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The Influence of Polystyrene Thermal Insulation on Fire Load

Today, there are already a huge number of types of polystyrene thermal insulation available with different properties and different behaviour to fire. The literature does not provide clear data and still only one type of polystyrene insulation is listed in the standards. Yet simulation testing of polystyrene insulations and fire spread is not a widespread method. Studies prove that radiant heat causes heat development in polystyrene insulation which can modify the fire load of a building. In this paper, the behaviour of polystyrene thermal insulation, which is densely used in Hungary is examined, under the influence of radiant heat in simulation environment, and its influence on fire load is investigated.

Keywords: *polystyrene thermal insulation, radiant heat, fire safety, simulation, heating value of polystyrene, fire load*

Introduction

Fire safety is still a crucial topic nowadays. As material essentials, intellectual values and most importantly human lives can be at risk or damaged during a fire. Therefore, the fire protection of buildings is still a very important issue. One of the most combustible materials used in buildings is polystyrene thermal insulation. Yet, it is the most widely used due to its price and wide application. Former literature revealed that polystyrene behaves interestingly not only when exposed to fire, but also under influence of thermal radiation.[2] Simulations related to thermal insulation are getting more widespread, although they concern insulation used in ceiling,[3] or in horizontal position.[4] Simulations of facade fire can also be found,[5] but the effect of radiant heat is not investigated yet.

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2 Tóth-Pataki 2021.
3 Heong-won et al. 2019.
4 Prasad et al. 2009.
5 Hofmann et al. 2018.

However, laboratory tests have shown that radiant heat causes heat development in different polystyrene insulations – in expanded polystyrene insulation[6] as well as in extruded and in graphite expanded polystyrene insulation.[7] This can have a serious impact on the fire load calculation, as it can increase the amount of fire load, which e.g. in the case of a warehouse can even be significant.

In addition, for the calculation of fire load, the annex to a legislation based on an earlier standard provides a single calorific value (H_i) for polystyrene, although nowadays there are many[8] types of polystyrene, with different additives and production technology. Hence, their burning properties may differ, not to mention that new materials and innovations – such as organic insulations[9] or recycled plastic and polystyrene insulations[10] – are coming continuously, especially now that environmental protection aspects are being more and more emphasised.[11]

The purpose of this paper is to study the heating value of various polystyrenes. The behaviour of EPS with graphite additive (GPS) and XPS polystyrene is investigated under the influence of direct radiant heat. The simulation reconstruction of a previous laboratory test[12] and the comparison of their results with values calculated according to the legislation are presented.

Simulation reconstruction of a laboratory experiment

In a numerical environment one GPS and XPS sample was tested, from both types a sample with dimensions of 100 × 100 × 140 mm. The simulation test was performed using FDS software. The simulation environment was designed according to the laboratory test.[13] As a source of radiant heat, one of the planes of the model space has been set (yellow surface in Figure 1).

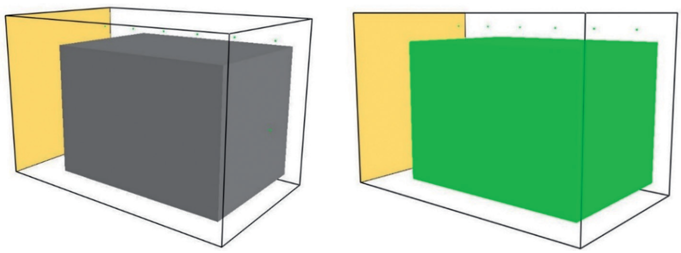

Figure 1: The simulation models – GPS left, XPS right
Source: compiled by the author

[6] Hajdu et al. 2021b.
[7] László 2024.
[8] Government Decree 239/2011 (XI. 18.).
[9] Zhou et al. 2022.
[10] Fard–Alkhansari 2021.
[11] Abu-Jdayil et al. 2019.
[12] László 2024.
[13] László 2024.

The simulation time was 600 s according to the laboratory measurement.[14] The measurement points were also the same as the composition made up in the laboratory (Figure 2): the thermocouples were placed at 3 cm from each other in the samples and a thermal sensor in front of the specimen was located in line with the specimen at 5 cm from the heat source.[15] The mesh size was 5 × 5 × 5 mm (Figure 3), based on literature experiences and previous own experience.[16]

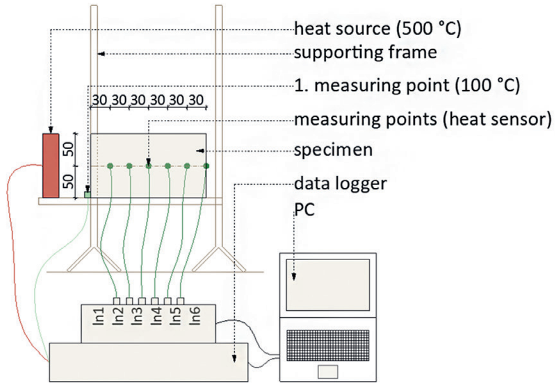

Figure 2: Sketch of the measurement
Source: compiled by the author

In the simulation there are two options for defining fire. One is to give the fire with the value of HRRPUA (heat release rate per unit area).[17] In this case, it is relatively easy to adjust the parameters of the fire and the model can be easily validated with a Cone-calorimeter measurement.[18] The other option is to give the properties of substances, and the source of ignition is a spark.[19] In this case, the spread of fire depends entirely on the properties of combustible materials.[20] The latter method was chosen, so the properties of the materials had to be specified. The following material properties were defined in the simulation: heat of consumption, heat of reaction, conductivity, specific heat, density. Unfortunately, as it was mentioned previously, literature provides different data on the material properties of polystyrene, so the exact adjustment and calibration of the simulation itself is a separate research task and one of my other goals.

14 László 2024.
15 László 2024.
16 Hajdu et al. 2021a.
17 Takács 2013.
18 Ahn–Kim 2011.
19 McGrattan et al. 2019.
20 See: https://fdstutorial.com/your-first-fds-simulation

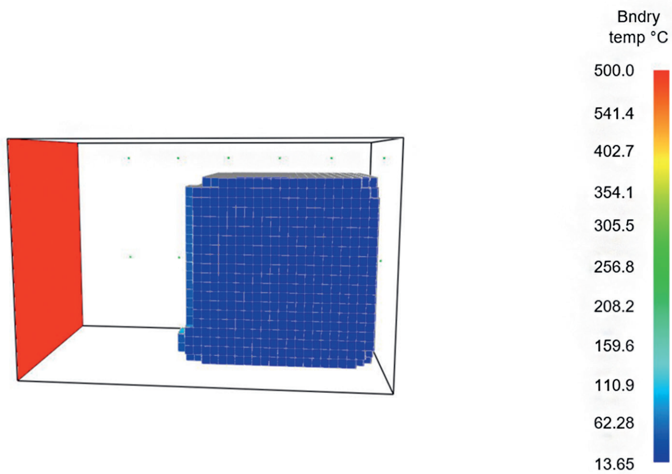

Figure 3: Meshing of the model
Source: compiled by the author

The graph below (Figure 4) shows the simulation results of the GPS sample compared to the temperature values of the laboratory experiment. Based on the results, it can be said that the processes were more even and consistent in the laboratory than it is experienced in the simulation. The maximum values of the temperature in the simulation are lower than in reality. However, the time to reach the maximum value is about the same in In1 sensor.

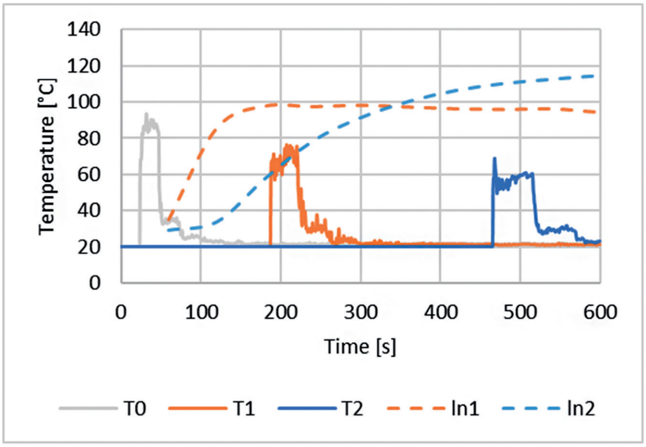

Figure 4: Simulation and laboratory results of the GPS sample
Source: compiled by the author

The following graph (Figure 5) shows a comparison of the XPS sample. The results were similar. Based on them, further refinement of the definition of substances is needed.

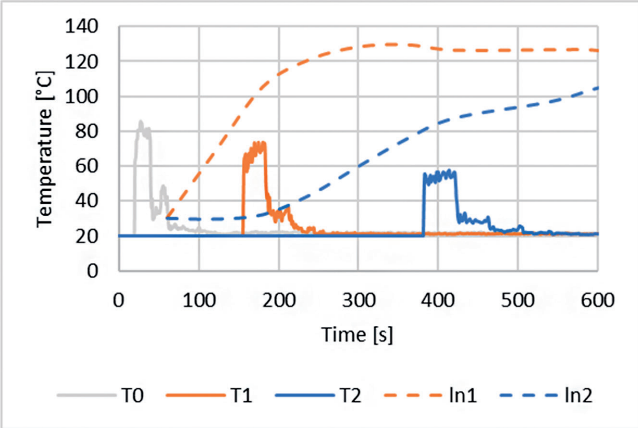

Figure 5: Simulation and laboratory results of the XPS sample
Source: compiled by the author

Comparison of released heat and calorific values

The heating value (H) is an important data in terms of calculating fire load of any facility. This section presents a comparison of the heating value (H) for the GPS and XPS sample with dimensions of 100 × 100 × 140 mm calculated based on literature data, the laboratory and the simulation results.

The parameters of the specimens are in Table 1.

Table 1: Parameters of GPS and XPS sample

	PARAMETERS	
	GSP	XPS
volume [cm³]	1400.00	1400.00
weight [g]	21.74	46.19
density [g/cm³]	0.02	0.03
specific heat (c) [kJ/kg × K]	1.40	1.50
heating value (Hi) [MJ/kg]	40.61	40.61
weight loss in laboratory test [g]	0.18	0.33
temperature change in laboratory (ΔT) [°C]	91.00	119.00
temperature change in simulation (ΔT) [°C]	76.98	65.88

Source: compiled by the author based on Government Decree 239/2011 (XI. 18.) product data sheets, László 2024 and simulation results

In Table 1 the volume, the weight and the density are measured and calculated before the laboratory test. The temperature changes are measured during the laboratory[21] and

21 László 2024.

simulation tests. The specific heat is based on product data sheets, and the heating value is based on literature.[22]

In order to obtain the heating value (H), the released heat (Q) has to be defined first. The amount of heat released (Q) can be calculated based on two different equations:

$$Q = M_i H_i \tag{1}$$

where M_i is the mass of the *i*-th substance [kg], H_i is the heating value of the *i*-th substance [MJ/kg]. This equation gives a theoretical, maximum heat value of the combustion released in clear oxygen during perfect combustion.

$$Q = c \cdot m \cdot \Delta T \tag{2}$$

where c is the specific heat [J/kgK], m is the mass of the substance [kg] and ΔT [°C] is the temperature change. This equation gives a real heat value of the combustion released during incomplete combustion at 21% oxygen.

With these equations, the amount of heat released (Q), the temperature change (ΔT) and the heating value (H) can be calculated based on both the literature data,[23] the laboratory[24] and the simulation results. In the case of the literature, a clear data for heating value (H) is given for polystyrenes, which is 40,61 MJ/kg,[25] as one can see in Table 1 above.

So, in the first step I calculated the amount of heat (Q) using formula (1) based on this H value. In the laboratory tests, the temperature change (ΔT) could be measured. To compare the laboratory experiences with the literature, the temperature change has been calculated with the (2) formula as the next step.

The laboratory calculations are based on the measured temperature change (ΔT). During the examination the whole specimen was not combusted, hence in the calculations, the measured weight loss was used as the weight of the specimen. Firstly, the amount of heat released (Q) has been calculated using formula (2), and then applying formula (1), I obtained the heating value (Hi).

In the simulation the ΔT was measured also, therefore the steps of the calculation was the same as in the case of the laboratory.

It is interesting to compare the amount of heat released based on this value with the simulation, as well as comparing the temperature difference between the laboratory and the simulation results (Figure 6 and Figure 7). It can be seen that the results of the simulation and the lab, although they are different but also, they are close to each other. However, the values calculated according to literature are significantly inferior to those that we have experienced in reality in all respects. Only the amount of heat released (Q) is lower in the lab than according to the literature, but it is so different because the entire mass was not burned

[22] Government Decree 239/2011 (XI. 18.).
[23] Government Decree 239/2011 (XI. 18.).
[24] László 2024.
[25] Government Decree 239/2011 (XI. 18.) Annex 4.

there, so a smaller amount of heat was released by definition. It also must be mentioned that in the laboratory an imperfect combustion was examined, while the literature is based on perfect combustion, this can also lead to a difference. The most important fact, it seems, that the heating value is higher in the reality than according to the literature.

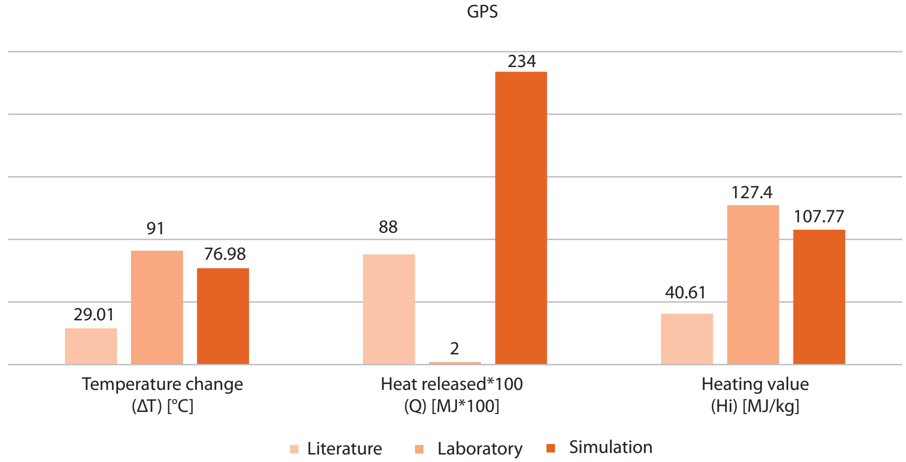

Figure 6: Comparison of GPS sample values
Source: compiled by the author

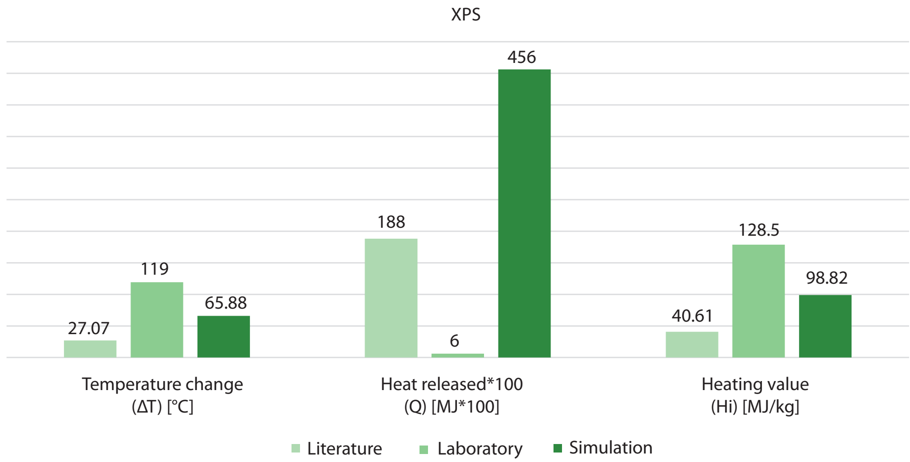

Figure 7: Comparison of XPS sample values
Source: compiled by the author

To make it more realistic what these differences would mean, the fire load of an average warehouse was calculated and examined. The hypothetical warehouse has average size and GPS and XPS thermal insulation is stored in it (Figure 8).

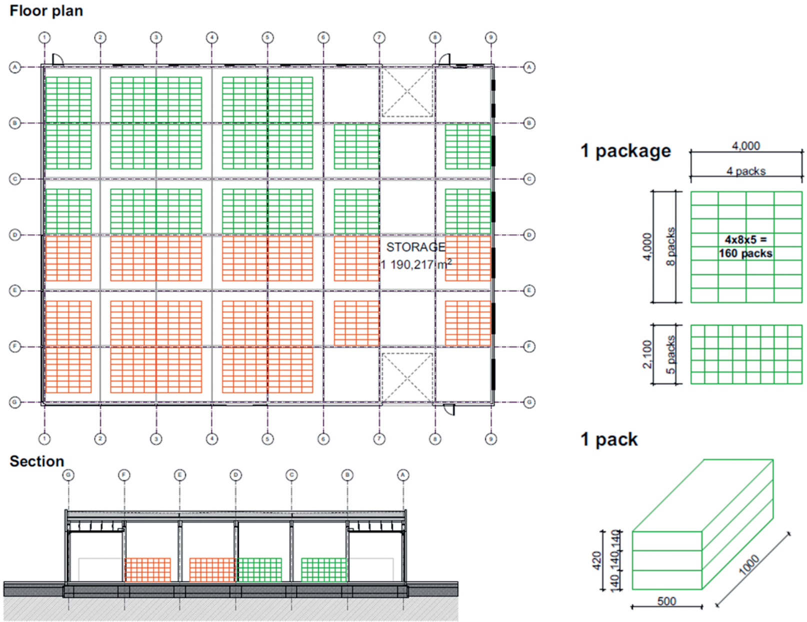

Figure 8: Floor plan (top left), section (bottom left) and storage of thermal insulation boards in packs (bottom right) and packages (top right)
Source: compiled by the author

Thermal insulation is stored as follows: in one pack there are 3 boards, and the packs are arranged in packages of 4 × 8 × 5 pieces. There are 19–19 packages of EPS and XPS.

The fire load of the warehouse can be calculated by the formula:[26]

$$p = \sum_{i=1}^{j} \frac{M_i H_i}{S} \quad (3)$$

where:

p value of the fire load

M_i mass of the *i*-th substance [kg]

H_i the *i*-th amount of heat released during combustion from 1 kg of weight of the material [MJ/kg]

S area of the building / part of the building [m²].

Performing the calculations, it can be seen that the value of the fire load, based on what we experienced in the lab, is almost three times higher than the literature values[27] (Table 2). The fire load values calculated on the basis of simulation and laboratory data converge quite well, but to obtain quite accurate values, further development of the simulation is necessary.

[26] Government Decree 239/2011 (XI. 18.); Kreisz 1987.

[27] Government Decree 239/2011 (XI. 18.).

Table 2: Initial data of the calculation and the fire load of the hall based on literature (blue colour), laboratory tests (orange colour) and simulation (green colour)

	GPS	XPS
Insulation board [pcs]	10,080	10,080
Weight of 1 pc board [kg]	1.09	2.31
Total weight of insulation [kg]	10,987.20	23,284.80
Area [m^2]	1,190.22	1,190.22
Heating value (HL) [MJ/kg]	40.61	40.61
Heating value (HM) [MJ/kg]	127.40	178.50
Heating value (HS) [MJ/kg]	107.77	98.92
Fire load (TL) [MJ/m^2]	374.88	794.47
Fire load (TM) [MJ/m^2]	1,176.06	3,492.07
Fire load (TS) [MJ/m^2]	994.87	1,935.22

Source: compiled by the author

Summary

The results of the reconstruction of laboratory tests in a simulation environment suggest that further studies of the combustion properties of polystyrene are required for the calibration of the simulation. However, the simulation results produced closer values when calculating the heating value or the fire load of a warehouse than the results obtained from the literature data.

Calculations confirm that examining the combustible properties of various polystyrenes is a topical and important issue. In order to know more accurately this phenomenon, it is necessary to conduct additional studies. The analysis of the fire load calculation and increase of fire safety in industrial buildings is promoted with this research.

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