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# Assessment of the fire toxicity of building insulation materials

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ABSTRACT

A significant element in the cost of a new building is devoted to fire safety. Energy efficiency drives the replacement of traditional building materials with lightweight insulation materials, which, if flammable can contribute to the fire load. Most fire deaths arise from inhalation of toxic gases. The fire toxicity of six insulation materials (glass wool, stone wool, expanded polystyrene foam, phenolic foam, polyurethane foam and polyisocyanurate foam) was investigated under a range of fire conditions. Two of the materials, stone wool and glass wool failed to ignite and gave consistently low yields of all of the toxic products. The toxicities of the effluents, showing the contribution of individual toxic components, are compared using the fractional effective dose (FED) model and $LC_{50}$ (the mass required per unit volume to generate a lethal atmosphere under specified conditions). For polyisocyanurate and polyurethane foam this shows a significant contribution from hydrogen cyanide resulting in doubling of the overall toxicity, as the fire condition changes from well-ventilated to under-ventilated. These materials showed an order of increasing fire toxicity, from stone wool (least toxic), glass wool, polystyrene, phenolic, polyurethane to polyisocyanurate foam (most toxic).



## 1. Introduction

The primary function of most buildings is to provide shelter from wind and rain, and to protect their occupants from uncomfortable temperatures. Traditional building materials, such as brick, stone and timber have higher thermal capacities and higher thermal conductivity, and were suited to systems providing poor or slow control of the indoor temperature. Modern, lightweight building materials are cheaper to produce, transport and erect, and offer improved thermal insulation, allowing more efficient temperature control. In the US, 50–70% of domestic energy usage is for temperature control [1]. However, in comparison to traditional materials many insulation materials present a greater fire hazard, being less effective fire barriers, more combustible and having higher fire toxicity. The increased use of lightweight insulation materials will help to meet targets for carbon emissions, but this should not be at the expense of fire safety.

By design, when heated, the surface of insulation materials gets hot very quickly. If the material is combustible, this will result in ignition and rapid flame spread. The flammability of a material (or its ease of ignition and flame spread) is inversely proportional to the product of its thermal conductivity ($k$), density ($\rho$) and heat capacity ($C$), collectively known as the thermal inertia ($k\rho C$). For insulating materials this always has a low value.

### 1.1. Common insulation materials

There are wide variety of materials and methodologies for insulation of buildings to suit different circumstances. For large temperature gradients, reflective panels reduce the radiative heat transfer. For smaller temperature gradients most heat is transferred by conduction and/or convection, and the most effective (but not the most cost efficient) insulation is a vacuum. Gases have low thermal conductivity, but do allow convective heat transfer. Most common insulation materials comprise gases trapped in a matrix to inhibit convection. In this study six such materials in the form of rigid insulation panels were compared. These fall into two categories, inorganic fibres and organic foam products. The thermal insulation properties of these materials have been compared elsewhere [2], and are summarised in Table 1.

Both glass wool and stone wool are classified as non-combustible or limited combustibility depending on the binder content. While both loose small (~5%) quantities of pyrolysable binders, most of the mass will not burn and there is insufficient fuel for a flame to propagate through the bulk of the material, so their contribution to the fuel load is negligible. The foamed materials are organic polymer based, and depending on the fire conditions a significant part of their mass is lost as fuel, and may contribute to the overall size of the fire.

### 1.2. Fire hazard assessment

Fire safety requirements for building products are divided into fire resistance (the ability to maintain structural integrity in a fire)

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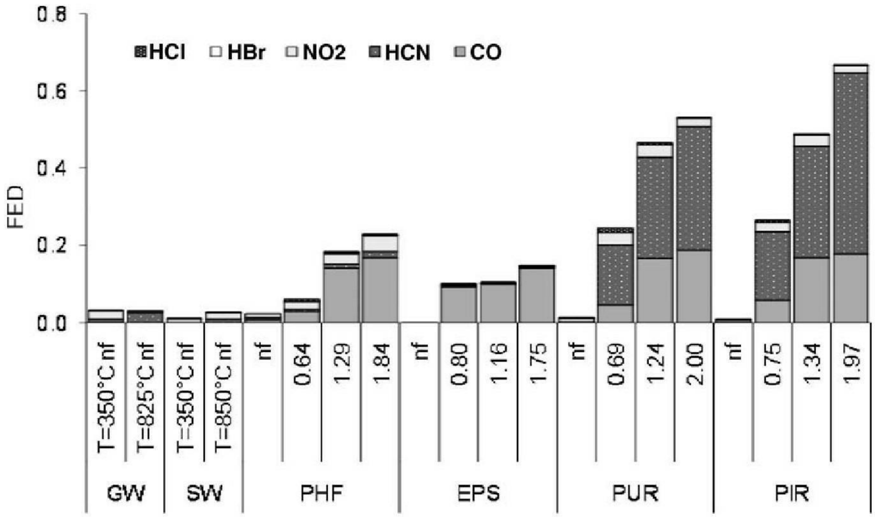


**Fig. 11.** Fractional effective dose for different products (as a function of equivalence ratio for flaming conditions).

The FED values were calculated using Purser's model as presented in Eq. (1).

Fire toxicity can also be expressed as an $LC_{50}$, the loading per $m^3$ predicted to be lethal to 50% of the population. The smaller the $LC_{50}$, the greater the fire toxicity. These values are shown in Table 8.

For example this shows that 8 g of PIR or 11 g of PUR foam burning in under-ventilated conditions would make 1 $m^3$ of air toxic, or 1 kg of such foam burning in under-ventilated conditions would provide lethal concentration of toxicants in a 100 $m^3$ room.

## 4. Conclusions

Fire toxicity is an essential component of any fire risk assessment. As the toxic products of some materials vary as a function of ventilation condition, it is necessary to perform assessments of fire toxicity under the more dangerous, but most likely under-ventilated burning conditions. The ISO TS 19700 steady state tube furnace is a suitable tool for undertaking such assessments.

Earlier studies of the fire toxicity of insulation materials [14,16] were only undertaken under well-ventilated conditions, and inconsistencies in the methodology made it difficult to extrapolate the measured toxicity to real fire conditions. However, both studies showed an increase in fire toxicity from glass wool and stone wool to polyurethane foam.

The current work shows lower carbon monoxide yields for all materials under well-ventilated conditions, compared to under-ventilated conditions, although the presence of halogens (presumably present as flame retardants) increases the CO yield in well-ventilated conditions. For the two nitrogen containing materials, PUR and PIR, the yields of hydrogen cyanide also increases with decrease in ventilation. When these yields are expressed in terms of the fire toxicity this shows a dramatic decrease in toxicity for the most common and most toxic under-ventilated condition: PIR > PUR > PHF > EPS. For the well-ventilated condition the order is similar: PIR > PUR > EPS > PHF.

Since neither GW nor SW undergo flaming combustion, while they can be tested under conditions which would represent well-ventilated or under-ventilated flaming, the data cannot properly be described as either. However, it is evident from the data presented here and that of other studies that the contribution to the fire toxicity for either glass wool or stone wool is negligible compared to that from any of the foam products. These results also indicate that fire toxicity of expanded polystyrene foam is lower that of PUR, PIR or even phenolic foam. However, the EPS determination should be repeated for the non-flaming condition to confirm the low yields, and identify the volatiles corresponding to the mass loss.

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