Experimental Research on the Behaviour of the Systems for Ventilated Facades, Exposed to the Fire Action

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Abstract. When establishing the constructive structures that must reach the required levels of fire performance, one must start from the fact that the fire is an accident. The structures must remain viable for the normal fire time considered. The behaviour of the construction to the fire is dependent, besides other factors, on the contribution to the fire of the elements and parts of the construction, of the materials and products for the construction, as well as on the fire resistance of some of them. Due to the fact that the initiation and evolution of the fires is different, it was imposed that the determination of the fire behaviour of the constructions and the materials that enter their composition should be done under specified conditions, by exposing them to a specified ignition source, in a good context.

1. Introduction
The requirement of the built space regarding the "Fire safety" of the constructions requires, in order to be satisfied, that they should be designed and executed so that, in the case of a fire, the following objectives are ensured:
- maintaining the carrying capacity of the construction for a certain period of time;
- limiting the production and propagation of fire and smoke inside the construction;
- limiting the spread of fire to the neighboring constructions;
- intervention for evacuation, respectively rescue of the people caught inside the construction;
- security of the intervention teams.

Meeting the criteria and levels of performance regarding the "fire safety" requirement must be ensured by a set of interdependent measures, regarding the conditions of placement, configuration and fire conformation of the constructions, the performance conditions for the structures, for products, utilities and installations, including for fire safety installations. These measures are subject to specific technical regulations regarding the location, design, execution and operation of constructions, developed under the authority of the line ministries.

Construction products represent, through their fire performance, one of the determining factors for:
- assessing the development of a fire in a room, including the emission of smoke, the spread of fire and smoke in the building and in the neighboring buildings [6];
- evaluating the fire performance of the construction and establishing the design rules for the different parts of it, relevant for the fire safety.

The general purpose of fire safety legislation [1] is to provide fire safety. To achieve this goal, the requirements for structures (load bearing capacity), building materials (fire prevention and limitation of fire propagation, limitation of fire size), modalities of evacuation the buildings (including the prevention of fire propagation to other neighboring buildings) are established to define how they should be designed and executed according to their purpose. The structural design rules, including those regarding fire, are laid down by Eurocodes, in force in the territory of the EU member countries. The aim of the Eurocode program initiated by the European Commission is to establish a harmonized set of technical rules for the design of constructions and for civil engineering works. These rules initially served as an alternative to the national provisions of EU member countries, replacing them later (SR EN 1991-1-2: 2004/AC:2009). The European classification system does not include requirements for the toxicity of the resulting combustion products. The toxicity of the combustion products and the environmental aspects of the industrial products are of increasing interest. Also, an increasing importance is given to the type and concentrations of the products resulting from the burning of construction materials. These aspects must also be subject to legislative action. The spread of flame on the surface of a solid body and the existence of combustible materials are important factors in the issue of fire safety because it influences the initial development of fire and the rate of heat emission. In an enclosure fire, the first object that ignites is usually singular. If it is located near a wall covered with combustible material, the wall cladding can ignite and maintain fire. In this case, the vertical flame spread is significant and rapid, especially in the presence of air in the case of a ventilated façade [4]. The propagation and growth of the fire were extensively studied during the years 1980-1990 [2]. For example, the research program EUREFIC (European Reaction to Fire Classification) provided valuable information on the evaluation of surface coatings. Within this program, large-scale tests were carried out by three laboratories: MTB-Finland, NBL-Norway and SP-Sweden [7] in order to collect data for the development of a prediction model for fire growth in fire propagation tests in the test rooms (ISO/DIS 9705) based on the results of calorimetry tests (ISO/DIS 5660). The patterns of fire propagation and fire growth vary in complexity, from simple empirical correlations to approaches that solve the conservation equations of gas and solid phase integrated into numerical models [5].

2. Experimental procedures
Researchers from the INCERC Fire Safety Research and Testing Laboratory conducted several experimental tests to assess structural behaviour of buildings with ventilated façades exposed to the action of fire (Figure 1). Specifically, it refers to an approach in designing and evaluating the structural components of buildings with ventilated façades, which are efficient in their fire performance.

Researchers found important to understand what performance criteria is chosen when selecting a particular material or method [3], including exposure to fire, duration, aesthetics, cost and maintenance. The application of protective and insulating materials is one of the most common means of protection of structural metallic elements in fire. The purpose of the data collection is to evaluate the position of all metallic structural elements in relation to the position of the exterior facade of the brick and to promote the construction materials that are effective in both a fire and have good thermophysical and hydrothermal properties. The parameters evaluated in the fire test were:

- The effective bending resistance of steel exposed to high temperature;
- Tilt of the linear elastic zone of the steel exposed to high temperature;
- The factor of reducing the effective flow resistance of steel exposed to high temperature;
- Reduction factor for the effective slope of the linear elastic range of steel exposed to high temperature;
- Structural temperature of steel.
Temperature variations in materials lead to changes in their properties and to changes in structural strength characteristics, a fact that becomes evident when the temperature rises significantly. The unique possibility of obtaining a passive control of the resistance of the steel section during the fire, is its protection against fire by a properly chosen specific insulating materials. In addition, the passive protection of the system is taken into consideration when designing the cover and must be properly maintained in operation. The sustainability indicators of a metal structure exposed to fire can be grouped as follows: the first indicator indicates the safety and strength of the structure, the other refers to the impact on society and at last, the passive design of a protection against fires and the environment, including the life cycle aspects of the materials used. This is an assessment that leads to limiting the costs of protection that would be disproportionately large compared to the costs of the structure itself. In the Eurocode, fire resistance is the capacity of a structure to perform its function required for a certain fire exposure and a period of time. For a certain load level, the temperature at which a failure of a structural steel element is expected is characterized by a critical temperature where an effective flow force is large enough to generate plastic stresses, according to Eurocode 3.1. The first limit of temperature is 1400 °C, where both structural safety and damage limitation resistance are taken into account; the second is 2600 °C, where, result that structural failure and collapse are inevitable. An image that shows structural damage during the experimental test is shown in Figure 2.

Figure 1. Ventilated facade system before fire resistance testing.

Figure 2. Fire affecting the ventilated façade system. Breaking the windows under the action of the compartment fire and propagation the fire outside from compartment and on the façade.
At this point the temperature of steel was higher than 700 °C and the bending of the steel structure can be seen.

3. Results and discussions
The mechanisms of flame propagation on the vertical surface of the facades depend on many factors, of which the most important are:
- the presence of combustible materials;
- the existence of cavities as part of the exterior plating system or as defects / local degradation of the products used in plating.

Under the conditions of a facade fire, the flames can extend five to ten times higher than the initial height of the flame, regardless of the nature of the materials from which the facade system is made.

A real fire produced in a room grows, evolves and extinguishes in direct correlation with the mass and energy balance in the compartment in which it is produced. The energy developed depends on the type and quantity of available fuel and the ventilation conditions. In the pre-flashover phase the room temperature is reduced and the fire is still local (minimal). This period is usually particularly important for fire escape and fighting. It usually does not produce effects on structures. If the fire evolves towards stage 3 (generalized fire), the structure of the ventilated façade is affected. Following the largescale tests, during fire reaction tests carried out by the INCERC laboratory for applied research and construction tests, similar results were obtained.

The materials tested by our laboratory are presented in table 1 and figure 3 and for them, the maximum heat release rate (HRR) and total heat dissipated was found.

Table 1. Index of materials

| Acronym   | Description                              | Maximum HRR (kW/m²) | Total heat (kW) |
|-----------|------------------------------------------|---------------------|-----------------|
| ACM_PE1   | Higher density Polyethylene              | 1364                | 106             |
| ACM_PE2   | Lower density Polyethylene               | 1123                | 107             |
| ACM_FR1   | Polyethylene with mineral filling (medium size) | 123                 | 62              |
| ACM_FR2   | Polyethylene with mineral filling (maximum size) | 195                 | 71              |
| ACM_FR3   | Polyethylene with mineral filling (minimum size) | 144                 | 66              |
| ACM_NC1   | Polyethylene with aluminum               | 14                  | 3               |
| ACM_NC2   | Polyethylene with corrugated aluminum    | 30                  | 1               |
| HPL_PF    | High pressure laminate                   | 530                 | 172             |
| HPL_FR    | High pressure laminate with mineral filling | 263                | 67              |
| MWB_1     | Mineral wood board (low density)         | 150                 | 38              |
| MWB_2     | Mineral wood board (high density)        | 194                 | 28              |
| PF1       | Phenolic foam (medium density)           | 64                  | 19              |
| PF2       | Phenolic foam (low density)              | 62                  | 18              |
| PF3       | Phenolic foam (high density)             | 65                  | 20              |
| PIR1      | Polysiocyanurate (high density)          | 116                 | 16              |
| PIR2      | Polysiocyanurate (medium density)        | 107                 | 14              |
| PIR3      | Polysiocyanurate (low density)           | 104                 | 13              |
| SW        | Stone wool                               | 6                   | 0,07            |
| GW        | Glass wool                               | 9                   | 0,8             |

The materials chosen are similar to the materials used in the study of the fire at the Greenfell tower (only the density could not be correlated exactly) because it was desired to make a comparison between
the results. They also cover the largest range of construction products commonly used in ventilated façade systems. Special materials and nano-materials have not been studied because they represent emerging technologies with a very small percentage of the total materials used in construction in 2019. If we compare same products of the generic type (like the ACM_FR, or PIR), there is a small difference in combustion and combustion behavior for the respective product type, as well as for insulation materials, in smoke toxicity. The HPL_PF is identified as problematic during the tests. The combustion behavior under laboratory conditions for PIR and PF the more resistant character of PIR material (which has a higher initial peak followed by a lower HRR) compared to PF material (with a lower peak HRR, but with higher constant HRR). This difference is also found in toxicity tests. No heat release from mineral wool and glass wool is to be expected, but it is crucial to also demonstrate the existence of non-flammable alternative insulating materials (Figure 3).

![Fire reaction parameters of materials tested.](image)

Smoke toxicity data showed a higher growth factor for PIR materials compared to the PF materials. The non-combustible GW and SW products indicate a smoke toxicity much lower than PIR product.

The graphic shown in figure 3 that show the total heat release and the peak of HRR show large differences in the fire behavior of the materials and highlight the most dangerous combinations of materials used in building the facades. Preventing the spread of fire on the ventilated façade must be done along the length of the construction, not just the vertical it, regardless of the fire stability level / degree fire resistance insured. Thus, every 20 linear meters of the façade, or dilatation, coughing or anti-seismic, which occurs first will provide fire resistant barriers E30. In the situation where a façade it has a length of less than 40 m and more than 20 m, then the barrier fire resistant will be mounted at half distance. Ventilated facades adjacent to the escape routes used in the case fire will be made of non-combustible materials, according to the provisions of the specific technical regulations regarding security at fire. This determines adjacent means at distances less than 3.00 m in front of the exterior staircase. Preventing the spread of fire on the ventilated facade can be integrated into the architectural achievement.

In the situation of the facades ventilated with glass windows, the following protection of the facades must be achieved:
- through the protection and finishing component / the finishing material the façade system;
- through the rhythmic interruption of the vertical void inside the façade system;
- by the thermal insulation component / the thermal insulation material;
- by protecting the contour of the glazed or unprotected hollow;
- by parapets with a height of at least 1.20 m, fireproof E30 near floors or screens with a height of at least 0.50 m, fireproof E30.

4. Conclusions
Architectural features of ventilated facades are proposed for environmentally friendly or sustainable buildings. In such cases there are potential risks of rapid spread of fire through the cavity the facade due to the "horn effect" and such design normally does not can be accepted if all the measures are not fully respected fire protection. Currently, buildings with ventilated facades are not on fully covered by the legal regulations in the field of construction, especially when the combination of normal ventilation is desired building with ventilation in front due to the advantage of the exchange of the heat. Scenario for the capture and spread of smoke and heat in the cavity of the facade is identified as quite dangerous and should be better understood. Studying the spread of fire is a necessity, considering the fire as a complex action on the constructions and the effects it produces. Therefore, the experimental determinations were made within the Laboratory, with the purpose of determining the optimal test parameters, the optimal mounting positions of the temperature sensors and the other measuring and control devices, as well as the flame propagation mechanisms on the glass front, under natural ventilation conditions. The fire measures have proved successful in the case of buildings completely protected by sprinkler systems or those where the space between the curtain wall and the floor was properly sealed by the perimeter barrier. These seem to be the conditions under which architects can put their innovative design ideas into practice. The results of the tests that show the heat release and the emission of toxic gases show that the polyisocyanurate and the mineral insulation behave in a similar way during the fire, which can be summarized that insulation products do not constitute a fire safety hazard. The tests done in the laboratory show that using the fire reaction only, we can estimate the fire safety of a building façade by testing the materials and the combination of the materials that form it. Real scale test for the ventilated facades got similar results as those predicted by the fire reaction tests. This lowers the cost to improve the fire safety in building by conducting smaller and efficient test. However, in order for the results to be accurate, specialist in the fire safety with experience must determine the dangerous combinations between different materials and create a new methodology that must be approved by local legislation. This will drastically improve the fire safety of ventilated facades which right now represent an uncontrolled fire hazard that can be dangerous in certain conditions. This is mainly because in a high building with a ventilated façade there is a danger that smoke and hot gases from a space set on fire to spread through the existing gaps in the facade and to can accumulate and spread horizontally or vertically in other spaces they have openings related to the intermediate space between the facades for the purpose of natural ventilation. Fire behaviour conditions and security measures, materials and equipment used in the design and construction ventilated façade systems are to be determined very accurate and presented in the technical documentation by the specialized fire designers.

The fire resistance can be ensured by the solid support, concrete type reinforced or masonry. In the case of light walls, multilayer fire resistance will be found by testing the particular type of wall together with the façade ventilated. Continuity of the fuel components of the facades ventilated should stop at least next to the joints clamping, expansion or seismic constructions, through systems with non-combustible products of at least 1 m wide, limiting the fire propagation. Permanent consideration must be given to setting the risks in a high-rise building, such as the design and implementation of automatic fire extinguishing systems, the fire department's response capacity, the occupancy of the building and the associated loading, the concept of evacuation, compartmentalization, and not in lastly, the scenarios for evaluating security threats.

5. References
[1] BS 8414-1 2002 Fire performance of external cladding systems applied to the face of the building
BSI 4-6 (London: British Standards Institution)
[2] ISO 13785-1 2002 Reaction-to-fire tests for façades. Part 1: Intermediate-scale test, Part 2: Large-scale test (London: British Standards Institution)

[3] Klopovic S and Turan O F 2001 Fire Safety Journal 36(2) 99-133

[4] Klopovic S and Turan O F 2001 Fire Safety Journal 36(2) 135-172

[5] Simion A and Dragne H 2017 IOP Conference Series: Materials Science and Engineering 209 012102

[6] Suzuki T, Sekizawa A, Yamada T, Yanai E, Satoh H, Kurioka H, Kimura Y 2000 Proceedings of the Fourth Asia-Oceania Symposium of Fire Science and Technology, Tokyo, Japan 363-373

[7] Swedish National Testing and Research Institute 1994 SP FIRE 105. External wall assemblies and façade claddings – reaction to fire 5