SUSTAINABLE FIRE SAFETY DESIGN FOR BUILDING FRONTAGES

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ABSTRACT
Within the last decade, in Romania, hundreds of buildings, mainly blocks of flats, were insulated with expanded polystyrene. Being a combustible material, expanded polystyrene (EPS) can be considered a hazardous material related to fire safety concern when is used as a cladding system at the exterior face of a wall. The national General Regulations concerning the buildings fire safety recommend that the combustible cladding systems for frontages to be interrupted by non combustible strips, to prevent the upward fire spread to the next floors. The norm doesn’t give any requirements or specification about the materials to be used, the dimensions or the positions for the non combustible strips, therefore this provision is often disregarded or improperly set up.

In the article is proposed a calculation method based on numerical simulations for the estimation of the minimum height for the horizontal stripes of mineral wool, build-up over the window openings.

Keywords: expanded polystyrene, mineral wool, fire behaviour, numerical simulation, performance based design

INTRODUCTION
In the context of the harmonized European technical regulations for building design, in Romania were enacted the Eurocodes in order to comply with the new requirements and performance based criteria. The regulation process is developing slowly, for some domains like fire safety engineering, hindered by the lack of specialists.

Due to the huge amount of energy loss in the constructions sector, it was initiated a national program for the thermal rehabilitation of civilian buildings. The storeyed blocks of dwellings took priority over the other structures and within over ten years the expanded polystyrene (EPS) was the prevalent solution for thermal insulation. Although it has good thermal insulation properties, low weight and economicity, EPS, also has some drawbacks concerning the fire behaviour and ignitability, being a combustible material. In accord with the General Norms for Fire Safety, Article 52 [1], in case of using combustible cladding systems for building frontages, these would have to be interrupted by non combustible strips. The mineral wool is the most appropriate material for this purpose, since it is a non combustible material and a good thermal insulator.

Based on the fire reaction tests carried out on cladding systems made with polystyrene (EPS) and with mineral wool, the aim of this research was to determine by numerical simulations, the optimal, satisfactory height of the non combustible strips.

MATERIALS AND METHODS
During this work research were carried out two series of fire reaction tests: The Ignitability, according SR EN ISO 11925-2 [2] and Single Burning Item-SBI, according SR EN 13823 [3] on four cladding systems produced by Saint-Gobain Weber Romania s.r.l., having the following commercial designation and characteristics:

- Therm Weber Family – M1- expanded polystyrene with special adhesive and acrylic plaster;
- Therm Weber Family – M2- expanded polystyrene and acrylic plaster;
- Weber Therm Prestige – M3- mineral wool and silicate plaster [4];
- Therm Weber Family – M4- expanded polystyrene with special adhesive and silicate plaster.
The test results from FBI test were modeled with the software Fire Dynamic Simulator, version 5 (FDS 5), which is a free open source computational fluid dynamics model for low speed thermally driven flow. Smokeview is a visualization program used to display the output of FDS [5].

The study case analyzed in this article for upward flame spread on the facades of residential buildings is a block of flats, type T 770 having P+4E.

1. Polystyrene versus mineral wool based cladding systems

The ignitability and the burning properties of the materials used for the exterior wall cladding system have an important role in the fire behaviour of a building frontage. The shape of the fire plume outside a ventilated fire compartment and the upward flame spread is influenced by the total heat flux emerging from the window openings, the thermal properties of the cladding system as thermal inertia and ignition temperature and the environmental conditions like external temperature, wind speed rate and pressure [6].

Expanded polystyrene (EPS) is a suitable material for the thermal insulation of the exterior walls, having the thermal conductivity around 0.036 [W/m·K]. It is easy to carry off and it does not increase much the dead load of a frontage due to its low density ranging between 16 and 640 [kg/m³]. The cladding systems based on expanded polystyrene are inexpensively compared with other materials like mineral wool, slag wadding or fiber glass, therefore the thermal insulation with EPS gained the top of popularity in Romania. Although it has multiple advantages, one of the major drawbacks of expanded polystyrene is its fire behaviour. Under the fire action polystyrene is highly flammable and while burning it produces carbon dioxide and toxic products as polycyclic aromatic hydrocarbons [6] and chlorine. The use of polystyrene for exterior cladding was restricted in many countries like United Kindom, Germany or Canada, being considered a fire hazard. In many cases the coarse execution or the use of low class materials lead to the failing of the plaster which protects the insulating material, as it can be seen in the Figure 1, below.

![Fig.1. Flawed plaster of a cladding system with expanded polystyrene](image)

In order to decrease the fire hazard for the exterior cladding systems the design norms recommend the use of non combustible materials. Mineral wool has the highest fire reaction class, namely, A1 and good thermal properties, which make it suitable in case of thermal insulation and fire protection systems for buildings.

2. Fire reaction tests

In order to analyze and compare the fire behavior of thermal systems, two series of fire reaction tests were carried out on three cladding systems based on expanded polystyrene, respectively M1, M2 and M4 and one cladding system based on mineral wool, foregoing denoted...
M3. All test samples had the same thickness of insulation, both polystyrene and mineral wool, of 10 cm.

2.1. Ignitability. The first series, Ignitability, according SR EN ISO 11925-2 [2] estimates whether the product sample inflames under the exposure of small flame, for 30 seconds. As it can be seen in the Figure 2, the pictures took after the test indicate a good fire behavior for both kind of cladding systems. The acrylic plaster, either silicate plaster didn’t set on fire.

![Fig.2. Test samples after the Ignitability fire reaction test](source: pictures from the Fire Reaction Test Results from National Fire Test Laboratory, Bucharest)

2.2. Single Burning Item (SBI). The Single Burning Item (SBI), according SR EN 13823 [3] is a fire reaction test which simulates a natural scale object burning in a corner of 3m x 3m x 3m room. The reaction of the samples to a burner located inside the room is monitored instrumentally and visually. In Figure 3 it is shown the SBI test for a system based on expanded polystyrene.

![Fig.3. Single Burning Item (SBI) fire reaction test](source: pictures from the Fire Reaction Test Results from National Fire Test Laboratory, Bucharest)

1. Numerical simulations using FDS 5

The numerical simulation integrates the test result data from Single Burning Item fire reaction test approaching a combination between the fire model based on nominal temperature-time curves and computer models based on fluid dynamics (CFD) in order to study of the fire phenomena occurring during the fully developed stage of an enclosure fire. This method is appropriate for current design cases, when no reliable data are available about the chemical composition and the real distribution of the fire load inside a fire compartment. For the current study research, it was modeled a bedroom from a flat, situated at the first etage of a four storey block, type T 770. The
thermal load was estimated as the quantity of heat release rate while burning the furniture and fabric materials, based on other studies available in the fire safety literature.[9], [10] Thus, the maximum heat release rate (HRR) for the fully developed fire was calculated according the Annex E of Eurocode 1991-1-2 [8], using the following formula:

\[ Q = HRR_f \cdot A_f \]  

(1)

where: \( HRR_f = 250 \text{ [KW/m}^2\text{]} \) for dwellings, according Table E.5 [8], and \( A_f \) represent the floor area of the fire compartment, which is 11.22 m\(^2\) for this study case, having the size dimensions shown in Figure 4, below.

![Fig.4. The fire compartment floor as it was modeled in FDS](image)

a. The fire compartment where the ignition started, b. The upper floor of the fire compartment

The calculation domain for the numerical simulation was a cuboid, having 5.40 m x 4.00 m x 5.40 m, divided by FDS in 116 640 unit volumes. The initial state condition were the ambient temperature and pressure and the total simulation time was set at 900 seconds. For each time step it was measured the external temperature and the heat loss in 12 points on the frontage, with 12 termocouples and it was calculated the profile of the temperature variation in front of the spandrel between the first and second floor of the building. The frontage was insulated with the system M4, based on expanded polystyrene, using the fire reaction tests data. It was analised the plan temperature field, crossing the center of the window opening.

RESULTS AND DISCUSSIONS

Even though the four insulation systems were classified in the same fire reaction class, B s1 d0, the fire behaviour of the system with mineral wool is much better. The smoke production rate and the fire spread rate are centralized in the graphs below, for the analyzed insulation systems and it can be seen that the mineral wool based system, namely M3 had the slowlier rates for both parameters in discussion.
Mineral wool is a very suitable material for the thermal insulation of the building frontages, increasing the fire performance. It can be applied for any kind of structure: masonry, concrete or wood and it does not affect the architecture of the frontage. Another noticeable feature of mineral wool insulation, compared with polystyrene is that the former can be also used in case of curved frontages, while the latter is only possible to use on straight surfaces. Even though it has many advantages, mineral wool is not very popular in Romania due to its cost. To increase the sustainability of the building frontages and in order to comply with the General Norms for Fire Safety, it should be adopted a mixed solution for thermal insulation, with expanded polystyrene and mineral wool, as it is shown in Figure 6.b.

The efficient height of the non combustible strips can be determined for different building types depending of the destinations, the dimensions of the fire compartment and opening factors, considering several fire scenario. In this article it is analyzed for the wide spread block, type T770 having P+4E. Providing non combustible strips over the window openings increases the general fire behaviour of a building and prevents the upward fire spread on the exterior cladding.

CONCLUSIONS
The numerical simulations performed with Fire Dynamic Simulator, version 5, for residential buildings, revealed that the fire plume emerging from a window opening of 1,80 m width and 2,10 m height, is about 2,5...2,8 m long and it does not attach to the spandrel above.
In order to improve the passive fire protection of a frontage insulated with expanded polystyrene based cladding system and to comply with General Norms for Fire Safety, it is proposed a solution of a mixed cladding, by providing non combustible strips made with mineral wool on the spandrel between two adjacent floors of the building. The strips must be continuous on the frontage and their height has to be at least 80 cm, to be effective.

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REFERENCES