# Occupant toxic exposure to fires in rain-screen cladding systems

*An experimental investigation of fire gas exposure from un-fire-stopped penetrations through the external envelop of a building in association with the use of materials in the make-up of rain-screen cladding systems that may contribute to fire*

28th November 2018

## Executive Summary

*Within the limitations of a single set of experimental data, this study suggests that currently allowable building design detailing and material choices may have the potential to expose occupants to a toxic challenge from rain-screen cladding fires, at locations remote from the fire seat, that are meaningful in respect of their ability to effect an escape and survive, for some common material combinations. Exposure from typically compliant combinations of insulation and ACM were tested in association with a material configuration approximating to that used on Grenfell. These results, produced at a reduced scale that may underplay the toxic challenge, are believed to be sufficient to prompt further investigation of (a) the role that toxicity should play in building material selection, and (b) whether the passive measures within building regulations are sufficient for separating occupants and smoke where rain-screen systems are used, to confirm if a problem requiring a solution exists. Future further analysis of other measured species will consider any longer-term health and life expectancy implications for occupants, firefighters, and local residents, as well as refining these immediate-threat FED calculations.*

## Introduction

In a previous study conducted by the Fire Protection Association on behalf of the Association of British Insurers, the BS8414 test method was reviewed in the context of its ability to meaningfully assure the fire safety of materials used in the make-up of rainscreen cladding systems. Relevant to this study were the findings that:

- There is currently no requirement to fire-stop penetrations through the rain-screen cladding system, such as vents and ducts. Tests showed that this could allow very early and direct flame attack of materials within the rain-screen void, and additionally offered a route for the communication of fire, heat, and potentially toxic smoke to all other inhabited communicating spaces connecting via ducts or poor detailing with the rain-screen void.
- Cavity barrier systems, designed to close under the action of heat, have an operation time associated with them that has no requirement to be aligned with the ignition or smoke producing properties of the materials they seek to separate. As such, they may fail in isolation to be able to assure the limitation of spread of flame, heat, and potentially toxic smoke across the building envelop materials, or to inhabited areas.
- Evaluation of building product safety for external walls in current statutory guidance is limited to consider only fire spread. No consideration is given to how materials might contribute to fire in other ways that could be important to forming a more rounded view of safety, such as toxic contribution, and structural integrity of the façade as a system under fire.

Using the same basic experimental detailing as the previous study, this work sought to build upon the findings to investigate how material choice, penetration detailing, and assessment criteria, might impact upon the well-being of occupants at locations remote from the fire.

This work was funded by the UK insurance industry through RISCAuthority and conducted at the Fire Protection Association's (FPA) fire laboratory, with toxicant analysis being made by the University of Central Lancashire (UCLan). Material supply and design detailing were made through generous support by Ash & Lacy, and Ove Arup Partners Ltd, respectively.

This is an interim note to insurers on initial findings and considerations. A full peer-reviewed publication of the work will be produced in due course which will consider a more comprehensive toxicity model and detail other species relevant to longer-term health issues. This note will be shared with the various Grenfell Inquiry working groups, and others, to assist with ongoing conversations on:

- review of statutory guidance Approved Document B (AD B)
- material combustibility / participation
- test methods and safety evaluation criteria

- building height and function / occupancy
- stay-put evacuation policies
- occupant tenability associated with materials other than those in the occupied space
- collateral toxic risks to land and people
- fire stopping and cavity barrier specification

## Methodology

Using the same cut-down BS8414 style rigs used in the previous study, a total of four tests were conducted to compare the potential contribution from smoke toxicity that might be made by different cladding / insulation configurations as follows:

- Stone wool fibre insulated system with A2 ACM panels – Graph key 'SW/A2'
- Polyisocyanurate (PIR) foam insulated system with A2 ACM panels – Graph key 'PIR/A2'
- Phenolic foam insulated system with A2 ACM panels – Graph key 'PF/A2'
- Polyisocyanurate (PIR) foam insulated system with Polyethylene (PE) ACM panels (Grenfell approximation) – Graph key 'PIR/PE'

For all of these tests the cavity barrier and firestopping systems were identical.

## Toxicity measurement

Amongst other things, the toxicity of fire gases is heavily influenced by the materials involved, the amount of oxygen present in the flame, and what happens to the gases after by way of cooling and dilution. Meaningful measurement of toxicity therefore demands consideration of both the potential exposure routes and the various locations of formation. Whilst this study might focus around exposure of occupants to toxic gases through un-fire-stopped ducts and vents and perhaps poor window soffit detailing, consideration was also given to where exposure is via an open or broken window. These might be characterised as follows:

- Duct / vent / window soffit exposure: flames, possibly oxygen limited, within cladding void and fire products transferred directly to the occupied space without dilution and only limited cooling
- Open / broken window exposure: fire seat possibly well oxygenated on external cladding face with resultant fire products cooled and diluted with air

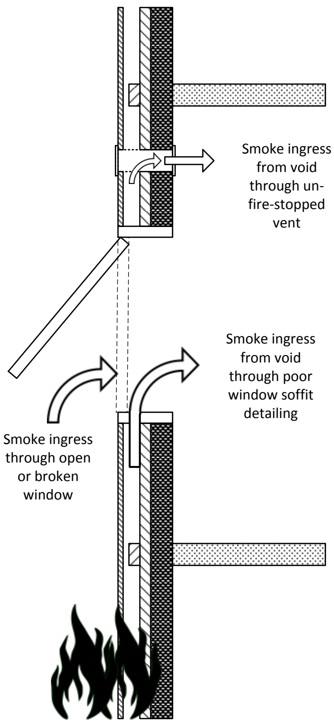


Figure 1 - Potential routes for occupant exposure to smoke originating from cladding system

To approximate these two scenarios gases were sampled at two representative locations: within an installed un-fire-stopped duct penetrating the cladding system; and within the test laboratory's smoke extract system as shown in Figure 2.

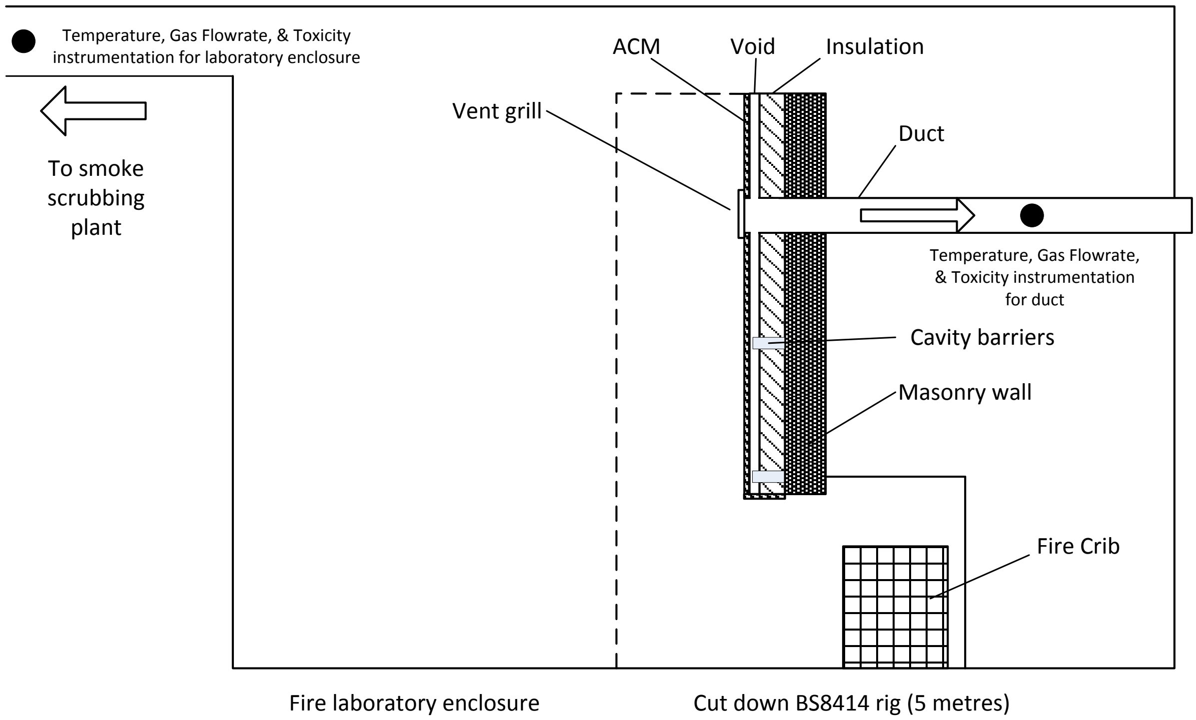


Figure 2 - Gas sampling configuration

For the purposes of this study the through-cladding duct was sleeved through to the void with the grill attached to the external face of the cladding system. This is a not uncommon method of installation. This configuration would also be representative of a continuous plastic sleeved vent that has melted or burned through in a fire as observed in the original ABI test programme. To accommodate flow measurement equipment and correct downstream pressures the length of the duct was greatly extended to pass through to a position external to the fire laboratory. This configuration will act to restrict the flow of gases through the duct thereby lowering the rate of contamination of any connected spaces and this should be taken into consideration when interpreting the results in respect of occupant exposure (these tests may underplay the actual threat).

## Cladding System specification

These tests were designed to be indicative in nature without being specific to any particular manufacturers' products. The flat panel ACM system was riveted to the support framework with a panel gap of 20mm. The thickness of insulation used in each test was established against a standard level of thermal performance. All test specimens had a common cavity width of 50mm. Cavity barriers were provided around the fire box window simulation, and horizontally across the rig at approximately 800mm above the lintel to approximate where a typical floor might be expected above a window. All other detailing was in accordance with the BS8414 rig dimensions aside from a restriction on height to 5 metres.

A 100mm diameter galvanized steel vent was included at the top of the test rig, to the left of the crib opening, to represent vent openings frequently incorporated in façade systems. No fire damper was installed within the vent as this is not currently normal practice.

## Test imagery

Images from each of the four clad tests are given in Figures 3 to 6. The location of the vent can be seen in the top left-hand corner of the main face of the cladding system. All tests were allowed to progress for a duration of 30 minutes with the exception of the PIR / PE ACM configuration which had to be stopped prematurely at 12 minutes for safety reasons, due to the fire size. Approximate estimation of total fire heat release rate for each test gave a value of around 3 MW.

Figure 3 - Stone wool insulated system with A2 ACM panels

Figure 4 - PIR insulated system with A2 ACM panels

Figure 5 - Phenolic insulated system with A2 ACM panels

Figure 6 - PIR insulated system with PE ACM panels (note test had to be stopped early, after 12 minutes)

## Measured quantities

The threat presented to occupants by fire products are many, complex, and interrelated. In rough order of immediacy of threat to occupants in this scenario, they include:

- Loss of visibility which may hinder escape (i.e. soot particulates)
- Substances irritant to the eyes and lungs which may hinder escape (i.e. hydrochloric acid, formaldehyde, and acrolein)
- Poisons that cause asphyxiation (preventing oxygen getting to the body) (a) by preferential combination with haemoglobin in the blood (carbon monoxide); and (b) by inhibiting cytochrome oxidase which prevents the use of oxygen by the body's cells (hydrogen cyanide)
- Gases that stimulate respiration thereby increasing the impact of other toxicants (carbon dioxide)
- Reduced oxygen availability as it is consumed by the fire
- Substances that exhibit a longer-term toxicity to humans (i.e. particulates, carcinogens such as polycyclic aromatic hydrocarbons, and endocrine disruptors).

Figures 7 to 14 show results for some of the species measured in the laboratory extract system, and cladding duct, respectively. Other species measured included (amongst others) acrolein, formaldehyde, and polycyclic aromatic hydrocarbons. These measurements will be reported in full together with their contribution to overall toxicity in a future paper. Carbon monoxide was sampled at a rate of 1 reading per second. Hydrogen Cyanide was measured using batch sampling over periods of 5 minutes.

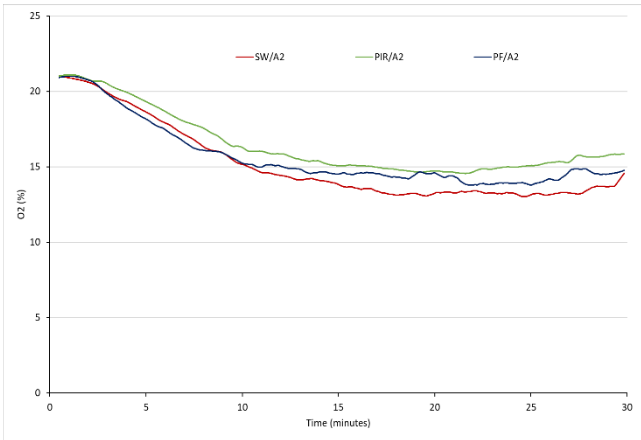


Figure 7 - Oxygen concentrations measured in laboratory extract system

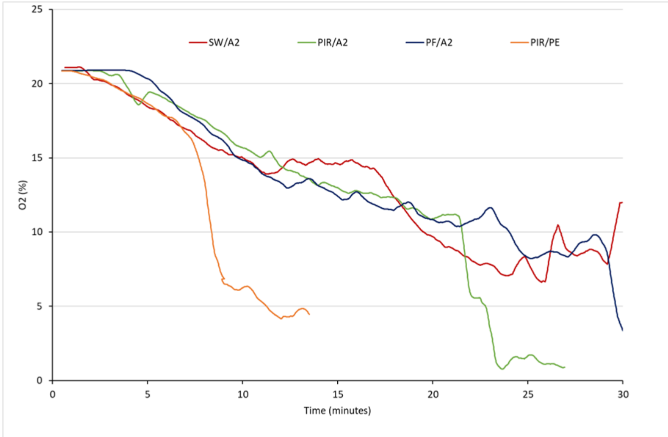


Figure 8 - Oxygen concentrations measured in cladding system vent

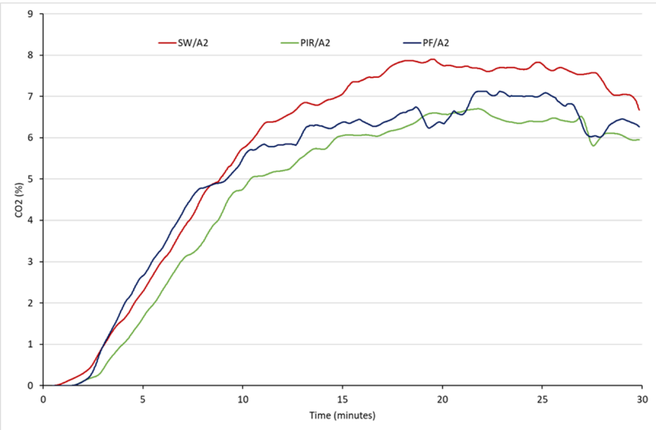


Figure 9 – Carbon Dioxide concentrations measured in laboratory extract system

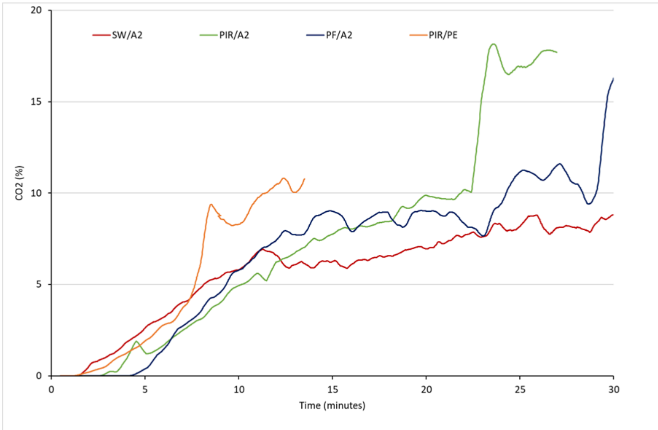


Figure 10 – Carbon Dioxide concentrations measured in cladding system vent

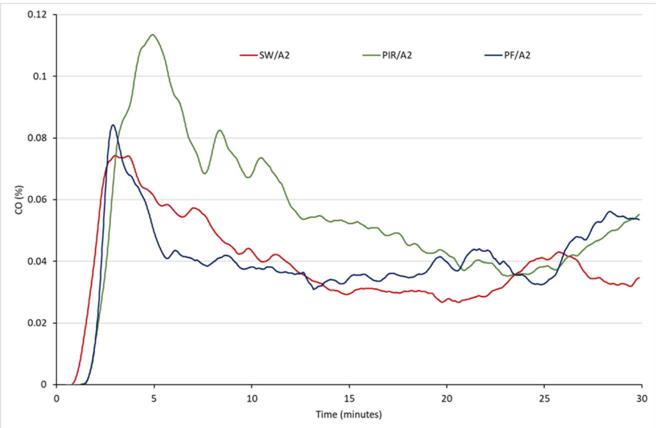


Figure 11 – Carbon Monoxide concentrations measured in laboratory extract system

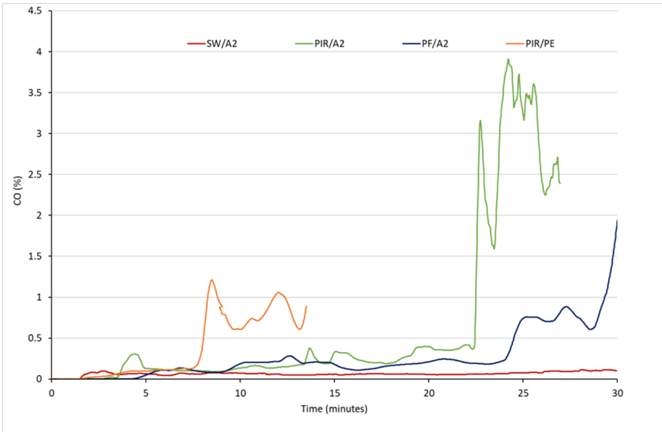


Figure 12 – Carbon Monoxide concentrations measured in cladding system vent

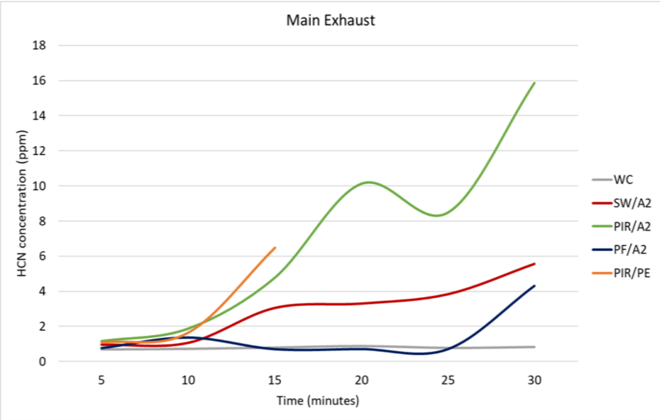

Figure 13 – Hydrogen Cyanide concentrations measured in laboratory extract system

Figure 14 – Hydrogen Cyanide concentrations measured in cladding system vent

## Data analysis

Toxic assessment of conditions is described in terms of Fractional Effective Dose to Incapacitation (FED(I)), and Fractional Effective Dose to Lethality (FED(L)).

A value of unity for FED(I) Incapacitation, predicts the time at which 50% of occupants would be unable to effect an escape unaided, in this case from a compartment of the size described. Values above unity give insight into the time at which incapacitation occurs for larger compartment sizes.

A value of unity for FED(L) Lethality, predicts the time from which 50% of occupants would die in the following 30 minutes if they are unable to escape from the compartment and were to remain exposed to the same toxic gases, for example as a result of incapacitation.

Toxicant data is used to predict occupant survivability in the configurations of:

- Smoke ingress through a window – this uses the data collected from the laboratory smoke extract system, and could be described as the effect on occupants immediately above the apartment of fire origin, assuming a mainly cellulose based fire (i.e. main contribution derives from the burning wood crib).
- Smoke ingress from the small duct into a room of 50m$^3$ – typical of a kitchen / living room where the insulation and ACM of the cladding system make a greater contribution to the entering gas composition.

**FED analysis of gases in laboratory extract system (Open / broken window approximate simulation):**

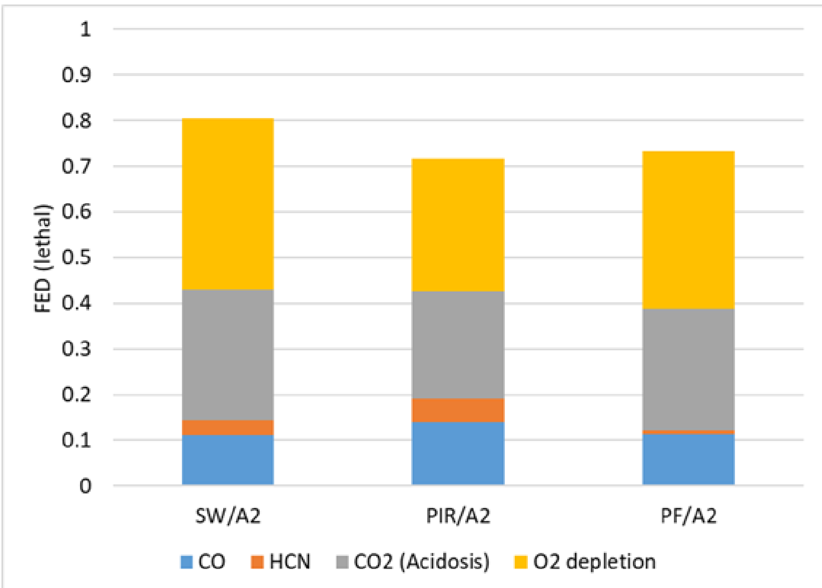

Figure 15 – Predicted incapacitation from breathing effluent from main exhaust for 5 minutes

Due to the limited size of the test rig / cladding specimen in relation to the size of wood crib fire challenge, the toxic signature measured in the laboratory extract system is overwhelmingly influenced by the wood crib fire itself ($O_2$ depletion and $CO_2$ Acidosis) and so no meaningful conclusions can be drawn from the data. This situation would be analogous to the effluent from the burning contents a room of fire origin (of cellulosic material) spilling into the flat above. In reality however, where there may be much greater fire involvement of the cladding system materials below an open or broken window, the toxic components of any entering smoke are likely to be much greater. Testing on a more realistic scale (and fire source to cladding exposure ratio) would be required to gain a better understanding of the toxic threat posed by ingress of smoke through a window.

**FED analysis of gases in 50m³ room connected to cladding void via a 100mm diameter vent:**

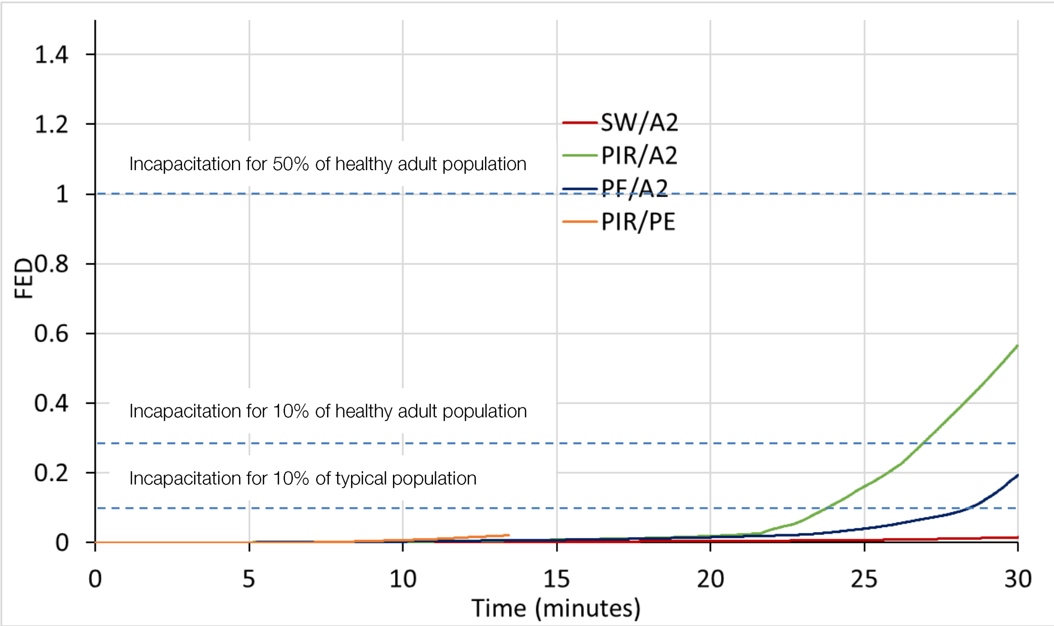


Figure 16 – Total FED for incapacitation for gases entering a 50m³ room from cladding through 100mm vent (The curve for PIR/PE is shown until the wood crib was extinguished at 12 minutes)

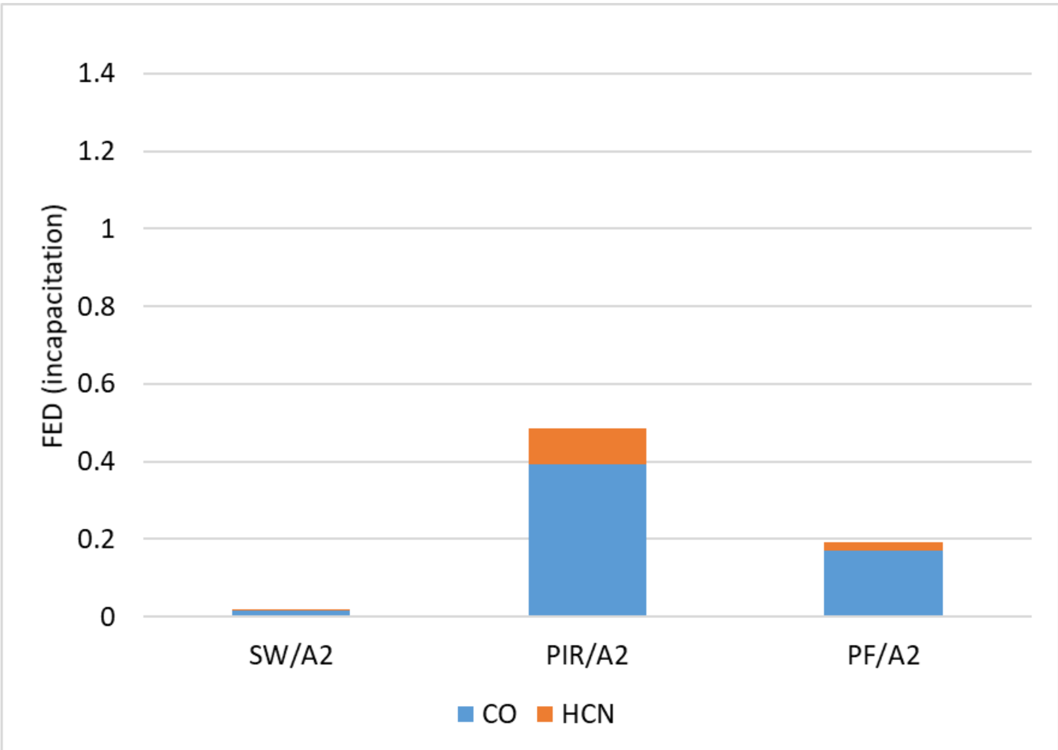


Figure 17 – Contribution of CO and HCN to incapacitation at 30 minutes for gases entering a 50m³ room from cladding through 100mm vent

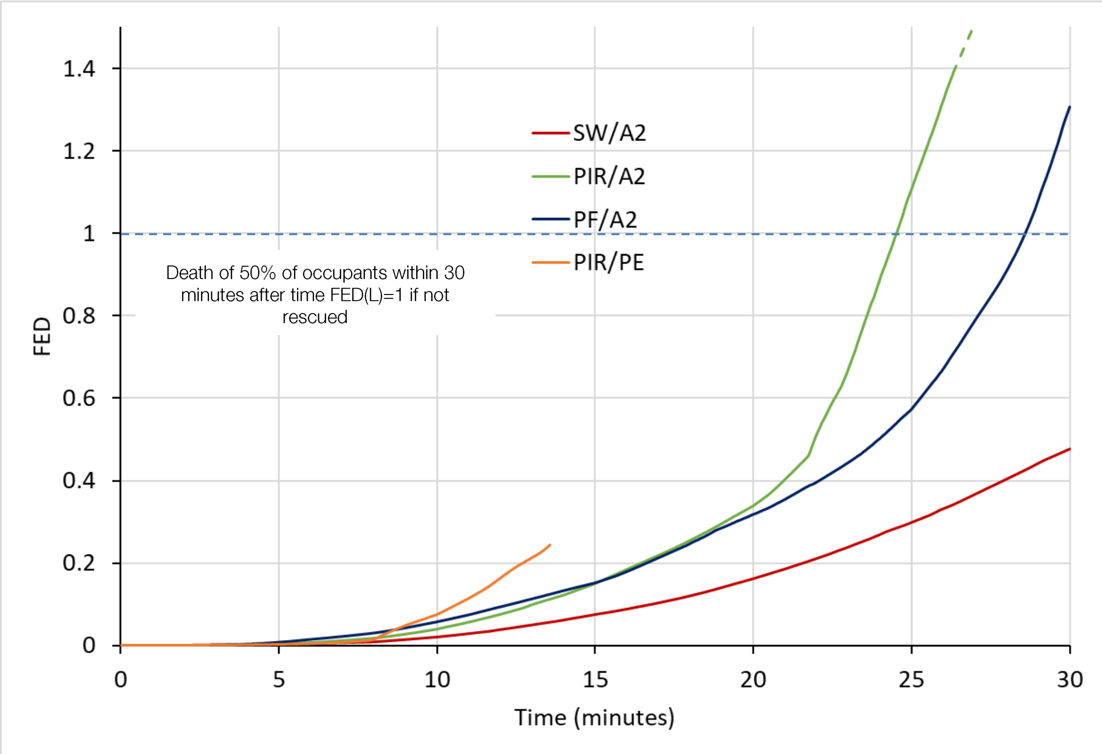


Figure 18 – Total FED for lethality for gases entering a 50m$^3$ room from cladding through 100mm vent (The curve for PIR/PE is shown until the wood crib was extinguished at 12 minutes)

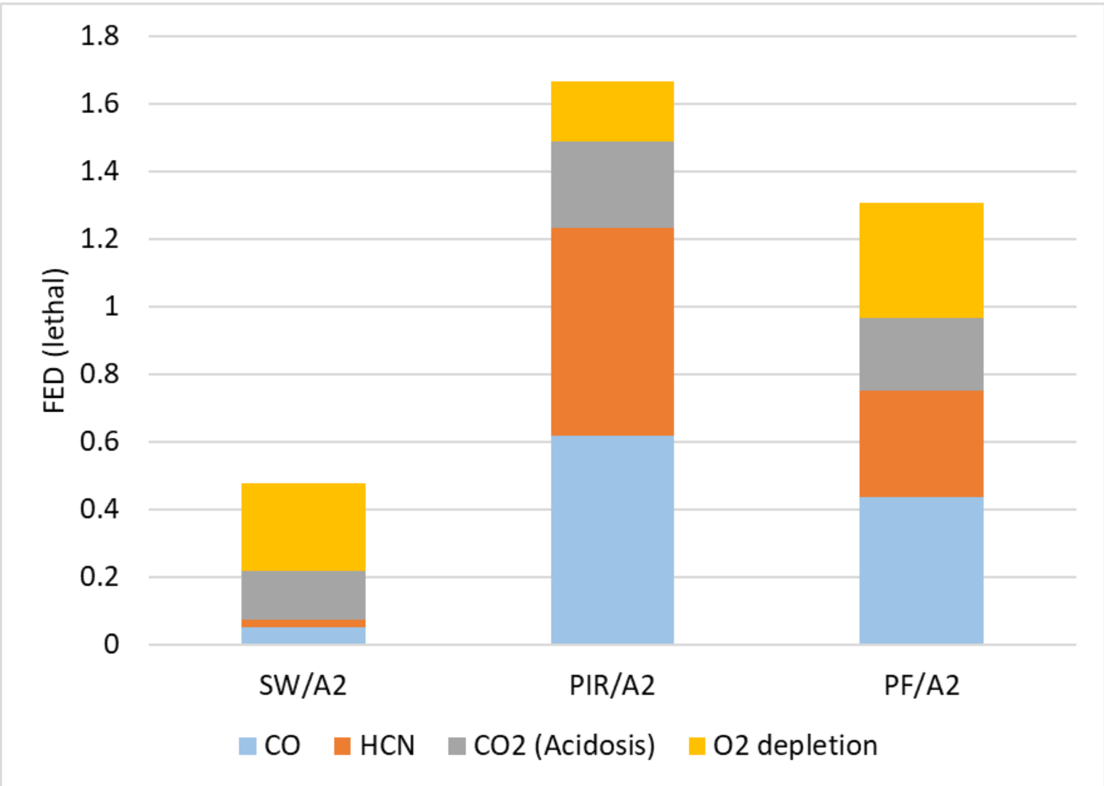


Figure 19 - Contribution of CO, HCN, $CO_2$ and $O_2$ to lethality at 30 minutes

Figure 19 shows the almost equal contribution of HCN and CO to the lethal concentration. As the wood crib produces no HCN the additional toxicity probably results from involvement of the cladding system. In each case the $CO_2$ (acidosis) and oxygen depletion, which predominantly results from the wood crib, also makes a significant contribution. This is because most of the fuel in this test is from the wood crib.

The fire effluent flowing in to cladding vent is observed to be representative of that in the laboratory extract system up to the point where fire breaks in to the section of the façade containing the vent. There is then an observed sharp increase in the concentrations of toxic gases in the void which transfer to the occupied space.

Incapacitation is generally predicted for 'healthy' adult populations and fire engineering judgement might be used to adjust the data to lower margins to ensure no more than 10% of this population are incapacitated (FED(I)=0.3). A working FED(I) value of 0.1 might typically be chosen to account for populations that deviate from the definition of 'healthy'.

For a 50m$^3$ room, connected to the rain-screen void via a 100mm vent, the results suggest that for some material combinations (ones with higher combustible content) incapacitation can occur in around 10 minutes after the fire breaks into the location of the cladding system containing the vent (at around 7, 22, and 29 minutes for PIR/PE, PIR/A2, and PF/A2, respectively), and, if they cannot escape before becoming unconscious, that death may follow within 30 minutes if they are not rescued.

## Conclusions

This reduced height and limited test programme has demonstrated a potential for human exposure to fire products from materials that make up rain-screen cladding systems from configurations that are compliant in terms of the materials used and the current fire-stopping requirement of penetrations that breach the connecting void. Whilst significantly important toxic challenges have been measured for some material combinations (those having higher combustible content) further testing would be required to establish a truer understanding of the extent of risk that might exist. Some features of this test regime might lead to an underestimation of risk, particularly in respect of the duct configuration which, due to its long length, might limit measured flows and contamination rates and quantities into the occupied space, and the ratio of wood crib fire load to cladding system frontage.

Perhaps one of the most important messages of this study is to question the very limited amount of information collected from the BS 8414 test regime. Curtailment of understanding and effort to pass only a threshold test temperature at a specific time seems not in the spirit of having a true desire to understand the safety of materials in use when so many other factors are additionally important.

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