Impact of Grenfell Tower fire disaster on polyisocyanurate industry*)

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DOI: dx.doi.org/10.14314/polimery.2018.10.8

Abstract: The paper summarizes commonly available information on the fire of the Grenfell Tower, which took place in Central London on 14 June 2017. The fire was very similar in its nature to several other spectacular fires at tall buildings, which have happened around the world since 1999 but unlike the previous one, the London fire claimed an enormous number of victims – 71. The tragic outcome of the fire was blamed on a combination of several human and natural factors: faulty evacuation procedures, unsuitable fire extinguishing equipment, mistakes by the housing association managing the building, lacking fire safety provisions in the tower, weather, confusing building regulations, *etc*. However it was established that the main reason for so tragic an outcome of this fire was the speed of fire spread *via* decorative aluminum composite materials (ACM) containing polyethylene (PE), installed on the outer of a building as a part of a rain-screen cladding system. The other part of the system was polyisocyanurate (PIR) thermal insulation. The paper focuses on the role of PIR in this fire and a couple of practices in the PIR industry highlighted by the tragedy. It reflects on the origin of PIR and evolution of PIR technologies as well as PIR definition. Finally it reports on a bottom-up initiative started at the Polyurethanes 2017 Conference aiming at changing current attitude of the European thermal insulation industry to Open Access to reports on fire testing of thermal insulation products. This small but concerted effort of scientific and industrial thermal insulation communities has a good chance of helping to drive further improvement of fire resistance of thermal insulation and to restore public confidence in these important materials.

Keywords: Grenfell Tower fire, skyscraper fire, thermal insulation, polyisocyanurate foams, PIR definition, external thermal insulation claddings, aluminum composite material, ACM, fire resistant polymers, BS8414.

Wpływ tragicznego pożaru w Grenfell Tower na przemysł izolacji poliizocjanurowych

Streszczenie: Artykuł stanowi podsumowanie powszechnie dostępnych informacji dotyczących pożaru wieżowca Grenfell Tower w centrum Londynu 14 czerwca 2017 r. Pod wieloma względami pożar był bardzo podobny do kilku innych spektakularnych pożarów w wysokich budynkach, które wydarzyły się w różnych krajach od 1999 r., ale różnił się od nich ogromną liczbą ofiar (71 osób). Tak tragiczne skutki tego pożaru były spowodowane wieloma czynnikami, m.in.: wadliwą procedurą ewakuacyjną, nieodpowiednim sprzętem gaśniczym, błędami w zarządzaniu budynkiem, brakiem odpowiednich zabezpieczeń przeciwpożarowych, niejasnymi przepisami budowlanymi, niesprzyjającą pogodą itd. Ustalono jednak, że główną przyczyną tej tragedii była zaskakująca szybkość rozprzestrzeniania się ognia obejmującego dekoracyjny aluminiowy materiał kompozytowy (ACM) zawierający polietylen (PE), zainstalowany na zewnątrz budynku w ramach systemu osłony przeciwdeszczowej. Drugą część tego systemu stanowiła poliizocyjanurowa (PIR) izolacja termiczna. W artykule skoncentrowano się na roli, jaką odegrała w tym pożarze izolacja PIR oraz na analizie kilku praktyk stosowanych w przemyśle PIR, uwydatnionych przez tę tragedię. Opisano oddolną inicjatywę, podjętą podczas konferencji Polyurethanes 2017, mającą na celu zmianę praktyki stosowanej w europejskim przemyśle izolacji termicznych, ograniczającej dostęp do raportów z badań ogniowych wyrobów termoizolacyjnych. Ten niewielki, lecz wspólny wysiłek społeczności naukowców i firm produkujących izolacje termiczne ma duże szanse przyczynić się do poprawy ognioodporności takich izolacji i przywrócić publiczne zaufanie do tych ważnych materiałów.

*) Material contained in this article was presented at the Science and Technology Conference "Polyurethanes 2017 – materials friendly to humans and environment", Ustroń, Poland, 8–11 October 2017.

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Słowa kluczowe: pożar w Grenfell Tower, pożary wieżowców, izolacje termiczne, pianki poliizocyjanurowe, PIR, zewnętrzne okładziny cieplne budynków, kompozyty aluminiowe, ACM, ognioodporne polimery, BS8414.

THE FIRE DISASTER FACTS

Grenfell Tower was a 23-storey residential building in Central London. In the middle of the night on 14 June 2017 a faulty fridge caught fire in a flat on the fourth floor. The fire quickly managed to get out through a window and then with unprecedented speed at first shot up to the top of the building in less than 30 minutes and then within 2 hours engulfed the whole building outside and inside (Fig. 1).

Although the fire brigade arrived within 6 minutes of the emergency call, the speed of the fire spread totally outpaced the capabilities and efforts of more than 200 firemen and 40 fire engines. The fire eventually subsided 24 hours later leaving behind a burnt out skeleton of the building. Seventy-one people lost their lives in the fire.

Fig. 1. Burning Grenfell Tower 14 June 2017 London (with permission of Rex Features)

Previous similar incidents

The scale of the tragedy shocked not only the general public but also all professional groups in the building industry.

The flames spread on the outside of the Tower in a manner, which unfortunately has been seen before. Several similar fires in tall buildings had happened around the world. In 1999 in the Scottish town of Irvine, a fire from one flat spread up over 8 floors. In 2009 a fire in 14-storey Lakanal House in London claimed 6 victims and in Beijing a huge fire engulfed the 31-storey Television Cultural Centre. In 2012 a fire went up the full height of the 18-storey Mermoz Tower in Roubaix in France. In 2013 a fire ripped through facade of a skyscraper in Grozny in Russia. In 2014 in Melbourne, Australia a candle like fire burst up the 23-storey Lacrosse Tower. Dubai was the scene of several spectacular fires: in 2012 in the 34-storey Tamweel Tower, in 2015 in the 336 m high Torch Skyscraper and on New Year's Eve of 2016 at the 63-storey Address Downtown Hotel. The difference between these fires and the Grenfell Tower disaster was the sheer number of casualties. All the above fires claimed in total 10 victims, while the Grenfell Tower tragedy claimed 71 victims in one night.

Fire evacuation procedure

Some of the reasons for the high number of casualties were put down to mistakes in evacuation procedure and issues with fire safety provisions around and within the Tower.

– It was reported that the access to the Tower for fire engines was restricted. The fire brigade platforms could only reach the 20th floor. The top floors of the building were beyond their help and these were the floors on which most of the inhabitants died.

– The flats did not have sprinklers. It is widely believed that sprinklers may have stopped the fire at its source, or at least have allowed more time for effective evacuation – as they did in some of the previous skyscraper fires mentioned above.

– The fire alarm system did not work properly. Some people were not aware of the fire for more than an hour. Several inhabitants did not attempt self-evacuation because they followed "Stay put" procedure recommended for the building. The concrete building was constructed in 1974 with just one staircase in the middle and no external covering. Then it was assumed that any fire could be

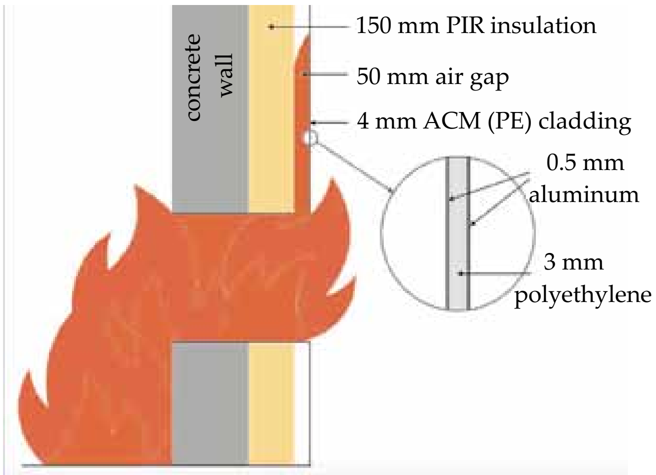


Fig. 2. The structure of the rain-screen cladding installed on the Grenfell Tower and the mode of fire spread *via* "chimney effect"

contained within the flat in which it originated. The occupiers of the flats unaffected directly by the fire were advised to stay in their flats and wait for the fire brigade to extinguish the fire or come and evacuate them. Several people did exactly this, especially because for many self--evacuation quickly became impossible due to the dense smoke in the only staircase. The evacuation routes were reportedly obstructed by flammable rubbish in the corridors. It was also claimed that several elements of the Tower's fire safety system were not maintained properly.

The cladding

However, the most obvious reason for the extent of the disaster was the unbelievable speed at which the fire spread around the building *via* the external rain-screen cladding.

The cladding was a thermal insulation system consisting of 10–15 cm thick polyisocyanurate (PIR) boards and aluminum composite material (ACM) panels separated by a 50 mm air gap (Fig. 2).

The PIR panels were supplied by Celotex UK under a trade name RS5000 and made of rigid polyisocyanurate foam covered on both sides with 50 microns aluminum foil. The panels were attached directly to the external concrete walls of the building and acted as an efficient thermal insulation layer. The air gap was there to enable moisture management and to prevent undesired local condensation pockets. The external ACM panels were manufactured by Arconic under a trade name Reynobond PE and constructed from two 0.5 mm sheets of aluminum bonded together with 3 mm low-density polyethylene (PE). The ACM (PE) panels provided rain protection and the external aesthetic appearance of the Tower.

It was believed that once the initial fire got out of the first flat, it began to be fuelled by the highly flammable polyethylene present in the ACM (PE) and then spread rapidly due to a "chimney effect" of the air gap (Fig. 2). Naturally the chimney effect propagates fire mainly upwards, but the night of 14th of June 2017 in London was windy and warm. The wind helped the fire to spread horizontally around the whole tower. Due to the warm weather, windows in several of the flats were open and flames quickly found their way back inside the building on most of the floors.

The cladding obviously was not fit for purpose. It did not behave in the fire as expected, despite apparently conforming to mandatory UK national building regulations.

The cladding was installed on Grenfell Tower a year before the fire, as a part of a renovation project aimed at improving the building's appearance and boosting its thermal insulation. However the execution of the project went through a complicated chain of contractors [1]. Some contractors were changed along the way and a couple of cost-cutting measures were introduced, one of them involved a change of the cladding material. The initial building permission for the cladding was granted for a system consisting of zinc rain-screen panels and Celotex RS5000 grade of PIR insulation – a combination which was believed to meet the criteria of UK building regulations. However, in the course of the reiterations applied to the project plan, the zinc cladding was substituted by ACM (PE). The substitution saved the Council managing Grenfell Tower almost £ 300 000 and was considered to provide a better aesthetic appearance – two good reasons justifying the substitution [2].

THE FIRE TESTING COMMISSIONED BY UK GOVERNMENT

The fire spectacularly defied UK safety regulations and as the first response to the tragedy the UK government commissioned a series of large scale BS8414 fire tests on a cladding system replicating the installation on Grenfell Tower plus 6 additional similar rain-screen systems with different types of thermal insulations and ACMs.

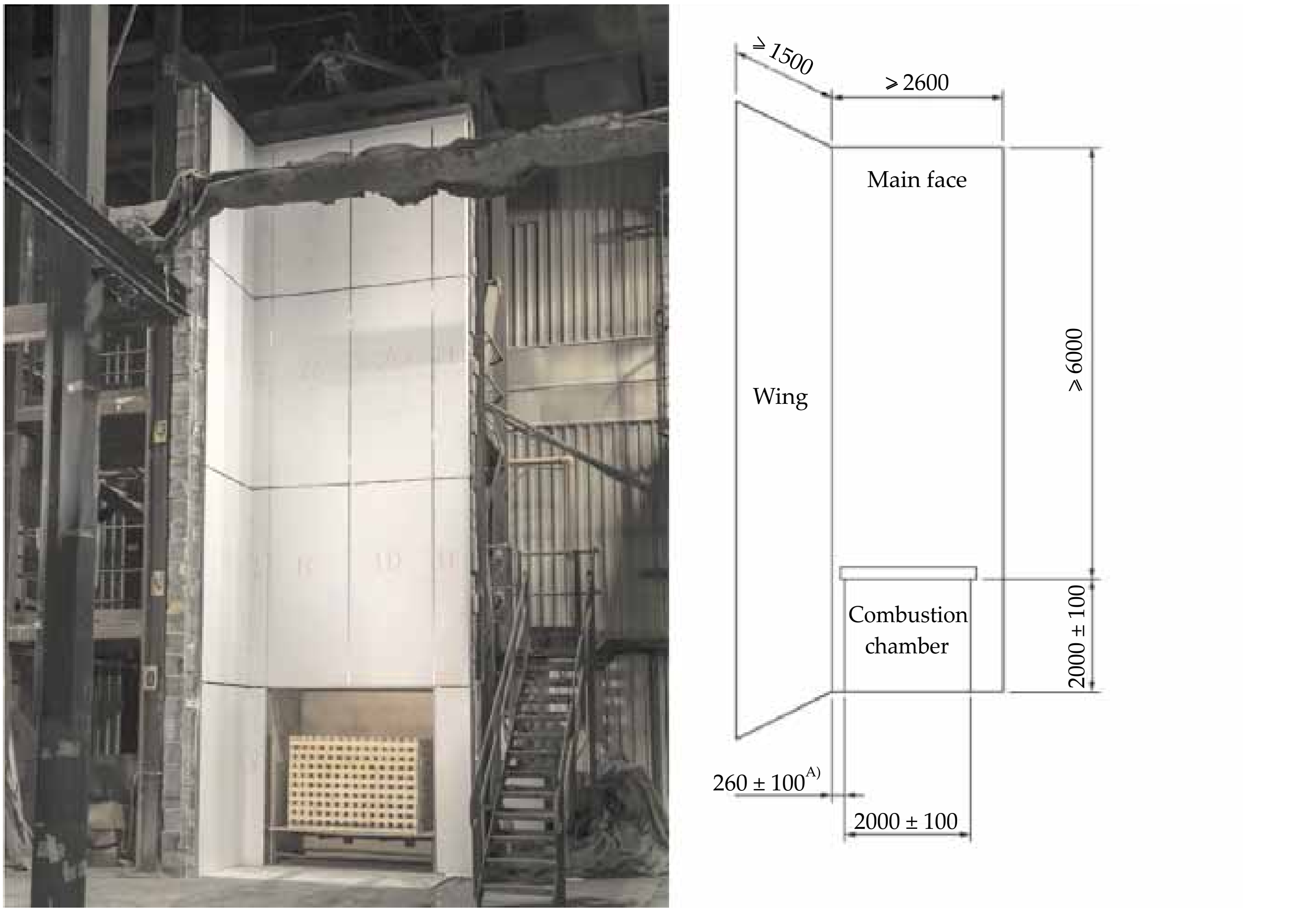
The British Standard BS8414 fire test was designed to certify fire behavior of wall cladding systems on buildings over 18 m high. Figure 3 shows the BS8414 test rig and its dimensions. The test lasted up to 60 minutes and had 3 pass/fail criteria:

1. The temperature measured on the external face of the building (measured at a point approximately 1 storey above the fire floor), or

2. The temperature measured on the internal face of the building (measured at a point approximately 1 storey above the fire floor), could not exceed 600 °C for 30 seconds or more during the initial 15 minutes of the test.

3. Mechanical performance determined by an assessment of the system collapse, spalling, delamination, flaming debris or pool fires. This criterion was not specified in detail by the standard, leaving the pass/fail decision to the discretion of the test executors.

The tests were carried out by BRE Global in the UK in July/August 2017 on 7 different cladding system combina-



A) The finished face of the cladding system applied to the side wing

Fig. 3. The test rig for the fire test BS8414 (from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/639357/DCLGtest7_BS8414_Part_1_test_report_Issue_2_0.pdf)

tions shown in the Table 1. The insulation materials were: PIR foam, stone wool and phenolic foam. The thickness of each insulation layer was chosen to provide the same thermal insulation value conforming to current UK government requirements.

The examined ACM panels were ACM (PE), its so-called fire retarded version ACM (FRPE) and ACM (LCMF) considered to be a grade with limited combustibility. The ACM (PE) grade (the one installed on Grenfell Tower) consisted of two 0.5 mm aluminum sheets bonded with 3 mm of low-density polyethylene core. In the ACM (FRPE) panels, the core was fire retarded polyethylene containing about 70 % by weight of limited combustibility mineral fibers. The core of the ACM (LCMF) panels contained 90 % of limited combustibility mineral fibers and the rest was polyethylene.

Both tests in which ACM (PE) was used over PIR insulation (test no. 1) or stone wool (test no. 2) had to be terminated after 7–8 minutes, due to the flames spreading well above the 8 m height of the rig but neither of the insulation products showed much fire damage (Fig. 4). These tests clearly replicated the speed of fire propagation observed on the Grenfell Tower.

T a b l e 1. Cladding combinations tested to BS8414 standard and the tests results

Test No.	ACM core	Insulation	Thickness mm	Test result	Test termination time from setting the fire to the crib, min:s
1	PE	PIR foam	100	Failed/fire put down	8:45
2	PE	Stone wool	180	Failed/fire put down	7:09
3	FRPE	PIR foam	100	Failed/fire put down	25:12
4	FRPE	Stone wool	180	Pass/fire self extinguished	34:40
5	LCMF	PIR foam	100	Pass/fire self extinguished	51:00
6	LCMF	Stone wool	180	Pass/fire self extinguished	40:13
7	FRPE	Phenolic foam	100	Failed/fire put down	28:14

Fig. 4. The PIR (left) and stone wool insulations (right) after BS8414 tests no. 1 and no. 2 and removing the ACM (PE) decorative cladding

Two other tests (no. 3 and no. 7) in which ACM (FRPE) was installed over PIR and phenolic foams were also terminated, although in these cases the time for the flames to reach the top of the rig was much longer: 25–28 minutes. The ACM (FRPE) passed the test only in combination with stone wool (test no. 4).

The combinations of ACM (LCMF) with both PIR insulation and stone wool also passed (tests no. 5 and no. 6).

The full reports from all the tests were made freely available on the UK government website https://www.gov.uk/guidance/building-safety-programme.

THE SPREAD OF THE PROBLEM IN UK

Following these tests, the UK government facilitated a nation-wide survey of hundreds of multi-storey buildings with similar cladding systems. The survey found 299 (as in January 2018) of them to be covered by rain-screen systems proven to be too flammable by the large scale BS8414 testing [3].

In this context it became clear that the choice of ACM (PE) cladding for Grenfell Tower was not a one-off case of negligence or misfortune. The fire exposed a deep and systematic fault in the building and fire regulation system in the UK. How deep and wide it was is the subject of a Public Inquiry established by the British government. Some issues related to specifics of UK fire safety and building regulations, national fire testing or UK building industry practices which are widely thought to compound indirectly to the Grenfeel Tower tragedy are discussed in more detail in the publication [4].

WHAT IS PIR

The PIR insulation which was used on the Grenfell Tower passed the BS8141 when installed according to the manufacturer's recommendation with low-combustibility rain-screen cladding. The pictures of the burnt out Tower suggest that the PIR insulation behaved in the fire as it was supposed to do. It burnt initially, charred and the char stayed put protecting the walls behind. Although the BRE testing absolved PIR to some extend of direct responsibility for the tragedy, the fire should be a wake up call for the PIR insulation industry to take stock and review its practices.

The fire highlighted widespread misconceptions amongst the general public and the press about PIR insulation. The public did not see the difference between PE, PIR, PUR (polyurethanes) and other insulation materials. Most worryingly neither did the majority of building professionals: architects, building specifiers, building fire safety experts, testing houses or even certification bodies like BRE. The BRE test reports were very general about the grade of PIR insulation examined in the BS8414 tests. The reports provided only three pieces of information: the generic name – PIR, the density – 31.2 g/cm^3 and the thickness – 100 mm. This is frighteningly little having in mind that the quality of PIR, especially its fire performance, depends on multiple factors starting from complicated chemical composition, through variable and influential processing parameters and ending at the curing procedures. Each parameter on its own can make or break PIR's fire resistance.

The industry needs to take a good look not only at the beliefs regarding the PIR insulation widely propagated outside the industry but also at its own practices and assumptions, especially at their own understanding of what exactly PIR is.

The first PIR foams appeared in 1960's and were made from diethylene glycol (DEG) and high viscosity (around 2000 mPa · s) and high functionality (above 3.2) polymeric methylene diphenyl diisocyanate (MDI). At that time this high viscosity MDI was a waste residue left after the production of pure MDI supplied mainly for flexible and elastomeric applications. This residue looked like black molasses, even got a nickname "crapy-PAPI", and used to be disposed of by burning.

As the idea behind the new product was to use as much of the waste polymeric MDI as possible, the index (MDI/polyol ratio · 100) of the first PIR foams was purposely very high, usually above 400. The scientific definition of PIR describes it as a material having more polyisocyanurate bonds than polyurethane bonds – which means an index above 400, thus this first and "real" PIR got its name.

The first PIR foams were blown with trichlorofluoromethane (R11). It was an ideal blowing agent: totally non-flammable, with very low gas thermal conductivity and boiling point convenient for easy processing. The R11 was also used at that time in popular halogen fire extinguishers, so it can be said that every cell of the first PIR foams was equipped with its own "personal" fire extinguisher. The foam had very good mechanical strength, thermal resistance and finally also impressive temperature and fire resistance. Because of inherent fire retardancy of the polyisocyanurate structures and the presence of R11, the formulations did not need fire retardants and in fire conditions the foams produced little smoke. It was an extremely good thermal insulation product. Its name "PIR" started to be well-known as associated with high quality and unique fire resistance. The fame and subsequently the demand for PIR were quickly growing, accelerated to a large extent by insurance companies supporting PIR as a material able to prevent large fire damage claims.

But in the 1980's R11 was eventually proven to destroy the ozone layer and was banned. Next generations of non-flammable blowing agents were much more expensive and more and more flammable. Finally the industry ended up using mainly pentanes – as flammable as petrol. In the 1990's and 2000's the success of PIR put significant pressure on polymeric MDI supply. The shortage of MDI supply and subsequent MDI price increases started to push the industry towards PIR formulations with less and less MDI. Another force driving the index of PIR foams down was the need for heated laminators – essential processing equipment for efficient PIR panels manufacturing. New machines or conversions of already existing PUR machines into lines suitable for manufacturing PIR required significant upfront investment, which was not always available, especially for smaller producers.

These factors compounded to drive the average index of PIR down and down, at first to 300, then 280, and then even lower. In 2017 the definition given by Wikipedia stated that PIR is a material with the index above 180. Nowadays the worldwide understanding of PIR relates rather to its famous fire resistance than to its index or chemical composition. "PIR" is very often used as a synonym for a foam passing just the B2 test according to the DIN 4102 standard, which of course is far, far worse than the B1 performance of the original PIR.

Our research published in 2015 on the use of FT-IR and FT-NIR (FT- Near Infra-Red) in quality control of PIR foams [5] determined real trimer content in 7 PIR products manufactured by 3 different companies. These PIR foams had index between 400 and 200 visibly proving the devaluation of the name PIR. As the fire performance is strongly linked to the real trimer content (thus usually also to the index), the fire resistance provided by small amounts of trimer structures in lower index products is small. To achieve the required B2 fire resistance these low index formulations are very often highly loaded with fire retardants thus create a lot of smoke in the fire conditions.

The PIR industry for its own goodness, for the comfort and safety of its customers and for the benefit of our planet, needs to become much clearer, decisive and stricter about what can be called and marketed as PIR and what shouldn't. There is a wide range of products between "real PIR" and PUR with unlimited number of more or less fire retarded PIR/PUR – PUR/PIR hybrids in the middle of this spectrum. They all look the same but fake PIRs in next fire may be lethal for people as well as highly damaging for the thermal insulation industry itself.

ONE SMALL STEP FORWARD

Although the first European PIR products were manufactured in UK in the 1970's, today in 2018 the PIR industry is present and strong in all European countries, from UK to Russia. That is why the warning from Grenfell Tower is not only for the UK. It is for all communities involved in research, development and manufacturing of PIR insulation, wherever they work as well as for thermal insulation users wherever they live.

The tragedy raised global concern and also a global will to prevent something like that happening again. There were multiple factors contributing to the Grenfell Tower tragedy, some specific to UK, others more universal. Different communities can address different factors within their remits. The will for change was easy to see also amongst the international academic and industrial establishments represented at the Polyurethanes 2017 Conference. There are a few things the scientific world can and should do to contribute to the change.

One of the industry practices thought to create a system in UK which allowed construction of 300 unsafe buildings, is the principle of keeping fire tests reports confidential. Companies commissioning the tests maintain full copyright and usually don't publish anything other than information required by quite liberal regulations or marketing departments, even if the tests were done for certification reasons and the certificates were awarded. This practice is seen as being very obstructive to a transparent and reliable system of declaring true fire performance of insulation products or insulation systems. It also does not allow for healthy self-regulation within the industry or easy scrutiny by the users, should they wish to do so.

This industrial practice is in visible disharmony with the open access attitude quickly advancing in science. In this case the scientific world is able not only to develop safer materials but also to "break the mould" of dubious industrial habits, by independent testing and openly publishing the data.

The reports from the Grenfell Tower fire and BRE tests strongly suggested that the RS5000 PIR grade installed on the Tower behaved as expected from PIR. However because this grade was manufactured only to order, it was not possible to obtain any samples for the independent testing. Similar grade PIR – FR5000, named by the manufacturer as the predecessor of the RS5000, was sourced from the market and chosen to act as the first benchmark and reference PIR product. Samples of FR5000 were tested by the following independent scientific and industrial establishments spread across the whole Europe:

– Polychemtech Ltd. in UK – for the index and trimer content using FT-IR;

– Chemical Safety Laboratory, Department of Chemical, Biological and Aerosol Hazards, Central Institute for Labour Protection, National Research Institute in Warsaw in Poland (CIOP) – for fire resistance using cone calorimeter;

– Latvian State Institute of Wood Chemistry (LSIWC) – using cone calorimeter and bomb calorimeter.

The results of this first Pan-Europe testing and further considerations on what can be called PIR, will be published soon with Open Access.

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Received 14 V 2018.

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