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 9

Routes for fire spread out through the window openings

REPORT OF

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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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9 Routes for fire spread out through the window openings

9.1 Purpose of this section

9.1.1 In Section 7 of my report, I have explained so far as possible, the location of the fire when it entered the external wall construction, in Flat 16, on Level 4, on the East elevation.

9.1.2 In Section 8, I have identified and provided descriptions of the presence, orientation, configuration and material of each of the external wall components as installed at Grenfell Tower. I have also explained the concealed spaces (cavities) created by these components.

9.1.3 In this Section 9, I will analyse the possible routes of fire spread out through the construction of the new window opening.

9.1.4 I will therefore explain the means by which a localised fire (the early stages before the more severe flashover fire) could ignite any part of those lining materials beside the window opening in Flat 16, and spread by multiple potential routes through the window construction and into the extensive cavities within the external wall construction.

9.1.5 I will also identify the possible means for fire to break back into the building through the same window openings.

9.1.6 I am not proposing to express a definitive view here on exactly how the fire got out the window in Flat 16 (as this is being dealt with by other Experts to the Inquiry). However, I will demonstrate in section 9.5.12.1, that there were multiple ways fire could have broken out through the kitchen window in Flat 16 and into the cladding. I will also identify the evidence from Flat 16 that those construction materials were involved in the fire.

9.2 Internal cavities around the new windows and materials within

9.2.1 Localised cavities behind the window reveal linings

9.2.2 As described in Section 8 of my report, the new windows along with the new overcladding, as it was applied to the exterior of the building, created the following cavities, moving from the inside of the building to the outside:

9.2.3 Vertical cavity between window jamb and concrete columns, underneath the uPVC reveal lining (Figure 9.1);

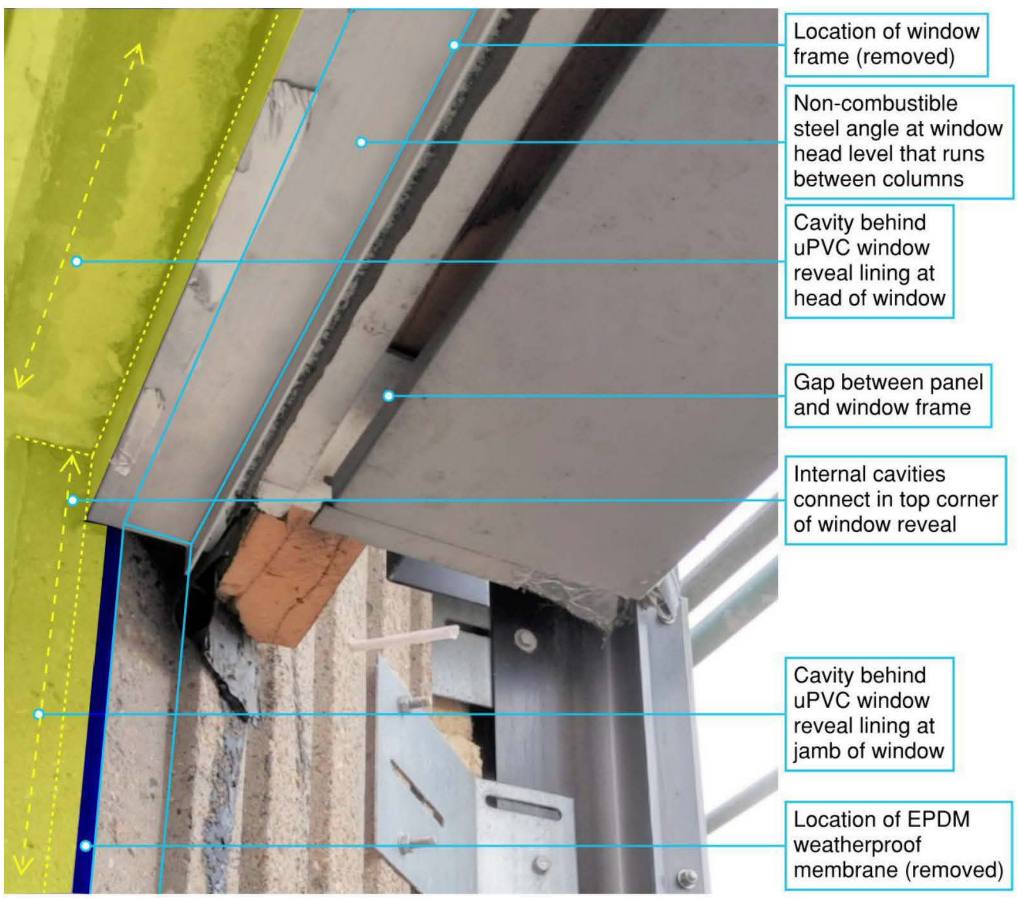


Figure 9.1: Cavities underneath window reveal linings at head and jamb of window and that they are connected.

9.2.4 Horizontally, underneath new uPVC window cill reveal lining (Figure 9.2);

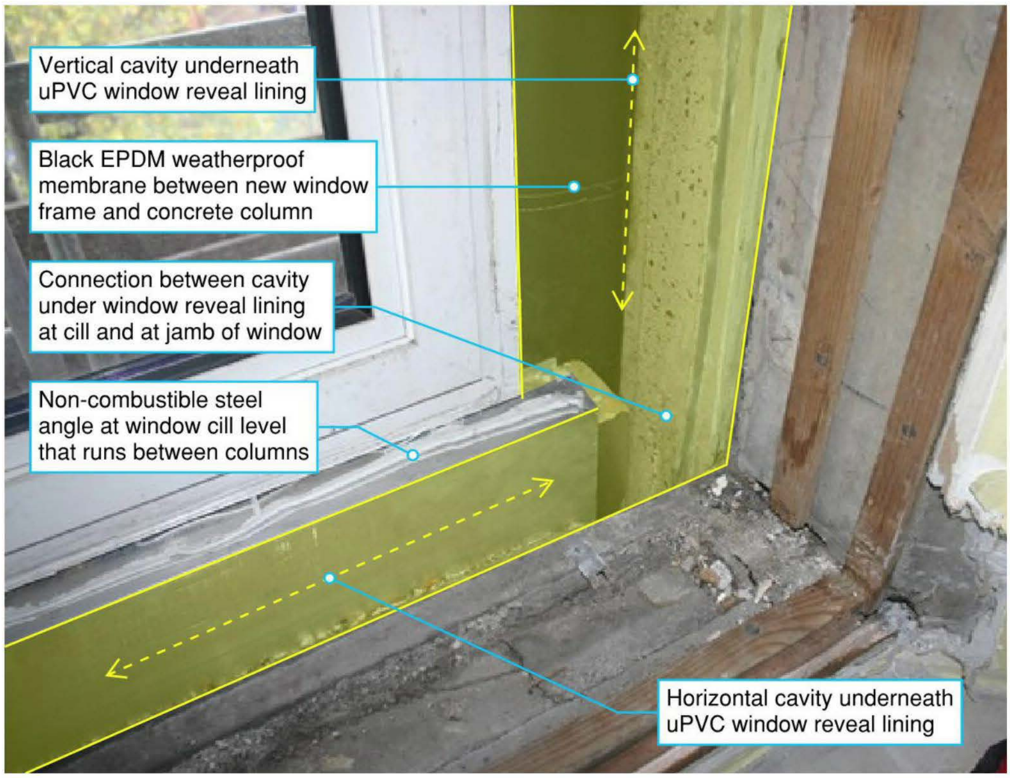


Figure 9.2: window reveals after uPVC linings removed showing cill and jamb next to column (Flat 13, Level 4)

9.2.5 Figure 9.2 shows the cavities behind the uPVC window reveal linings at the jamb and cill of the windows, highlighted in yellow. These cavities were formed by the movement of the new windows out away from the building relative to their original position, and were also partially filled with 25mm combustible insulation, glued to the underside of the uPVC window reveal linings. Note that they are connected where they meet in the bottom corner.

9.2.6 Horizontally, at the head of the window above the new uPVC reveal lining (Figure 9.1 & Figure 9.3);

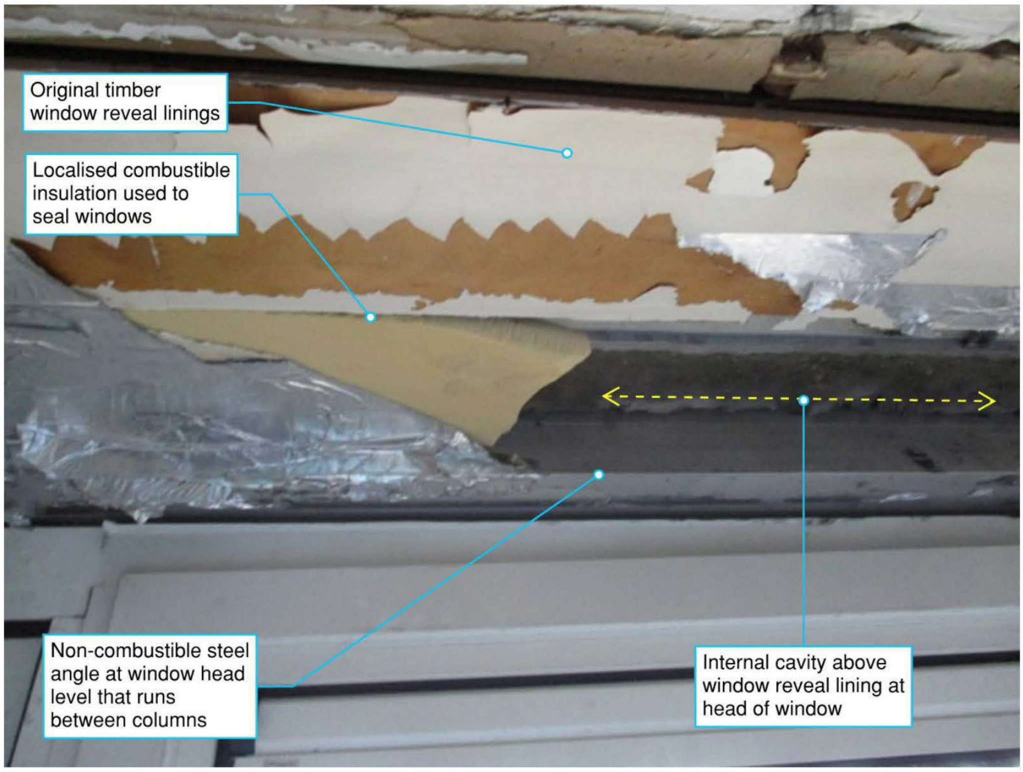


Figure 9.3: materials and cavities under uPVC window reveal lining at head of window

9.2.7 Figure 9.3 shows the cavity at the head of the window behind the uPVC window reveal lining which has been removed. It also shows how localised combustible insulation was placed within this internal cavity.

9.2.8 There were also cavities vertically and horizontally between the original infill panel between windows, and the new combustible insulating core panel installed between windows (Figure 9.4);

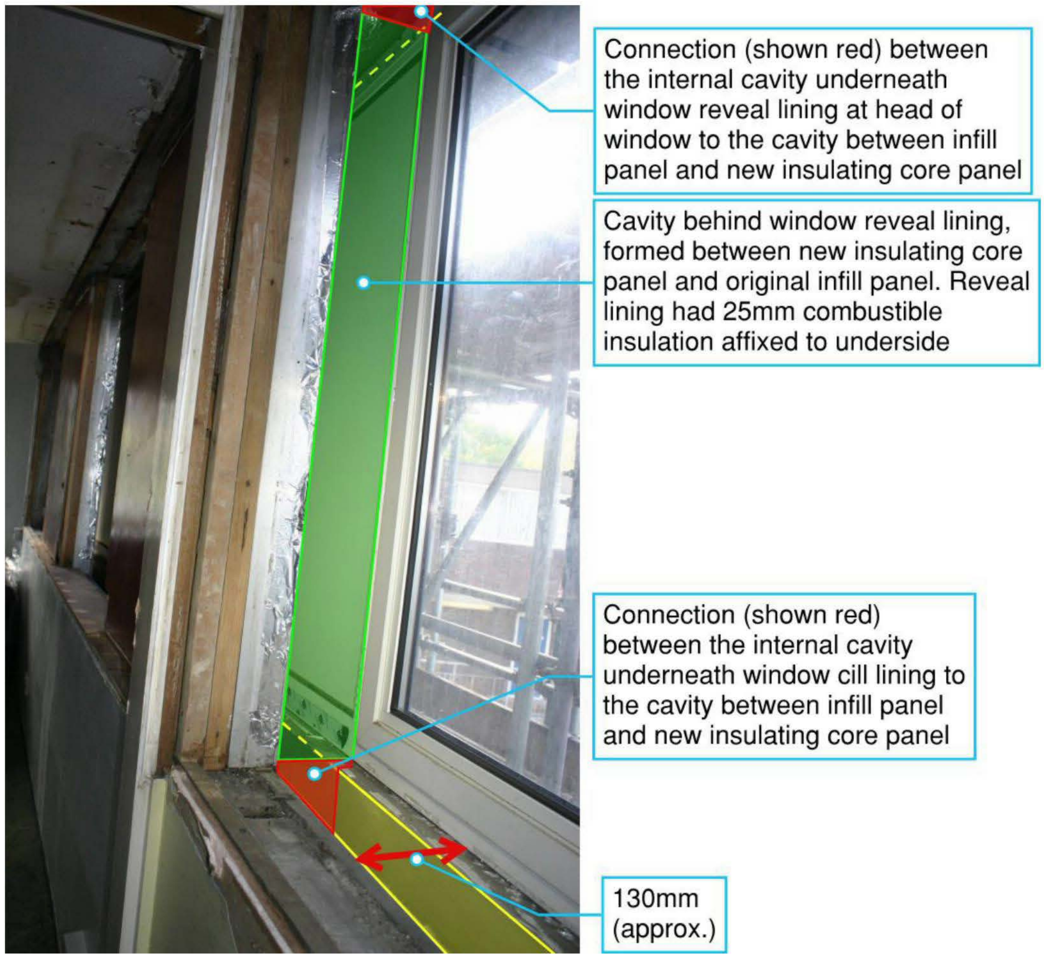


Figure 9.4: cavity and materials under uPVC window reveal lining at infill panel side jamb of window

9.2.9 Figure 9.4 shows that, at the side opposite the column, a large cavity is formed by the space between the original infill panel between the windows and the new insulating core panel which was installed (shaded green, Flat 13). There is a connection with the internal cavities under window reveal linings at both the head and cill of the windows outlined in Figure 9.2 and Figure 9.3, which is shaded in red.

9.2.10 There was an external wall cavity formed by the aluminium composite cladding panels and the new insulation affixed directly to the original external wall (Figure 9.5).

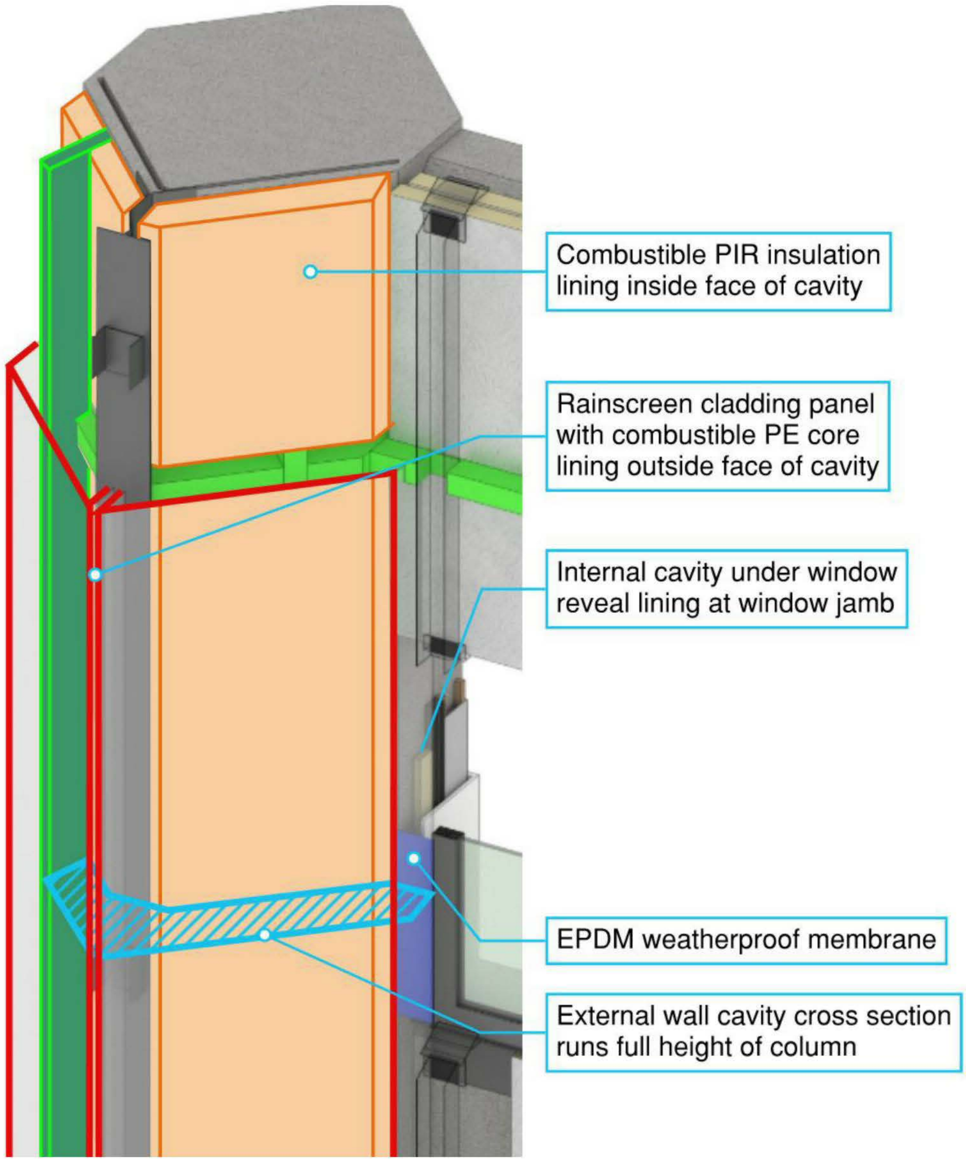


Figure 9.5: 3D render of the external wall construction

9.2.11 The relationship of that external wall cavity to the internal cavity at the jamb is also shown. It is clear in Figure 9.5 that the EPDM weatherproof membrane is the only thing separating these two spaces.

9.2.12 I have reproduced Figure 8.3 from Section 8 here (Figure 9.6 below) as a reminder of the location of the new window, relative to both the old and new external wall, and this is the reason for the creation of these cavities, in behind the window reveal linings.

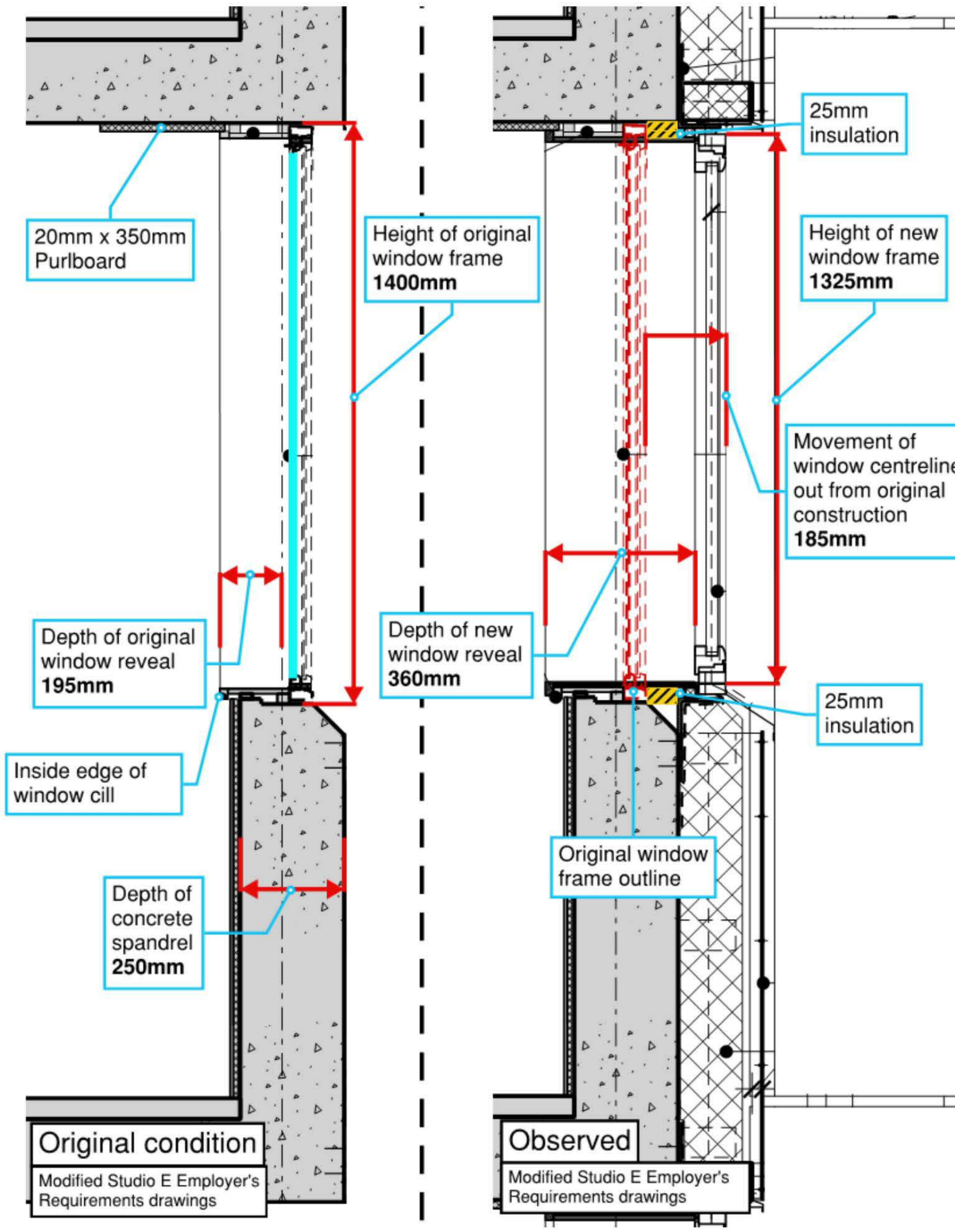


Figure 9.6: Vertical section view of original [left] and post refurbishment [right] window openings (Based on SEA00013045)

9.2.13 Each of these cavities contained combustible insulation. In the internal cavities (a) to (d) above, these were localised insulation materials attempting to seal the window (Figure 9.1). In the main external wall cavity this was the Celotex/Kingspan product attached to the original concrete wall.

9.2.14 The cavities around the window also contained remnants of the original wooden window reveal linings and supporting timber battens. These items were left in place during the refurbishment works, with the new uPVC reveal linings being glued to the outside of the timber reveal linings. The original timber reveal linings are a further set of combustible materials behind the uPVC reveal linings (visible in Figure 9.2).

9.2.15 Additionally, the following construction separates these cavities underneath the window reveal linings, from the primary external wall cavity:

a) Continuous metal angles at the head and cill of the window. As described in Section 8, these angles are used to fix the window frames to the existing concrete structure. (Annotated in Figure 9.2 & Figure 9.3)

b) The combustible EPDM weatherproof membrane fitted between the existing concrete columns and the new window frames. (Annotated in Figure 9.2 & Figure 9.5)

c) Combustible extruded polystyrene (XPS) filled insulating core in fill panels used as unglazed elements between windows as well as for the kitchen fan insert. (shown between windows on Figure 9.7)

d) The glazing in the new windows themselves (Figure 9.7)

9.2.16 Therefore, this combination of interconnected cavities behind the uPVC window reveal linings formed a network that spanned the full width between each column. This is represented on the exterior of the building in Figure 9.7.

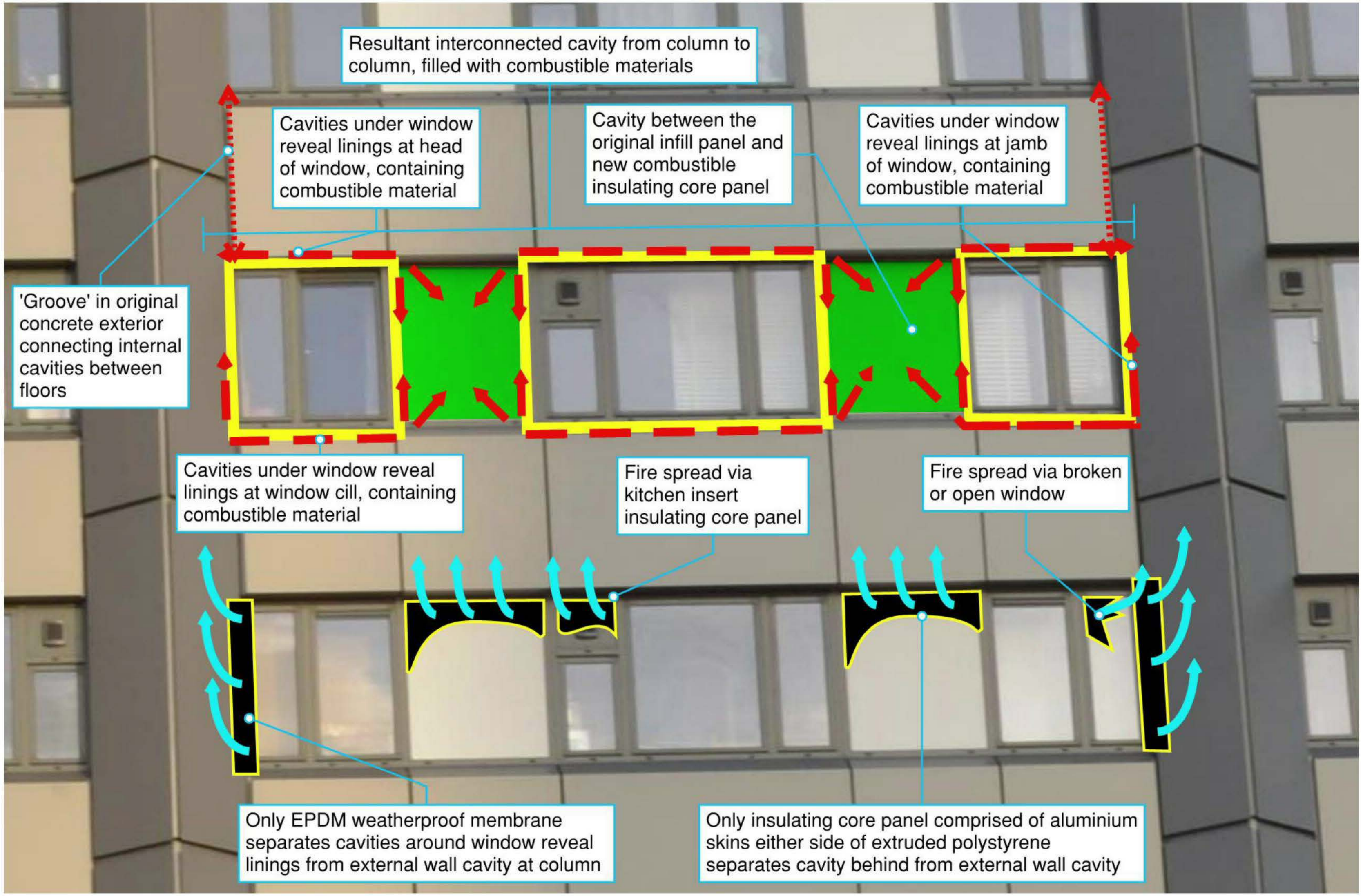


Figure 9.7: Resultant network of cavities superimposed on exterior of building, and routes into external wall cavity (SEA00000350)

9.2.17 In Figure 9.7 above:

a) yellow lines represent the cavities around the window reveal linings;

b) green shading represents the cavity formed between the original infill panel and the new insulating core panel.

c) red dotted arrows therefore demonstrate the connections between the above internal cavities (see 9.2.19 onwards).

9.2.18 The second row of windows with black areas and blue arrows, summarises the routes that a fire within this network of cavities could then take to break into the external wall cavity formed by the rainscreen cladding applied to the building. I will explain all of these routes in section 9.3

9.2.19 **Cavity formed by groove in original concrete exterior of building**

9.2.20 There is a further cavity caused by the original external wall shape, relative to the rainscreen overcladding system – see Figure 9.9 below.

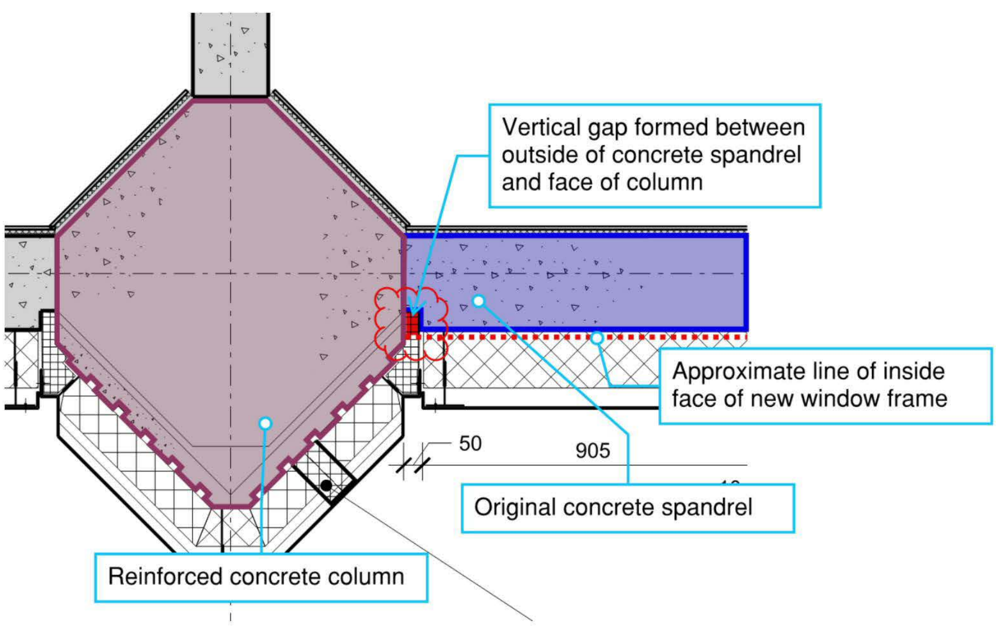


Figure 9.8: Marked up diagram showing gap formed by original concrete exterior of the building marked in red (horizontal section based on SEA00013045)

9.2.21 The Studio E drawing (SEA00013045) identifies that the gap between the column and spandrel should be filled with insulation.

9.2.22 I found evidence of this vertical gap or groove on site as I have presented in Figure 9.9 and Figure 9.10. This groove is formed by the original concrete exterior of the building, which after the refurbishment works, was situated on the interior side of the EDPM weatherproof membrane (see Figure 9.9).

9.2.23 This gap travels the length of each floor between windows and was observed both filled (Figure 9.10) with combustible expanding foam and also unfilled (Figure 9.9).

9.2.24 Where filled, a combustible expanding polyurethane foam product (HAR00001323) appears to have been used, and from below only.

9.2.25 This gap also bypasses the floor slab compartment line (and it is repeated beside each column and on each floor).

9.2.26 This gap was not fire rated and represents a potential path of internal fire spread vertically between flats, without breaking the EPDM weatherproof membrane.

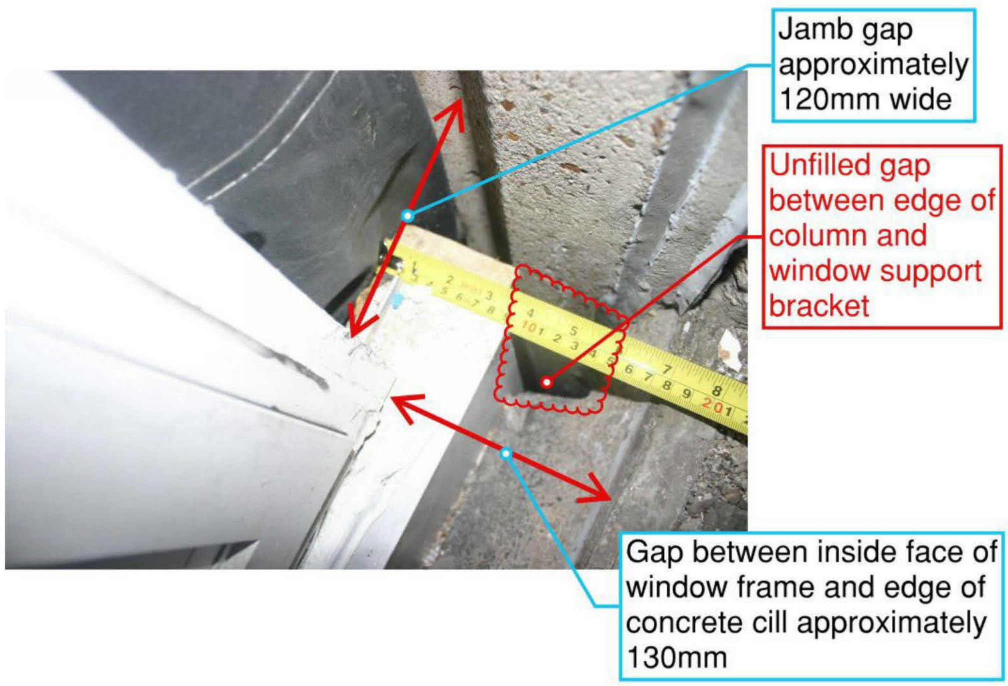


Figure 9.9: Unfilled gaps in the internal window construction – cill level (Flat 13)

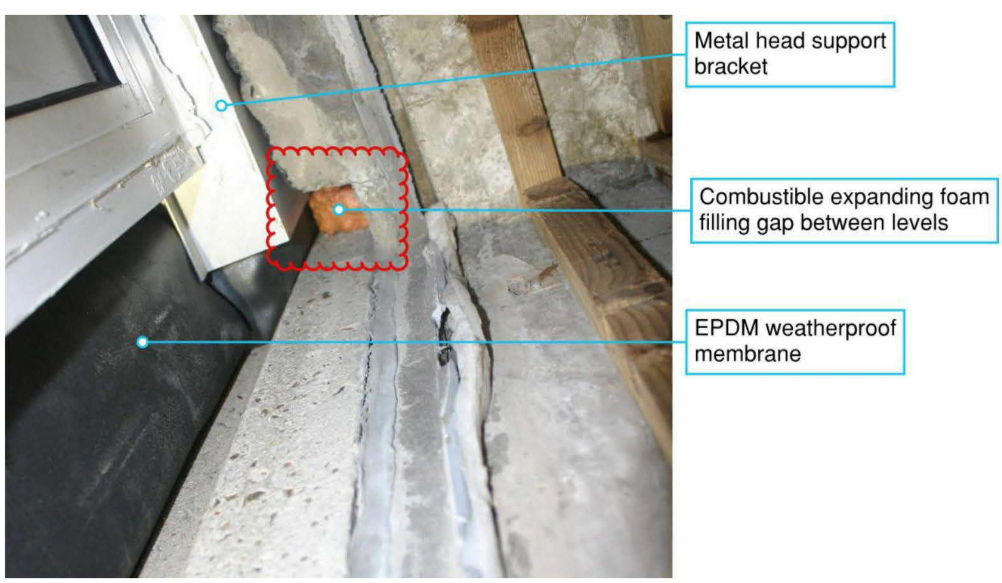


Figure 9.10: Gap filled with expanding foam in the internal window construction – Looking up at window head (Flat 13)

9.3 Routes for fire spread between the inside and outside of the window detail

9.3.1 In this section I describe the routes of fire spread, assuming a localised fire near any part of the window reveal linings from the flat interior to the building external wall, using the network of internal cavities outlined in Figure 9.7.

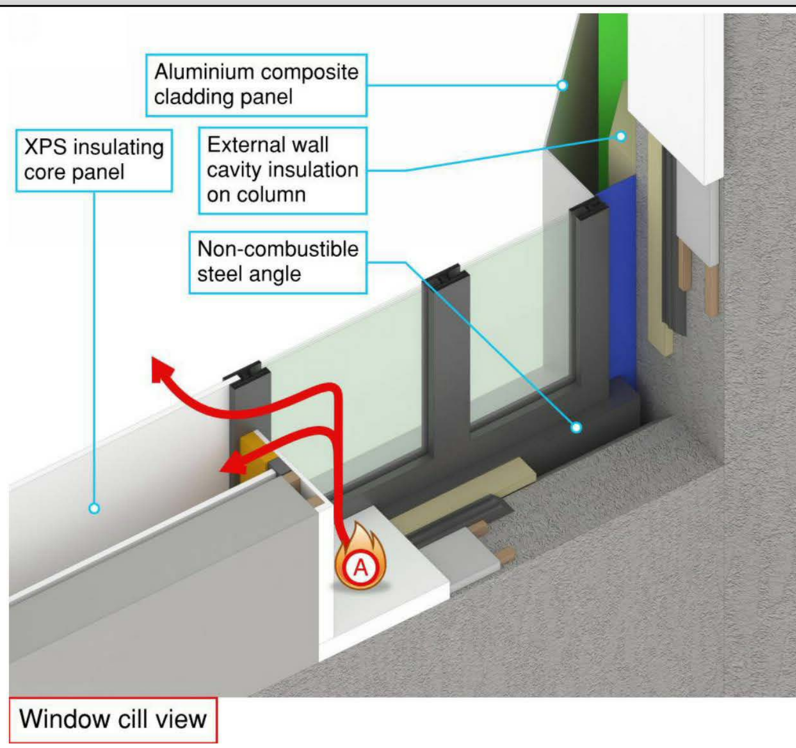
9.3.2 I describe how for multiple fire scenarios affecting any part of the window lining, fire may spread out into the extensive external cavities of the rainscreen cladding system.

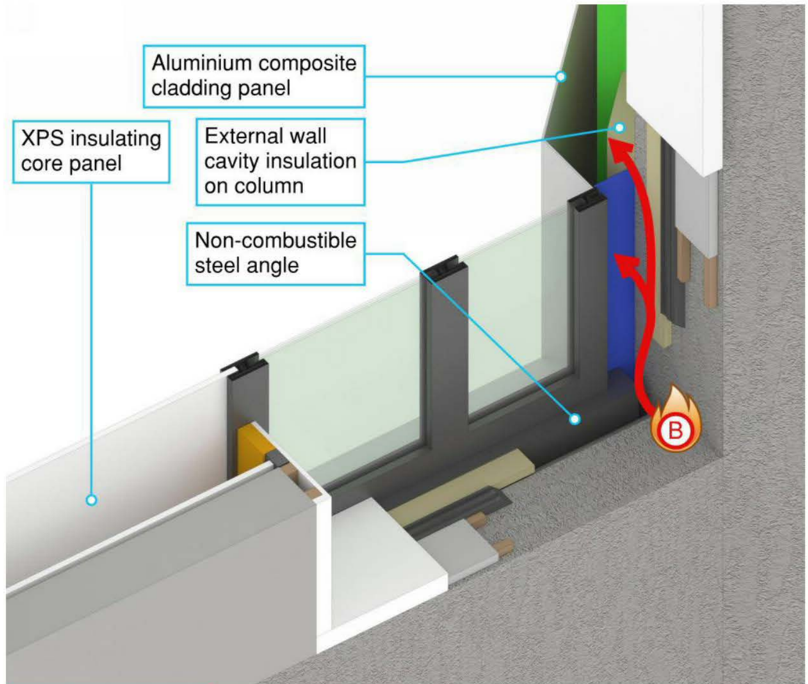
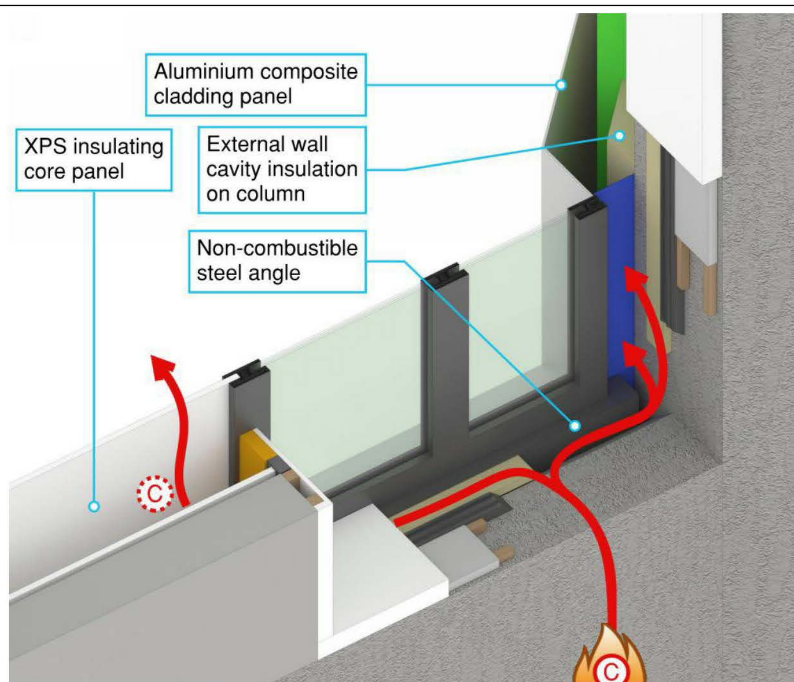
9.3.3 The science of the material performance and temperatures that enable the combustion process for these materials in all these locations is being dealt with by Professor Luke Bisby and is not addressed any further here.

9.3.4 In Table 9.1 I summarise the overall location of the five fire scenarios I have considered.

9.3.5 I have also illustrated and explained for each, using a schematic illustration of the Grenfell Tower external wall, the routes by which these fire scenarios are able to spread through the window construction and into the extensive external rainscreen cavities.

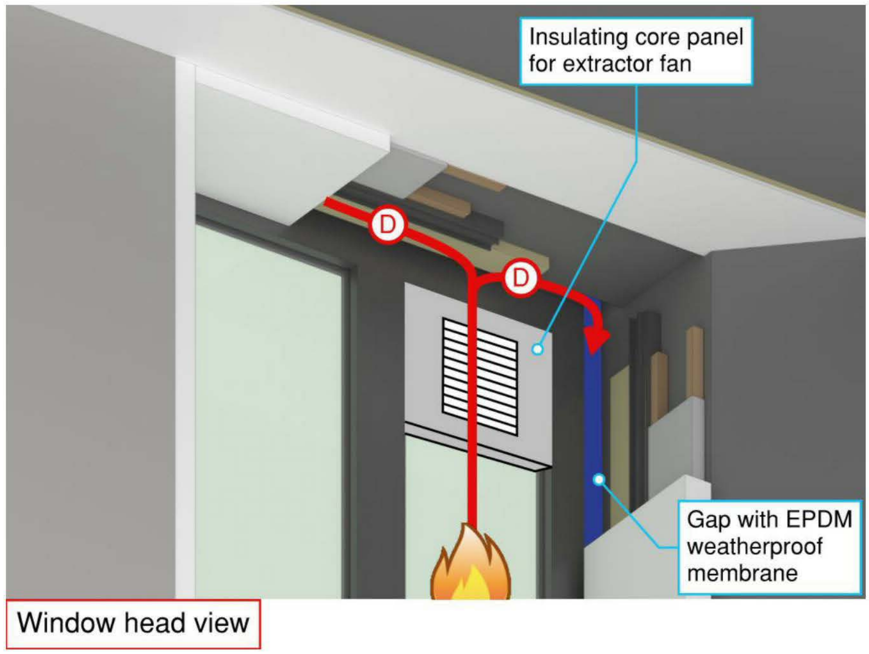
Table 9.1 Five fire scenarios and routes of fire spread through the window openings into the extensive external wall cavity

Fire Scenario	Route of fire spread through the window to the extensive external wall cavities
A A fire starts adjacent to the window jamb at the infill panel side of the window, it could spread into the cavity behind the window reveal and onwards into the external wall cavity via the new combustible insulating core panel. Fire source: Combustible flat contents stored/positioned on the window cill, or near the window jamb	

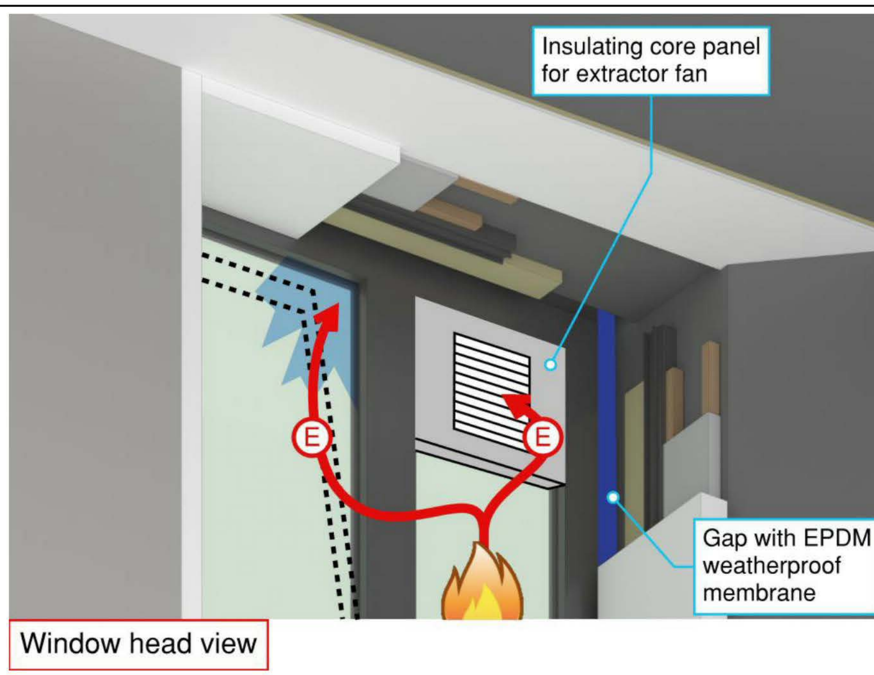
Fire Scenario	Route of fire spread through the window to the extensive external wall cavities
B A fire starts on the column side of the window, it could break through the window reveal lining there and into the external wall cavity via the gap at the window jamb which is sealed with a damp proof membrane only. Fire source: Combustible flat contents stored/positioned on the window cill or near the window jamb	 Window cill view
C A fire starts under or next to the window cill, it could break into the materials forming the window reveal there and spread through those materials into the external wall cavity. This could occur via the gap between the window cill and window jamb. And also via the gap into the insulating core panel cavity. Fire source: Combustible flat contents stored/positioned next to the window	 Window cill view

<table>
<tr><th>Fire Scenario</th><th>Route of fire spread through the window to the extensive external wall cavities</th></tr>
<tr><td>D

A fire could spread into the cavity at the head of the window, and onwards into the external wall cavity via the gap at the window jamb and via the insulating core panel.

Fire source: Ceiling jet from fire within the kitchen or from combustible flat contents positioned/stored next to window</td><td>
</td></tr>
<tr><td>E

A fire could break through the window frame via the insulating core panel which houses the extractor fan, or via broken or open glazing and into the external wall cavity above and adjacent.

Fire source: Ceiling jet from fire within the kitchen or from combustible flat contents positioned/stored next to window</td><td>
</td></tr>
</table>

9.3.6 I explain the following in detail below.

9.3.7 A) Internal localised fire beside the new insulating core panel side of the window

9.3.8 In Figure 9.11 I have illustrated the route of fire spread from a localised fire at or near the insulating core panel side of the window to the spandrel external wall cavity above. In this position radiative heat, hot gases or burning particles from the fire could impinge the vertical materials lining the window jamb. First the uPVC surface lining, then the 25mm combustible insulation affixed to the underside of the uPVC.

9.3.9 Once the fire is within the vertical cavity, it will directly impinge the new insulating core panel, which is comprised of a combustible extruded polystyrene core sandwiched between aluminium skins. Once the fire has spread to the insulating core panel, flames can impinge directly into the spandrel external wall cavity above and below.

9.3.10 Figure 9.11 shows the ACP cassette where it is folded in towards the insulating core panel, above the window.

9.3.11 Figure 9.12 shows the ACP cassette where it is folded in towards the insulating core panel, below the window at cill level.

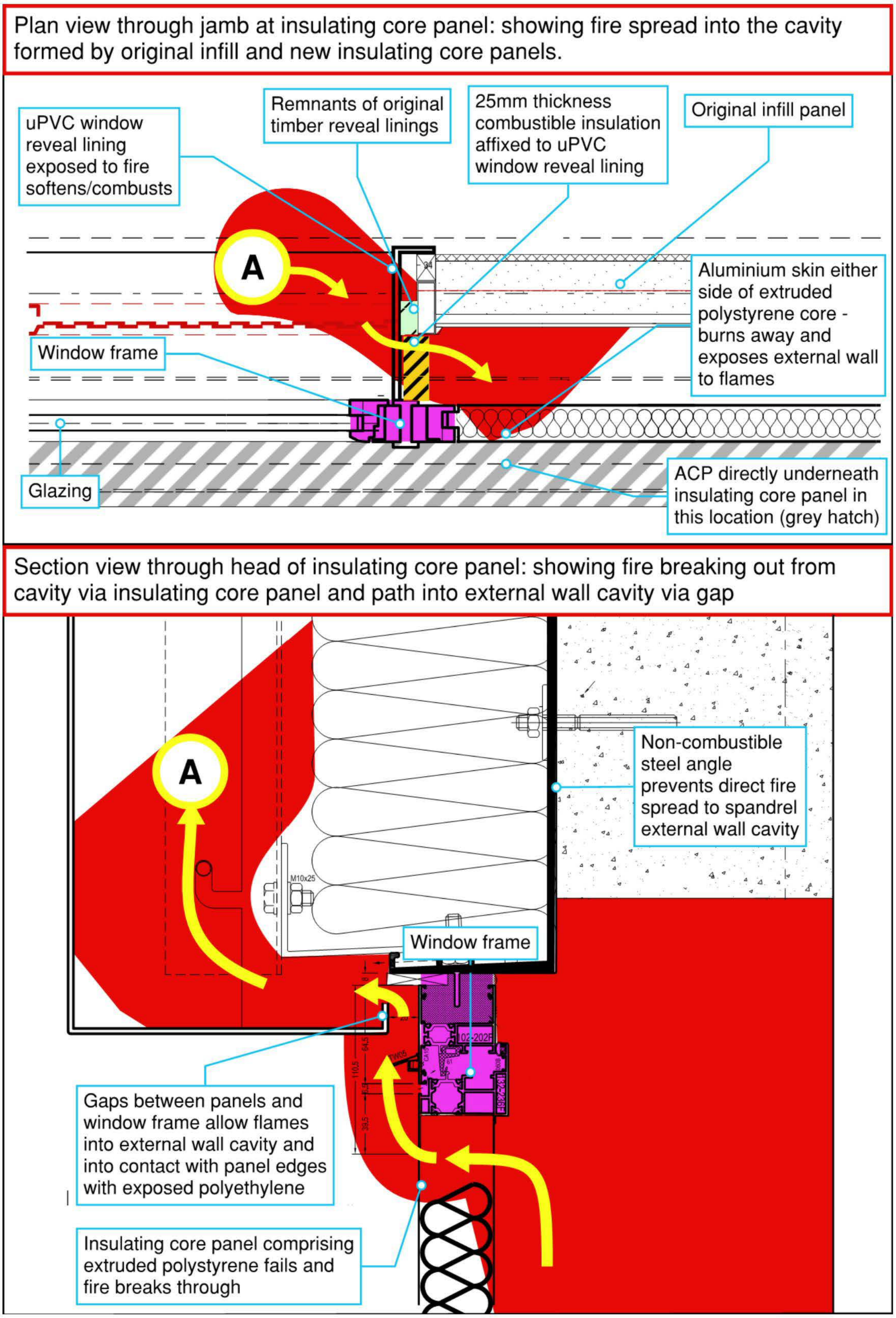


Figure 9.11: Diagram of route A (in two parts) originating from a localised fire on or adjacent to cill. (SEA00013045, HAR00008901).

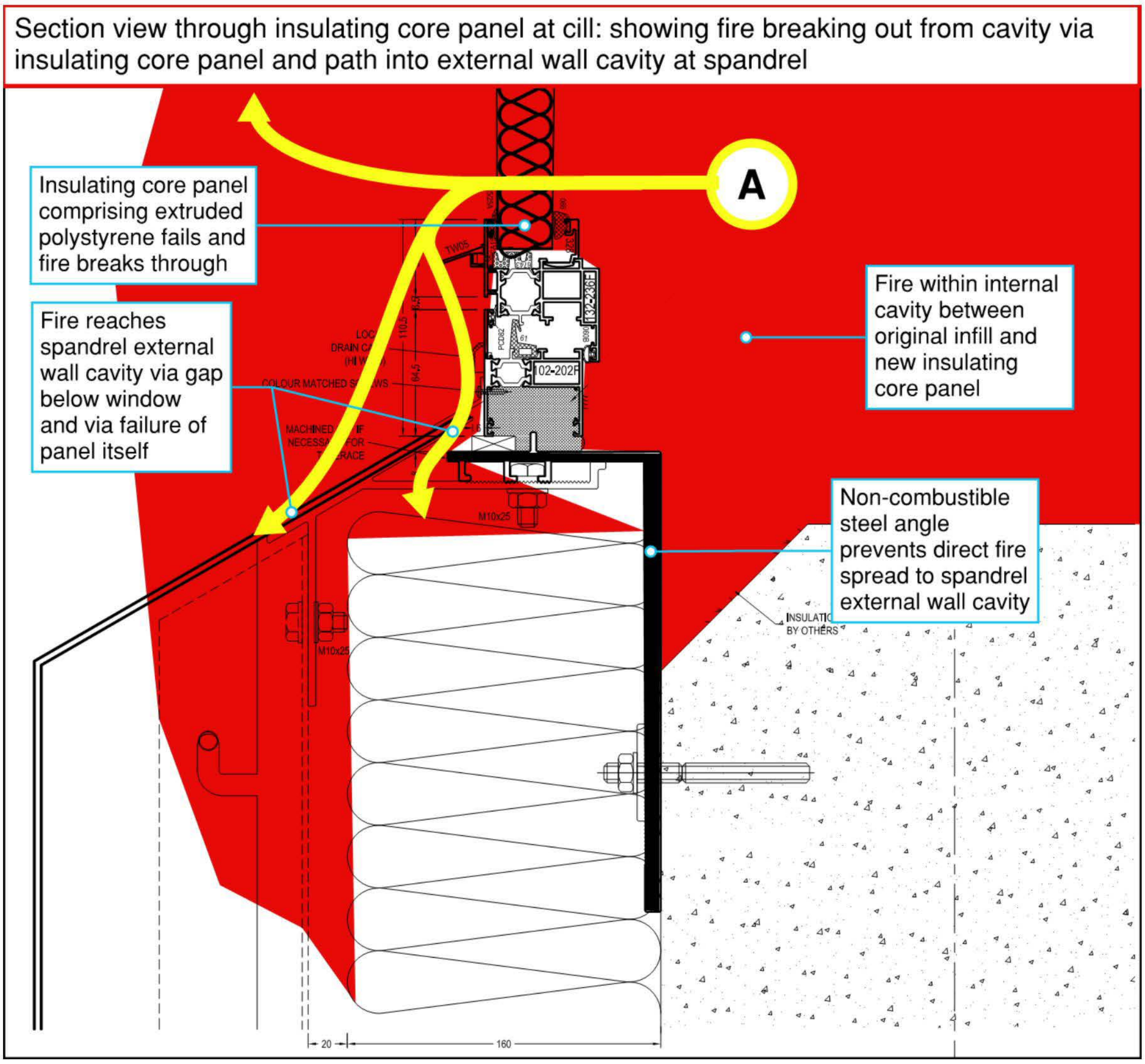


Figure 9.12: Diagram of route A also showing further route into external wall cavity on spandrel panel at cill of window (HAR00008879)

9.3.12 I have also included in Figure 9.13 an example of a heat affected vertical window lining beside the new insulating core panels which I observed onsite. In this photograph the uPVC window lining has softened and deformed to reveal the 25mm combustible insulation behind.

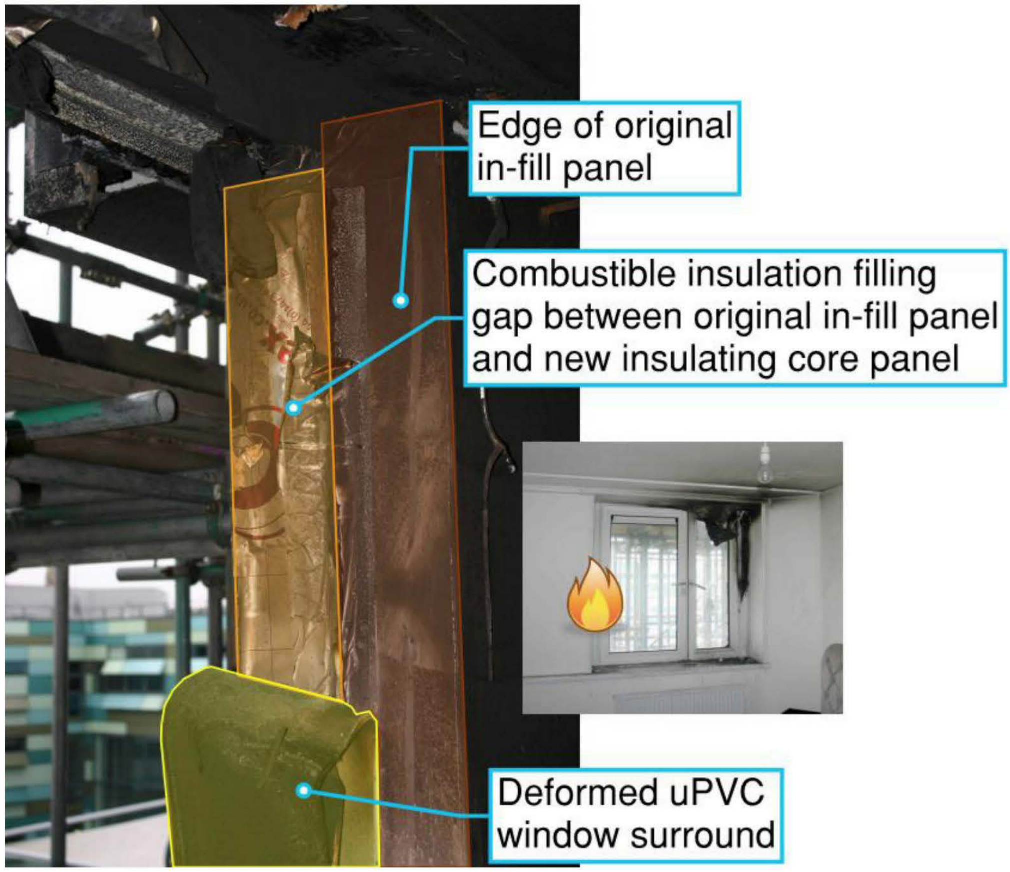


Figure 9.13: Fire on the infill panel side of the window (Flat 16 living room window) with example location inset

9.3.14 **B) Internal localised fire beside the column side of the window**

9.3.15 In Figure 9.14 I have illustrated the route of fire spread from a localised fire at or near the column side of the window and the external wall column cavity.

9.3.16 In this position, radiative heat, hot gases or burning particles from the fire could impinge on the vertical materials lining the window jamb. First the uPVC surface lining, then the 25mm combustible insulation affixed to the underside of the uPVC and the retained timber batons from the original window frames.

9.3.17 Once the fire is within the vertical cavity behind the window jamb it can spread directly to the column external wall cavity through the combustible EPDM weatherproof membrane'

Plan view through column/ jamb: showing fire spread into uPVC window reveal lining at window jamb, through EPDM directly into external wall cavity

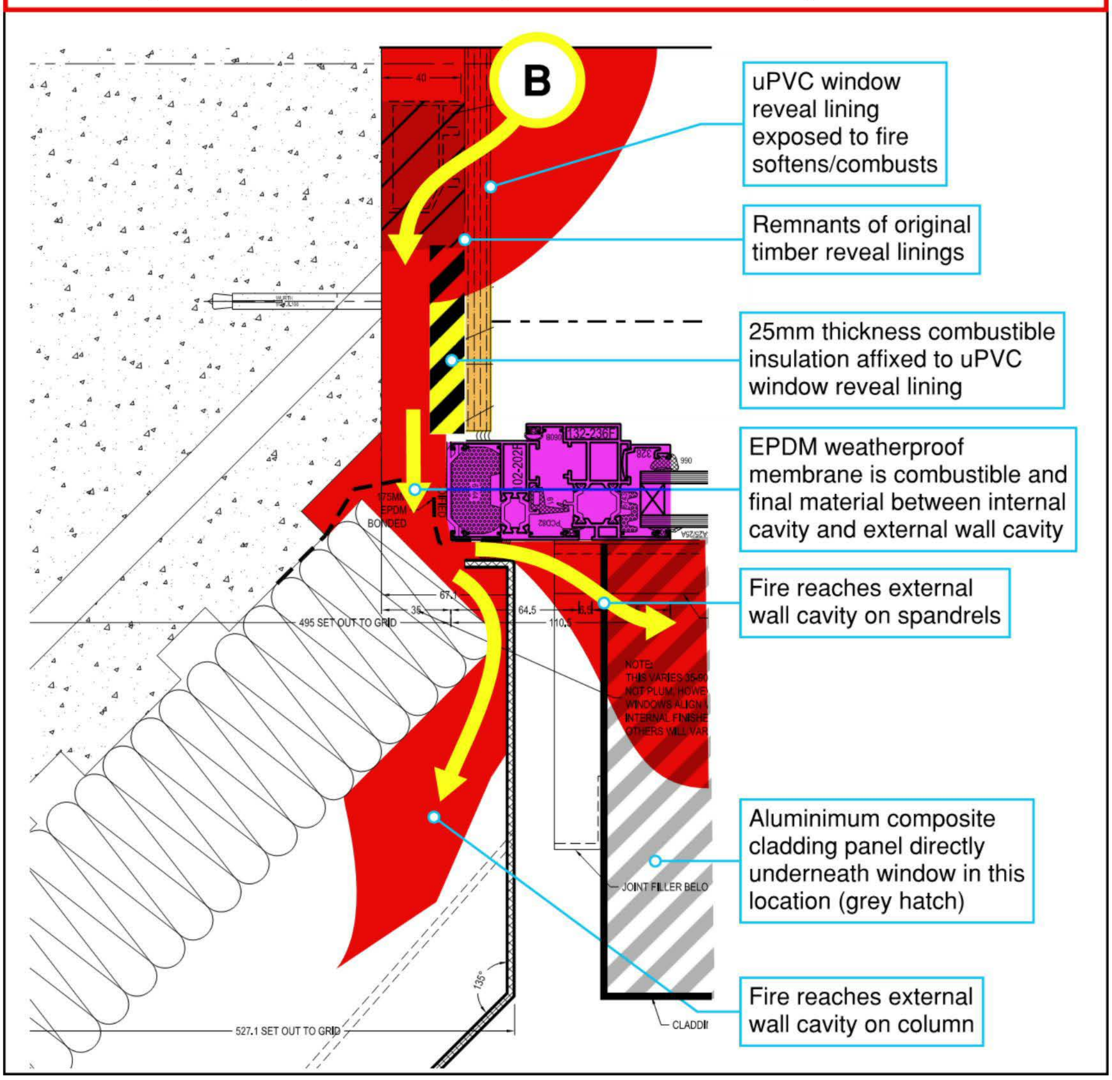


Figure 9.14: Diagram of route B originating from a localised fire adjacent to window jamb (HAR00008902).

9.3.18 **C) Internal localised fire under the window cill**

9.3.19 In Figure 9.15 I have provided a marked up drawing of the route of fire spread from a fire under or near the window cill into the column cavity of the external wall.

9.3.20 In this position radiative heat, hot gases and/or burning particles from the fire could impinge directly upon the combustible materials of the window cill. First the uPVC surface lining, then the 25mm combustible insulation affixed to the underside of the uPVC surface lining. Any gaps between the uPVC surface lining and horizontal wall would increase in size.

9.3.21 Once the fire is within the cill cavity, in order to spread to any of the external wall rainscreen cavities, it would need to first spread laterally as the cavity beneath the window cill is separated from the external wall cavity by a non-combustible steel shelf angle.

9.3.22 If the fire spread laterally along the cavity beneath the window cill towards the column it could then spread through the combustible EPDM to the column external wall cavity. (Figure 9.15)

9.3.23 If the fire spread laterally along the cavity beneath the window cill towards the insulating core panels it could then spread up the materials behind the window reveal lining at the jamb and directly impinge on the combustible lining filling the gap between to the XPS filled insulating core panel and original infill.

9.3.24 As per route A, once failure of the insulating core panel occurs the fire can spread into the external wall cavity on the spandrel above, and below. This route is illustrated in Figure 9.15.

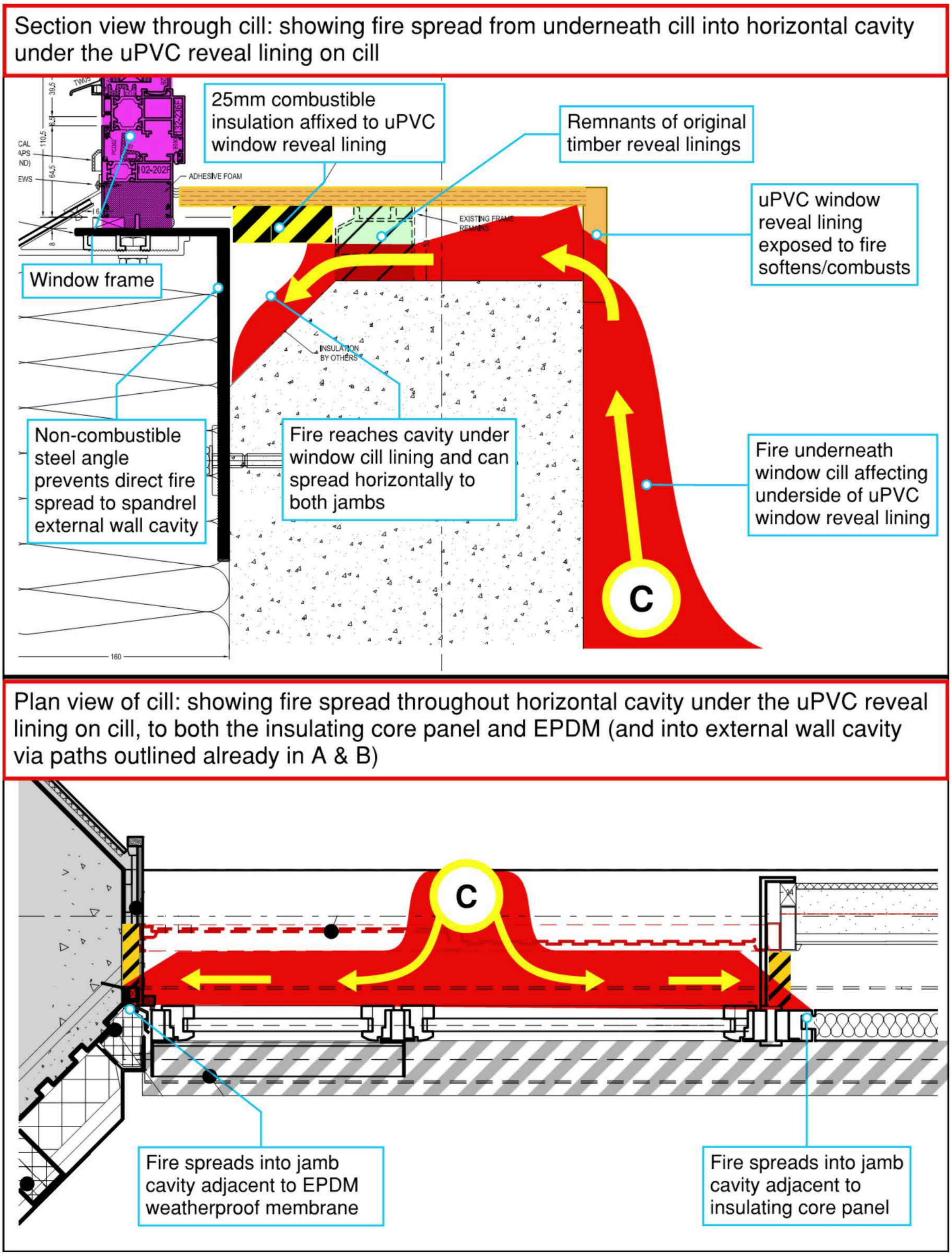


Figure 9.15: Diagram of route C (in two parts) originating from a localised fire underneath cill and spreading into cill internal cavity, with onward spread to behind both jambs and using the remainder of routes A & B to reach the external wall cavity (HAR00008879, SEA00013045).

9.3.25 **D) Fire at the head of the window**

9.3.26 In Figure 9.16 I have illustrated the route of fire spread where a localised fire is at or near the head of the window and travels to the column external wall cavity. In this position radiative heat, hot gases or burning particles from the fire could impinge on the horizontal materials lining the window jamb. First the uPVC surface lining, then the 25mm combustible insulation affixed to the underside of the uPVC.

9.3.27 Additionally, the original construction of the building included a section of "Purlboard" as a filler strip between the original head reveal lining and the concrete ceiling soffit. This material consists of a layer of plasterboard with a combustible fronting. This provides further combustible material, within the flat, that would promote rapid fire spread near the window head reveal lining.

9.3.28 As for a localised fire at or adjacent to the window cill, once a fire is within the window head cavity, it is separated from the external wall cavity by a non-combustible steel shelf angle. The fire must therefore spread laterally towards either the column or the new insulating core panels. Once the fire is in the head cavity it could spread laterally along the cavity until it reaches the EPDM weatherproof membrane at either the column jamb or the XPS filled insulating core panel located between the windows.

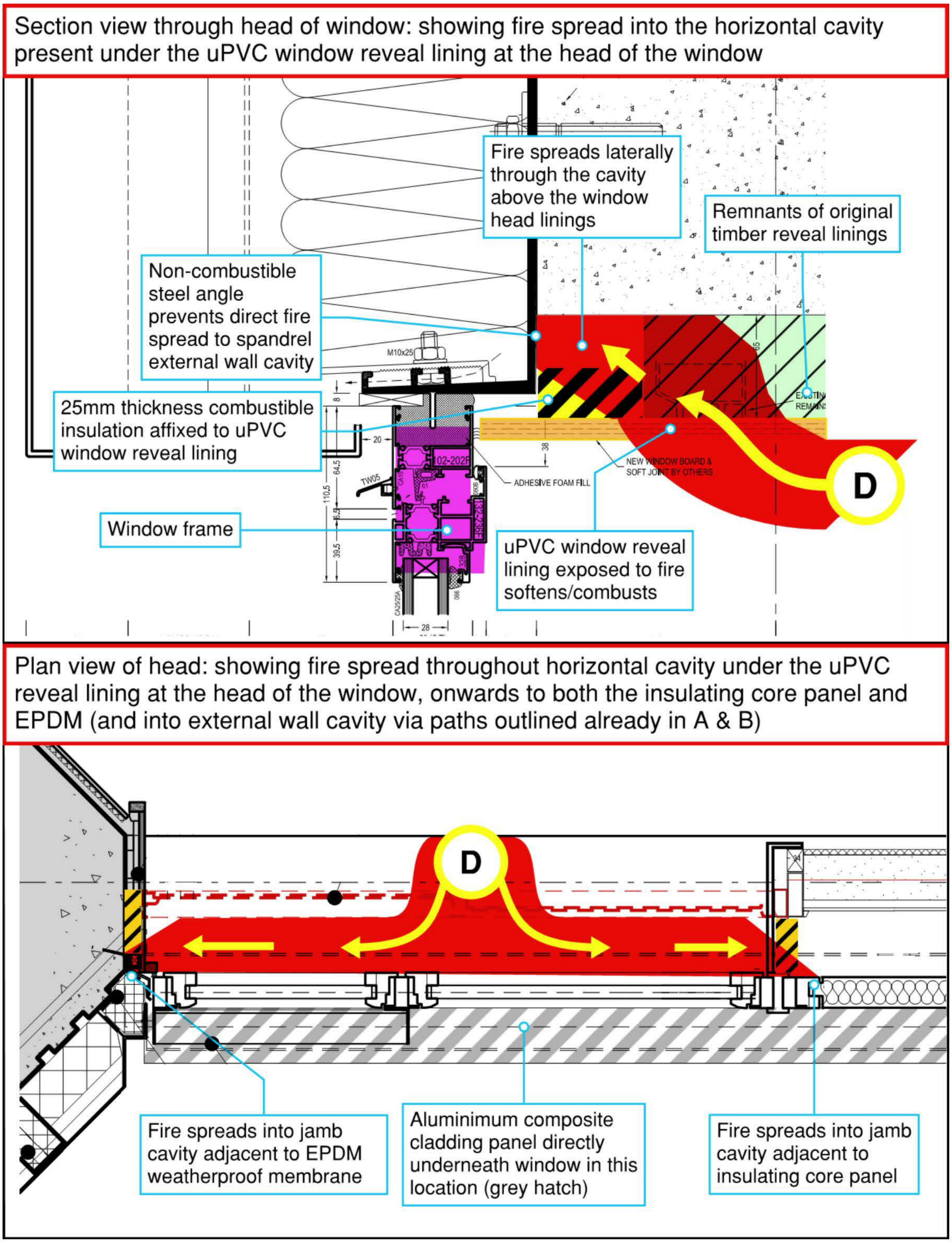


Figure 9.16: Diagram of route D (in two parts) originating from a localised fire on or adjacent to cill, or from a fire remote to window with ceiling plume. Onward spread to behind both jambs and using the remainder of routes A & B to reach the external wall cavity. (HAR00008901, SEA00013045).

9.3.29 **E) Fire on or near window cill affecting window directly**

9.3.30 An internal fire may also affect the window itself directly, this provides a further route of fire spread from the flat interior via the widow openings to the external wall cavities.

9.3.31 As displayed in Figure 9.17 there are three ways a fire could break out of the flat via the window directly:

a) Via the combustible insulating core panel in the window that houses the ventilation fan for the kitchen;

b) Via an open window;

c) Via broken glazing in the window.

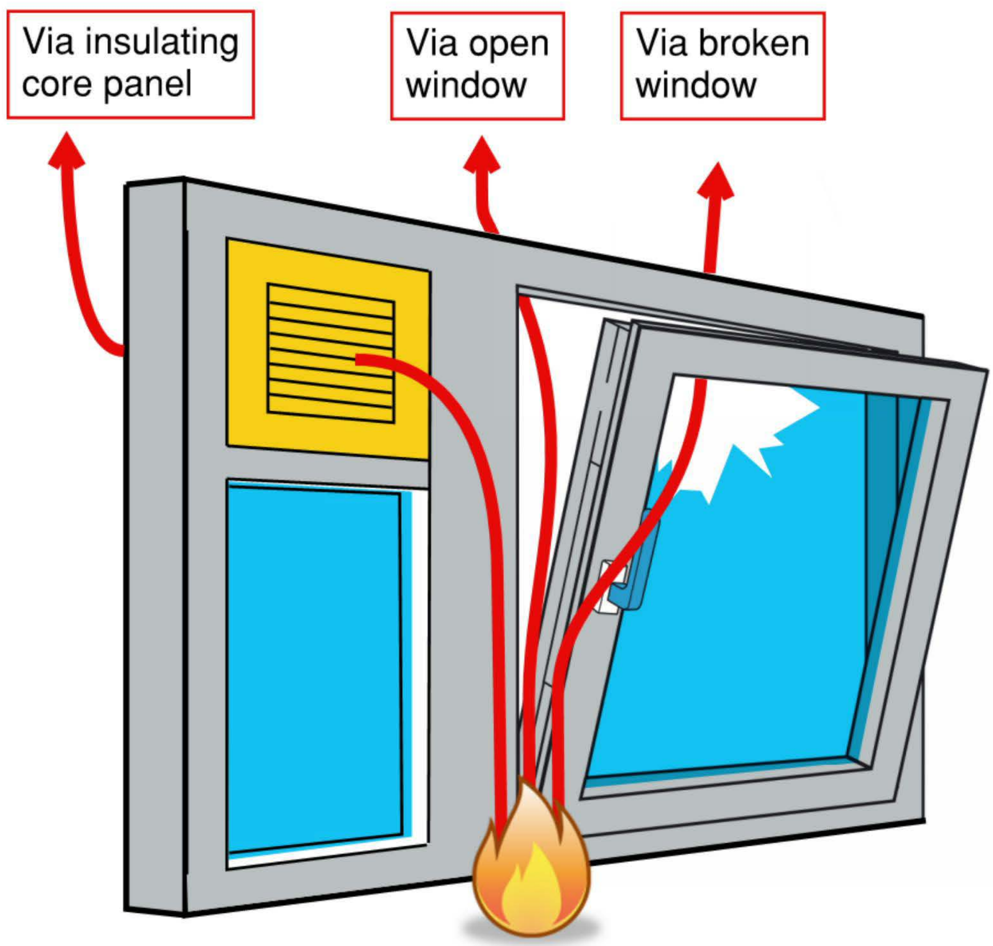


Figure 9.17: Routes for fire spread directly through a window

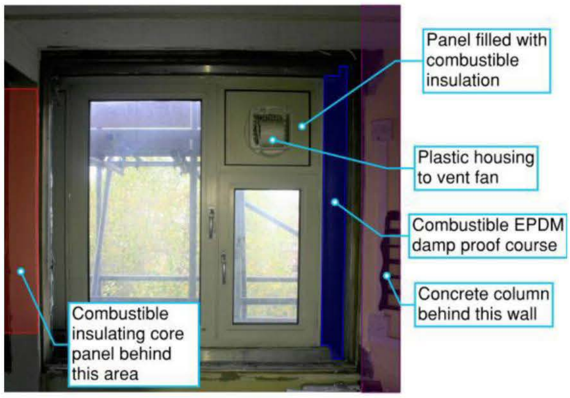


Figure 9.18: (a) Example kitchen window from Flat 13, (b) Evidence of window insert construction

9.3.32 Once flames from the fire are able to penetrate the window by any one of the three scenarios described above, the heat and smoke from the fire could impinge directly on the ACP overcladding on the vertical column and also on the ACP overcladding located above and below the window. Flames can enter both the horizontal and vertical rainscreen cavities through ventilation gaps between the aluminium composite rainscreen panels (Figure 9.22) and also cause ignition of the exposed PE core, shown in Figure 9.19.

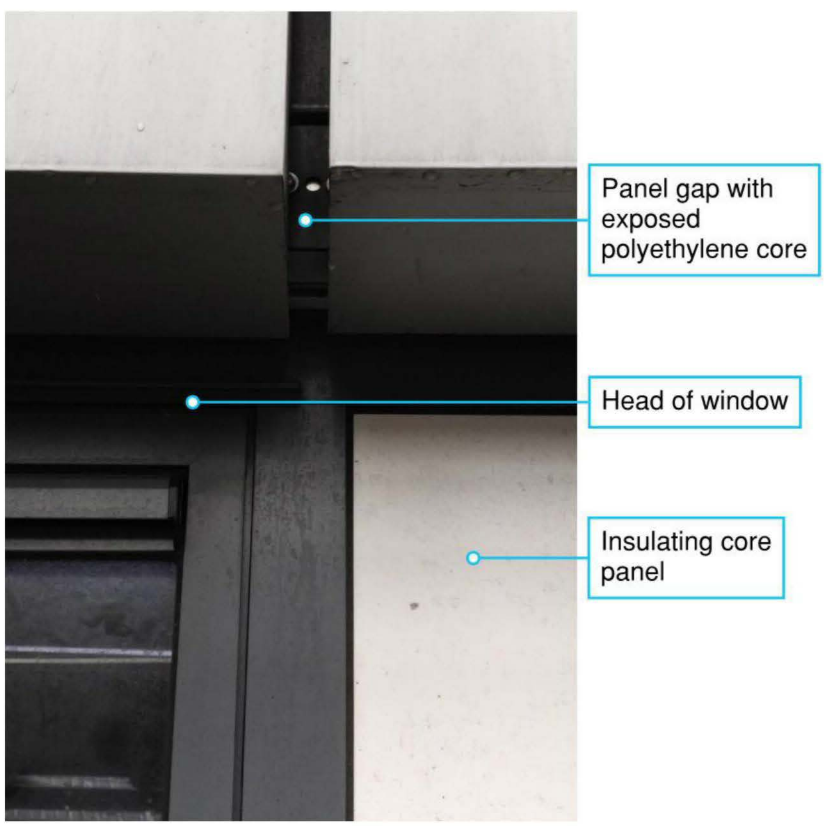


Figure 9.19: External wall photograph showing proximity of panel gaps to window and insulating core panel

9.3.33 The polyethylene core was exposed along the sides of the panels in this location, as indicated by Figure 9.20. My onsite observations confirm it was exposed and also that it had melted, as shown in Figure 9.21:

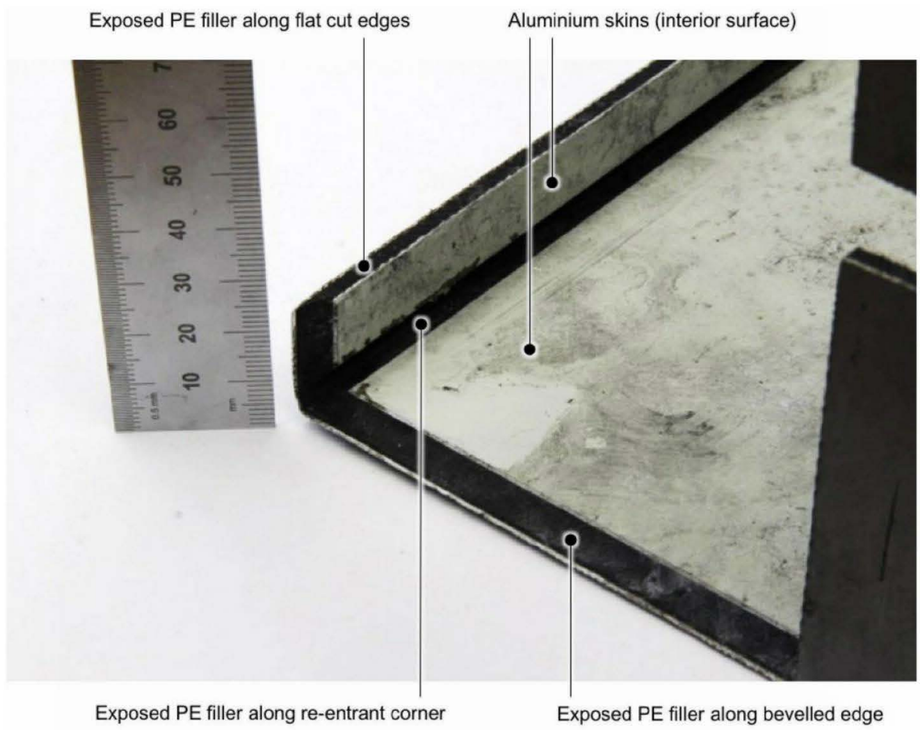


Figure 9.20: Prof. Bisby's phase 1 report, figure 20 showing photograph of spandrel cladding panel sample provided by MPS

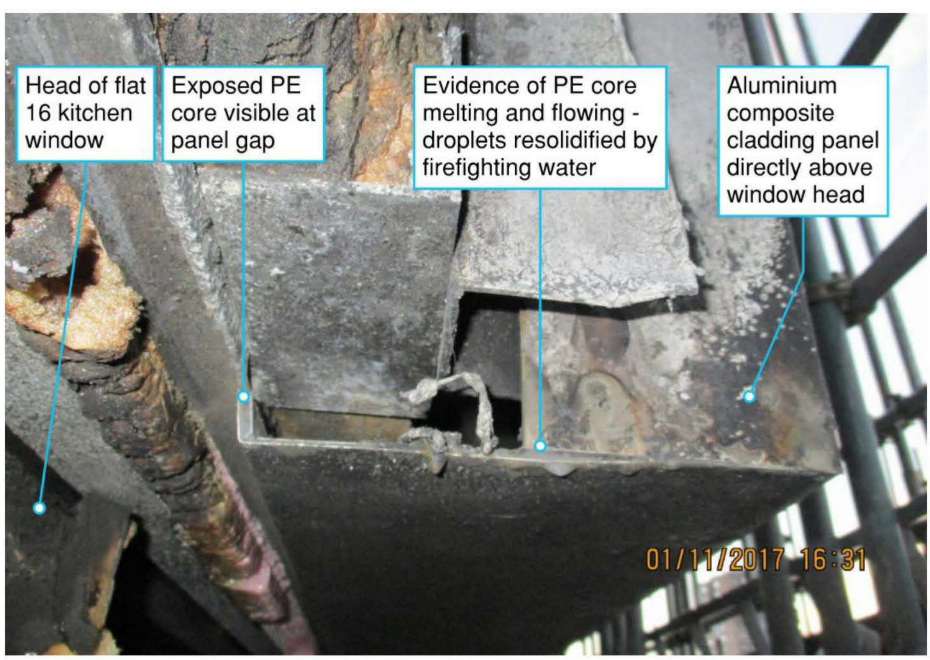


Figure 9.21: Photograph of cladding panel directly above flat 16 kitchen window

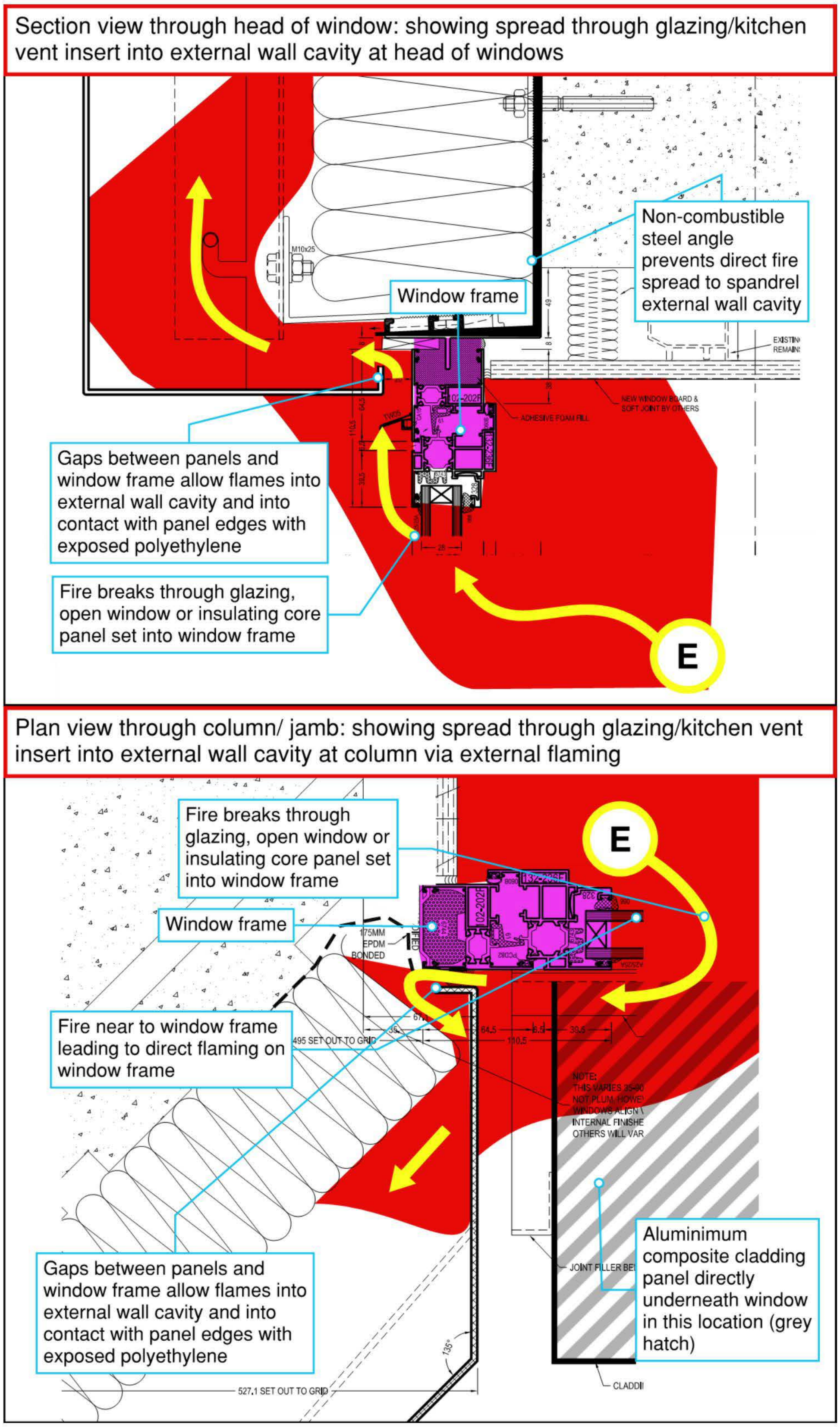


Figure 9.22: Diagram of route E originating from a localised fire on or adjacent to cill, or from a fire remote to window with ceiling plume. External flaming resulting

in fire spread to the external wall cavity at both the column (above) and the head of the window (below) (HAR00008901, HAR00008902).

9.4 Routes for fire spread from the external wall construction into the interior of flats

9.4.1 These same routes also provide a route for fire spread from the exterior of the building back into the interior.

9.4.2 In the following sections, I describe the ways in which an external fire scenario created by the building envelope could pass back into the building.

9.4.3 In Section 10, I have identified 6 external pathways of fire spread around the external wall (A-F); five of these interact with the window construction directly.

9.4.4 The following sections are aligned with those pathways. External fire spread Pathway F is not addressed here as it involves the crown construction only, nevertheless there is evidence of burning material from the crown construction dripping down onto Level 23 and then causing any of the routes presented (A-E) in this section to break back into the flat.

9.4.5 **Pathway A – Vertically along the columns**

9.4.6 As I have explained in Section 5 of my report, there was rapid flame spread observed up the columns of Grenfell Tower on the 14th June 2017. Figure 9.23 is replicated from Section 5 to visualise this spread.

9.4.7 The horizontal section diagram through the column-window jamb featured in Figure 9.14 (route B) shows the same route, which allows the fire to break back into the flat by reversing the direction of the arrows. In the event of a fire in the building envelope around a column, the only material separating the interior of the flat from the façade cavity is a thin layer of combustible EPDM (behind the window reveal lining).

9.4.8 A fire in the cavity would be able to ignite and penetrate this layer, allowing the fire access to the combustible materials of the window reveal lining inside the flat. This includes the uPVC window reveal linings on the jamb, cill and head of the window, the combustible insulation in the cavity underneath the reveal linings, and the original timber window reveal linings left in place underneath the new uPVC reveal linings.

9.4.9 The photograph in Figure 9.29, discussed in Section 9.5.1, illustrates that this was a feasible route for fire spread into the flat.

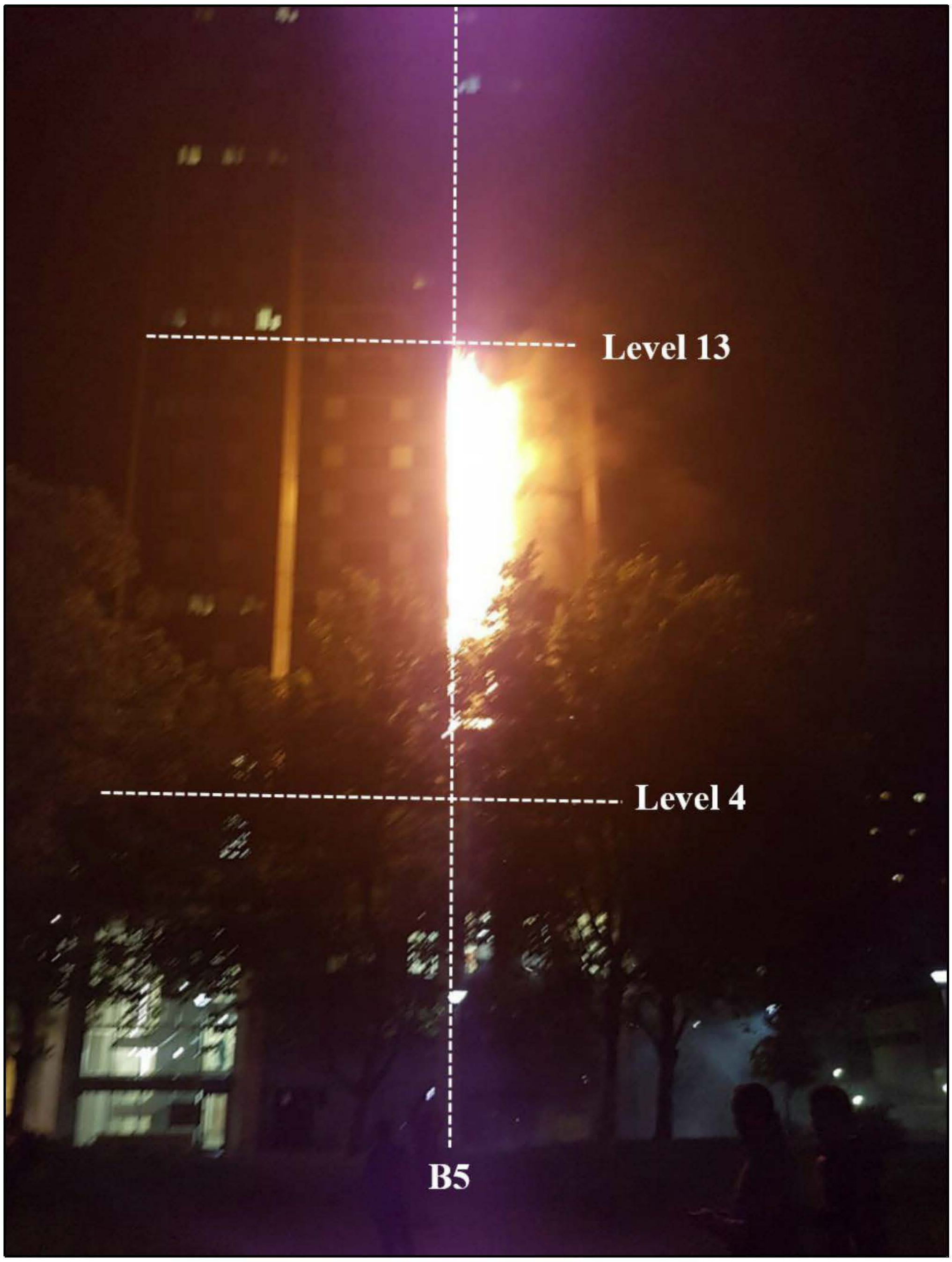


Figure 9.23: Evidence of flame spread up column at 01:22 (approx)[1]

9.4.10 Pathway B - Fire spread along the spandrels above and below the windows

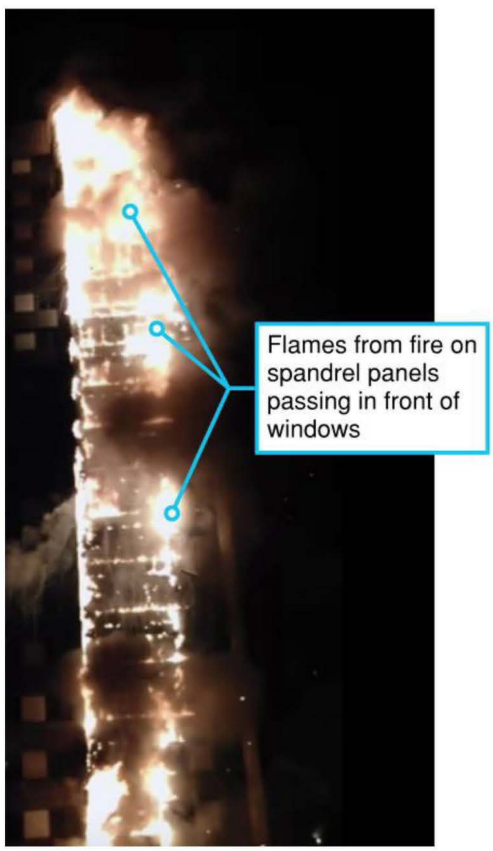
9.4.11 Figure 9.24 presents evidence from the fire on the 14th June 2017 and shows that flames coming from burning spandrel panels were able to engulf some or all of the windows directly above.

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

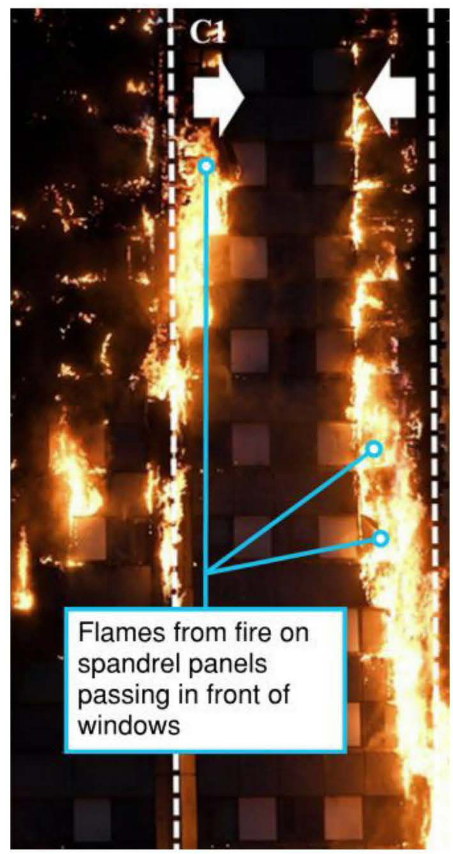
9.4.12 Before any failure of glazing, the combustible materials outlined previously in this report (purlboard, uPVC window reveal linings) within the flat, as well as any contents of the room, could be exposed to intense radiated heat through the glazing. This could lead to auto-ignition of these materials without the need for direct flame impingement.

9.4.13 Additionally, the insulated core panel housing the extractor fan would be in direct contact with flames, and after any failure of glazing, all three routes through the window itself outlined in section 10 could act in reverse.

9.4.14 As above, the combustible materials lining the window reveals, as well as any room contents within the flat, would then be exposed to direct flame contact permitting conditions where piloted ignition could occur.



a) East façade at 01:29 (approx.)[2]



b) West façade at 04:25 (approx)[3]

Figure 9.24: Evidence of fires from spandrels causing flame fronts in front of windows

[2] https://www.youtube.com/watch?v=AKTsQxbvXiU

[3] 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]

9.4.15 Pathway C, Pathway D and Pathway E– Horizontal and vertical spread via the aluminium composite cladding panels, and via the insulating core panels

9.4.16 Figure 9.25 below, presents evidence from the fire on the 14th June 2017 of horizontal fire spread along the head and cills of the windows.

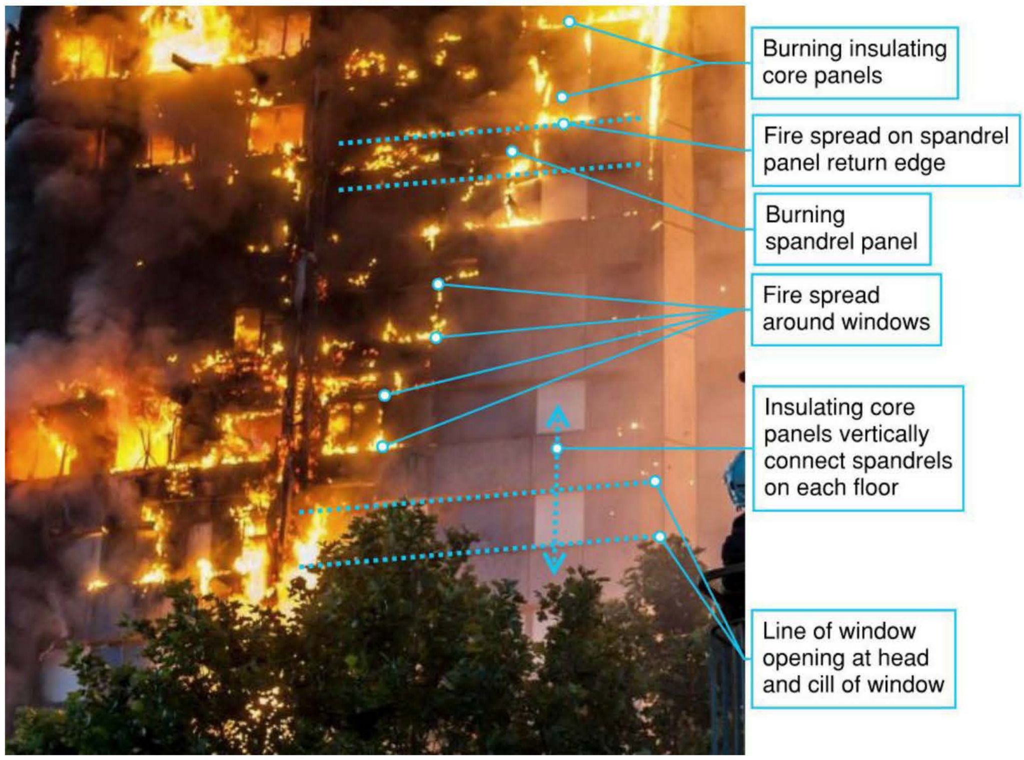


Figure 9.25: Example of Pathway C (replicated from Section 10)[4]

9.4.17 Figure 9.26 below presents evidence of vertical fire spread via the infill insulating core panels and the combustible insulation between the insulating core panel and the window jambs.

[4] 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]

Figure 9.26: Photo evidence of vertical fire spread at the junction between the insulating core panels and windows[5]

9.4.18 What this also means is that the insulating core panel (extruded polystyrene core sandwiched between aluminium skin) is the only material separating the external flames from the spandrel cladding panels and from extending into the network of internal cavities (see Figure 9.25 below).

9.4.19 It also provides a route of fire spread back into the flats.

5 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]

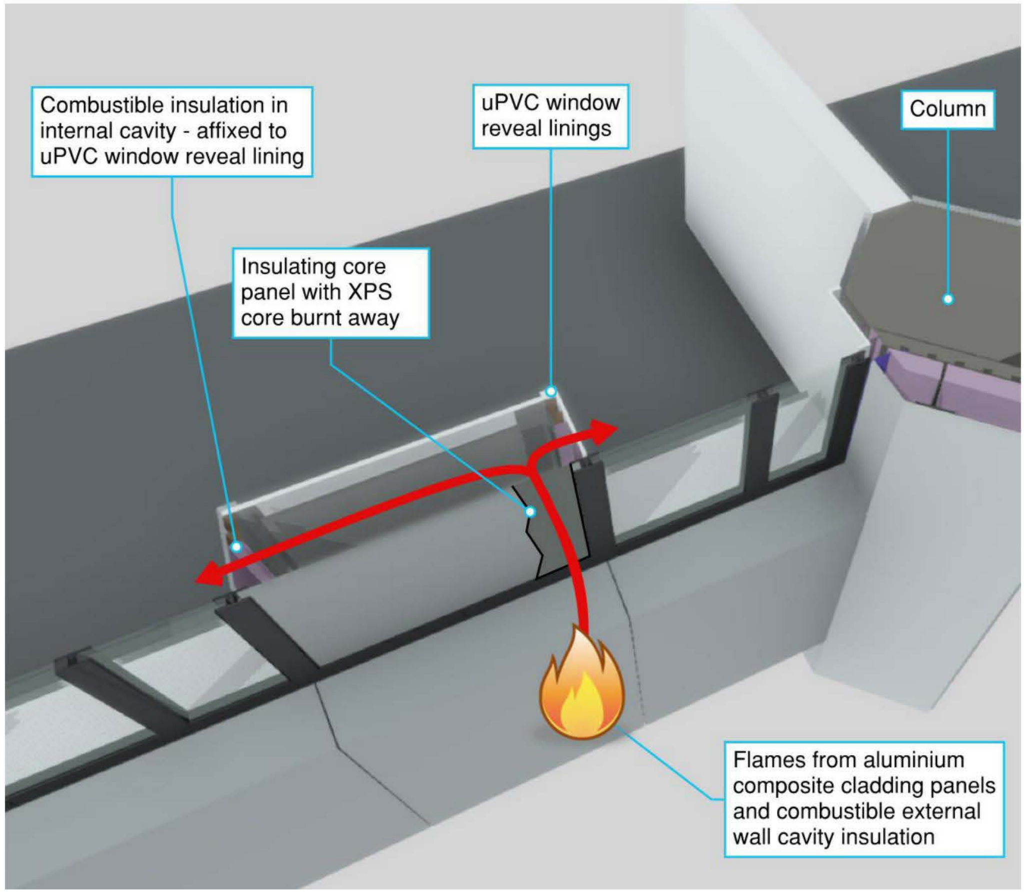


Figure 9.27: 3D model indicating routes of fire spread into flats via combustible seal either side of the new Styrofoam XPS insulating core panels, or via a failed panel itself.

9.5 Physical evidence of fire spread via a window route

9.5.1 Evidence from post fire inspection on 7th to 9th November 2017

9.5.2 In my inspection of Flat 15 on Level 4 (Figure 9.28), I observed that there was a window exhibiting evidence of fire spread from outside the building to the inside, shown in Figure 9.29. The evidence of fire spread showed that the entry route for the fire was in the top corner of the window, adjacent to the column, consistent with the mechanism of fire spread presented in Section 9.4. That is a fire being able to penetrate from outside the building, into the cavity behind the new uPVC reveal linings via the EPDM weatherproof membrane (route B).

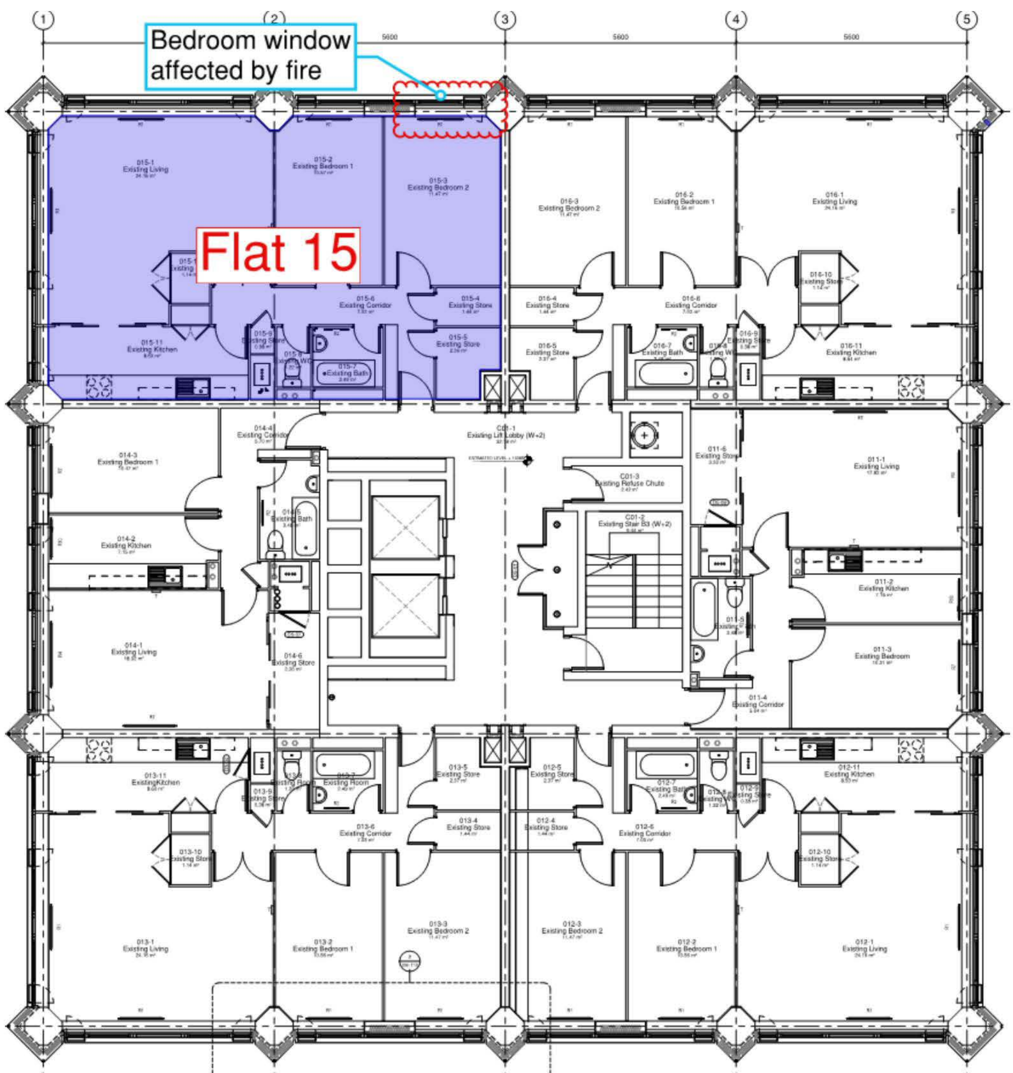


Figure 9.28: Marked up Studio E drawing indicating location of Flat 15, and the window shown in Figure 9.29 (Based on SEA00010474)

Figure 9.29: Fire spreading into flat from outside (Flat 15 bedroom)

9.5.3 Resident evidence featuring details of fire spread through windows

9.5.4 Maria de Fatima Alves, who was outside Grenfell Tower, saw the moment the kitchen window of Flat 16 failed (3rd October 2018, Transcript page 119), representing evidence of the route via glazing failure (route E):

"There was a sudden flash like lightning. I saw window explode and the glass shatter. I saw flames shoot out of the window. It was coming out and burning on to the outside cladding about three feet high. This must have been around 01:15am"

9.5.5 Jose Vieiro of flat 46 on the 7th floor gave the following evidence which describes route E to the Inquiry on the 17th October 2018 (Transcript pages 129-132):

"Q. Could you see anything else burning around the window at that time?
A. The first thing I noticed burning was the extractor. That's the one -- it put the fire on the curtains
…
Q. Okay. Did you see any flames around the edges of the windows?
A. No, the flames first came through the fan, the hole where the fan was."

9.5.6 On page 130-131 of the Transcript, he then describes what happened next:

"Q. Is that the only place at that time where fire was coming in?
A. At the beginning, it was the only place. Then it start to come through the left side of the window.
Q. The left side of the window?
A. Yes.
Q. At the bottom of the window or the side or the top?
A. All the left side.
Q. The whole of the left side?
A. But more towards the top than the bottom.
…
Q. It stay put, okay. Did you see what had caused the window on the left side to cave in in that way?

A. No, I assume it was the fire, that it was covered in it.
Q. Could you see what was happening to the windowsill?
A. The windowsill, it start to melt, top and left side first and then all around the window and the sill down.
Q. Once it started to melt, did it start to drip and pull away? Did it start to melt away from the window?
A. Yes, it was completely separated. Only the skeleton of the window stays there, the rest was melting"

9.5.7 Flat 46 has the same configuration of the kitchen window as flat 16, and Figure 9.18, thus the 'left hand side' of the window is the side opposite the column and kitchen vent insulating core panel. This therefore represents evidence in support of route A, fire spreading via the window reveal lining covering the cavity between the infill panel and insulating core panel.

9.5.8 His evidence also describes the uPVC window reveal linings softening and providing a path for fire spread between the inside of the flats and the cavities around the window reveals.

9.5.9 Shantilal Patel of Flat 56 on level 8 in his witness statement provides his own account of fire spread via the kitchen vent insulating core panel (route E):

11. My windows were all closed that night. I went across to the kitchen window and noticed that light smoke was coming through the vent in the window. At first it was a grey colour and not that dense. As I watched the flames suddenly shot up covering the whole of the window and also the middle window.

12. Heavier smoke started coming into the kitchen through the vent and I realised that the fire was just underneath our flat. Even then though, I thought that the flames would not make it into the flat.

13. I moved closer to the window and thought for a moment that I could possibly block the vent and stop the smoke from coming in. I looked down out of the window and I think the people watching from down below could see me and they were waving to warn or alert me, but I am not sure. I quickly realised it was not going to be possible to block the vent and so I moved back, out of the room and into the passage. As I watched the vent simply fell into the kitchen and thick black smoke started to pour in to the flat. The extractor fan was made from ordinary plastic, and it just melted under the heat. The smoke that came in was very dense and was coming in through the gap where the vent had been very quickly, as if it was shooting in from a hose. It quickly filled the kitchen and moved across the room. I was terrified. That was when I realised how serious it was and that we had to get out immediately, and I ran back to tell my wife and Chiraag that we had to leave.

Figure 9.30: Witness statement of Shantilal Patel (IWS0000798)

9.5.10 Nadia Jafari of Flat 86 describes in her witness evidence (Figure 9.31) and oral evidence (8th October 2018 Transcript page 25,) how the fire spread from the external wall through the insulating core panel housing the kitchen extraction vent and through the glazing itself (route E):

17. When my father was in the toilet, I noticed the fire was getting higher. While I was standing near the kitchen window waiting for my father, the fire reached our flat. The fire came through the small circular vent at the top of the window. I picked up some rugs and I threw them into Maria's room and I shut the door. I moved my mother's iPad from the window sill. I thought things would be fine if I just moved them away from the window.

18. I noticed the wires started to burn near to the fan in the kitchen window. I knocked on the toilet door and told my father that the fire was in the kitchen. My father came out quickly, and as he looked round the door, the glass in the kitchen window smashed from the fire and the flames then covered the entire window area. The whole window in the kitchen broke in two. The vent completely collapsed. I saw the glass break and the fire come through as I was standing there. The plastic around the window was burning. Before, the windows had wooden frames or edges, and when they fitted the

Figure 9.31: Witness evidence of Nadia Jafari, Flat 86 (IWS00000683)

9.5.11 Shahid Ahmed similarly describes how fire spread through his kitchen window, due to failure of the glazing itself (route E):

33. On the Tuesday evening before the fire (13 June) it was a normal night for me. We went to bed around 11.30pm but I couldn't really sleep. I must have fallen asleep but it wasn't a very deep sleep. I think our bedroom door was slightly open that night because it was hot. My kitchen window was open too and the smoke must have come in which is why the smoke alarms went off. All of a sudden all of my smoke alarms went off at the same time. As set out above I had one carbon monoxide alarm in the kitchen, a smoke alarm in the living room, and two smoke alarms in the hallway including one directly above my front door. The alarm was very loud. I got up but didn't see any smoke until I went into the kitchen. As soon as I got to the kitchen and looked down out of the window I saw a big fireball coming up from the outside of the building. It was the colour of a burning sunset. I initially thought it must have been a fire in the flat below. The kitchen window then exploded inwards. I was lucky I wasn't close to the window. I dialled 999 on the

Figure 9.32: Witness evidence of Shahid Ahmed (IWS00000388)

9.5.12 Antonio Roncolato when providing explanations about the photographs he submitted in his witness statement (IWS00001109) states that smoke came through the bottom of the window in his living room at around 02:30 on 14th June. This is further evidence of the interconnected network of cavities that allowed smoke to proliferate and then ultimately supported fire spread (routes C and D).

9.5.12.1 Submitted videos and LFB thermal imaging evidence from routes for fire spread in flat 16 specifically

9.5.13 The following images are stills extracted from videos taken by the resident of Flat 16 on his mobile phone and a photograph submitted to the inquiry by a witness (MET000083356, MET000083357 and IWS00000051). Whilst the precise time of the videos is not known, the file name would suggest that the videos were taken at approximately 01:08 and 01:09 respectively. The precise time will depend on the accuracy of the timings on the mobile phone. The footage has been shot from the direction indicated in Figure 9.33. The photograph in Figure 9.35 is estimated to have been taken at 01:08.

9.5.14 Figure 9.34, Figure 9.35 and Figure 9.36 show how flames are present at the head of the Flat 16 kitchen window.

9.5.15 Additionally, Figure 9.35 identifies that burning droplets began falling outside the building at around 01:08.

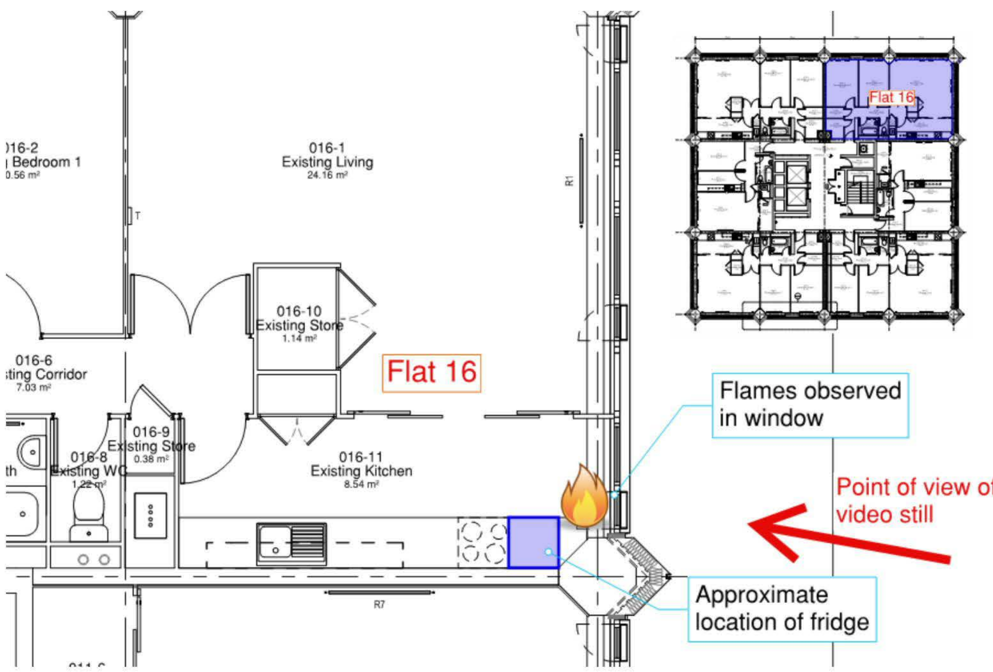


Figure 9.33: Marked up Studio E drawing indicating location and orientation of resident camera footage (Based on SEA00010474)

Figure 9.34: Still No.1 from video footage - (MET000083356)

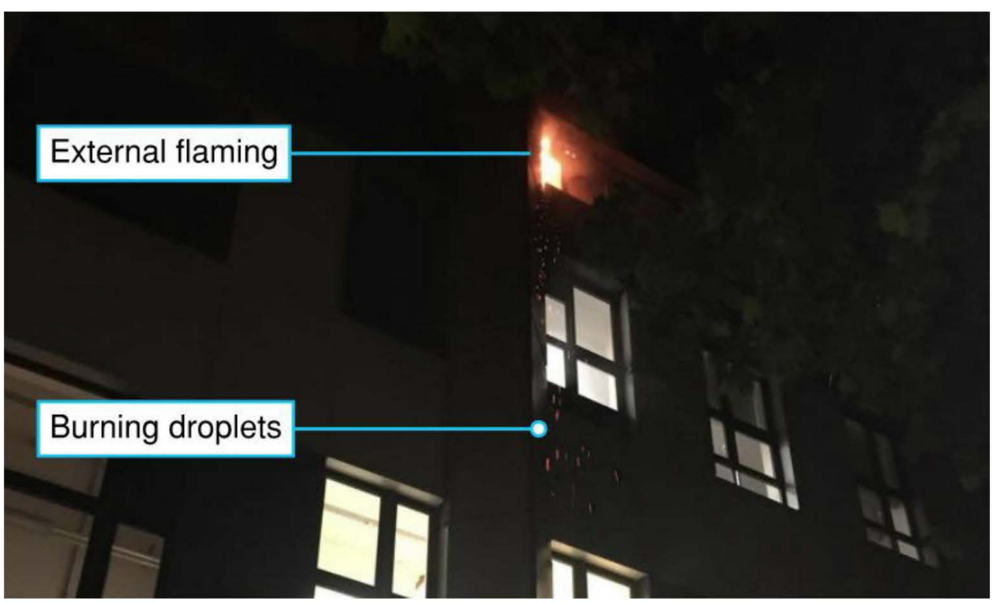


Figure 9.35: Photograph at 01:08 submitted by witness (IWS00000051)

Figure 9.36: Still No.2 from video footage – (MET000083357)

9.5.16 Figure 9.37 is a video still from LFB thermal imaging footage of the first fire fighters entering the kitchen in Flat 16 (MET00006109). This footage is taken at approximately 01:14 and also identifies flames at the top corner of the window, behind the side of the fridge freezer (please refer to Professor Niamh Nic Daeid's report regarding the Flat 16 kitchen and the fire), and in the region near the fan insert.

9.5.17 The LFB footage does not indicate that a post flashover fire had occurred at that time (01:14). It is clearly a localised fire beside the window opening only.

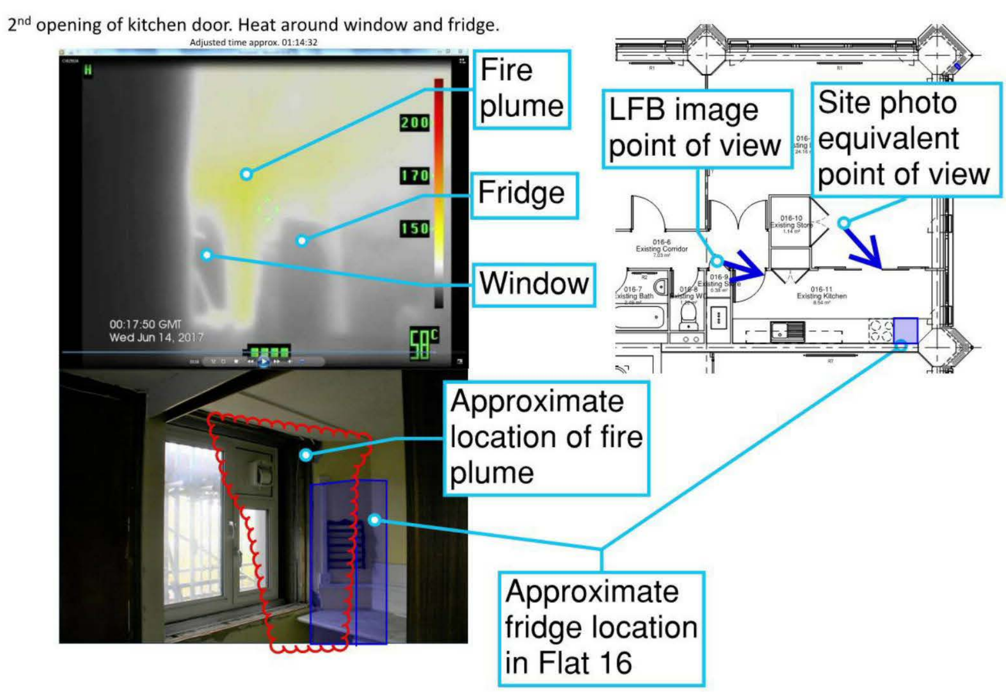


Figure 9.37: LFB thermal imaging camera footage - 01:14 (MPS document JRB TIC 01, MET00006109) above a marked up site photograph of Flat 13, where the kitchen

window position is equivalent to that of Flat 16. (Plan sketch based on SEA00010474)

9.5.18 Figure 9.38 shows the extent of the area that was subjected to the hot plume observed within the flat 16 thermal imaging camera footage. This therefore also shows the extent of materials that were exposed to the heating from the initial fire, and the possible routes available for fire spread into the external wall cavity.

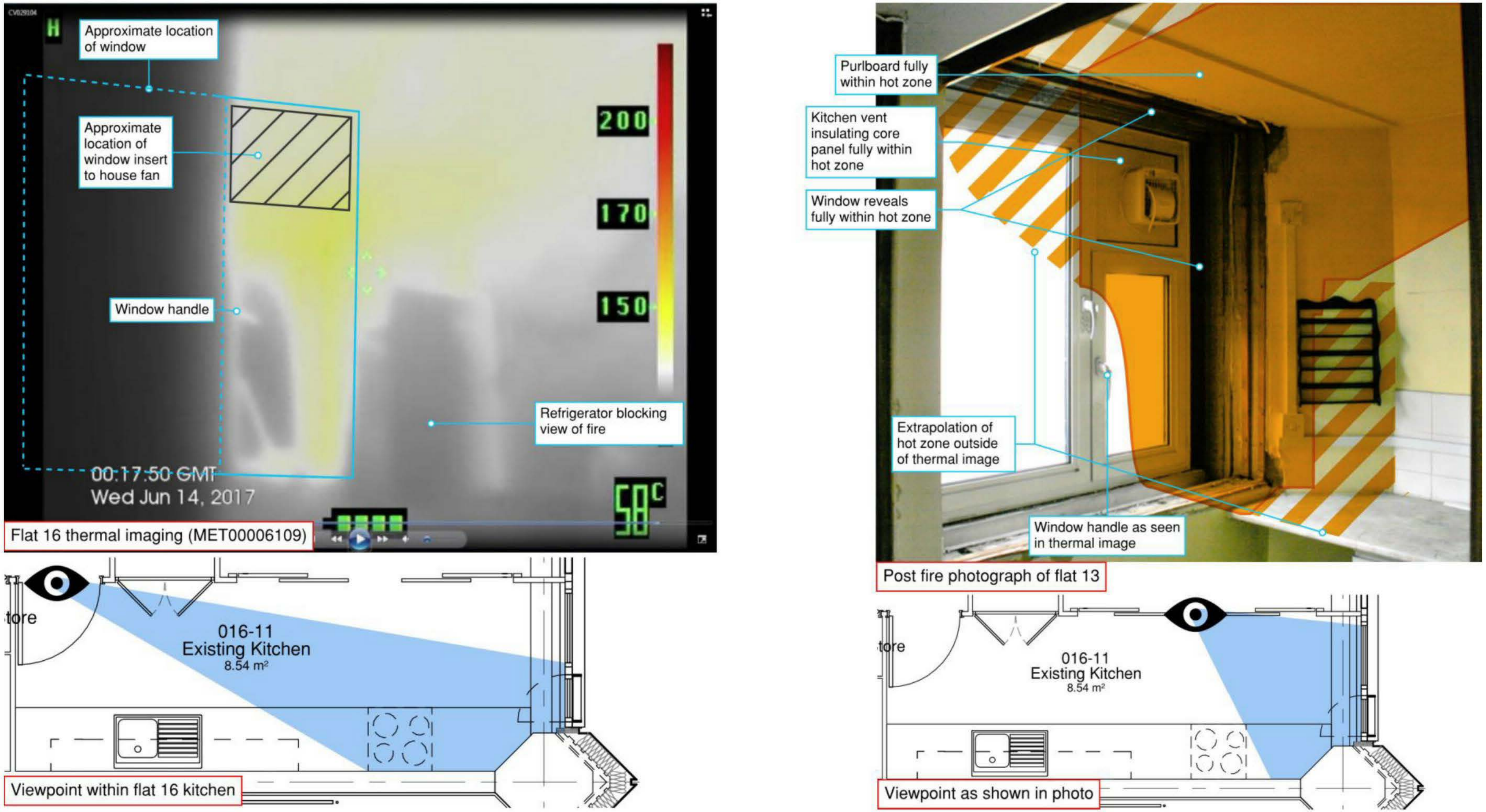


Figure 9.38: Comparison figure of the area exposed to the hot fire plume observed in thermal imaging from flat 16 (plans: SEA00010474)

9.5.19 Therefore, using Figure 9.38, the exposure from the hot zone could lead to the fire reaching the external wall cavity **by either routes B (via jamb/EPDM), or E (directly through the window glazing/kitchen vent panel):**

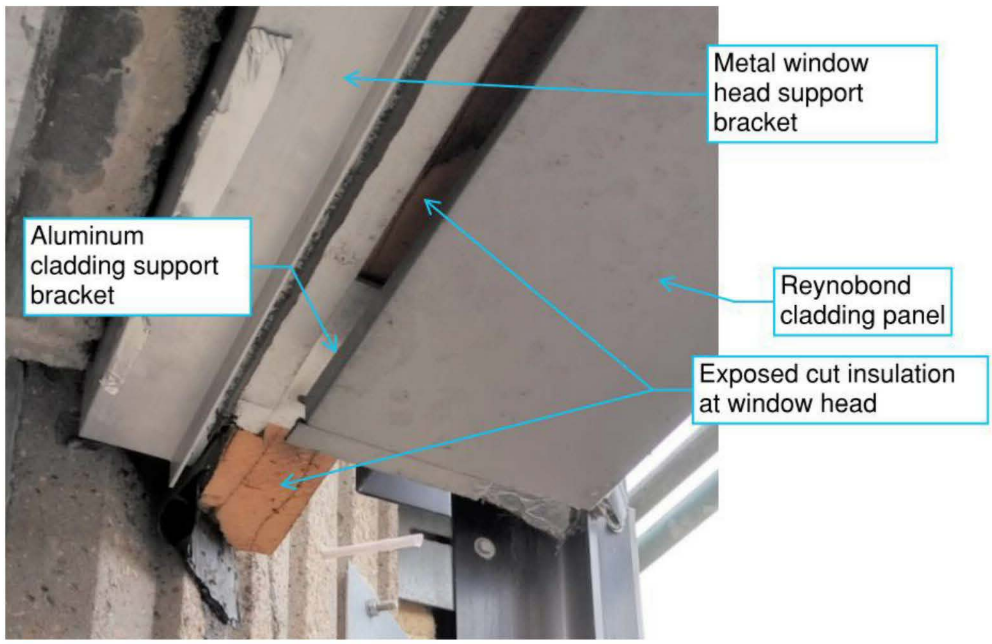


Figure 9.39: Evidence of cut insulation edge above window head

9.5.20 Figure 9.40 includes a still taken from LFB thermal imaging camera of the first fire fighter to enter the kitchen of Flat 16 on the 14th June 2017 timestamped 01:21. The right hand side of this image shows a view out of the kitchen window. Burning droplets are apparent, falling outside the window. Furthermore, the kitchen vent insulating core panel does not appear to be visible, indicating that it had already been affected by fire and fallen away (as discussed in route E).

9.5.21 The site photograph included in Figure 9.40, taken in Flat 16 on the 8th November 2017, corroborates this evidence by indicating that the worst damage to the kitchen window in Flat 16 was in the top corner where the vent insert was originally positioned. Please refer to Figure 9.38 showing the original window configuration with the vent insert in the top right corner.

9.5.22 The details of how the fire started in Flat 16 and the step by step explanation of how it spread into the rainscreen cladding system is being dealt with in detail by Prof Niamh Nic Daeid and Prof Jose Torero.

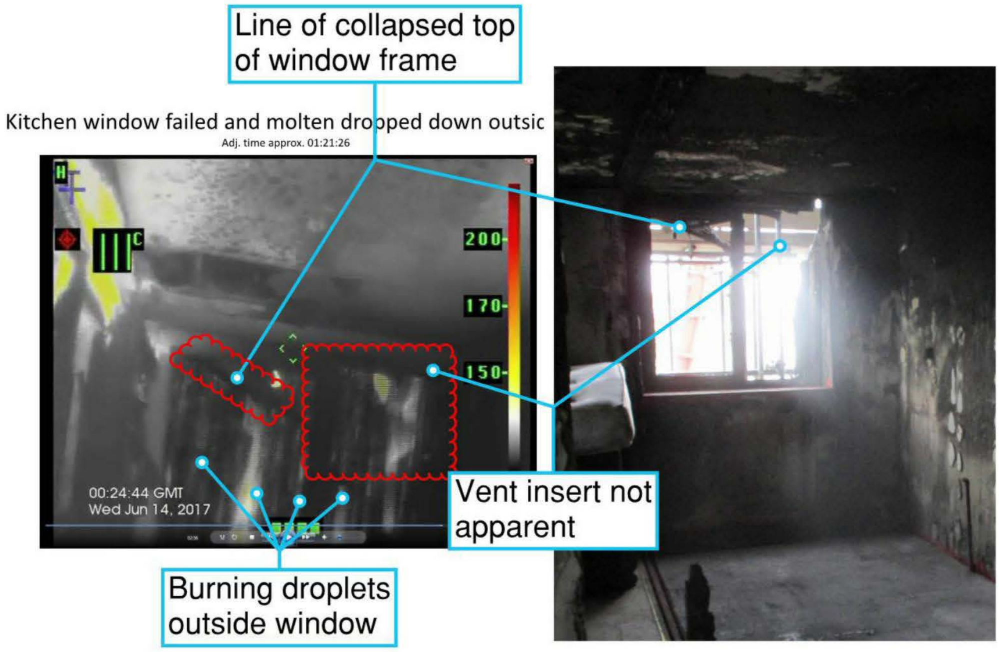


Figure 9.40: Evidence of loss of vent insert (MET00006109), compared with post-fire photograph of Flat 16 kitchen window

9.5.23 **Ongoing fire spread beyond the fire exit point of the window**

9.5.24 It is important to note that the first materials in the rainscreen system to be exposed to flames breaking through the window glazing/kitchen vent panel are the edges of the Reynobond 55 PE panel and the cut edges of the cavity insulation that were not covered in foil (please refer to Section 8).

9.5.25 Exposed PIR or phenolic is combustible, while the foil used to seal the sides of the PIR panels is not combustible. Therefore, a flame impinging on the uncovered cut face of the Celotex/Kingspan insulation in the external wall cavity will ignite the insulation more quickly than if a flame impinged on a foil covered panel.

9.5.26 However, even though cavity barriers were not installed around the windows, the fire interface with insulation in the column (indicated in Figure 9.22) would still occur, permitting fire to spread vertically into the column external wall cavity.

9.5.27 Regardless, the aluminium composite cladding panel would be subjected to external flaming at the window head due to the overhang of the panels.

9.5.28 I address this in detail in Section 10 and Section 12 of my report.

9.6 Consequences of the reconfigured window installation

9.7 The consequences of the reconfigured window installation, and the interface between the refurbished external wall and the existing construction for fire spread, can be summarised as follows.

9.7.1 In my opinion, once any localised fire occurred near a flat window – regardless of how that fire started – the majority of the construction materials around the window had no potential fire resisting performance. Therefore, no part of the construction had the ability to substantially prevent fire spread from inside the building into the external wall cavity.

9.7.2 This is because of:

a) the presence of combustible materials, enclosing the windows;

b) the presence of combustible materials closing the cavity between the old and new window infill panels;

c) the majority of new external wall materials, except the window glazing and the aluminium window frames, support the combustion process;

d) the windows were not enclosed with fire resisting cavity barriers around their perimeter;

e) further routes between the interior and exterior via failure or opening of the glazing in the windows, or the insulating core panel housing the kitchen extraction fan.

9.7.3 As a result, it is my opinion that the interface between the window reveal linings, and the cavities beneath, with (a) the column rainscreen cladding system and (b) the lateral rainscreen cladding system above the window, was the primary cause of the early stages of fire spread from the interior of Flat 16 into the column rainscreen cladding system.

9.7.4 I have explained the heating effect through the reveal, caused by the internal fire in the corner of the kitchen in Flat 16, and how it spread out through the reveal and into the column cavity. The type of materials and the way in which they were arranged around the window, provided no means to limit the spread of fire and smoke from the relatively small kitchen fire, to the column cavity.

9.7.5 Rapidly after that, the kitchen extractor vent failed, together with the glazing, as the witness evidence describes.

9.7.6 In my opinion, due to the arrangement of the window within the overall cladding system, once a fire inside a flat within Grenfell Tower was close to the window (including the window reveal linings), there was a real likelihood that fire would penetrate the rainscreen cladding system.

9.7.7 This could be either via the window reveal and an "internal" exit of the fire into the internal side of the ACP within the column, or via the glazing system itself which causes heating of the external side of the ACP outside the column.

9.7.8 As I explain in Section 10, once a fire penetrated into the rainscreen cladding system, there was no provision made in the system (whether in the materials or their arrangement) to impede the spread of fire and smoke around the building. This created the conditions for a catastrophic fire event to occur.