Three typical scenarios of fire spread across façades

1. Spread of the **external fire onto combustible façade by radiation** from the neighboring, separate building,

2. Spread of the **external fire onto combustible façade from the source of fire located next to the façade**, with the consequence of radiation or direct exposure to fire (litter on the balcony, parked cars etc.),

3. An **internal fire that has started in a space inside a building spreads through openings in the façade** (windows, doors etc.) onto higher or lower floors which is the most often case.
Flame heights with temperatures across façade depending on airflow

Fire spread onto façade through openings

*Figure* Development of fire across a façade due to combustible thermal insulation *(J. Mayr, L. Battran, Handbuch Brandschutzatlas Grundlagen – Planung – Ausführung. FeuerTrutz, 2014)*
The objective of fire protection measures regarding façades is:

- The prevention of fire spread to more than two floors above the floor where the fire started before the firefighters’ intervention.
- The firefighters’ intervention should prevent falling of the combustible parts of a façade or larger parts of an external wall.

Figure spreading of fire across facade (Source: Khotoff, 2015)
Fire Façade Test (FFT)

- Conducted on 28.5.2014. [www.grad.unizg.hr/fft](http://www.grad.unizg.hr/fft)

- Organisers:

- Partners during testing:
Experimental testing

- The main aim the experimental testing was twofold:
  - To provide **deeper understanding** of the fire performance of ETICS systems with **combustible insulation**
  - To investigate whether and how the **fire barriers** constructed above openings **influence fire performance** of ETICS systems with combustible insulation

Results of testing are presented in the following scientific paper:


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Experimental methodology and set-up

- **BS 8414-1 test method** used as a “guide” (fire scenario: fire occurs inside a building and spreads to the facade due to venting through an opening)
- tests were performed **outside and additional measurements** were performed in addition to the standard temperature measurements defined by BS 8414-1

**Table Description of test specimens**

<table>
<thead>
<tr>
<th>TEST SPECIMEN</th>
<th>Thermal insulation material and thickness</th>
<th>Render</th>
<th>Fixing method</th>
<th>Reaction to fire classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS_1</td>
<td>Expanded polystyrene (EPS) – 150 mm</td>
<td></td>
<td></td>
<td>B-s2,d0</td>
</tr>
<tr>
<td>TS_2</td>
<td>Expanded polystyrene (EPS) – 150 mm + fire barrier 150 mm thick x 200 mm high; right above fire chamber</td>
<td>Basic render reinforced with glass fibre mesh and final organic (acrylic) render – 5 mm</td>
<td>Bonded and mechanically fixed</td>
<td>B-s2,d0</td>
</tr>
<tr>
<td>TS_3</td>
<td>Mineral stone wool (MW) – 150 mm</td>
<td></td>
<td></td>
<td>(A2-s1,d0) barrier</td>
</tr>
</tbody>
</table>

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FIRE BARRIERS is a non-combustible (reaction to fire classes A1 or A2-s1,d0) insulation structure used to break up continuous combustible insulation panel to hinder fire spread.
Experimental methodology and set-up

- **Two tests performed** on identical test specimens

  repeatability of testing → comparability of obtained results → confirmation of fire performance of tested systems

- Weather conditions were monitored in order to be able to take into account their possible influence on testing and obtained results

**Table** Weather conditions during Test 1 & Test 2

<table>
<thead>
<tr>
<th>Test</th>
<th>Air temperature</th>
<th>Air velocity</th>
<th>Wind direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>11.2 – 12.3°C</td>
<td>1.8 – 5.4 m/s</td>
<td>N - E</td>
</tr>
<tr>
<td>Test 2</td>
<td>20.5 – 22.2°C</td>
<td>2.2 – 4.5 m/s</td>
<td>N, N - W</td>
</tr>
</tbody>
</table>
Temperature measurements – positions of thermocouples

Level 1
- + + + + + + + + +

Level 2
- + + + + + + + + +

Main face
- + + + + + + + + +

Wing
- + + + + + + + + +

Level 6add
- + + + + + + + + +

Level 5add
- + + + + + + + + +

Level 4add
- + + + + + + + + +

Level 3add
- + + + + + + + + +

Legend:
- External thermocouple 1,5 mm - BS 8414-1
- Internal thermocouple 1,5 mm - BS 8414-1
- Additional internal thermocouple 1,5 mm
- Load cell under the support platform legs
Average surface temperatures at Level 1 on main facade

• Higher surface temperatures on TS_1 compared to TS_2

• Temperature profiles of TS_1 characterized with stronger peaks compared to TS_2

• Differences in developed temperatures during the Test 1 and Test 2 reach up to 200°C (Level 1) for TS_1 and up to 150°C (Level 1) for TS_2

• Differences in developed temperatures during the Test 1 and Test 2 reach up to 150°C (Level 2) for TS_1 and remain practically the same at Level 2 for TS_2

Caused by changes in weather conditions and different burning rate of fire source

*Average temperatures imply an average of several thermocouples at the same level
Temperature measurements—internal themocouples

- TS_2 has considerably lower temperatures compared to TS_1
- Fire barrier has limited the fire development within the insulation of TS_2
- Peak temperature reached 800°C (Test 1) and 720°C (Test 2) within insulation of TS_1
- Time shift of first peak occurrence on TS_1 when comparing Test 1 and Test 2
- The same value of average temperature within insulation of TS_1 and TS_2 up to 8 min (Test 1) and up to 10 min (Test 2)
- Fire barrier caused the temperatures within insulation to stay below 300°C up to Level 6add (3 m above combustion chamber)
Conclusions of the Fire Facade Test

• Apart from high-rise buildings for which use of non-combustible materials in façades is demanding, one of the possibilities to delay spread of fire across façades of buildings, in which combustible insulation materials is allowed, is to build in fire barriers at certain locations across façades.

• Results showed that the fire barrier has function to delay the spread of fire and falling off the burning droplets.

• However, the results also show as whereas a stone wool fire barrier can slow down and decrease the fire spread in EPS ETICS it cannot fully prevent the EPS from contributing in the fire development - safety margin of ETICS systems with fire barriers are limited.

• Thus, fire barriers are not recommended for all building types, especially in buildings with users of reduced mobility capabilities as hospitals, retirement homes, kindergartens etc.
General scheme of Croatian legislation regarding fire protection

When designing and executing a building, fire protection must be provided, as one of the essential requirements for buildings prescribed by a special regulation regulating physical planning and construction, so that in case of fire:

1. the load-bearing capacity of the construction can be assumed for a specific period of time,
2. the generation and spread of fire and smoke within the works are limited,
3. the spread of fire to neighboring construction works is limited,
4. occupants can leave the works or be rescued by other means,
5. the safety of rescue teams is taken into consideration.

The most important: Ordinance on Fire Resistance and other Requirements for Buildings in Case of Fire (Official Gazette 29/13, 87/15)

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In accordance to *Ordinance on Fire Resistance and other Requirements for Buildings in Case of Fire* (Official Gazette 29/13, 87/15)

Publication with overview of existing Ordinance, provisional proposals of new amendments and points of interest for the design and execution.
In accordance to Ordinance on Fire Resistance and other Requirements....(Official Gazette 29/13, 87/15): BUILDING SUBGROUPS

<table>
<thead>
<tr>
<th></th>
<th>ZPS 1</th>
<th>ZPS 2</th>
<th>ZPS 3</th>
<th>ZPS 4</th>
<th>ZPS 5</th>
<th>High-rise buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Height of the highest residence floor, h</strong></td>
<td>7 m</td>
<td>7 m</td>
<td>7 m</td>
<td>11 m</td>
<td>&lt; 22 m</td>
<td>≥ 22 m</td>
</tr>
<tr>
<td><strong>Total floor area, m²</strong></td>
<td>≤ 400</td>
<td>≤ 1200</td>
<td>No limit</td>
<td>No limit</td>
<td>No limit</td>
<td>No limit</td>
</tr>
<tr>
<td><strong>Gross floor area of single business units/apartments</strong></td>
<td>≤ 400</td>
<td>≤ 400</td>
<td>No limit</td>
<td>No limit</td>
<td>No limit</td>
<td>No limit</td>
</tr>
<tr>
<td><strong>Maximum number of units</strong></td>
<td>1</td>
<td>≤ 3</td>
<td>No limit</td>
<td>No limit</td>
<td>No limit</td>
<td>No limit</td>
</tr>
<tr>
<td><strong>Number of users</strong></td>
<td>≤ 50 total</td>
<td>≤ 100 total</td>
<td>≤ 300 total</td>
<td>≤ 300 total</td>
<td>≥ 300 total in a unit</td>
<td>No limit</td>
</tr>
</tbody>
</table>
In accordance to Ordinance on Fire Resistance and other Requirements.... (Official Gazette 29/13, 87/15): REQUIREMENTS FOR FAÇADES

### REACTION TO FIRE CLASSIFICATION

<table>
<thead>
<tr>
<th>Building elements</th>
<th>ZPS1</th>
<th>ZPS2</th>
<th>ZPS3</th>
<th>ZPS4</th>
<th>ZPS5</th>
<th>High-rise buildings</th>
</tr>
</thead>
</table>

#### Suspended ventilated façade systems

<table>
<thead>
<tr>
<th>Classified system</th>
<th>E</th>
<th>D-d1</th>
<th>D-d1</th>
<th>C-d1</th>
<th>B-d1</th>
<th>A2-d1</th>
</tr>
</thead>
</table>

or

<table>
<thead>
<tr>
<th>Installation with the following classified components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finishing layer</td>
</tr>
<tr>
<td>Substructure</td>
</tr>
<tr>
<td>– lined</td>
</tr>
<tr>
<td>– pointed</td>
</tr>
<tr>
<td>Insulation</td>
</tr>
</tbody>
</table>

#### Thermal contact façade systems

<table>
<thead>
<tr>
<th>Classified system</th>
<th>E</th>
<th>D</th>
<th>D-d1</th>
<th>C-d1</th>
<th>B-d1</th>
<th>A2-d1</th>
</tr>
</thead>
</table>

or

<table>
<thead>
<tr>
<th>The composition of the layers with the following classified components</th>
</tr>
</thead>
<tbody>
<tr>
<td>– finishing layer</td>
</tr>
<tr>
<td>– insulation layer</td>
</tr>
</tbody>
</table>
Additional requirements for ETICS facade of buildings that contain combustible insulation material and belong to subgroup ZPS 4 and ZPS 5:

1. buildings considered as one fire compartment:
2. buildings with multiple fire compartments

- north façade
- south-west façade
- south façade
- north-east façade
- west façade
- east façade

ground floor

characteristic floor
Suspended ventilated façade systems

- When installing suspending ventilated façade elements it is necessary, when both combustible and non-combustible thermal insulation is used, to prevent fire spread through the ventilating layer through the openings in a façade or at least on every alternate floor along the entire perimeter of the building.

- This barrier in classified façade systems is installed according to the manufacturer’s instructions, and in systems with individual components according to the accepted regulations in technical practice.
Example of fire incident in Croatia:

**CVJETNO NASELJE STUDENT DORMITORY FIRE, ZAGREB, 2017**

- The fire that started on the roof of a student dormitory vertically spread along the façade of the adjacent building towards next upper three floors
- Combustible thermal insulation (EPS) on the renovated ETICS façade
- Strong wind definitely contributed to the fast spread of fire and smoke

*Figures*  
(a) Fire in student dormitory  
(b) the façade after the fire was extinguished, source: CROPIX
General conclusions

- Fire incidents around the world showed that occurrence of fires is hard to prevent, but buildings can be designed, built, and maintained in a more proper way which would increase safety of their users.

- The fire safety regulation unfortunately does not follow the pace of modern technologies and new materials. Things start to speed up only after a tragedy.

- There is a need for close cooperation between political decision makers, researchers, experts, fire fighters, and government in order to make sure that the gap between fire safety legislation and “real-life circumstances” is as small as possible.
Façade fire tests
Towards a new European harmonized testing method

• Lars Boström, RISE Sweden, the Coordinator
Current situation in Europe

- All EU/EFTA Member States have regulatory provisions on the fire performance of facades
- The regulations are mainly based on the existing European system on reaction to fire and fire resistance
- 14 Member States state that they have additional requirements, not covered by EN 13501 part 1 and 2
- Some countries specify a specific test method, some enables performance based testing
- 12 different test methods has been identified to presently be used
## Current situation in Europe

<table>
<thead>
<tr>
<th>Test methods</th>
<th>Countries using the test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. PN-B-02867:2013</td>
<td>Poland</td>
</tr>
<tr>
<td>BS 8414-1:2015 and BS 8414-2:2015</td>
<td>UK, Republic of Ireland</td>
</tr>
<tr>
<td>DIN 4102-20</td>
<td>Switzerland, Germany</td>
</tr>
<tr>
<td>ÖNorm B 3800-5</td>
<td>Switzerland, Austria</td>
</tr>
<tr>
<td>Prüfbestimmung für Aussenwandbekleidungs-systeme</td>
<td>Switzerland/ Lichtenstein</td>
</tr>
<tr>
<td>Technical regulation A 2.2.1.5</td>
<td>Germany</td>
</tr>
<tr>
<td>Lepir 2</td>
<td>France</td>
</tr>
<tr>
<td>MSZ 14800-6:2009</td>
<td>Hungary</td>
</tr>
<tr>
<td>SP Fire 105</td>
<td>Sweden, Norway, Denmark</td>
</tr>
<tr>
<td>Engineering guidance 16 (unofficial test method)</td>
<td>Finland</td>
</tr>
<tr>
<td>ISO 13785-2</td>
<td>Slovakia</td>
</tr>
<tr>
<td>ISO 13785-1</td>
<td>Czech Republic</td>
</tr>
</tbody>
</table>
Current situation in Europe – examples on test methods

- DIN 4102-20
- BS 8414
- PN-B-02867:2013
- Prüfbestimmung für Aussenwandbekleidungssysteme
- LEPIR 2
- MSZ 14800-6
- ÖNORM B 3800-5
- SP Fire 105
- ISO 13785-1
- ISO 13785-2
## Handling of the regulatory provisions

<table>
<thead>
<tr>
<th>Regulation characteristics</th>
<th>Slovak republic</th>
<th>Hungary</th>
<th>Switzerland</th>
<th>Sweden</th>
<th>Austria</th>
<th>Germany DIN</th>
<th>Germany - technical regulation</th>
<th>Finland</th>
<th>Poland</th>
<th>England &amp; Wales, Scotland, Irelands</th>
<th>France, Denmark-Norway</th>
<th>Proposed criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flame spread – vertical</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>Yes</td>
</tr>
<tr>
<td>Flame spread horizontal</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Flame spread – internal</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Yes</td>
</tr>
<tr>
<td>Connection between floor and facade</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td>Optional (Fire resistance)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smouldering</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>EN 16733</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Falling parts</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Yes</td>
</tr>
<tr>
<td>Smoke</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Only observations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat (through temperature or flux)</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Detailing (window openings, fire stop, etc)</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>Definition of scop</td>
</tr>
</tbody>
</table>

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Current situation in Europe

- Harmonized assessment methods are needed

- About 20 years CEN got a mandate from EC to develop a European method
  - Did not succeed

- About 10 years ago EFTA got the same mission
  - Produced a report containing the DIN 4102-20 and BS 8414 methods
  - Difficulties to get acceptance for the proposal

- About more than 1 year ago EC made an Invitation to tender on the topic
The "Facade project"

- Develop a European approach to:
  - assess the fire performance of facades
  - define all relevant details
  - classify facades
- The BS 8414 series and DIN 4102-20 should be used as a basis for testing
- "Falling off" shall be included
- Meet the regulatory provisions

- Project group with members from RISE (Sweden), BRE (UK), BAM (Germany), EMI (Hungary) and Efectis (France)
- Large group of sub-contractors
Assessment method

- The shape and size of the different methods are quite similar.
- Two different heat exposures are proposed
  - medium fire exposure (30 kg wood crib)
  - large fire exposure (400 kg wood crib)
- Detailing around openings is introduced
- Classification in four different classes, two for the large fire exposure and two for the medium fire exposure
 Flames spread

- Assessed by measurements
- Measure with thermocouples
- Temperature rise < 500 K over a period of 30 s during the test frame time of 60 min
Falling parts and burning debris/droplets

• The criterion is that falling parts shall not be a risk for the evacuation, the rescue personnel nor the fire brigade. **As a guideline the weight of a single falling part shall not exceed 5 kg and the area of a falling part that may be dangerous (e.g. glass panes, panels) shall not be larger than 0.2 m².**

• The general criterion is that burning particles and/or droplets shall not be able to spread the fire downwards. If the material falling down continues to burn for more than 20 seconds, it is considered to have failed the criterion.
Test procedure

- Document the test set-up
- Confirm that all measurement devices are functioning
- Determine the ambient test conditions; wind speed, precipitation and local temperatures
- Begin data logging and audio-visual recording equipment.
- Ignite the timber cribs following the relevant procedure for the selected fire load scenario
- **Monitor and record the behaviour of the test sample during the full 60 minute test period**
- The fire load shall be extinguished 22 or 30 minutes, depending on fire scenario, after the ignition using the technique detailed in the relevant clauses.
- Continue to record measurements and observations for the full duration of the test.
- **Terminate the test 60 mins after ignition of the timber crib.**
- Record observations of damage to the test samples following the test.
Classification

- LS1 – **Large** test fulfilling flame spread and falling parts
- LS2 – **Large** test fulfilling flame spread but not falling parts

- LS3 – **Medium** test fulfilling flame spread and falling parts
- LS4 – **Medium** test fulfilling flame spread but not falling parts

- LS1 will cover all other classes
- LS2 will cover LS4
- LS3 will cover LS4
Information about final report

• „We are now putting the last details into the final report. We are still keeping the proposal that was presented earlier, but with some more clarifications. On the request from the Commission we have also added an Option in the report to use the DIN and BS standards as they are, but with optional measurements on falling off and detailing around openings.”

Lars Boström (Lars.bostrom@ri.se), 7th March 2018