AN INVESTIGATION INTO THE RELEVANCE OF THE CONTRIBUTION TO TOXICITY OF DIFFERENT CONSTRUCTION PRODUCTS IN A FURNISHED ROOM FIRE

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1. Abstract

There is a trend to low energy buildings triggered by tighter energy regulations across the globe. In most cases, this translates into the use of increased insulation layer thicknesses in buildings. The use of high performance insulation products increases with these demands, in order to allow for more efficient building design and increased floor-area. Current research suggests that fires could develop differently in these modern buildings caused by factors including triple glazing and air tightness. It is also emphasised by some that the increased use of organic insulation products generate larger volumes of toxic combustion gases.

This paper presents and evaluates two fire tests conducted in a furnished domestic room only differing in the type of the used wall insulation product to assess its relative contribution to the fire compared to the room content. The test results with regard to heat release rates, smoke and toxic gas emissions show that the organic polyisocyanurate insulation and the mineral fibre insulation behave similarly during the fire and the main threat for occupants emanates from the room contents.

2. Introduction

Building fires, and the evaluation of the toxic hazards from them, are very complex. The risk of building occupants being affected by toxic fumes depends on several factors such as the amount and availability of combustible material, stage of the fire, conditions of the combustion process, etc.

It is known that modern domestic room fires can become fully developed, and flashover can occur after only a few minutes. If an occupant has not escaped by this time, then they would be unlikely to survive. Occupants in other rooms may also be exposed to related smoke while in situ or while evacuating a building, although without themselves suffering the effects of the heat from flashover (because they are separated from the original fire). The question has been raised in recent European discussions about what the role of construction products is in the overall generation of toxic smoke.

In addition to all of the above, generation of toxic combustion products is not simply a material property: the smoke produced by burning construction products, and the resulting hazard, are strongly dependent on the way a product is integrated into the building, the fire scenario (e.g. room size, temperature, ventilation), and exposure time.

This overall complexity makes it difficult to evaluate the smoke toxicity of a single product, in particular a construction product, which generally burns after the building contents, in the later stages of a fire. It has also led international standardisation committees addressing fire safety of building and construction to conclude that, so far, there is no suitable test method for assessing the contribution of individual construction products to the emission of toxic gases linked to real fires. Therefore, the described approach has been chosen to conduct two comparative tests incorporating data generated during the three different phases of a room fire, phase 1 being fire development, phase 2 the flashover (fully developed fire) and phase 3 the decay phase of the fire.

2.1 Objective of the study

The objective of this study was to assess the contribution of the building fabric versus that of the building contents to heat release rate, smoke production and toxicity of fire effluents in the case of a fire in a furnished domestic room. In order to establish the influence of the construction products two test setups were chosen in two rooms constructed with different insulation materials, under the same fire conditions and the same content within the room.

2.2 Scenario

The chosen fire scenario for this comparative testing simulates a waste bin fire (propane burner, 30 kW as defined in ISO 9705) that ignites the curtain and spreads to the armchair (first 5 minutes of the test). The burner was therefore placed in a corner and the curtain was installed just above the burner. After 5 minutes the burner was turned off and the further development of the fire was observed and analysed.

The ignition of the armchair was chosen to be the start of the analysis to minimise variations in fire spread in the early stages of the fire (burning curtains).

3. Description of the test configuration

3.1 Principle

The experimental procedure was conducted in a furnished room insulated and covered with a paper faced gypsum board. The only variation in the two test set-ups was the insulation material used behind the plasterboard. In order to achieve comparable thermal transmittance of the build-ups insulation thickness differed (80 mm vs. 140 mm) to match thermal performance. Both rooms were identically furnished.

3.2 Room set-up

Inner dimensions of the test room without insulation were in accordance with the dimensions given in ISO 9705 (3.6 m x 2.4 m x 2.4 m). The floor, ceiling and walls were made of cellular concrete. The walls, excluding the wall containing the door, were covered with the two different insulation systems. Details for the insulation products are given in table 1.

In order to achieve the same inner volume of the test room in the second test with PIR insulation, an additional inner wall was constructed inside the ISO-room wall (thickness 50 mm) which also consisted of cellular concrete before mounting the insulation system. In both tests the insulation products were placed between wooden battens (distance in both cases 570 mm) which were fixed on the concrete wall. The insulation layer was covered with gypsum cardboard (thickness 12.5 mm) according to EN 520. The gypsum board lining was applied with vertical joints, located on top of the wooden battens, without horizontal joints. A power socket was placed near to the armchair, to create a realistic weak spot in the gypsum layer.

With this build-up two comparable test configurations were achieved.

	Test 1	**Test 2**
Insulation Product	Mineral wool without facing *(according to EN 13162)*	PIR insulation boards with Kraft aluminium facing on both sides *(according to EN 13165)*
Reaction to fire classification according to EN 13501-1 for the product as placed on the market	A1	E
Thermal conductivity according to ($W/*m^{-1}*K^{-1}$)	0.035 *(according to EN 13162)*	0.022 *(according to EN 13165)*
Thickness of insulation product used in test (mm)	140	80

Table 1: Insulation products used in Test 1 and Test 2

3.3 Room contents

Both rooms were fully furnished.

The contents of the rooms were:

- Curtain (fabric): installed width of 80 cm with a curtain rod (installed 15 cm from the wall and 5 cm from the ceiling);
- Armchair (timber and foam filling, 80 cm x 70 cm x 55 cm) with 2 pillows;
- Small table (timber, 55 cm x 55 cm x 50 cm) with a few magazines and a remote control;
- TV bench (timber, 120 cm x 40 cm x 74 cm);
- TV (19 inch);
- Bookcase (timber, 40 cm x 28 cm x 202 cm) with 7 identical books.

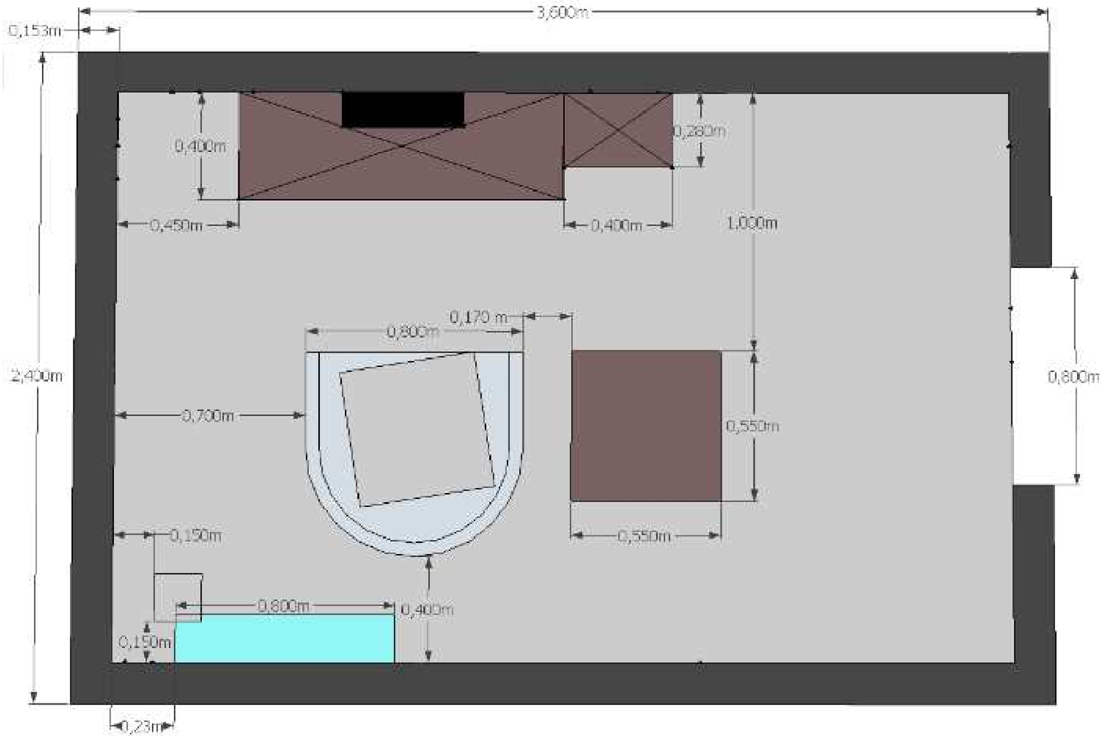


Figure 1: Contents of the tested rooms in relation to the burner

Figure 2: Photos of the room content and the power socket

4. Measurements taken

4.1 Temperature measurements

Thermocouples were installed directly behind the gypsum plasterboard and behind the insulation material in three heights. In addition, a thermocouple tree with seven thermocouples was placed on the left side of the doorway. The temperatures were recorded throughout the entire duration of the test.

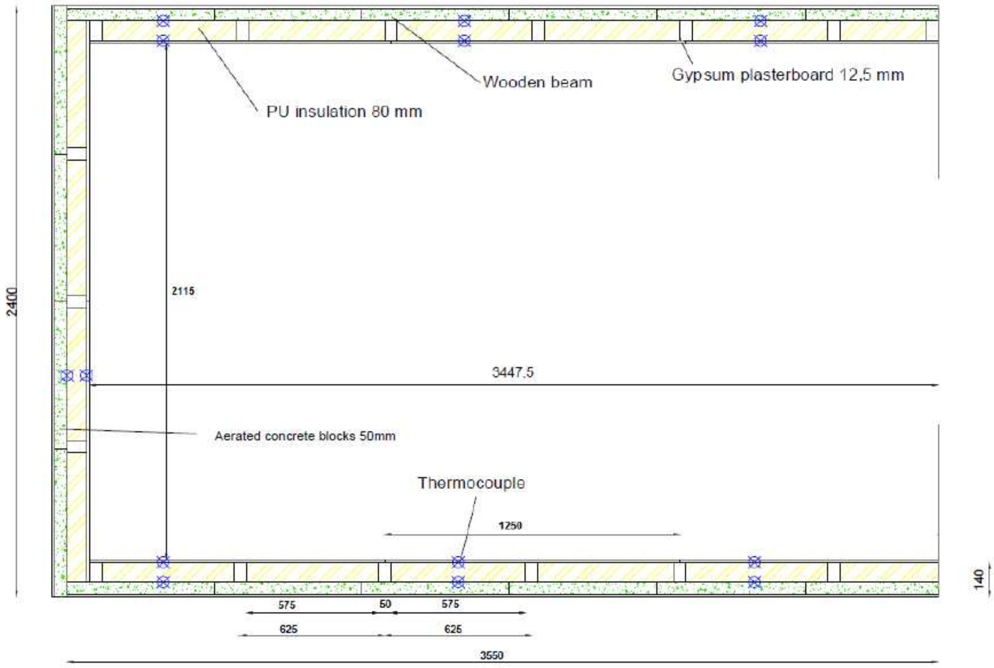


Figure 3: Thermocouple locations at heights of 0.3, 1.2 and 1.8 m from the floor shown in blue

4.2 Heat release rate

The heat release was measured and recorded using the oxygen depletion method according to ISO 9705-1:2016 and the European standard EN 14390:2007. The sampling port was installed in the exhaust duct and oxygen and carbon dioxide were continuously measured which allowed for determination of the heat release rate.

4.3 Smoke obscuration

The smoke obscuration was measured with an optical path system in the exhaust duct using white light as described in ISO 9705. The smoke production rates were measured in m2/s. The calculation was in accordance with ISO 9705 and EN 14390.

4.4 Concentration of effluent gases

The fire effluent gases were measured with an FTIR spectrometer. The sampling and the analysis were done based on ISO 16405 (Room corner and open calorimeter - Guidance on sampling and measurement of effluent gas production using FTIR technique) and ISO 19702 (Guidance for sampling and analysis of toxic gases and vapours in fire effluents using Fourier Transform Infrared (FTIR) spectroscopy).

The following effluent gas components were analysed:

- Carbon monoxide (CO)
- Carbon dioxide (CO_2)
- Hydrogen cyanide (HCN)
- Formaldehyde (CHOH)
- Acrolein (C_3H_4O)
- Sulfur dioxide (SO_2)
- Hydrogen Chloride (HCl)
- NO_x (measured by the sum of N_2O, NO and NO_2)

Gas sampling was installed in the duct work of the smoke exhaust system of the testing facility. This sampling position represents cooled and diluted fire effluents. ISO 16405 states that this sampling position is often preferred over sampling outflowing gases directly at the top of the doorway as matrix effects from the fire effluents are minimized by the dilution. At this position due to cooling and dilution effects all chemical reaction in the fire effluent would have ceased which would not be the case when sampling directly from the immediate vicinity of the fire where further chemical reaction, combustion and decomposition could take place. Using the known volume flow rate in the exhaust duct, the dilution effect has been reversed prior to calculating the Fractional Effective Dose (FED) and Fractional Effective Concentration (FEC).

5. Results and discussion

5.1 Course of tests, time scales for data presentation and heat release

In both tests the burner was shut off after 5 minutes. In the first test, the curtain was ignited by the burner after 5 seconds, fell down and ignited the arm chair after 4 minutes. In the second test the curtain did not cause ignition of the arm chair. Therefore, the arm chair was moved closer to the burner and the burner was started again. In this test the arm chair was only ignited 9:40 minutes after the start of the test. Following the ignition of the armchair in both tests the fire spread to the other contents of the room, subsequently leading to further development of the fire (phase 1).

As the purpose of the test was to analyse the relevance of the contribution to toxicity from the applied insulation products in relation to the contribution from the contents burning in the room, the start of the test, in both cases, was defined as the moment when the arm chair was ignited and hence the fire started to develop in the room. This approach is confirmed by the fact that the time to flashover (phase 2) in the room, caused by burning of the contents of the room only, was 7:24 minutes after ignition of the chair in Test 1, and 6: 55 minutes in Test 2. Therefore, the point of time when the chair ignited is referred to as "start of the test" in the following discussion and in the diagrams.

In both tests flashover occurred about 7 minutes after the start of the test (see Figure 4). A second peak of the heat release rate was observed some minutes later. Subsequently, the fire decayed (phase 3). First cracks appeared in the gypsum plasterboard in both tests after about 20 minutes.

During the decay phase (from the 20th minute onwards) a difference in the heat release rate was observed by a slightly less steep decay in test 2, however, the HRR curves of both tests were below 50 kW after approximately 50 minutes.

The following diagrams illustrate heat release rate versus smoke production and later some of the toxic gas components.

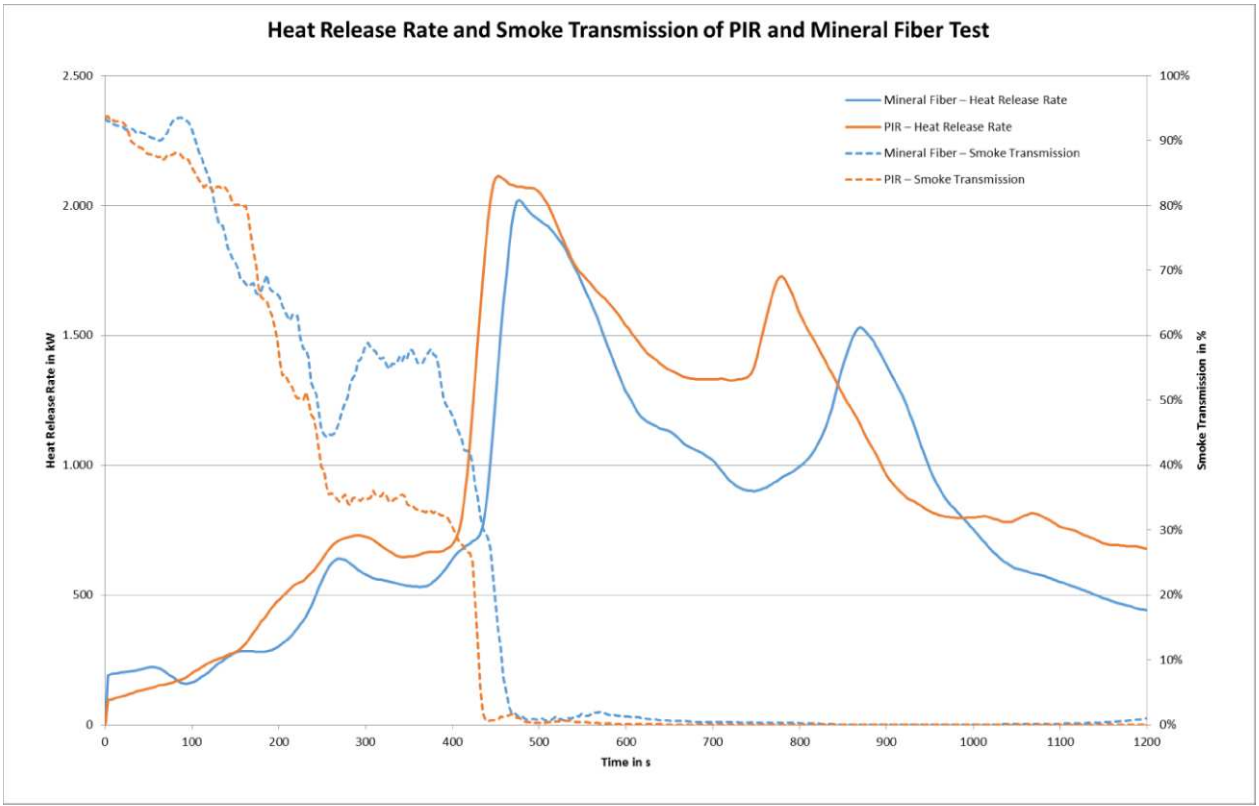
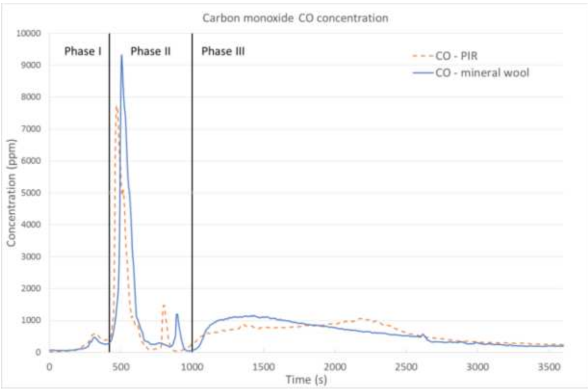


Figure 4: Heat Release rate versus smoke transmission

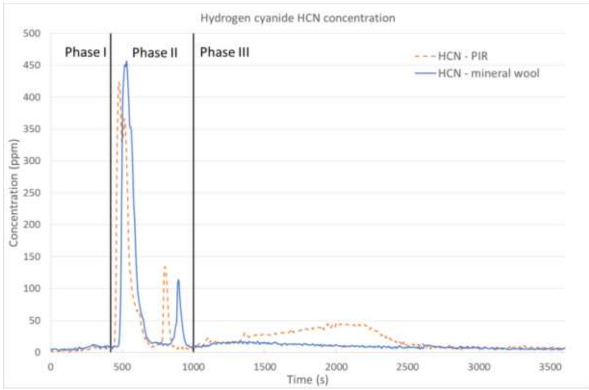
5.2 Gaseous Effluents

The concentrations of the measured gases also correspond to the course of the heat release rate and the smoke obscuration. The example curves below in Figure 5 show that for CO no significant difference can be seen. For HCN only in a very late phase of the test (more than 20 minutes after the start of the test) there is a slight increase in concentration in Test 2 compared to Test 1. This phenomenon can be attributed to the PIR insulation product which was partly exposed to radiative heat and direct flame impingement from the room's interiors by this time. However, this occurred far after much higher concentrations were reached in both tests due to the burning room contents (very similar in both tests).

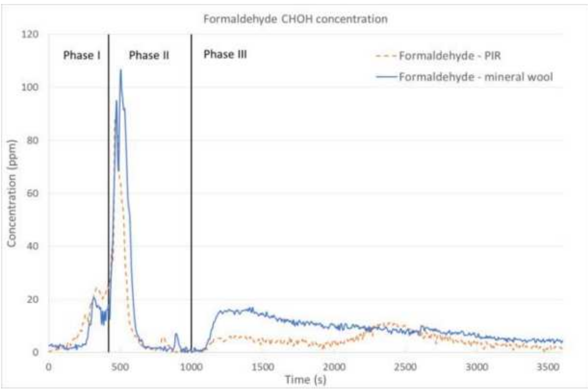
The formaldehyde and acrolein data, on the other side, indicate that in the same late phase of the tests the insulation was contributing. Here, after more than 20 minutes, the concentrations were slightly higher in Test 1 – where the mineral fiber insulation had been installed. Also these increases show that the contribution from the insulation product took place very late and the concentrations were significantly lower than those reached during the second (flashover) phase, when the contents of the room were burning intensely.



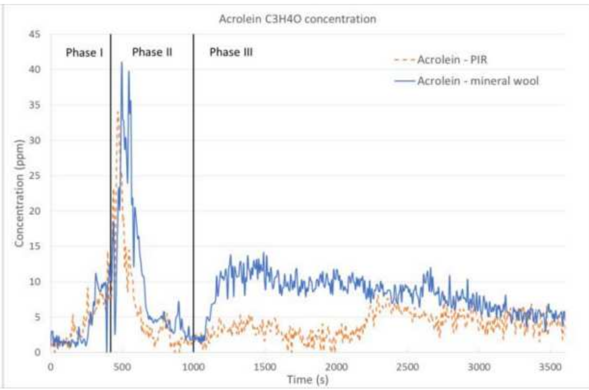
Concentration of Carbon monoxide



Concentration of Hydrogen Cyanide



Concentration of Formaldehyde



Concentration of Acrolein

Figure 5: comparison of some gas concentrations measured during the test

5.3 Comparative toxicity assessment

The Fractional Effective Dose (FED) and Fractional Effective Concentration (FEC) values were computed according to ISO 13571: 2012 and based on all the fire effluents measured during the fire tests and mentioned earlier. This means that the effluents from the armchair and other furniture contents were the major contributors to both the FED and FEC values, particularly in the fully developed phase of the fire (between 6 and 17 minutes). In detail, FED was calculated based on the concentrations of carbon monoxide (CO), hydrogen cyanide (HCN) and carbon dioxide (CO2) measured during the tests. The data is uncorrected for the gas burner output, but this is consistent in both tests.

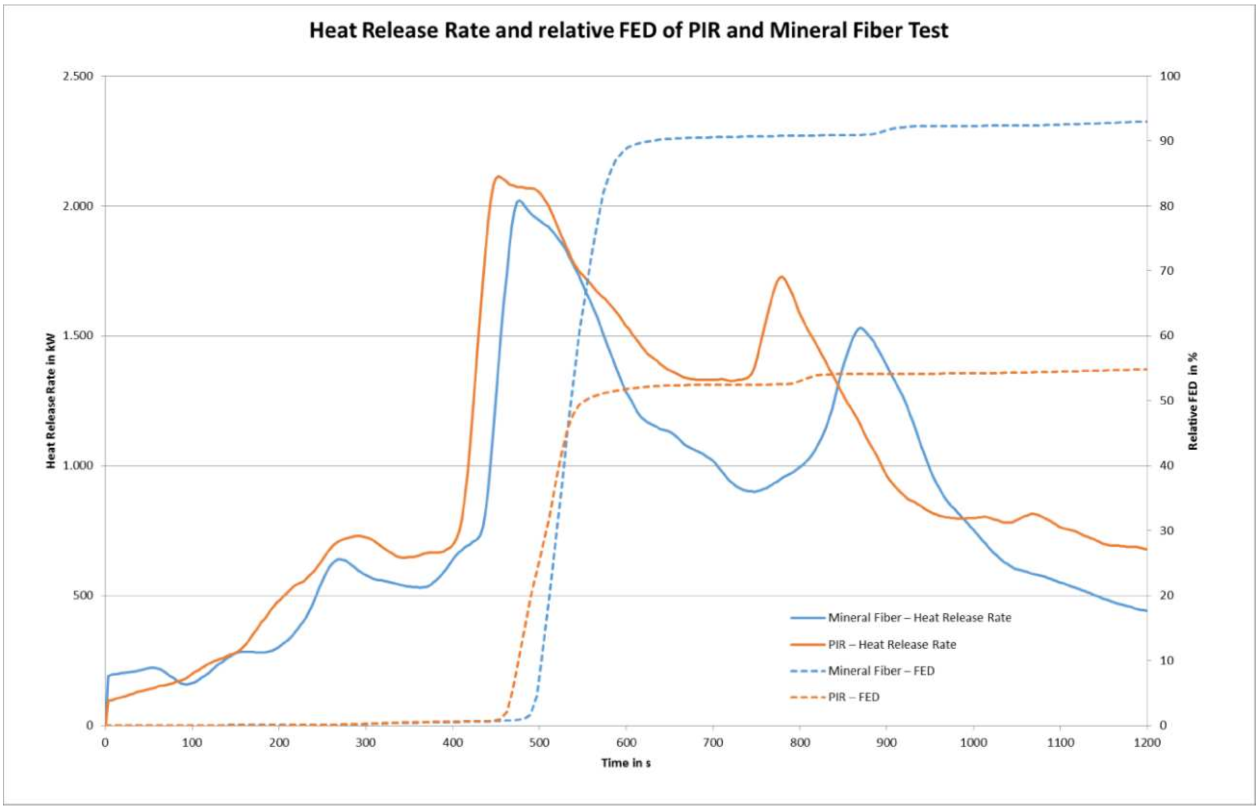


Figure 6: FED comparison

FEC was calculated based on the concentrations of formaldehyde (CHOH), acrolein (C_3H_4O), sulphur dioxide (SO_2), hydrogen chloride (HCl) and nitrous oxides (NO_X). Of course numerous other irritant species can be formed in fires. The range of effluent species selected for analysis covered those species of toxicological significance that could reasonably be expected to be released, based on knowledge of the composition of the material and in consultation with the published documentation for exposure criteria.

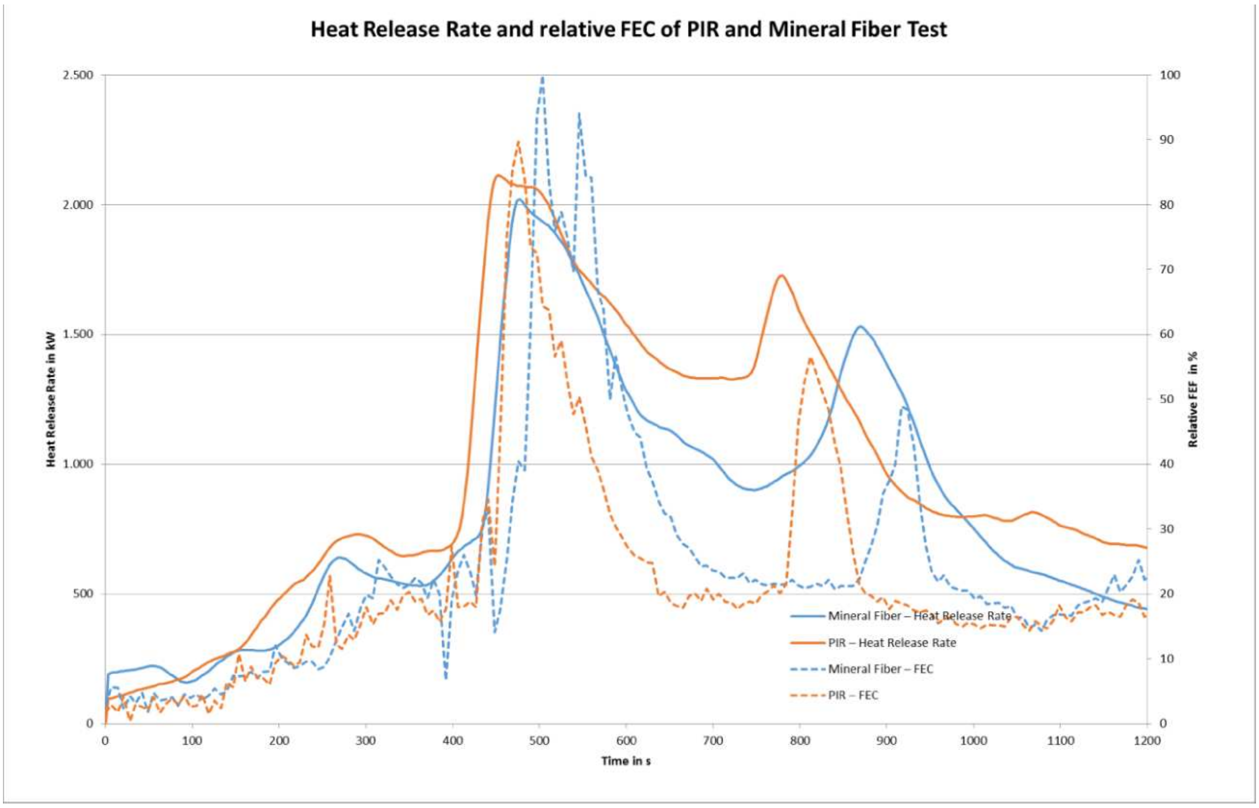


Figure 7: FEC comparison

Note: Toxicity is only to a certain degree a material property. It is strongly influenced by the environment, availability of oxygen, thermal attack, air flow and surfaces available for combustion. The chemistry of the combustion of a given material can therefore proceed along various routes and produce species in very different quantities dependant on conditions to which it is subjected. Such changes would impact the FED and FEC values.

The toxicity evaluation via FED and FEC – as shown in figures 6 and 7 – clearly demonstrates that the major part of the toxic hazard was already reached in the early phases of both tests, where the wall insulating construction products were not yet contributing. Already after less than 10 minutes of testing time, the FED did not change much more. For the FEC in both tests similar developments could be observed. Only about 18 minutes after the start of the test, a slight increase in the FEC occurred in Test 2 (PIR insulation). But also here the increase and the absolute values were significantly lower than the peak values reached in the flashover phase.

6. Conclusions

It is acknowledged that – with regard to domestic fire deaths – smoke inhalation causes or at least contributes to the majority of the fatalities. The results of tests presented here, demonstrate that in the considered domestic fire scenario the toxic potential caused by gaseous emissions basically arises from the burning and consequent smoke emission of the combustible building contents. This occurs significantly before the building envelope has even been affected by the fire. However in the tests presented here, minor contributions to the concentrations of the critical gases due to the involvement of the insulation products in the fire could be observed in a very late phase of the fire. However this was far after substantial FED and FEC values had been reached due to the burning of the contents of the room.

Accordingly, to reduce the risk to occupants induced by smoke gases, it is crucial to detect fires early within a building. This then allows occupants to evacuate before they are exposed to smoke inhalation. Therefore, it is important to investigate suitable fire safety options such as stipulating the installation and maintenance of smoke detectors for all buildings and to improve their design in order to facilitate means for fast and safe evacuation. In this way then early detection of and fast response to fires constitute very effective measures to ensure the safety of occupants.

Acknowledments

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7. References

[1] ISO 9705: 2016 - Reaction to fire tests - Room corner test for wall and ceiling lining products - Part 1: Test method for a small room configuration

[2] ISO 16405: 2015 - Room corner and open calorimeter -- Guidance on sampling and measurement of effluent gas production using FTIR technique

[3] EN 13501-1: 2007+A1:2009: Fire classification of construction products and building elements – Part 1: Classification using data from reaction to fire tests

[4] EN 520: 2004 + A1:2009: Gypsum plasterboards - Definitions, requirements and test methods.

[5] EN 13165: 2012: Thermal insulation products for buildings. Factory made rigid polyurethane foam (PU) products. Specification

[6] EN 13162: 2012+A1:2015: Thermal insulation products for buildings. Factory made mineral wool (MW) products. Specification

[7] ISO 13571: 2012 - Life-threatening components of fire - Guidelines for the estimation of time to compromised tenability in fires

[8] ISO 19702: 2015 - Guidance for sampling and analysis of toxic gases and vapours in fire effluents using Fourier Transform Infrared (FTIR) spectroscopy