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The Effect of Radiant Heat on Polystyrene Thermal Insulation Materials

As a result of the increasingly stringent energy requirements of recent years, the issue of façade thermal insulation is gaining more and more prominence. Due to these requirements, layer thickness of insulation increases, or the use of materials with a better coefficient of thermal conductivity is preferred. These requirements are met by polystyrene insulation materials. Therefore, it is extremely important to know as much as possible the behaviour of polystyrene thermal insulation under the influence of fire and radiant heat. Its regulation is not coordinated in Europe, and the effect of radiant heat is not addressed by any country's standard. In this paper, the behaviour of polystyrene thermal insulations, which are densely used in Hungary is examined, under the influence of radiant heat.

Keywords: *façade fire spread, radiant heat, polystyrene thermal insulation, façade thermal insulation, fire safety*

Introduction

Nowadays, still relatively few people are engaged in fire protection of façades and research on the possible spread of fire. When some major fire happens, fire protection becomes a central theme for a while, and then over time it is again forgotten. Fires inside buildings affects directly or indirectly building structures, installed thermal insulation and other materials during its spread. Thus, the fire safety examination of the behaviour of the applied building materials under the influence of the heat load generated during combustion has become a particularly important and topical issue.[2] In the aspect of human life protection, residential buildings pose the greatest risk, since human habitation is permanent there – statistics show that the rate of burns and suffocatings caused by flames cannot be permanently reduced to less than 5% of the number of accidents at home.[3] In addition, the escape capacity of the occupants can

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[2] Bozsaky 2019: 107–116.
[3] László 2019: 155–164.

be very diverse, and there is usually no built-in fire alarm or fire extinguishing system.[4] Thus, during a fire, the flames can quickly reach the façade and endangering the inhabitants of the other floors. In the case of apartment fires, the second most common form of fire spread – after horizontal spread inside the dwelling – is façade fire spread.[5] In case of residential buildings, the most commonly used insulating materials – due to their more favourable price and good coefficient of thermal conductivity – are various polystyrene ones. Surveys also confirm this fact.[6] Furthermore, the emphasis of polystyrene insulation is increasing by the energy requirements in Europe in recent years.[7] As a result of the regulations, either a thicker insulating layer is applied to new buildings or a thermal insulation material with a better coefficient of thermal conductivity (λ) must be used. For the time being, these requirements can only be met by combustible insulation materials.

A large-scale examination of a thermal insulation façade system abroad revealed that polystyrene thermal insulation[8] behaves extremely poorly under the influence of fire.[9] Studies and simulations have already been carried out to investigate the spread of fire on the façade depending on placement of doors and windows – placed in the plane of wall, or in the plane of insulation –, the effectiveness of the application of rock wool above or between doors and windows, and the effectiveness of test methods used in Europe.[10] Some literature deals specifically with polystyrene thermal insulation and the evaluation of their test methods.[11] The behaviour of combustible slab insulation in the event of fire has also been investigated.[12] However, few people have addressed and there is no standard for what happens with polystyrene insulation under the influence of radiant heat. It is possible that even if a fire in a neighbouring building or near the building does not spread to it, it can be seriously affected even under the plaster due to the heat load generated by the combustion.

The purpose of this paper is to study the behaviour of various polystyrenes. EPS with graphite additive and XPS polystyrene is investigated under the influence of direct radiant heat. Laboratory testing of the above-mentioned materials is presented.

Requirements for façade fire spread

The rate of energy efficiency of buildings is regulated and prescribed by the European Union. Energy efficiency can be achieved by reducing energy demand. The first step of it is to create the correct thermal envelope of buildings i.e. proper thermal insulation.[13] Thus, the issue of

4 Kuti–Zólyomi 2023: 67–76.
5 Kuti et al. 2018: 16–21.
6 Ragács–Elek 2018: 56–70.
7 Directive 2010/31/EU.
8 Bjegović et al. 2016: 357–369.
9 Wi et al. 2022.
10 Anderson et al. 2021: 598–608; Tóth–Pántya 2021: 121–133.
11 Hofmann et al. 2018; Tóth-Pataki 2021.
12 Suh et al. 2019.
13 European Commission 2020; Takács 2013.

façade fire spread has become a controversial topic nowadays. The examinations required to place the building materials used on the market are the same in the EU. However, looking at the regulations on façade fire spread, we can find very different test methods and criteria in different countries.[14] As a first step towards harmonising standards, a study was conducted in 24 European countries, collecting and comparing façade testing methods. In the survey, 14 out of 24 countries make requirements for façade systems and examine features that are not included in the already harmonised EN 13501-1 and 13501-2 standards. The targets of these requirements and tests are shown in Table 1 by the countries they are applied in.

Table 1: Façade fire spread test criteria

Regulated characteristics	SK	HU	CH	SE	AT	DE-DIN	FI	PL	GB, IE	FR	DK, NO
Fire spread – vertical	x	x	x	x	x	x	x	x	x	x	x
Fire spread – horizontal		x	x		x	x			x	x	
Fire spread – internal	x		x	x	x	x	x	x	x	x	x
Façade + slab connection		x		x						x	
Smouldering						x					
Falling pieces		x	x	x	x	x	x	x	x		x
Smoke				x		x					
Heat (temperature or flux)		x		x	x						x
Details (window opening, fire suppression)		x		x						x	x

Source: compiled by the author based on Anderson et al. 2021

It can be seen that quite a few different factors are being examined by different countries, however, the behaviour to radiant heat is not among them. In the following table (Table 2), the names of each standard, the countries in which they are applied, and the main criteria for the standards are collected. It can be observed that neither the size or process of fire, nor the size or design of the object, nor even the test criteria are the same. Thus, the result obtained in one test cannot be compared with another. Practically in the case of a façade system, it is necessary to carry out a test before being placed on the market in each country.

Table 2: Façade fire spread tests in Europe

Standard	BS 8414-1	LEPIR II	MSZ 14800-6	SP FIRE 105	Önorm B 3800-5	DIN E 4102-20	PN-B-02867	ISO 13785-2	ISO 13785-1
Country	UK, IE	FR	EN	NO, DK, SE	AT, CH	DE, CH	PL	SK	CZ
Fire exposure	wood stack, max. heat 3.5 MW, 4500 MJ	600 kg of wood stack	650 kg of wood stack/ 10 kg of diesel	60 l of heptane	25 kg of wood / 320 kW of propane	25 kg of wood / 320 kW of propane	20 kg of wood stack + air flow blowing towards the wall (2m/s)	calibrated, propane	propane 100 kW
Max heat flux on the surface	70 kW/m^2, at an altitu-de of 1m	not deter-mined	not deter-mined	15 or 80 kW/m^2	not deter-mined	70-95 kW/m^2 at 1m height	not deter-mined	55 kW/m^2 at an altitude of 0,6 m	not deter-mined.

[14] Lestyán 2020.

Standard	BS 8414-1	LEPIR II	MSZ 14800-6	SP FIRE 105	Önorm B 3800-5	DIN E 4102-20	PN-B-02867	ISO 13785-2	ISO 13785-1
Country	UK, IE	FR	EN	NO, DK, SE	AT, CH	DE, CH	PL	SK	CZ
Max temperature on the surface	600°C/20 min	average 500°C, peak 800°C	600°C in 0.5 m high / 50 min	450°C / 12 min	not determined	not determined	800°C temperature - maximum	min. 800°C	max 150°C at 0.5 altitude
Test duration	30 min	min. 30 min	45 min	min. 12 min	30 min	21 min gas, 30 min wood	30 min	23-27 min	30 min
Test type	corner, 2.5 x 8.0 + 1.5 x 8.0 m	flat wall 5,0 x 7,4 m	flat wall 6,0 x 7,0 m	flat wall 4,0 x 6,7 m	corner 3x6 + 2x6 m	corner 3 x 5.2 + 2 x 5.2 m	flat wall 2.3 m high	corner 3 x 5.7 + 1.2 x 5.7 m	corner 1.2 x 2.4 + 0.6 x 2.4 m
Base structure	masonry or light frame	not determined	masonry	aerated concrete	aerated concrete	aerated concrete	masonry	not determined	12 mm Ca-Si sheet
Criterion	heat. boundaries	flame on the 2nd floor	temperature rise, spread of fire, falling pieces	flames on 2nd floor, falling pieces	temperature rise, fire spread, falling pieces	temperature rise, fire spread, falling pieces	temperature limits, burning particles	no	no

Source: compiled by the author based on Anderson et al. 2021 & EU Commission 2020

In a word, the energy requirement is becoming more and more stringent in Europe, which means that we have to use ever thicker layer of insulation, however, there is no harmonised standard for façade fire spread testing, so the requirement, test aspects and test process also varies from country to country. Additionally, programs for insulating panel buildings subsequently have also been launched, which in many cases are implemented incorrectly.

Setting up of a laboratory experiment

Examined specimens

First, the specimens had to be prepared. They were cut out with laser cutters from thermal insulation material left on construction site. The specimens had a uniform cross section size of 10 × 10 cm and a length corresponding to different thicknesses. During the test, samples of different thicknesses (80, 100, 120, 140, 150, 160) as well as samples of approximately the same thickness, but from different manufacturers (manufacturer A, C, D) were also examined from both types of thermal insulation (graphite expanded polystyrene foam, GPS; extruded polystyrene foam, XPS). The GPS specimens are shown in Figure 1, while in Figure 2 the XPS specimens can be seen after the test. Samples covered with plaster were also tested (Figure 3). These samples were marked with a "V". The plaster was 3 mm thick and consisted of a reinforcing coat laid in a base coat of mortar, finished with silicone colouring plaster. The marking and characteristics of the specimens are shown in the table below (Table 3).

Table 3: Test specimens (GPS – expanded polystyrene foam with graphite, XPS – extruded polystyrene foam, GPS-V – plastered graphite expanded polystyrene foam, XPS-V – plastered extruded polystyrene foam)

Specimen	Width (mm)	Height (mm)	Thickness (mm)	Weight (g)	Manufacturer /Product
GPS1	100	100	160	25,27	C/2
GPS2	100	100	140	21,89	C/2
GPS3	100	100	100	16,23	C/2
GPS4	100	100	140	21,74	C/3
GPS5	100	100	80	12,52	C/3
GPS6	70	100	100	16,86	A/2
XPS1	100	100	140	46,19	C/4
XPS2	100	100	120	37,87	C/5
XPS3	100	100	100	28,14	C/6
XPS4	100	90	100	28,69	D/1
XPS5	100	90	120	32,62	D/1
XPS6	100	90	150	41,87	D/1
GPS-V1	100	100	140	64,65	C/3V
GPS-V2	100	100	140	61,66	C/2V
XPS-V1	100	100	140	92,41	C/4V
XPS-V2	100	100	120	93,31	C/5V
XPS-V3	100	100	150	107,44	C/6V

Source: compiled by the author

Figure 1: GPS specimens after test – from left to right GPS1-GPS6
Source: compiled by the author

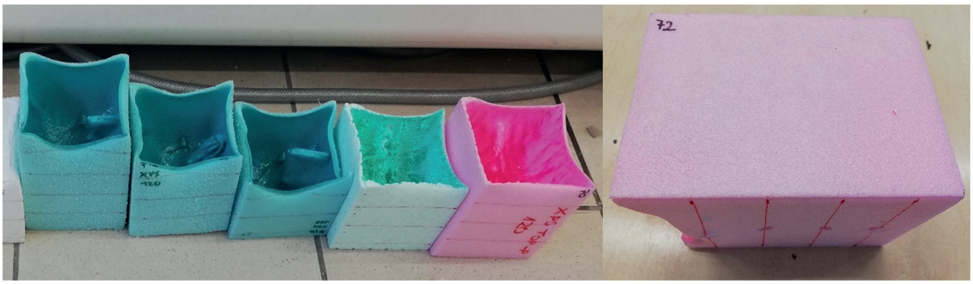


Figure 2: XPS specimens after test – from left to right XPS4-6, XPS3-1
Source: compiled by the author

Figure 3: Plastered specimens after test – from left to right GPS-V1-2, XPS-V1-3
Source: compiled by the author

The placement of thermocouples

The measurements were carried out using a heat source with adjustable temperature (500 °C), the thermal sensing thermocouples placed in front of and inside the test specimen and the connected six-channel data logger. The measurement results were recorded by a computer attached to the data logger. Figure 4 and Figure 5 show the used equipment and the measurement sketch.

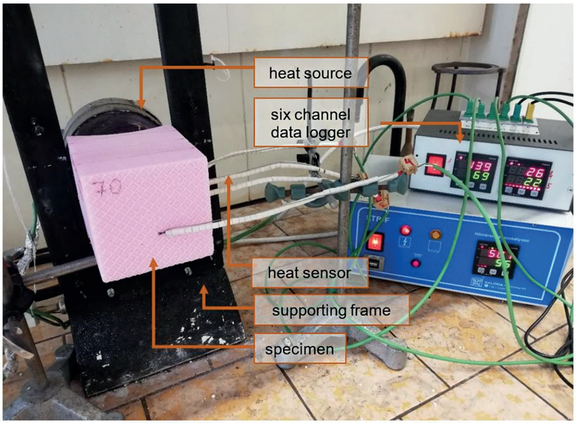


Figure 4: Devices used for the measurement
Source: compiled by the author

In each sample, the thermocouples were placed at a depth of 5 cm from the side at a distance of 3 cm from each other (Figure 5), and then the sample was fixed on the frame. During the measurements, the temperature of the heat source was set to 500 °C, the sample was fixed 5 cm in front of the heat source. The thermal sensor in front of the specimen (mounted on the frame) was located in line with the specimen at 5 cm from the heat source and was set at 100 °C at the start of the experiment. The samples were exposed to radiant heat at 100 °C for 10 minutes and for 16 minutes for the 20 cm thick sample.

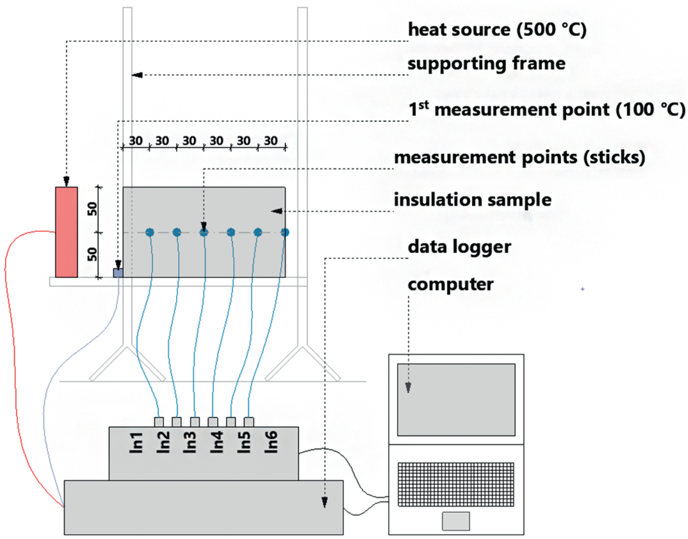


Figure 5: Sketch of the measurement
Source: compiled by the author

Evaluation of the results of a laboratory experiment

General facts

During the measurements heat release was experienced in each sample after approximately 4 and 8 minutes depending on the type of insulation. The temperature at the first thermal sensor placed in the sample (ln1) increased above 110–140 °C. This suggests that exothermic processes begin after a short period of time in polystyrene samples even under the influence of a heat load of 100 °C. In case of GPS, this occurred 6–8 minutes after the start of the experiment and 4–5 minutes in case of XPS.

As for the plastered specimen, the plaster delays the start of the exothermic process by 4–5 minutes. During the measurements, the highest temperature values were measured at the first measuring point i.e. in line with the surface of the sample. The results are summarised in Figure 6. The highest temperature values were measured for XPS specimens, regardless of size. GPS samples produced nearly identical values, except for one or two outliers. However, the outliers belong to the products of another manufacturer, which suggests that the combustion properties of the same type of thermal insulation may also differ from manufacturer to manufacturer. The plaster-coated GPS and XPS samples all produced higher maximum temperatures than the uncovered ones.

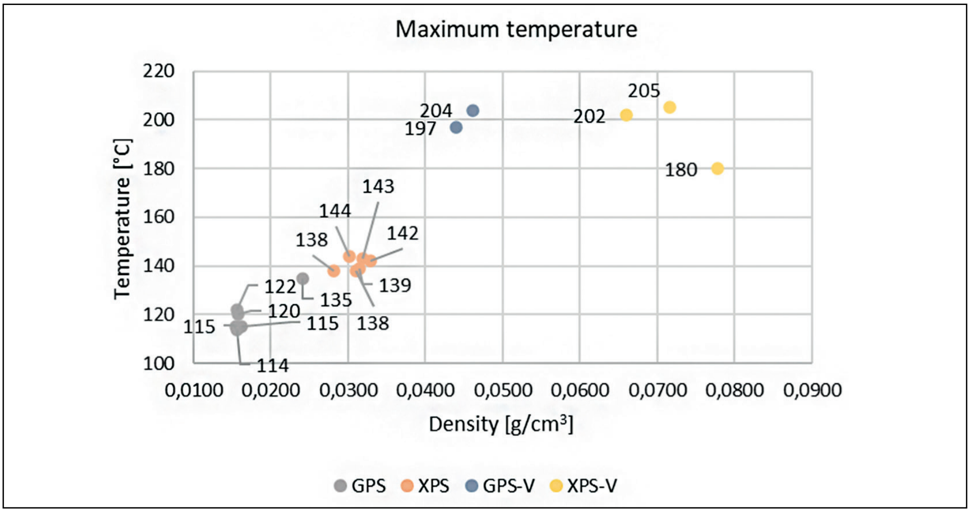


Figure 6: Maximum temperature of specimens
Source: compiled by the author based on measured data

Before and after the measurement, the mass of each sample was weighed to determine the loss of mass (Fig. 7.). Results are similar to the maximum temperatures. The loss of mass of GPS specimens is almost the same, between 0.1–0.25 g. In all XPS specimens a greater loss of mass is observed than the GPS, which is 0.3–0.5 g. But the greatest loss of mass was observed in plastered samples. For plastered GPS samples, this means nearly 0.8 g, while for coated XPS samples, values above 1.0 g were measured.

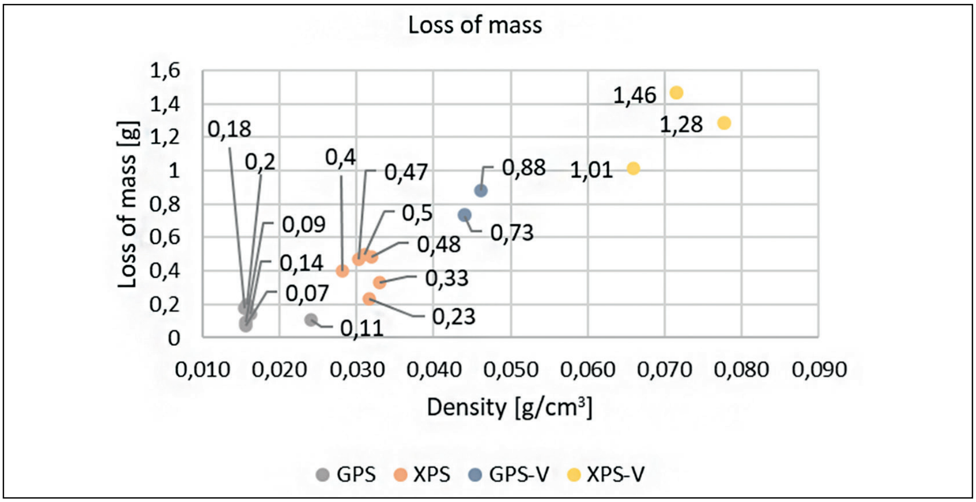
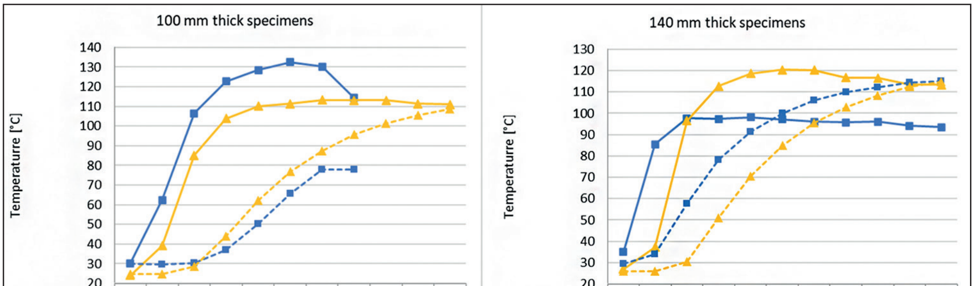


Figure 7: Loss of mass of specimens
Source: compiled by the author based on measured data

Comparison of products from different manufacturers

As it was mentioned before, according to temperature measurements, products from other manufacturers behaved differently during the test. So, the phenomenon for both types of thermal insulation was investigated. In Figures 8 and 9, the temperature-time curves of GPS and XPS façade thermal insulation can be seen measured with sensors located inside the sample at 3 cm (ln1) and 6 cm (ln2) thickness. The colours and the markers symbolise the different manufacturers.



	1	2	3	4	5	6	7	8	9	10	11
GPS6-ln1	30,3	62,4	106,4	122,7	128,5	132,5	130,2	114,3			
GPS3-ln1	24,1	39,1	85,2	103,8	110,1	111,4	113,3	113,1	113,1	111,4	111
GPS6-ln2	30	29,5	30,3	37,1	50,4	65,8	77,9	78			
GPS3-ln2	24,7	24,9	28,5	43,8	62,3	76,9	87,4	95,7	101,4	105,6	108,6

	1	2	3	4	5	6	7	8	9	10	11
GPS4-ln1	35	85,4	97,6	97,3	98,1	97,1	96,1	95,7	96,1	94,2	93,5
GPS2-ln1	26,9	37,2	96,6	112,8	118,6	120,4	120,3	116,7	116,5	113,3	113,3
GPS4-ln2	29,5	34	57,6	78,3	91,2	100,1	106,2	110	112,3	114,3	114,9
GPS2-ln2	25,8	25,8	30,5	51	70,6	84,9	95,4	103	108,4	112,4	114,7

Figure 8: Comparison of the temperature of graphite EPS façade thermal insulation from A/2 (GPS6) and C/2 (GPS3) manufacturers (left) and C/3 (GPS4) and C/2 (GPS2) manufacturers (right) measured with ln1 and ln2 sensors
Source: compiled by the author based on measured data

In the case of GPS (Figure 8), one of the samples was 100 × 100 × 100 mm (GPS3), and the other (GPS6) was 70 × 100 × 100 mm (its cross-section, unfortunately, is different, but its thickness is the same). Although the cross-sectional size of the GPS6 sample was smaller, it apparently caused much greater heat evolution, with a persistent deviation of 20 °C.

Specimens in the right diagram are each 100 × 100 × 140 mm. GPS2 has a manufactured coated surface, designed to slow down the heating of thermal insulation to solar radiation. It also performed this function against radiant heat, as it warmed up more slowly than the uncoated sample. However, beyond one point (probably when the coating has melted off the insulation), it shows a much higher value, differs 20 °C than the uncoated sample, that is stagnant around 98 °C.

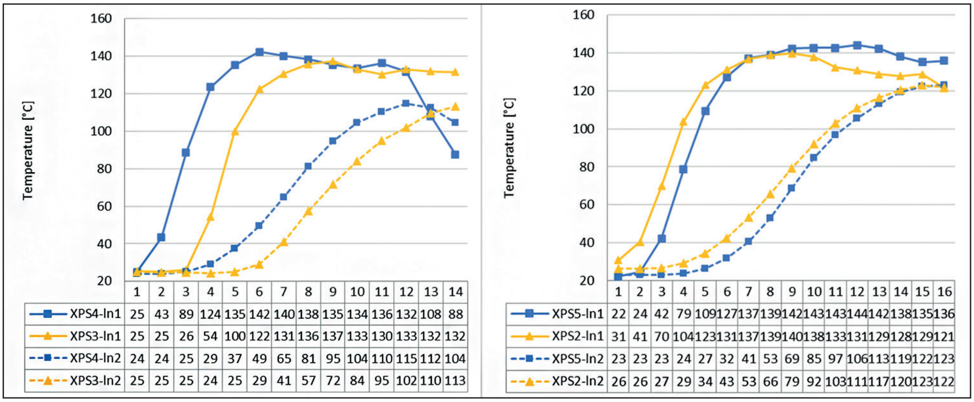


Figure 9: Comparison of the temperature of XPS façade thermal insulation from D/1 (XPS4) and C/6 (XPS3) manufacturers (left) and D/1 (XPS5) and C/5 (XPS2) manufacturers (right) measured with ln1 and ln2 sensors
Source: compiled by the author based on the measured data

A similar phenomenon can be observed in case of XPS (Figure 9), although there are slightly minor differences here. Data from sensors at 3 cm (ln1) and 6 cm (ln2) were examined also here. Specimens in the left diagram have dimensions of 100 × 100 × 100 mm (XPS3) and 100 × 90 × 100 mm (XPS4). In case of the sample with a smaller cross-section (XPS4), faster heat development can be seen, however, the maximum values became almost the same for the two manufacturers. Specimens in the right diagram are 100 × 100 × 120 mm (XPS2) and 100 × 90 × 120 mm (XPS5). Here, interestingly, the smaller cross-section (XPS5) sample warmed up more slowly, but then again achieved similar maximum values with the sample from the other manufacturer. So, in the case of the XPS, the process of warming up and heat development differs rather, the maximum temperature values are about the same.

Considering the experiences of the figures above, it can be clearly stated that the behaviour of thermal insulation under the influence of thermal radiation differ depending on the manufacturer, and consequently so do their combustion properties. This may be one of the reasons why very different values have been reported in literature and publications about the melting point, ignition temperature and heating value of the same type of polystyrene.

Summary

During the laboratory tests, exothermic processes with thermal development were experienced in polystyrene specimens even under the influence of a relatively low (100 °C) radiant heat source, started after different periods of time depending on the type of thermal insulation. Mass loss and deformation was also experienced in the specimens.

The highest heat release, the highest temperature and the greatest loss of mass were measured in XPS thermal insulations. There was no significant difference among the results of graphite EPS. Plaster-coated specimens usually warmed up more slowly, but then reached a higher temperature than uncoated samples. An interesting observation was that there was a difference in the combustion properties of the products depending on the manufacturer for the same type and size of sample. Thus, the behaviour of polystyrene under the influence of thermal radiation depends not only on size, but the type and also the manufacturer.

In order to know this phenomenon more accurately, it is necessary to conduct additional studies. The analysis of the phenomenon of façade fire spread and thus the increase of fire safety in residential buildings is promoted with this research.

References

Anderson, Johan – Boström, Lars – Chiva, Roman – Guillaume, Eric – Colwell, Sarah – Hofmann, Anja – Tóth, Péter (2021): European Approach to Assess the Fire Performance of Façades. *Fire and Materials,* 45(5), 598–608. Online: https://doi.org/10.1002/fam.2878

Bjegović, Dubravka – Pečur, Banjad Ivana – Milovanović, Bojan – Rukavina, Jelčić Marija – Bagarić, Marina (2016): Comparative Full-Scale Fire Performance Testing of ETICS Systems. *Građevinar,* 68(5), 357–369. Online: https://doi.org/10.14256/JCE.1347.2015

Bozsaky, Dávid (2019): Recent Studies on Thermodynamic Processes in Nano-Ceramic Thermal Insulation Coatings. *Pollack Periodica,* 14(1), 107–116. Online: https://doi.org/10.1556/606.2019.14.1.11

Directive 2010/31/EU OF THE European Parliament and of the Council of 19 May 2010 on the energy performance of buildings

European Commission (2020): COM/2010/0639 Communication from the Commission to the European Parliament, the council, the European Economic and Social Committee and the Committee of the Regions Energy 2020, A strategy for competitive, sustainable and secure energy

Hofmann, Anja – Kaudelka, Sven – Hauswaldt, Sebastian (2018): Fire Safety of FACADES with Polystyrene Foam Insulation. *Fire and Materials,* 1–9. Online: https://doi.org/10.1002/fam.2662

Kuti, Rajmund – Zólyomi, Géza (2023): A tűzesetek során képződő füst veszélyei [Hazards of Smoke from Fires]. *Védelem Tudomány,* 3(2), 67–76. Online: https://ojs.mtak.hu/index.php/vedelemtudomany/article/view/13254

Kuti, Rajmund – Zólyomi, Géza – Kegyes-Brassai, Orsolya K. (2018): Assessing the Impact of Positive Pressure Ventilation on the Building Fire – A Case Study. *International Journal of Geomate,* 15(48), 16–21. Online: https://doi.org/10.21660/2018.48.18042

László, Gabriella (2019): Lakófunkciójú épületek általános tűzterhelésének változása Magyarországon [Change in the General Fire Load of Residential Buildings in Hungary]. *Műszaki Katonai Közlöny,* 29(2), 155–164. Online: https://doi.org/10.32562/mkk.2019.2.13

Lestyán, Mária (2020): *Homlokzati tűzterjedési gátak, tűzvédelmi célú sávok tervezési elvei az EU-ban és Magyarországon* [Design principles of façade fire barriers and fire protection lanes in the EU and Hungary]. BM OKF Scientific Council and Defence Disaster Management Review Conference, 02.11.2020.

Ragács, Nikoletta – Elek, Barbara (2018): Hőszigetelő anyagok kiválasztásának szempontjai lakossági felmérés alapján. *Védelem Tudomány,* 3(1), 56–70. Online: https://ojs.mtak.hu/index.php/vedelemtudomany/article/view/13231/10671

Suh, Heong-Won et al. (2019): Fire Spread of Thermal Insulation Materials in the Ceiling of Piloti-Type Structure: Comparison of Numerical Simulation and Experimental Fire Tests Using Small- and Real-Scale Models. *Sustainability,* 11(12), 3389. Online: https://doi.org/10.3390/su11123389

Takács, Lajos Gábor (2013): *Alacsony energiaigényű épületek tűzeseti tapasztalatai* [Fire Experience in Low-Energy Buildings]. BME Épületszerkezettani Tanszék. Online: http://www.vedelem.hu/letoltes/document//9-alacsony-energiaigenyu-epuletek-tuzeseti-tapasztalatai.pdf

Tóth, Péter László – Pántya, Péter (2021): Építészeti tűzvédelem, a nyílászárók és beépítésük hatása homlokzati tűzterjedésre [Architectural Fire Protection, the Effect of Doors and Windows and their Installation on Façade Fire Spread]. *Műszaki Katonai Közlöny,* 31(1), 121–133. Online: https://doi.org/10.32562/mkk.2021.1.9

Tóth-Pataki, Zs. (2021): *Polisztirol alapú homlokzati rétegek viselkedése sugárzó hővel szemben* [Behaviour of Polystyrene-Based Facade Layers against Radiant Heat]. Budapest: Óbuda University Ybl Miklós Faculty of Architecture and Civil Engineering.

Wi, Seunghwan – Yang, Sungwoong – Kim, Young Uk – Kim, Sumin (2022): Toxicity Characteristics and Fire Retardant Performance of Commercially Manufactured Organic Insulation Materials for Building Applications. *Construction and Building Materials,* 341. Online: https://doi.org/10.1016/j.conbuildmat.2022.127898