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Contribution to smoke toxicity of thermal internal insulation products in end-use conditions

Comparative room fire tests to investigate the contribution to smoke toxicity of the building envelope versus the building content

Executive summary

Glossary

- FEC: Fractional Effective Concentration
- FED: Fractional Effective Dose
- Fire scenario: typically defines the ignition and fire growth processes, the fully developed fire phase, the fire decay phase, and the environment and systems that impact on the course of the fire
- Flashover: Near-simultaneous ignition of most of the directly exposed combustible material in an enclosed area
- PIR: Polyisocyanurate
- PU: Polyurethane (PUR/PIR)
- HRR: Heat Release Rate (rate of thermal energy production generated by combustion)
- Smoke obscuration: Reduction in the intensity of light due to its passage through smoke
- MW: Mineral wool

The fire safety of buildings is one of the major priorities for the construction industry. However, PU Europe strongly believes that discussions should not be limited to the reaction to fire of individual construction products: this is not always sufficient to assess the fire safety of complete buildings. In order to be able to assess the contribution to smoke toxicity of the building envelope and that of the building content in the event of a fire developing inside a room, a test programme was carried out to compare smoke toxicity emissions in a furnished room internally insulated with either combustible (PIR) or non-combustible (MW) thermal insulation products and finished with plasterboard. This enabled assessment of the contribution of the building envelope and that of the building content in the event of a fire developing inside a room.

Key learnings from the test programme are:

- In the early phase of a fire, when people are still able to escape, the contents of a room are a dominant

factor for fire development, smoke obscuration and toxicity;

- Contribution of the building envelope (including the thermal insulation layer – class A1 MW and class E PIR) to development of heat and smoke starts only in a later phase of a fire and is less significant compared to the effects from burning building contents during the evacuation period.

Which lead to general considerations that:

- The performance of the complete build-up is more relevant than that of the individual construction products;
- Smoke toxicity is strongly influenced by the environment, availability of oxygen, thermal attack, airflow and surfaces available for combustion;
- Eventually, as smoke inhalation often contributes in case of occupant fatalities, early detection and other measures like extinction and safe escape are key for the fire safety.

Introduction

As most fires in buildings start within a room, PU Europe decided to commission a test program [...] to look at the relevance of the contents versus the envelope in a room fire scenario [...].

Construction products sold with a CE mark within the European Economic Area (EEA) have to be tested and classified against their reaction to fire and/or resistance to fire performance.

The European classification system for reaction to fire includes measurement and classification of smoke development, by measuring smoke obscuration over time.

Regulators in the different member states have to use these classifications as a basis for defining the level of safety in their buildings. Most countries currently concentrate in their regulations for buildings on avoiding development and spread of smoke and fire. This includes measures like early detection and extinction of fires, compartmentation of larger buildings (no spread of fire or smoke to other compartments), ventilation and provision for safe escape ways where fire and smoke cannot be expected.

Recently the question was raised whether it is necessary to measure and regulate on toxicity of combustion gases from construction products, in order to increase fire safety in buildings. Back in 2016, the European Commission ordered a study [1] to evaluate the need to regulate via



Video taken at the start of the test (<https://youtu.be/3zjeq5drQVU>)

the Construction Products Regulation (EU) 305/2011 and – after compiling existing national requirements and asking stakeholders their expert views on the matter – found no evidence for doing so.

As most fires in buildings start within a room, PU Europe decided to commission a test program at Exova Warrington Fire Gent (Belgium) to look at the relevance of the contents versus the envelope in a room fire scenario (this factsheet is based on a scientific paper presented at the 2017 Fire and Materials conference in San Francisco [2]). A test set up was chosen with a fully furnished room and the walls of the test room were insulated and covered with gypsum plasterboard as a typical end-use configuration.

Experimental setup

The walls of the test room were insulated with MW in the first test and with PIR in the second test.

Test room

A test room according to ISO 9705 [3], also referred to as Room Corner Test, was used: ISO 9705 represents a fire scenario which starts under well-ventilated conditions in a corner of a specified room with a single open doorway. The wall build-up (insulation products and inner covering) was mounted inside this room. The walls of the test room were insulated with MW in the first test and with PIR in the second test. Details for the insulation products

are given in Table 1. The thicknesses of the insulation products differed (140 mm vs. 80 mm) so that the U-value (thermal transmittance) of the wall was identical. The insulation layer was lined with 12.5 mm plasterboard. A power socket was placed near to the main fire load, to create a realistic weak spot in the plasterboard lining.

Both rooms were identically furnished, with a curtain (fabric), an armchair, a small table, a TV cabinet, a TV and a bookcase.

	Test 1	Test 2
Reaction to fire classification according to EN13501	A1	E
Thermal conductivity (W/mK)	0.035	0.022
Thickness (mm)	140	80

Table 1: Insulation products in test 1 and test 2

Fire scenario

A gas burner was used underneath the curtain to initiate the fire. This fire scenario was chosen in order to simulate a waste bin fire in a small room.

The time of ignition of the armchair was chosen as the starting point of the analysis, to minimise variations in fire development in the early phases of the fire.

Recorded data

Temperatures in the room as well as inside the wall construction were measured and recorded. In addition heat release rate, smoke obscuration and smoke gas concentrations were recorded during the entire test.

All relevant gases including – but not limited to – carbon monoxide (CO), carbon dioxide (CO₂), acrolein (C₃H₄O) and hydrogen cyanide (HCN) were measured.



Test room according to ISO 9705, also referred to as Room Corner Test

Test results

It can be observed that the two flashovers were caused by the content of the room.

Heat Release Rate (HRR)

Flashover occurred 7'24" after ignition of the chair in the MW test, and 6'55" in the PIR test.

Flashover was caused by burning of the contents of the room. In both tests, a second peak of the HRR was observed after 13-15 min caused by the collapse and subsequent ignition of the so far unexposed surfaces of the TV cabinet. Subsequently, the fire decayed [4]. During

the decay phase there was a slightly less steep decay in the PIR test than in the MW test. However, the HRR curves of both tests were below 50 kW after approximately 50 min.

As first cracks appeared in the gypsum plasterboard in both tests only after about 20 min it can be assumed that the two flashovers were caused by the content of the room.

Heat Release Rate and Smoke Transmission of PIR and MW Test

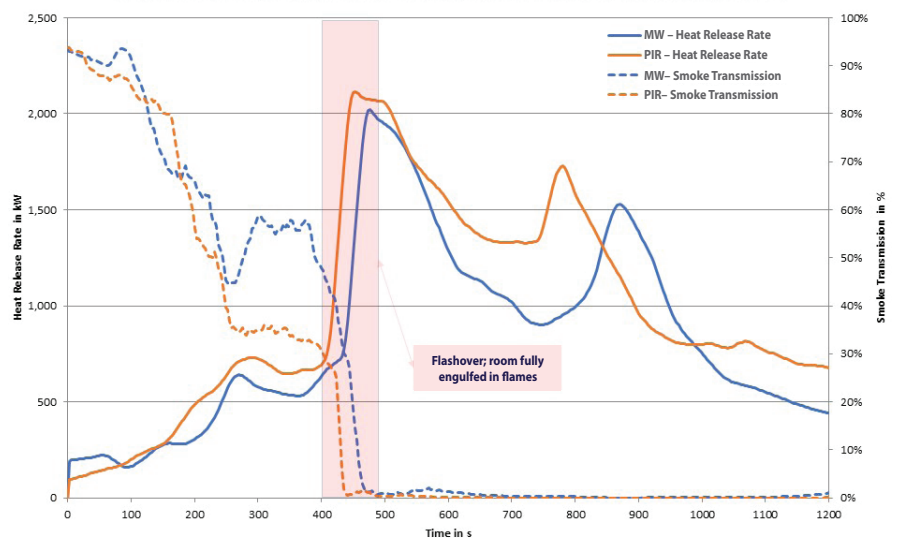


Figure 1: Graphs of Heat Release Rates and smoke transmission (percentage of light intensity transmitted through smoke) in both tests

Concentration of gaseous effluents

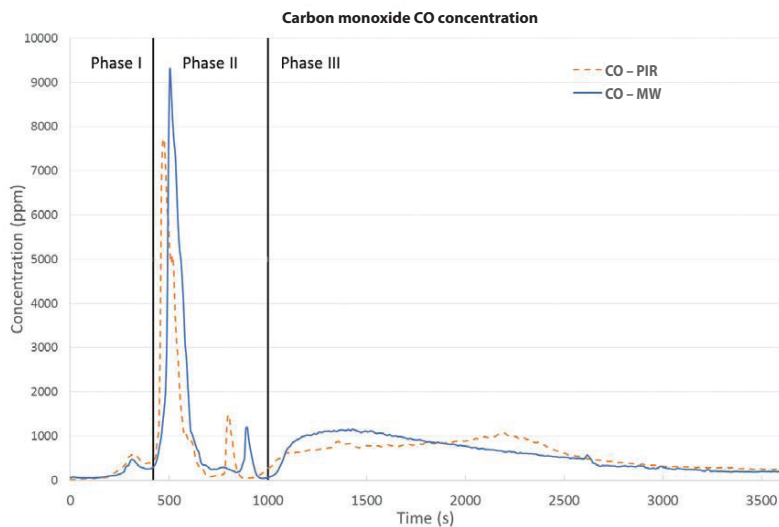
Gas concentrations correlated well with HRR. The example curves in **Figure 2** show that for CO and CO₂ no significant difference can be seen between both tests. It has to be noted that lethal concentrations can vary with higher percentages of CO₂. CO₂ can cause hyperventilation, which increases the rate of uptake of other toxic gases and thus decreases the time to incapacitation. As an approximation, it should be assumed that there would be little effect below 3% CO₂, while above this amount the time to incapacitation by e.g. CO should be halved [5].

For HCN, only in a very late phase of the test (more than 20 min after the start of the test) there is a slight increase in concentration in the PIR test compared with the MW test. This phenomenon can be

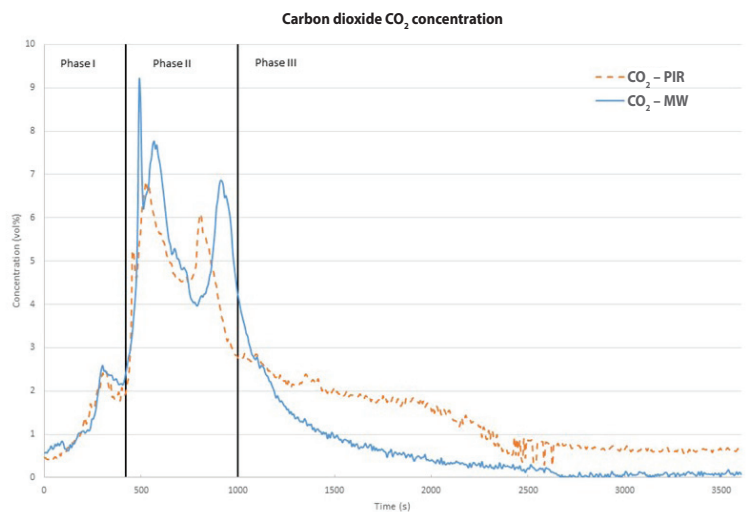
attributed to the PIR insulation being partly exposed to radiative heat and direct flame impingement from the room's interiors by this time. The acrolein curve indicates that in the same late phase of the tests the insulation was also contributing. However, in this case there is a slight increase in concentration in the MW test compared with the PIR test.

Based on observation of the test and the fact that the measured data show an increase of some species concentrations, when inside the room the decay phase had started, it may be concluded, that in that phase of the fire in both tests the insulation products started to contribute to toxicity. Nevertheless much higher concentrations were reached in both tests due to the burning room contents in the early phases of the fire.

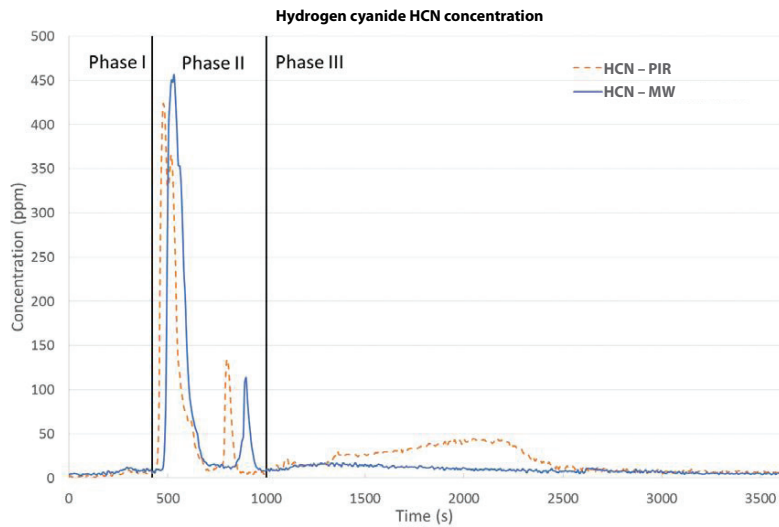
Concentration of carbon monoxide (CO) – 30 minute LC50 [6] at 5700 ppm.



Concentration of carbon dioxide (CO₂) – high concentration can cause hyperventilation which increases the rate of uptake of other toxic gases.



Concentration of hydrogen cyanide (HCN) – 30 minute LC50 at 165 ppm.



Concentration of acrolein (C₃H₄O) – 30 minute LC50 at 150 ppm.

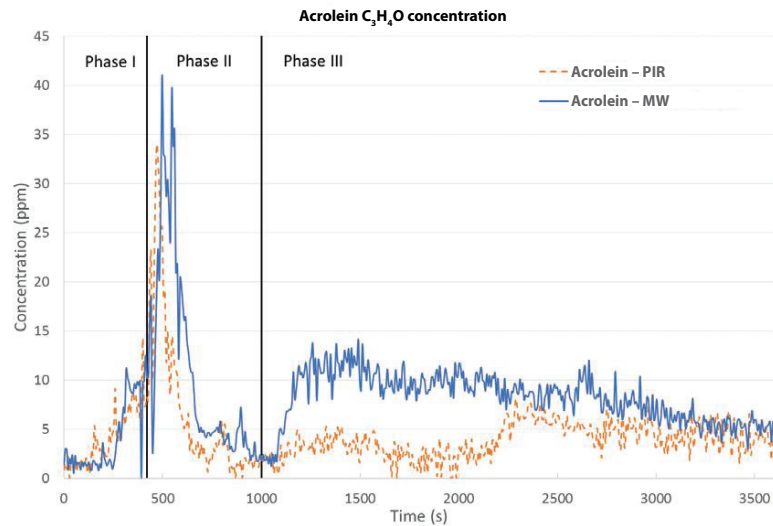


Figure 2: A selection of the recorded graphs on toxic effluents

Calculated values (FED and FEC)

In order to assess the relative toxicity of the gaseous effluents from both tests in the different phases of the fire, the Fractional Effective Dose (FED) and Fractional Effective Concentration (FEC) were computed by Exova Warringtonfire (UK) based on all effluents measured during the fire tests.

FED is an indication for untenable conditions due to the effects of asphyxiant gases.

FEC is an indication for untenable conditions due to the effects of irritant gases.

FED and FEC clearly demonstrate that the early phases of both tests, during which time the construction products were not yet involved in the fire, contribute the most to human toxicity. FED remained fairly static after about 10 min. A slight increase in FEC occurred in the MW test after about 18 min, but the increase and the absolute values were significantly lower than the peak values reached during flashover.

This means that the contents of the room were the major contributors to both FED and FEC.

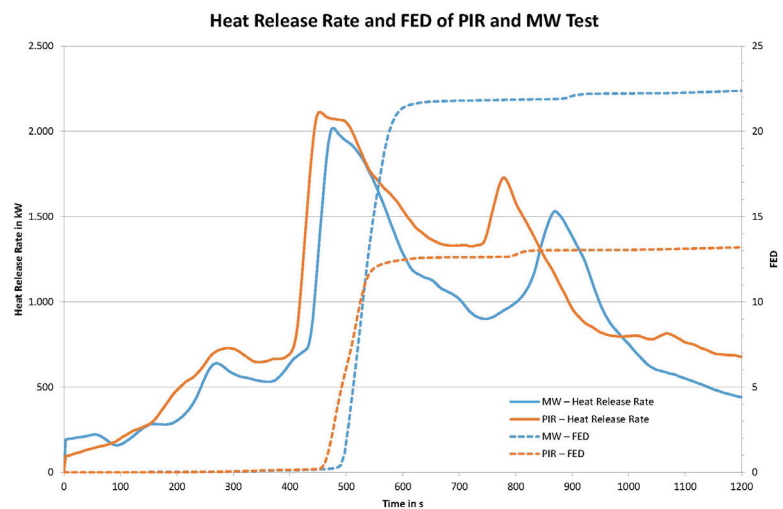


Figure 3: Heat Release Rate and FED of PIR and MW test

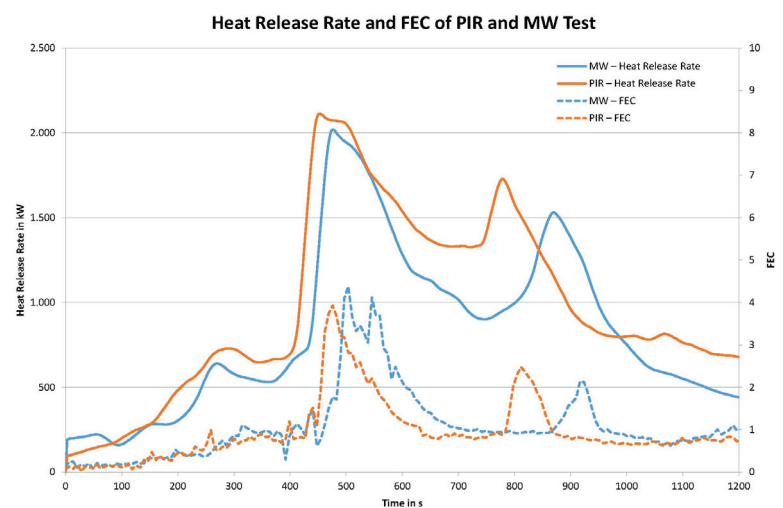


Figure 4: Heat Release Rate and FEC of PIR and MW test

Summary and conclusions

[...] in the early phase of a fire, which is decisive for safe escape, the content of the room is dominant for the fire development, smoke obscuration and smoke toxicity.

In every fire toxic smoke gases are generated which can lead to hazardous conditions for occupants. It is acknowledged that the toxicity of combustion gases from products and systems is strongly influenced by the environment, availability of oxygen, thermal attack, airflow and surfaces available for combustion.

The goal of this research was to determine whether the contribution of the building envelope to the overall smoke toxicity in a room is relevant. In order to investigate this, two tests were performed with a fire starting in furnished rooms with two different types of wall insulation.

It could be shown that in the early phase of a fire, which is decisive for safe escape,

the content of the room is the major contributor for the fire development, smoke obscuration and smoke toxicity. The contribution of the building envelope to generation of heat and smoke starts only in a further developed phase of the fire and is less significant than the contribution from burning building contents. In addition these tests show that the performance of the entire construction is more relevant than that of single construction products for the safe escape of occupants.

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 and therefore ensure the safety of occupants.

Disclaimer

While all the information and recommendations in this publication are to the best of our knowledge, information and belief accurate at the date of publication, nothing herein is to be construed as a warranty, expressed or otherwise.

References and notes

- [1] Study to evaluate the need to regulate within the Framework of Regulation (EU) 305/2011 on the toxicity of smoke produced by construction products in fires <https://ec.europa.eu/docsroom/documents/27346/attachments/1/translations/en/renditions/native>
- [2] [Fire and Materials conference 2017](#) proceedings pages 352-363 to access the research papers submitted by PU Europe.
- [3] *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*
- [4] Fire decay: Phase of fire development after a fire has reached its maximum intensity and during which the heat release rate and the temperature of the fire are decreasing
- [5] *SFPE – Handbook of Fire Protection Engineering*, edition 2016
- [6] LC50: Concentration of a toxic gas or fire effluent, statistically calculated from concentration-response data, that causes death of 50% of a population of a given species within a specified exposure time and post-exposure time