Thoughts on the Grenfell Tower Fire: When the Colour of Fire is Grey

Prof Ed Galea
Director Fire Safety Engineering Group
University of Greenwich
27/07/17
e.r.galea@gre.ac.uk
http://fseg.gre.ac.uk

The blackened edifice of Grenfell Tower looms like a tombstone over west London, and a nation, where such monumental tragedy from fire had been thought impossible. The inferno that consumed the tower on the morning of 14 June 2017, left it a symbol of unfathomable loss: at least 80 men, women and children who lost their lives, their loved ones lost in grief, and public trust in the institutions and authorities that failed them, lost too, or at least greatly diminished.

But though the tragedy cast a long, dark shadow, it also threw light on the better angels of human nature, particularly the firefighters who ran through the ghosts of 9/11 into the burning tower. Those men and women are heroes to me and a nation. I was deeply moved by the professionalism of all the emergency services that night, and the humanity of the volunteers, who embraced the grieving and displaced in the days and weeks that followed.

These selfless acts of bravery and humanity give me some solace, but they cannot redeem the human failings that led to this tragic and completely avoidable loss of life. Rather than being 'unprecedented', as stated by some observers, similar cladding fires on tower blocks around the world, and at Lakanal house in the London borough of Southwark, were beacons warning of the risk of covering buildings in combustible materials. These warnings were ignored.

There are a number of important issues concerning the Grenfell Tower tragedy that must be addressed, not only to understand what caused this fire and to ensure that a similar event can never happen again, but also to determine what led to the unprecedented loss of life. It is likely that the failures at Grenfell Tower, resulting in the rapid fire development and the large loss of life, were caused by systemic failures of not just one, but a number of complex systems. Thus, there is unlikely to be a single root cause of this tragedy, but rather a number of contributory causes arising from failures across the systems and processes, upon which we rely for safety in the built environment.

Much of the discussion in the media has focused on one component of the façade, overlooking that a building façade is a complex system, made up of many components, each of which may have had a role to play in preventing or supporting the rapid external flame spread that occurred at Grenfell.

The Grenfell Tower façade is a complex system made up of thermal insulation material (primarily Celotex RS5000, a polyisocyanurate (PIR) insulation board covered in aluminium foil on both sides), the aluminium composite panel

(Reynobond PE) or ACP (consisting of two 0.5mm thick aluminium sheets covering a 3mm or 4mm polyethylene (PE) core), which protects the thermal insulation from the weather, a 50 mm void between the insulation and the cladding to provide ventilation for the insulation layer and various horizontal and vertical fire barriers, intended to prevent both vertical and horizontal fire spread within the void. In addition, the façade has a number of penetrations, such as windows and vents. Each of these penetrations are supposed to be protected by fire stopping surrounding the perimeter of the penetration. Finally, the façade of the Grenfell Tower had a number of vertical columns (or ribs) on each of its four faces. These columns were covered in both the PIR insulation and the ACP panels. How the insulation, cavity barriers, fire stopping and cladding were applied and fixed to these columns is an important component of the façade system, as each column provides a continuous vertical link extending for the full height of the building.

While rapidly spreading façade fires have occurred in many high-rise buildings around the world (see list), many with the potential to cause a large loss of life, most resulted in no fatalities, and none led to the loss of life on the scale of Grenfell. So what made Grenfell different? Why did so many people die?

- Ajman (UAE, Ajman One Towers (towers six and eight), 28 Mar 2016, 26 floors, 0 fatalities)
- Dubai (UAE, The Address, 31 Dec 2015, 63 floors, 1 fatality?)
- Sharjah (UAE, Nasser Tower, 1 Oct 2015, 32 floors, 0 fatalities)
- Baku (Azerbaijan, 19 May 2015, 16 floors, 15 fatalities)
- Dubai (UAE, Marina Torch, 21 Feb 2015, 79 floors, 0 fatalities)
- Melbourne (Lacrosse building, 25 November 2014, 0 fatalities)
- Chechnya (Grozny-City Towers, 3 April 2013, 40 floors (hotel and apartment) 0 fatalities)
- Roubaix France (Mermoz Tower, 14 May 2012, 18 floor, 1 fatality)
- Shanghai (fire during retrofitting building with cladding, external bamboo scaffolding and plastic covering involved, 15 Nov 2010, 28 floors, 58 fatalities)
- Busan Korea (Wooshin Golden Suites, 1 Oct 2010, 42 floors, 0 fatalities)

In the case of Grenfell, public and government attention has fixated on just one component of the façade system: the aluminium composite panel (ACP), which no doubt played a significant role in this tragedy, but is unlikely to have been the sole culprit leading to the rapid fire development over the façade; and it is unlikely to be the sole contributing factor leading to the large loss of life. Indeed, other complex systems and processes interacting with the façade system, such as the glazing units, the façade and glazing installation processes, the internal compartmentation system, the 'stay or go' principle, the building evacuation system, the fire brigade response, the 999 call handling system, etc., may also have played a significant role in this tragedy.

It is thus essential that the official Inquiry into the Grenfell disaster considers a number of issues associated with these complex systems, including:

- **Building regulations - are they appropriate for building façade systems and are they sufficiently clear? (see Part 1).**

- **Façade construction, and why the fire spread so rapidly – were the materials compliant and are they appropriate? (see Part 1).**
- **The compartmentation concept - which components of this system failed and why? (see Part 2).**
- **The ‘stay put’ principle - was this the correct strategy, and should there be a Plan B? (see Part 3).**
- **Fire Brigade tactical response and 999 call handling - do fire incident commanders have a Plan B when compartmentation has clearly failed, how/when are the 999 call handlers told to change the standard advice? (see Part 3).**
- **The evacuation system - is a single stair appropriate? (see Part 4).**
- **Fire alarms - how do you alert people of the need to evacuate without one? (see Part 4).**
- **The role of sprinklers - would they have made a difference? (see Part 5).**

In the following discussion each of these issues are examined in turn. The discussion is split into five parts, with each part focusing on one of the above issues. The longest discussion is Part 1 and concerns the regulations.

(1) Part 1 - Building Regulations and Façade Construction:

While I do not claim to be an expert on the building regulations, it is worth exploring the details of both the regulations and the associated approved document, and how they relate to building façades.

In England and Wales, the Department for Communities and Local Government (CLG) is responsible for the Building Regulations. The regulations apply to most new buildings, and many alterations to existing buildings. The detailed requirements of the Building Regulations for England and Wales are set out under 14 separate headings (‘Part A’ to ‘Part R’), and cover a range of requirements, from Part A, which deals with structure, to Part R, dealing with physical infrastructure for high-speed electronic communication networks. The section dealing specifically with fire safety is Part B.

Along with the regulations there are a series of approved documents (AD) that provide general guidance on how specific aspects of building design and construction can comply with the building regulations. However, the AD are not legally binding; rather, they present the expectation of the Secretary of State concerning the standards required for compliance with the building regulations, and the standard methods used to achieve these.

One of the sections of Part B of Schedule 1, of the Building Regulations 2010, that is relevant to the Grenfell fire is Section B4. The first part of this regulation states the following requirement (see page 91 of AD B Vol 2):

"B4. (1) The external walls of the building shall adequately resist the spread of fire over the walls and from one building to another, having regard to the height, use and position of the building."

Immediately we find an important aspect of the regulation that is open to interpretation - the external walls of the building shall '***adequately resist the spread of fire over the walls***'. What does 'adequately' mean, and how is it quantified with regard to the identified factors? To address these issues, we have the AD B, which should explain and quantify the intent of the regulation.

AD B, section B4 goes on to provide guidance on how to meet this requirement, and provides guidance on what is meant by 'adequately resist spread of fire'. The section on external wall construction states (see AD B page 93):

"12.5 The external envelope of a building should not provide a medium for fire spread if it is likely to be a risk to health or safety. The use of combustible materials in the cladding system and extensive cavities may present such a risk in tall buildings.

External walls should either meet the guidance given in paragraphs 12.6 to 12.9 or meet performance criteria given in the BRE Report, 'Fire Performance of external thermal insulation for walls of multi storey buildings (BR 135) for cladding systems using full scale test data from BS8414-1:2002 or BS8414-2:2005.

The total amount of combustible material may also be limited in practice by the provisions for space separation in Section 13 (see paragraph 13.7 onwards)."

The opening paragraph of 12.5 allows the use of combustible materials in the façade system, if it can be shown not to be a risk to health and safety. This is a meaningless statement; nothing is without risk, so a level of acceptable risk should be specified. Unfortunately, it does not quantify what level of risk is considered unacceptable.

However, the second paragraph of 12.5 goes on to provide two possible routes to satisfy the fire spread issue associated with combustible materials in the façade (and hence presumably demonstrate that the risk associated with use of such materials is acceptable). One approach, commonly known as the prescriptive approach, is to follow the requirements of sections 12.6 to 12.9, the other, to satisfy the performance requirements of a full-scale fire test of the façade system using the specified British Standard (BS) test method: BS8414. Clearly, the latter approach is more onerous and costly, as it requires a full-scale fire test of a representative portion of a building. So the prescriptive route, specified in paragraphs 12.6 to 12.9 is likely to be preferable to architects and fire engineers.

1.1 PRESCRIPTIVE ROUTE TO SATISFYING PARAGRAPH 12.5

The key requirement of the prescriptive route relevant to the Grenfell fire is split into three parts describing the complex façade system: 12.6 refers to the external surfaces of the walls of the façade system (in the case of Grenfell, this would be the Reynobond PE ACP), 12.7 refers to the internal insulation materials used in the façade system (in the case of Grenfell this would be the Celotex RS5000), while 12.8

and 12.9 refer to the void space between the external cladding and the internal insulation of the façade system, and the fire barriers within the void (see AD B, pages 93 and 94).

In discussing material fire properties both UK and EU standards are used. This can be very confusing and so the following table is provided as a rough guide to the comparison between the various fire ratings.

Comparison between UK and EU fire ratings for materials

UK Classification BS 476 series	EU Classification EN-13501	Example Product (tested to EU classification)
Non-Combustible	**A1**	**Stone wool, glass wool, etc.**
Limited Combustible	**A2-s3, d2 or better**	**High density and high binder or faced Stone and Glasswool**
Class 0	**B-s3, d2 or better**	**Some Phenolic foams**
Class 1	**C-s3, d2 or better**	**Some PIR foams**
Class 3	**D-s3, d2 or better**	**Most PIR foams**

In this table, S3 refers to 'no limitation on smoke production' and d2 refers to 'no limitation on flaming droplets/particle production'.

Consider each major component of the façade system:

(a) EXTERNAL CLADDING:

First, consider the requirements for the external cladding. The relevant paragraph states:

12.6 The external surfaces of walls should meet the provisions in Diagram 40. …..

According to Diagram 40, for a building over 18 m high, if the building faces are less than 1.0 m from a boundary, they must satisfy ***UK Class 0*** or European Class B-s3, d2 or better. This requirement is primarily designed to prevent spread of a façade fire to neighbouring structures. If the building faces are more than 1.0 m from the boundaries, then the building faces below 18m should have an 'I' index (see test methodology description) of not more than 20, according to the BS 476-6 test or, according to the European Class be C-s3, d2 or better. For the surfaces of the building above 18 m, the faces should be the same as for buildings less than 1 m from the boundary.

At this point the guidelines do not explicitly specify how to demonstrate that the external cladding meets UK Specification Class 0. This is not a classification identified in any BS test. Here, again, the guidance document becomes difficult to follow. To determine what is meant by Class 0 we must refer to Appendix A of AD B.

In Appendix A, page 118 in the section on fire resistance, paragraph 5 states that:

"5 Performance in terms of fire resistance to be met by elements of structure, doors and other forms of construction is determined by reference to either:
a. (National Tests) BS 476 Fire Tests on building materials and structures ….
b. (European Tests) …."

This suggests that the external cladding materials could be tested using one or several of the fire tests specified in BS 476 OR the European test methodology could be followed. Note the various BS 476 tests are described at the end of this article. While there is no section in the Annex that explicitly refers to external cladding materials and the required testing methodology, Section 10 to 16 refer to internal linings, making explicit mention of Class 0 (see Annex A, page 119). Here the word 'internal' in reference to linings is assumed to mean within the walls and ceiling of the fire compartment. However, it is commonly assumed that it also applies to the external façade materials.

"Internal Linings
11 Under the National classifications, lining systems which can be effectively tested for 'surface spread of flame' are rated for performance by reference to the method specified in BS 476-7:1971 Surface spread of flame tests for material, or 1987 Method for classification of the surface spread of flame of products, or …. Under which materials or products are classified as 1, 2, 3, 4 with class 1 being the highest.

12 To restrict the use of materials which ignite easily, which have a high rate of heat release and/or which reduce the time to flashover, maximum acceptable fire propagation indices are specified, where the National test methods are being followed. These are determined by reference to the method specified in BS 476-6:1981 or 1989……

13 The highest National product performance classification for lining materials is Class 0. This is achieved if a material OR the surface of a composite is either:
a. composed throughout of materials of limited combustibility; or
b. a Class 1 material with a fire propagation index (I) of not more than 12 and sub-Index (i1) of not more than 6."

Paragraph 13 provides two (conflicting) options for a material to be classified as Class 0. The paragraph gives the impression that both options are equivalent, when they are clearly different. Note, when dealing with a composite material (such as ACP), paragraph 13 suggests that the proposed criteria need only apply to the surface of the composite.

The first option (paragraph 13a) is that the material can be a Material of Limited Combustibility. This sentence is confusing as it stipulates that the material in question should be 'composed throughout' and hence not just the surface as the main part of paragraph 13 states. Materials of limited combustibility are defined earlier in Appendix A in paragraph 9 as follows:

"9 Materials of limited combustibility are defined in Table A7:
a. (National Classes) by reference to the method specified in BS 476: Part 11: 1982 or

b. (European Classes) in terms of performance when classified as class A2-s3, d2 in BS EN 13501-1:207 …"

However, BS 476: Part 11 is not appropriate to test an ACP because the panels are clearly composite materials which are excluded from the testing protocol. The alternative route is to accept the European classification of materials of limited combustibility and only consider materials that are classified as A2. ***Had this approach been adopted the ACP with PE core would have been considered unacceptable.***

However, Paragraph 13 offers an alternative approach using paragraph 13b. Combining the requirements of limited flame spread (paragraph 11) and limited combustibility (paragraph 13b), a Class 0 material is defined as a Class 1 material (determined by BS476-7), thereby satisfying the limited flame spread requirement (paragraph 11), and it must also have index (I) (determined by BS 476-6) of not more than 12 and sub-Index (i1) of not more than 6, thereby satisfying the limited flammability requirement (paragraph 13). Such a material is considered Class 0, i.e. a material that protects the surface from the spread of flames (BS 476-7) and limits the amount of heat released from the material during combustion (BS 476-6).

The contradictory nature of paragraph 13 arises because it suggests that a material of limited combustibility (i.e. Euroclass A2) and Class 0 materials (i.e. equivalent to Euroclass B) are equivalent, which clearly, they are not. ***Materials of limited combustibility exceed the performance of Class 0 materials.***

The difficulties with these requirements are:

1. They do not explicitly reference external cladding, but they do provide a means to demonstrate compliance with Class 0 and Class 1 requirements, which are required by the external face of the façade system, as described by paragraph 12.6.
2. Aluminium will satisfy Class 1 requirements according to BS476-7, and so if the ACP test sample surface is exposed to the test conditions, the ACP will achieve a Class 1 rating. However, if an edge of the ACP is exposed to the test conditions, or if the surface of the ACP is damaged, revealing the core, it may or may not pass the test, depending on the nature of the core material. Edges of ACP panels in external cladding may be exposed to flame if the panel is not correctly installed. Furthermore, when the ACP is exposed to high temperatures of a post flashover spill plume, the surface of the ACP is likely to rapidly delaminate, exposing the core material. A PE core material is highly unlikely to pass under these circumstances.
3. Paragraph 13 allows ONLY the surface of a composite to be tested according to BS476-6. If the surface aluminium of an ACP is tested under the conditions of BS476-6, it generally performs well in this test, and may meet the requirement of Class 0. It is not clear if the Reynobond PE panels used in Grenfell satisfied the Class 0 requirements, or underwent the testing required by BS 476-6 and -7, but it is claimed that the product meets the ASTM E84 fire test and is classified as Class A[1], which is believed to be equivalent to Class 0.
4. The small-scale test methodologies prescribed in BS 476-6 and BS 476-7 are primarily designed to test internal linings subjected to fire. The tests simulate

fire conditions in a compartment in the early pre-flashover stage to near flashover conditions[2]. The nature of the fire assault on internal lining materials and external cladding materials found in facades are likely to be very different. One likely mechanism for the external cladding material to be assaulted by fire is via the spill plume emerging from the window of a post-flashover fire compartment, as is possibly the case in the Grenfell Tower and Lakanal House fires. Under these conditions, the external cladding will be exposed to very different temperature and radiative flux profiles than an internal lining that is exposed during a developing fire. So it is questionable whether these small-scale tests are appropriate for external cladding materials subjected to post-flashover spill plumes. Furthermore, due to the chimney effect, which may occur in façade systems with an internal void or cavity (similar to the Grenfell installation), both faces of the external cladding may be exposed to fire assault, which is not considered in these tests.

So according to the small-scale fire test specified in AD B, the ACP with PE core may have passed the requirements for Class 0. It remains to be seen if there is appropriate documentation to demonstrate compliance. It is noted that the alternative mineral-filled ACP, Alucobond A2, is claimed to meet the Class 0 requirement and the European A2 requirement[3].

Recent government tests on cladding materials have focused on the core of the ACP i.e. the PE[4]. As of 20th July 2017, flammability tests had been conducted on the cladding material from 189 tower blocks in the UK that are over 18m in height, and found all of them to be non-compliant i.e. failing to meet the Class 0 requirement[5]. It is not surprising that the PE failed, as it is known to be highly combustible. What is surprising is that so many buildings have used the ACP with PE core when there are so many other better options available. The difficulty lies with the ambiguity of AD B paragraphs 12.6 to 12.9. The external wall i.e. the ACP cladding can be shown to satisfy 12.6 (as suggested above) and so the ACP with PE core can be argued to be compliant with 12.6. Paragraph 12.7 can be taken to apply only to the insulation materials that form the façade system (in the case of Grenfell, the PIR used in the Celotex RS5000), and not to refer to the core of the external cladding i.e. the PE. However, the government has interpreted paragraph 12.7 to also apply to the external cladding, which is covered by paragraph 12.6. So here the guidelines can be argued to be open to interpretation.

RECOMMENDATON 1: When making use of the prescriptive route, as specified in paragraphs 12.6 to 12.9, referring to the external surface of the façade system (paragraph 12.6):

- **a)** The guidelines should explicitly refer to the façade system and identify each of the components that make up the façade system and the fire performance required for each component.
- **b)** Clear, unambiguous guidelines should be provided to specify the suitability of the external cladding of a façade system.
- **c)** Test methods used to demonstrate compliance of the external cladding material should be appropriate for the severe fire conditions that the material may be subjected to in practice. The most severe likely conditions would result from a post-flashover spill plume emerging from a vent of a fire compartment (eg a window). If the façade system involves cavities, the

testing should assume that both faces of the external cladding are subjected to fire assault.

d) The current test methodology only requires that the surface of a composite panel meets the specified requirements. However, if an edge of a composite panel is exposed to the test conditions, or if the surface of the composite panel is damaged, revealing the core, or if the surface of the composite panel delaminates due to the extreme nature of the fire event, then the composite panel may not pass the test, depending on the nature of the core material. The test methodology should be adapted to consider exposing edges of composite panels to appropriate test conditions, or a separate test should be devised to consider the core of composite panels.

e) The external façade of a building is a highly complex system made up of many interacting components. It is unlikely that small-scale tests on individual components of the façade (even if the tests can be shown to adequately represent the fire environment to which the façade is likely to be subjected) will reveal how the façade system as a whole is likely to perform in a fire. Ideally, if adopting this approach to approve materials used in the construction of the façade system, the materials should satisfy the more demanding non-combustible classification. Alternatively, if combustible materials are to be utilised within the façade, then the performance route (see 1.2) must be adopted to demonstrate compliance of the façade construction.

(b) FAÇADE INTERNAL INSULATION:

Next consider the requirements for the façade internal insulation. In the case of Grenfell, this relates to the PIR insulation, reported to be ***Celotex RS5000 polyisocyanurate (PIR),*** placed against the external surface of the solid wall of the building.

"12.7 In a building with a storey 18m or more above the ground level any insulation product, filler material (not including gaskets, sealants and similar) etc. used in the external wall construction should be of limited combustibility (see Appendix A). This restriction does not apply to masonry cavity wall construction which complies with Diagram 34 in Section 9."

Paragraph 12.7 again uses the term ***'limited combustibility',*** without specifically saying what this means. However, as seen earlier, Appendix A of AD B provides guidance on what this means. Materials of limited combustibility are defined in Appendix A, page 119 paragraph 9.

"9 Materials of limited combustibility are defined in Table A7:
a. (National classes) by reference to the method specified in BS 476: Part 11: 1982 or
b. (European classes) in terms of performance when classified as class A2-s3,d2 in BS EN 13501-1:207 …

Table A7 also includes composite products which are considered acceptable and where these are exposed as linings they should also meet any appropriate flame spread rating."

This suggests that materials of limited combustibility are defined according to the small-scale test method BS 476: Part 11: 1982, or according to European classes (A2). Furthermore, Table A7 provides definitions of materials of limited combustibility. The relevant part of this to the Grenfell fire is section 8, which states that 'Insulation material in external wall construction referred to in paragraph 12.7 should satisfy any of four criteria'. The ones relevant to the Grenfell Celotex RS5000 PIR material are:

- ***"(b) Any material of density 300 kg/m^3 or more, which when tested to BS476-11:1982, does not flame and rise in temperature on the furnace thermocouple is not more than 20 C.***
- ***(d) Any material of density less than 300 kg/m^3, which when tested to BS476-11:1982, does not flame for more than 10 seconds and the rise in temperature on the centre (specimen) thermocouple is not more than 35 C and on the furnace thermocouple is not more than 25 C."***

Option (d) would apply to the Grenfell Celotex RS5000 PIR material. However, the Celotex RS5000 does not appear to have undergone this testing. Rather, it is claimed that it meets the Class 0 requirements by satisfying BS 476-6 (fire propagation) and BS 476-7 (surface spread of flame)[6]. The reference to the Celotex RS5000 satisfying Class 0 requirements presumably refers to the requirements described in paragraph 13, page 120 of Appendix A. Here again, the interpretation is that the alternative options provided by paragraph 13 of Appendix A suggests that materials of limited combustibility (Euroclass A2) and Class 0 materials (Euroclass B) are equivalent, which clearly, they are not. Satisfying the Class 0 requirements does not mean that the material is of limited combustibility (Euroclass A2), and so AD B is confusing and prone to misinterpretation.

In addition to satisfying Class 0, the Celotex RS5000 data sheet also specifies that the material satisfies the requirements of the BS 8414 test[6,7] – this is the alternative performance-based approach, provided by the AD B to meeting the requirements specified in paragraphs 12.6 to 12.9 - and furthermore is the first PIR board to do so[7]. Presumably, this is intended to provide additional justification for its compliance with the requirements of AD B and its use in external façade systems.

The difficulties with this approach are:

1. The small-scale tests prescribed in BS 476-6 and BS 476-7 are primarily designed to test internal linings. The nature of the fire assault on internal lining materials and external façade materials may be very different. One likely mechanism for the external insulation material in the façade to be assaulted by fire is via the spill plume emerging from the window of a post-flashover fire compartment. This can attack the insulation, either when the external cladding has failed, exposing the insulation material directly to the spill plume, or via the chimney effect where the spill plume gains access to the façade void. Under these conditions the insulation material in the façade may be exposed to very different temperature and radiative flux profiles than an internal lining during a developing fire (or during the testing regime for BS 476). So it is questionable if these tests are even appropriate for insulation materials within facades.
2. As already stated for the external cladding system, the small-scale BS 476-7 and -6 tests expose the surface of the insulation to the test conditions. As the

PIR is covered in Aluminium foil it is not clear if the PIR material itself can satisfy the test conditions. For example, if an edge of the Celotex RS5000 test sample is exposed to the test conditions or if the surface of the test sample is damaged revealing the PIR, will it still pass? Edges of PIR insulation boards may be exposed to flame if the boards are not correctly installed or if the boards are damaged or become dislodged during the fire incident.

3. Given that we cannot guarantee that the boards will be installed correctly and that their surfaces may be damaged, it is prudent to also ensure that the unprotected insulation material can meet the requirements.
4. The Celotex RS5000 (PIR) brochure[6] does not state it meets European Class A2, but does state that it passes BS 476-6 and it is Class 1 according to BS 476-7. However, what does passes BS 476-6 mean? What was the value for index (I) and sub-index (i1)? Presumably, these parameters meet the requirements of the 'I' index being not more than 12 and the 'i1' sub-index being not more than 6, and hence meet the Class 0 requirements? However, Class 0 is the equivalent of European Class B, not European Class A2, required to be classified as a material of limited combustibility.
5. None of the UK small-scale test methodologies specify smoke or toxic gas production. The UK tests explicitly do not specify performance requirements for smoke production and toxic gas generation, and the UK requirements for the European classifications specifically stipulate 'S3' performance i.e. 'no limitation on smoke production'. PIR is relatively difficult to ignite and the material chars when burnt. The charring tends to inhibit fire development. However, when PIR burns, particularly in under-ventilated conditions, it produces black smoke laden with highly toxic Hydrogen Cyanide (HCN) gas. While all fuels produce toxic gas, particularly Carbon Monoxide (CO), when they burn incompletely in a fire, PIR (and other members of the Polyurethane (PUR) family) produces a particularly lethal combination of CO and HCN[8]. While CO is the main killer in most fires, HCN is between 10 and 30 times more toxic than CO. Fires that have involved PUR often result in large numbers of fatalities e.g. Rhode Island night club and the Kiss Night Club, were arguably a result of the production of toxic effluent, which includes large amounts of HCN. PIR has been shown to produce even greater amounts of HCN in fire test conditions then PUR[8]. While it may never be known how many fire fatalities in Grenfell were due in whole or in part to HCN inhalation, it has been reported that some of the survivors of the Grenfell fire were treated for HCN inhalation[17]. Covering buildings in materials that can produce such a lethal cocktail of fire effluent is not currently prohibited by the AD B. Indeed, there is no mention of smoke production or toxic gas production in the AD B.
6. The Celotex RS5000 brochure[6] mentions the Class 0 compliance of the material and that it has also satisfied BS 8414. These are two different routes to compliance, and it is inadvisable to cherry pick compliance performance from different routes. This is particularly important as the façade is a complex system, and so a material tested using the performance test specified in BS 8414 may be reliant on the performance of other components of that system in order to achieve a satisfactory outcome. Either the component of the façade system can be shown to satisfy the prescriptive route (following the route specified by paragraphs 12.6 to 12.9), or the performance route (satisfying BS 8414), but the two should not be mixed.

RECOMMENDATION 2: When making use of the prescriptive route, as specified in paragraphs 12.6 to 12.9, referring to the internal insulation of the façade system (paragraph 12.7):

a) The guidelines should explicitly refer to the façade system and identify each of the components that make up the façade system and the fire performance required for each component.

b) Clear, unambiguous guidelines should be provided to specify the suitability of the internal insulation used within the façade system.

c) Test methods used to demonstrate compliance of the insulation material used within the façade should be appropriate for the severe fire conditions that the material may be subjected to in practice. The most severe likely conditions would result from a post-flashover spill plume emerging from a vent or window of a fire compartment.

d) Test methods should also not be restricted to the surface of the material, taking into consideration the implications of materials with damaged surface coatings and the impact of edges being exposed to fire, through damage or incorrect installation.

e) The building regulations should take into consideration the toxicity of the fire effluent produced by burning materials.

f) If using the prescriptive approach, then all materials used in the façade construction should satisfy the prescriptive requirements. Cherry picking performance of façade components based on components of the prescriptive route and the performance route, should not be permitted.

g) The external façade of a building is a highly complex system made up of many interacting components. It is unlikely that small-scale tests on individual components of the façade (even if the tests can be shown to adequately represent the fire environment to which the façade is likely to be subjected) will reveal how the façade system as a whole is likely to perform in a fire. Ideally, if adopting this approach to approve materials used in the construction of the façade system, the materials should satisfy the more demanding non-combustible classification. Alternatively, if combustible materials are to be utilised within the façade, then the performance route (see 1.2) must be adopted to demonstrate compliance of the façade construction.

(c) CAVITY BARRIERS:

The third part of the façade system is the void and the cavity barriers within the void.

"12.8 Cavity barriers should be provided in accordance with Section 9.
12.9 In the case of an external wall construction, of a building which by virtue of paragraph 9.10d (external cladding system with a masonry or concrete inner leaf), is not subject to the provisions of Table 13 ……., the surfaces which face into cavities should also meet the provisions of Diagram 40."

An entire chapter of the AD B is devoted to cavity barriers - Section 9. A key concept is given in paragraph 9.2 and 9.3 (page 80):

"9.2 ……The provisions necessary to restrict the spread of smoke and flames through cavities are broadly for the purposes of sub-dividing:

a) cavities, which could otherwise form a pathway around a fire-separating element and closing the edges of cavities; therefore reducing the potential for unseen fire spread; and
b) …..

9.3 Cavity barriers should be provided to close the edges of cavities, including around openings"

This implies that there must be suitable cavity barriers within the façade to isolate each compartment (flat) resulting in a network of fire barriers extending both vertically (to prevent horizontal fire spread) and horizontally (to prevent vertical fire spread). Furthermore, there must be cavity barriers within the façade protecting openings such as windows and vents.

"9.13 Every cavity barrier should be constructed to provide at least 30 minutes fire resistance. …..

9.14 A cavity barrier should, wherever possible, be tightly fitted to a rigid construction and mechanically fixed in position. …..Where this is not possible, the junction should be fire-stopped."

If correctly installed, cavity barriers should prevent fire from spreading through the façade cavity and potentially attacking other compartments (above or to the side) for at least 30 minutes. In refurbishments such as Grenfell, potential difficulties may arise if cavity barriers are placed onto the surface of the façade insulation material rather than directly onto the surface of the external wall of the building. If placed on the surface of the insulation material, the cavity barrier is unlikely to prevent fire spread, if the insulation material is itself burning or compromised by fire assault. Ideally, the cavity barrier should be placed directly onto (and attached securely to) the external masonry wall of the building. Furthermore, in situations where the façade insulation does not make contact with the building masonry external wall, as may have been the case with the vertical columns present in the external faces of the Grenfell building, then appropriate fire stopping should be placed between the external wall and the façade insulation.

RECOMMENDATION 3: When making use of the prescriptive route as specified in paragraphs 12.6 to 12.9, referring to cavity barriers within the façade system (paragraph 12.8 and 12.9):

- **a)** The guidelines should explicitly refer to the façade system and identify each of the components that make up the façade system and the fire performance required for each component.
- **b)** Cavity barriers should be placed directly onto the external wall of the existing building and not on-top of the façade insulation materials.

1.2 PERFORMANCE ROUTE TO SATISFYING PARAGRAPH 12.5

The alternative route to satisfying the requirements of the AD B is the performance route. As specified in the second paragraph of 12.5, this involves undertaking a full-scale fire test of the façade system using the test methodology specified in BS 8414. This testing approach is superior to the alternative prescriptive approach (i.e. following 12.6 to 12.9) as it attempts to treat the façade as a complex system taking into consideration how each component of the façade system will react to a representative fire threat. Unlike the prescriptive approach (i.e. following 12.6 to 12.9) the test deals with representative large panels of the materials, with the cavity barriers in place all subjected to a realistic fire assault intended to represent the conditions of a post flash-over spill plume.

This is the new test that the government is currently undertaking[5,9], reportedly on six different combinations of cladding and insulation. These involve three types of ACP with core materials of: PE, Fire retardant PE and non-combustible mineral and two forms of insulation: rigid PIR and non-combustible mineral wool[9].

While one of these six combinations (ACP with PE core and PIR insulation) is equivalent to the combination used in Grenfell, this test will not necessarily provide the definitive explanation to what happened at Grenfell, or what caused the death of at least 80 people. The reasons for this are to do with a number of inadequacies of the BS 8414 test methodology.

1. While BS 8414 (and hence the additional tests ordered by the Government) will assess the materials used in a particular façade installation, the test methodology does not necessarily include the manner in which the materials are actually installed. In the case of Grenfell, the building had five vertical columns on two of its external faces and four vertical columns on the other two faces, extending all the way up the building (see Figure 1). The manner in which the façade is fitted over these protruding surfaces is not included in the standard BS 8414 test. The external wall of the test facility upon which the cladding is placed is assumed to be flat. However, these columns provide continuous vertical channels of flammable material extending from the bottom of the building to the top, essentially providing a continuous 'wick' for the external fire to propagate. It is essential to understand the nature of the cavity barriers and the fire-stopping within the façade system covering the columns. This building feature may have provided a possible mechanism by which the Grenfell fire spread so rapidly up the building façade (see Figure 2). Once the fire is burning up the vertical column, it can then spread sideways into the main façade panels. This highlights a potential weakness of the BS 8414 methodology, in that it is too general, and may therefore be unrepresentative of the specific challenges presented by a particular façade installation.

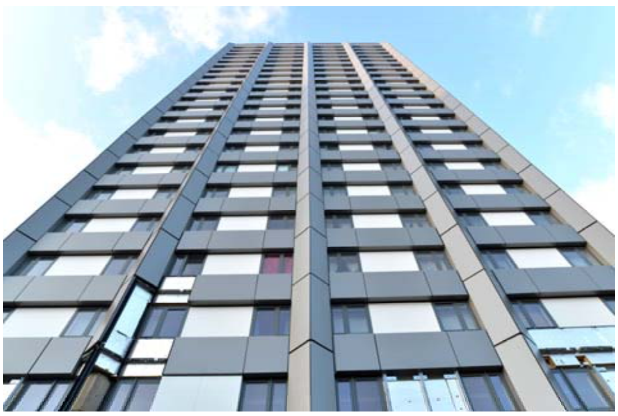


Figure 1: Grenfell Tower showing five vertical columns on one building face extending the entire height of the building.

		
Picture from the BBC showing a burnt column with evidence of fire spread to the sides	Picture from The Sun clearly showing the burning column with fire spread to the sides	Picture from The Express clearly showing a burning column from top to bottom[10]

Figure 2: Burning columns, a possible mechanism for the rapid vertical fire spread

2. The BS 8414 method only considers flame spread and combustibility of the external cladding and insulation of the façade system. It does not take into consideration the impact of glazing units, or how these may fail, or other vents penetrating through the façade, and so only partially represents the complexity of the façade system. As a result, the proposed testing will not explain how the fire and smoke gained access into the building.
3. The BS 8414 methodology only considers expert fitting of the insulation, cavity barriers and cladding and so may not always reflect the situation in a realistic or actual installation, where there may be flaws or inconsistencies in the installation.
4. The BS 8414 methodology does not take into consideration the amount of smoke and toxic products produced by the combustion of the façade materials. These components of fire effluent make evacuation difficult and are the main cause of death in building fires.
5. As already mentioned, architects and engineers may cherry pick performance of selected materials that have satisfied the BS 8414 test, without reference to the entire complex façade system that was actually tested. For example, the Celotex RS5000 brochure[6] states that this material has satisfied BS 8414. However, in the tests in which the RS5000 was examined, Fibre Cement panels were also used, presumably as the external cladding, with no mention of combining the RS5000 with ACP with PE cores. While this is made very clear in the RS5000 brochure, some engineers/architects/approval authorities may assume that the RS5000 can be used in any configuration as it has passed the particular BS 8414 test. Clearly, this is not a failing of the BS 8414 methodology, but demonstrates how the results from this test can be misinterpreted. Clearly, cherry picking results from the prescriptive and performance approach to make the case that a façade system is compliant is not appropriate.

RECOMMENDATION 4: When making use of the performance route as specified in paragraph 12.5:

a) The BS 8414 test methodology should consider the specific manner in which the façade is fitted to the building and not generalise performance, based on an idealised test configuration. This is particularly important when non-standard features (not included in the test methodology) are present in the proposed building.

b) Either the BS 8414 test methodology should be modified to take into consideration the impact of openings in the façade, such as windows and vents, or another full-scale test method should be defined that considers how the façade may fail leading to ingress of fire and smoke into the building.

c) Either the BS 8414 test methodology should be modified to take into consideration the amount of smoke generated and its toxic load produced by the façade fire, or another test method should be developed to take these aspects into consideration.

d) If using the prescriptive approach, then all materials used in the façade construction should satisfy the prescriptive requirements. Cherry picking performance of façade components, based on the prescriptive route and the performance route, should not be permitted.

Concerning the BS 8414 tests currently underway ordered by the Government[9], based on the fire behaviour exhibited in the Grenfell fire and the fire performance of the ACP with PE core, the likely outcome of these tests is predicted to be:

- Cladding: ACP with PE core, plus Insulation: rigid PIR foam - **FAIL**
- Cladding: ACP with PE core, plus Insulation: non-combustible mineral wool - **FAIL**
- Cladding: ACP with FR PE core, plus Insulation: rigid PIR foam – **PROBABLY FAIL**
- Cladding: ACP with FR PE core, plus Insulation: non-combustible mineral wool - **PROBABLY FAIL**
- Cladding: ACP with non-combustible mineral filler core, plus Insulation: rigid PIR foam **– PROBABLY PASS**
- Cladding: ACP with non-combustible mineral filler core, plus Insulation: non-combustible mineral wool - **PASS**

SUMMARY OF PART 1:

a) AD B fails to adequately explicitly identify the external façade system and its complexities.

b) When referring to components of the façade system, the AD B is ambiguous and confusing.

c) The prescriptive route to meeting compliance (paragraphs 12.6 to 12.9) is ambiguous and open to interpretation, the small-scale BS tests (BS 476 series) may not be appropriate for external façade systems, as it is not clear if they adequately represent the type of conditions materials will be subjected to, the approach does not take into consideration smoke or toxic gases produced by burning materials, it only requires the surface of composite materials to meet the requirements, and so on.

d) The performance route to meeting compliance (paragraph 12.5) is more rigorous, but the test methodology BS 8414 has several potential weaknesses, such as failing to take into consideration specific installation peculiarities associated with a particular building, assuming perfect installation practices have been followed, only considering combustibility and flame spread, not mechanisms by which glazing or other vents in the façade system may fail, allowing the fire to gain access to the interior of the building, not considering the amount of smoke produced or its toxic load, and so on.

e) The AD B does not explicitly rule out the possibility of cherry picking results, mixing aspects of the prescriptive and performance routes.

f) Given the ambiguity in the AD B, it is quite possible that the ACP with PE core and the PIR insulation used in the Grenfell Tower may have been considered to be compliant as both appear to satisfy Class 0 requirements.

g) The building regulations do not take into consideration the amount of smoke and toxic products produced by the combustion of building materials. These components of fire effluent make evacuation difficult and are the main cause of death in building fires.

h) The external façade of a building is a highly complex system made up of many interacting components. It is unlikely that small-scale tests on individual components of the façade (even if the tests can be shown to adequately represent the fire environment to which the façade is likely to be subjected) will reveal how the façade system as a whole is likely to perform in a fire. Thus, if adopting the prescriptive route to approve materials used in the construction of the façade system, the materials should satisfy the more demanding non-combustible classification. Alternatively, if combustible materials are to be utilised within the façade, then the performance route must be adopted to demonstrate compliance of the actual façade construction.

i) A possible mechanism by which the Grenfell fire spread so rapidly up the building are the vertical columns on the faces of the building, which potentially provide a continuous 'wick' of flammable material up the entire height of the building.

(2) Part 2 - Compartmentation:

2.1 Compartmentation Concept

Many UK buildings such as high-rise flats, hospitals, care homes, schools, etc., are built on the compartmentation principle. This assumes that the confining boundaries of each compartment have sufficient fire resistance to contain a fire for at least 30 minutes (i.e. between at least 30 minutes and at least 60 minutes depending on the nature of the boundary). It includes all openings within the walls, ceiling and floors created by doors, windows, vents and other services (such as plumbing, electrical and gas). An individual flat within a high-rise block of flats is considered to be a single fire 'compartment', with the external door(s) of the flat (leading to the communal areas) being a suitable fire rated door providing at least 30 minutes fire protection.

If a fire should start in one of the compartments, its occupants should be alerted by their local fire alarm, evacuate from the compartment, ensure that the fire door closes behind them and immediately call the fire brigade. The use of passive fire safety measures (i.e. fire resisting walls) means that the compartmentation principle should prevent the fire from spreading to adjoining flats for at least 60 minutes and contain the fire within the compartment of fire origin for at least 30 minutes after which a fire rated door may fail. Furthermore, other building occupants located in non-adjoining flats are also expected to be safe for at least 60 minutes as they are located within compartments protected by fire doors with at least 30 minutes of fire protection. This should provide sufficient time for the fire brigade to arrive and extinguish or suppress the fire without the need for occupants of other unaffected compartments to evacuate. As a precaution, on arrival, the fire brigade may evacuate the other occupants of the floor affected by the fire, and possibly the floor above and two floors below.

The communal stairs of the block of flats are also considered to come under the compartmentation principle. Thus the stair walls are required to be fire resistant, the doors to the stairs should be fire rated, providing 30 minutes of fire protection and any services that penetrate the stair core should be adequately fire stopped. In this way, the stairs should offer at least 60 minutes of fire protection (30 minutes fire compartment to communal area and a further 30 minutes to access the stair core via the stair door).

The compartmentation principle directly influences the evacuation strategy for the whole building. As the other residents of the building have at least 60 minutes of fire protection, the logic of the compartmentation principle suggests that there should be no need to evacuate the entire building. This gives rise to the 'stay put' principle i.e., in the event of fire in a block of flats, it is safer to remain in your flat. According to the 'stay put' policy, there will be no need to evacuate the entire building, so there is also no need for a communal alarm system and there is also no need to have more than one stair.

2.2 Problems with the Compartmentation Concept

There is something akin to a religious zeal in support of the compartmentation principle by many members of the fire safety community (government, local authorities, building operators, fire brigade). As a result, they put all of their faith in the concept, and there is little or no resilience in the design of the building or the evacuation strategy. Theoretically, the concept is difficult to argue against, as UK fire statistics suggest that each year we have hundreds of fires in high-rise residential tower blocks, built using the compartmentation principle, with few resulting in multiple fatalities.

However, compartmentation can be compromised, for example, if a fire rated door is not fitted to the flat of fire origin, the fire rated door is wedged open, it does not have an automatic door closer, it is damaged, renovations (both official and unofficial) have breached the external walls, and these have not been adequately fire stopped, or if the initial build quality was substandard.

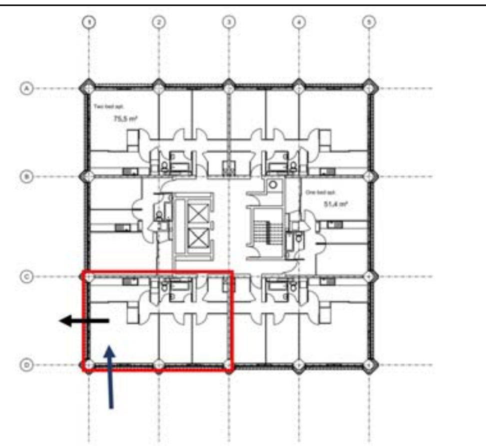
An example where the compartmentation principle failed was Lakanal House. Consider another potential example, where compartmentation may have failed in a modern purpose-built care home - the recent fire in Cadmore Lane, Cheshunt which claimed the lives of two elderly residents[11]. The Chief fire officer for Hertfordshire, Darryl Keen, reported that the fire "had spread inside the roof all the way along the entire property….". While the reason for the rapid fire spread has not yet been officially determined, it is reasonable to assume that had the appropriate compartmentation been present both in the roof void and on the first floor, this extensive spread of fire should not have been possible[12].

Clearly, for compartmentation to be reliable, we must ensure that buildings are designed, built, approved, maintained, renovated, inspected and managed correctly. If compartmentation fails then the consequences can be severe, as we have placed all our eggs in the one basket.

RECOMMENDATION 5: As the consequences of compartmentation failing are severe, it is prudent to ensure that there is resilience in the fire safety strategy, by building in additional safety measures to either suppress the fire, such as a sprinkler system (see Part 5), or to facilitate a mass evacuation, should it be necessary, such as communal fire detection and alarm systems, stairs that are sufficiently wide to allow two people abreast to descend, and an additional emergency exit stair (see Part 4).

2.3 Compartmentation within Grenfell Tower.

The majority of the residential floors in the Grenfell Tower were arranged with four two-bedroom flats and two one-bedroom flats per floor. Some floors consisted of four flats with four-bedrooms (see figure 3). Typical compartments are highlighted in red in figure 3, essentially marking the perimeter of a flat. Each flat on the floor would be considered a single compartment, as would the communal lobby and the staircase. The two- and one-bedroom flats have a single external door leading to the communal lobby area, while the four-bedroom flats have two external doors. Each of these external doors, and the door to the stairs, should have been 30-minute fire rated doors, with functioning automatic door closers attached.



Typical floor with four two-bed and two one-bed flats. Typical compartment highlighted in red.

Floor with four four-bed flats. Typical compartment highlighted in red.

Figure 3: Typical Grenfell Tower floor arrangements showing compartmentation principle

The vertical and horizontal extent of a typical two-bedroom compartment is also shown in elevation view in figure 4. Note that the compartment would extend around the corner of the building as depicted in figure 3.

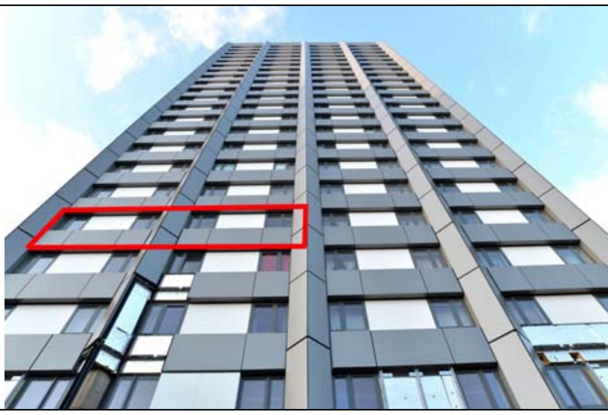


Figure 4: Vertical view of Grenfell Tower showing extent of a compartment.

2.4 Possible compartmentation failure resulting in fire and smoke spread.

The fire at Grenfell Tower is known to have spread up the façade of the building – the precise mechanism for this is yet to be determined (see Part 1 for suggestions). Once there is an external fire on the façade, it is only a matter of time before the fire gains entry into the building through a number of possible mechanisms, including:

1. The failure of the compartmentation concept through the failure of the exterior glazing.
2. The failure of the compartmentation concept through the failure of the façade cavity barriers protecting the glazing or vents.
3. The failure of the compartmentation concept through the failure of fire stopping around the glazing or vents.
4. The failure of the compartmentation concept through inappropriate installation of the glazing units.
5. The failure of the compartmentation concept due to windows being left open.

It will be up to the Inquiry to determine how the fire breached the exterior component of the compartments. However, as it was a hot night, it is likely that something as simple as leaving the exterior windows open for ventilation may have made a substantial contribution to the failure of the fire compartmentation. This was also an issue in the Lakanal House fire.

RECOMMENDATION 6: As the consequences of compartmentation failing are severe, it is odd that the exterior boundary to the fire compartment is not required to be protected by a fire rated window. While this should be considered as part of the building regulations, even a correctly installed fire rated window that is open breaches the compartmentation principle. As suggested in recommendation 5, it is thus prudent to ensure that there is resilience in the fire safety strategy, by building in additional safety measures to either suppress the fire, such as a sprinkler system (see Part 5), or to facilitate a mass evacuation, should it be necessary, such as communal fire detection and alarm systems, stairs that are sufficiently wide to allow two people abreast to descend, and an additional emergency exit stair (see Part 4).

Once the fire has gained access to a compartment, if it is allowed to develop it can spread to the other face of the building, again through the failure of the window as depicted in figure 3 (note the direction of the arrows). This can in turn set fire to the façade on the other face of the building. However, as suggested in Part 1, the façade fire could also spread around to the other faces of the building via the vertical columns on the edges of the building.

Both these mechanisms are possible and it will be up to the Inquiry to determine the dominant mechanism.

Many of the communal areas (and in particular the stair core) in the Grenfell Tower were reported to have been affected by dense toxic smoke. It is not clear how these areas would have been affected if the compartmentation was adequate.

It will be important for the Inquiry to determine when and how the communal areas on each floor became compromised by smoke.
This could be the result of:

1. The eventual failure of the 30 minute fire doors on each of the fire affected flats. However, this is likely to have taken much more than 30 minutes from the start of the fire, as the fire must first gain access to the whole flat and then develop into a fire that will compromise the door.
2. Poorly fitted or worn fire doors allowing leakage of smoke.
3. Occupants who evacuated a flat leaving their doors open (i.e. failure of the door closer, absence of a door closer or the door was wedged open).
4. Failure of fire stopping around penetrations into the various compartments (including the stairs).
5. Eventual failure of the 30 minute fire doors on the stairs. This is not expected to occur for at least 60 minutes.
6. Design or renovation fault with the compartment fire barriers between the flats and the communal areas.

Similarly, the stairs in the Grenfell Tower were reported to have been affected by dense toxic smoke. It is not clear how the stairs would have been affected.

It will be important for the Inquiry to determine when and how the stairs, on each floor became compromised by smoke. This could be the result of:

1. Ingress of smoke from the communal areas, when groups of people enter the stairs.
2. Ingress of smoke from the communal areas, due to firefighting measures.
3. The eventual failure of the 30-minute fire doors on the stairs. However, this is likely to have taken much more than 30 minutes from the start of the fire, as the fire must first gain access to the communal area and then develop into a fire that will threaten the door.
4. Occupants who evacuated into the stairs leaving the stair door open (i.e. failure of the door closer, absence of a door closer or the door was wedged open).
5. Failure of fire stopping around penetrations into the stairs.
6. Design or renovation fault with the compartment fire barriers between the stairs and the communal areas.

(3) Part 3 – Stay Put Principle (To flee or not to flee, that is the question!):

The ‘stay put’ principle like the compartmentation principle is followed devoutly by the fire brigade, building operators and local government. As already described (see Part 2), it is based on the compartmentation principle, and is a sound philosophy to follow **IF (and only if)** compartmentation can be guaranteed. Indeed, in the vast majority of fires in high-rise council flats, the fire statistics support the concept, as there are hundreds of fires each year in these types of building, with very few of them resulting in multiple fatalities.

In many respects, 'stay put', if applicable, is preferable to fully evacuating a high-rise building. High-rise evacuation does not come without its own hazards, especially for people with movement disabilities, the elderly, the infirm, families with young children and infants, the visually impaired, etc.

However, it must clearly be understood, that 'stay put' only works if compartmentation is maintained and the fire is contained within the compartment of fire origin. In the very early stages of the Grenfell fire, when it was confined to the kitchen of the flat on the fourth residential floor, the advice to building occupants to 'stay put' was sound. It was reported that:

"When the fire was first reported at 00:54 BST, residents were initially given advice to "stay put" inside the building"[13].

However, the official recommendation to evacuate if possible, came at 02:47 BST, some 1 hr and 53 min after the first emergency call[13].

With the fire racing up the façade of the building, it is highly likely that a catastrophic failure of the compartmentation principle was in progress (see part 2) meaning that multiple flats, and their occupants, would be at risk. At this point the 'stay put' principle should have been abandoned and advice given to evacuate, if safe to do so. Without a communal full building alarm system, the only way to alert occupants, apart from the fire brigade undertaking a door knock, would have been for the incident commander to inform the 999 call centre to change their advice from 'stay put' to evacuate if safe to do so. While both these approaches could have started the early evacuation of some of the occupants, they are extremely slow inefficient methods to initiate an evacuation in a high-rise building, which would have greatly slowed the overall evacuation, putting people at risk.

The devotion to 'stay put', born out of its success in most high-rise fires, may have conditioned incident commanders not to question the strategy, even in situations where the basic tenet of the principle – compartmentation – is clearly no longer valid. The expectation that compartmentation will be maintained, and the devotion to 'stay put', may have contributed to the reluctance of incident commanders to switch to 'plan B' early enough in the fire, or perhaps even to have a viable plan B for high-rise fires.

With regards to the 'stay put' policy and the fire brigade strategic response to the fire, it will be for the Inquiry to establish:

1. Is it part of the fire brigade standard operating procedures to instigate a change in strategy from 'stay put' to evacuate when the need arises?
2. What are the criteria that would influence such a change in strategy?
3. How would such a change in strategy be implemented in a high-rise building without a communal alarm system?

4. What specific training, if any, do fire brigade commanders have to assist in making such strategic decisions during rapidly evolving situations?
5. At what time did the fire begin to visibly race up and along the façade of the building?
6. At what time were the communal areas on each floor considered non-viable for safe evacuation?
7. At what time were the stairs considered non-viable for safe evacuation?
8. What delayed the incident commander in changing the strategy from 'stay put' to evacuate?
9. What factors influenced the incident commander to change the strategy from 'stay put' to evacuate?

It is suggested that the poor evacuation provision provided in UK high-rise residential buildings (see part 4) may have contributed to the reluctance of the incident commanders to abandon the 'stay put' strategy.

(4) Part 4 – The Evacuation System:

In the UK, the concept of evacuation in high-rise residential tower blocks comes a poor third to the concepts of compartmentation and 'stay put'. The devotion to these two concepts means that evacuation provision is almost non-existent. Essentially all that is provided is a single access stair which should provide 60 minutes of fire protection. It has been reported that the stair in the Grenfell Tower was just over 1m wide:

"The stairwell is not wide. Just over 1m (3ft)[14]"

This is sufficiently wide to accommodate only a single person per stair tread (see Figure 5). It is also reported that while the building had local fire alarms – within each flat – there were no communal alarms, or at least no working communal alarms. So, while a resident could be alerted about a fire in their own flat, they had no idea if there was a fire in the communal areas which could potentially threaten their safety.

Figure 5: Only means of escape from Grenfell Tower

The evacuation provision in the Grenfell Tower is the norm for high-rise residential buildings in the UK. While it is legally compliant, it does not reach the basic requirements of internationally recognised best practice.

The evacuation process has two key phases: the evacuation response phase, and the evacuation movement phase. In the evacuation response phase, occupants are alerted to the need to evacuate - through a traditional bell alarm, for example, or, more effectively, by a modern voice alarm system. This phase is essential because if occupants are not aware of the danger, they cannot take appropriate action and will not start to evacuate. This is of critical importance in residential dwellings and hotels because occupants, as in the Grenfell incident, may be asleep during the incident. Many fatalities in fires are the result of occupants delaying their initial response.

The argument against installing building-wide communal alarm systems is that they are not needed because of the 'stay put' and compartmentation principles. However, as already mentioned (see part 2), this puts all of our eggs in the one basket, and provides no resilience. If there is a need to evacuate the entire building how can this be achieved if you cannot alert the occupants – especially at night when people are likely to be asleep? If there is an urgent need to evacuate the building – because the first line of defence, compartmentation, has failed - door knocks or occupant calls to 999 are the only way to alert occupants of the need to evacuate, and this takes far too long, wasting precious time that would be better spent actually evacuating.

In addition, it is often argued that if these alarm systems were introduced: they would be vandalised; there would be frequent malicious false and genuine false alarms, resulting in needless frequent evacuations. If such problems persisted, the alarms would become ineffective as they would be increasingly ignored. Modern detection and alarm systems can overcome most of these problems by requiring multiple detectors to be activated.

In the evacuation movement phase the occupants commence their movement towards the final exit, which in high-rise residential buildings, means utilising the stairs. It is a common standard around the world to provide at least two different means of escape from a compartment. This is for a number of reasons, but the most significant is that one of the evacuation routes may become compromised by the fire and so an alternative route is provided to increase resilience. The width of the stairs is also important; if the stairs are narrow, as in Grenfell Tower, then occupants will only be able to descend in single file. This slows the evacuation, making it difficult for people to assist disabled occupants, injured occupants, or family groups including children and infants. It also makes it difficult for fire fighters who are ascending while occupants are descending. Another reason for having two sets of stairs is that one staircase can be devoted to firefighting actions while the other staircase can be used by occupants to evacuate. All of these issues were highlighted in the evacuation of the Twin Towers during the WTC 9/11 disaster[16].

The argument against installing two sets of emergency stairs is that they are not needed because of the 'stay put' and compartmentation principles. However as already mentioned (see part 2), this puts all of our eggs in the one basket, providing no resilience. If there is a need to evacuate the entire building how can this be achieved if the only means to evacuate is compromised by smoke, or becomes heavily congested through necessary use by the firefighters?

The authorities use a circular argument in defending the lack of resilience in high-rise residential buildings. On the one hand, they argue that because of compartmentation and ‘stay put’, there is no need for alarms or a secondary means of escape. But when compartmentation fails, as in Grenfell, it is argued that it is difficult to instigate or manage an evacuation because there is no alarm and there is only a single stair that is needed for firefighting purposes.

Two high-rise buildings that suffered rapidly developing façade fires are the Lacrosse building in Melbourne and the Grenfell building in London. While the Grenfell and Lacrosse buildings are very different structures, built in different countries, using different building regulations with different fire safety philosophies (Grenfell based on a prescriptive code relying on compartmentation, Lacrosse designed using a fire engineering approach relying on sprinklers) and constructed some 40 years apart, there are striking similarities and differences between the two buildings, the fires and their outcomes. In particular, the Lacrosse building had a very different evacuation capability to that in the Grenfell building. These differences, together with the different fire response strategies that were implemented probably contributed to the significant differences in outcomes.

The Lacrosse building has a rise in storeys of 21 and contains 23 storeys in total and is a residential building with retail and car parking[15]. There are typically 15 flats per floor[15]. It is reported that the fire started at 02:24 on the 25 November 2014 on the 8th floor balcony and at that time there were some 400 residents in the building[15]. The building was clad in ACP with PE core. The first fire units arrived at 02:29, at which point the fire had already spread up 6 floors. By 02:35, only 6 minutes later, the fire has reached the top of the building (floor 21). It is reported:

“External wall construction and materials used in this building allowed for the rapid vertical spread, involving a relatively large portion of the high-rise building as opposed to a single level. In light of this fire, Officers had no choice but to evacuate the entire building.”[15]

Due to the rapid fire progress up the building and ingress into the building, the fire brigade ordered an evacuation which was underway by 02:32 and appears to have been completed without injury by 02:55.

The main similarities and differences between the two buildings and resulting fires is summarised below:

- Similarities:
    - Grenfell 24 floors with lower 2 floors not used for residential
    - Lacrosse 23 floors with 2 floors not used for residential
    - Both clad in ACP with PE core.
    - The stairs in both buildings were approximately 1m wide.
    - Both suffered rapidly developing façade fire which spread the entire height of both buildings within minutes of starting.
    - Both fires started in the early hours of the morning, when residents were mostly sleeping – Grenfell 00:54, Lacrosse 02:24,
    - Both fires had rapid fire brigade response, arriving within 6 minutes of fire starting.
- Differences:
    - Lacrosse building had sprinklers
    - Lacrosse building had two sets of emergency stairs.

- It is reported that the Lacrosse building had virtually no internal fire resistance (i.e. little or no fire resisting compartmentation e.g. no fire rated doors, poor fire stopping, etc)[18].
- Stairs in Lacrosse building were pressurised keeping smoke out of the stairs.
- Communal areas in the Grenfell Tower had a smoke management system designed to extract smoke from a single communal lobby on the fire floor. This system is unlikely to be able to manage fires on multiple floors.
- Lacrosse building had a building wide alarm system.
- At the Lacrosse fire, partial evacuation started on alarm, but the fire brigade ordered a building wide evacuation within 3 minutes of arriving (door knock); at Grenfell it took the fire brigade 1 hour 53 minutes before ordering the evacuation.
- Grenfell had PIR insulation in the façade, Lacrosse didn't.
- The Lacrosse fire did not extend laterally over the entire façade whereas in Grenfell it did.
- Fatalities at Lacrosse – 0
- Fatalities at Grenfell – 80+

It should also be noted that not everything worked at Lacrosse as intended. The building wide alarm system (Emergency Warning and Intercommunication System – EWIS) failed very early in the fire, and so only a few floors are thought to have been alerted to evacuate. The sprinkler system in the building was a combined hydrant/sprinkler system that was designed to function with four sprinkler heads and two hydrants operating at any one time. During the fire it is reported that 26 sprinkler heads over multiple floors were in operation and two hydrants; however, it is not known if both hydrants were in operation at the same time as the sprinklers, which may explain why so many sprinkler heads were activated. Also, as the fire occurred early in the morning, there was not a large demand for water and so the water pressure to the building would have been excellent. The sprinkler system is reported to have performed in excess of its design parameters and assisted in limiting the spread of the fire[15]. They were also lucky on the night of the fire as the wind direction was such that it did not blow the fire, smoke and toxic gases further into the building[15].

A significant difference between the two fires is that in the Lacrosse fire, there was no hesitation by the fire brigade to instigate a building wide evacuation. This rapid decision is no doubt supported by the ability to stage a building wide evacuation as the building was equipped with two evacuation stairs, which were pressurised and a building wide alarm system.

It is arguable that had the evacuation of Grenfell Tower been initiated immediately it became clear that compartmentation was lost, the human toll of this fire may not have been so horrific. Furthermore, if the Grenfell Tower had a functioning communal alarm system and a second means of escape, it is possible that the human toll resulting from this devastating fire would have been very different.

RECOMMENDATION 7: Rather than abandoning the fire safety concepts of compartmentation and 'stay put', they must be supported through the

incorporation of additional safety features such as fire suppression and/or improved evacuation capability increasing the overall resilience of the fire safety strategy. However, these improvements should not be at the cost of reduced compartmentation.

(5) Part 5 - Sprinklers:

As discussed in Part 4, sprinkler systems are designed to suppress a fire sufficiently to allow the occupants of the compartment of fire origin to evacuate safely and to limit the growth of the fire, enabling the fire brigade to safely extinguish the fire. Sprinklers have been shown to be very effective at controlling internal fires, but are not without their limitations. Fires in ceiling voids for example will not be suppressed by a sprinkler – unless the ceiling void is equipped with sprinklers - similarly, hidden fires in wall cavities and ducts are unlikely to be suppressed.

A typical system is designed to have a small number (e.g. 4 to 6) of sprinkler heads in operation at any one time. To operate many more heads simultaneously would require a greater water pressure and potentially a large dedicated water supply, adding to the cost and maintenance issues associated with sprinkler systems.

It is thus unlikely that an internal sprinkler system would be able to control an external façade fire, such as the Grenfell fire, and prevent it from gaining entry into multiple compartments on multiple floors at the same time. However, in the Grenfell fire, the fire is known to have started within an electrical appliance (refrigerator) on the fourth floor. Had a sprinkler system been installed, there is a high probability that it would have at least controlled the fire, preventing it from spreading to the external cladding and therefore preventing the Grenfell tragedy from occurring.

Unlike the Grenfell fire, many of the façade fires that have occurred around the world have started externally. These can be for a number of reasons e.g. discarded cigarette, external electrical fault, external waste fire, etc. An internal sprinkler system is unlikely to prevent these façade fires from spreading to the interior of the building, threatening the lives of the occupants.

An internal sprinkler system does not completely compensate for having a highly combustible external façade.

Given a choice of living in the Grenfell building pre-renovation or the renovated Grenfell building with a sprinkler system, I would choose the Grenfell building pre-renovation. This is because, while the sprinkler system will control most internal fires, as suggested above, an internal sprinkler system is unlikely to control an externally-initiated façade fire. In contrast, the pre-renovation building will not be subjected to a similar devastating façade fire while internal fires are likely to be contained by compartmentation, in which case 'stay put' would be viable.

(6) CONCLUDING COMMENTS

The range of issues associated with the Grenfell tragedy are extremely complex. There is unlikely to be a single culprit, but rather a systemic failure of multiple systems that we rely on for fire safety. While there is an understandable clamour for clarity and justice, in which tragedy is painted in black and white, the failures that led to the horrific loss of life are likely to have their root in a world that is far more grey.

It is thus essential for the Inquiry to go beyond the cause of the rapidly spreading façade fire, to determine why so many lives were lost in this particular façade fire. What made this rapidly spreading, full-height façade fire different from all the others that have occurred around the world? Identifying and addressing these issues will be the legacy of the Grenfell fire and its victims.

In the meantime, what are we supposed to do with the multitude of high-rise buildings that have been found to have the same type of combustible façade materials? Simply removing the ACP with PE core is not the answer – as this may be creating an even greater problem by exposing combustible insulation material. Ideally, if façades are found to contain both the cladding and insulation materials used in Grenfell, then both should be removed and replaced. Another possibility is to remove the exterior cladding material, check the cavity barriers and fire stopping and temporarily replace the cladding with non-combustible sheeting until a more permanent solution can be found.

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The UK FIRE TESTS:

BS 476-7:
Provides a means to test lateral flame spread along the surface of a vertical specimen of a product. Specimen size is 885mm x 270mm. Heating is by a radiation panel that is 850 mm square. A pilot flame is applied for 1 min. The classification of the material is based on the flame spread measured after 1.5 and 10 minutes. To qualify as Class 1, the flame spread must be less than 165 mm after both 1.5 and 10 minutes.

BS476-6:
This test takes account of the combined effect of factors such as the ignition characteristics, the amount and the rate of heat release and the thermal properties of the product in relation to their ability to accelerate the rate of fire growth. The higher the index the greater the influence of the product on accelerating fire growth. The specimen size is 225 mm by 225 mm. It is a comparative measure of fire growth primarily intended for internal wall linings. The specimen is placed in the test chamber and subjected first to the flame from a gas jet (530 W) and then to electrical radiant heat (1800 W) which are turned on after 2 min 45 sec. Their output is reduced to 1500 W at 5 minutes and maintained at this output until the end of the test. Temperatures generated within the chamber are recorded and compared with the calibration test (i.e. the differences are considered) and the sum of the three indices are taken during three time periods from the start of the test to its conclusion (20 minutes) are expressed as a performance index. The time intervals are 30 sec from the start to 3 minutes, 1.0 min intervals from 4 min to 10 mins and 2.0 min intervals from 12 min to 20 min. The total index $I = i1 + i2 + i3$. The i index is determined by $(Ts – Tc)/10t$, this is then summed over the subinterval e.g. for the first subinterval, it is determined every 30 sec and then summed to give the i1 value.

BS 476-11:
This test assesses the heat emission from building material when inserted into a furnace at a temperature of 750 C. The method is only applicable to simple materials or mixtures of materials that are reasonably homogenous. This method is not normally suitable for assessing combinations of materials, such as those that are surface coated, veneered or faced or that contain discrete layers of materials that have been fixed or glued together as laminates. This test is thus not appropriate for the ACP.

BS 8414:
The BS 8414-1 Fire performance of external cladding systems, Part 1: Test method for non-loadbearing external cladding systems applied to the face of the building test method forms the basis of the full scale test in this standard. This test does not cover exposure to radiant heat from a fire in an adjacent building and does not assess the fire resistance characteristics of the system. The test is intended to represent the action of a fire impinging on the external surfaces of the cladding system and on the lower edge of the cladding system at an opening to the fire compartment (e.g. compartment window). This type of fire can occur as the result of an external fire in close proximity to the building envelope, such as fires involving general waste or malicious fire setting or as the consequence of a fire developing to flashover within a building and breaking out from the room of origin through a window opening or doorway. The fire load is a wood crib producing 3 MW peak output and 4500 MJ over 30 min. Thermocouples are installed within the façade at various heights and monitor the

temperatures (surface, void and insulation) to determine internal fire spread over the 30 min fire duration and 30 min post fire period.

There are a range of pass/fail criteria based on internal and external façade temperatures and burn through. For external fire spread, failure is defined if any of the external thermocouples at Level 2 exceeds 600 C for a period of at least 30 seconds, within 15 minutes from the start. For internal fire spread, failure is defined if the temperature rise of the internal thermocouples at Level 2 exceeds 600 C for a period of at least 30 seconds within 15 minutes from the start. Where burn through occurs allowing the fire to reach the internal surface, failure is deemed to have occurred if continuous flaming, defined as a flame with a duration in excess of 60 seconds, is observed on the internal surface at or above the height of 0.5 m above the combustion chamber opening within 15 minutes of the start time.