Grenfell Tower – fire safety investigation:
The fire protection measures in place on the night of the fire, and conclusions as to:

the extent to which they failed to control the spread of fire and smoke;
the extent to which they contributed to the speed at which the fire spread.

Phase 1 Report – Section 10

Routes for vertical and horizontal fire spread throughout the building envelope

REPORT OF

Dr Barbara Lane FREng FRSE CEng

Fire Safety Engineering

24th October 2018

Specialist Field	:	Fire Safety Engineering
Assisted by	:	Dr Susan Deeny, Dr Peter Woodburn, Dr Graeme Flint, Mr Tom Parker, Mrs Danielle Antonellis, Mr Alfie Chapman
On behalf of	:	Grenfell Tower Inquiry
On instructions of	:	Cathy Kennedy, Solicitor, Grenfell Tower Inquiry
Subject Matter		To examine the circumstances surrounding the fire at Grenfell Tower on 14th June 2017
Inspection Date(s)	:	6th October, 1st November, 7-9th November 2017

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10 Routes for vertical and horizontal fire spread throughout the building envelope

10.1 The primary observed routes of fire spread

10.1.1 As I have explained in Section 7 of my Report, the fire started in Flat 16 on the 4th floor of Grenfell Tower. I have explained in Section 9 how the construction around the kitchen window in Flat 16 enabled fire spread from the internal compartment (the flat) into the cavity formed between the main rainscreen cladding panel provided as the external surface, and the new insulation attached to the original Grenfell Tower concrete backing wall. Section 9 also explains how fire could then spread back from the building envelope into a flat.

10.1.2 The question then becomes, when one observes the fire spread evidence from the night of the fire (see Section 5) how did the construction materials (including the required materials to limit fire and smoke spread) perform? What materials were present, and in what form? How did those materials enable the substantial fire spread vertically, and horizontally, and so throughout the building envelope? And consequentially, throughout the internal rooms of the building?

10.1.3 In Section 5 of this report I provided Figure 10.1 setting out on the plan drawing of the 4th floor, a diagram summarising the primary direction of the observed fire spread routes during the Grenfell Tower fire. Figure 10.1 also shows a schematic of the fire spread in 3 dimensions on an isometric representation of Grenfell Tower.

10.1.4 Those column references are again used in this Section for orientation.

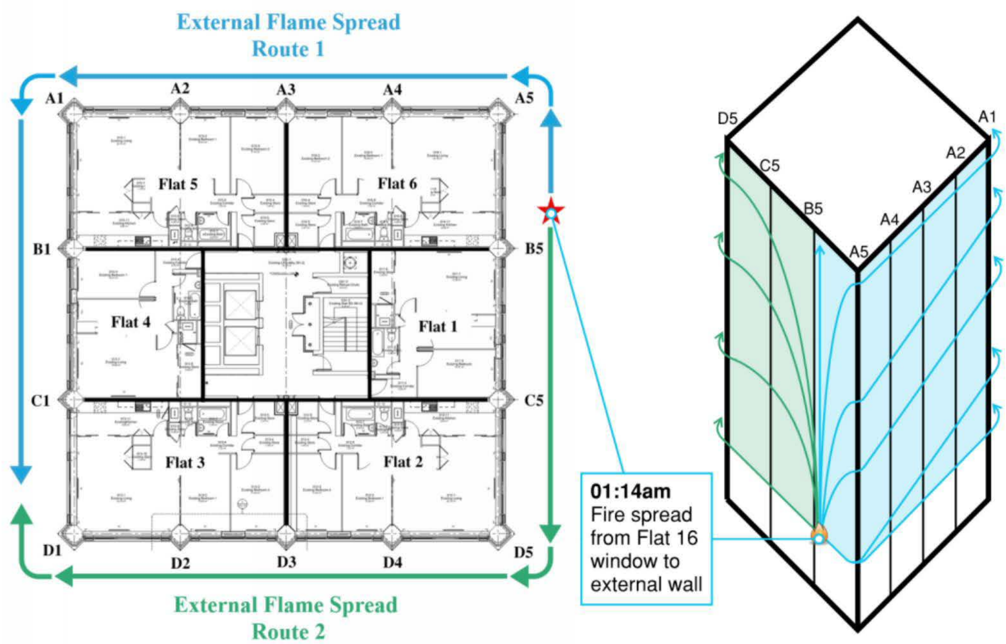


Figure 10.1: Plan (based on SEA00010474) and isometric views of Grenfell Tower showing fire spread observed and column references for orientation

10.1.5 The External Flame Spread Routes 1 and 2, as observed, demonstrate vertical and horizontal fire spread, creating a process that eventually engulfed the majority of all four elevations of the building.

10.1.6 From my review of the photographic evidence – presented throughout this Section 10 – I have identified this was possible due to at least six (6) separate Pathways:

a) Pathway A: Vertically, up and down columns

b) Pathway B: Horizontally, across the spandrel cladding panels (above and below the window/insulating core panel sections)

c) Pathway C: Horizontally along the edges of the head and cill of the windows, and the edges of the top and bottom of the infill insulating core panel

d) Pathway D: Vertically along the edges of the window and the edges of the infill insulating core panel (noting an insulating core panel is always set between two windows; and a window always has a column and an insulating core panel at its edge);

e) Pathway E: Vertically by means of the insulating core panels which connect between spandrel panels;

f) Pathway F: Around the crown of the building.

10.1.7 Figure 10.2 identifies Pathways A to E on an undamaged portion of the façade of Grenfell Tower. These Pathways are also indicated on a rendered schematic of the building envelope in Figure 10.4.

10.1.8 Figure 10.3 identifies Pathway F on an image of the façade from before the fire.

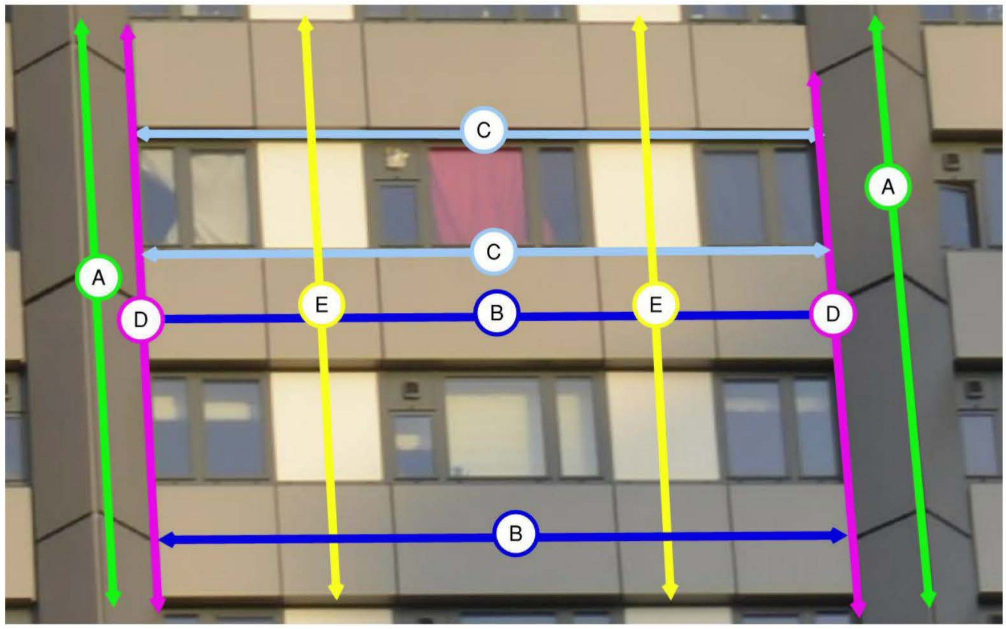


Figure 10.2: Pathways A to E identified on undamaged façade (SEA00000350)

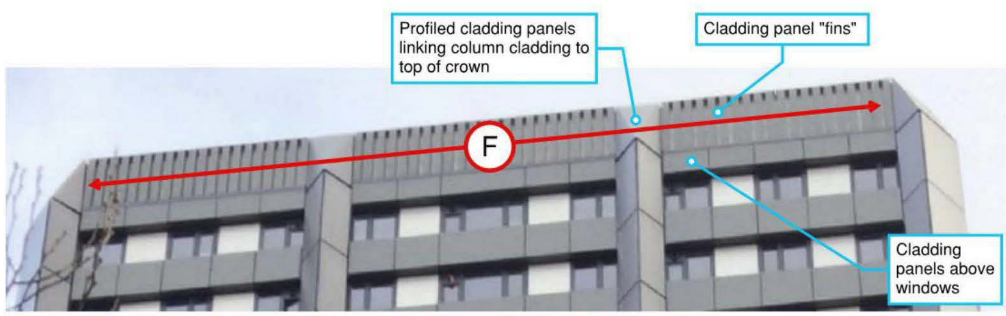


Figure 10.3: Pathway F identified on undamaged façade (SEA00000322)

10.1.9 These pathways are shown on a rendered representation of the rainscreen cladding installation based on design drawings and observations from my post fire inspection in Figure 10.4.

10.1.10 These pathways are also demonstrated on photographs of external fire spread on the West elevation of Grenfell Tower in Figure 10.5.

10.1.11 In the following sections I will describe how the construction materials present at Grenfell Tower enable each of these Pathways, with reference to footage of the fire.

10.1.12 Please note it is not my intention to create a very detailed fire spread map in this part of my report. It is an analysis to understand general flame front routes, and importantly overall timescales where individual building elevations became fully involved in the fire. The very fine detail of the combustion process and fire and smoke behaviours throughout the fire are being dealt with by Professor Jose Torero for the Public Inquiry.

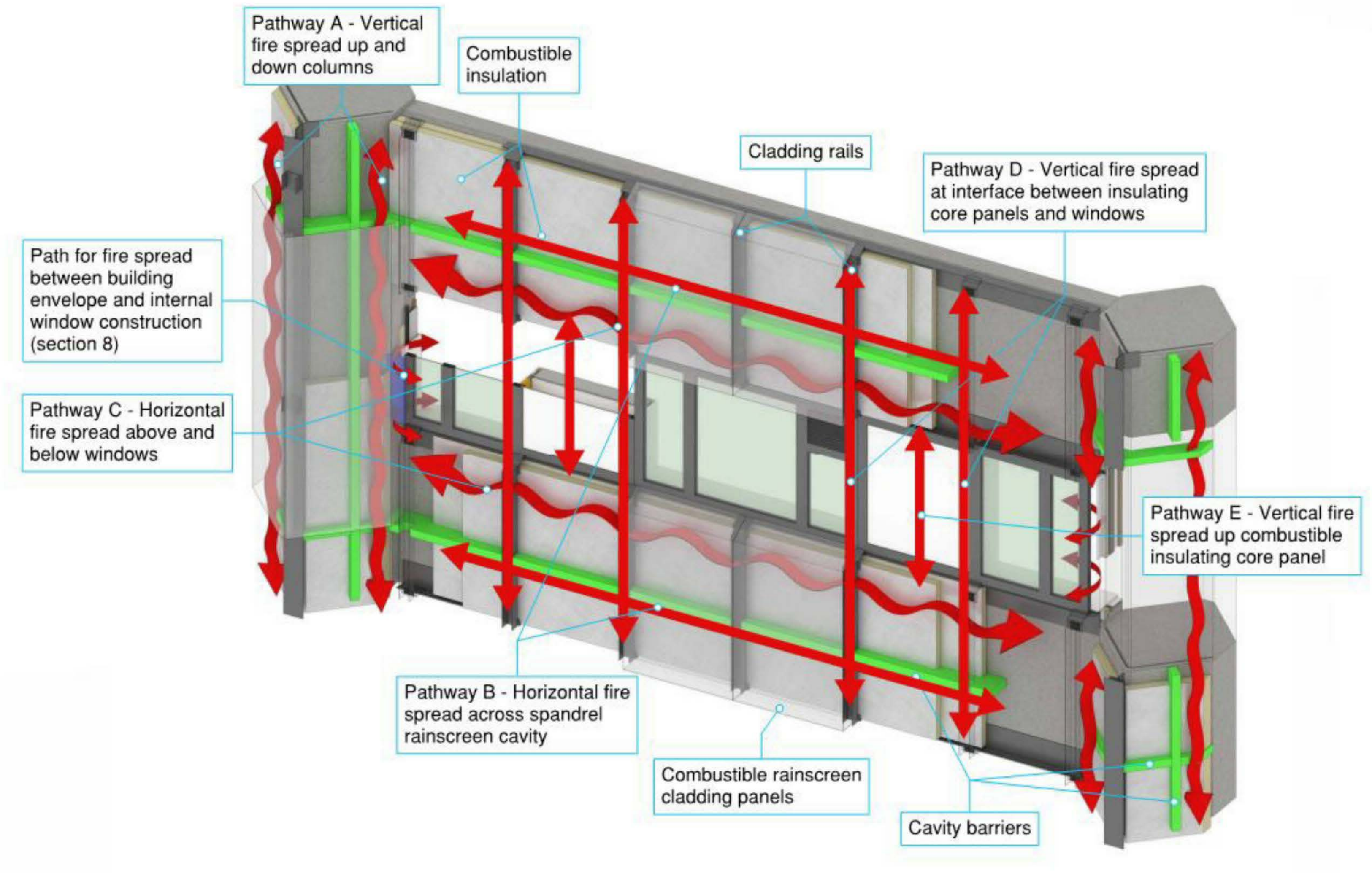
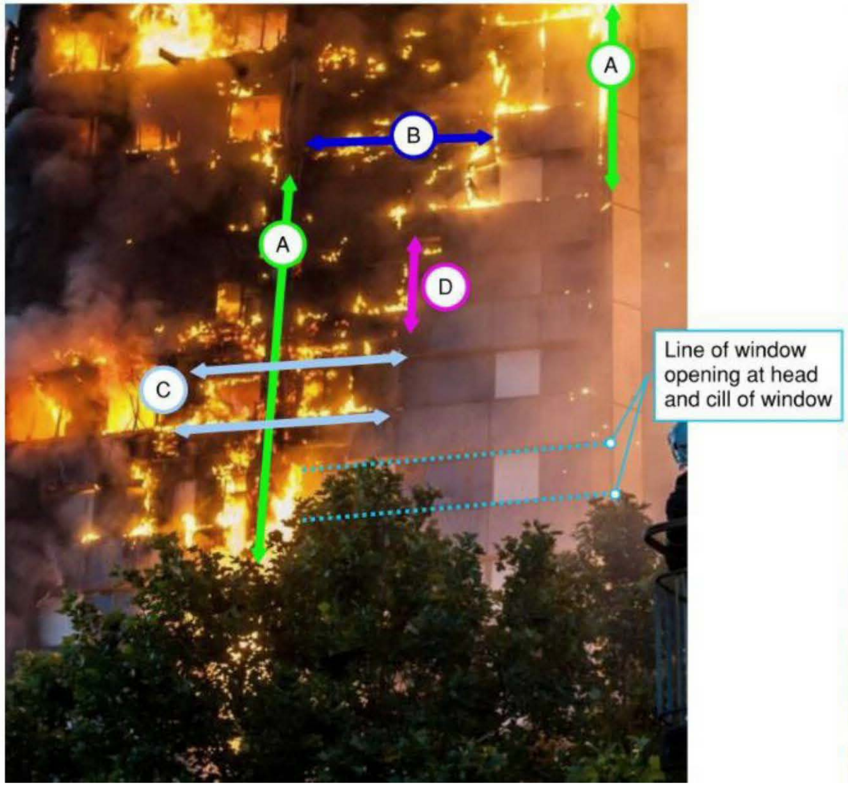
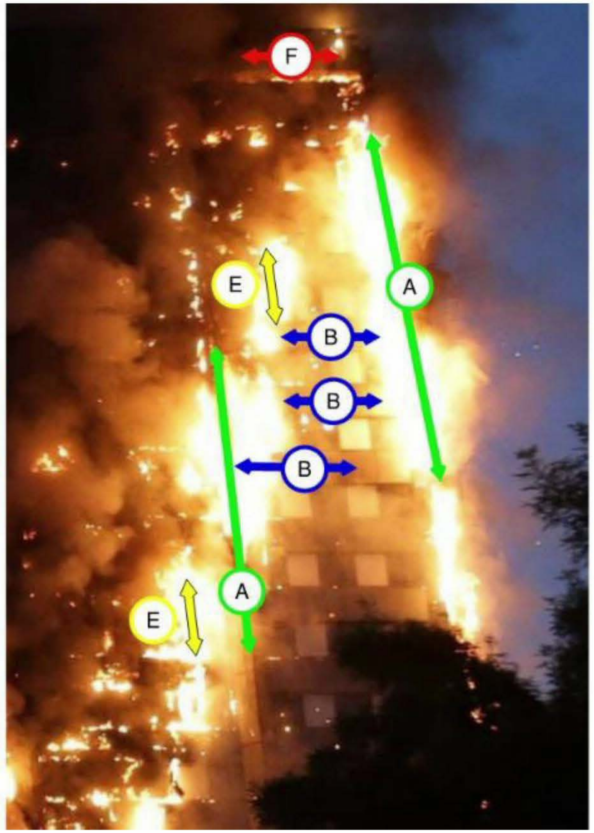


Figure 10.4: Pathways A, B, C, D and E shown on a rendered representation of rainscreen cladding installation based on design drawings and observations from post fire inspection



(a) Photographic evidence of Pathways A, B, C and D[1]



(b) Photographic evidence of Pathways A, B and E[2]

Figure 10.5: Fire spread on West elevation of Grenfell Tower

[1] Paris Match, 2017. Les pompiers héroïques de la Grenfell Tower racontent l'horreur [online] Available at: https://www.parismatch.com/Actu/International/Les-cris-la-fumee-Les-pompiers-heroiques-de-la-Grenfell-Tower-racontent-l-horreur-1318214 [Accessed 20 October 2018]

[2] Daily Star, 2017. Family managed to escape Grenfell Tower inferno by turning on their TAPS [online] Available at: https://www.dailystar.co.uk/news/latest-news/622497/Grenfell-tower-fire-London-Latimer-Road-Ladbroke-Grove-inferno-escape-taps [Accessed 20 October 2018]

10.2 Requirements for fire spread

10.2.1 There are 3 components that are required for fire to spread:

a) A source of fuel
b) A source of oxygen
c) Heat

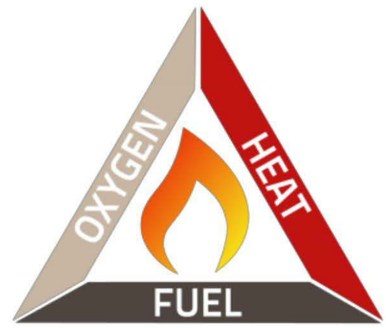


Image © Elite Fire Protection

Figure 10.6: Fire triangle

10.2.2 In the following sections I will identify how each of the Pathways introduced in Section 10.1 had access to each of these 3 components of fire spread.

10.3 Pathway A: Vertical spread up (and down) the full height of the columns

10.3.1 **Evidence of Pathway contributing to fire spread at Grenfell Tower**

10.3.2 The initial fire spread via Column B5 was upwards and rapidly led to the full height of column B5 (which is approximately 52m in height) becoming involved in the fire within approximately 12 minutes.

10.3.3 Figure 10.7 and Figure 10.8 show the origin and subsequent fire spread vertically up the column as a Pathway. This occurred on several other columns during the fire, and fire spread down the columns was also observed for example as shown in Figure 10.9.

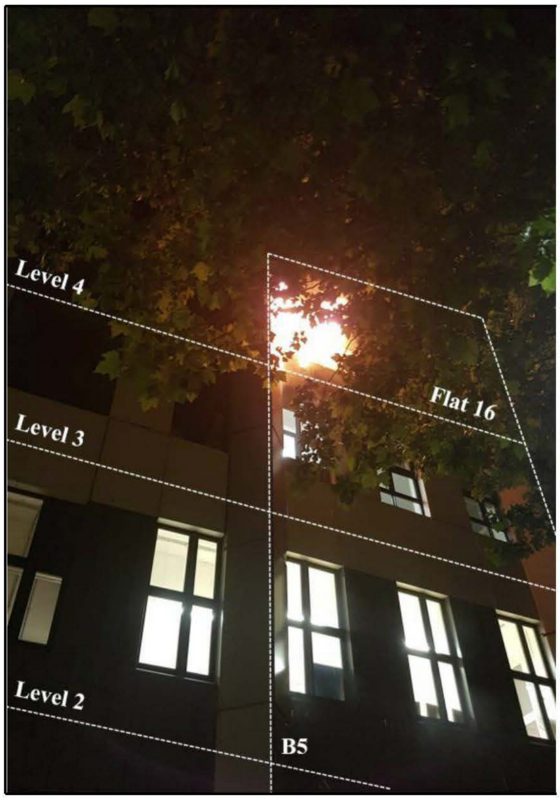


Figure 10.7: Earliest image of external fire observed on Level 4, at 01:14 on 14 June 2017 (MET00006589)

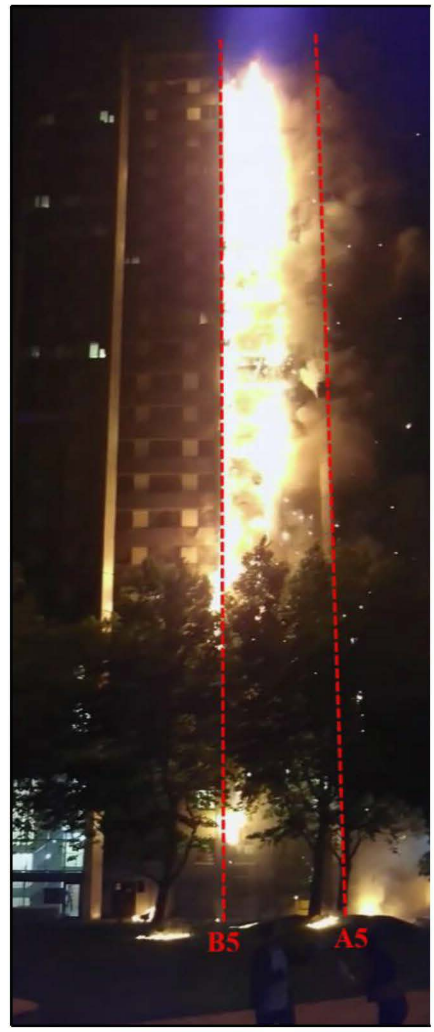


Figure 10.8: Fire on the full height East elevation of the building envelope on 14 June 2017, estimated time 01:26[3]

[3] https://www.youtube.com/watch?v=6AYUZ5Snxzo

10.3.4 Figure 10.9 shows fire spread vertically down a column as a Pathway.

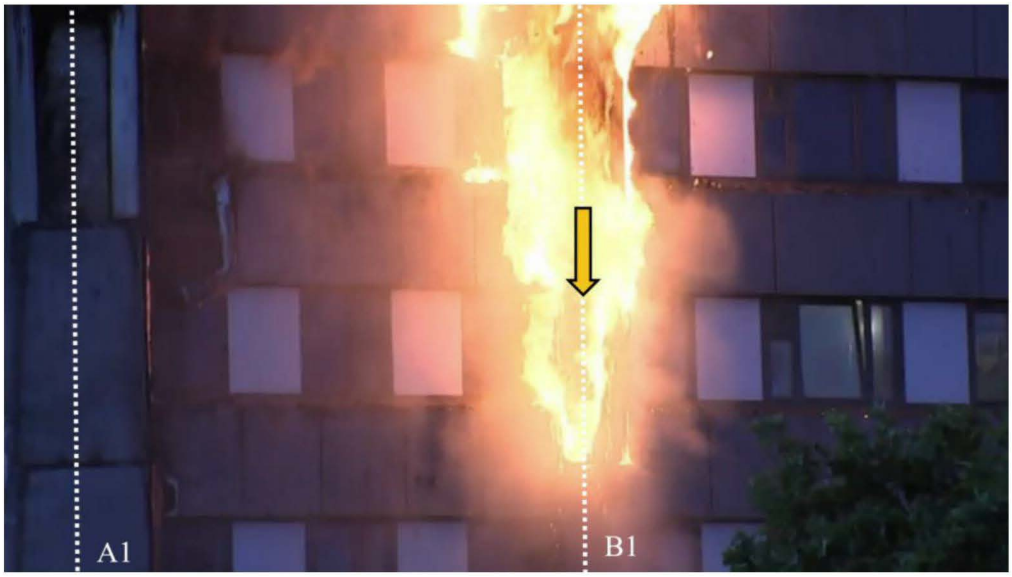


Figure 10.9: Downwards fire spread along column B1 on the West elevation[4]

10.3.5 Materials and construction supporting Pathway A

10.3.6 I have described in Section 9 how a fire could spread from within flats to the external wall cavity, via the cill, jamb or head adjacent to a column, directly into column rainscreen cavities.

10.3.7 The photographic evidence I presented in Section 9 shows the most probable route for the original fire spread from flat 16 was the higher portion of the kitchen window in flat 16 through the column-side jamb and head of the window.

10.3.8 Once flames have penetrated through to the column rainscreen cavity there is fuel, oxygen and heat to sustain the fire.

10.3.9 Firstly, fuel is available for ignition around the columns themselves, through the combustible exposed polyethylene core of the Reynobond 55 PE rainscreen cladding panels at the outer leaf of the column cavity (Figure 10.10). Polyethylene ignites at between 270°C and 443°C (Table 15, V. Babrauskas, *Ignition Handbook*, SFPE, 2003).

10.3.10 The inside face of the inner leaf of the cavity (the concrete column itself) was lined with combustible Celotex RS5000 PIR insulation (Figure 10.11). PIR is a type of polymeric material and is combustible. It ignites at approximately 378°C (Table A.36, SFPE Handbook, 5th Edition).

10.3.11 Also present in the column cavity at the window jamb was the EPDM weather proof membrane. This is a combustible synthetic rubber material that ignites

[4] https://www.my5.tv/grenfell-tower-minute-by-minute/season-1/grenfell-tower-minute-by-minute

between 180°C and 378°C (Table 15, V. Babrauskas, *Ignition Handbook*, SFPE, 2003).

10.3.12 Therefore, there is evidence of fuel lining each face of the cavity over its whole height.

10.3.13 Figure 10.10 shows photographs taken of the column outside Flat 13 (left) and the column outside Flat 11 (right). In the left hand image, the rainscreen panels and insulation have been removed from the nearest half of the column, to show the layers on materials on the other half of the column. Figure 10.10 also identifies routes for air to pass into the cavity behind the Reynobond rainscreen cladding panels. The right hand image shows the construction of the panels featuring the exposed PE core material around all edges of each panel.

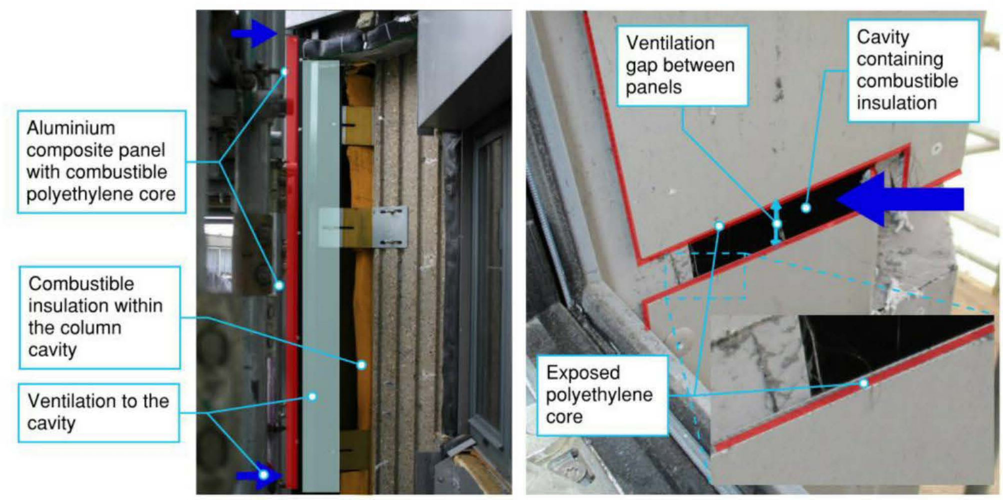


Figure 10.10: Images of available fuel and ventilation within column cavities from Grenfell Tower site inspection (left image – Flat 13, right image – Flat 11)

10.3.14 Figure 10.11 shows a marked up horizontal section drawing through a column identifying each of the components, and the resulting cavity between the face of the Celotex RS5000 insulation and the rear of the Reynobond 55 PE rainscreen cladding panel. This was approximately 140mm in depth. This image also shows the construction of the panels at the column nose, where the panels fold over and a separate fin of ACP is fitted to close the gap.

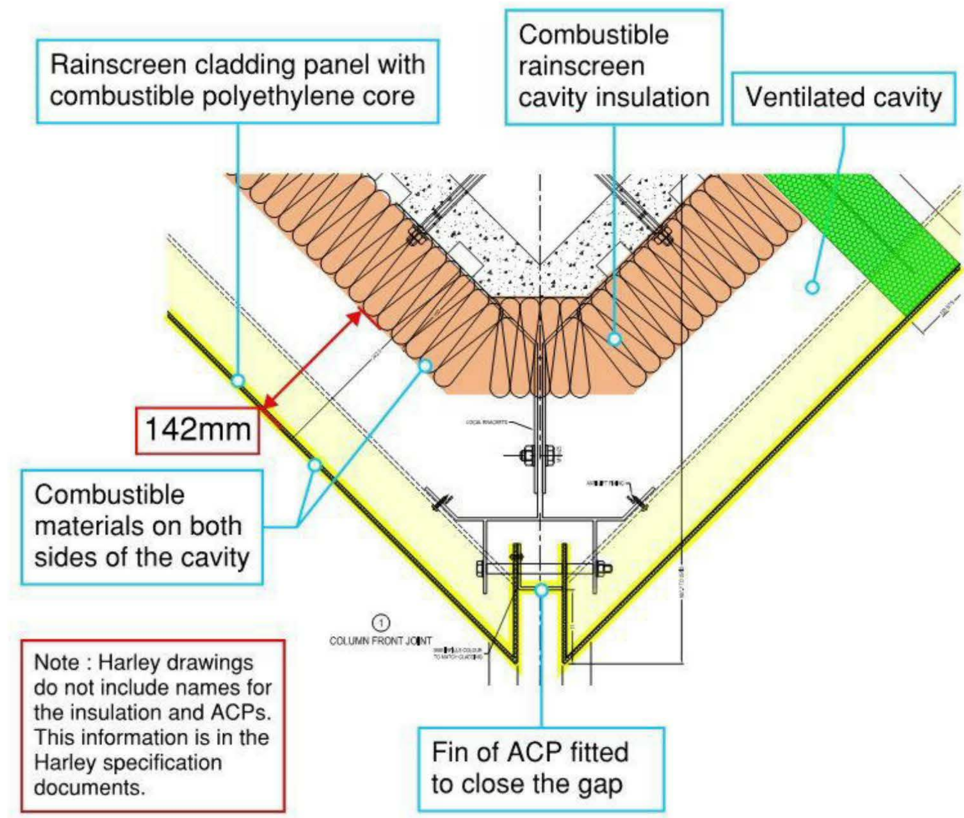


Figure 10.11: Harley design drawing showing column in plan view showing that both interior surfaces of the cavity contain combustible materials (Based on HAR00008902)

10.3.15 A ventilated rain screen should have the following key elements:

a) An outer layer (the rain screen), intended to shelter the building from the majority of direct rainfall. Some joints between panels or at the edges of the rain screen should be left open.

b) A cavity, which can include insulation, intended to collect any water which passes through the joints in the rain screen layer, and to permit such water to flow down to a point where it is collected and drained from the cavity. The insulation layer should not completely fill the cavity.

c) A backing wall, intended to provide a barrier to air infiltration and water ingress into the building

10.3.16 A ventilated rain screen cladding system is either pressure-equalized or drained and ventilated. The ventilated rain screen system installed at Grenfell Tower was a drained and ventilated system.

10.3.17 In the case of Grenfell Tower, this cavity runs the full height of every column from ground level to the roof level. As explained in Sections 8 and 9 of my report, the Reynobond 55 PE panels were designed to have gaps between them to permit air to enter the cavity. These gaps are also identified in Figure 10.10, Figure 10.11 and Figure 10.12.

10.3.18 Therefore, the design of the rainscreen is explicitly designed to permit air to enter the cavity, providing a source of oxygen to a fire in the space.

10.3.19 In Section 9 I identified the means by which a fire could reach the rainscreen cavity from a fire within the flat. Figure 10.12 provides the key mechanism of this fire spread through the junction between the window jamb and the column, through the combustible EPDM weather proof membrane. This mechanism permits heat and flames to enter the column cavity.

10.3.20 Once within the column cavity, the heat from the fire will be contained in part, between the thermally insulating Celotex insulation and the Reynobond panels, raising the surface temperature of all the materials within the cavity to the point at which they can ignite.

10.3.21 Once a fire can ignite the materials within the cavity, the natural flow of air into the cavity, driven by the rising hot air inside the cavity, will provide a continuous supply of oxygen to the fuel sources creating a self-sustaining fire.

10.3.22 Once the fire enters the cavity, the strongest route of flame spread is upward. This is because the rising flames pre-heat the materials above the fire making it easier to ignite. However, downward fire spread is also possible and was observed during the fire.

10.3.23 In the case of the Grenfell Tower building envelope, the mechanisms by which flames could spread downwards along columns (Pathway A) are:

a) Polyethylene from the Reynobond 55 PE panels melting and running down the building, while ignited; and

b) Radiation from the fire within the cavity (acting directly and reflecting off internal surfaces) heating materials below the fire within the cavity.

10.3.24 In Section 10.10.14, I provide additional evidence of downwards fire spread in my explanation of the effect of fire spread along the architectural crown on lower levels of the building.

10.3.25 Cavity barrier/fire stops were fitted in the construction with the purpose of restricting the spread of smoke and flames through the rainscreen cavity. In the next section I describe how these barriers were ineffective [please also refer to Section 11 of my report].

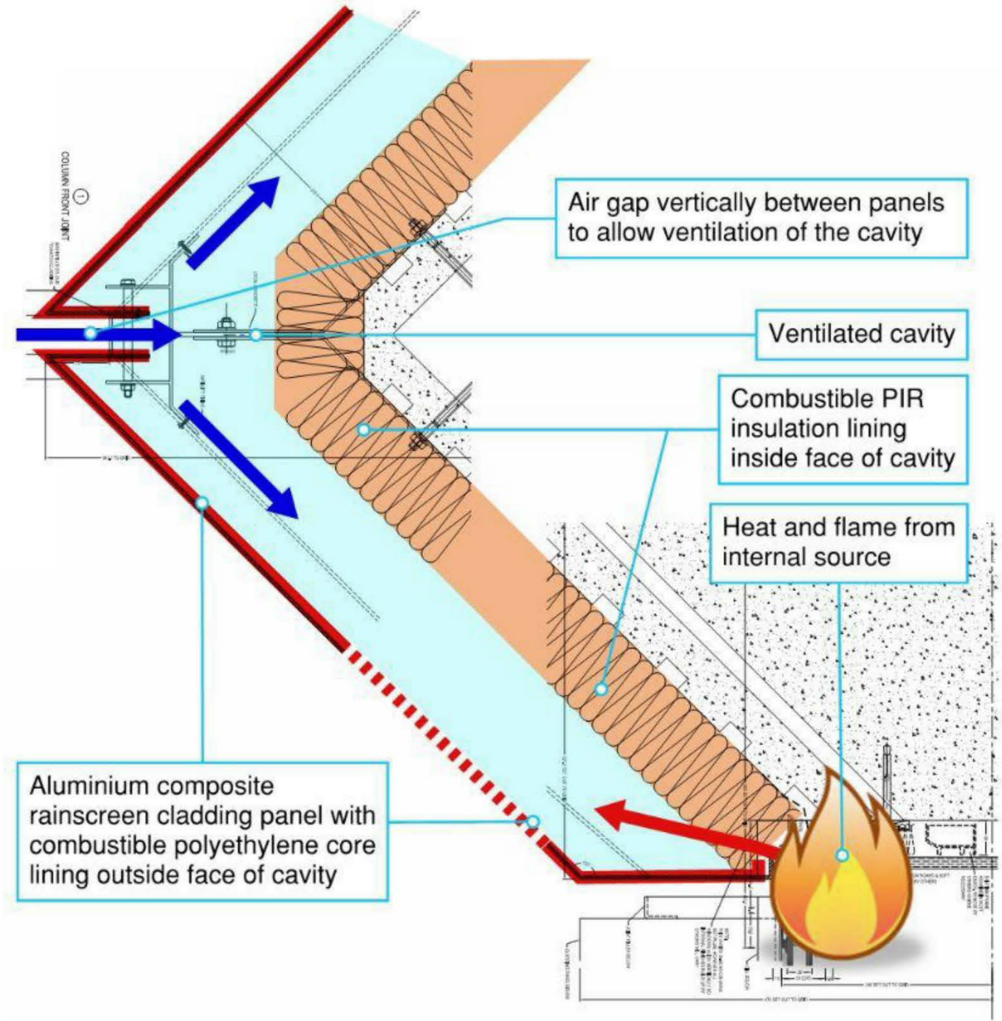


Figure 10.12: The fuel, ventilation and heat available within the column cavity of Grenfell Tower adjacent to Flat 16 (based on Harley drawings HAR00008880 & HAR00008902) to support combustion (dotted line denotes continuation of panel between underlying drawings)

10.3.26 In summary, the vertical fire spread observed up and down the columns, was caused by:

a) The presence of fuel (the combustible polyethylene core of the Reynobond panels, the combustible Celotex insulation and the combustible EPDM weather proof membrane);

b) The presence of oxygen entering the rainscreen cavity through the specifically designed air gaps;

c) Heat from a fire within a flat passing into the cavity via the window construction described in Section 9; and

d) Polyethylene from the Reynobond panels melting and running down the building, while ignited.

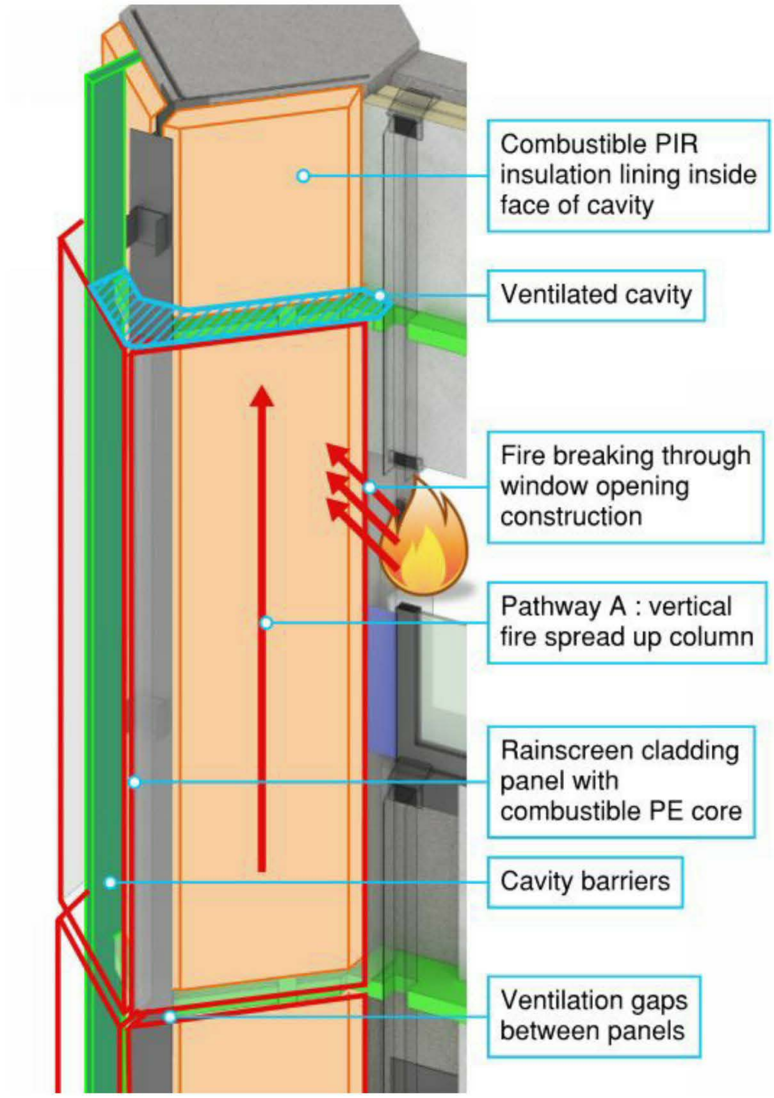


Figure 10.13: 3D image of the fuel, ventilation and heat available within the column cavity of Grenfell Tower to support combustion

10.3.27 **Construction provided to resist the spread of fire via Pathway A**

10.3.28 The rainscreen cavity was subdivided at every floor level with *Siderise RH25 'open state' horizontal cavity barriers*. In Section 8, I presented evidence of these items from site and explained how these items did not provide an effective seal in the cavity. They were provided approximately in line with each floor of Grenfell Tower. These cavity barriers are therefore positioned approximately every 2.6m up the full height of the column.

10.3.29 An open state cavity barrier does not initially fully close the cavity. The particular cavity barriers installed in Grenfell Tower (See Section 11 and Appendix E) were designed to leave a 25mm gap between the outer surface of the cavity and the outer face of the cavity barrier. This gap is to allow free ventilation and drainage over the full height of the column. The outside face of the horizontal cavity barrier is lined with an intumescent material (visible as the black strip in Figure 10.17) which is intended to activate under heat and expand to close the 25mm gap. Therefore, initially in a fire, the entire column cavity over the entire building height was fully connected.

10.3.30 Vertical cavity barriers/fire stops were provided with the intention to fully fill the ventilated cavity on the specific columns identified in Figure 10.14.

10.3.31 As explained in Section 8, these vertical fire stops were not the specific vertical cavity barriers/fire stopping product specified by the designer, they were the horizontal cavity barriers/fire stopping product inserted in a vertical orientation. I observed the presence, or remains of, vertical cavity barriers/fire stops on each corner column, and each column adjacent to party walls. At column B1 I saw no remnants of a vertical cavity barrier on the upper levels inspected and I was not able to inspect the remaining cavity at Level 4 (See Note Figure 10.14).

10.3.32 Due to access restrictions I was not able to inspect the cavity in this location, where it remained, for the presence of a vertical cavity barrier and I did not observe the remnants of any cavity barriers on the top storeys of the building.

10.3.33 As identified in Figure 10.14 the column cavity barriers were fitted on one side of the column only, and to specific columns only (these appear to be intended to align, in part, with the general location of the internal compartmentation to individual flats). The compliance of the cavity barrier/firestop provision is outlined in Section 11 of my report.

10.3.34 Please see Figure 10.15 demonstrating the horizontal extent of the column cavities either side of the vertical cavity barrier. The vertical spacing between horizontal cavity barriers was approximately 2.6m. This means an approximate area of column cavity (between fitted barriers) beside one window of $0.78m^2$, and $2.7m^2$ on the other side.

10.3.35 For the columns with no vertical fire stop this results in a cavity of $3.64m^2$ in area over the face of the column, between each horizontal fire stop (Figure 10.16).

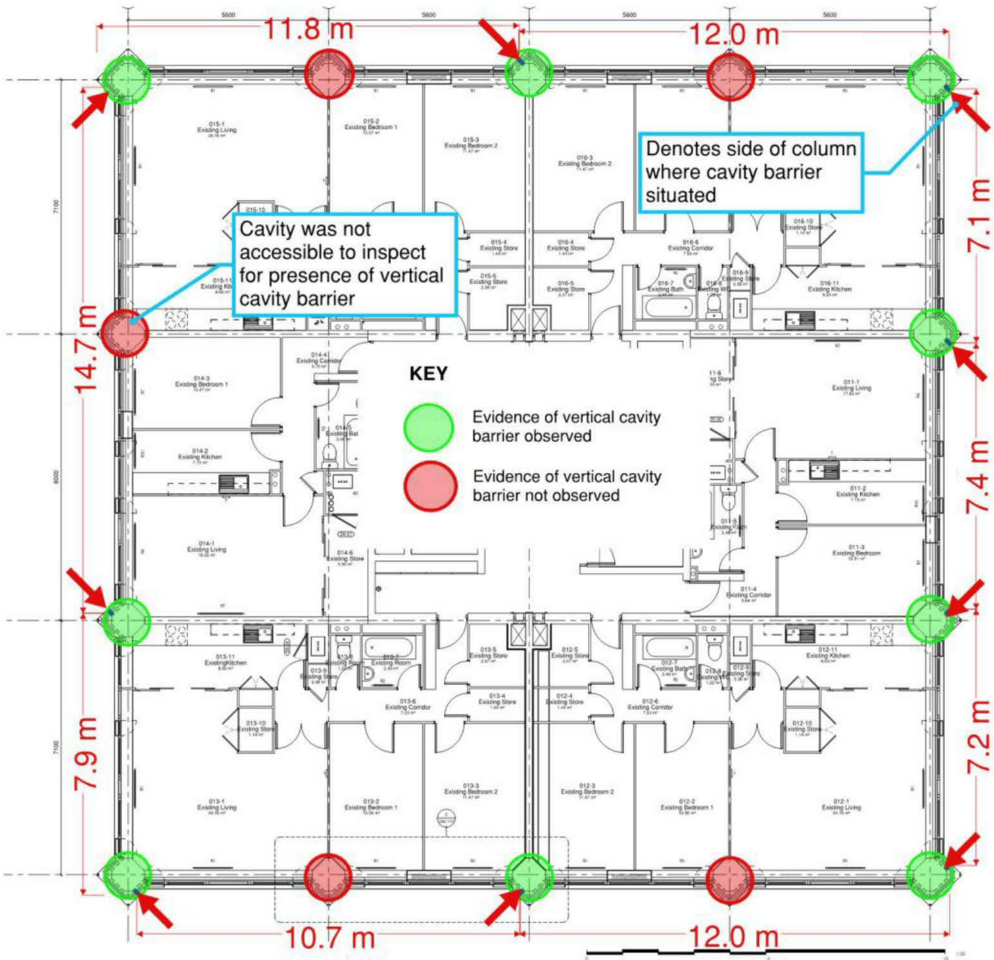


Figure 10.14: Location and separation (as measured from plan) of vertical fire stops as identified during post fire inspection (SEA00010474)

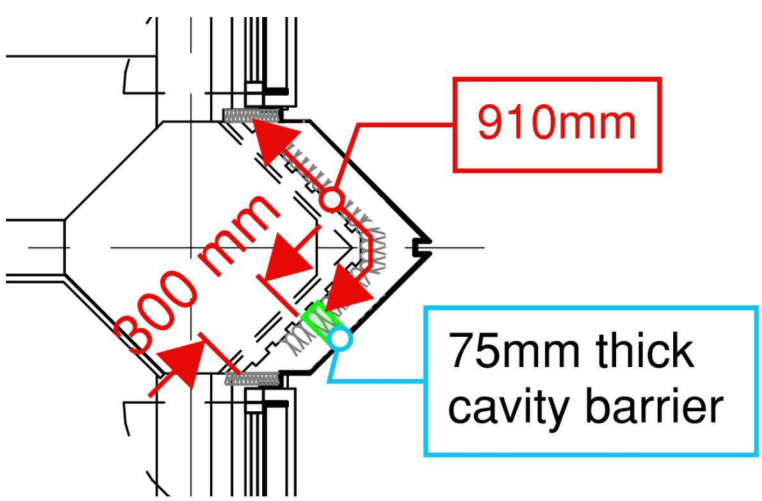


Figure 10.15: Horizontal extent of column cavity where a vertical fire stop is provided (based on SEA00010474 and thickness of barrier from Harley specification HAR00008991)

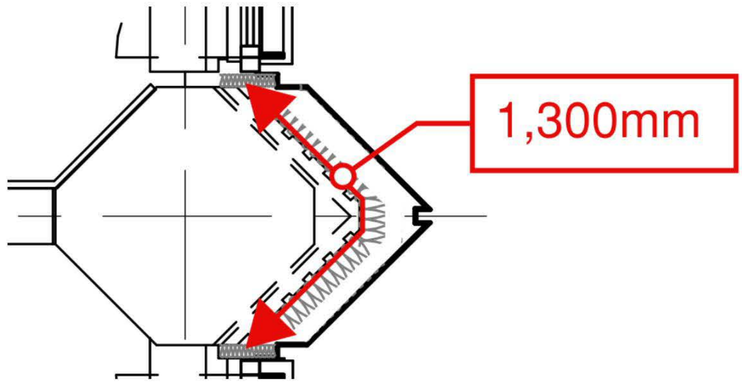


Figure 10.16: Horizontal extent of column cavity where no vertical cavity barrier is present (based on SEA00010474)

10.3.36 Fire spread can occur past these horizontal and vertical fire stop/cavity barriers in the following ways.

10.3.37 **Horizontal cavity barriers** - The initial condition of the cavity is that it is continuous up the full height of the column, prior to activation of the intumescent coating (Figure 10.17):

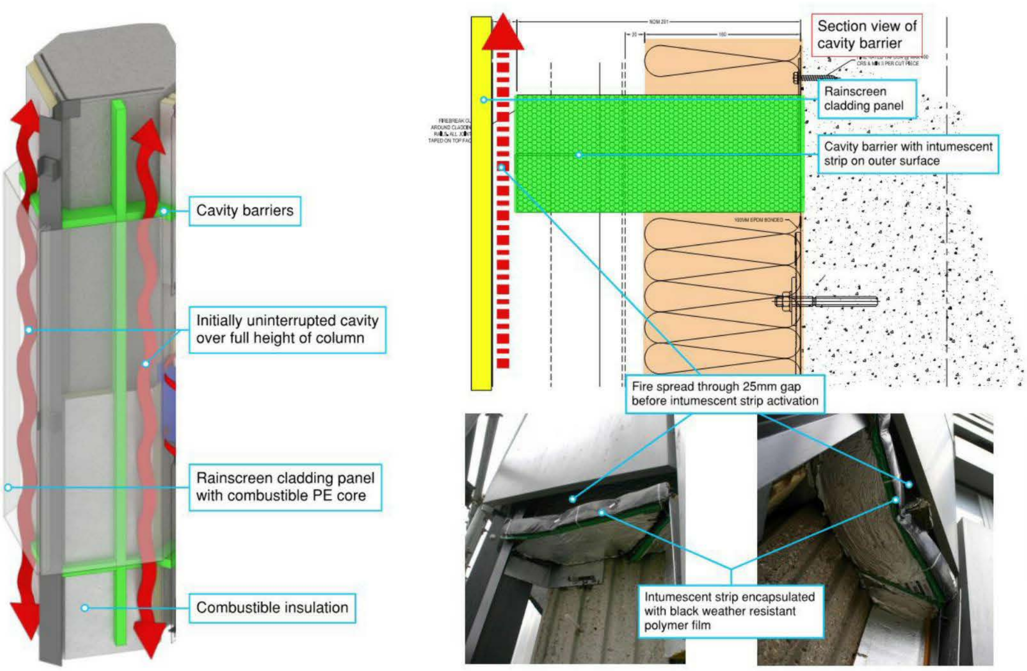


Figure 10.17: Continuity of the cavity within the column rainscreen over cladding system and evidence of 25mm gaps at locations of cavity barriers (Photos external of Flat 14). (HAR00008901)

10.3.38 **Horizontal & vertical barriers** – The combustible polyethylene core of the rainscreen cladding panel itself provides a route of fire spread, bypassing the cavity barriers (Figure 10.18):

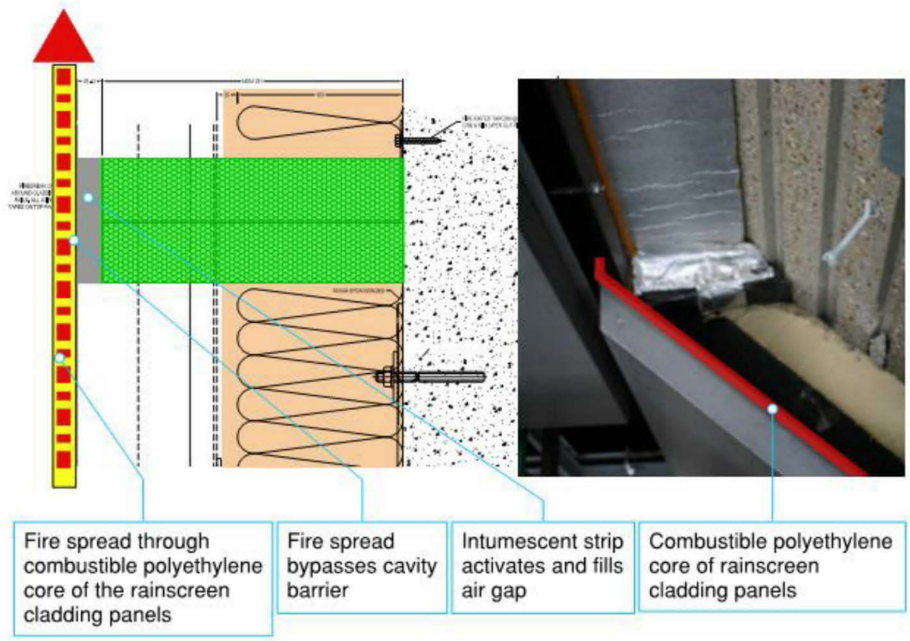


Figure 10.18: Fire spread through the combustible rainscreen cladding panel core (Photo external of Flat 14) (HAR00008901)

10.3.39 **Horizontal & vertical barriers** – Rainscreen cladding panels can distort when heated, either through heating of the panel itself or by failure of the supporting fixtures. This can allow further gaps between the cavity barriers and the rainscreen cladding panels to form (Figure 10.19):

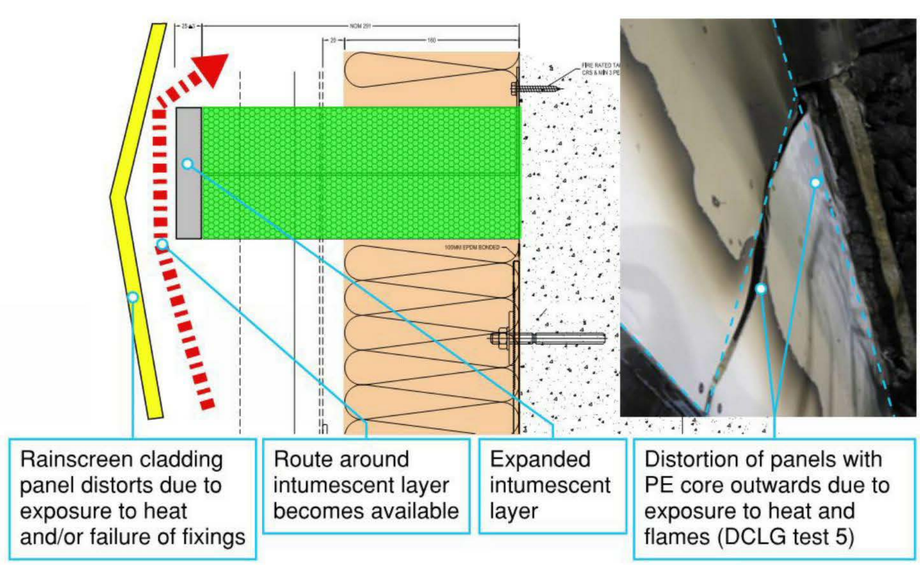


Figure 10.19: Integrity failure of rainscreen cladding (HAR00008901) (photo: CLG00016837)

10.3.40 The performance of the cavity barriers in restricting the spread of fire was also compromised at the nose of the column, due to the specific geometry of the ACP and support bracket. As illustrated in Figure 10.20, a gap where the horizontal cavity barrier was not present existed at the nose, which provided another route of fire spread past the horizontal cavity barriers.

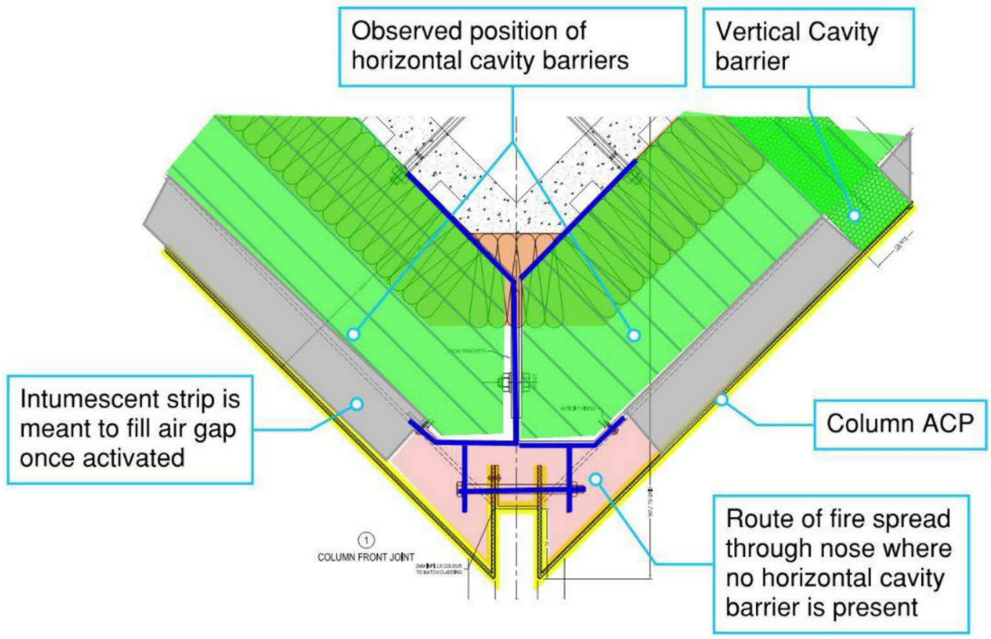


Figure 10.20: Harley design drawing showing column in plan view showing a gap where the horizontal cavity barrier was not present at the nose of the columns (Based on HAR00008902)

10.3.41 **Columns with no vertical cavity barriers** – In this case the column contains no impediment to the horizontal spread of fire around the building envelope (For example Column A2, A4, D2 and D4).

10.3.42 **Corner columns with vertical (and horizontal) barriers** – as described in Section 9, the materials and construction of the window installations also provide a Pathway for fire to spread rapidly between the flats and the rainscreen cavity (from inside to outside, and vice versa). This introduces a further avenue for bypassing the vertical cavity barriers situated on the corner columns (Figure 10.21):

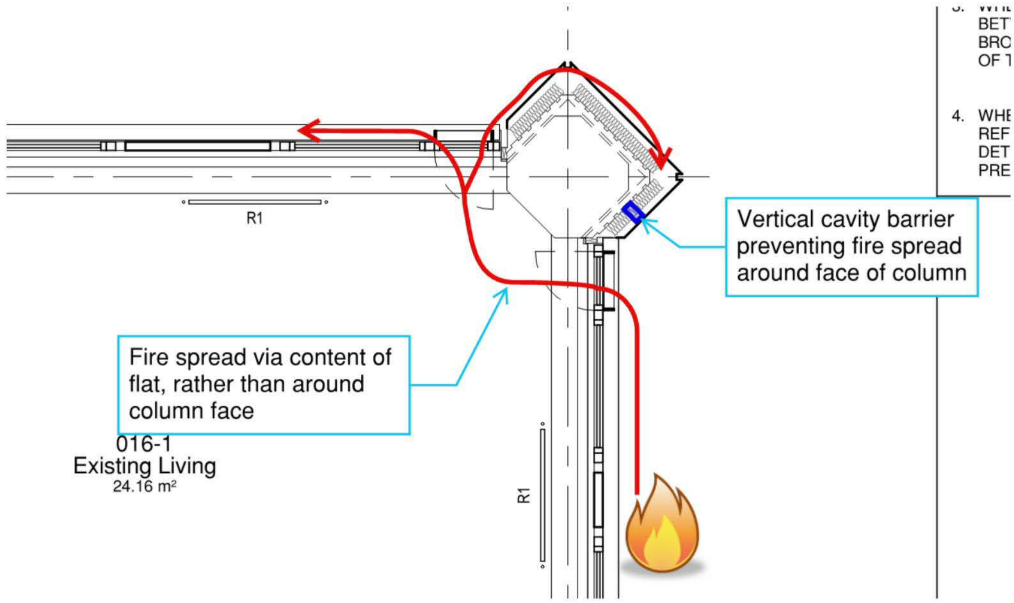


Figure 10.21: Route for fire to bypass corner column cavity barrier (based on SEA00010474)

10.3.43 These five mechanisms for fire spread therefore represent avenues to premature integrity failure in the performance of both the horizontal and vertical cavity barriers.

10.3.44 Specifically, regarding the installation at Grenfell Tower, during my post fire inspections I found the installation of a number of cavity barriers to be defective. This is discussed in Section 8, however a summary list and example photographs of the main defects are shown below:

a) Horizontal cavity barriers were installed above the line of the compartment floors and around 700mm below the window cill.

b) Channels in the outside surface of the original concrete column created cavities that were not sealed by the horizontal cavity barriers.

c) Both horizontal and vertical cavity barriers were cut to shape roughly so therefore were poorly fitting with the original concrete, cladding support structure and adjoining cavity barriers, and also fitted poorly against the rainscreen panels in the case of the vertical cavity barriers.

d) The same product (Siderise RH25 with an intumescent strip) used for horizontal cavity barriers was used for the vertical cavity barriers, with the intumescent strip facing the concrete.

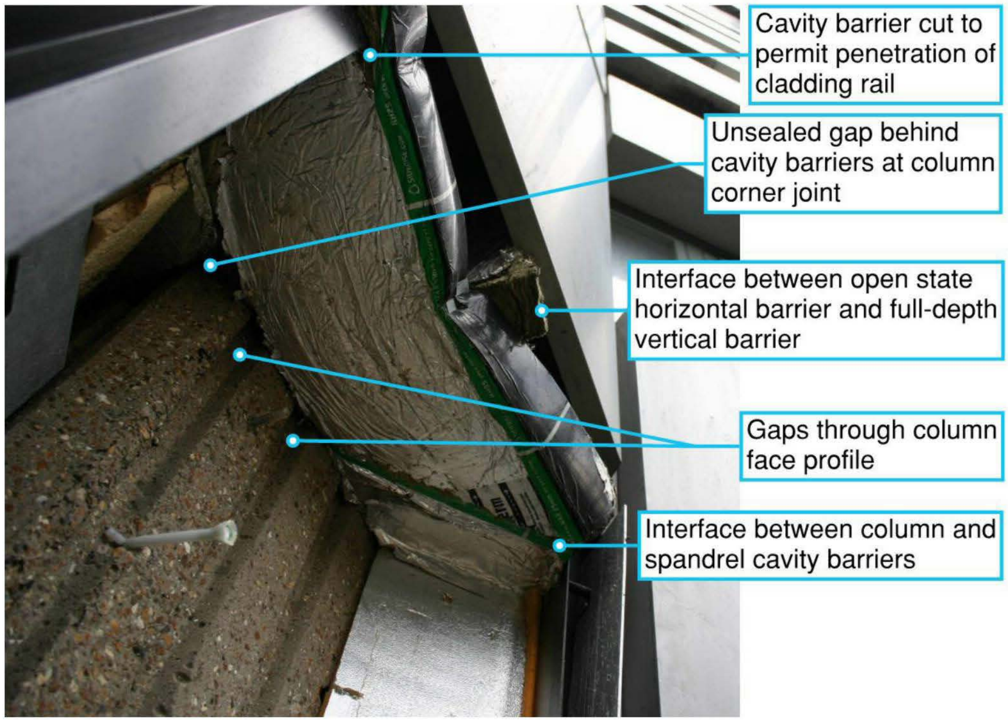


Figure 10.22: Horizontal column cavity barrier example - floor 4, external Flat 12.

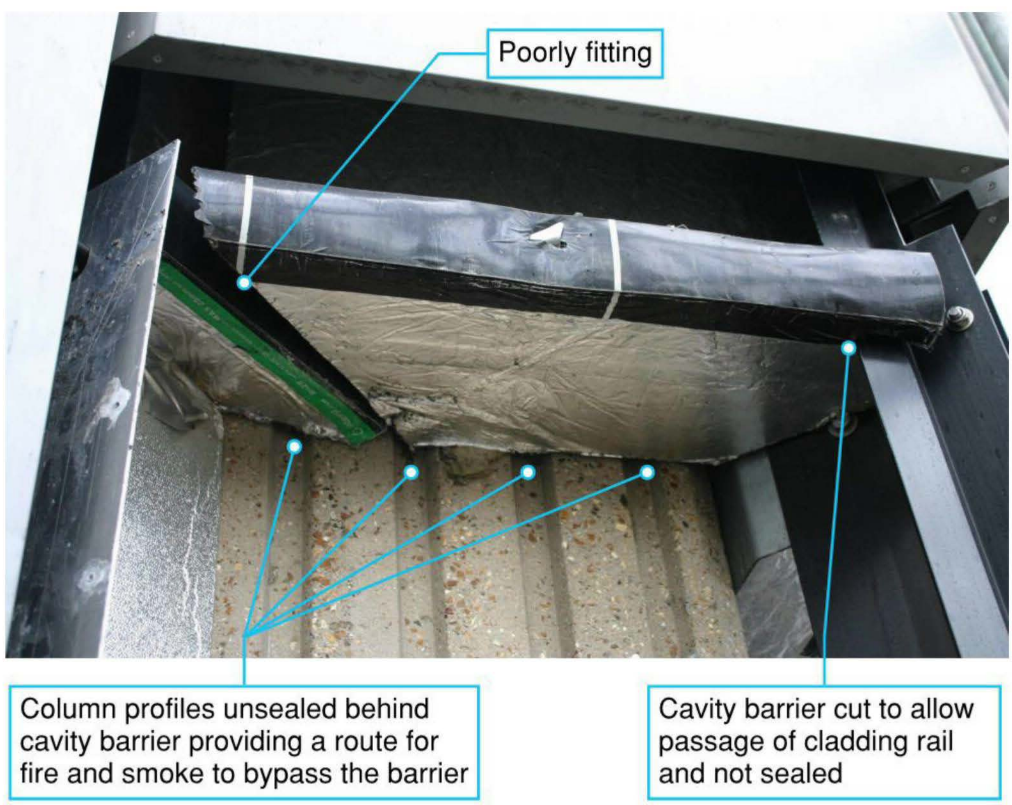


Figure 10.23: Horizontal cavity barrier in column cavity - floor 4, external Flat 12.

10.4 Pathway B: Horizontal spread across the Reynobond spandrel panels

10.4.1 Evidence of Pathway B contributing to fire spread at Grenfell Tower

10.4.2 Specific evidence of fire spread via this Pathway is presented in Figure 10.24. Additionally, this Pathway is evident in Figure 10.30 and Figure 10.34.

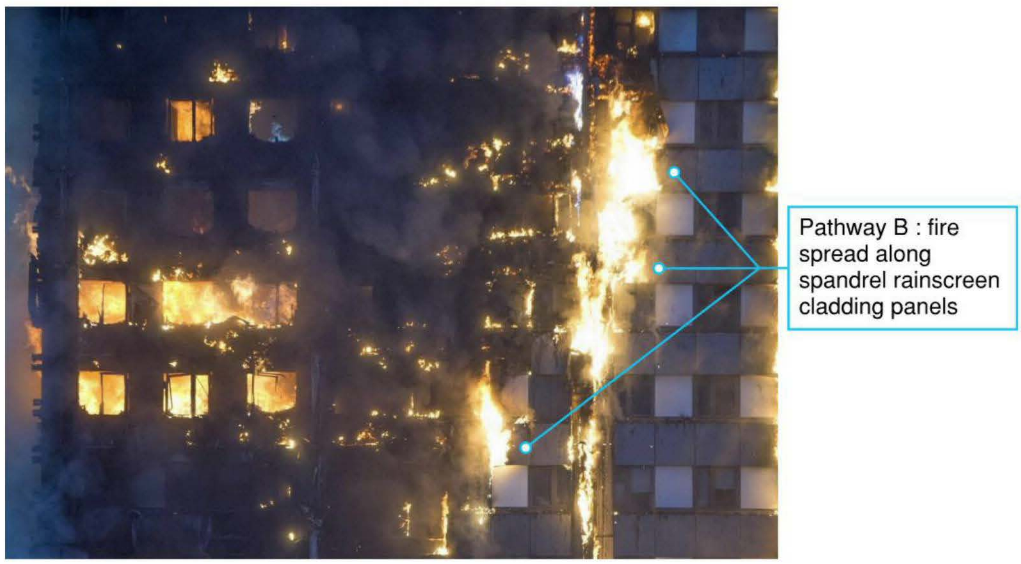


Figure 10.24: Evidence of fire spread along Reynobond panels[5]

10.4.3 Materials and construction supporting Pathway B

10.4.4 Figure 10.25 identifies the materials present in the building envelope on the outside of the concrete spandrels. These are: Reynobond rainscreen panels, with either Celotex PIR or Kingspan K15 phenolic foam (PF) combustible beneath; cavity barriers and metal support structure for the Reynobond panels.

[5] London Evening Standard, 2017. London fire: Terrified residents 'jump from 15th floor' as others desperately wave from windows [online] Available at: https://www.standard.co.uk/news/london/london-fire-terrified-residents-jump-from-15th-floor-to-escape-grenfell-tower-inferno-a3564536.html [Accessed 20 October 2018]

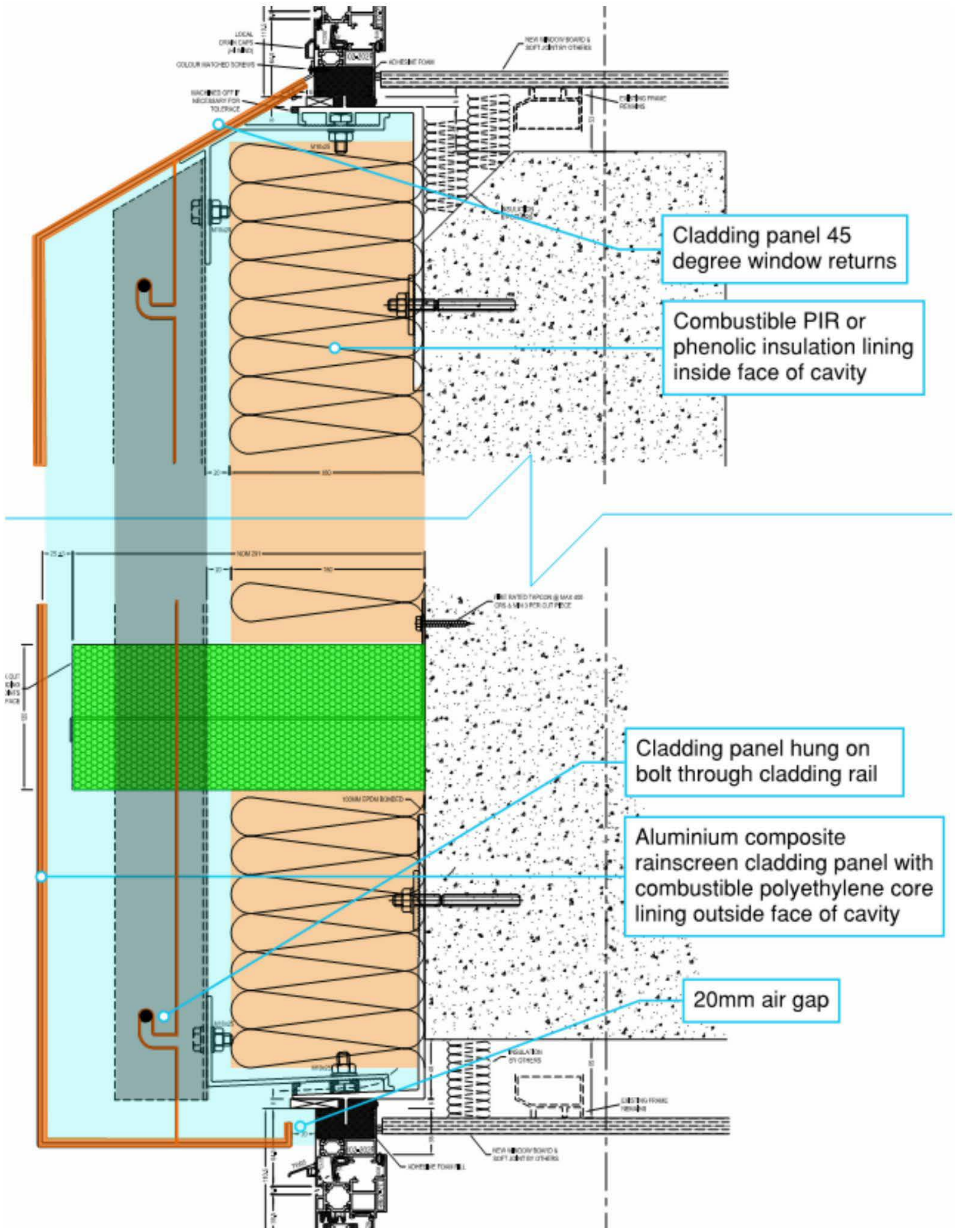


Figure 10.25: Vertical section through building envelope at spandrel level (based on HAR00008879 & HAR00008901)

10.4.5 The means by which the fire can spread horizontally along the spandrel panel is similar to Pathway A described in Section 10.3.4.

10.4.6 The materials of construction in this horizontal area are the same as Pathway A, that is: combustible Reynobond cladding panels and combustible insulation (either Celotex PIR or Kingspan PF) fixed to the existing concrete external wall.

10.4.7

10.4.8 Air is able to penetrate into the cavity through the specifically designed gaps that were part of the rainscreen cladding system and identified in Figure 10.26. The combustible PE core of the rainscreen ACP is also exposed at the returned edges of the panels.

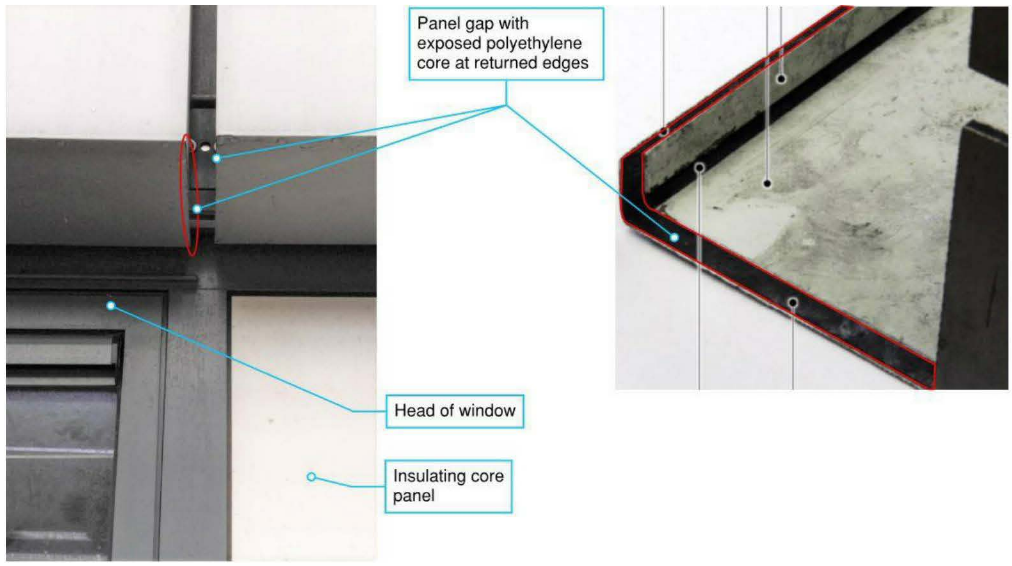


Figure 10.26: Photograph outside Flat 10 showing gaps (with combustible PE core exposed at panel edges) permitting air into the cavity (also refer to Figure 10.2) (Prof. Bisby's phase 1 report figure 20)

10.4.9 Fire can penetrate into the spandrel cavity either via Pathway A or by flames from internal fires breaking out of windows, passing into the cavity by the ventilation gap provided directly above the window head as identified in Figure 10.27.

10.4.10 Once flames and hot smoke are contained within the cavity, or passing over the outer face of the Reynobond panel, it will raise the temperature of the Polyethylene core such that it may be ignited.

10.4.11 The flames and hot gasses within the spandrel cavity will be trapped in part, in the cavity, by the panel returning to meet the concrete spandrel at the window cill (Figure 10.25), allowing them to spread horizontally across the face of the building.

10.4.12 In summary, the horizontal fire spread observed across the face of the spandrels was caused by:

a) The presence of fuel (the combustible polyethylene core of the Reynobond 55 PE panels and the combustible Celotex RS5000 or Kingspan K15 insulation);

b) The presence of oxygen entering the rainscreen cavity through the specifically designed air gaps; and

c) Heat from a fire within a flat passing into the cavity via Pathway A, or exiting from the flat via the window construction described in Section 9.

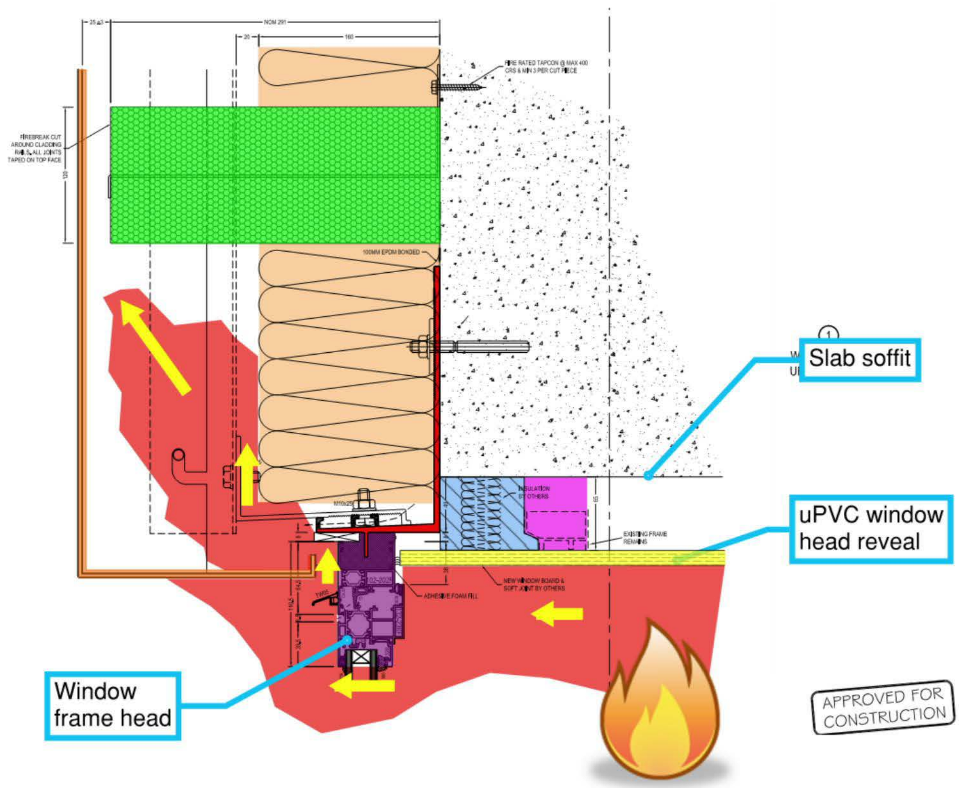


Figure 10.27: Mechanism for fire to enter spandrel cavity at window head (replicated from Section 9) (HAR00008901)

10.4.13 As identified in Figure 10.28, the exposed edges of the insulation support flame spread to a greater extent than if the edges had been covered in aluminium foil taping. PIR or PF insulation covered by aluminium foil has a higher resistance against flame spread compared to the uncovered material. This is because the aluminium foil covering acts to reflect radiant heat, and to prevent flames from reaching combustible gasses being released as the PIR heats up. However, this protection only lasts until the thin layer of aluminium is damaged or destroyed by the fire. So in the early stages of fire spread across the material, the cut edges will be more prone to support flame spread.

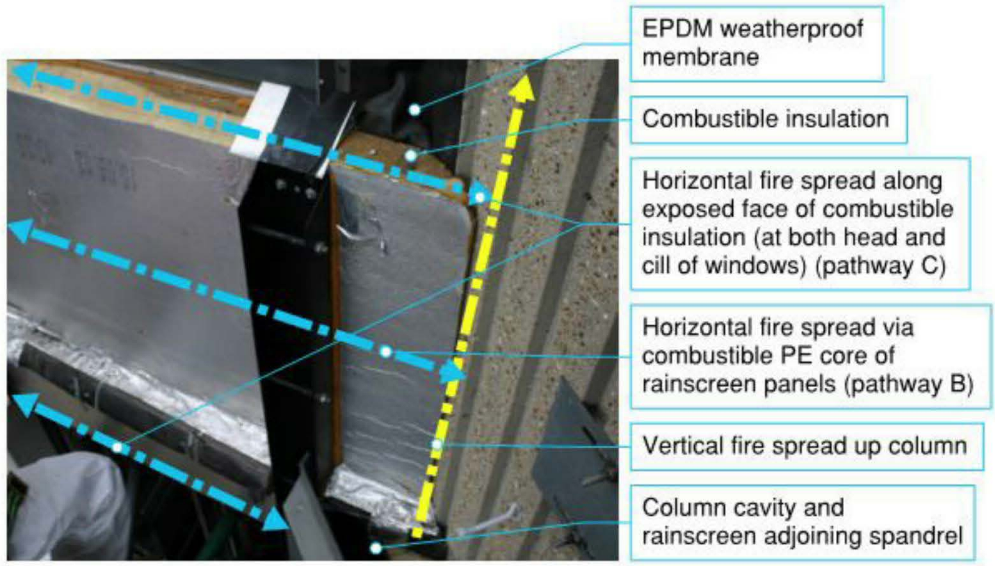


Figure 10.28: Exposed insulation in spandrel panel rainscreen cavity (External Flat 14)

10.4.14 Figure 10.28 demonstrates the connection between horizontal Pathways B & C and vertical Pathway B that existed within the rainscreen cavity where the spandrel meets the column, on every floor.

10.4.15 **Construction to resist the spread of fire via Pathway B**

10.4.16 As identified in Section 8 and Figure 10.4, there was no construction within the spandrel panels to resist the horizontal spread of fire.

10.4.17 The only barriers to horizontal fire spread via Pathway B were the vertical cavity barrier in specific columns, as identified in Figure 10.14. However, the Reynobond panels ultimately connect every column.

10.4.18 The spandrel panels were provided with horizontal cavity barriers to restrict vertical fire spread.

10.4.19 The mechanisms for integrity failure/bypassing of the horizontal cavity barriers were outlined in Section 10.3.27 (Construction to resist the spread of fire via Pathway A), and the same principles apply to the cavity barriers situated on the spandrel panels.

10.4.20 Additionally, the cladding rails installed on the spandrels as the supporting structure of the Reynobond cladding panels contribute to vertical fire spread by providing a route through the horizontal cavity barriers as shown in Figure 10.29. As can be seen in Figure 10.35 and in Figure 10.4, these cladding support rails are provided at the junction with the column, and directly below each end of the new combustible insulating core panel.

10.4.21 Therefore, the construction of the spandrel panel provided no effective means of preventing fire spread via Pathway B.

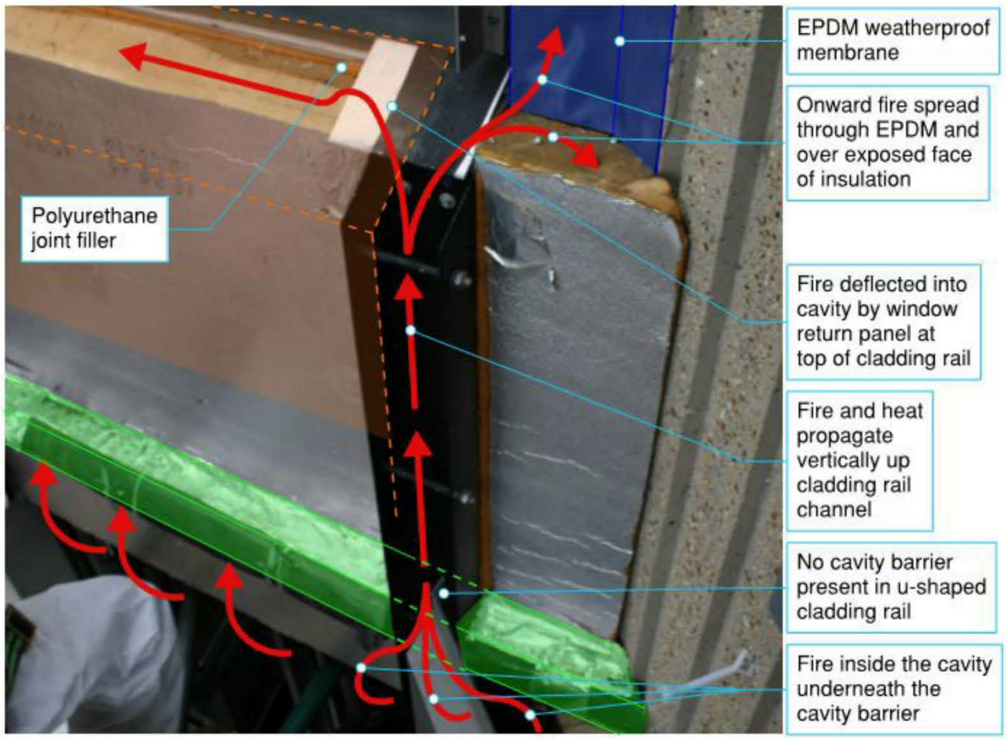


Figure 10.29: Schematic of possible fire spread via cladding support rail (External Flat 14)

10.5 Pathway C: Horizontally along the edges of the head and cill of the windows, and the edges of the top and bottom of the insulating core panel

10.5.1 Evidence of Pathway C contributing to fire spread at Grenfell Tower

10.5.2 Fire spread was observed along the line of the window openings (all sides), as shown in Figure 10.30, and along the edges of the infill panel:

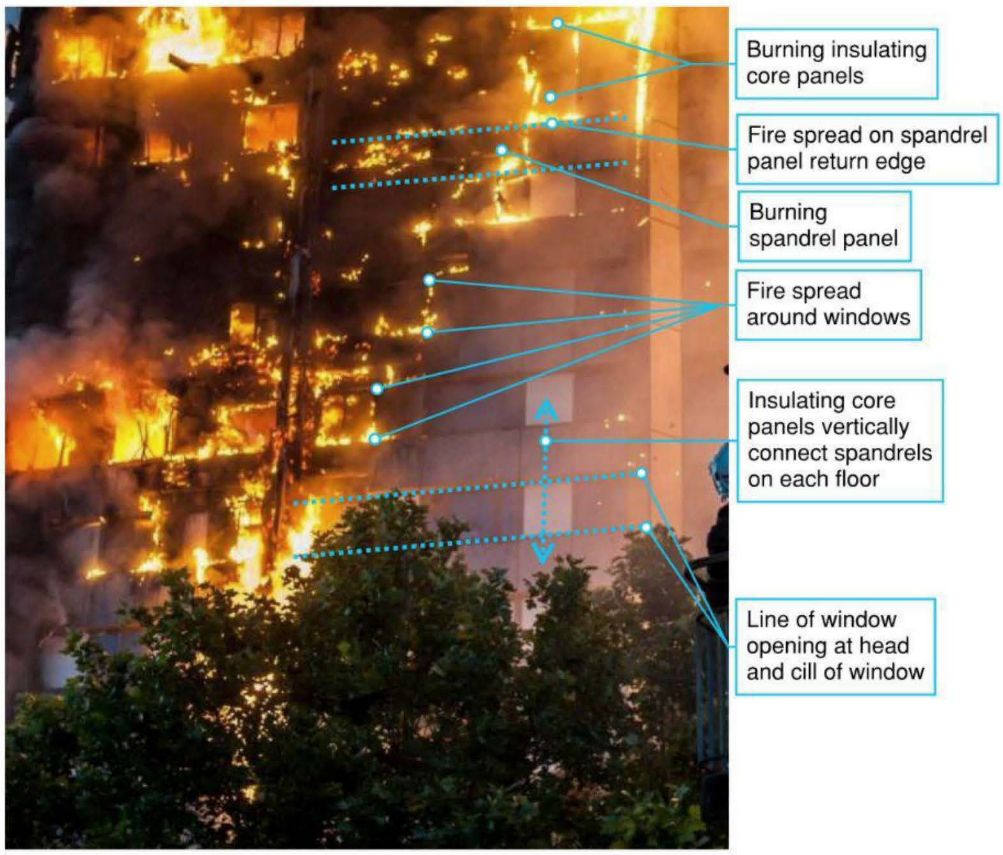


Figure 10.30: Photo evidence of fire spread observed along the line of window openings, at head and cill[6]

10.5.3 Materials and construction supporting Pathway C

10.5.4 I have described in Section 9 how a fire could spread from within flats to the external wall cavity, via the window cill, jamb or head adjacent to the columns, directly into the external rainscreen cavities.

10.5.5 The fuel available for this Pathway involves the combustible materials that make up the internal window surrounds. As described in Section 9 the window reveals were constructed of uPVC which created a cavity at the head and cill which was then provided with 25mm thick polymeric insulation. The

[6]Paris Match, 2017. Les pompiers héroïques de la Grenfell Tower racontent l'horreur [online] Available at: https://www.parismatch.com/Actu/International/Les-cris-la-fumee-Les-pompiers-heroiques-de-la-Grenfell-Tower-racontent-l-horreur-1318214 [Accessed 20 October 2018]

specific polymeric insulation materials identified in these locations during my post fire inspection was Celotex PIR and Kingspan Therma range PIR foam. Both of these materials are combustible (Section 11).

10.5.6 Additionally, the new uPVC window reveals were fitted over the top of the original timber widow frames and reveals. This provides a further combustible material on the line of the window edges.

10.5.7 Please refer to Figure 10.31 for a diagram indicating the materials in the window surrounds.

10.5.8 This creates specific linear runs of combustible materials at the head and cill of each window.

10.5.9 Whilst no insulation appears to have been fitted within the head or cill cavity between the original non-combustible in-fill panel and the Aluglaze insulating core panel, the presence of the Aluglaze panel in this form, provides a source of fuel which connected the cill and head of each window, vertically via the Panel (as seen in Figure 10.30). (These panels also connect each storey of spandrel rainscreen cladding panels between windows – See Section 10.7 of my report).

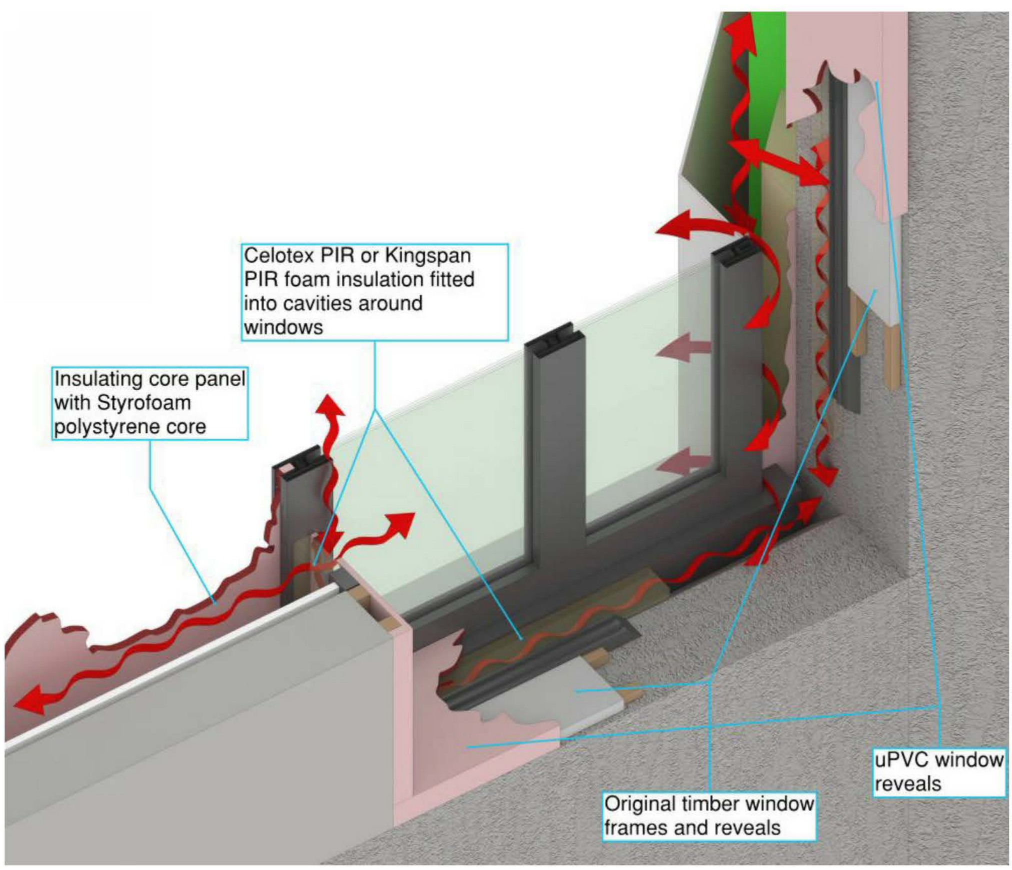


Figure 10.31: Materials making up the window surround

10.5.10 In summary, the horizontal fire spread observed along the cill and head of each window was caused by:

a) The presence of fuel (the combustible new uPVC window reveals, the original timber window frames and reveals, the combustible Celotex PIR or Kingspan therma PIR insulation behind the new uPVC cill and head reveals and the new Aluglaze extruded polystyrene insulating core panels) as shown in Figure 10.31 & Figure 10.32 ;

b) The presence of oxygen from the outside atmosphere, or from within the flat; and

c) Heat from a fire within a flat or in the external building envelope directly impacting the fuel identified in a) above.

d) The presence of the Reynobond panel - either the cassette condition above a window or the cassette conditions below a window also provides a fire spread route (part of Route B).

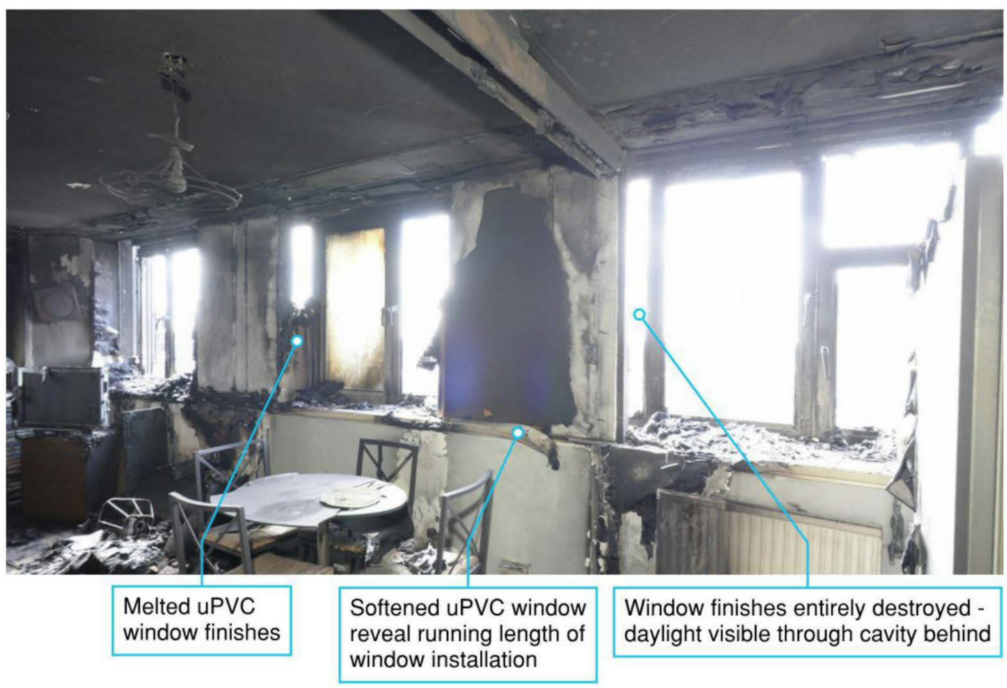


Figure 10.32: Internal example showing the uPVC cill reveal spanning the length of the window internally, passing by the inside of the original in-fill panel

10.5.11 Construction to resist the spread of fire via Pathway C

10.5.12 In Section 11 and Appendix E I have carried out a detailed review of the materials included in the construction of the building envelope and their compliance with the Building Regulations. This review, and the information presented in Section 8, identifies that there were no cavity barriers fitted around window openings. Therefore, there was no construction within the window construction provided for the purpose of preventing fire spread via Pathway C.

10.5.13 It is useful to note that in Appendix E, I investigated two large scale rainscreen tests commissioned by Celotex. I found in each of these tests the openings to the rainscreen cavities to be lined with non-combustible cement particle boards. This was not the case at Grenfell Tower.

10.5.14 In Section 9 I found multiple pathways for fire to spread through the window construction and into the external rainscreen cavity. In Figure 10.33, I have replicated from Section 9 an external perspective showing how fire can spread from within flats to the external rainscreen.

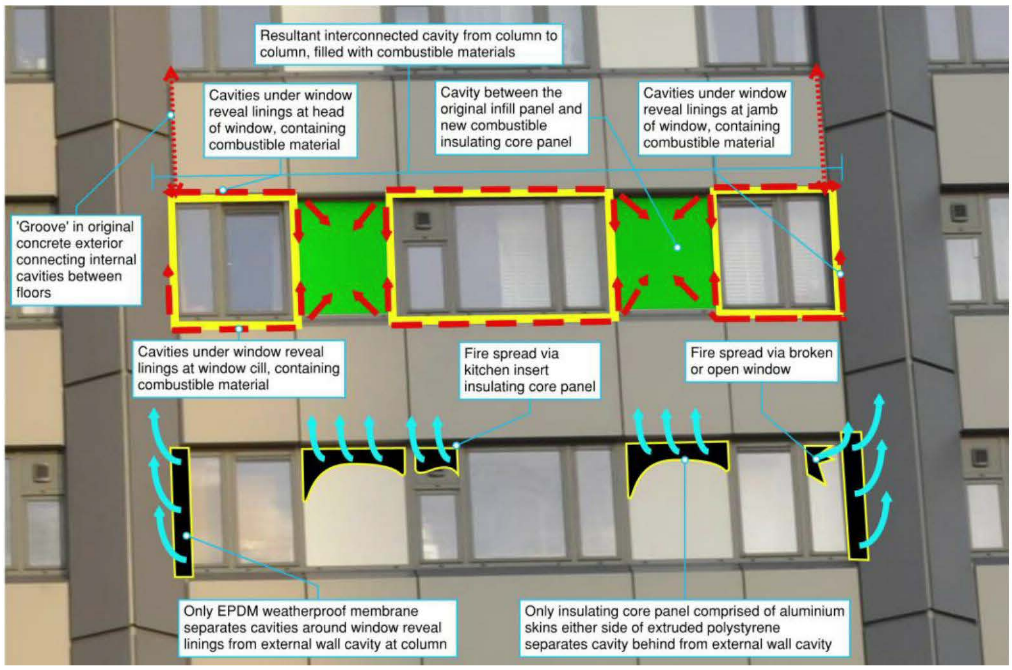


Figure 10.33: Network of window cavities superimposed on exterior of the building and routes into external wall cavity (SEA00000350)

10.6 Pathway D: Vertically along the window edge and along the edge of the Aluglaze insulating core panel

10.6.1 Evidence of Pathway D contributing to fire spread at Grenfell Tower

10.6.2 Figure 10.34 provides evidence that fire spread vertically along the edges of the window and the edges of the infill insulating core panel. Figure 10.34 shows external fire spread observed between columns C1 and D1, where Route 1 and 2 (Figure 10.1) met on the West elevation.

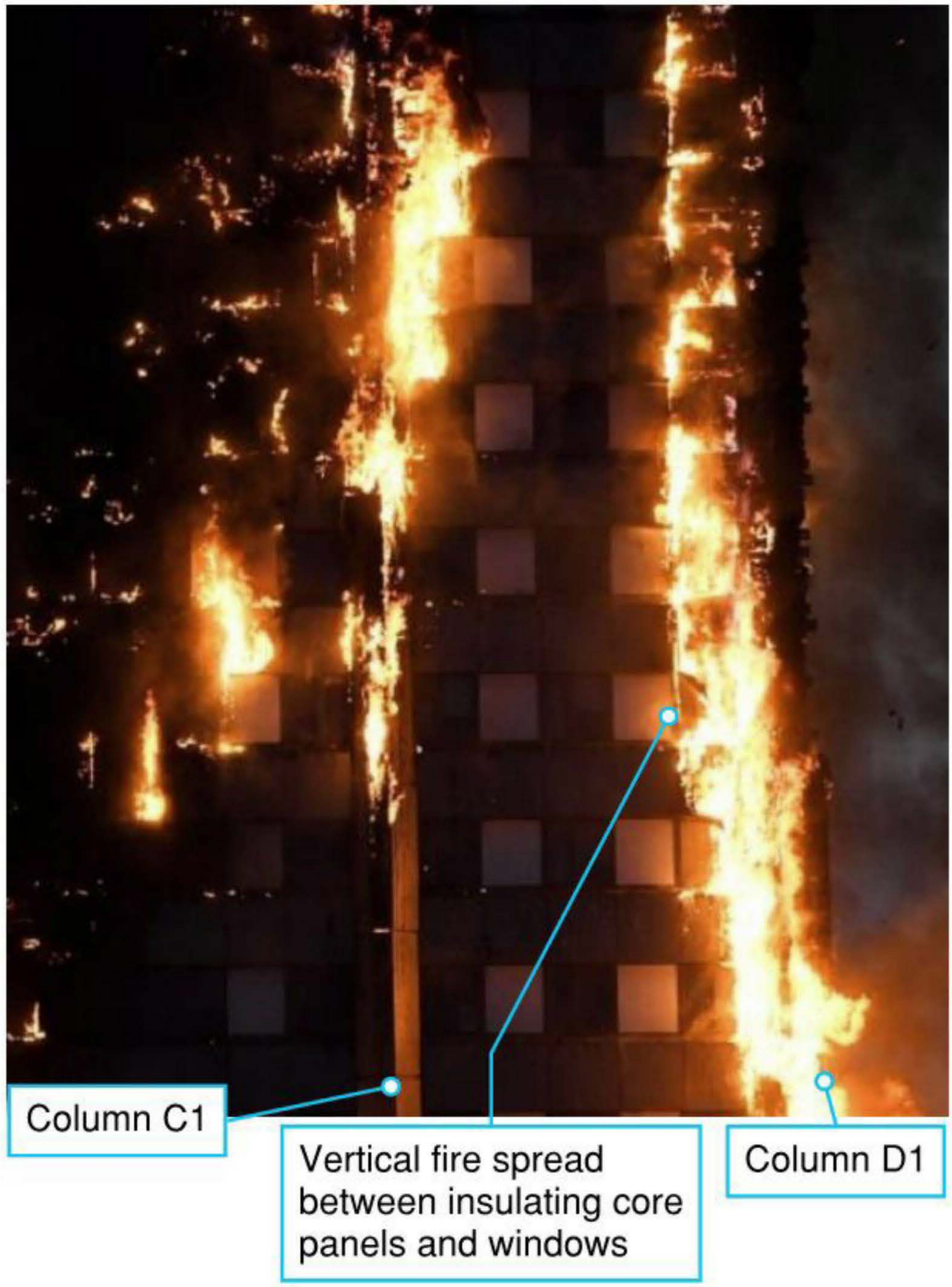


Figure 10.34: Photo evidence of vertical fire spread at the junction between the insulating core panels and windows[7]

[7] El Confidential, 2017. Las imágenes del incendio de la torre residencial de Londres [online] Available at: https://www.elconfidencial.com/multimedia/album/mundo/2017-06-14/incendio-londres-imagenes-video-torre-llamas_1399064#18 [Accessed 20 October 2018]

10.6.3 Materials and construction supporting Pathway D

10.6.4 In the "flat" portion, between columns, vertical fire spread is also possible by 2 separate sets of combustible materials in the building envelope.

a) Via the new Aluglaze infill insulating core panels with Styrofoam XPS cores described in Section 8; and

b) Via the combustible insulation (Celotex PIR and Kingspan PIR) and uPVC surround fitted at the window jamb adjacent to the new insulating core panel described in Section 9 (Figure 10.36).

10.6.5 Styrofoam is extruded polystyrene (XPS) and is a combustible material with an ignition temperature between 296°C and 405°C (Table 15, V. Babrauskas, *Ignition Handbook*, SFPE, 2003).

10.6.6 uPVC is a combustible material with an ignition temperature between 360°C and 441°C (Table 15, V. Babrauskas, *Ignition Handbook*, SFPE, 2003).

10.6.7 The uPVC window surrounds were exposed to the atmosphere inside each flat, providing a supply of oxygen to the fire. The insulation behind the uPVC window surrounds was exposed to oxygen within the relevant cavity in which they were placed. Additionally, as identified in Figure 10.36, once the uPVC became affected by the fire, the insulation behind would quickly become exposed directly to the air.

10.6.8 As described in Section 8, the new Aluglaze insulating core panels were installed approximately 130mm in front of existing precast concrete infill panels, and then sealed with a combustible vertical piece of combustible insulation on either side. Evidence of damage caused by the fire is provided in Figure 10.35. In this figure, the original in-fill panels that survived the fire can be seen to have been wrapped in plastic foil by investigators after the fire in order to stabilise them.

10.6.9 It can be seen in the case of the fire damaged panels that the aluminium skin has failed and revealed the 25mm Styrofoam XPS core, allowing oxygen in the air to access the fuel surface.

10.6.10 Section 9 describes the means by which fire could spread through the cavities associated with each of these materials.

10.6.11 In summary, the vertical fire spread observed up the edges of the new insulating core panels and the windows was caused by:

a) The presence of fuel (the combustible Styrofoam XPS core of the new insulating core panels, the combustible Celotex or Kingspan insulation installed between the original in-fill panel and the new insulating core panel and the timber and uPVC window reveals);

b) The presence of oxygen from the outside atmosphere, or from within the flat; and

c) Heat from a fire in the external building envelope (Pathway B or Pathway E) or from a fire inside the flat.

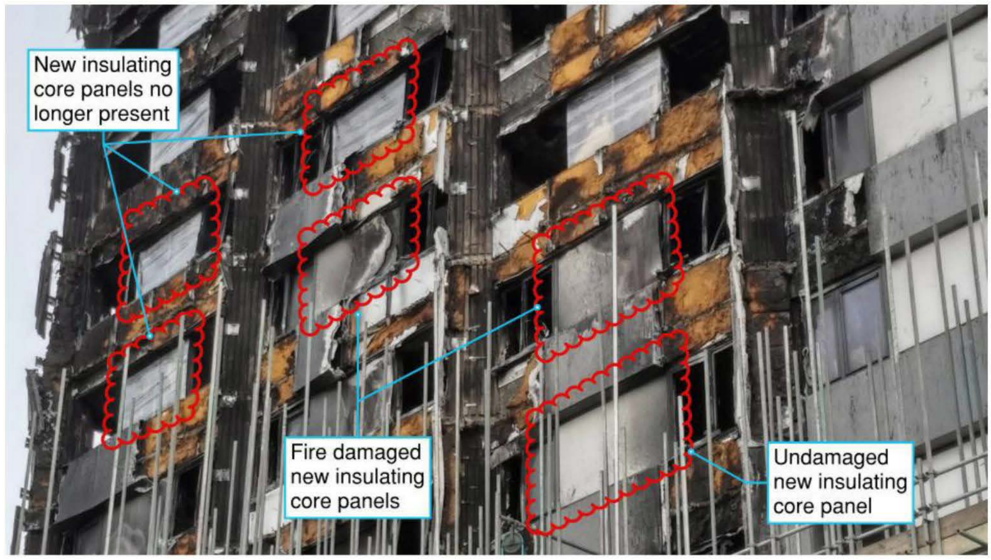


Figure 10.35: Evidence of fire damage to new insulating core panels

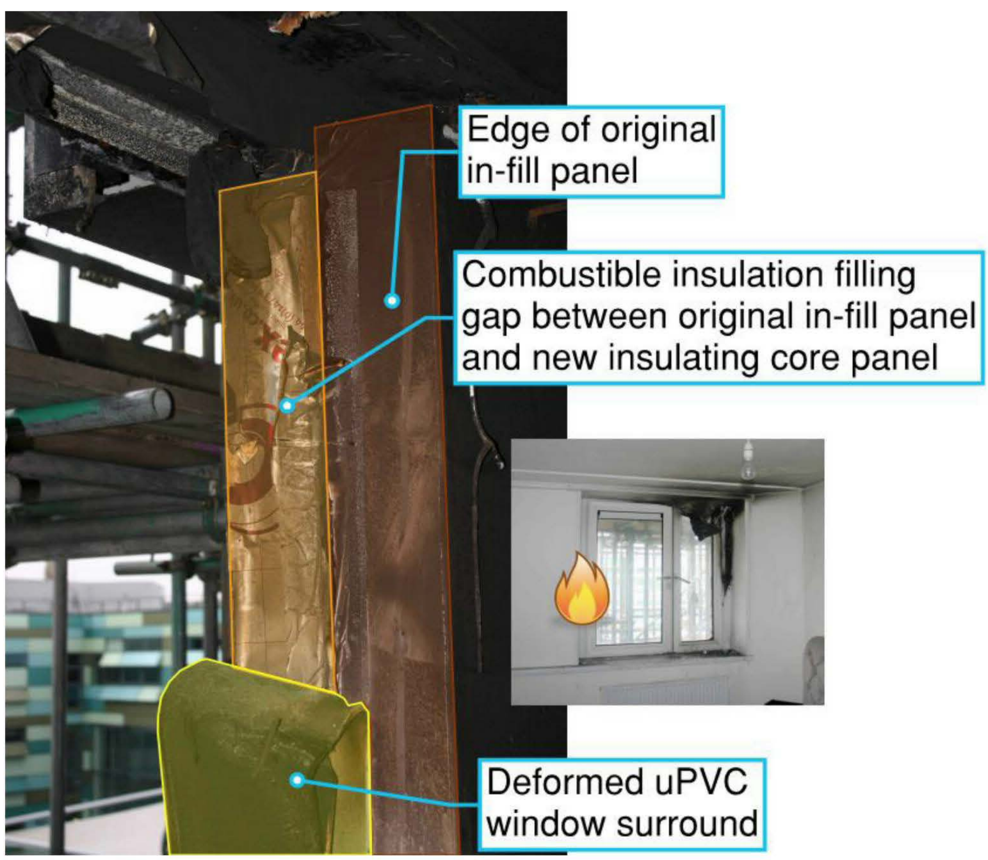


Figure 10.36: Effect of fire on the infill panel side of the window (Flat 16 living room window) with example location inset

10.6.12 Construction to resist the spread of fire via Pathway D

10.6.13 As described in Section 11 of my report, the new window construction was not fitted with cavity barriers. Nor was the cavity formed by the Aluglaze infill panel and the original infill panel.

10.6.14 Therefore, there was no part of the construction, in that form, which could be considered capable of resisting fire spread via Pathway D.

10.7 Pathway E: Vertically by means of the Aluglaze insulating core panels which connect between spandrel panels

10.7.1 Evidence of Pathway E contributing to fire spread at Grenfell Tower

10.7.2 Figure 10.37 shows the photographic evidence of the surface of the insulating core panels and the spandrel panels contributing to fire spread at Grenfell Tower.

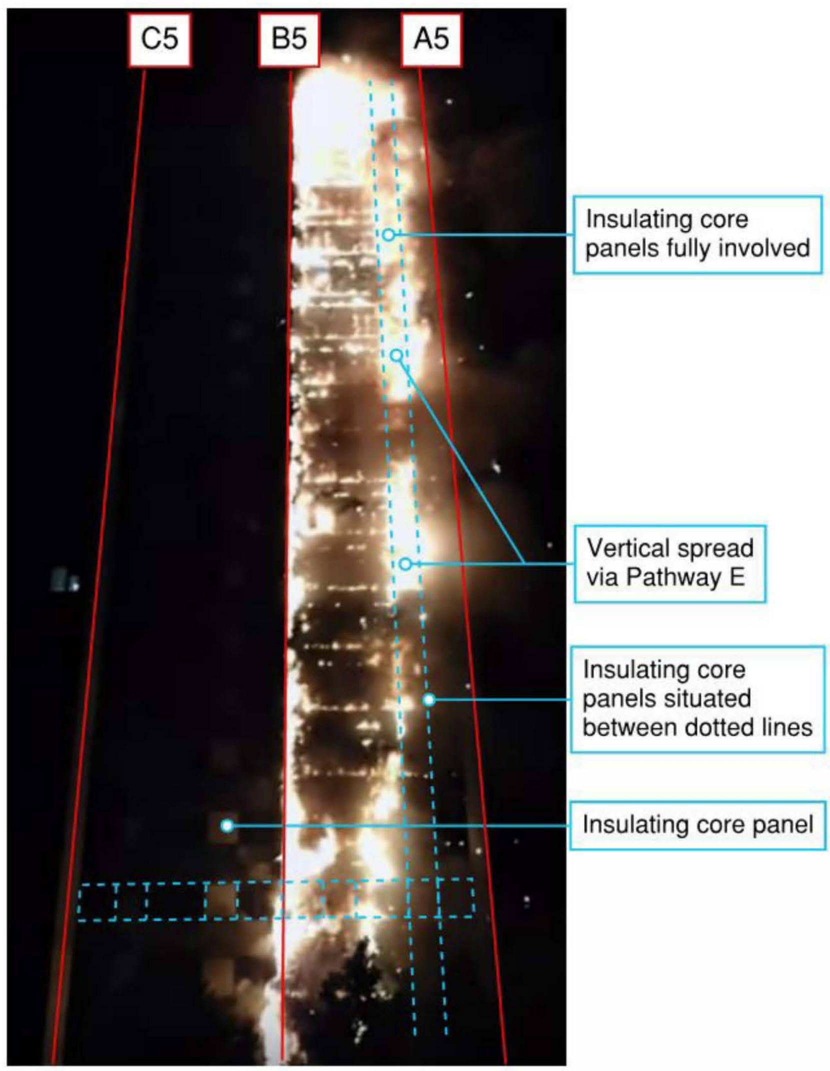


Figure 10.37: Photo evidence of vertical fire spread up insulating core panels, estimated time 01:26[8]

10.7.3 Materials and construction supporting Pathway E

10.7.4 The combustible materials and construction supporting Pathway E are the same as those supporting Pathways B and D. That is the combustible

[8] https://www.youtube.com/watch?v=6AYUZ5Snxzo

Styrofoam XPS core of the Aluglaze insulating core panels installed in between the windows, and the combustible Reynobond, Celotex and Kingspan materials fitted to the face of the spandrels. Please see Figure 10.38

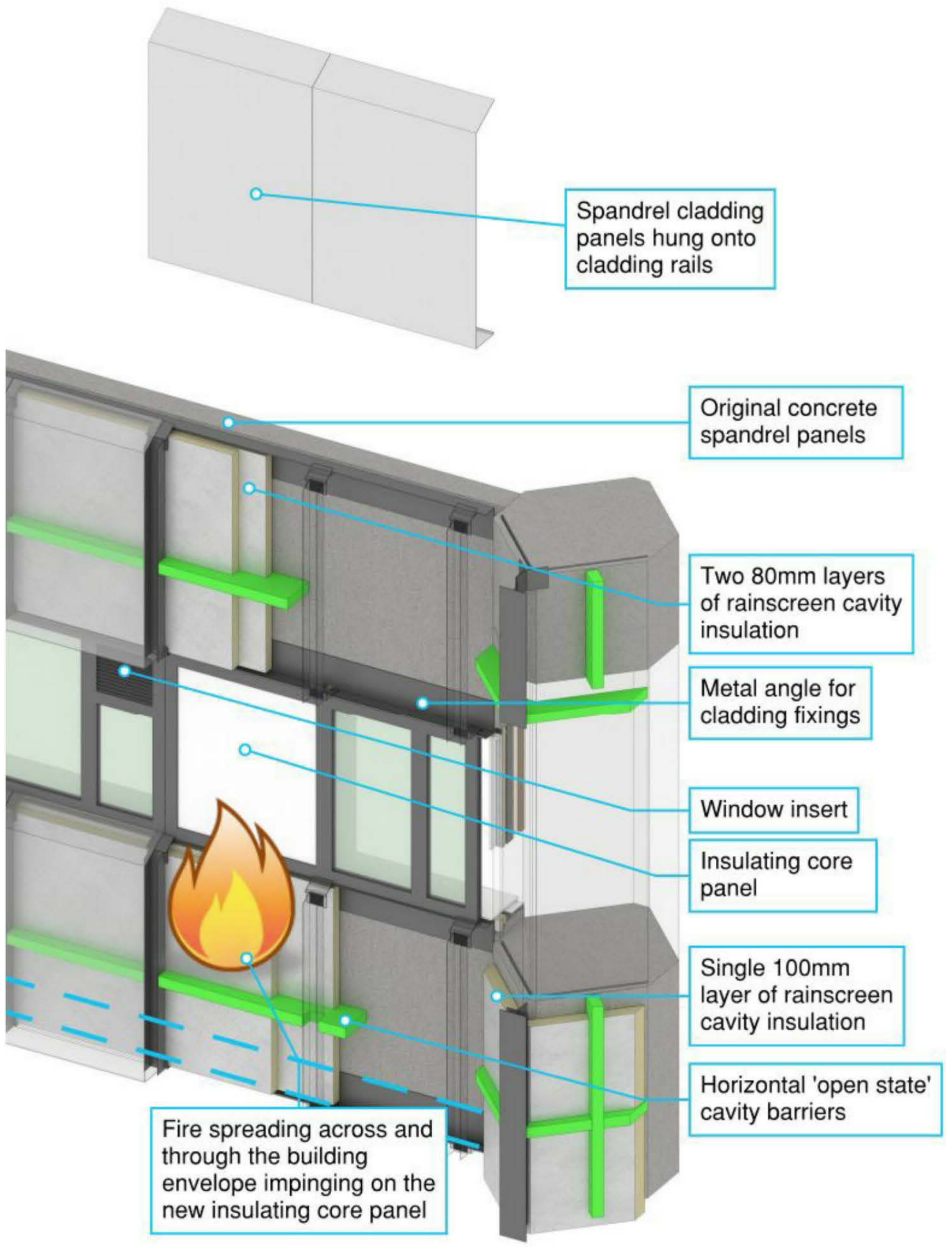


Figure 10.38: Materials of the facade around the new combustible insulating core panels

10.7.5 In summary, the vertical fire spread observed up the edges of the new insulating core panels and the windows could have been caused by:

a) The presence of fuel (the combustible Styrofoam XPS core of the new insulating core panels, the combustible Celotex or Kingspan insulation installed between the original in-fill panel and the new insulating core panel and the timber and uPVC window reveals);

b) The presence of oxygen from the outside atmosphere, or from within the flat; and

c) Heat from a fire in the external building envelope (Pathway B or Pathway D) or from a fire inside the flat.

10.7.6 **Construction to resist the spread of fire via Pathway E**

10.7.7 As described in Section 8, one horizontal cavity barrier was positioned at approximately mid-height on the spandrel panels (Figure 10.29). There were no cavity barriers/firestops around the window openings, nor around the cavity formed by the Aluglaze infill.

10.7.8 Therefore, there was no construction provided in the façade construction that could prevent fire spreading vertically from the spandrel panels upward over the new insulating core panels.

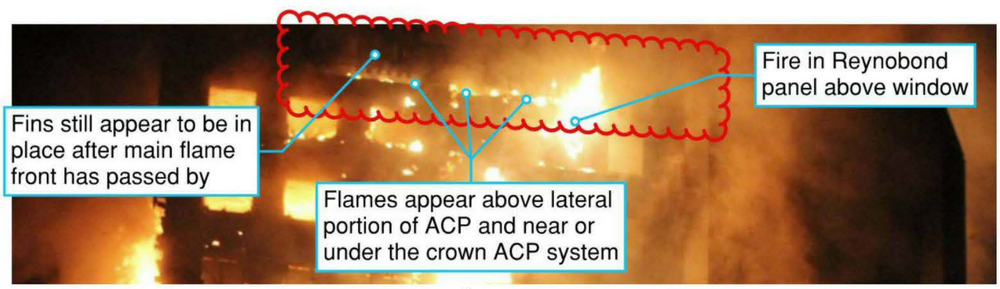
10.8 Pathway F: Around the crown of the building façade

10.8.1 Evidence of Pathway F contributing to fire spread at Grenfell Tower

10.8.2 Fires were observed to be burning in and around the crown cladding construction, as shown in Figure 10.39.

10.8.3 I have investigated the construction of the crown and its materials as a possible route of fire spread using the currently available construction drawings. It is clear from the post fire photographs in Figure 10.40 that little of the architectural crown construction remained after the fire.

10.8.4 Therefore, my investigation presented here uses the design drawings to describe the construction of the crown. Should any further physical evidence be provided regarding the construction and materials used for the crown my analysis may require revision.



a)

b) c)

Figure 10.39: Fire in the crown construction (see Video 5 accompanying Prof. Bisby's supplemental Phase 1 report)[9, 10]

10.8.5 It appears there was a form of rainscreen ACP cladding attached to aluminium fins running along the original concrete roof-edge balustrade.

[9] International Business Times, 2017. Grenfell Tower fire: Videos show devastating inferno rip through 24-storey London building [online] Available at: https://www.ibtimes.co.uk/grenfell-tower-fire-videos-show-devastating-inferno-rip-through-24-storey-london-building-1626253 [Accessed 20 October 2018]

[10] Daily Star, 2017. Family managed to escape Grenfell Tower inferno by turning on their TAPS [online] Available at: https://www.dailystar.co.uk/news/latest-news/622497/Grenfell-tower-fire-London-Latimer-Road-Ladbroke-Grove-inferno-escape-taps [Accessed 20 October 2018]

10.8.6 There was a horizontal strip of rainscreen cladding underneath the crown – and so above the windows to the flats at Level 23.

10.8.7 Figure 10.40 presents an annotated image of the remains of the crown cladding after the fire. These images demonstrate that fire did spread around the crown cladding construction on the 14th June 2017.

10.8.8 Figure 10.40 specifically identifies that, although the ACP panels on the face of the spandrels above the Level 23 windows and on columns were completely destroyed, it appears that some portions of the ACP system on the fins above the Level 23 windows may not have been fully destroyed by the fire.

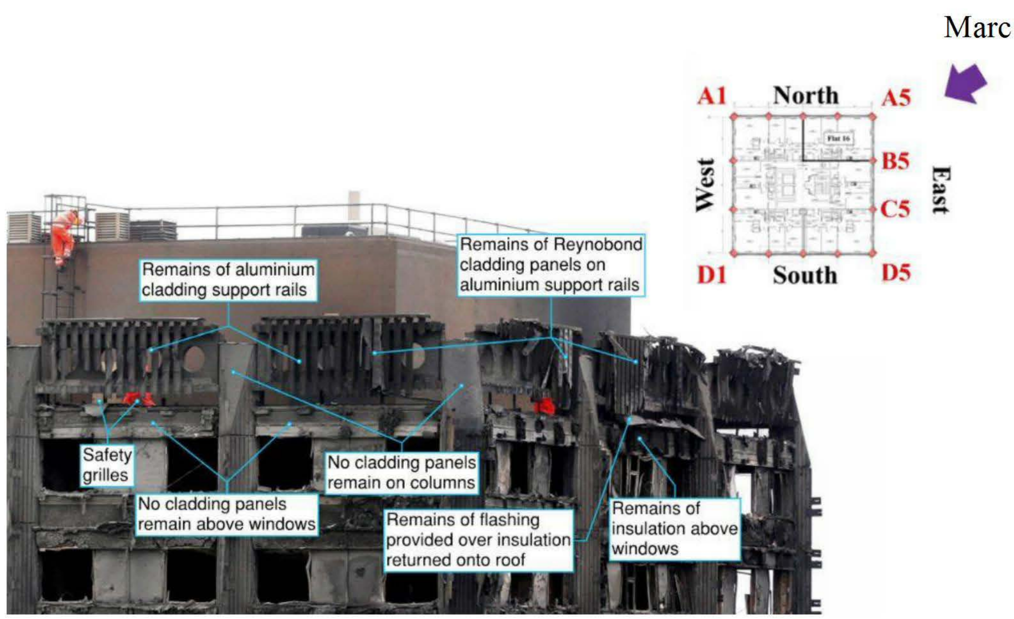


Figure 10.40: Post fire remains of crown cladding[11] (Plan drawing: SEA00010474)

10.8.9 In most of the photographic and video evidence I reviewed of external fire spread after 02:08, I observed a consistent diagonal pattern of fire spread along both External Flame Spread Route 1 and 2, as shown in Figure 10.41, Figure 10.42 and Figure 10.43. The most advanced point of fire spread along the diagonal at any one time is located at the Crown.

[11] The Mirror, 2017. Brave firefighters scale Grenfell Tower roof in painstaking search for bodies on top floors where 'nobody escaped alive' [online] Available at: https://www.mirror.co.uk/news/uk-news/brave-firefighters-scale-grenfell-tower-10634754 [Accessed 20 October 2018]

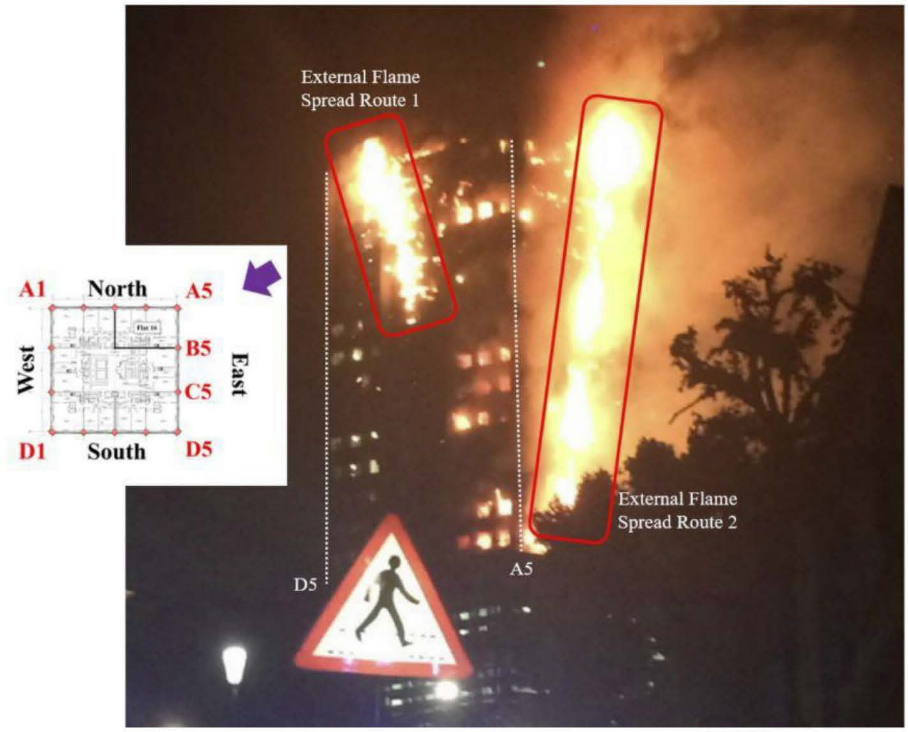


Figure 10.41: Diagonal pattern for External Flame Spread Routes 1 and 2 at 02:08 on 14th June 2017 (MET00012593) (SEA00010474)

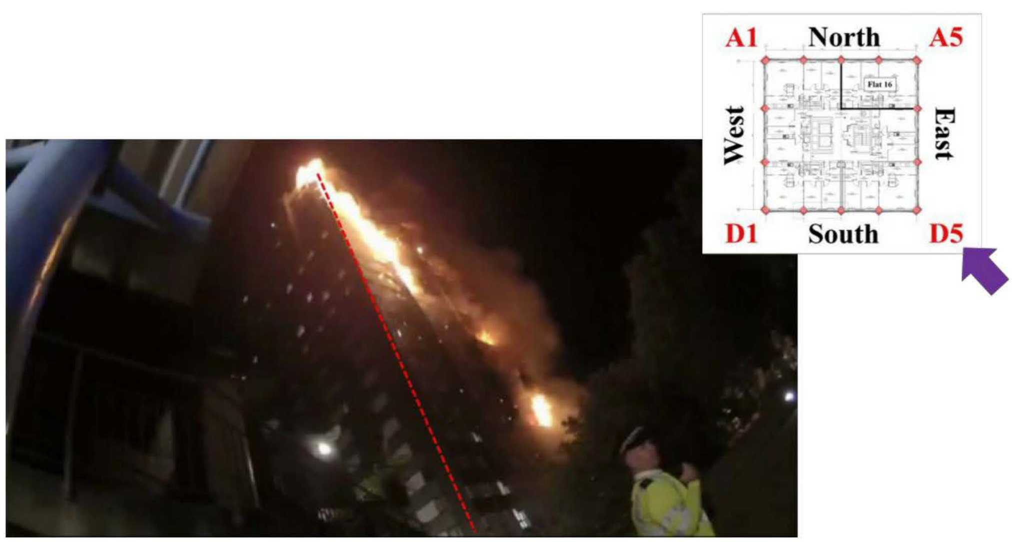


Figure 10.42: Diagonal flame front along External Flame Spread Route 2, that is, around column D5 (southeast corner of building), from East elevation to South elevation of the building envelope at 02:33 on 14 June 2017 (MET00012593) (SEA00010474)

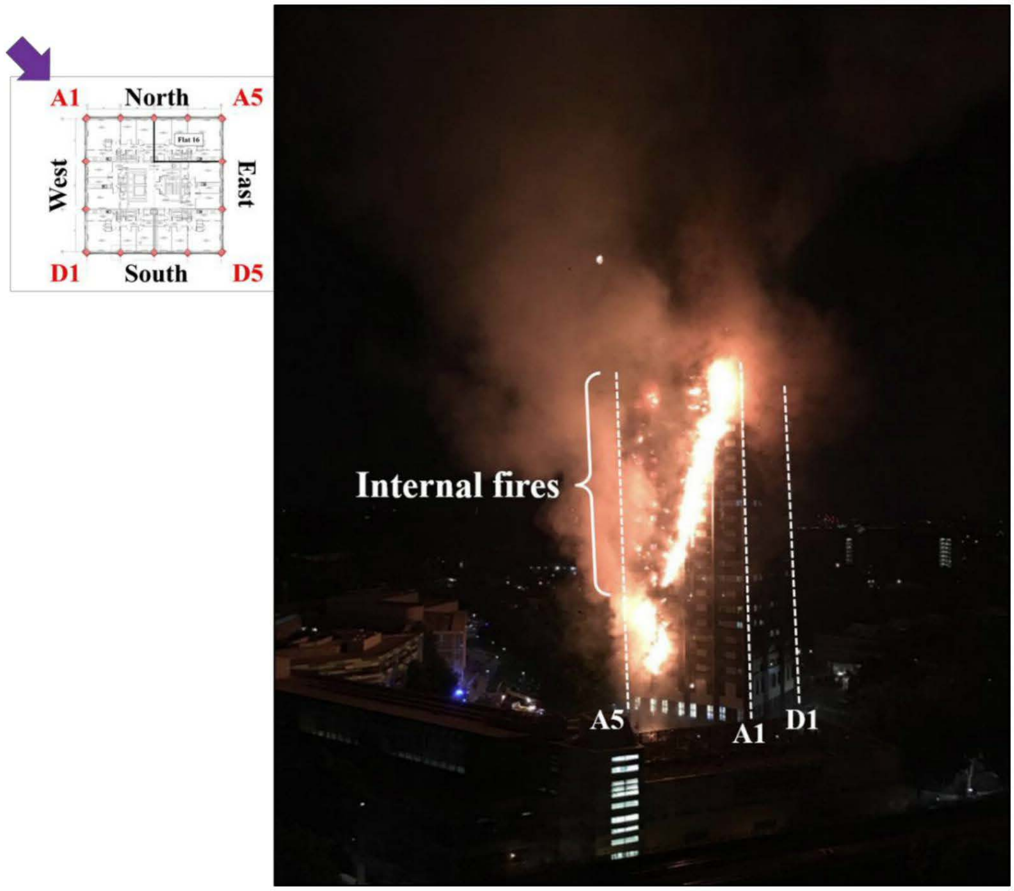


Figure 10.43: Diagonal flame front along External Flame Spread Route 1, that is, on the North elevation of the building envelope at 02:34 on 14 June 2017 (MET00012593) (SEA00010474)

10.8.10 This consistent diagonal pattern of flame spread indicates that fire advanced laterally along the crown before it spread to lower levels. In Section 10.10.14, I will describe the effect of the fire spreading at crown level before lower levels.

10.8.11 Behind the balustrade is the roof top plant room as well as a walking area; refer to Figure 10.45.

10.8.12 Figure 10.44 and Figure 10.45 identify that there is no evidence of fire spread over the surface of the roof. Damage and debris are largely present only at the perimeter of the roof.

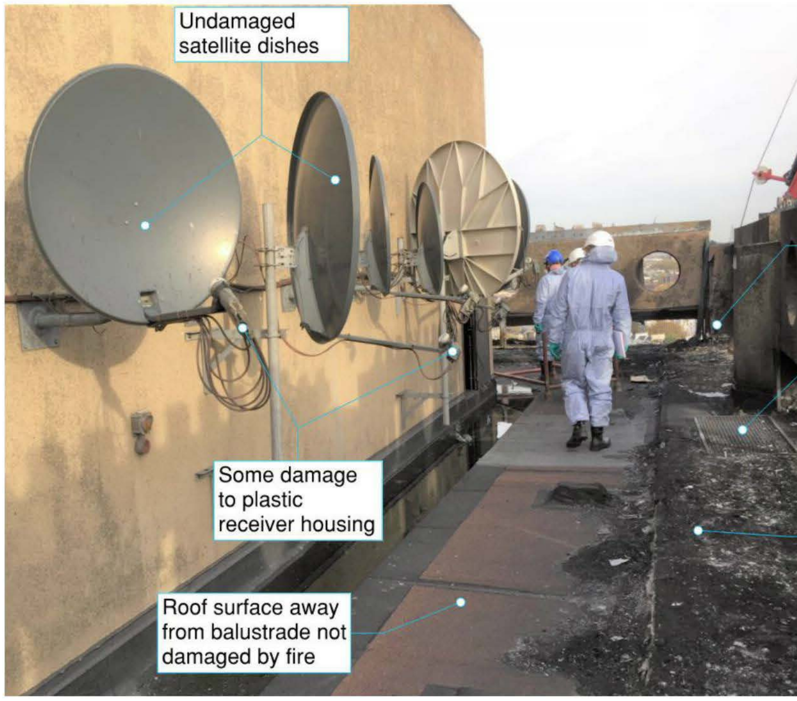


Figure 10.44: Evidence of post-fire condition along the South of the roof taken during my inspection [South]

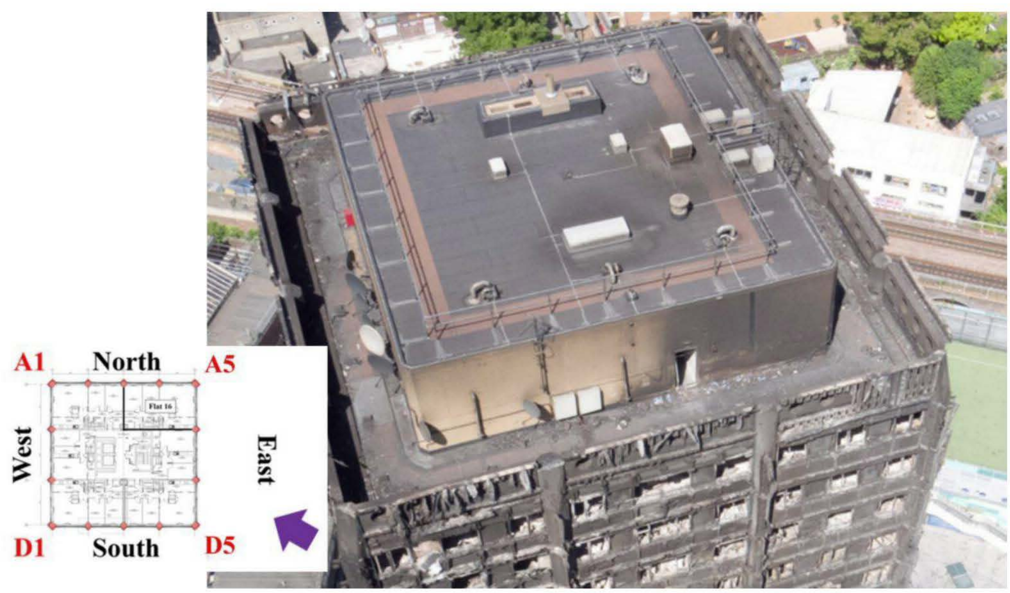


Figure 10.45: Aerial view of overall roof conditions post-fire [East] (MET00012593)

10.8.13 **Materials and construction supporting Pathway F**

10.8.14 Figure 10.46 presents a section through the crown construction based on the Studio E "As-Built" drawings (SEA00002551).

10.8.15 Figure 10.47 presents the specific materials used at the balustrade sections, based on Harley's design drawings (excerpted from SEA0003242 and SEA00013263).

10.8.16 This drawing shows that the crown design adds cladding panels arranged as “hit and miss” fins to obscure the original concrete balustrades at the roof edge. Additionally, profiled cladding panels are added above the columns to terminate the column cladding in the crown cladding.

10.8.17 Figure 10.48 is an excerpt from the crown details in the Harley design drawings (SEA00003242) showing the panel types to be used in specific locations around the crown construction. As can be seen in this diagram, all of the panels for use in the crown construction were to be type R1. In accordance with the Harley specification (HAR00008991) the R1 type panel is for aluminium composite panels. As I have presented in Appendix E, this panel type was the Reynobond 55 PE product.

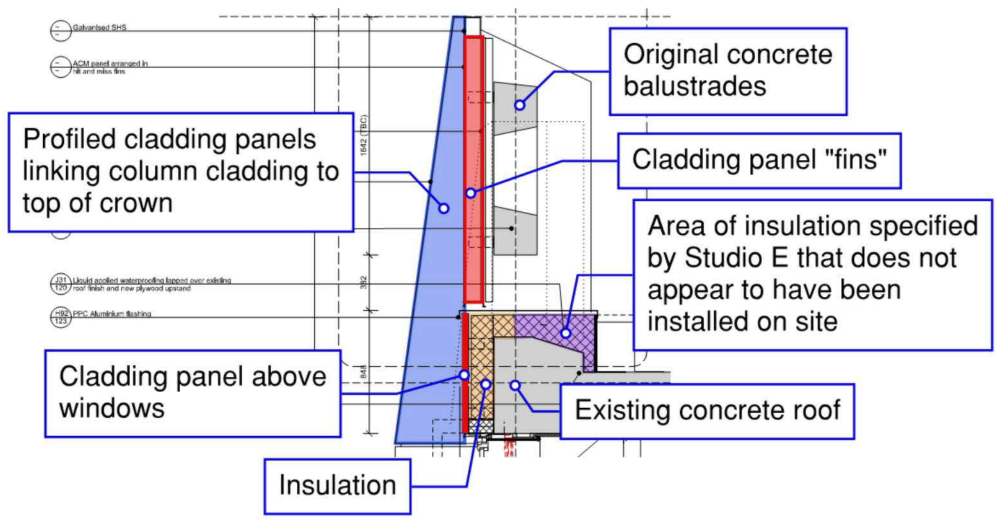


Figure 10.46: Materials used in construction of the crown cladding (based on SEA00002551)

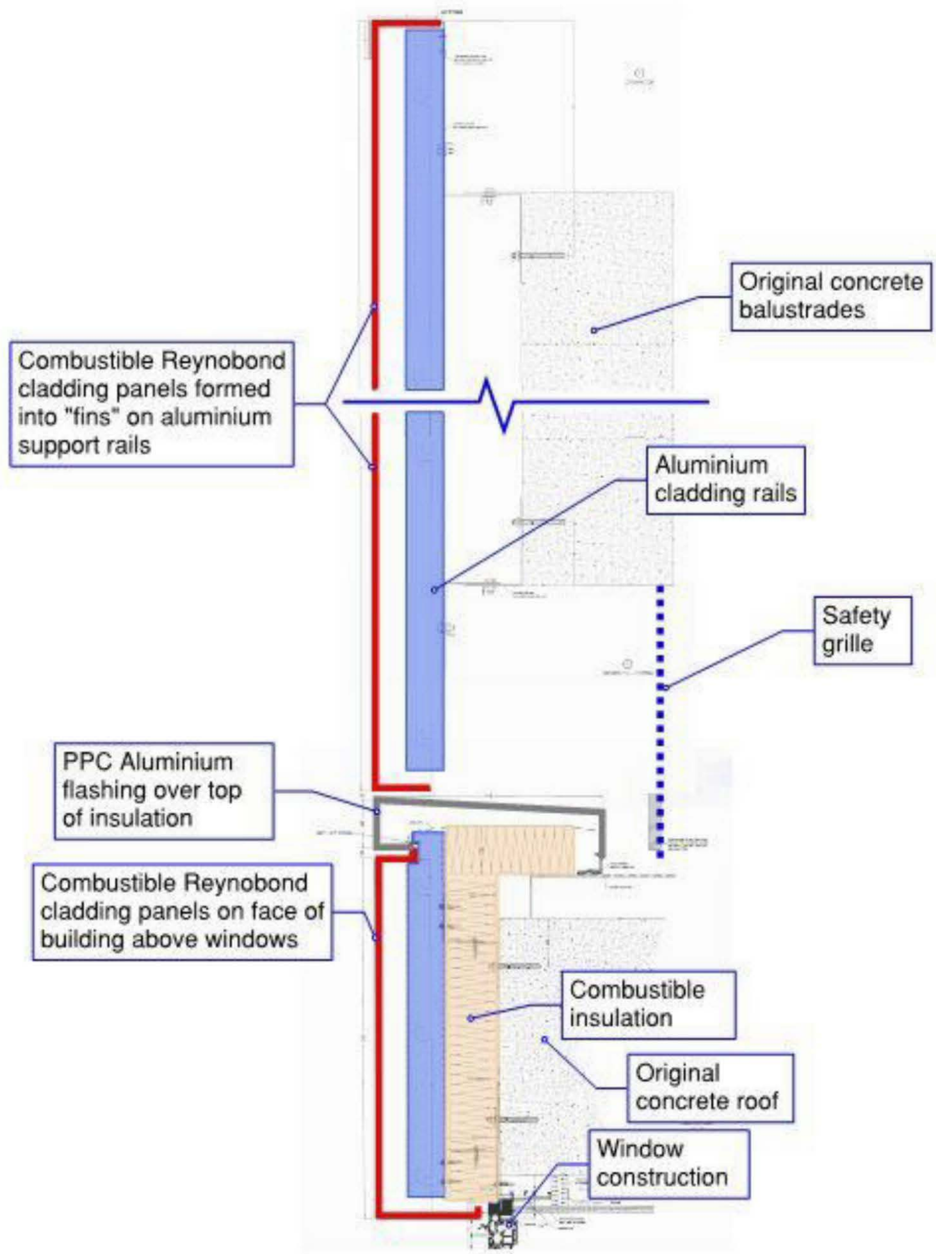


Figure 10.47: Materials used in balustrade sections of roof (excerpted from SEA00003242 and SEA00013263)

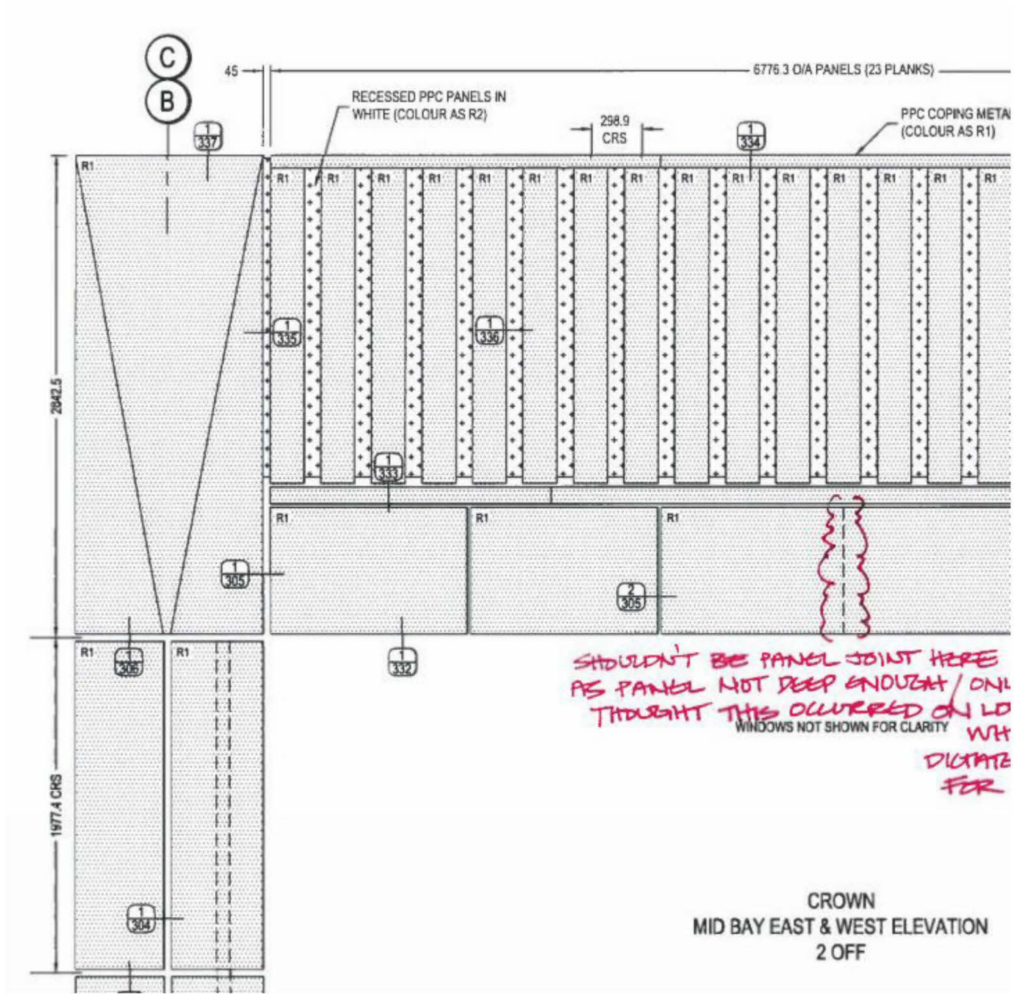


Figure 10.48: Excerpt from Harley drawing C1059-216 – red over-marks from original document (SEA00003242)

10.8.18 The Studio E and Harley drawings indicate that the fins attached to the outside of the existing balustrade were Reynobond cladding panels supported on an aluminium cassette.

10.8.19 The safety grille indicated in Figure 10.47 was a steel mesh used to cover the gap between the bottom of the original concrete balustrade and the surface of the roof top, and was intended to be used as edge protection.

10.8.20 Therefore, fire spread around the crown of the cladding system would have been supported by the presence of the combustible cladding panels and insulation above the Level 23 windows that wrap over the top of the roof edge.

10.8.21 The cladding fins attached to the original concrete balustrades were also combustible, however they did not have any combustible insulation behind and were not continuous. Therefore, it is currently unclear to what extent the burning of the cladding fins may have contributed to fire spread at roof level.

10.8.22 In summary, the spread observed around the crown of Grenfell Tower was caused by:

a) The presence of fuel (the combustible polyethylene core of the Reynobond 55 PE panels);

b) The presence of oxygen from the outside atmosphere, or from within the flat; and

c) Heat from a fire in the external building envelope (Pathway B or Pathway D) or from a fire inside the flat.

10.8.23 **Construction to resist the spread of fire via Pathway F**

10.8.24 There is no evidence currently available that any provisions were made to prevent horizontal fire spread around the crown cladding. The Harley "approved for construction" drawings (Figure 10.49) indicate that the vertical cavity barriers provided behind the new column cladding were to terminate at the level of the top of the windows at Level 23. This would allow fire to spread over the top of the cavity barrier.

10.8.25 As indicated in Figure 10.47 and Figure 10.48, the Harley drawings did not appear to include a requirement for a horizontal cavity barrier/fire stop above the Level 23 windows. Therefore, no provision was made to prevent vertical fire spread from level 23 up to the roof area, including the Crown.

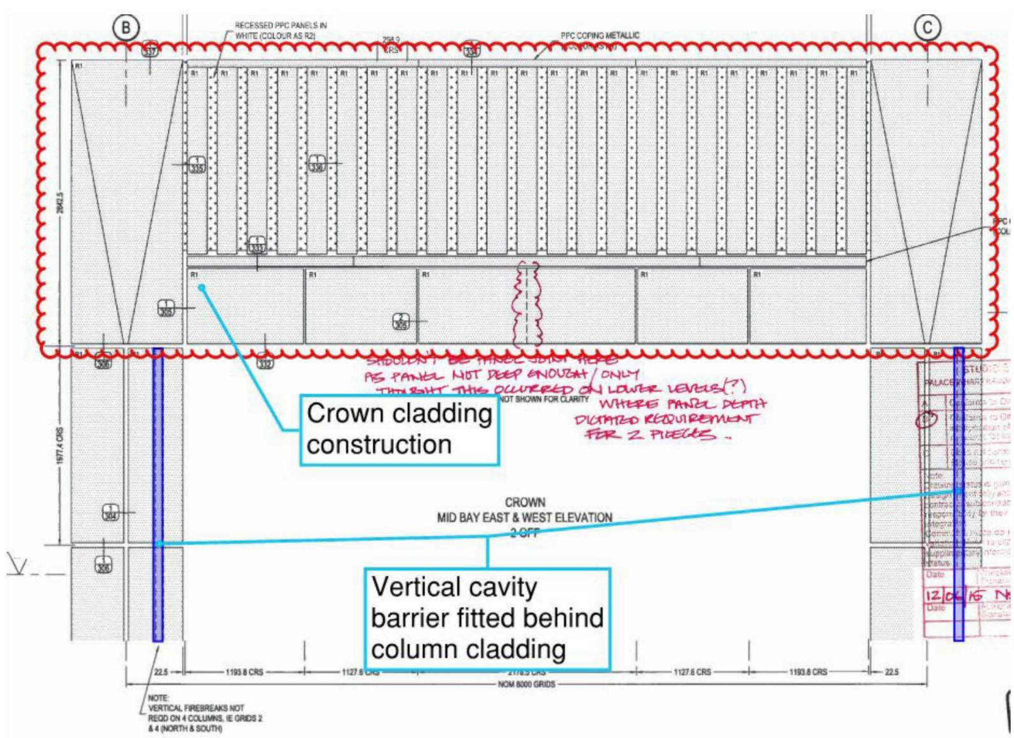


Figure 10.49: Harley "approved for construction" design drawings showing vertical cavity barrier extent (based on SEA00003242 red writing from original document)

10.9 Evidence from my site inspection of the combustion of the materials forming the rainscreen cladding system

10.9.1 I conducted a post fire inspection of Grenfell Tower between the 1st of October and the 9th of November 2017. In this section I present evidence of combustion involving the cladding materials that I have identified in Sections 8, 9 and 10 of my report.

10.9.2 **Reynobond 55 PE cladding panel and Styrofoam insulating core panels**

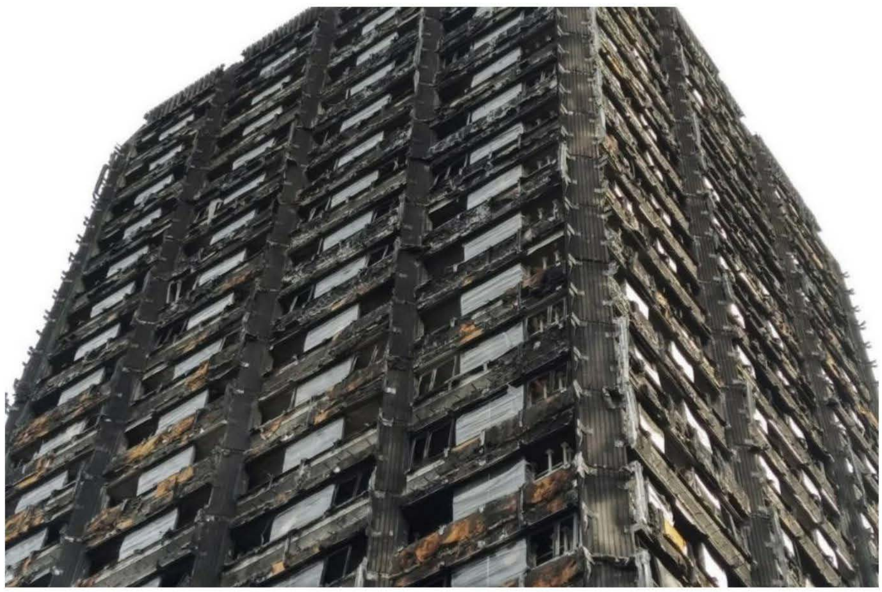


Figure 10.50: Reynobond 55 PE panels and Styrofoam XPS insulating core panels destroyed in all areas

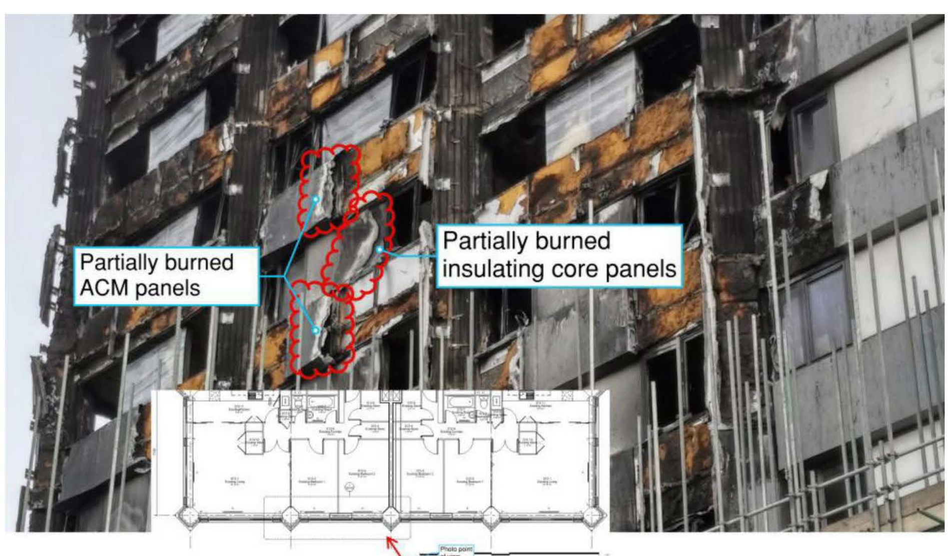


Figure 10.51: Partially burned Reynobond 55 PE panel and Styrofoam XPS insulating core panel on South façade on lower levels

10.9.3 Rainscreen insulation

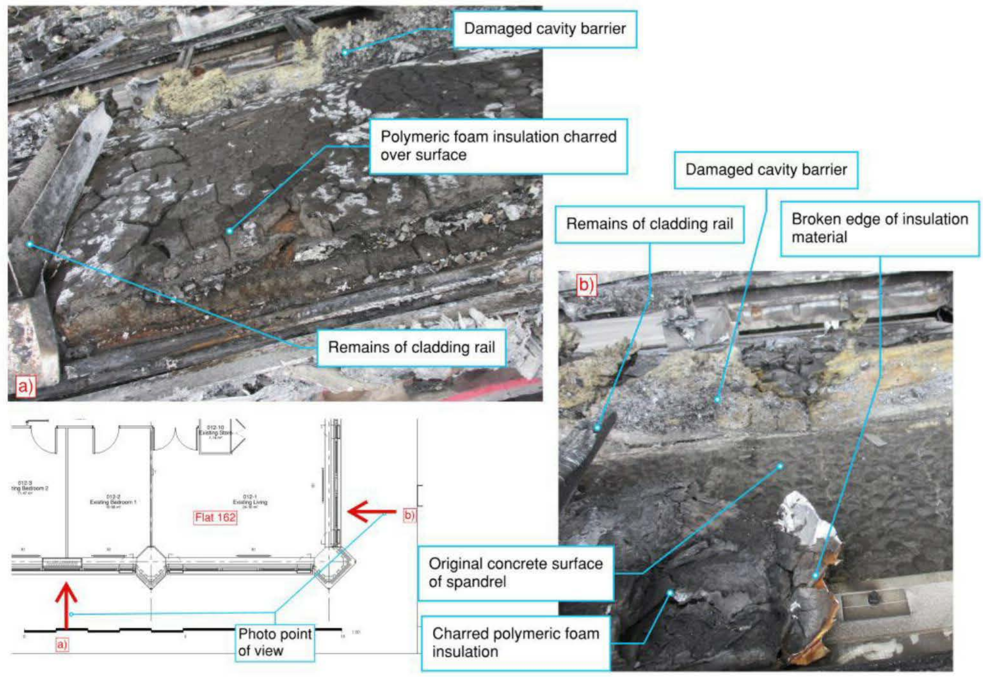


Figure 10.52: Charred polymeric foam insulation on the outside of Flat 162 (photos taken looking down out of window)

10.9.4 Window surround insulation

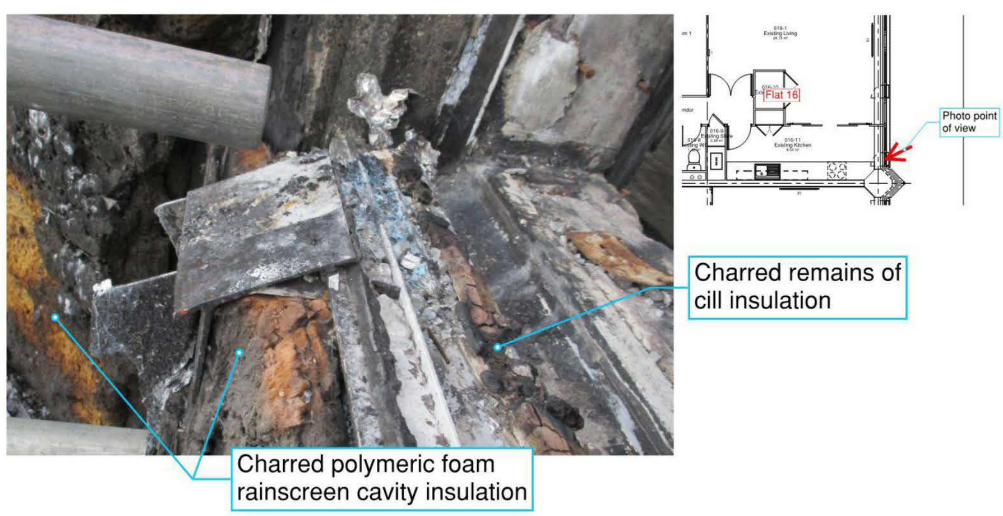


Figure 10.53: Charred polymeric foam insulation in cill cavity and in rainscreen cavity

10.9.5 uPVC window reveals

Figure 10.54: Evidence of burned uPVC and cill insulation in Flat 15

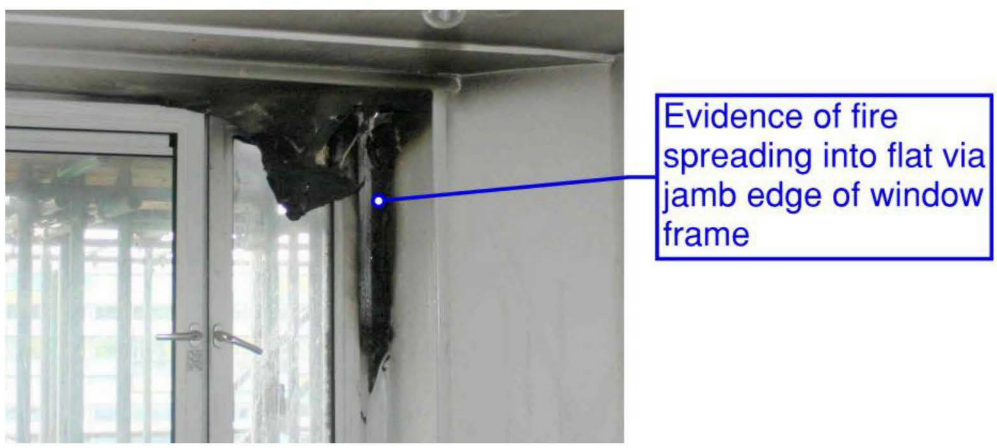


Figure 10.55: Burned uPVC frame in Flat 15

10.9.6 Original timber window frames and reveal

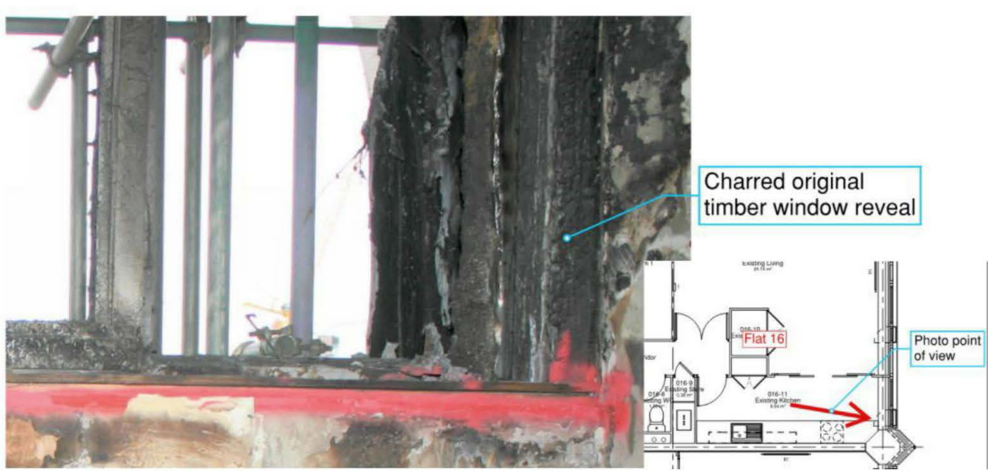


Figure 10.56: Charred timber reveal in Flat 16

10.10 Resultant fire spread routes, created due to Pathway types A, B, C, D, E and F

10.10.1 I have explained the 6 Pathways (A, B, C, D, E and F) shown in Figure 10.57 and how they permit vertical and horizontal fire spread along the building envelope.

10.10.2 Each of the Pathways described are also all interconnected and so a continuous process of fire spread along each of them, in all sorts of combinations, was therefore possible.

10.10.3 The construction materials supporting Pathways A to E also allow fire spread from outside the building, back into the building. Pathway F, the Crown system at the top of the building, is fully external and does not interface with the internal parts of the building.

10.10.4 Observations of the fire from the night clearly demonstrate the resulting geometric grid formed by multiple Pathways for fire spread over the external wall. This is due to the interconnection of all the Pathways via the rainscreen cladding panels, combustible insulation, combustible materials around the windows and insulating core infill panels.

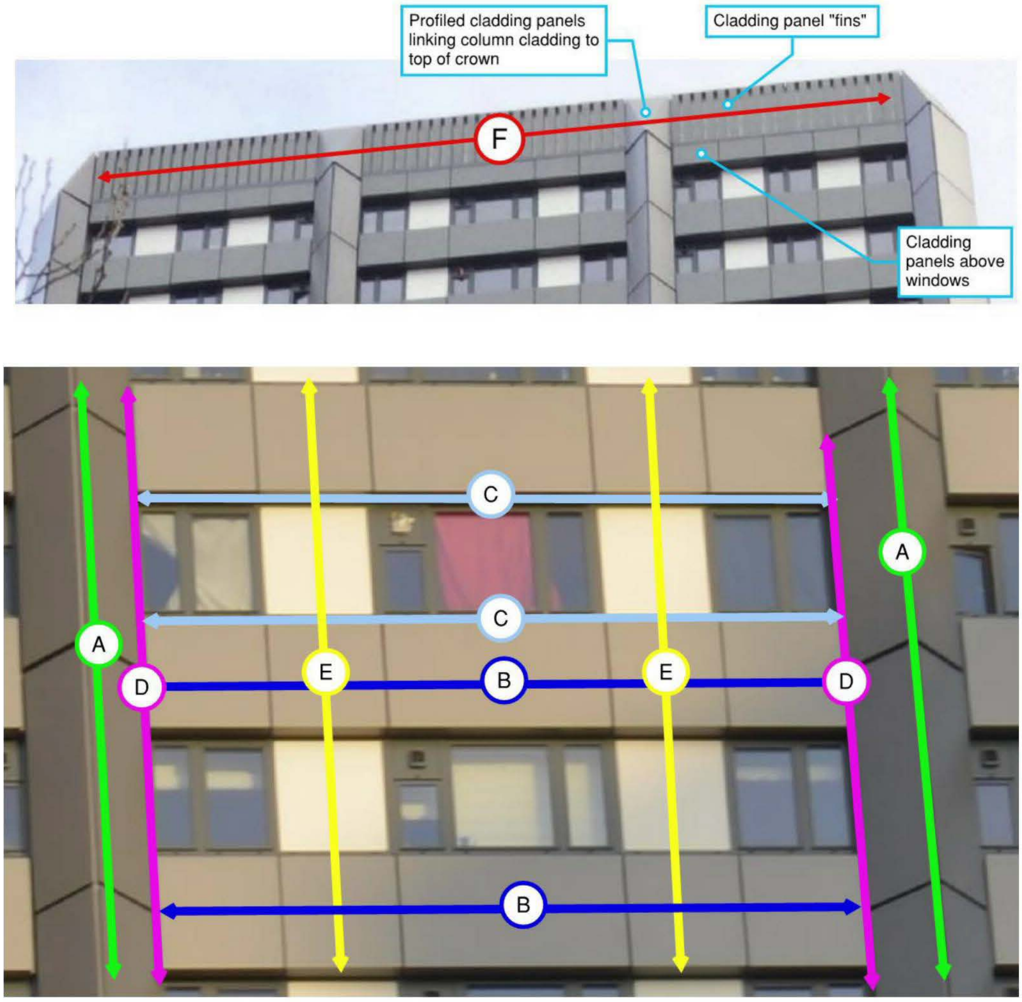
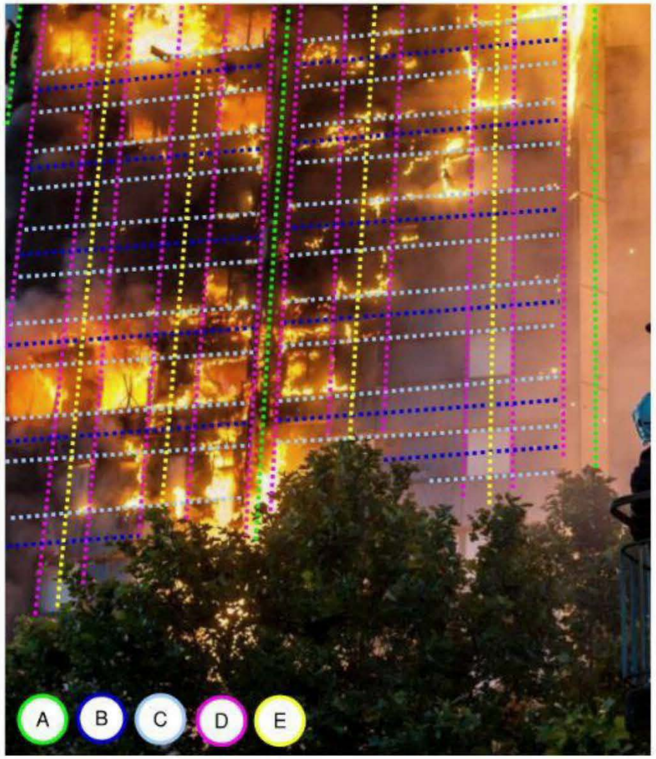


Figure 10.57: Pathways A to E (lower image) and F (Crown) identified on undamaged façade (SEA00000350; SEA00000322)

10.10.5 Geometric grid for fire spread via all six pathways

10.10.6 This fully connected grid facilitated fire spread in both the vertical and horizontal directions on all elevations of the building and between elevations, connecting the entire building envelope of Grenfell Tower. Figure 10.58 shows photographic evidence of fire spread via each of the six pathways on the West elevation of Grenfell Tower.



(b) Photographic evidence of Pathways A, B, C and D[12]

(b) Photographic evidence of Pathways A, B and E[13]

Figure 10.58: Fire spread on West elevation of Grenfell Tower

[12]Paris Match, 2017. Les pompiers héroïques de la Grenfell Tower racontent l'horreur [online] Available at: https://www.parismatch.com/Actu/International/Les-cris-la-fumee-Les-pompiers-heroiques-de-la-Grenfell-Tower-racontent-l-horreur-1318214 [Accessed 20 October 2018]

[13] Daily Star, 2017. Family managed to escape Grenfell Tower inferno by turning on their TAPS [online] Available at: https://www.dailystar.co.uk/news/latest-news/622497/Grenfell-tower-fire-London-Latimer-Road-Ladbroke-Grove-inferno-escape-taps [Accessed 20 October 2018]

10.10.7 These six pathways and their connections permitted the fire to encompass the whole of the façade and penetrate inwards to the majority of the flats. I have presented in Section 9 the specific routes that I have identified that could permit fire to spread from inside a flat into the building cladding, but importantly fire could spread from the outside of the building back inside, as shown in Figure 10.59.

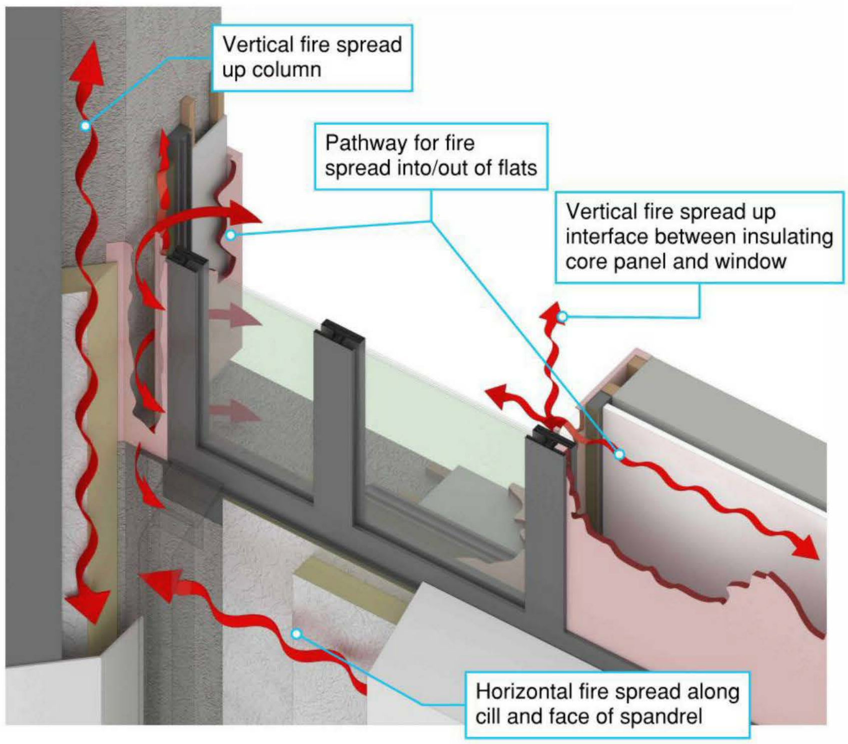


Figure 10.59: Pathway between external wall cavity and inside of flats

10.10.8 On this basis the scenario of multiple compartment fires developing on multiple floors, and soon after the initial fire spread, was made possible and in fact occurred. Multiple compartment fires on several floors burning simultaneously can be seen in Figure 10.60, which is a photograph of the East elevation of the building at 02:08.

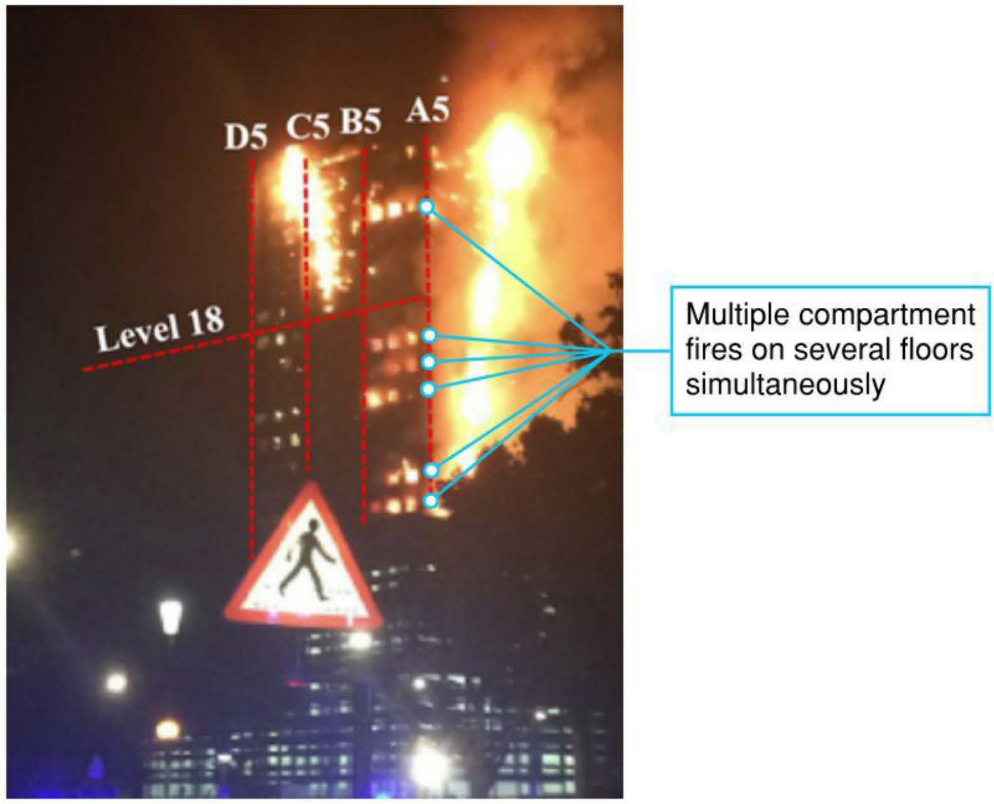


Figure 10.60: Multiple simultaneous compartment fires (as external flaming from several windows observed on multiple floors) at 02:08 (MET00012593)

10.10.9 **Fire spread via Pathway A and B only**

10.10.10 I have described up to 6 possible pathways for external fire spread and how these could have combined to allow fire spread across the entire perimeter the Grenfell Tower external wall.

10.10.11 In this section I have considered the two pathways relevant to the external rainscreen cladding system only (Figure 10.61), that is:

a) Pathway A: Vertically via the Reynobond 55 PE and Celotex RS5000 insulation attached to the columns; and

b) Pathway B: horizontally via the Reynobond 55PE and Celotex RS5000 or Kingspan K15 thermal insulation attached to the spandrels.

10.10.11.1 I wanted to understand potential fire spread mechanisms without the contribution of the combustible construction materials around the windows. And their infill panels.

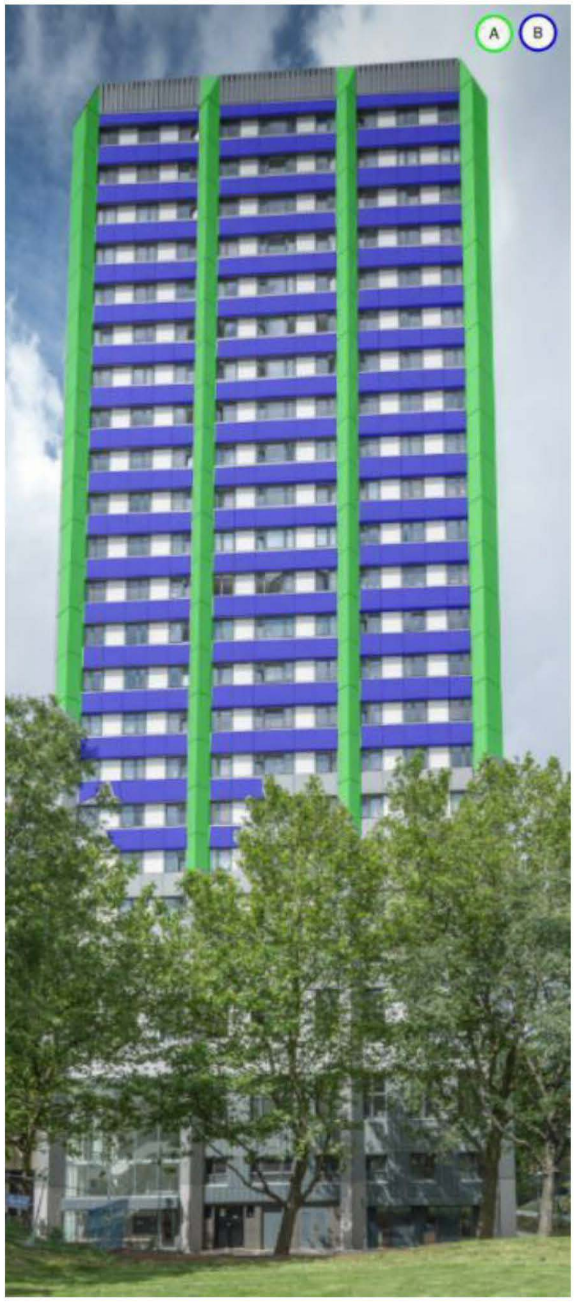
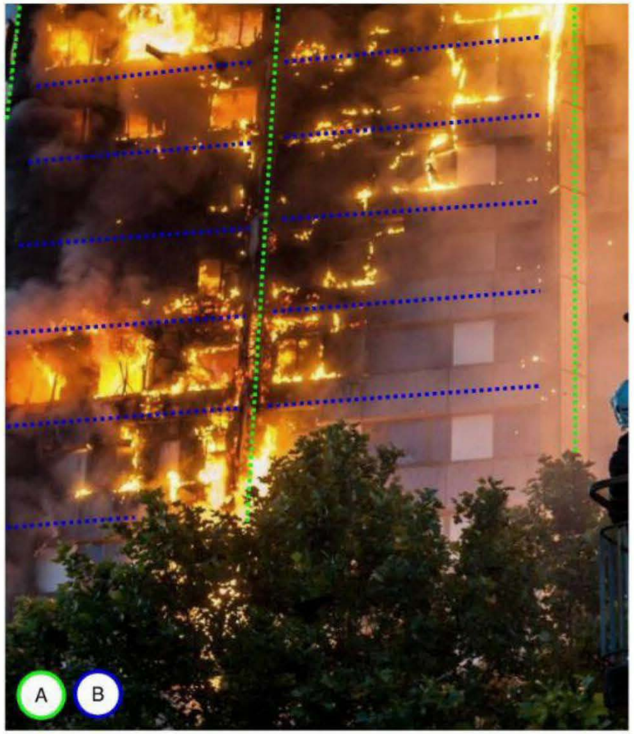


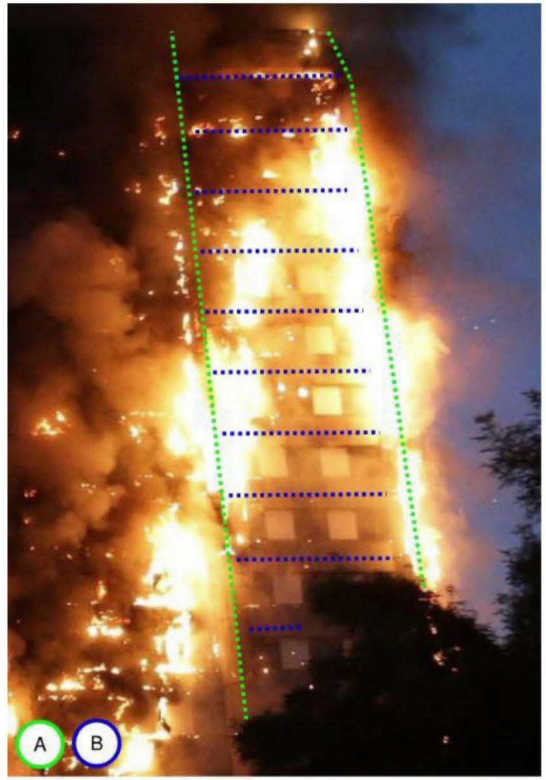
Figure 10.61 Pathways for external fire spread: pathway A and B (SEA00000387)

10.10.12 In Figure 10.61 I have over-marked a photograph of Grenfell Tower before the fire on 14th June 2017. The vertical and horizontal connection between the columns and spandrels creates a grid and therefore resultant pathway for fire to spread over the full extent of the exterior of Grenfell Tower.

10.10.13 Figure 10.62 shows photographic evidence of fire spread via Pathways A and B on the West elevation of Grenfell Tower. The installation of Reynobond 55PE ACM panels and Celotex RS5000 or Kingspan K15 thermal insulation along the columns and spandrel panels in the rainscreen system created a grid covering all parts of the external wall in isolation.



(a) Photographic evidence of Pathways A, B, C and D[14]



(b) Photographic evidence of Pathways A, B and E[15]

Figure 10.62: Fire spread on West elevation of Grenfell Tower

[14] https://londonnewspictures.photoshelter.com/image?_bqG=1283&_bqH=eJxNjssKwjAQRf.mGxFaFMRCFnmpAduUTCLUTVBpjaWKtoL69yZF1EUm5w7MmYn1dnMFaJ5N9sqKFZzHjuwpuL5.pMkkmadJHIfnq7AMKDp21aWu2nZUn7oqGnoW5wzdPVOhS.R_0FjzAFSaXKvSCpAhCrCKrzkGzj6x.M9SCZ77USHzwSKVRsybPBvgygqGTLiE9K68yRlZumlkKbHCa_z.D5ovqsUPs4CYatRXu.7gIhpsb_aCTDc-)

[15] https://www.gettyimages.co.uk/detail/news-photo/fire-engulfs-grenfell-tower-a-residential-tower-block-on-news-photo/695801196

10.10.14 Effect of fire spread along the architectural crown on lower levels of the building

10.10.15 As I have explained in Section 10.8 lateral fire spread was observed at the level of the architectural crown (Pathway F). In Section 10.8, I explained that there was a consistent diagonal pattern of flame spread for both External Flame Spread Routes after 02:08, which indicates that fire advanced laterally along the crown before it spread to lower levels.

10.10.16 Through my review of photographic and video evidence, I observed that lateral fire spread via the Crown may have increased the rate/progression of lateral fire spread on lower levels of the building envelope.

10.10.17 I observed that fire spread from the crown to lower levels of the building through three distinct steps, which I describe below.

10.10.18 These observations are based on my review of photographic and video evidence of external fire spread and post-fire damage of the façade.

10.10.19 I do not have a chronological set of photographs that demonstrate these three steps for a specific area of the building, at any one time during the fire.

10.10.20 Therefore, I have provided examples of each step as I have observed it, from different areas of the building envelope.

10.10.21 I have also provided a photograph of post-fire damage for each building elevation because I observed the resulting final damage pattern to be similar to my observations of these steps in fire spread from the architectural crown to lower levels of the building.

10.10.22 I observed that lateral fire spread along the architectural crown contributed to the spread of fire to the lower levels by the following means:

1) Fire spread laterally across the crown itself (refer to Pathway F in Section 10.8) – see photographic evidence in Figure 10.63; and

2) Once the fire at crown level reached a column, it ignited that column at crown level and then spread down the column to lower levels of the building (refer to pathway A in Section 10.3) – see photographic evidence in Figure 10.64 and Figure 10.65; and

3) On each level affected by the burning column, fire then spread laterally away from the column in both directions (refer to pathways B & C in Sections 10.4 and 10.5) – see photographic evidence in Figure 10.66 and Figure 10.67.

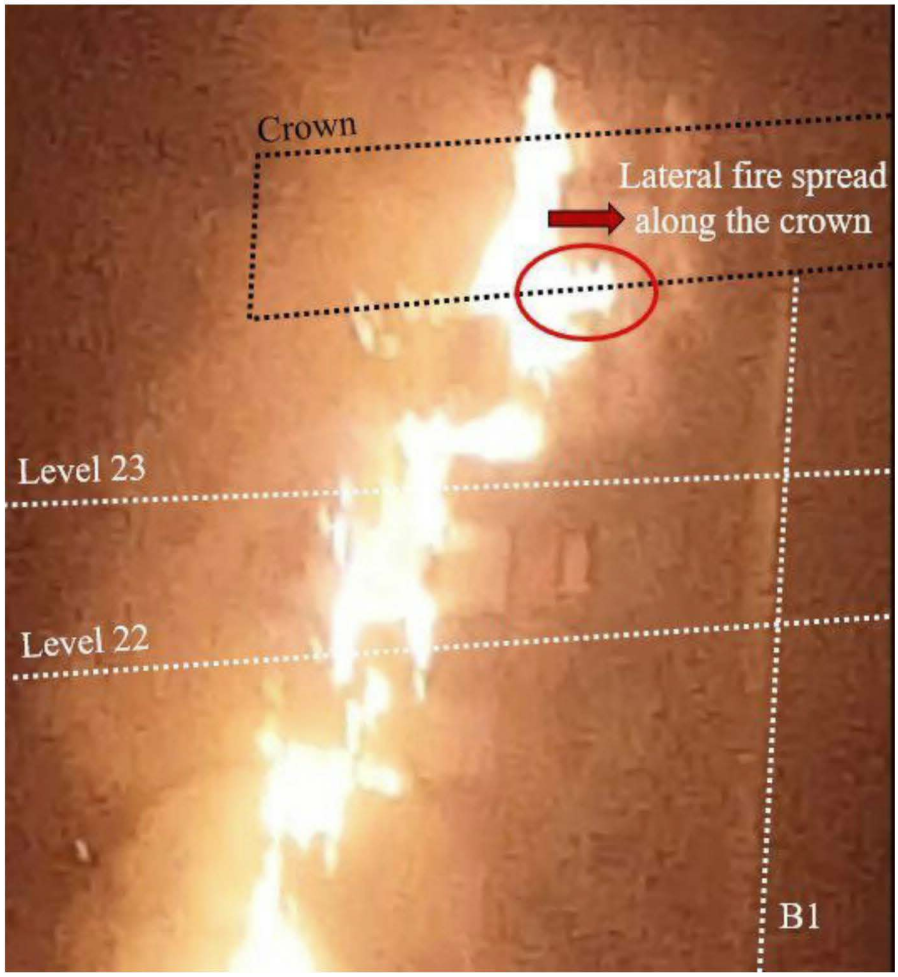


Figure 10.63: Lateral fire spread along the crown on the West elevation at 03:03 on 14th June 2017 (see Video 3 accompanying Prof. Bisby's supplemental Phase 1 report.)

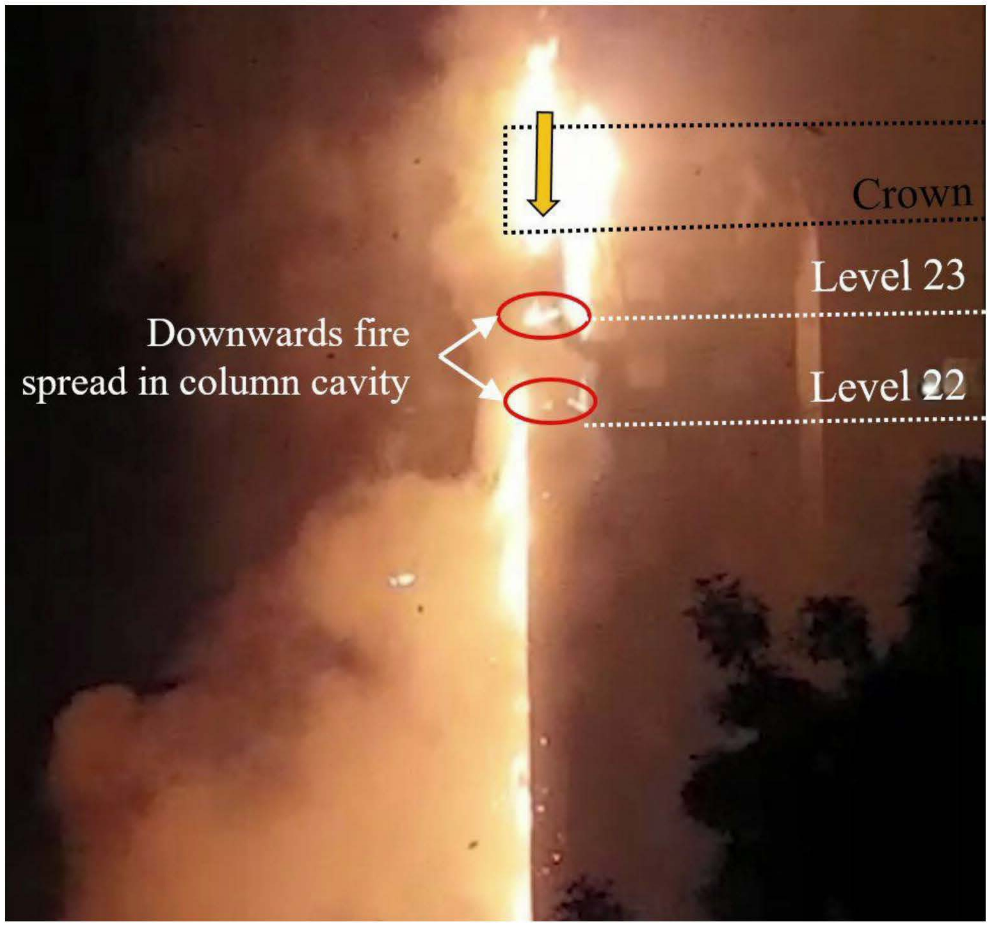


Figure 10.64: Fire spread down the Northwest column (A1) and within the column cavity at 02:51 on 14th June 2017 (see Video 3 accompanying Prof. Bisby's supplemental Phase 1 report)

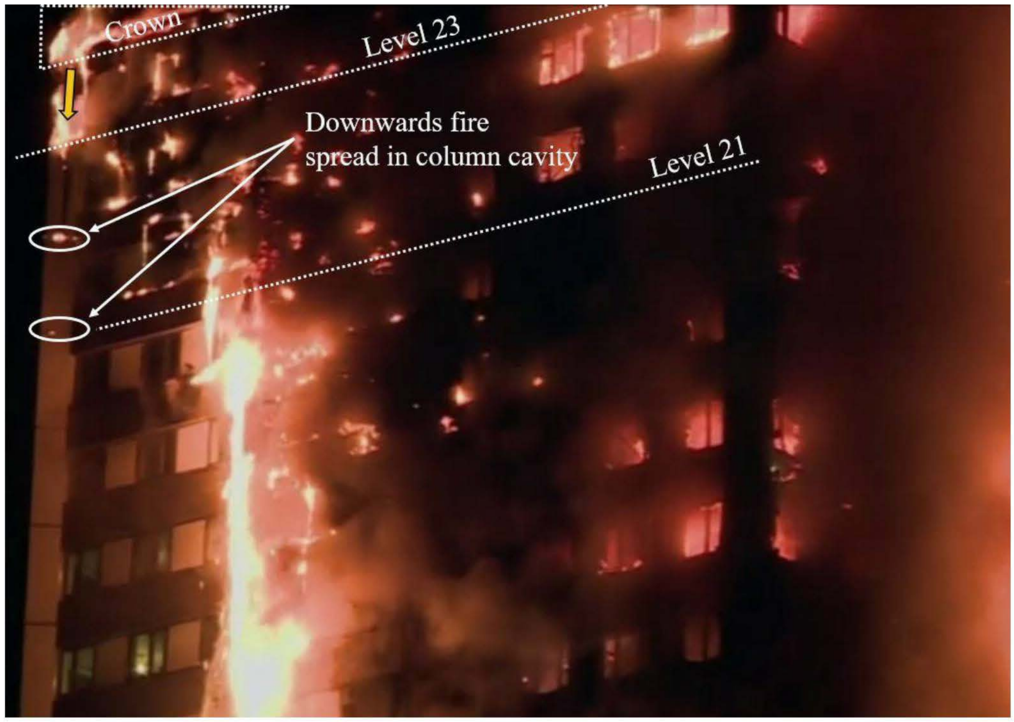


Figure 10.65: External fire spread along the exterior of the Southeast column (D5) and within the column cavity[16]

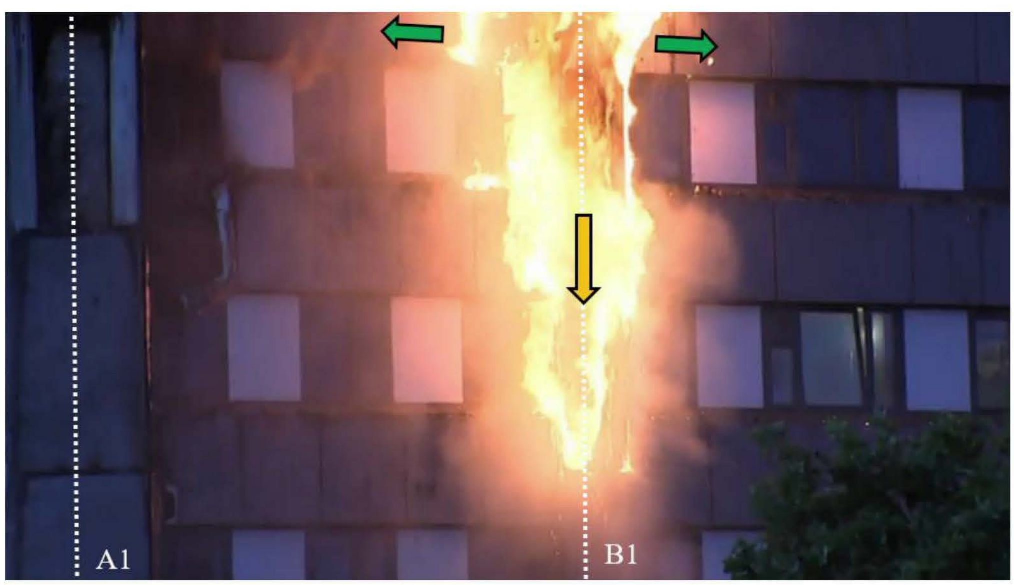


Figure 10.66: Downwards fire spread along column B1 and lateral fire spread in both directions from the column on the West elevation[17]

[16] https://www.bbc.co.uk/programmes/b09xptp8
[17] https://www.my5.tv/grenfell-tower-minute-by-minute/season-1/grenfell-tower-minute-by-minute

Figure 10.67: Downwards flame spread along columns on the West elevation.[18]

10.10.23 I observed these three steps of external fire spread on all elevations of Grenfell Tower through my review of photographic and video evidence.

10.10.24 The diagonal pattern of flame spread I observed along both External Flame Spread Routes after 02:08 (refer to Figure 10.41) indicates that fire spread laterally across the crown on all elevations of Grenfell Tower (step 1 described in Section 10.10.22).

10.10.25 I observed a V-shaped pattern on the photographs of post-fire damage shown in Figure 10.68 through Figure 10.71. This V-shaped pattern is centred on each column on each elevation of Grenfell Tower, except for Column B5, which the column the fire spread up initially. These final damage patterns are further evidence that fire spread down the columns (step 2 described in Section 10.10.22) and then laterally away from the column in both directions (step 3 described in Section 10.10.22).

[18] https://www.my5.tv/grenfell-tower-minute-by-minute/season-1/grenfell-tower-minute-by-minute

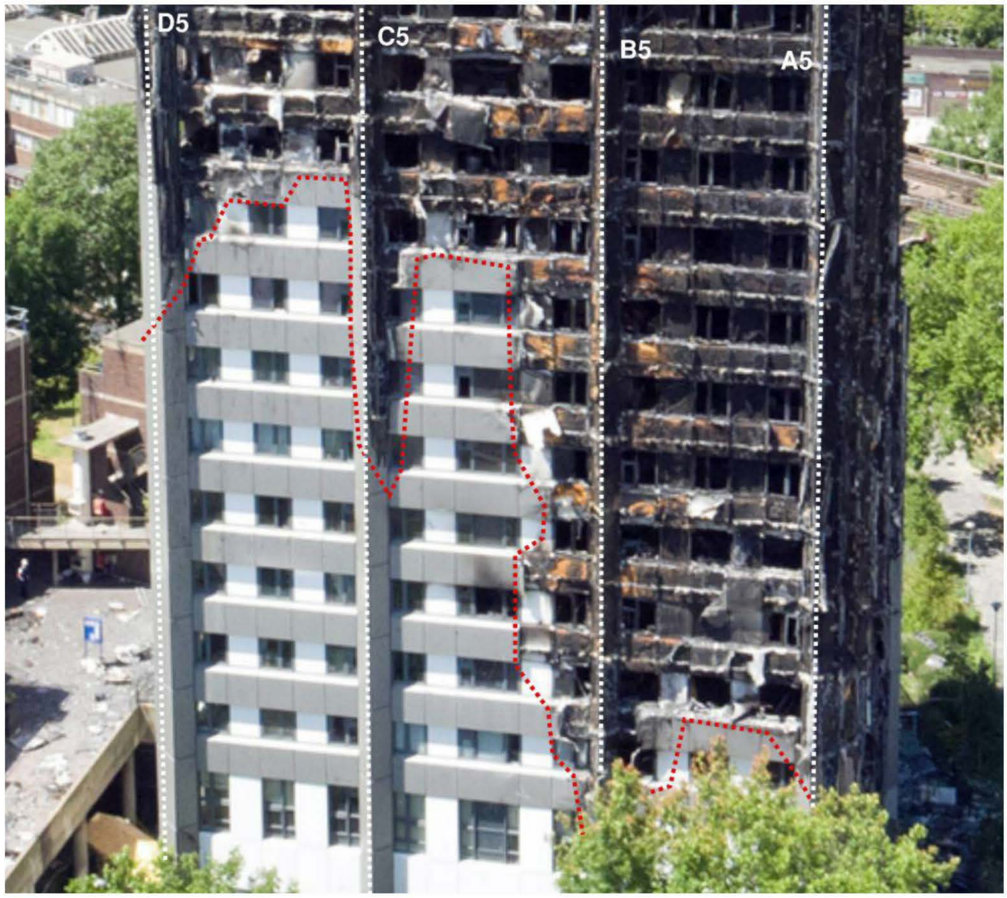


Figure 10.68: Post-fire damage on East elevation of Grenfell Tower (METS00020589)

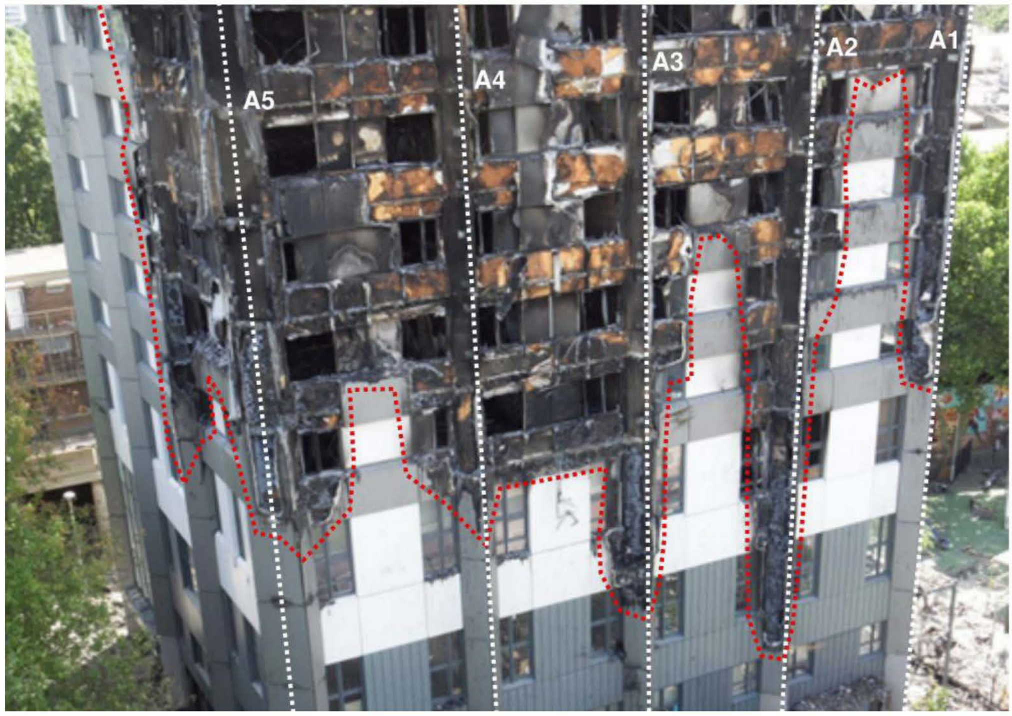


Figure 10.69: Post-fire damage on North elevation of Grenfell Tower (METS00020592)

Figure 10.70: Post-fire damage on South elevation of Grenfell Tower (METS00020582)

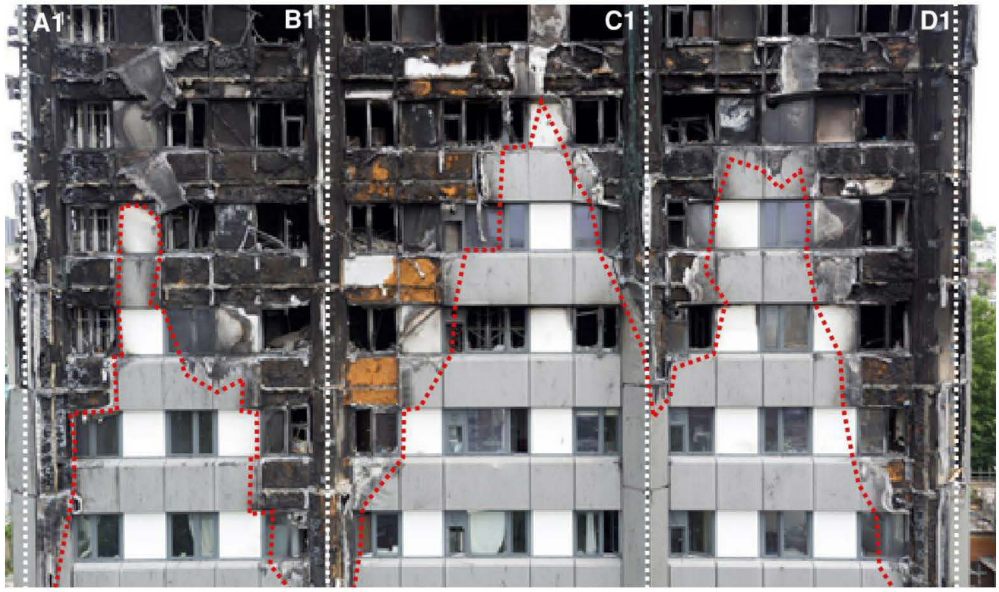


Figure 10.71: Post-fire damage on West elevation of Grenfell Tower (METS00020661)

10.10.26 In Figure 10.72, I provide a schematic of these three steps of external fire spread caused by the crown, as I observe them to be, to demonstrate the effect of fire spread along the architectural crown on lower levels of the building over time.

10.10.27 This schematic is based on photographic and video evidence of external fire spread on the West elevation of Grenfell Tower.

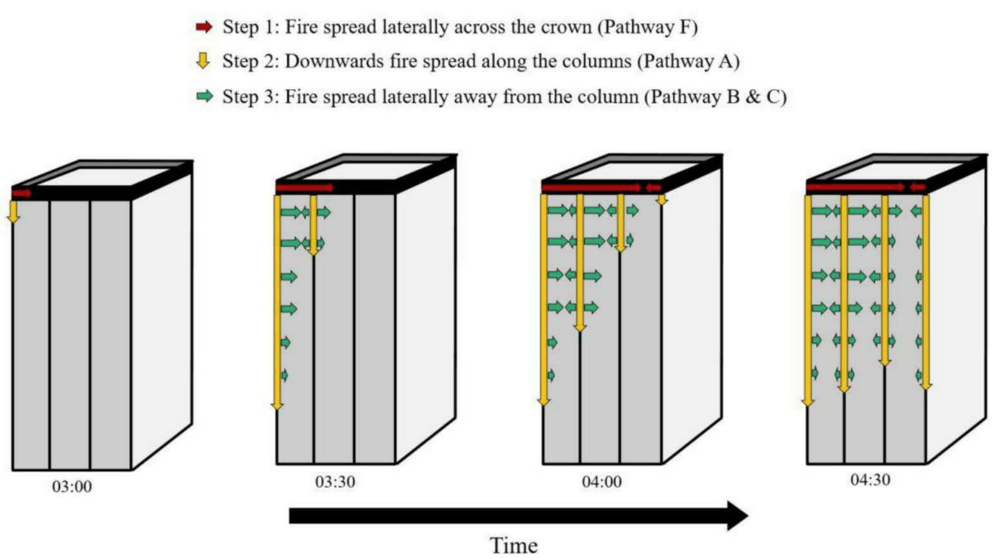


Figure 10.72: Schematic demonstrating the effect of fire spread along the architectural crown on lower levels of the building over time, on the West elevation of Grenfell Tower (MET00012593) (see Videos 2-5 accompanying Prof. Bisby's supplemental Phase 1 report.)

10.10.28 Pathway for fire along the architectural crown to spread into flats at Level 23

10.10.29 In total 24 people died at Level 23 in Grenfell Tower.

10.10.30 The architectural crown is in close proximity to Level 23. The lateral fire spread along the Crown provided a path for external fire to spread into flats on Level 23 by the following means:

a) Fire spread from combustible cladding panel "fins" on the architectural crown to the combustible cladding panels, insulation and cavity above the Level 23 windows (refer to Figure 10.73) – see photographic evidence in Figure 10.74; and

b) Polyethylene from the Reynobond 55 PE panels on the crown melting and running down the building, while ignited – see photographic evidence in Figure 10.75.

10.10.31 Once any portion of the building envelope was ignited on Level 23, fire could then spread via pathways B, C, D or E and then from the building envelope back into a flat, as I explain in Section 9.

10.10.32 In Section 12 of my Expert report I present evidence regarding the development and spread of internal fires within Grenfell Tower.

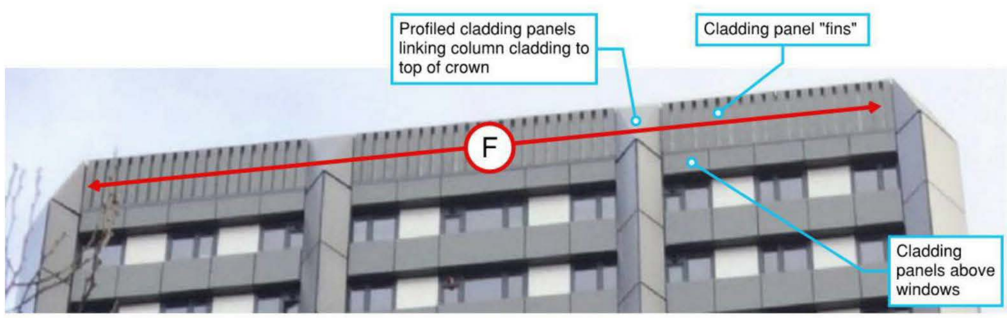


Figure 10.73: Pathway F (Crown) identified on undamaged façade (SEA00000322)

Figure 10.74: Fire in cladding panel above [19]

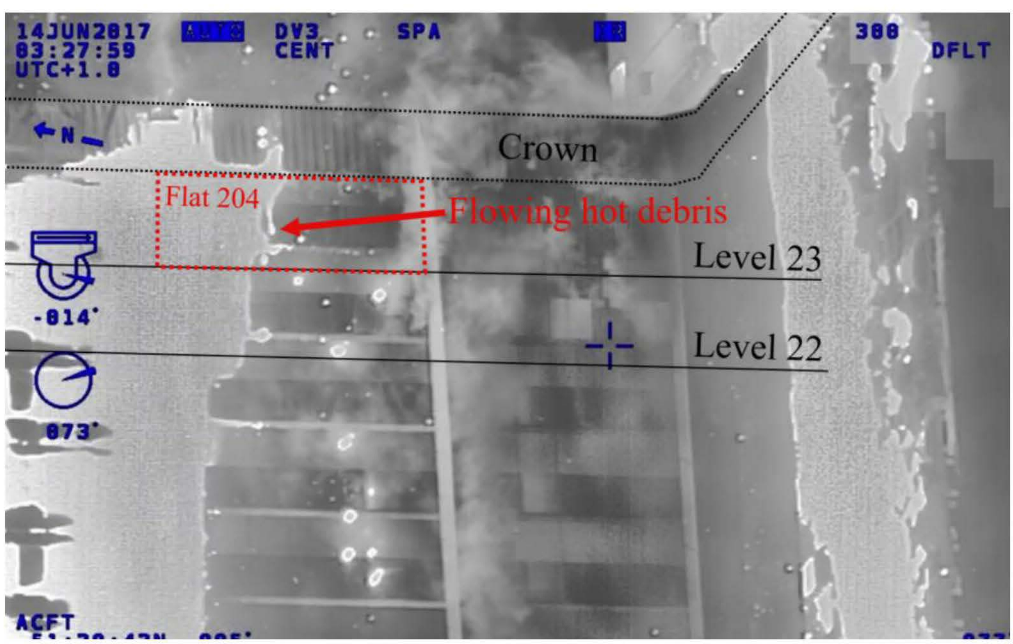


Figure 10.75: Thermal image showing flowing hot debris falling from panels above Level 23 windows on the West elevation of Grenfell Tower at 03:27 on 14th June 2017 (see Video 5 accompanying Prof. Bisby's supplemental Phase 1 report)

[19] International Business Times, 2017. Grenfell Tower fire: Videos show devastating inferno rip through 24-storey London building [online] Available at: https://www.ibtimes.co.uk/grenfell-tower-fire-videos-show-devastating-inferno-rip-through-24-storey-london-building-1626253 [Accessed 20 October 2018]