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An Analysis of the Design, Installation & Materials of the Rainscreen Cladding System at Grenfell Tower

An Insight into what went wrong

Frances Maria Peacock

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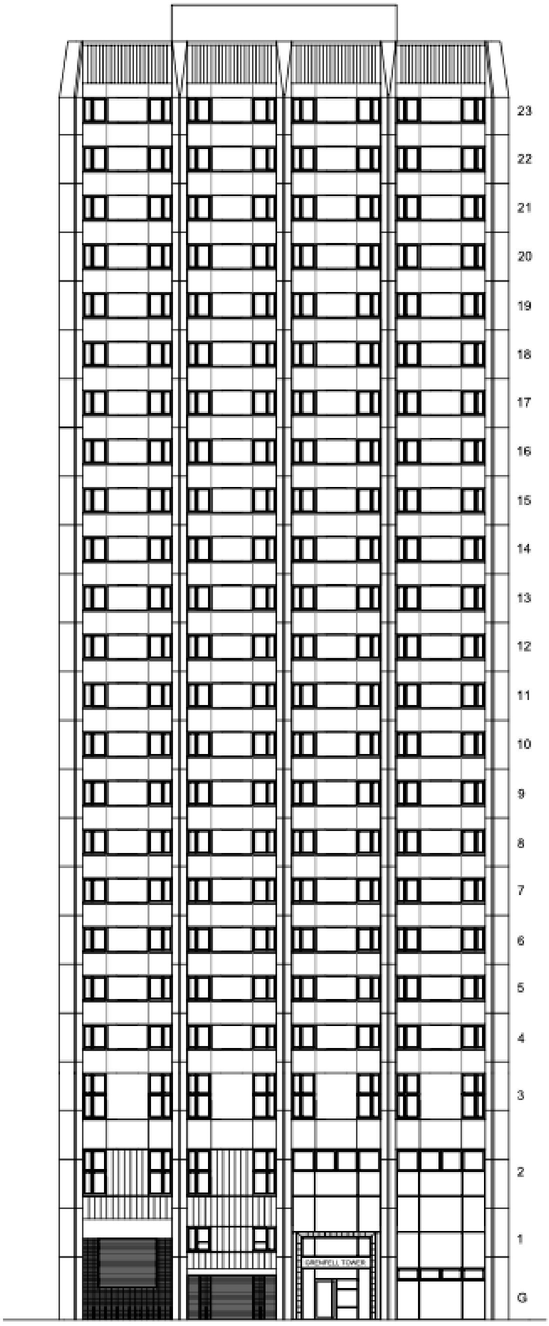
September 2020



By Frances Maria Peacock MCIAT, IHBC, MIFireE, MSFPE, PG. Cert., BSc, Dip. HE

1. Introduction

1.1 This is the second revised and updated version of a report which was first written in November 2018 under a slightly different title and submitted to the Grenfell Tower Inquiry. It also encompasses some of the information contained in my early reports – a series of seven – which were written during the first few weeks and months after fire, setting out my initial thoughts and analysis. In January 2020 the report underwent its first revision, taking into account recent developments at the time. This second revision considers the findings of the Inquiry since January, and evidence which emerged during the hearings in February and March 2020, just before they were suspended due to the Coronavirus pandemic. The hearings resumed on 6 July, before once again being put on hold for the summer holiday season, after which they resumed again on 7 September.

1.2 This report will help explain some of the evidence which was heard at the Inquiry in a clear and logical way, as well as give an understanding of what the cladding system was like. Despite all the denial, excuses and buck passing going on between the companies, it is clear to me where things went wrong and I offer an insight into this. It also includes issues with the cladding system which have been identified through my own examination and analysis. These issues have not yet come out at the Inquiry and may not do so, but it is important that my findings are reported and understood as they help explain what went wrong.

1.2 Primarily, this report is concerned with three fundamental issues relevant to Grenfell Tower; one of these is the concept behind the *design* of the system itself, and another is the way in which it was *installed*, both in terms of the procedure which was followed and the quality of the workmanship. Thirdly, it is necessary to consider the physical and chemical properties of the materials which were used, as these will have had an influence upon the performance of the materials during the fire.

Overview

1.3 The report begins by looking first at the correct procedure for installing a rainscreen cladding system. The example used is fairly standard, and although this may vary slightly depending on the type of system used, there are certain safety principles which must nevertheless be adhered to if the system is to be capable of adequately resisting the spread of fire.

1.4 It then considers the issues relating to the size and position of the new windows, which were smaller both in width and height than their predecessors, and were relocated to the thermal envelope of the building (cladding system), forward of their original position within the concrete framework of the Tower. The windows did not fit well within the new openings, and in general the cladding system was poorly fitted to the Tower. This report examines what went wrong.

1.5 The design of the cladding system itself is also evaluated, including the issue of cavity barriers. The fact that these were not positioned around the windows is well documented, but this report looks at why this did not happen. Why is there a general lack of cavity barriers throughout the building, and why are those which are present positioned where they are? Why was it believed that cavity barriers were not needed? These are questions my analysis attempts to answer by considering the relevant evidence. Although it has been stated that cavity barriers would not have been very effective due to the combustible nature of the materials present in the cladding system, consideration is given to the reasons why and it is asked whether there is a possibility that they could have made a difference, even if it was only to slow the progression of the fire.

1.6 The physical and chemical properties of the materials within the façade system are an important consideration. Although it is well known that the cores of the cladding panels and the insulation used were highly combustible, what is it about these materials which makes them so dangerous? How do they actually burn and were there any factors present which introduced additional hazards, thereby exacerbating the danger and intensifying the fire?

1.7 At this point I should emphasise that it is not the objective of this report to determine responsibility for specific failings, although I shall express my personal opinion if it seems to me that a particular person or company is at fault. Such views are my own professional opinion and should not be taken as fact because it is the job of others – including the courts at a future date - to determine exactly who is responsible for what and therefore who is actually to blame.

1.8 Finally, it is necessary to look at the level of knowledge and understanding designers have when it comes to fire safety. One of the Inquiry's experts, Paul Hyett stated that the architects could not be expected to know that certain materials were flammable. This raises serious concerns about the knowledge of architectural (and other) designers, when it comes to specifying fire-safe products, and exposes a significant gap in their training.

1.9 The lack of fire protection around the windows, the use of combustible materials, poor design and bad installation, all combined to create a situation where the cladding system was incapable of resisting the spread of fire, and was thus a disaster waiting to happen. The new size and position of the replacement windows was also a critical factor.

1.10 It may appear to the reader that certain issues have been overlooked, but this is purely because it is not the intention here to repeat what appears in other expert reports. This is only used insofar as to set the findings here into context. The objective is to produce an independent analysis from a different perspective, and to concentrate of issues which have not been covered (or fully covered) elsewhere. My findings are based on my own examination of the Tower (from the outside only), as well as drawings, photographs and video footage. Other sources used are listed in the reference section at the end of the report.

Contents

2. Installation of a Rainscreen Façade

Procedure for Installing a Rainscreen Cladding System

2.1 If a rainscreen cladding system is to maintain its integrity and function correctly, as well as inhibit the spread of fire, the following procedure should be followed:

1. The vertical fire barriers should be fixed in place. These should always take precedence over the horizontal barriers, as it is these which provide the zoning within the cladding system necessary to restrict fire spread. The barriers should be at least the full width of the cavity to ensure a tight seal;
2. The horizontal cavity barriers should be fitted, and these must be tightly butted up against the vertical barriers, so as not to allow any flames or smoke through the joint in the event of a fire. All joints should be sealed with foil based tape;
3. Once all cavity barriers are in place, the insulation boards must be added. These must be accurately cut to fit between the fire barriers and all joints taped. The barriers and the insulation must fit tightly against each other. If there is a change of direction (eg. Around an internal or external corner, or a protrusion from the façade such as a column, the fire barriers and insulation boards must be cut exactly to the right shape so that they are continuous without any gaps;
4. The next step is to install the support rails for the cladding panels. These will inevitably interrupt the horizontal cavity barriers, which should be carefully cut to accommodate them. These barriers and the rails should fit tightly against each other. Alternatively, the rails may be broken at intervals so that the fire barriers may remain intact. Given that it is considered that the vertical channels created by the U shaped support rails at Grenfell Tower helped the fire spread vertically upwards within the cladding system, it would be a better option to give the intumescent cavity barriers priority and break the rails at intervals, leaving the barriers intact. This would avoid the presence of vertical channels which run the full height of the building;
5. Finally, the cladding panels should be fixed to the rails.

2.2 It is absolutely vital that this procedure is followed. Even though types of insulation, cladding panels and fixings vary from system to system, this standard method is always the same if a safe system is to be installed. That way the system can ventilate in the intended way without compromising fire safety. It is important to note that all components of the system must sit tightly against each other if the overall system is to be deemed capable of restricting the spread of fire.

2.3 The vertical barriers must always fill the entire width of the cavity, and be tightly fitted between the masonry wall and the cladding panels which form the outer layer of the rainscreen façade system. To ensure that the tightness is adequate, an extra 10mm should be added to the width of the barrier. This will make it slightly bigger than the gap it is designed to fill, and thus a compressive tightness will be achieved.

2.4 When determining cavity barrier size, it is also necessary to consider the thickness of the insulation, as the latter is installed after the vertical barriers have been fitted (ie. The insulation is fitted between the barriers) and therefore accounts for some of the width. For example, if the width of the ventilation cavity is 156mm and the total thickness of the insulation on the spandrels is 160mm – installed at Grenfell as two 80mm layers - the depth of the barriers required would be 160 + 156 + 10 = 326mm. This would then ensure effective zoning within the cladding system capable of restricting the spread of fire.

2.5 The installation of cavity barriers divides a cladding system into separate compartments (zones), each of which is independent of its neighbours and is ventilated individually. The independence of each zone will also enable a fire to be contained within its boundaries, therefore restricting its spread within the interior of the cladding system. It is important that the cladding zones do not contain windows within their area, which must be isolated from the rest of the system by cavity barriers in order to prevent the ingress/egress of fire via the windows (*Diagram 1*). At Grenfell this did not happen, and windows were included within the zones. In fact every zone created in the spandrel bays had a window within it. Consequently, the whole concept of zoning throughout the building was dangerously undermined (*Photo 1*).

2.6 Where horizontal barriers are concerned, the dilemma is keeping the cavity open to allow ventilation, whilst at the same time ensuring adequate fire protection. Horizontal barriers differ from vertical cavity barriers in that they are designed to activate and close the cavity only in the event of a fire, whereas vertical barriers are closed all the time. In order to comply with the regulations, the horizontal barriers must not be less than 50% of the ventilation cavity. Therefore, if the cavity is 156mm, the gap allowed between the horizontal fire barrier and the cladding panels should be a *maximum* of 78mm, although in practice this gap would be too large. Again, allowing for the thickness of the insulation which is installed after the barriers have been fixed, the size of the horizontal barriers at Grenfell should have been 160 + 78 = 238mm, as a *minimum*. The actual gap was in fact 25mm which would be more effective in the event of fire, and therefore a horizontal barrier size of 291mm was required on the spandrels.

2.7 On the columns, the insulation was 100mm thick and the ventilation cavity 142mm, which means that the required depth for the vertical cavity barriers would have been 252mm, and for the horizontal barriers (allowing for a 25mm gap), 217mm.

Summary:

The issues affecting the method of installation of the rainscreen cladding system can be summed up as follows:

- A lack of continuity during the installation process;
- Correct procedures not followed;
- Insufficient fire protection;
- Poor understanding and implementation of the concept of zoning;

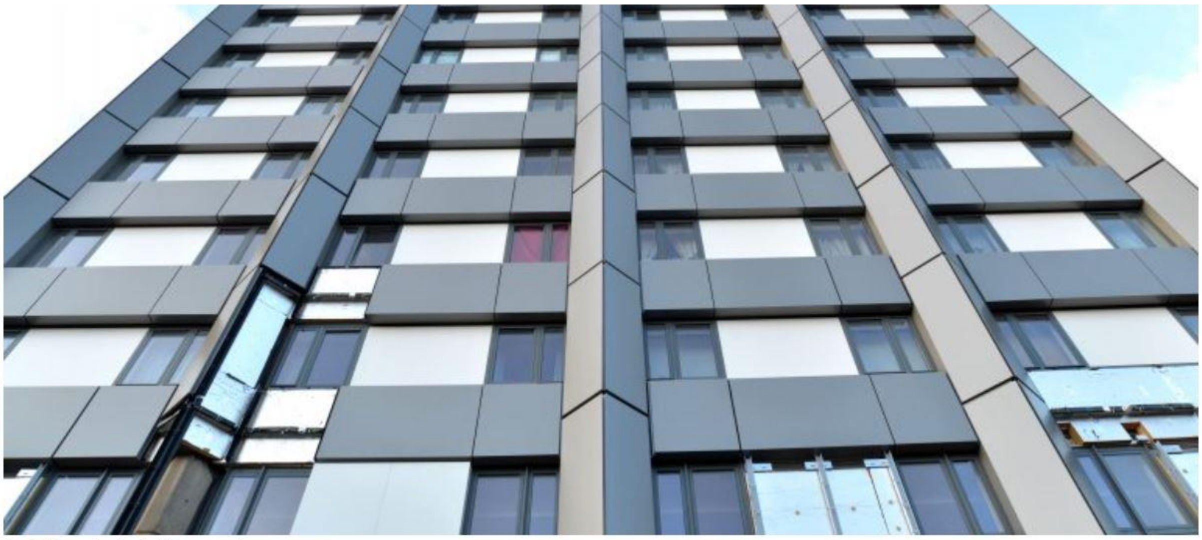
Installation Defects and the Quality of Workmanship

2.8 For the purposes of this report, the resulting defects are best explained using the following widely available photos taken during the installation of the cladding system:

<u>Photo 1</u>: This view shows the east face of the tower from the third floor upwards during the installation of the cladding system. The position of the cavity barriers in relation to the windows shows that there is no proper zoning in place and that the concept is undermined to the extent that fire cannot be contained.

Photo: Studio E Architects

2.9 *Photo 1* is a good example of a departure from the safe procedure for installing a rainscreen cladding system, most obviously from the fact that support rails for the cladding panels can be seen hanging in mid-air around the columns, without any cavity barriers or insulation having been installed first. By contrast it is worth noting that the cladding system has been installed to the level of completion on some of the adjacent spandrels, which demonstrates a lack of continuity in the installation process. If the integrity of the rainscreen cladding system is to be maintained throughout the building as a whole, the spandrels and columns need to be clad systematically as part of the building in its entirety, not separately from each other as is shown to be the case here. It is therefore necessary to reiterate that the fire barriers and insulation must be continuous throughout the building, tightly abutted, accurately cut around corners and architectural features, and the joints sealed with foil tape.



Grenfell Tower London cladding exposed

Photo 2: This is a view of the north side of the tower from the 3rd to the 9th floor, with some cladding panels removed to reveal the internal details of the rainscreen system.

Photo: Studio E Architects

2.10 The installation of the rainscreen cladding system has largely been completed on this façade, although some of the ACM panels have deliberately been left off to expose the interior detail for the purposes of the photograph.

2.11 It can be seen that horizontal cavity barriers are visible at an intermediate level on the fourth and fifth floor spandrels, each with a notch matching the position of the one on the next floor (*Photos 2 & 3*). The purpose of these notches is unclear as they do not seem to correspond with the observed locations of the carrier rails. Most notable perhaps is the position of the horizontal barriers which offer no direct protection at either window head or cill level, and they are not in line with the floor slab. It is also worth noting that Studio E in one of their drawings did in fact show a cavity barrier present at the window head – and also in line with the floor slab – but in many of their drawings fire protection is completely absent. Harley Facades show the fire barrier in a position further above the window head, but nevertheless still in line with the floor slab. Upon installation the position of the barriers was raised even further (*Diagram 1*).

2.12 The company which carried out the installation – Osbourne Berry Installations Ltd. – provides an explanation. If the cavity barriers had been installed in the position shown by Studio E, they would have obstructed the steel shelf angles which were necessary to support the windows (see *paragraph 2.19*), and therefore Harley Facades revised the position of the barriers in order to obtain the necessary clearance. However, it was then realised that the cavity barriers would perforate the EPDM seal at window head level so the position was raised again. None of the companies seemed to have been concerned about the fact that the cavity barriers would now no longer offer direct protection at the head of the window in the event of fire. Shelf angles were also present at cill level and EPDM was also used around the cills and the jambs as well.

2.13 An interesting observation can be made in *Photos 2* & *3* where it can be seen that the position of the cavity barriers on the spandrels corresponds with the panel joints on the adjacent columns. It is behind these joints that the horizontal cavity barriers on the columns are located, and the line of these seems to have been carried through across the spandrel bays. It therefore seems to have been the case that when the position of the spandrel barriers was raised, it was done so to line up with the corresponding line of cavity barriers on the columns. The system appears to have been designed so that the panel joints on the columns did not coincide with the position of the windows, and lined up with the spandrels instead. This was most likely - and rather ironically - done to reduce the fire risk and prevent any fire venting through a window from going into the joints.

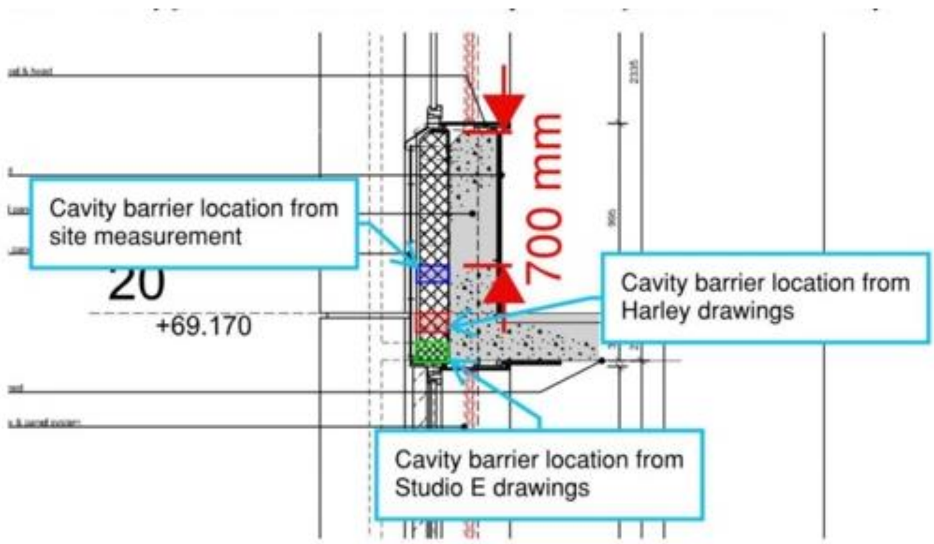


Figure 8.41: Horizontal cavity barrier locations (onsite measurement of 700mm and annotations based on SEA00002551)

<u>Diagram 1</u>: This drawing taken from Chapter 8 of Dr Barbara Lane's supplementary report shows how the proposed location of the cavity barriers at window head level was changed. The one shown in blue, which is above the level of the floor slab, is the actual location of installation. This is some 400mm above the head of the window and by moving the barrier so far up, direct protection at the window head was lost and the concept of zoning undermined.

2.14 The advice of the fire engineer Exova, was for a cavity barrier to be included at the window head to prevent the spread of fire between flats on different floors via the windows. Although Harley included a cavity barrier in its drawings, it admits that it considered this unnecessary due to the materials in the installation having a Class 0 fire rating, although Exova had advised that this did not mean that the materials were non-combustible. Indeed, the test for a Class 0 rating assesses surface spread of fire only and is not a test for combustibility. In order to achieve a Class 0 rating, the material must satisfy BS 476-6 which assesses the contribution of the surface to fire propagation, as well as BS 476-7 which assesses the speed of flame spread across the surface of the material. As an experienced Façade contractor, the limitations of the testing and the associated fire risks should have been appreciated.

2.15 Each individual window required a barrier at its head and at its cill, as well as a vertical barrier at each side, filling the full width of the ventilation cavity. Unfortunately none of these were present. Although an explanation has been given for the absence of barriers at the window heads, no explanation has yet been offered to explain their absence at the jambs and cills. It would appear from the drawings that barriers in these locations were never intended.

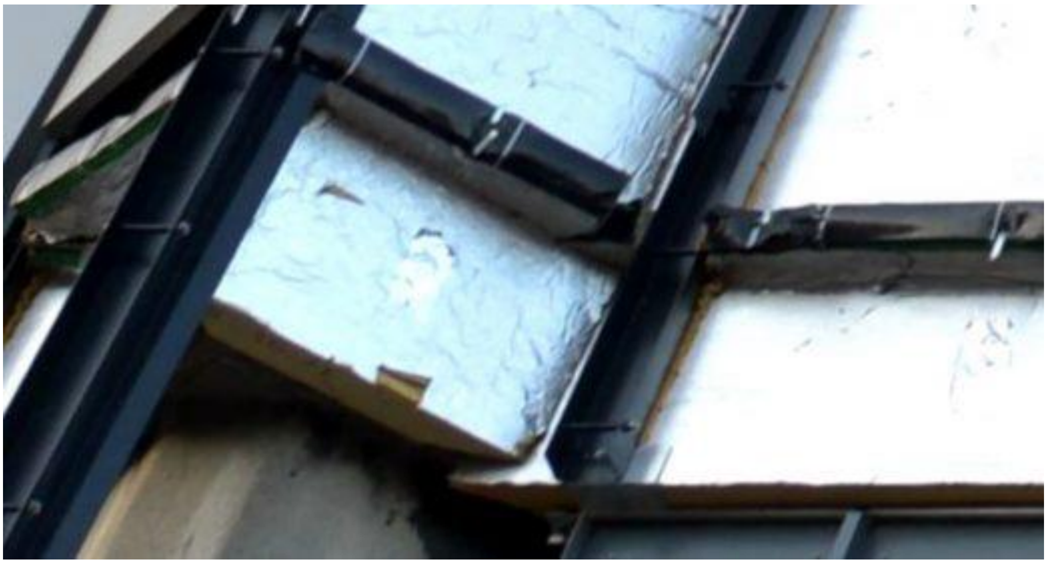


Photo 3: This is a close-up view of the column and spandrel shown in Photo 2. It can be seen that the cavity barriers correspond with the panel joints on the columns, and the line is carried through across the spandrels as a continuous band which is not in line with the floor slabs.

Photo: Studio E Architects

2.16 This photo is perhaps the most revealing of all, as it shows in close detail several major issues with the installation and design of the rainscreen cladding system:

- The foil facing of the insulation board on the column is damaged;
- The same insulation board is also not a flush fit with its neighbour on the spandrel, and the joint between the two has not been taped;
- The horizontal cavity barrier on this column appears to have a tear in it at a point close to where it meets the support rail on the adjacent spandrel. Damage of this type would prevent it functioning properly in the event of a fire;
- The horizontal cavity barriers do not sit tightly against the “U” shaped support rails, which effectively renders them useless;
- Absence of vertical cavity barriers in locations where they would normally be required;
- Due to the absence of fire barriers around the windows, bare insulation sits against the window head;

2.17 As shown in *Photo 3* (above) and *Photos 4* and *7* (below), there seems to have been great difficulty in fitting the cladding system around the columns due to their triangular shape and angle to the main building face. However, cladding systems have been fitted to buildings of all shapes and sizes, some very much more complex than Grenfell Tower, and manufacturers design their systems and products accordingly. Therefore, such difficulties with the installation should not have been encountered, especially if experienced designers were involved.

<u>Photo 4</u>: This photo shows the cladding system on one of the lower floors of the Tower. As in Photo 3, the insulation has been poorly cut and the piece on the column does not sit flush against that on the spandrel

Photo: Building Research Establishment (BRE)

Summary:

Main Findings:

- Companies indecisive about fire stopping and cavity barriers;
- Difficulties in applying the cladding to the geometric profile of the building;
- Inconsistencies in the drawings between different companies;
- Poor design which left room for errors;

Critical Factors:

- Lack of fire protections around the windows;
- Use of combustible materials;
- The unusual design;
- Poor quality of the installation;
- Change of size and position of the windows;

The Companies involved in the Installation

2.18 There were several companies which were involved either directly or indirectly with the actual installation of the rainscreen cladding system at Grenfell Tower. These are CEP Architectural Facades Ltd., Osbourne Berry Installations Ltd., Harley Facades Ltd., Kevin Lamb Bespoke Design and Studio E Architects Ltd. It would seem that Harley Facades and Studio E each had some responsibility for the design, CEP had the role of fabricating the cladding and windows, and Osbourne Perry carried out the installation itself. As Osbourne Berry claim to have many years' experience behind them, they ought to have been very familiar with the procedures involved. In addition, Rydon as the Contractor overseeing the work and Building Control also had a responsibility. The latter was the body with ultimate responsibility to inspect the work, as well as ensure that it had been carried out correctly and that complied with building regulations.

2.19 In its opening statement for Phase 2 of the Inquiry, Osbourne Berry (OB) describes the procedure it followed when installing the rainscreen cladding system (and windows) at Grenfell Tower:

1. At the request of Harley Facades, OB **checked the measurements** to ensure that the windows could be fitted in a straight line. Harley was aware that the columns of the tower were not completely straight, which meant that other vertical and horizontal elements would also be out of alignment;

2. A "jig" was used to align the top and bottom shelf angles for the windows and the horizontal sections of the cladding;

3. Holes for the bolts were drilled into the concrete and filled with resin into which the bolts were fixed. This ensured that they would be held securely;

4. The **shelf angles** were then fixed and the windows attached to these. OB interestingly says that "*all windows were fire foamed in place with EPDM at all edges.*" As is now known, the EPDM was highly flammable and was used to plug an awkward gap at the window jambs adjacent to the columns. Even at this early stage of the process it would seem that catastrophic errors had already been made, but these were not picked up.

5. **Angle brackets** to support the cladding rails were attached to the shelf angles and levelled up;

6. The next stage involved the installation of 2 x 80mm sheets of Celotex RS 5000 PIR **insulation** and the **horizontal cavity barriers**. The cavity barriers should have been installed first, but OB do not say in which order they installed either of these components. Most crucially, there is NO mention of vertical barriers which, if present, should have been installed before both the horizontal cavity barriers and the insulation. It would seem that another catastrophic error had been made.

7. The **cladding rails** were then fixed to the angle brackets and the **ACM panels** were attached;

The above refers to the procedure for the spandrels only. The installation procedure for the **columns** is as follows:

1. The measurements were checked, the holes were drilled and then filled with resin into which the bolts were set. This is the same as the method as that which was used for the spandrels;
2. Shelf angles were not required, but brackets (referred to as "vertical" brackets in this case) to support the cladding rails were then fixed;
3. Vertical and horizontal cavity barriers were next installed, although there is no mention of the inulation which is known to be a single 100mm sheet of Celotex RS 5000 PIR. Consequently it cannot be determined in which order these components were installed.
4. Excess "fire foam" – presumably EPDM – was removed and painted with mastic;
5. The ACM panels were installed.

2.20 OB were keen to state that the sequence of work was pre-determined by Harley. It is worth keeping an open mind as to whether this is strictly true, especially as such a statement implies that OB were aware that some of the procedures they followed were out of sequence and hence incorrect. OB goes on to state that in reality the sequence was determined by when the materials could be ordered and when they arrived on site. This also implies an acknowledgement that the installation was not carried out according to the correct procedures and sequence. As explained in *Paragraph 2.2* above, it is vital that the components are installed in the correct order, otherwise the whole integrity and safety of the system will be compromised. It is not acceptable to install components in the wrong order just to save time whilst waiting for others – which should have been installed first - to arrive on site. Osbourne Berry are clearly at fault here for going ahead with the installation, as are Harley Facades for allowing their contractor to carry out the work in this way. Rydon as the contractor and even Max Fordham as the project manager should have become aware that procedures were not being followed and acted immediately. Ultimately Building Control should have picked up on this by inspecting the cladding system at various stages of its installation and insisting that defects were rectified.

2.21 Dr Barbara Lane, an Expert Witness for the Inquiry, identified a number of installation defects, and I too from my own analysis have also identified certain defects. It is interesting to consider how Osbourne Berry and Harley attempt to explain this. OB refers to the defects identified by Dr Lane as isolated examples, whilst Harley states that Dr Lane only inspected limited areas of the cladding to which she had access. In other words both companies are implying that the majority of their work was to a satisfactory standard and that defects were few and far between. Considering that Dr Lane's examination of the structure was extensive and included every floor (as stated in her report), it would seem that the defects appear to have been fairly consistent across the tower. Otherwise it would have been expected that the defects would be localised, or else occurring randomly with the overall installation of a generally acceptable standard. Both companies claim to have carried out thorough inspections and say that if the defects had come to their attention they would have rectified them straight away. Clearly this was not the case and the issues were not picked up by building control either.

2.22 With regard to the taping of joints and edges, OB stated that neither the manufacturer (Celotex), the architect (Studio E) nor the supplier (Harley) had specified the use of tape. However, anyone with any experience and an understanding of façade systems should be well aware of the importance of taping and should do it anyway, even without a specification. It is part of standard procedure and I am not aware of any exceptional circumstances which dictate that it should not be done.

3. The Size and Position of the New Windows

3.1 The new replacement windows at Grenfell Tower were to be of the "tilt and turn" type with polyester powder coated aluminium frames. They would replace the originals from when the tower was built, which had aluminium frames with wooden surrounds, and could be opened by sliding horizontally. Most significant of all was the change in window position. This meant that the new windows would be positioned within the external cladding system (thermal envelope), rather than the existing concrete framework of the tower, as had previously been the case. The reason for this was to improve thermal efficiency. Comparable modifications have been made to many other high-rise buildings of a similar age and construction to Grenfell Tower in recent years. The three blocks of Cedar Court in Glasgow, each with 23 storeys, are an example. The refurbishment of these was completed in October 2019.

3.2 These buildings feature in an issue of the *Architects Journal*, Vol.246, Issue 21, dated 7 November 2019. In that article, Rupert Daly, the Project Architect states, "*The existing windows, while double glazed, had poor insulation and frame efficiency by current standards. New triple-glazed windows were specified and moved out to meet the insulation plane, significantly reducing heat loss at this repetitive junction.*" The existing windows at Grenfell Tower also had poor insulation and thermal efficiency, making conditions for occupants uncomfortable, especially in summer when there were complaints about the flats being too hot. Therefore, to move the position of the new windows forward so as to be within the external thermal envelope (insulation plane) would be a means of improving this.

3.3 Studio E architect, Bruce Sounes gives another reason for the change in window location. In his first witness statement to the Inquiry, he says that pushing the windows further out created an enlarged window cill which prevented the windows getting in the way of furniture when they were opened inwards. The design of the windows meant that they could be tilted inwards along their bottom edge (*Photo 5*), or the entire casement could be opened inwards along its side by releasing a catch (*Photo 6*) – hence the term “turn.” Interestingly, he seems to make no mention of thermal benefits in changing the position of the windows.

3.4 Considering the design of the windows further; the residents had been given a selection of designs to choose from, and those of the pivot type had proved to be the most popular. Windows of this type open by being rotated around a centrally positioned pivot. Nevertheless, a decision was made to go against the residents’ preferences and adopt windows of the tilt and turn type instead. It has been suggested that these were a cheaper option, and Claire Williams of Kensington & Chelsea Tenant Management Organisation (KCTMO) had stated in October 2013 that the “budget was under pressure.” Studio E do not give clear evidence to definitively state one way or the other regarding cost, but Bruce Sounes states perceived advantages of tilt and turn over pivot windows as the reason for the change in specification. As the casement can be opened fully inwards, they are easier to clean and allow for better ventilation. This is not something I would personally agree with, and whilst perhaps a casement which opens inwards is slightly easier to clean, the flexible nature of the pivot means that they can be cleaned easily too. The amount of ventilation is the same.

<u>Photo 5</u>: A close-up view of Grenfell Tower showing windows which have been opened using the “tilt” option. They are tilted inwards along their bottom edge.

3.5 It has been suggested that the contractors (or whoever else was responsible for the window design) got the measurements wrong. There is some evidence to support this; for example a witness statement from a resident - Meron Mekonnen (Flat 163, Floor 19) - refers to a meeting which took place with Rydon (the contractor) in which she was informed that “*the windows which had been ordered were smaller than the existing windows and they would* *therefore be pushing the windows out as they needed a new smaller frame.*" This could imply that the measurements were incorrect, and because of this error the windows had to be moved out of the existing building envelope to a new position within the cladding system. Ms. Mekonnen then goes on to say that "*They told us that as the windows had already been ordered, and they could not be returned and that Rydon would find a way to install them.*" This implies that the contractor was aware of a mistake with the measurements, but nevertheless had to find a way in which to fit the windows into the building.

Photo 6: A fire damaged window viewed from the inside which has been opened using the "turn" option to disengage the tilt mechanism and allow it to be fully opened as a side-hinged casement.

3.6 Alternatively, Rydon's statement could be interpreted as suggesting that the reduction in size of the new windows was intentional due to the decision to relocate them within the thermal envelope. There is also evidence to support this in the form of drawings by Studio E Architects and Harley Facades. Even though the design of the cladding system was later changed from the one which was first proposed, the drawings for both proposals show the windows in a position forward of the original building envelope. The windows as installed sit some 185mm forward of the original openings.

<u>Photo 7</u>: In this photo it can clearly be seen how awkwardly the cladding fits around the columns, and by its sheer bulk, it is difficult to keep it clear of the window opening. It can be appreciated how difficult it would have been to size up the width of the windows accurately and avoid the dangerous gap which was created at the jamb. ***Photo: Dr Barbara Lane's Supplementary Report, Part 8***

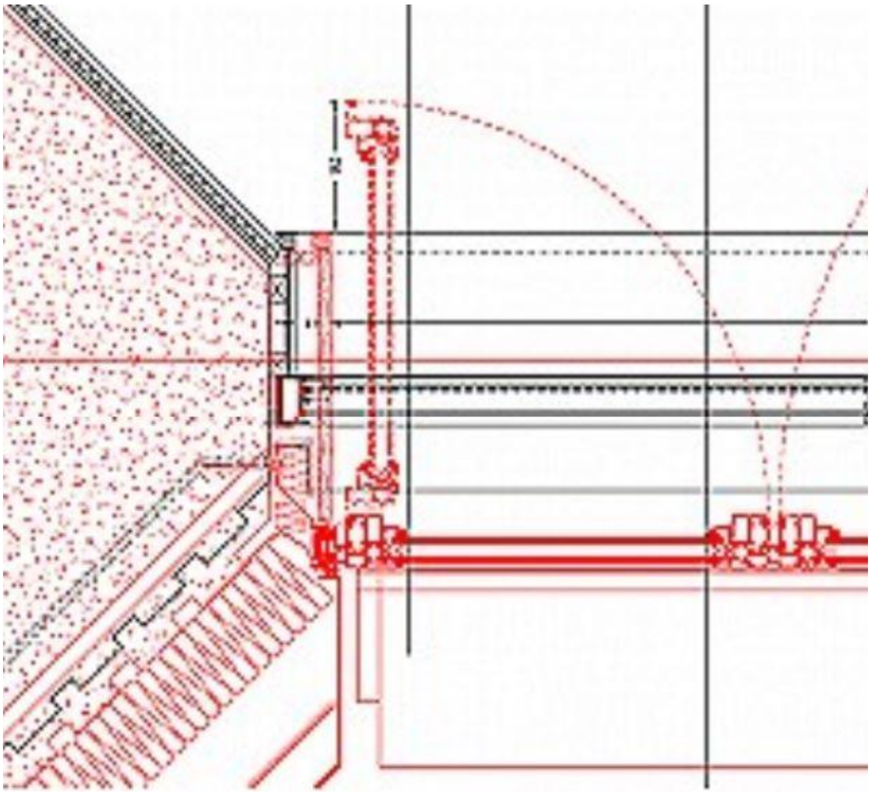
3.7 There was clearly much to be gained from pushing the position of the windows forward into the thermal envelope of the building, and therefore installing the new windows in the same location as their predecessors was not an attractive option. It is however worth considering whether it would have actually been possible to clad the building whilst leaving the windows in their original positions. In other words, would it have been possible to fit the cladding system, which was bulky, onto the tower without having to change the position of the windows? This, in my opinion, would have proved very difficult because the cladding system was so bulky it actually overlapped the window openings (*Diagrams 2 & 3* and *Photo 7*). This is a view I have consistently maintained since I first looked at this issue a few months after the fire. Therefore, it became necessary to find a way to accommodate the cladding system without it obstructing the windows, and it would seem that the way to achieve this was to move the position of the windows forward so that they would be situated within the cladding rather than the concrete structure of the tower.

3.8 This would mean that the reduction in window size was intentional rather than accidental. It is possible that the difficulty in fitting the cladding system to the profile of the Tower resulted in the window sizes being changed. The new windows were smaller than the originals, both in width and in height.

3.9 Ironically evidence heard at the Inquiry has suggested that the original intention had been to make the windows larger rather than smaller. An increased width could easily be accommodated within the external envelope by reducing the size of the non-structural infill panels. The proposed increase in window size was considered necessary due to the new frames being thicker and heavier than the old ones, and therefore widening of the window units would ensure that the same area of glazing could be maintained.

3.10 The bulkiness of the cladding system seems to have been acknowledged by Bruce Sounes, as he refers to the potential for it to block light from the windows due to the thickening of the columns (or pilasters as he describes them), which would result from its installation. Although it is not stated in his evidence, the thicker window frames seem to have been a way of accommodating a potential overlap. To put is simply, thicker window frames were necessary to ensure that the cladding was clear of the glazing, The thicker frames reduced the glazed area, and therefore the windows units need to be made wider overall.

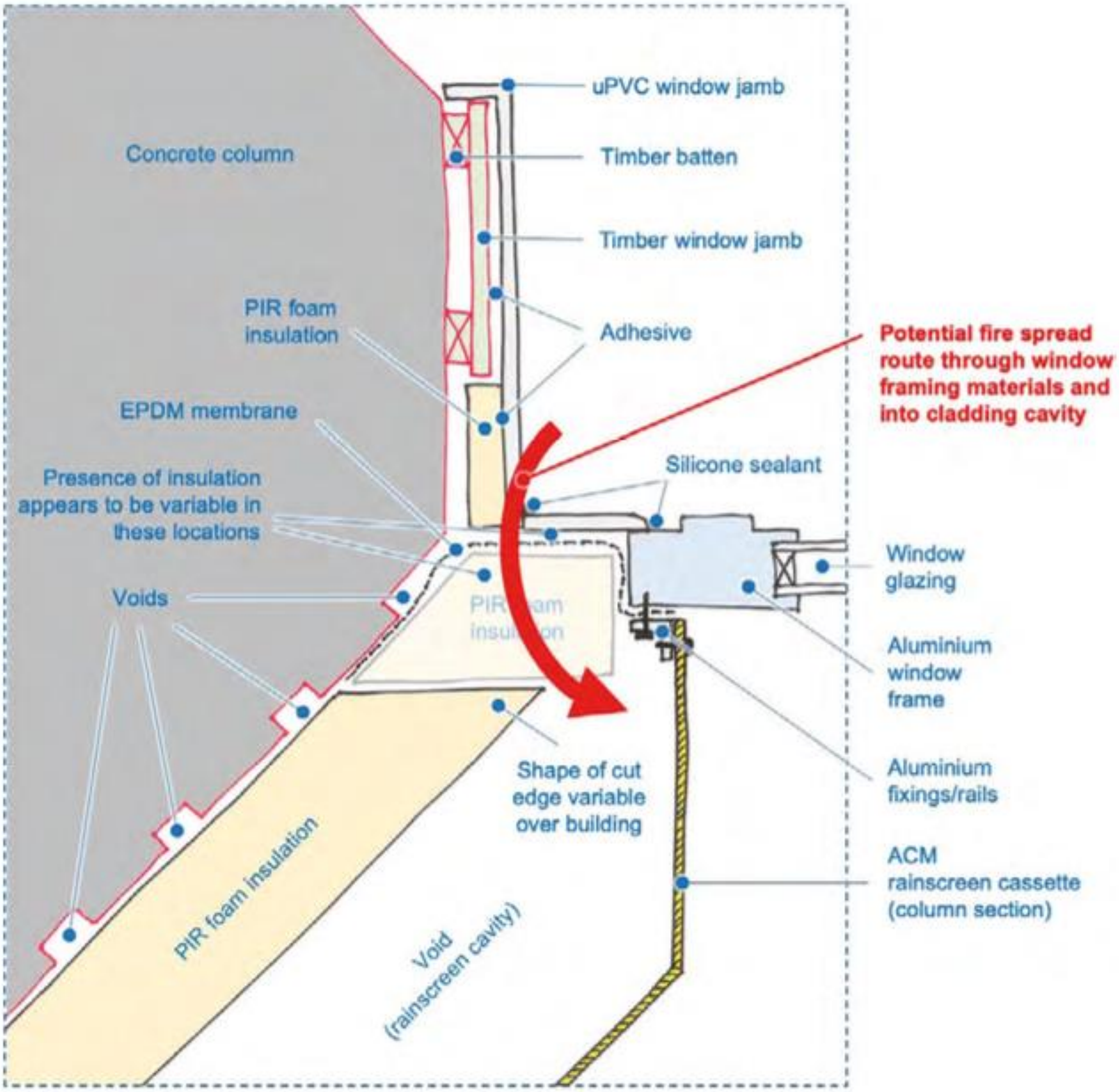
3.11 The proposed widening of the windows met with an objection from Kensington & Chelsea Tenant Management Organisation (KCTMO) because it did not want the expense of having to replace tenants' curtains and blinds which would no longer fit. As a solution Rydon proposed that the existing outer window frames should be left in place and new smaller windows fitted within them. The window size would be reduced from 1660mm to 1325mm and the width of the infill panel increased to compensate for the reduction in window width (*Diagram 4*). According to Rydon, this would make the work much easier and save a lot of time (and money). The implication here is that Rydon had did not envisage the position of the windows being moved out into the thermal envelope, although this does not appear to have been the case with Studio E. All their drawings from the outset, both before and after revisions, show the windows located within the thermal envelope.



<u>Diagram 2</u>: An extract taken from a Studio E Architects' drawing: This is a horizontal section through a column and an adjacent window; the original window is shown in black and the new window in red. The difference in width and size of opening is apparent, and it can also be appreciated how the insulation as applied to the column overlaps the original opening, meaning that the windows have had to be reduced in width to accommodate it.

3.12 However, if it is considered how awkwardly the cladding system as applied to the columns sits in relation to the position of the windows, it would have been very difficult to determine how wide the windows should be (*Photo 7*), especially as there are always constructional variations in a building and fitting something to the exact millimetre is generally not possible. It has already been noted by Dr Barbara Lane that the columns were not fully in alignment, which is why the gap at the jambs varied widely at different locations throughout the tower. Osbourne Berry also noted when they installed the cladding that the tower was not square. Consequently, it would have been very difficult – if not impossible – to produce accurate measurements capable of resulting in a perfect fit for every window opening in the tower. If the measurements for the width of the windows were not correct, this will be one of the reasons why.

3.13 A further complication resulted from modifications which were made to the design at the request of Rydon following objections by KCTMO to the proposed widening of the windows. This is illustrated in *Diagram 4.* The bottom image shows the arrangement after the design was modified, from which it can be realised that the windows are narrower, and the infill panels wider, than what was previously proposed (shown in the middle image where the windows are wider and the infill panels narrower). The fact that the window size was changed partway through the design process would have introduced another source of potential error regarding what the window size should be and by how much it should be reduced.



<u>Diagram 3</u>: This sketch by Professor Luke Bisby in his Final Expert Report for the Grenfell Tower Inquiry illustrates the difficulty in accommodating the cladding system on the columns at the interface with the windows. In this case an additional piece of PIR insulation has been used, although the fact that this was not present in all locations shows how awkward the fitting of the materials in relation to the window position was. It is worth noting here that the insulation overlaps the original window opening, despite the drawings in Diagram 3 (below) showing something different. The sketch is based on Professor Bisby's observations when he visited the Tower.

3.14 Later drawings indicate that the insulation on the columns would be cut back so as not to overlap the original window openings (*Diagram 4*), but by then the windows had already been sized, ordered and manufactured, meaning that it was too late to make such changes. This would support the witness statements in *Paragraph 3.5*. Therefore, although the reduced size of the windows was intentional, the measurements were not accurate.

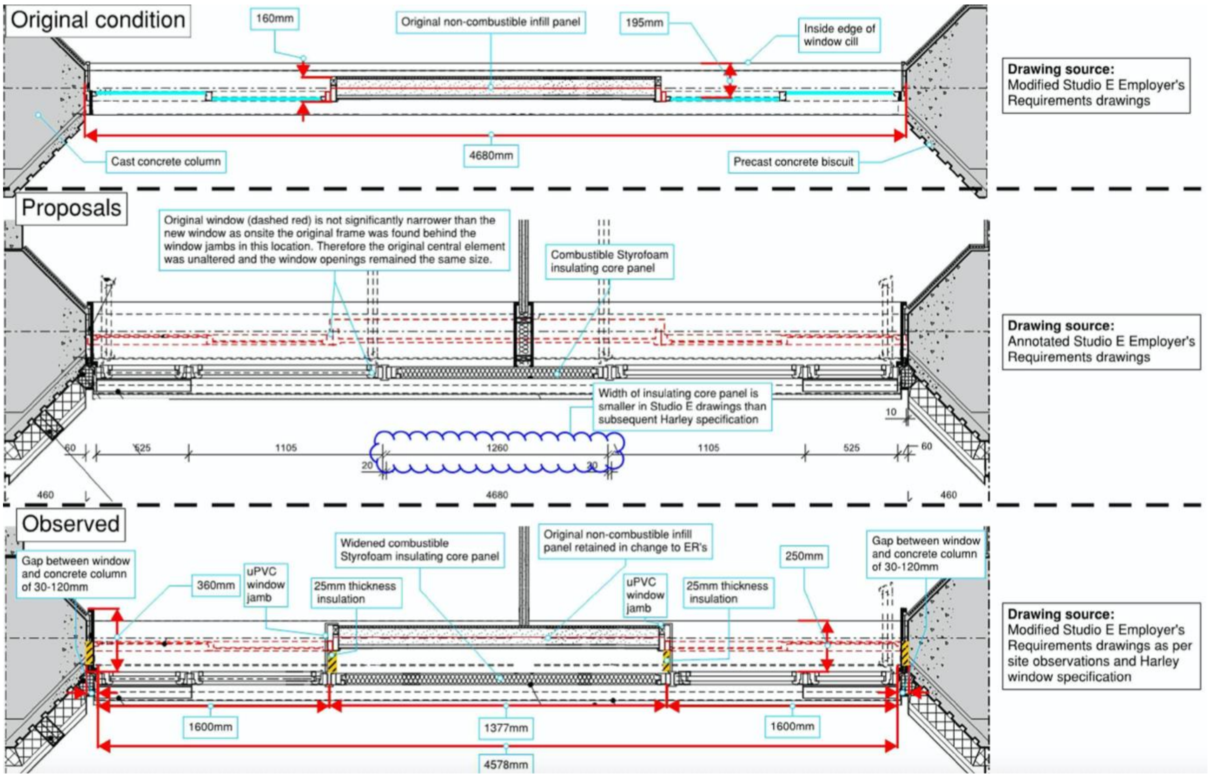
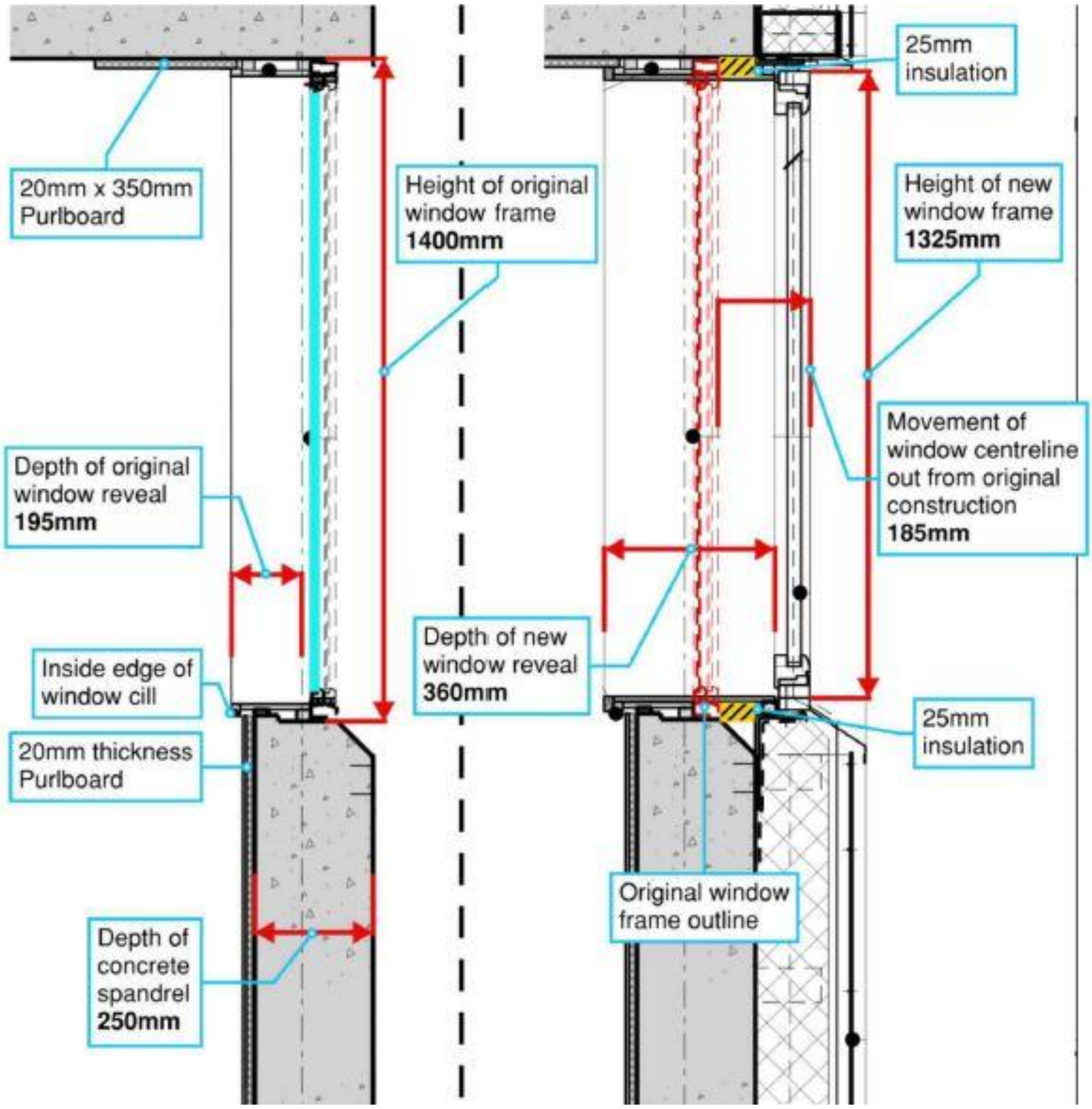


Diagram 4: The three configurations show the window arrangement before the refurbishment (top), as proposed (middle) and as installed (bottom). The latter is the arrangement as observed by Dr Lane and her team, and the images – all of which are by Studio E Architects – are taken from her Expert Report of April 2019. In all three images the cladding is cut so as not to overlap the new or original window position, but observations show that this was not the case, at least in some of the locations (*Diagram 3*).

3.15 As mentioned in Paragraph 3.8 the new windows were also shorter in height than their predecessors. This resulted in a poor fit in many locations, with gaps being present underneath the window ledges. In some places these gaps were so large that they were noticeable to several residents in the building. If there was a mistake with the measurements, then this is where it is likely to be. For example, Marcio Gomes (Flat 183, Floor 21)) says, "*The fact that the new window frames were smaller than the previous window frames resulted in substantial gaps being left around the edges of the windows and underneath the window ledge.*" Another resident, Yohannes Tesfaye (Flat 163, Floor 19) stated that, "*The gap was large enough to fit your hand inside it, and touch the cladding on the outside of the Tower.*" Mr. Tesfaye then goes on to say that there were "*gaps underneath the window ledge and you could fit your fingers in those gaps.*" Most probably the height of the window was underestimated in relation to the space taken up by the components of the cladding system at head and cill level.

3.16 However, unlike with the width of the windows, there was less room for error with the measurements for height. Unlike with the width which had to be measured between columns which were not fully in alignment, the measurements for the height were taken from the cill to the head which were not subject to the same variations. As the cladding system does not appear to overlap the window openings at the cill and head level (*Diagram 5*), there should not have been a need change the window height from that of the originals. Even if some slight adjustments were necessary to allow for any minor variations which may have become apparent, or components of the cladding system which were close to the head and cill (such as steel angles), the measurements should still not have altered so drastically as to create gaps which were large enough for residents to put their hands into.



<u>Diagram 5</u>: **Cross sections through the windows and spandrel sections at Grenfell Tower; the one on the left shows the original configuration, whereas the one on the right shows the arrangement as it was following the refurbishment. The new windows are 975mm shorter in length than the originals.** ***Source: Dr Barbara Lane's supplemental Report, October 2018***

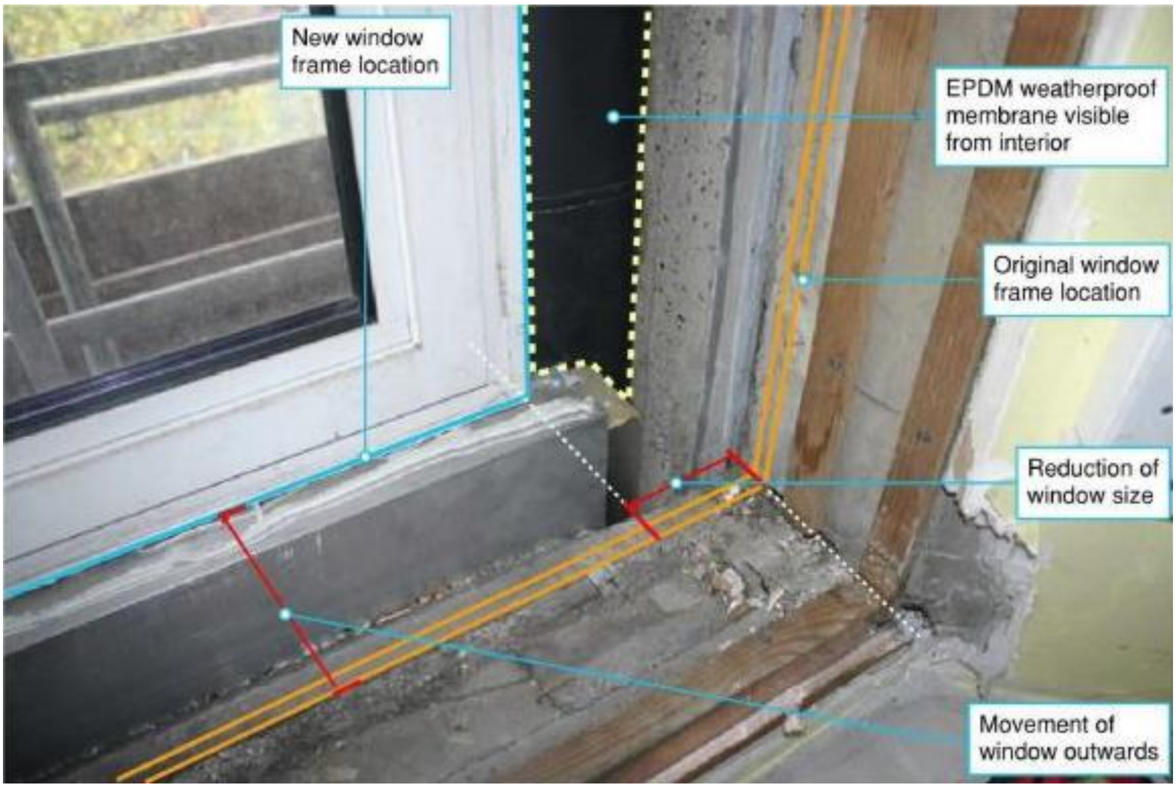


Photo 8: An image from Dr Barbara Lane's Supplementary Report showing the new position of the window in relation to the original.

4. Design of the Rainscreen Façade

The Original Design

4.1 The cladding system originally proposed for Grenfell Tower was a flat panel system. Below are two extracts from Drawing No. 1279 PL400 by Studio E Architects, dated 17 October 2012. It should be noted that this drawing was later deleted from the schedule, as is shown on a revised drawing issue sheet sent from IBI Taylor Young (IBI Group) to Kensington & Chelsea Borough Council on 29 July 2013 (ref. no. MW/KK/6075). No fire protection seems to have been designed into the cladding system. No vertical or horizontal cavity barriers are shown, and there is no fire protection around the windows.

4.2 The drawings support the assertion in *Paragraph 3.11* above, that the intention of Studio E as part of their design for the refurbishment, was for the windows to be moved out into the thermal envelope of the building (*Diagrams 6 & 7*). The position here of the window centre line is estimated as being approximately 75mm forward of the existing openings (to give a window reveal of 250mm) which is much less than the 185mm (window reveal 360mm) it later became after the design was changed (*Diagram 5* and *Photo 8*). The original window reveal – from when the Tower was built – was 195mm in depth.

4.3 At this stage it can be assumed that the width of the windows was larger than the originals (see *Paragraph 3.9* above), because it was not until October 2014 that Rydon and KCTMO expressed concern about the implications for residents' blinds and curtains (*Paragraph 3.11* above) if the windows were widened. The height however, is still likely to have been shorter than the originals – as continued to be the case later on – in order to allow for the inclusion of insulation at both window head and cill levels.

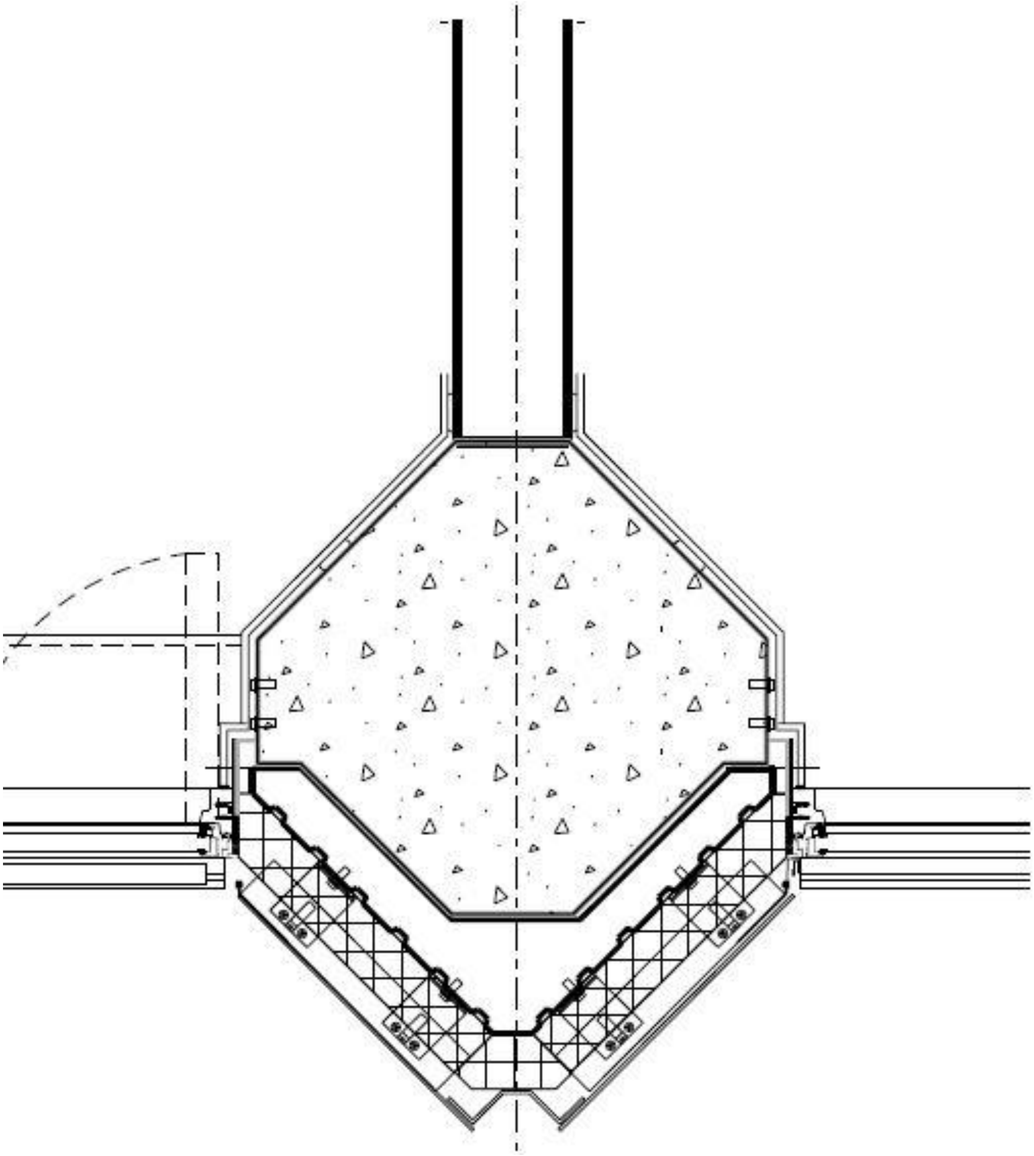
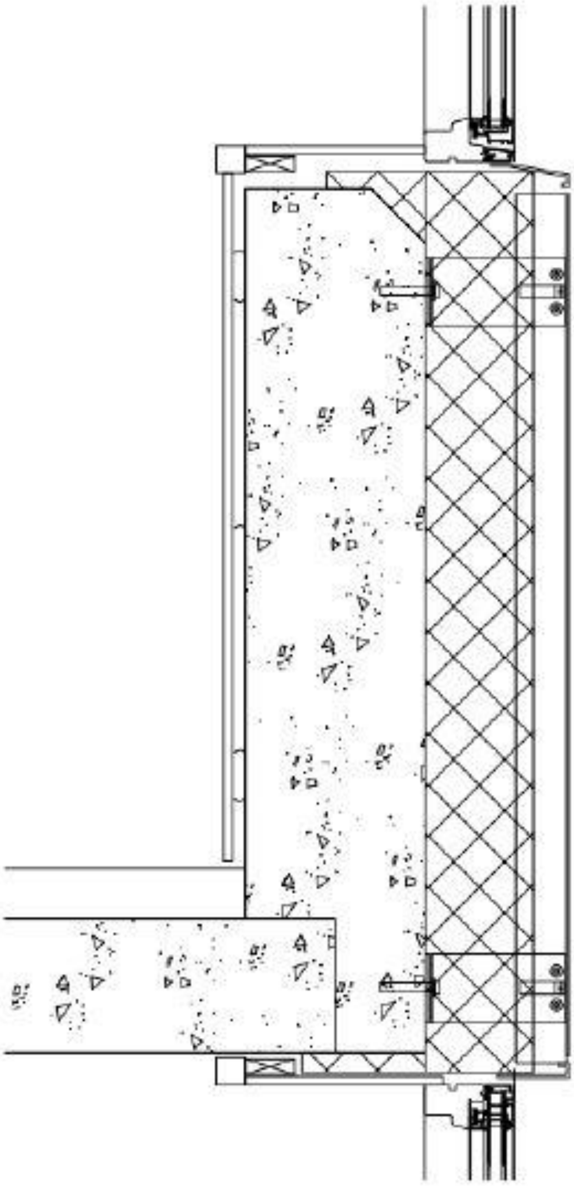


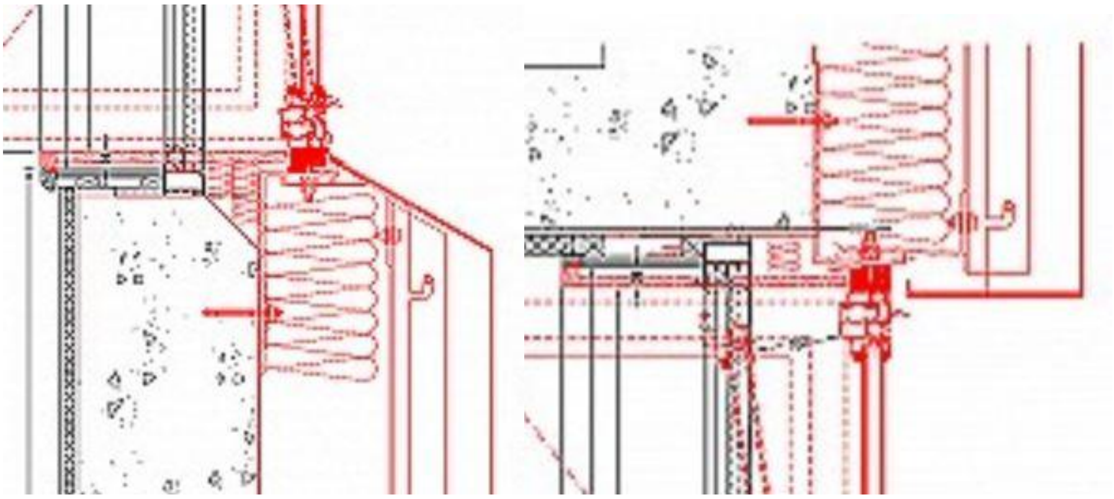
Diagram 6 : A horizontal section through a column showing the detail of the cladding system, which is attached to the ribbed piece of concrete at the front of the column. On either side there is a window. No fire protection is present and only a steel angle provides separation between the windows and the insulation on the column.

Diagram 7 (p.25): This drawing is a vertical section through a spandrel panel which shows the construction of the cladding system, as well as details at the head of the window and the cill. No fire protection is shown in either of these locations, where there are small gaps to allow the system to ventilate. Without adequate fire protection, the flames can gain easy access to the interior of the cladding system.

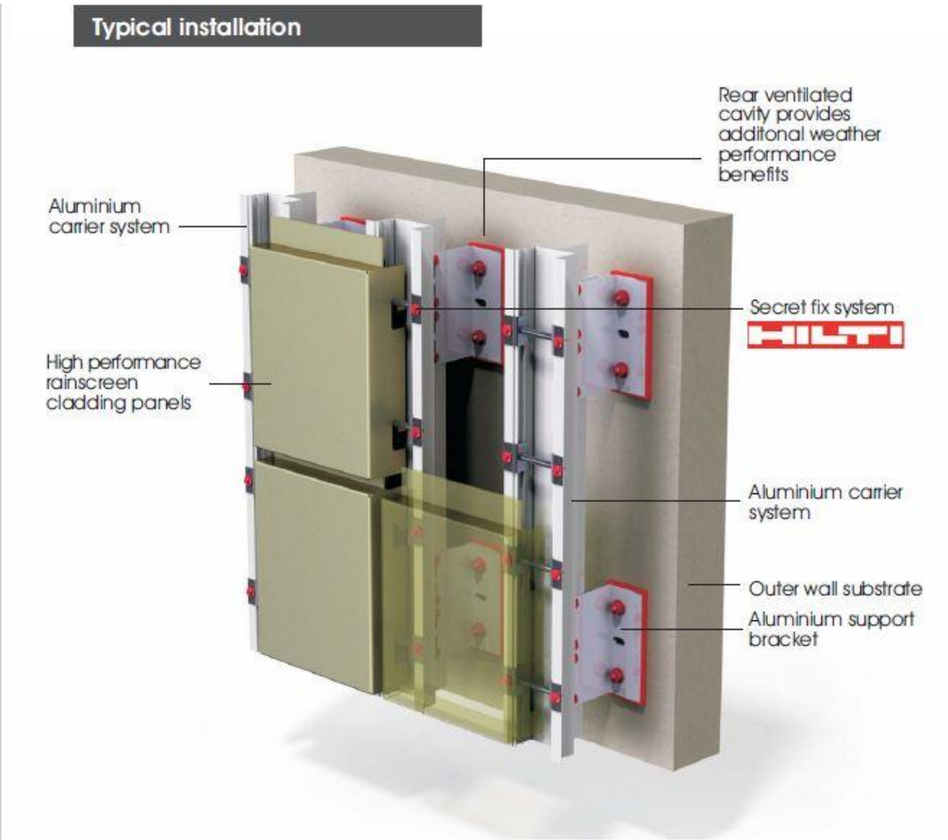


The Hook-on Façade System

4.3 Around the same time that the specification of the materials was changed, the type of façade system was also changed to a hook-on system (*Diagrams 8 & 9)*. This too lacked adequate fire protection, and as with the earlier drawings, no fire protection is shown. Cavity barriers were not designed into the system at the outset and were added retrospectively to the scheme. The reasons for the change of system type appear to be mainly aesthetic. As the panels are fixed internally, a smooth look could be created by avoiding the use of fixings such as screws and rivets which would be visible from the outside. The hooked attachments would also secure the panels much better than other invisible fixing methods such as adhesive. Panels fixed with adhesive will detach and drop off under certain conditions, including during a fire.



<u>Diagram 8</u>: Two extracts from a draft drawing by Studio E Architects dated 2014 showing details of the cladding system; the one on the left shows the details at cill level, whereas that on the right shows the details above the window head. It is much bulkier than the previous design and the carrier rails are shown with hook attachments for the panels.



<u>Diagram 9</u>: 3D image showing the typical arrangement inside a hook-on façade system; the carrier rails are attached to brackets fixed to the wall, and the rainscreen panels are hooked directly onto bolts between the two arms of the U-shaped rails. No insulation is shown in this image, but this is for clarity because insulation - if shown – it would obscure the bracket details.

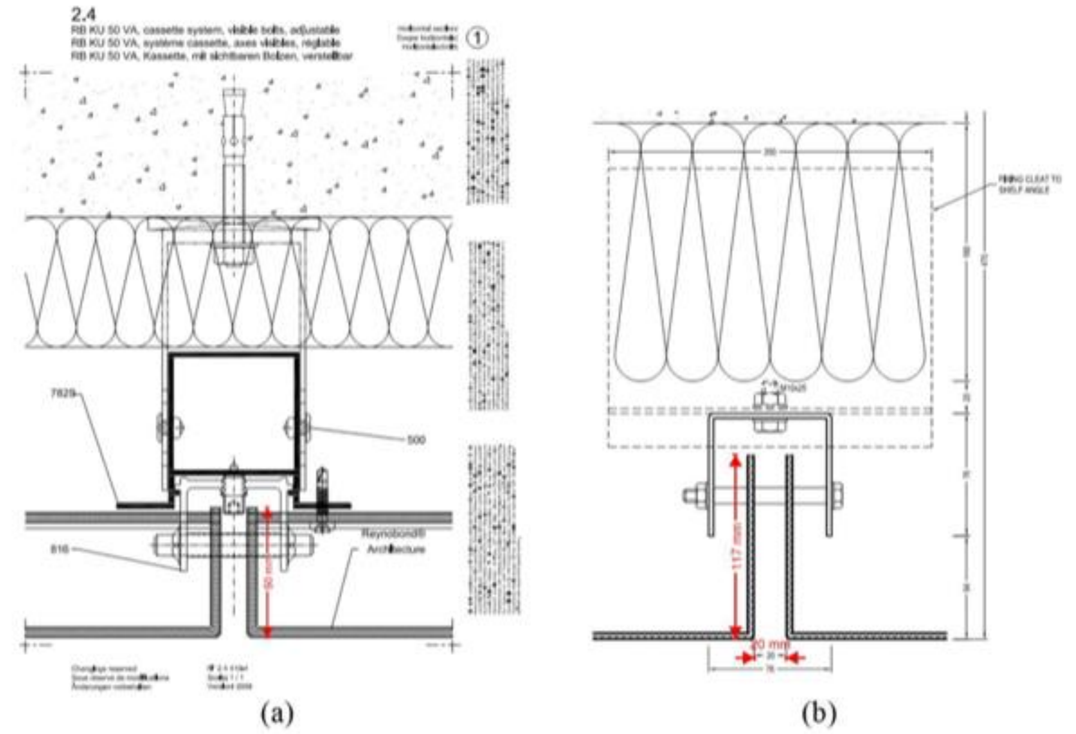


Figure 8.62 (a) Arconic Standard detail for KU50 (50mm return of ACP panel) (b) Depth of return of Grenfell Cladding panel (measured from C1059-305 Rev D [HAR00008903])

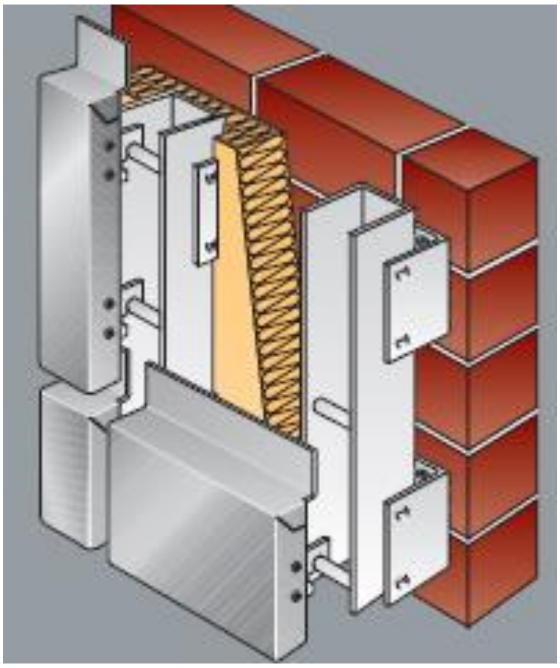
Diagram 10: A horizontal section through two different hook-on façade systems. The one on the left is a standard Arconic system of this type with the ACM panels configured in such way that they can be secured internally with screw fixings. The one on the right is what was installed at Grenfell Tower, with the panels configured in such a way that they cannot be secured with internal fixings, and rely on the hook-on method only. ***Source: Dr Barbara Lane's Supplementary Report.***

4.4 However, hook-on panels are not without their disadvantages either, because they can have problems withstanding increased wind loads. They are also prone to rattling, caused by minor movement of the panels as the wind speed increases. This will explain the noise described by some residents in their Witness Statements for the Grenfell Inquiry. This issue is usually dealt with by attaching a support sheet or rib to the rear of the panels to stabilise them, which in the case of Grenfell may be the "metal sheet" Dr Barbara Lane describes in her Expert Report, following her examination of the cladding system at the Tower. She says, "*The returns of the cladding panels at Grenfell Tower were also fitted with a metal sheet at the edge where it hangs on the bolt and carrier rail."* The fact that residents could still hear the noise despite this measure being in place, suggests that it was either not fitted correctly or was simply ineffective. It is not known whether these panel supports were consistently fitted throughout the building, or were present in certain locations only.

4.5 In view of the analysis above, the following remarks about the cladding system made in the witness statement of Roy Smith (Flat 95, Floor 12) are of relevance; "*When it was windy you could hear the cladding rattle. I telephoned Rydon and someone was sent round to inspect the cladding. He told me that the panels could not be screwed onto or riveted to the window reveal. He then took the cladding off, put it over his knee, bent it to reshape it and put it back* *on the building.*" The cladding was rattling because the panels did not have additional support such as the screws shown in *Diagram 10*, and they could not be screwed or riveted to the window reveal because the system was not designed that way. As the workman was able to remove the panel from the façade with such ease suggests that stabilisation sheets or support ribs were not present at this location, and all he had to do was unhook the panel from the bolt, reshape it, and then hook it back over.

Use of Cladding Rails to Achieve Zoning

4.6 Whilst working on this report, I examined numerous diagrams for various types of rainscreen cladding systems, including flat panel systems (fixed with screws, rivets and adhesive), hook-in systems (panels secured with a bolt through a hole) and hook-on systems (panels attached by being hooked over a bolt). It is the latter type of system which was present at Grenfell. One system I came across – of the hook-in type, rather than hook-on, but nevertheless based on the same concept – used carrier rails rather than vertical cavity barriers to divide the system into zones (*Diagram 11*). Although the details for this system (which were on a Far Eastern website) have since been removed, it is so similar to the system used at Grenfell Tower, it is worthy of further consideration.



<u>Diagram 11</u>: The arrangement of rails, fixings, panels and insulation which make up the hook-in rainscreen façade system as seen here; the U-shaped carrier rails are set back into the insulation, and at the front of the system they touch the rear of the lips on cladding panels (which they should sit against tightly with no gaps), thus creating an independent zone between the rails. The space between the lip at the top of one panel and the lip of the one above, enables segmental ventilation.

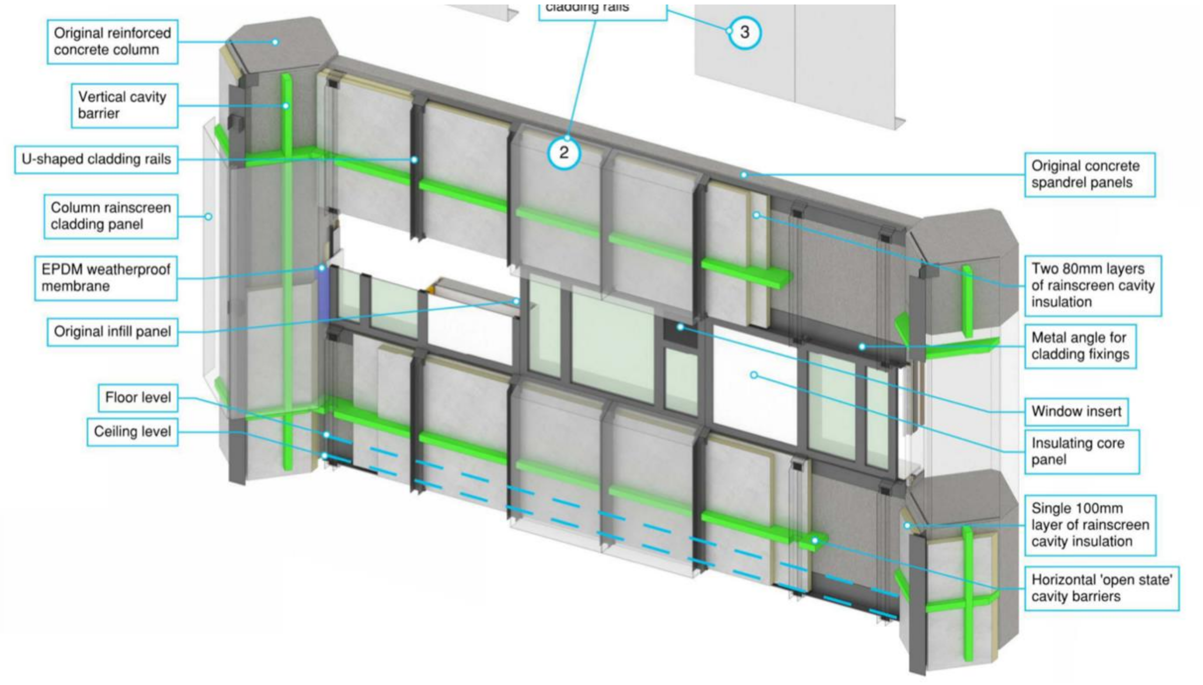


Figure 8.8: Render of external wall construction after completion of the refurbishment works

Diagram 12: Graphic of a spandrel bay at Grenfell Tower with two columns. The ACM panels have been removed to show the interior of the cladding system where cavity barriers are shown in green. The space is interrupted at intervals by the carrier rails to form "boxes" within which a fire could potentially be contained. On the columns some vertical cavity barriers are present, but these seem only to be in places where separation and division of the space cannot be achieved with carrier rails. There are no cavity barriers at the tips of columns because it was probably believed that a fire would never be able to pass the non-combustible metal rail located there. ***Diagram: Dr Barbara Lane's Supplementary Report, Part 8***

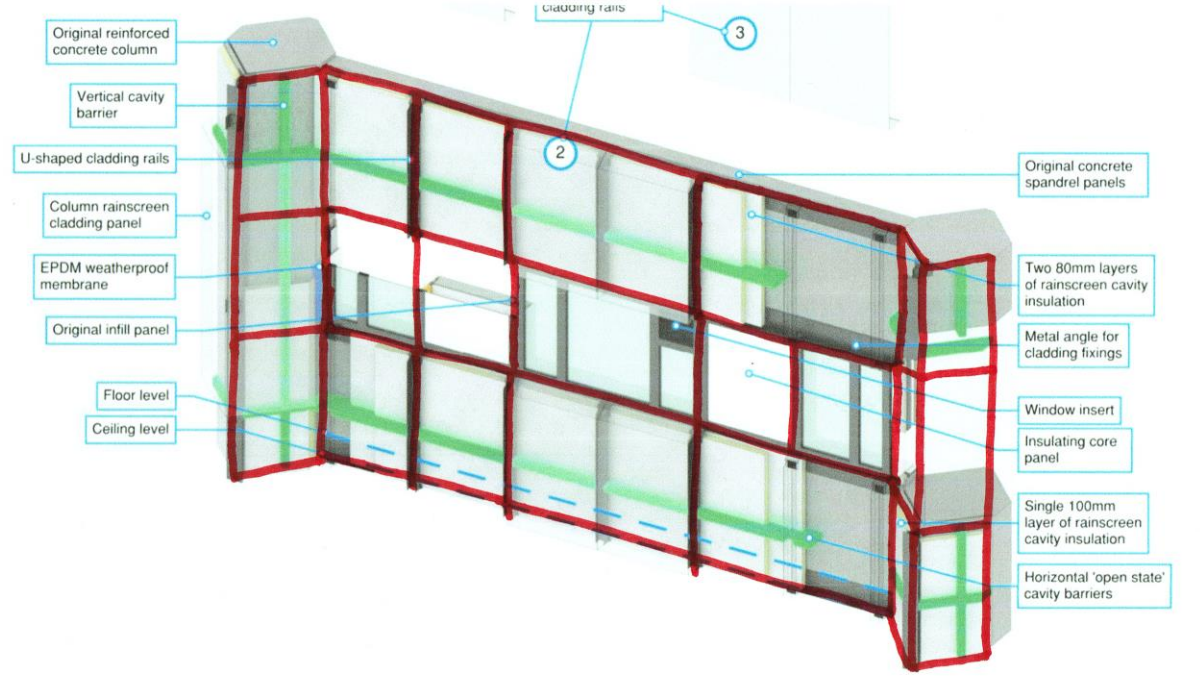


Diagram 13: I have hand-drawn in red the positions where vertical and horizontal cavity barriers should have been installed. Please compare with Diagram 10 above.

4.7 With this system, the carrier rails are set back into the insulation, and at the front of the system they touch the cladding panels, which they sit against tightly with no gaps. This divides the system into segments, allowing for expansion within the system and creating zones which can be individually ventilated. There is no mention of cavity barriers, and the accompanying literature refers specifically to the zoning being created by carrier rails, implying that this is something which can be achieved with a hook-in system, but not a flat panel system.

4.8 It would seem that as well as being individually ventilated, the idea is for the spread of fire to be contained within a single zone between the carrier rails which, if installed correctly, are so tightly fitted that the flames cannot spread into any of the adjacent zones. However, there is then an even greater reliance on installation taking place without any defects, than there would be otherwise. Perhaps most crucially, the concept also depends on the use of materials which are *non-combustible*, and this applies to *both* the insulation *and* the cladding panels. Even if one of these components is combustible, the system will not be fire proof.

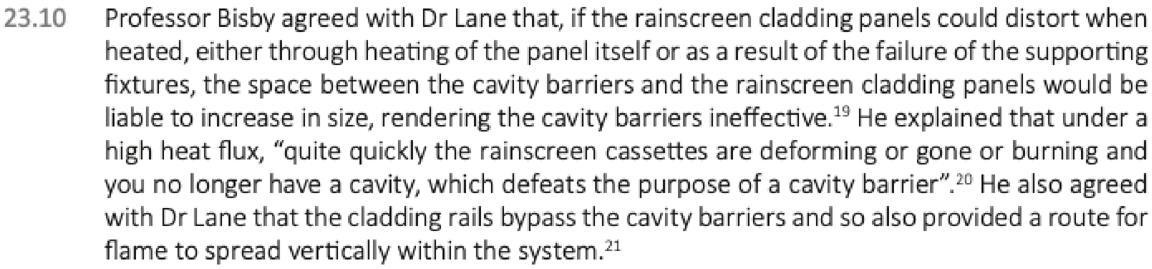
4.9 At Grenfell the carrier rails were arranged in such a way that they effectively divided the system into segments, each separated vertically by a carrier rail (*Diagram 12*). It is almost as if the designers believed that even without cavity barriers, the presence of the carrier rails would act as a substitute for vertical cavity barriers and restrict the spread of fire. If the fire was able to breach a window, it would have been assumed that the compartmented structure of the flat would be able to contain it. Clearly this notion was flawed, as was proved by the events of 14 June 2017.

4.10 However, this arrangement does not eliminate the need for horizontal cavity barriers where there is a change of direction (such as the columns), nor fire barriers around openings in the building envelope (such as windows) which should be isolated from the cladding zones by both horizontal and vertical barriers. These fundamental principles must always be followed regardless of the design of the cladding system. The cavity barriers hand drawn into *Diagram 13* therefore, are in the locations where one would expect them to be installed in order to make the system safe.

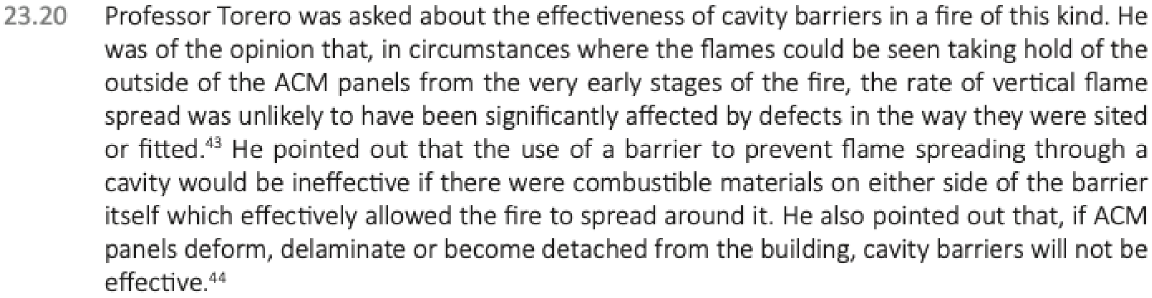
4.11 In general there seems to have been a lack of understanding and a considerable amount of confusion regarding the position of cavity barriers. For example, in an exchange of emails between Harley, Studio E and Exova in September 2014, the discussion centred around the chimney effect and positioning cavity barriers to prevent its occurrence. Consequently it was believed that although barriers should be present at every floor level, they were necessary on the columns only. In emails exchanged in March 2015, the lack of understanding is demonstrated further when the distinction between cavity barriers and fire stops is confused.

How Effective would Cavity Barriers have been?

4.12 According to the Inquiry's experts, Professor Luke Bisby, Dr Barbara Lane and Professor Jose Torero, the presence of cavity barriers, even if they had been correctly installed would have made little difference to the spread of fire because combustible materials were used in the cladding system. Both the cladding panels themselves and the insulation were flammable, and therefore able to render the barriers ineffective. Below are two extracts from the Grenfell Inquiry Phase 1 report, Volume 4, Chapter 23:



23.10 Professor Bisby agreed with Dr Lane that, if the rainscreen cladding panels could distort when heated, either through heating of the panel itself or as a result of the failure of the supporting fixtures, the space between the cavity barriers and the rainscreen cladding panels would be liable to increase in size, rendering the cavity barriers ineffective.[19] He explained that under a high heat flux, "quite quickly the rainscreen cassettes are deforming or gone or burning and you no longer have a cavity, which defeats the purpose of a cavity barrier".[20] He also agreed with Dr Lane that the cladding rails bypass the cavity barriers and so also provided a route for flame to spread vertically within the system.[21]



23.20 Professor Torero was asked about the effectiveness of cavity barriers in a fire of this kind. He was of the opinion that, in circumstances where the flames could be seen taking hold of the outside of the ACM panels from the very early stages of the fire, the rate of vertical flame spread was unlikely to have been significantly affected by defects in the way they were sited or fitted.[43] He pointed out that the use of a barrier to prevent flame spreading through a cavity would be ineffective if there were combustible materials on either side of the barrier itself which effectively allowed the fire to spread around it. He also pointed out that, if ACM panels deform, delaminate or become detached from the building, cavity barriers will not be effective.[44]

4.13 The first extract – 23.10 – sets out Professor Bisby's conclusions; the second extract – 23.20 – those of Professor Torero. From this it can be realised that even if more barriers had been in place, and had been better installed and positioned (including around the windows), they would not have prevented the spread of fire due to the presence of combustible materials within the façade. Nevertheless, poor installation cannot be excused because it has the potential to render a system which would otherwise be safe (ie. If it had no combustible materials present) dangerous.

4.14 In my Grenfell Tower Report 1 (August 2017, revised February 2018), I acknowledge the issue of fire being able to bypass the cavity barriers. I state:

"*If the fire is concentrated on the outside of the rainscreen cladding system and has affected the cores of the panels, there is nothing that the cavity barriers can do to contain it, and in this situation they are of limited use. A fire can also create its own cavities within the material inside the ACM panels and will behave in a similar way to a fire within a constructional cavity, with the flames becoming ever more elongated as they search for a source of oxygen. As a fire in this situation is also outside the area protected by the cavity barriers, there is nothing that they can do to restrict it.*"

This report was first written in the weeks following the fire and it was apparent to me then that this was likely to be an issue. Due to the combustible nature of the insulation and cladding materials, attempts to make the rainscreen façade safe by conventional methods such as cavity barriers, were doomed to failure.

4.15 However, in the case of Grenfell I am not prepared to dismiss cavity barriers completely because in some circumstances they may still have made a difference, even if it was very limited and only for a short time. If cavity barriers had been installed around the windows in the correct locations, they would have had the effect of surrounding each opening with a protective ring of non-combustible material which may have offered a limited amount of short-term protection. They may have helped in situations where the fire re-entered the building in multiple locations from the outside by breaching window openings. Given the highly combustible nature of the façade materials the fire would eventually have overcome the barriers by the methods stated in *Paragraphs 4.12, 4.14* and *4.16*, but in view of the loss of life which occurred, anything which may have made a difference is worth considering.

4.16 In summary, the following issues will render cavity barriers in a rainscreen cladding system ineffective:

- Distortion of the rainscreen cladding panels;
- Destruction of the rainscreen cladding panels;
- Cladding rails which create vertical channels through which flames can spread;
- Flames creating cavities within the cores of the cladding panels;
- Flame spread across the exterior of the panels;
- The presence of combustible materials, especially if both the insulation and rainscreen panels are made from substances which are flammable;
- It is also possible for flames to pass through the ventilation gap before the barriers have had chance to expand and close it.

5. Physical and Chemical Properties of the Façade Materials

5.1 The polyethylene (PE) cores of the aluminium composite panels (ACM) and polyisocyanurate (PIR) insulation boards are made from hydrocarbon-based materials with physical and chemical properties which encourage fire to spread rapidly.

Thermal Conductivity and Radiant Heat

5.2 There are several types of carrier rail present within the rainscreen façade at Grenfell Tower. Those used to support the in-fill panels between the windows consisted of L-shaped and T-shaped sections, which were silver in appearance (*Photos 2* and *3*). The other type – used to support the ACM (aluminium composite material) panels on the columns and spandrels – were U-shaped (described as C-shaped in some documents) with a dark-coloured coating. The panels were hung from bolts between the two arms of the “U”, and had a specially shaped attachment at the rear (*Diagrams 9, 10* and *11*).

5.3 It is possible that the metal rails within the cladding system helped the fire to spread by conducting heat to other parts of the system not yet affected by the fire. Metal is a good conductor of heat and a metal girder passing through a wall into a neighbouring compartment may conduct sufficient heat to enable the contents of that compartment to ignite, without the fire actually needing to enter the room itself (*Diagram 14*). This is recognised as a particular problem with steel framed industrial buildings. If this scenario is applied to a rainscreen cladding system, heat will be conducted along the rails and this may be sufficient to ignite combustible material ahead of the fire front.

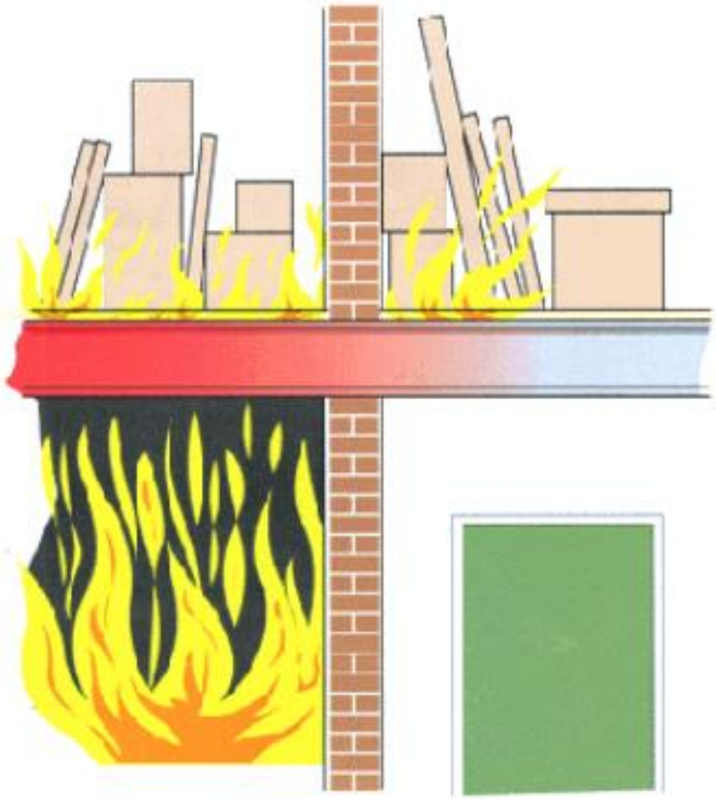


Diagram 14: An image taken from a Firefighters' training manual showing how the conduction of heat along a metal girder can cause the contents in adjacent compartments to ignite without the fire needing to enter these areas.

5.4 The colour of the carrier rails may also have had some influence upon the conduction of heat. As mentioned in *Paragraph 5.2*, the L-shaped and T-shaped rails are shiny silver, whereas the U-shaped rails are black. Objects with shiny surfaces will repel and reflect radiation, whereas those with matt surfaces will absorb it. Therefore, the different surfaces may also have had an effect upon the reflection or absorption of radiation within the cladding system. Objects with reflective surfaces will repel radiation coming from external sources, but if the heat source is inside the object, a rise in temperature will occur from within and the reflective surface will prevent it from escaping. Therefore the shiny silver carrier rails would have repelled the heat being radiated within the cladding system and reflected it back onto the combustible materials such as the extruded polystyrene (XPS) within the infill panels. If the heat from the fire was able to penetrate deeply into the metal, the shiny rails would then retain it and conduct the heat to other areas of the cladding system. The dark rails, although better at absorbing heat than the shiny ones, would be less able to retain it and conduct it to other parts of the rainscreen façade.

5.5 In view of the analysis in *Paragraph 5.3*, it can also be considered how the colour of the cores within the ACM panels may have affected the fire spread. Professor Bisby has indicated that he will look at this issue during Phase 2. Some of the ACM panels had light coloured cores, but most were dark, a change apparently being made midway through the installation because darker cores perform better in sunlight. Neither core had a particularly reflective surface, and it is likely that the darker cores – if exposed – would absorb more radiated heat than the lighter cores. In both cases, heat loss from the cores would be prevented by the aluminium skins, but only whilst they remained intact.

5.6 It is now worth considering the effect that the colour and finish of the ACM panels may have had upon their response to radiated heat. In the architects' specifications the colour is described as "smokescreen silver" with a metallic finish. Therefore they had a shiny surface and hence the potential to reflect radiated heat from external sources. However, the reflective surface would mean that any heat entering the cores of the panels internally would be prevented from escaping, causing a rise in internal temperature until the skins of the panels eventually deteriorated in the fire.

Insulation

5.7 There are various types of insulation – Extruded Polystyrene (XPS), Expanded Polystyrene (EPS), Polyurethane (PUR), Polyisocyanurate (PIR), phenolic and mineral wool. PUR and PIR have similar properties, and when exposed to fire, both will char to form a protective layer. As the char layer thickens, it begins to act as an insulator, protecting the undamaged material underneath from the effects of the heat. The char layer will to some extent control the rate of burning (pyrolysis), but it should not be relied on as a form of fire resistance because charring is part of the pyrolysis process and consequently the layer will only last for a limited period of time before it is consumed (*Photos 9, 10 & 11*). Char layers are also prone to damage, and as soon as the layer is punctured or becomes detached, fresh insulation will be exposed and will ignite. Mineral based insulation such as rock wool does not tend to burn, but it is dependent on correct installation because any gaps which occur will allow fire to spread.

5.8 The insulation at Grenfell is of the PIR type, in this case manufactured by Celotex with the product number RS 5000. There can be no doubt that this material is flammable should it come into contact with a naked flame. Even if it does not instantly ignite, it will nevertheless combust if enough heat is generated. Polyisocyanurate is of low density and will heat up rapidly when exposed to a heat transfer process such as radiation. This is because it has a low *specific heat capacity*, which means that it will heat up faster than materials with a higher heat capacity because it takes less energy to raise the temperature by a given amount.

5.9 The insulation boards are covered with a reflective foil sheet, and whilst this remains intact, it will repel any radiated heat and prevent the material from absorbing it. If the foil coating is damaged, but remains intact elsewhere, any heat which enters the insulation will be retained because the shiny surface of the foil will prevent it from escaping. Once the foil has degraded, the exposed PIR will heat up rapidly due to its low density and will quickly burn to form a char layer. The presence of moisture, which can be absorbed by the insulation during firefighting (see *Paragraph 5.27*), can also have an effect. This may delay the formation of a char layer, but once it forms, it is likely to last for longer than it would do if the material was dry.

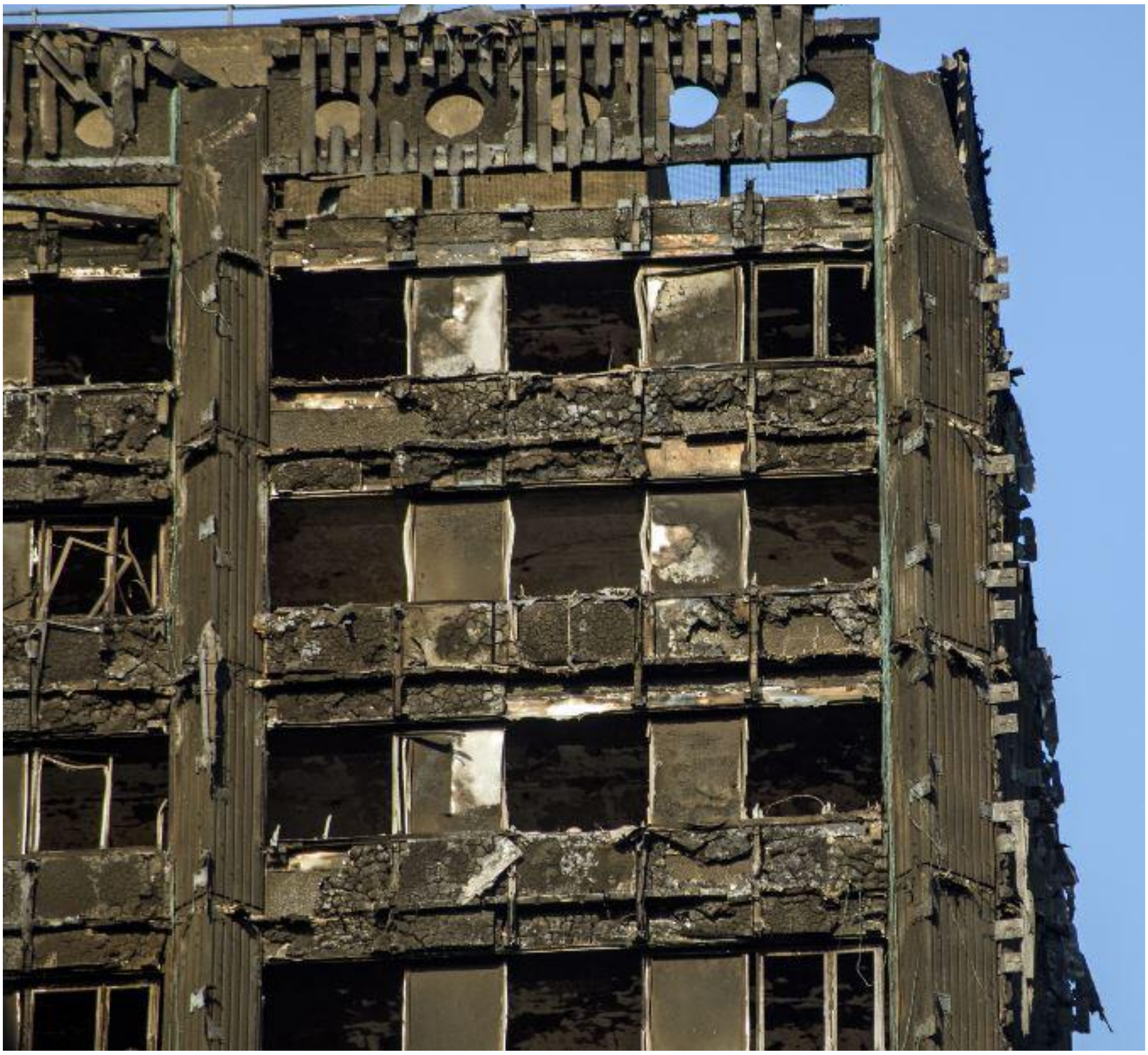


Photo 9: The upper floors of the west face of Grenfell Tower showing complete consumption of the PIR insulation despite the charring. It can be seen that the pieces of insulation which have survived at this level are charred all the way through, indicating that successive protective layers which formed as the material burnt were progressively destroyed as the fire continued.

<u>Photo 10</u>: A close-up of the north-west corner of Grenfell Tower showing damaged PIR insulation where the charred layer has detached to expose the material underneath. At these lower levels, the heat was less intense so the insulation has not completely burned through as it has on the upper levels.

<u>Photo 11</u>: The south face of Grenfell Tower showing the progressive change in the severity of damage to the PIR insulation with ascension up the façade

5.10 PIR is in widespread use and is not simply confined to external cladding systems on tower blocks (and other buildings such as schools, hospitals and hotels). It is also used as cavity wall insulation, roof insulation and floor insulation in thousands of ordinary domestic properties. Potentially, these buildings have all been constructed with total reliance on the fact that the insulation will be sufficiently well sealed within the construction of the building that a flame can never come into contact with it. This presumption relies entirely on the construction being carried out without any defects, and an assumption that the building will maintain its structural integrity in the event of a fire. It is also assumed that any fire stopping or barriers provided will be correctly installed and fully effective. Indeed, as well as there being a number of fires which have involved external materials, there have also been fires within cavity walls and roof spaces.

5.11 At Grenfell, the PIR insulation was not sufficiently well sealed within the construction for there to be a guarantee that flames could not come into contact with it if there was a fire. The edges were not taped, leaving the combustible material fully exposed to any flames which may enter the cladding system via the insulation gaps at window head and cill levels (*Photo 12* and *Diagram 15*).

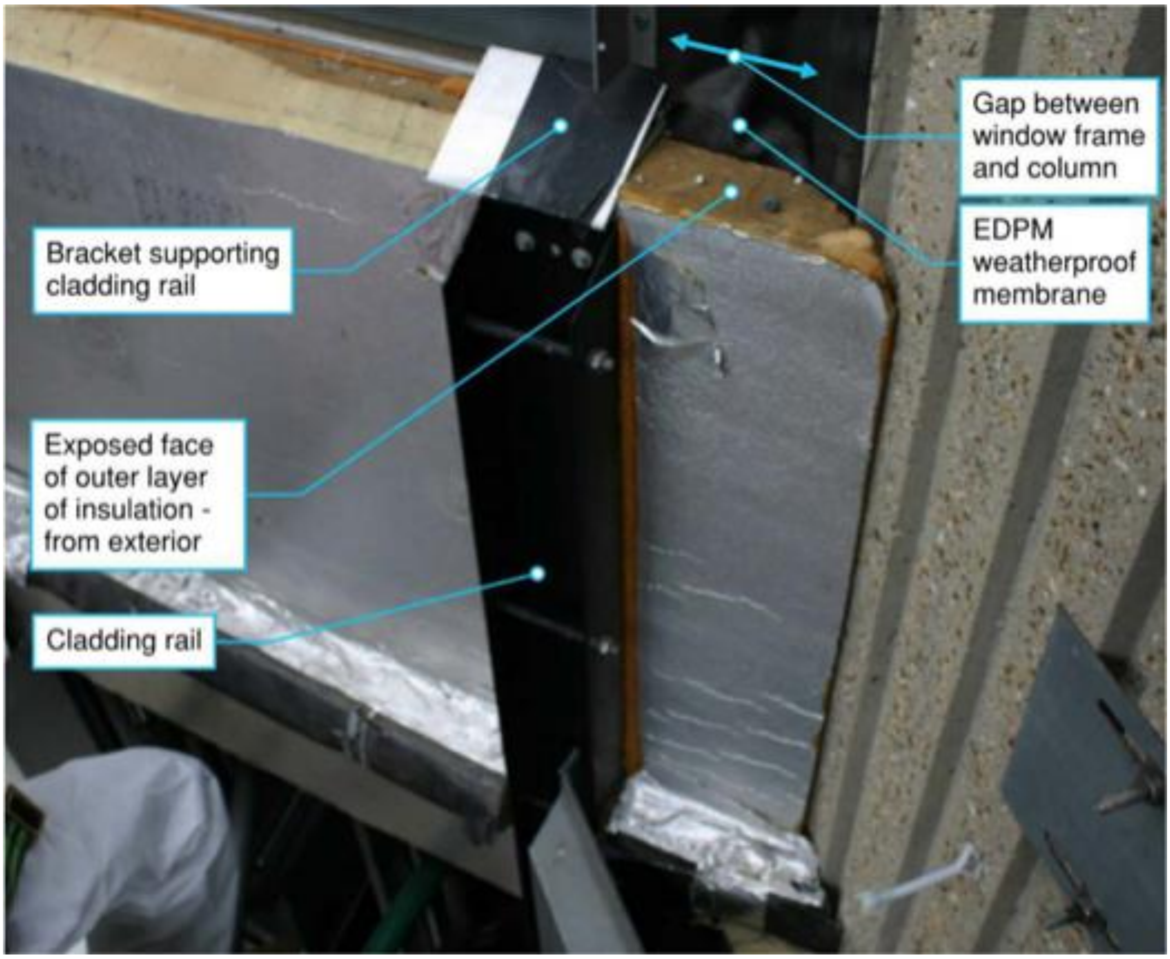


Photo 12: Insulation on a spandrel at Grenfell showing exposed PIR insulation along the edge at cill level. Such exposed insulation was also present at the window head and was accessible to flames through the ventilation gaps (see *Diagram 15*). *Source: Dr Barbara Lane's Expert Report*

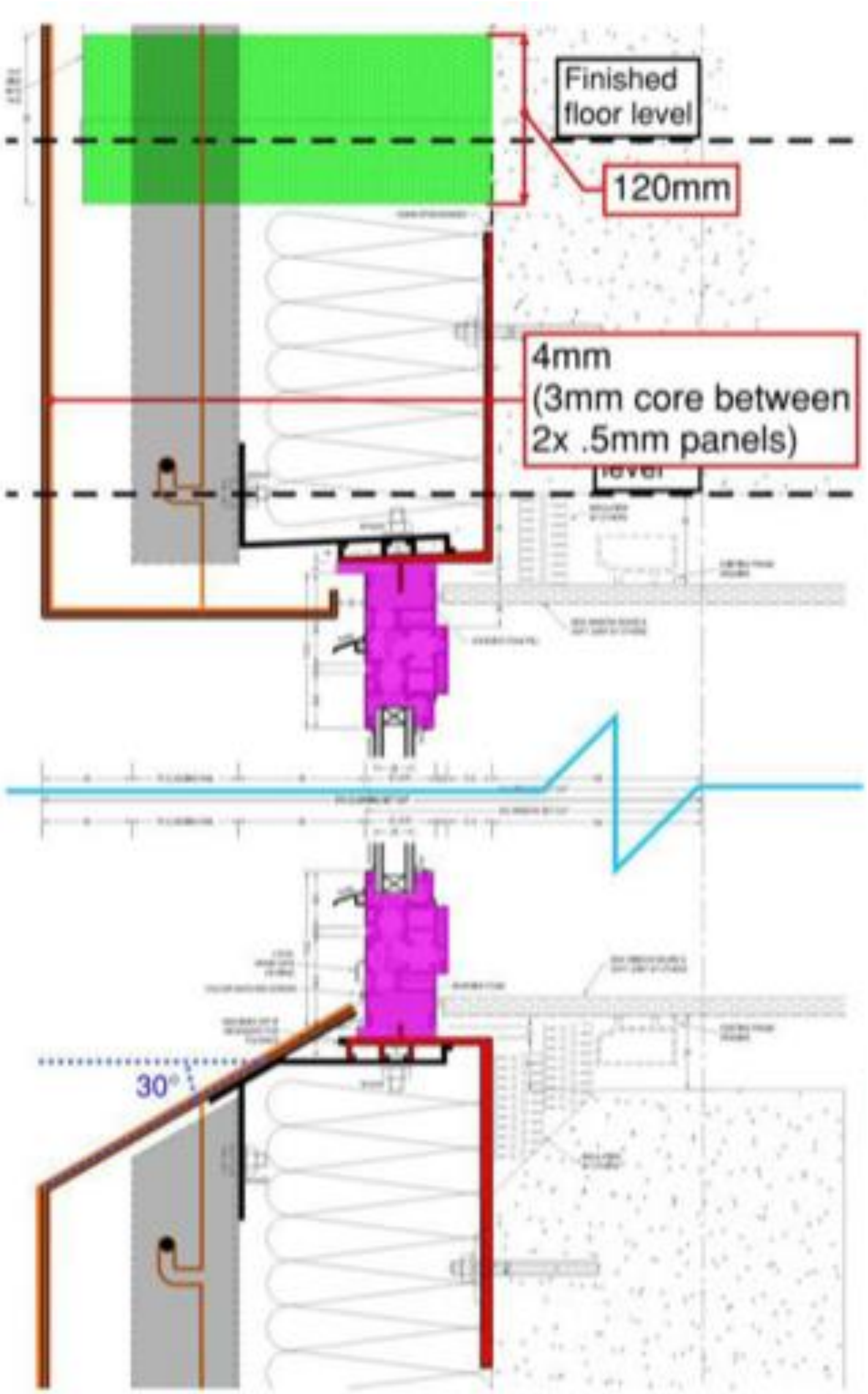
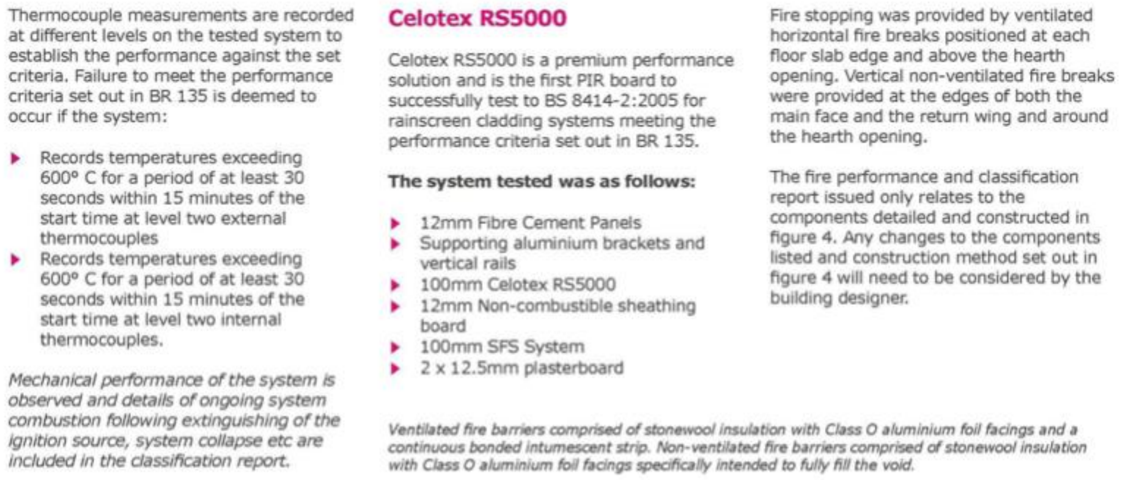


Diagram 15: In this diagram from Dr Barbara Lane's Supplementary report, the details of the cladding system at the window head (top of the diagram) and window cill (bottom of the diagram) are shown. Fire can easily enter the system through the ventilation gaps which are present at each of these locations. The ACM panels also had exposed edges, meaning that their Polyethylene cores were accessible to fire.

5.12 Despite the risks outlined above, the RS 5000 insulation nevertheless obtained Class 0 fire performance in accordance with BS 476 and was successfully tested to BS 8414-2:2005, thus fulfilling the performance criteria for Building Regulation 135. However, it should be noted that the product obtained this classification by being tested as part of a system which was rather different to that installed at Grenfell. The manufacturer's datasheet of December 2015 (*Fig.1*) states that *the fire performance and classification report issued only relates to the components detailed,* which means that the company cannot guarantee the safety and performance of the insulation when used with other components in a different cladding system. The RS 5000 insulation was tested as part of the following system which differed somewhat from that which was installed at Grenfell Tower:

- 12mm Fibre Cement Panels
- Supporting aluminium brackets and vertical rails
- 100mm Celotex RS 5000 PIR insulation
- 12mm non-combustible sheathing board
- 100mm SFS system
- 2 x 12.5mm plasterboard

Most notably it does not contain rainscreen cassette panels with potentially flammable cores, and a non-combustible sheathing board is present. It is important to note that there were no components within the cladding system at Grenfell which were termed "non-combustible."



Thermocouple measurements are recorded at different levels on the tested system to establish the performance against the set criteria. Failure to meet the performance criteria set out in BR 135 is deemed to occur if the system:

- Records temperatures exceeding 600° C for a period of at least 30 seconds within 15 minutes of the start time at level two external thermocouples
- Records temperatures exceeding 600° C for a period of at least 30 seconds within 15 minutes of the start time at level two internal thermocouples.

Mechanical performance of the system is observed and details of ongoing system combustion following extinguishing of the ignition source, system collapse etc are included in the classification report.

Celotex RS5000

Celotex RS5000 is a premium performance solution and is the first PIR board to successfully test to BS 8414-2:2005 for rainscreen cladding systems meeting the performance criteria set out in BR 135.

The system tested was as follows:

- 12mm Fibre Cement Panels
- Supporting aluminium brackets and vertical rails
- 100mm Celotex RS5000
- 12mm Non-combustible sheathing board
- 100mm SFS System
- 2 x 12.5mm plasterboard

Ventilated fire barriers comprised of stonewool insulation with Class O aluminium foil facings and a continuous bonded intumescent strip. Non-ventilated fire barriers comprised of stonewool insulation with Class O aluminium foil facings specifically intended to fully fill the void.

Fire stopping was provided by ventilated horizontal fire breaks positioned at each floor slab edge and above the hearth opening. Vertical non-ventilated fire breaks were provided at the edges of both the main face and the return wing and around the hearth opening.

The fire performance and classification report issued only relates to the components detailed and constructed in figure 4. Any changes to the components listed and construction method set out in figure 4 will need to be considered by the building designer.

Figure 1: Extract for Celotex product information sheet explaining the testing of their RS5000 insulation. Nowhere does it say that the product is "Class 0 throughout" as has been claimed by Harley Facades.

5.13 Although the sale of RS 5000 has now ceased for buildings over 18m tall, it was at the time claimed to be the first insulation product deemed suitable for use in buildings of this height. It had achieved a Class 0 rating, which was accepted by both Harley Facades and Studio E, despite the fact that it does not refer to a product's combustibility (see *Paragraph 2.14*), nor did it seem to be acknowledged that the product had been tested as part of a system which bore no resemblance to that which was to be installed at Grenfell Tower. At this stage it is worth keeping an open mind about the decisions which were made here, although the means by which the product was tested are clearly stated in the product data sheet (*Fig.1*). This however did not guarantee that the product was safe to use on high-rise buildings and it should not have been promoted as such.

5.14 The report of the Inquiry's architectural expert, Paul Hyett is not yet publicly available at the time of writing, but nevertheless some of the content is known from references in witness statements. In Paragraph 16.8 of his report, Mr. Hyett states that he would "*not have expected [architects] to be alert to the particular dangers arising from the use of ACP (aluminium composite panel) rainscreen cladding incorporating polyethylene cores*." This statement throws up a number of questions about architects' training and technical knowledge, and it is shocking that architects can specify products without being aware of their physical and chemical properties. Most significant is the apparent knowledge of how these materials will perform in a fire. Studio E had a key role in the design of the refurbishment and the specification of products, yet Mr. Hyett claims that they – as architects – not be reasonably expected to know whether or not a particular panel or insulation consisted of flammable material! This issue will be examined in further detail later in this report.

Cladding Panels

5.15 Reynobond ACM panels are manufactured by Arconic Architectural Products, based in France. There are several types, including ones which have fire retardant (FR) or non-combustible cores. The Reynobond Architecture panel with an FR core has a Class B fire rating and is described as "*non-flammable which prevents fires from spreading*." A product rated Class B is deemed to be *hardly combustible* and capable only of *limited combustion.* The Reynobond Architecture A2 panel is described as "*non-combustible*" and that "*it meets the stringent fire-reaction requirements for the European fire certification EN 13501-1*." A product rated A2 is deemed to be *incombustible* and able to achieve *zero combustion*. The company produces a brochure for its products which are termed as "fire solutions," and although the two types of Reynobond panels described above are included, the ones with PE cores which were used at Grenfell are *not*. This would imply that panels with PE cores are not suitable for use on tall buildings. The leaflet dates from December 2016 and pre-dates the Grenfell fire, but as it was published after the refurbishment was completed, it would not have been used by the companies involved in drawing up the specifications. The literature which was around at the time was not as clear about the fire risk, which is explicitly acknowledged in this later leaflet where it is stated that "*as soon as the building is higher than the firefighters' ladders, it has to be conceived with an incombustible material*." In other words, only the A2 panels will be acceptable in buildings as high as Grenfell Tower, meaning that the use of panels with PE cores should not even have been considered.

5.16 Of course the obvious issue with ACM panels is that unlike insulation they can never be sealed within a wall cavity, or any other aspect of the construction due to the fact that they are intended as an external feature. Therefore, they are fully exposed at all times with total reliance being placed on an assumption that the chance of a severe fire is relatively low and that the filler material and its outer coatings will have some resistance to fire. The events at Grenfell, as well as the tests commissioned by the Ministry for Housing, Communities and Local Government (MHCLG as it is now called) following the fire, have shown that this is a dangerous assumption to make. At Grenfell, the danger posed by the panels was greatly increased due to cut edges being left unsealed to expose the flammable core.

5.17 Polyethylene is a thermoplastic polymer with a low *thermal conductivity*, which means that heat has a tendency to accumulate at the surface rather than being transferred deeper into the body of the solid by conduction. This results in a rapid rise in temperature, enabling the material to ignite more easily. As polyethylene is of low density, it will heat up quickly when subjected to a heat, especially as it has a low *specific heat capacity*, meaning that it takes less energy to raise the temperature by a given amount. The PE cores of the panels have a high *heat release rate*, which results in a higher *rate of combustion*, causing extremely rapid fire spread. The *rate* at which the heat is released is of greater significance to the spread of fire than the *amount* of heat which is produced.

Summary:

As can be realised, the fire at Grenfell Tower was extremely complex with many different processes operating simultaneously. These are summarised below:

- Absorption of heat from within;
- Retention of heat due to the reflective coating on the ACM panels;
- High Heat Release Rate;
- High rate of combustion;
- Transmission and absorption of radiated heat;
- Low specific heat capacity;
- Low thermal conductivity;
- Conduction;

Chemical Reactions

5.18 The rainscreen panels at Grenfell Tower had a polyethylene core sandwiched between two thin metal sheets. These sheets are referred to as being made of aluminium, and it is true that they mainly did consist of this particular metal, but magnesium and manganese were also present in smaller quantities. Therefore the metal skins of the panels contained 6% magnesium and 1.5% manganese, both of which were added to give the skin additional strength. The panels also had a coating to give them their chosen finish, and this consisted of resin with a small amount of chromium (III) oxide.

5.19 It is widely known that in certain circumstances aluminium can be a dangerous metal which can be explosive. This is acknowledged in the product safety sheet which gives guidance for cutting, fabricating and recycling the panels, as well as firefighting should the panels be involved in a fire. In a bulky mass, the metal is stable and it oxidises in air in normal conditions to form a coating of aluminium oxide. However, if the metal is ground up into finer parts such as powder, dust or turnings, it becomes hazardous. It is also hazardous when molten.

5.20 It is the potential hazard from the metal in its molten form which is of relevance to Grenfell. If the molten metal comes into contact with water or moisture, or oxides from other metals, it may violently explode. The hazard is increased if the pool of molten aluminium is able to trap the water or moisture within or beneath it. When water comes into contact with molten aluminium, it produces hydrogen which is a highly explosive gas. Consequently, the information given in the product information sheet gives firefighters the following advice; "DO NOT use water in fighting fires around molten metal."

5.21 Magnesium is similarly hazardous and easy ignites in powder or ribbon form, but not as a bulky mass. If the burning metal comes into contact with water, it reduces the water to its constituent elements, oxygen and hydrogen. The oxygen increases the rate of combustion and the hydrogen has the potential to explode. Fires involving magnesium are capable of reaching extraordinarily high temperatures in excess of 2000°C.

5.22 Some witnesses have reported interesting observations. Tiago Elves (Flat 105, Floor 13) describes seeing a flash of light when the cladding panels ignited. He says, "*The fire reminded me of a chemistry lesson at school where you would watch magnesium burn. When magnesium first has initial contact in a fire, the fire doesn't burn the magnesium but there is a small flash of bright light as it ignites, and then the magnesium burns. As I looked at the Tower, I was reminded of this and it seemed that the grey cladding was burning in the same way.*" This suggests that the magnesium, even though present in a relatively low quantity, was reacting to the heat from the fire and igniting. It is higher up in the reactivity series than aluminium and will therefore react more readily.

5.23 As water was used as the means of extinguishing the fire at Grenfell Tower, it is worth considering whether a reaction between this and the skins of the ACM panels made a contribution to the fire. Although the flammable PE cores of the panels were most significant in facilitating the fire spread, the reaction of the aluminium and other metals present in the skins may have reacted with the water and increased the intensity of the blaze. It is difficult to quantify this at present because although the ACM covered a very large area (virtually the whole building with the exception of the windows and infill panels), the metal skins were very thin at only 0.5mm in thickness. Aluminium melts at a temperature of around 660°C, and once the fire was hot enough, the skins on multiple panels would begin to burn and melt simultaneously. The fire very quickly became well established on the façade of the building, spreading rapidly and affecting large areas of the exterior at any given time. Collectively, this is a considerable amount of aluminium, particularly as the material was present on both the inner and outer faces of every rainscreen panel on the Tower, which effectively doubled the surface area of it presence. The fact that the manufacturers of the ACM panels advise against fighting fires with water, implies that it is known that skins on the panels can react violently with water in the event of fire.

5.24 Aluminium and water will not generally react at low temperatures, but if the temperature is raised enough, a reaction will occur. As the temperature increases, the reaction rate also increases, resulting in a steady flow of potentially explosive hydrogen gas. Even if the water is cold, it will produce steam when it comes into contact with the hot metal and cause a violent reaction. Hydrogen is a very reactive gas with wide flammability limits, and it will burn in a concentration of just 4% in air. Several witnesses described hearing numerous bangs coming from the Tower, which were assumed to be gas explosions from cooking appliances and gas pipes present in the building. This is most likely to be the source of these explosions, but it is also possible that some of the bangs were coming from the metal in the cladding panels reacting with the water from the firefighters' hoses. It should be noted that some of these witness accounts relate to the early stages of the fire before much of the interior of the building became involved.

5.25 There is further evidence to support this in the form of a test carried out by Professor Laurence Harwood, a chemist from the University of Reading https://phys.org/news/2017-10-evidence-submitted-grenfell-tower-inquiry.html#jCp. In his experiment, Professor Harwood tested an ACM panel of a type similar to that which was used at Grenfell Tower. When I first read about this study, I was somewhat sceptical about the alleged impact the reaction between aluminium and water may have had, but additional research of my own has since changed my view and I am now of the belief that the Professor Harwood's findings are of significance. The reaction between these substances did indeed contribute to the intensity of the fire.

5.26 Professor Harwood is Director of the Chemical Analysis Facility at the University of Reading and is a well-respected scientist in his field. He was commissioned by the BBC to carry out the experiment for a programme it was making about the Tower, and he admits that the results were not what he was expecting. Professor Harwood states, "*While I knew something about the reactivity of aluminium, I was genuinely taken aback the first time I tested my proposal in the laboratory. I wasn't expecting such an intense reaction when I sprayed water onto a panel that I had heated with a blow torch*." In the experiment he had heated an ACM cladding panel to a temperature of over 300°C. Although only about half the temperature the metal needs to reach in order to become molten, it was nevertheless hot enough to produce a reaction. When water was sprayed onto the hot panel, more heat was produced as it turned to steam and reacted with the metal to produce hydrogen gas, which ignited and burnt violently. This shows that the aluminium does not necessarily need to be molten to react with water; it only needs to be hot and a reaction will occur before it reaches that stage.

5.27 Professor Harwood's experiment also revealed something else which is of concern. As the skins of the panels burned away, the PE core became exposed and began to burn. This in turn exposed the PIR insulation at the back of the cladding system which was shown to be capable of absorbing and retaining water. He says, "*The presence of water absorbed by the polyisocyanurate foam, over a lengthy period of exposure to the elements, could play a significant role in accelerating a cladding fire by causing hot aluminium to react violently, generating heat and hydrogen. The latter would then burn violently to produce more heat and* *steam, which would then allow polyethylene inner layers to be exposed over a large surface area, in turn burning to produce more heat and more steam, setting up a feedback loop and causing a runaway fire.*" Therefore, the experiment demonstrated that the insulation has the potential to trap moisture behind the hot or molten aluminium which, as explained in *Paragraph 5.20*, will create the right conditions to cause an explosive and violent reaction.

5.28 Zinc - which was original material proposed for the outer skin of the cladding panels - also reacts with water, but is lower down in the reactivity series and therefore higher temperatures will be required for a reaction to start. However, given the fact that zinc has a lower melting point than aluminium (420°C - 430°C), the metal would degrade much faster at high temperatures, and expose the cores of the ACM panels much sooner. Therefore, zinc would not have been any safer than aluminium if a flammable material was used as the core.

Architectural Designers and Fire Safety

5.29 It is of great concern that those tasked with designing buildings and other forms of construction, have an apparently scant understanding of fire safety issues and the combustible nature of certain materials. The statement made by architectural expert to the Grenfell Tower Inquiry (*Paragraph 5.14*) overtly highlights the issue by saying that it would not have been reasonable for Studio E Architects to be aware of the dangers of using cladding panels with polyethylene cores. Therefore, we have a situation where buildings are being designed all over the country by architects who are unaware of the physical and chemical properties of the materials they are specifying and consequently the hazards these materials may present. Indeed, Bruce Sounes of Studio E admitted that he not know that ACM panels could melt.

5.30 The problem can be traced back to an architect's training, which takes around seven years to fully complete and is in three parts. Part I is the equivalent of undergraduate study and takes three years, followed by Parts II and III which are at post graduate level and are completed largely in practice. An architect who has completed Part II – as was the case with Neil Crawford – is well enough qualified and should have a high enough level of competency – to be able to practice, even though the full training process has not yet been completed. This is the case with most professions, which, when a certain point is reached, the people are considered sufficiently competent to be able to practice. Despite this lengthy process, there is little or no training relating to fire safety.

5.31 The training of architects places emphasis upon thermal efficiency, sustainability, aesthetics, innovation, creativity, inclusivity and sociology. The properties of materials are considered in regard to their thermal efficiency and the U value they can achieve. Fire safety training is limited to the principles of compartmentation, the provision of fire resisting doors, basic fire stopping and means of escape. There has been some debate about this within the Institution of Fire Engineers (IFE), by whom it has been stated that the amount of fire-related tuition is as short as four hours in total on some courses.

5.32 Architectural Technologists fare little better because their courses too have limited course content when it comes to fire, and that also amount to no more than a few hours. Again, this is restricted and does not stretch beyond basic fundamental measures such as compartmentation and fire resisting doors. Both Architectural Technologists and Architects are equally competent when it comes to designing buildings, but there are some notable differences which are not easy to explain and remain little understood by many. Architectural Technology is often described as the "science of architecture," as the emphasis is on the use of technology within architecture, as well as science and engineering. The architectural technologist therefore sits midway between the architect, the scientist, the engineer and the technician. Architectural Technology is considered a STEM (science, technology, engineering and mathematics) subject, and due to its designation as a science, there is greater consideration of the properties of materials more generally, although it is still surprising how little consideration is given to the fire risks associated with some of these materials. As a Chartered member of CIAT I was once asked to judge some student work for a competition. Although the work was beautifully presented, most of the projects did not show any understanding of fire safety issues and I was horrified at the amount of combustible materials being specified. Consequently, I voted for the one I felt presented the lowest fire hazard.

5.33 Therefore, if the problems highlighted in these paragraphs are to be adequately addressed, training for architects, architectural technologists and other designers, has got to change. All architecture-based courses should have a whole module dedicated to fire safety, which should include the properties of materials (beyond their thermal efficiency) and how they may perform during a fire. They should also consider how fire spreads through structures, how it behaves on the exterior of buildings, as well as fire protection measures, access for firefighters, the building regulations (insofar as they relate to fire and Approved Document B) and the means by which materials are tested. I continue to openly advocate this change, but so far the industry seems very set in its ways.

5.34 I will end this discussion by commenting on how unusual many consider me to be when they realise that I am qualified both architecturally and as a fire engineer. "I have never met someone who is qualified as both," they say. Although I am not unique, I know of only a very small number of people who are qualified in both disciplines. This shows that being competent in architecture and fire safety/engineering are poles apart, and this situation will prevail until training is revised. Whilst it would not be practical to expect everyone to qualify in both areas, those in each profession should have an understanding of the fundamentals of the other. It could also be said that fire engineers should also have some architectural training so that they understand the construction of the buildings in which they may work.

5.35 If I was not qualified in both architectural technology and fire engineering, I would not have been able to write this report, or the other which is based on my main research project, *The Relationship between Building Design and Fire Spread: How the shape, form & features of a building can influence the behaviour of fire.* It is by collectively bringing together my knowledge of architecture, engineering and science, as well as fire safety that I have been able to think in the ways necessary to be able to research, examine and analyse these issues.

6. Conclusion

6.1 *Installation of the Rainscreen Façade:* It is important when installing a rainscreen cladding system for the correct procedures to be followed and for it to be ensured that all aspects of the system fit tightly together to avoid any gaps through which fire can spread. In the case of Grenfell, these procedures were not followed and there was a general lack of continuity throughout the installation. For example, the insulation should be installed before the carrier rails for the cladding panels, but at Grenfell this was done the other way round. The system also lacked fire protection throughout, most notably the absence of cavity barriers around the windows.

6.2 In order for a cladding system to be capable of adequately preventing the spread of fire through its interior, it is divided into zones within which a fire should be able to be contained. Each zone is independent of its neighbours and is ventilated individually. At Grenfell, the zoning was so severely compromised, it was virtually none-existent. It would seem that the designers of the cladding system (Harley Facades and Studio E Architects) did not understand the importance of, or concept of, zoning. Studio E admitted having no experience in cladding a high rise building, and this is evident throughout their involvement in the scheme.

6.3 *Installation Defects and the Quality of Workmanship:* The rainscreen cladding system at Grenfell Tower had multiple installation defects. This was partly due to its poor design, but also quality of workmanship which, despite being carried out by fitters who claimed to have many years of experience, was nevertheless substandard. Building Control failed to pick up on these defects, and the Tower was signed off without any rectifications being made.

6.4 Whilst not all of these defects would have necessarily had serious consequences for safety, others introduced significant hazards into the installation. There were multiple gaps in the construction which could be penetrated by fire, such as those which existed around badly cut pieces of insulation. There were also exposed edges of combustible polyethylene and polyisocyanurate at multiple locations throughout the building, including at the window heads where there was no fire protection.

6.5 *The Companies Involved in the Installation:* There were several companies which were involved either directly or indirectly with the design and installation of the rainscreen cladding system at Grenfell Tower. The actions of these companies collectively resulted in serious failings in both the design of the cladding system and the means by which it was installed. The project was dominated by time pressures and the desire to avoid extra costs. It seems that there were delays in getting certain materials onto the site, which resulted in a deviation from correct procedures, with materials being installed as and when they arrived. Consequently, this meant that façade components were installed in the wrong order, because keeping the project within time and budget was seemingly more important for the contractors. If projects overrun, this pushes up the costs, so waiting for certain materials to arrive before installing others was not considered a viable option. The result was serious defects in the installation, such as joints not being taped, and even though it is claimed that this was not specified, an experienced installation contractor should have known that this needed to be done anyway.

6.6 *The Size and Position of the New Windows:* The main reason for the new windows being located forward of their predecessors was to improve thermal efficiency. This was achieved by positioning the windows within the thermal envelope (cladding system) due to its better thermal properties, rather than the concrete frame of the existing building. The new position of the windows created an uncomfortable gap at the interface with the columns. Although this was plugged with an EPDM membrane, over which there was the uPVC lining of the internal window reveals, this did not protect the jambs from penetration by fire, especially as the materials offered no fire resistance and no cavity barriers were present.

6.7 A number of factors gave rise to problems with the window sizing. Most notable was the difficulty in accommodating the bulk of the cladding around the columns so that it would not overlap the window openings. The initial intention was to widen the windows to allow for a thicker frame, but due to concerns of KCTMO about the cost of replacing tenants' curtains and blinds (which would then no longer fit the windows), a decision was made against this. Further complications arose from the fact that the concrete columns are not perfectly aligned, which made accurate sizing of the new windows difficult.

6.8 *Design of the Rainscreen Façade:* The original system chosen for Grenfell Tower was a flat panel system which was later changed to a hook-on façade system. The latter had certain advantages, namely that the panels could be secured without visible fixings such as screws or rivets which would spoil the external appearance. However, a major disadvantage with hook-in systems is that they do not perform well when exposed to an increased wind load, and the panels tend to rattle. This problem is dealt with by providing extra internal support in the form of screws or support ribs.

6.9 *How Effective would Cavity Barriers have been?* Inquiry Experts such as Professor Torero have concluded that the defects were of less significance than combustible nature of the materials themselves, and are therefore they are likely only to have had a minor impact upon the spread of the fire. However, I consider that the whole integrity of the cladding system was severely compromised by the numerous defects, and despite the presence of highly combustible materials, the spread of fire may have been slowed if the system had been installed correctly. Setting aside the presence of combustible materials and the fact that it is possible for flames to pass through the ventilation gap before the barriers have fully expanded to close it, the following issues will render cavity barriers ineffective:

- Distortion of the rainscreen cladding panels;
- Destruction of the rainscreen cladding panels;
- Cladding rails which create vertical channels through which flames can spread;
- Flames creating cavities within the cores of the cladding panels;
- Flame spread across the exterior of the panels;

6.10 A combination of sub-standard work, bad design, poor decision making, ineffective management, and time and budget pressures, all amalgamated to allow a dangerous cladding system, containing large amounts of combustible material and incapable of resisting the spread of fire, to be installed on Grenfell Tower.

6.11 It is surprising how much of the content of my early reports - which were written in the first few weeks and months following the fire - has proved to be an accurate prediction of what would emerge at the Inquiry three or so years later. At I had to work with whatever resources were available at the time, some of the my analysis was carried out without having all the information I would have liked. Nevertheless, because I had ideas and felt that I had answers, it was important to pursue these further in order to help determine what went wrong and why. Those who had lost family members, friends and their homes deserved some answers, and it was also important that those who needed to learn from the tragedy, including the construction industry and fire service, could begin to do so at the earliest opportunity. Those early reports are the embryonic stages from which work which is better informed and greater significance would later develop. The report you are reading now has its roots in that original series of seven, as does my main research project which looks at the effects of building geometry upon the spread and behaviour of fire.

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