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Purpose	BRE Global has been awarded a contract by the Department for Communities and Local Government (DCLG) to continue fire investigation activities on behalf of DCLG until 2018. An important element of this contract is to ensure that findings from fire investigations are made available to the fire community, and other stakeholders. The aim of this article is to address the intentions behind Part B4 Section 12 of Approved Document B – Volume 2 which is concerned with the construction of external walls of buildings. Part 1 of this article discusses previous and current guidance for external fire spread and also discusses several case studies of external fire spread since the introduction of the BS 8414 test series. Following the conclusions of Part 1, it was agreed with DCLG to carry out a new experimental scoping study focusing on the issue of external fire spread. The findings from this experimental study are provided in Part 2 of this article. Overall, the findings from this research show that there is a clear and demonstrable need to ensure that buildings are designed and constructed so that the spread of fire across the external surface is inhibited, as required by the Building Regulations. There is adequate guidance available in the public domain to allow this to be achieved.		
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Approvals:	**Signature**	**Date Sent (Marketing)**	**Date returned (Approver)**
Lead Technical Approval Corinne Williams	Approved 26/05/2015		
Client Approval Brian Martin (DCLG)	By Email 29/05/2015 (with some minor comments)		
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External fire spread – Part 1 Background research

By Ciara Holland, Dr David Crowder and Martin Shipp

Introduction

BRE Global carries out fire investigation activities on behalf of the Department for Communities and Local Government (DCLG); the contract 'Investigation of Real Fires', for which this work was undertaken was completed in 2015 but has since been renewed until 2018.

BRE Global, through this contract with DCLG attend fires of special interest, investigate issues that may have implications for Building Regulations and the guidance that supports Building Regulations, such as the Approved Documents. Access to fire scenes is achieved through contacts with the Fire and Rescue Services and other agencies and their assistance is gratefully acknowledged.

An important element of this contract is to ensure that findings from fire investigations are made available to the fire community, and other stakeholders.

Scope

Part B4 Section 12 of Approved Document B – Volume 2 (AD B) [1] is concerned with the construction of external walls of buildings. The aim of this article is to clarify the background to these recommendations, their objectives and intended outcomes. The requirement of Part B4, Schedule 1 of Building Regulations 2010 [2] with regards to external fire spread is as follows:

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

2. *The roof of the building shall adequately resist the spread of fire over the roof and from one building to another, having regard to the use and position of the building.*

This article focuses on the Building Regulations requirements in bold above, namely, fire spread across the face of a building. This article does not discuss building separation and fire spread from one building to another, although it needs to be acknowledged that the external wall construction should not only be considered in this regard but holistically since the differing requirements clearly interact.

Background

As part of this research, previous guidance was reviewed to understand current guidance; the Model Byelaws [3], of circa 1952, recommended that *"A reasonable degree of protection* [for buildings of fully protected construction] *could be obtained by providing at least 3 ft of construction (of which at least 2 ft should be above floor level) of the same grade of fire resistance as the walls, between the lintel of the lower window and the sill of the one above".*

In 1960, Ashton and Malhotra [4] carried out a series of large-scale experiments to assess the value of this recommendation which looked at the effect of fire on the external walls of buildings. They concluded that the recommendations for 3 ft vertical separation or 2 ft horizontal separation between windows in adjacent storeys were "*inadequate to prevent the entry of flames from a fire in the lower storey unless fire resisting glazing is used*" and "*the fire resistance required of the spandrel wall could be substantially reduced even below ½ hour, without any significant reduction in fire safety to a building or its occupants*".

It was these findings that underpinned later recommendations intended to satisfy the Building Regulations.

However, the construction of buildings has changed since 1960, when Ashton and Malhotra carried out their experiments and Building Regulations and supporting recommended guidance, AD B, have changed. There have been a number of fires, both historical and more recent, which have raised concerns regarding fire spread over external walls and have consequently resulted in the introduction of guidance documents and test procedures to assess the fire performance of external wall construction. The first edition of the BRE report BR 135 (Fire performance of external insulation for walls of multi-storey buildings) [6] was published in 1988.

One of the most significant of the historical fires is the 1991 fire in Knowsley Heights; a residential block of flats which had been refurbished with the addition of thermal insulation to the external walls of the block. The fire started externally to the block and ignited the combustible cladding system, resulting in extensive fire spread across the face of the building (mostly upwards). Although this was not the first incident of its kind, it raised many concerns and resulted in a change to the test methods used for external cladding systems, namely the introduction of a full-scale fire test method (similar to the BS 8414 test series [7] and [8]). However, BS 8414-1 (for non-loadbearing external cladding systems) was not published until 2003 as an accompaniment to the second edition of BR 135 [9]; this was following a review of guidance in this area instigated by a fatal fire at Garnock Court, Irvine in June 1999.

In 2002, Crook [5] carried out a review of international practices related to external fire spread via windows (and ways to mitigate such spread) but concluded that *"very few people are killed or injured from fire who are elsewhere than on the fire floor"* and *"most deaths or injuries on floors other than the fire floor are as a result of smoke"*. The overall findings of this later study confirmed the findings of Ashton and Malhotra. It stated that "*The evidence acquired for this project leads to the conclusion that the measures currently called upon through Approved Document B are still commensurate with the risk.*"

Fires can spread up buildings even without the involvement of the exterior materials of cladding system; there are numerous examples of fire spread from the flat of origin to the flat above via the windows, but most cause only property damage to the flat (or flats) above. However, more innovative ways to insulate buildings to improve their sustainability and energy efficiency are changing the external surfaces of buildings with an increase in the volume of potentially combustible materials being applied.

Existing guidance

Approved Document B recommends restriction of the combustibility of external walls to reduce the danger from fire spread up a building's external face and also to reduce the susceptibility of the surface to ignition from an external source [1]. It is considered that the use of combustible materials and/or extensive cavities in cladding systems in tall buildings can pose a route for fire spread and hence a danger to life as shown by the case studies. Hence, the recommendation is to limit both the combustibility of materials used on the external face of the building and the extent of cavities in cladding systems.

Diagram 40 of AD B sets out the provisions for external surfaces (or walls) relative to the relevant boundary, height and use of the building. The classification of the external surface of a building depends upon the distance to the relevant boundary; any external surface less than 1000 mm from the relevant boundary, regardless of its height, must be European Class B-s3,d2 or National Class O (as defined in AD B) or better. This increased level of protection for surfaces close to the relevant boundary is provided to mitigate building-to-building fire spread, rather than fire spread across the surface of one building.

However, when the external surface is 1000 mm or more from the relevant boundary, then the height and use of the building become relevant; a building less than 18 metres high has no restrictions unless it is an assembly or recreation building over one storey. The external surface of a building 18 metres or higher should have an index value (I; BS 476-6 [10] or Class C-s3, d2; BS EN 13501-1 [11]) not more than 20 up to 18 metres above ground but over 18 metres (of any dimension) should be Class B – s3,d2 or O. This is in part due to the reach of fire appliances.

AD B further makes recommendations that should the construction of external walls use combustible materials in the cladding system, then it should meet the performance criteria set out in BR 135 [9] using the full scale test methods BS 8414-1:2002 [7] or BS 8414-2:2005 [8] which involves testing the entire cladding system including the insulation among other components.

Fires since the introduction of BS 8414 test series

There have been several fires that we have investigated as part of our DCLG contract where external fire spread has had an implication and some of those incidents are summarised here.

Case study 1 – June 2008

A fire occurred in a first floor flat of a 1960s nine-storey block of maisonettes. The external walls of the flats incorporated uPVC window and door units (Figure 1) and some of the lower window panels had been replaced with painted metal panels (comprising two sheets of painted metal, possibly aluminium, and a thin layer of adhesive holding the two together). The fire melted the frames of the window units, allowing flames to extend up the exterior of the building. These flames were sufficient to melt the frames and break the window panes of the floors/flats above the flat of fire origin and caused fire and smoke damage within the flats from the third to the sixth floors of the block.

Figure 1 – Block of flats showing undamaged window sets; the fire damage is behind the scaffolding

Case study 2 – July 2010

A fire started on the balcony of a 12th floor flat of a 16-storey residential block of flats constructed in the 1960s. As can be seen from Figure 2, the fire spread from the balcony of origin to the 15th floor and the roof of the building. Several features of the building were attributed to the extent of fire spread including combustible insulating panels (which were clad onto the underside of all of the balconies), cladding panels (which had been installed onto the outer surface of the exterior wall and comprised a mineral fibre board face supported on timber batons, behind which there was a fibrous combustible insulation material) and plastic drain pipes (which were installed at each corner of the building and passed through the concrete floor slab on each floor). There was no evidence of any fire stopping, proprietary seal or sleeve where the pipe passed through the floor slab and which should have been provided to maintain the level of fire resistance afforded by the concrete floor slab.

Figure 2 – Block of flats showing extent of fire damage caused by holes in compartmentation on balconies

While external fire spread has been an issue as outlined by these case studies, the authors would also like to acknowledge that there have been successes as can be seen in Case study 3.

Case study 3 – February 2008

A fire occurred in a flat on the 11th floor of a 22-storey block of flats built during the 1960s and refurbished in 2006/7. This refurbishment included the fitting of a new cladding system to the exterior of the building which comprised an insulated render, the insulation for which was mineral wool and had been tested to and passed BS 8414-1. The fire developed to fully involve the flat of origin and broke out of the windows. The damage to the façade was localised to the immediate vicinity of some of the windows but beyond this the damage appeared to have been limited to surface charring and sooting (Figure 3).

Figure 3 – Block of flats showing limited damage to the non-combustible cladding system after a fire

Common misconceptions

Fires involving the exterior of a building, in particular high-rise flats, such as those described above, are visually impressive, high-profile and attract media attention. Any risks posed by inappropriate exterior or cladding materials should be identified and assessed as part of the fire safety risk assessment carried out under the Regulatory Reform (Fire Safety) Order 2005 [12] and, if necessary, remedial work carried out.

A further confusion arises since many elements required for fire safety in buildings are recommended to be "fire resisting", i.e. to demonstrate that they satisfy performance criteria as determined by BS EN 13501-2 [13] or BS 476 fire resistance tests [14]. Fire resistance tests subject a test specimen to a fire exposure that is similar to a fully flashed-over compartment fire. Such an exposure is appropriate for interior elements of a building and load bearing elements. However, it is not evident that such exposure conditions are appropriate for the exterior of a building. Further, as mentioned above the Class B-s3,d2 or O recommendation, and the other recommendations above, are intended to limit the rate of fire growth and fire spread and there is no evidence to date to suggest that these recommendations are inadequate.

In any case, high-rise flats are homes, and must provide light and ventilation. Flats must be provided with openable windows unless an (often expensive) alternative ventilation strategy can be provided (under Part F to the Building Regulations [2]) and, once open, such windows may offer a route for fire spread, in either direction in or out of the flat, irrespective of the other materials forming the exterior of the building. To prevent vertical spread of fire it would be necessary to ensure that all windows in such buildings were both fire resisting and sealed closed (fixed shut) (or were shut in an emergency, manually or automatically). A similar such recommendation is given for windows that open onto external escape routes (AD B Section 5.25 and Diagram 25 [1]) but would almost certainly conflict with the needs of everyday life.

Conclusions

As mentioned, BRE Global, through the contract with DCLG, investigate fires that may have implications for Building Regulations. With the exception of one or two unfortunate but rare cases, there is currently no evidence from these investigations to suggest that the current recommendations, to limit vertical fire spread up the exterior of high-rise buildings, are failing in their purpose.

However, as the need to improve energy efficiency becomes increasingly urgent, more innovative ways to insulate buildings to improve their sustainability and energy efficiency are changing the external surfaces of buildings with an increase in the volume of potentially combustible materials being applied. A number of significant fires, such as those discussed previously, have demonstrated the potential risks.

It was agreed with DCLG to carry out three experiments, to assess the performance of different external façades including non-fire rated double glazing, when exposed to a fire from below, representative of the external face of some buildings. This work did not test the performance of specific products/systems and was not a comprehensive research study but rather a scoping study and as such, the results need to be considered within this context. The findings of this new research will be published as Part 2 of this article.

References

[1] HM Government. The Building Regulations 2010 (For use in England). Fire safety. Approved Document B Volume 2 – Buildings other than dwellinghouses. London. DCLG, 2006 edition incorporating 2007, 2010 and 2013 amendments, Crown Copyright 2006.

[2] HM Government. The Building Regulations 2010.

[3] Ministry of Housing and Local Government, Model Byelaws, Series IV, .Buildings, Her Majesty's Stationery Office.

[4] Ashton, L. A. and Malhotra, H. L., F.R. Note No.436. Department of Scientific And Industrial Research and Fire Offices' Committee, Joint Fire Research Organization. External Walls of Buildings - Part I. The Protection of Openings Against Spread of Fire from Storey to Storey. Fire Research Station, Boreham Wood, Herts, July 1960.

[5] Crook, C., External fire spread via windows, BRE Client report for DETR, 2002.

[6] Rogowski, B. F. W., Ramaprasad, R. and Southern, J. R., Fire performance of external thermal insulation for walls of multi-storey buildings. BRE Report BR 135. First Edition, Bracknell, BRE Bookshop, 1988. (Now superceded).

[7] BS 8414-1:2002 Fire performance of external cladding systems. Test methods for non-loadbearing external cladding systems applied to the face of a building. British Standards Institution, 2002. Note Current version of this standard is dated 2015.

[8] BS 8414-2:2005 Fire performance of external cladding systems. Test method for non-loadbearing external cladding systems fixed to and supported by a structural steel frame, British Standards Institution, 2005. Note Current version of this standard is dated 2015.

[9] Colwell, S. and Baker, T., BRE Report BR 135 Fire performance of external thermal insulation for walls of multistorey buildings. Second edition, IHS BRE Press, 2003. Since superseded by Third Edition, 2013.

[10] BS 476-6:1989+A1:2009 Fire tests on building materials and structures. Method of test for fire propagation for products, British Standards Institution, 1989.

[11] BS EN 13501-1:2007+A1:2009 Fire classification of construction products and building elements. Classification using data form reaction to fire tests. British Standards Institution, 2009.

[12] The Regulatory Reform (Fire Safety) Order 2005.

[13] BS EN 13501-2:2007+A1:2009 Fire classification of construction products and building elements. Classification using data from fire resistance tests, excluding ventilation services. British Standards Institution, 2009.

[14] BS 476-20:1987. Fire tests on building materials and structures. Method for determination of the fire resistance of elements of construction (general principles), British Standards Institution, 1987 [and others in the series].

Acknowledgements

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BRE staff have carried out fire investigations in support of the Building Regulations (and its precursors) on an ad hoc basis since 1948, and with a dedicated team since 1974. BRE has been wholly owned by the BRE Trust since its privatisation in 1997. BRE's fire investigation team is independent and provides world class fire investigation services to a wide range of clients, including insurers, legal firms, fire and rescue services, police and government departments.

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External fire spread – Part 2 Experimental research

By Ciara Holland, Dr David Crowder, Martin Shipp and Nathan Cole

Introduction

BRE Global carries out fire investigation activities on behalf of the Department for Communities and Local Government (DCLG) by investigating issues that may have implications for Building Regulations and the guidance that supports Building Regulations, such as the Approved Documents.; the contract 'Investigation of Real Fires' under which this work was carried out was completed in 2015 but has been renewed until 2018. An important element of this contract is to ensure that findings from fire investigations are made available to the fire community, and other stakeholders.

There have been a number of fires, both historic and more recent, which have raised concerns regarding fire spread over the external walls of multi-storey buildings and have consequently resulted in the introduction of guidance documents and test procedures to assess the fire performance of external wall construction.

Part 1 of this article [1] discussed previous and current guidance for external fire spread and also discussed several case studies of external fire spread since the introduction of the BS 8414 test series [2] and [3].

Following the conclusions of Part 1, it was agreed with DCLG to carry out an experimental scoping study focusing on the issue of external fire spread, maintaining some similarity to Ashton and Malhotra's work, carried out in 1960 [4] but also calls upon BR 135 [5] and BS 8414 [2].

Objectives of the experimental research

The aim of this research was to carry out three experiments to assess the performance of different external façades including non-fire rated double glazing, when exposed to a fire from below, representative of the external face of some buildings to inform DCLG Building Regulations and Standards Division.

It should be noted that this work did not test the performance of specific products/systems and was not a comprehensive research study but rather a scoping study and as such, the results need to be considered within this context.

Methodology

BRE Global carried out three large-scale experiments in the BRE Burn Hall using different types of external façade systems of types used in residential properties that incorporate both non-fire rated double glazing units (same type in all experiments) and spandrel panels of varying combustibility.

Experimental rig

An experimental rig was designed and installed (Figure 1). This utilised one of the existing BRE Global BS 8414 test rigs [3]; a schematic of the BS 8414 test rigs can be found in BR 135 [5]. The intention of this experimental work was to evaluate potential fire spread from one building storey to another and therefore it was unnecessary to clad the entire height and return wing of the BS 8414 test rig.

A steel frame, 2850 mm wide by 2300 mm high was fabricated using 30 mm steel channel with 3 mm thick steel. This frame was installed onto the test rig, as shown in Figure 2, at the level directly above the fire source, approximately 2.7 metres from the ground and 700 mm from the top of the hearth. The frame was fitted to the leading edge of the concrete lintel resting on top of the lintel (see Figure 1) representing an external façade which is flush with the floor slab below. The frame was designed with two sections; the lower section contained the spandrel panel to be tested and the upper section contained the double-glazed units.

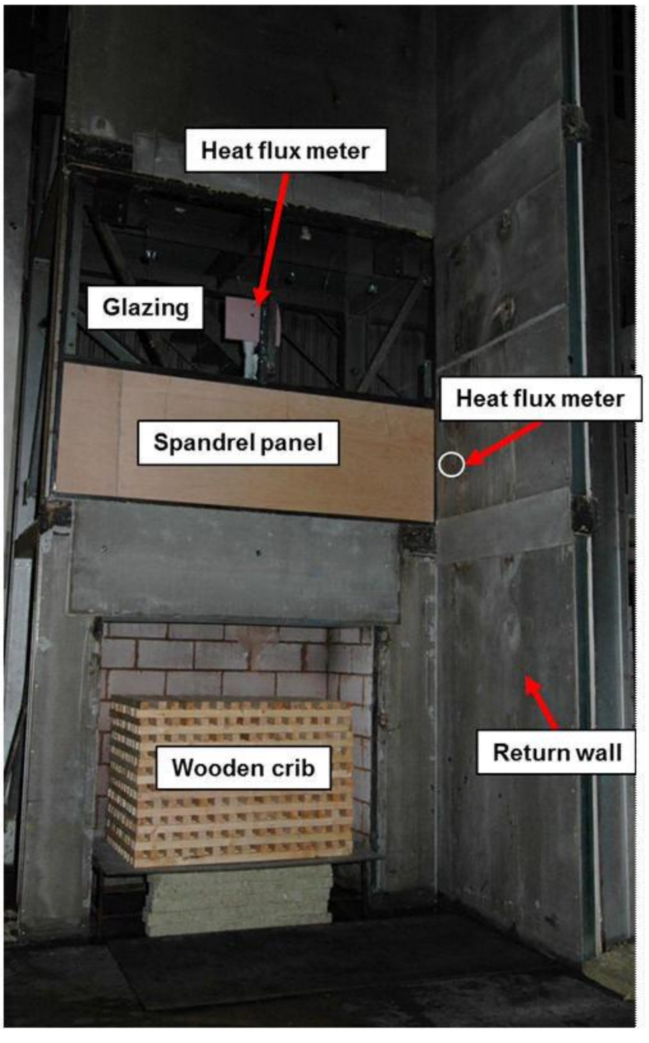

Figure 1 – Annotated image showing the front elevation of experimental set up

For each experiment, the resulting area exposed to the fire conditions was 1300 mm high x 2790 mm wide for the glazing and 880 mm high x 2790 mm wide for the spandrel panel. Two panels of glass were used due to the size and weight of the panels.

The spandrel panels were sealed into the frame by packing the channel with stone fibre wool insulation and the glazing units were sealed with glazing gasket, where necessary. Approximately 200 mm behind the spandrel panel, a sheet of standard 12.5 mm plasterboard (~ 500 mm x 2400 mm wide) was installed for mounting instrumentation on but also as a target to assess the potential damage (if any) from radiant heat or fire (Figure 2).

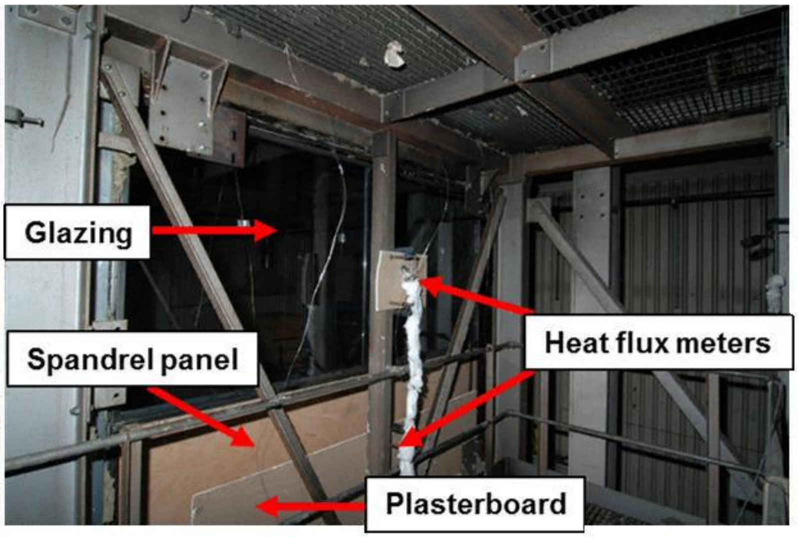

Figure 2 – Image of rear elevation behind the steel frame on level one of the test rig i.e. the level above the hearth

Materials

The following items were sourced by BRE Global and installed into the experimental frame:

- A cement fibreboard of dimensions 925 mm high x 2400 wide mm x 9 mm thick. A 450 mm wide section was cut from a second panel to fill the frame width and these sections were joined together using fire cement. This board could achieve a 60 minute fire resistance rating when installed in accordance with the details in the relevant BS 476 test report [7]. For the purposes of reporting this panel will be referred to as "fire resisting" from herein.
    - NOTE: BRE Global was not able to source an off-the-shelf fire resisting external board – the board that was used is sold for internal use. The panel is capable of achieving 60 minutes fire resistance when installed within a complete system and tested to BS 476-21:1987 [8]. However, for the purposes of this programme of work, the panel was not installed as per the test report.
- A sheet of structural hardwood plywood of dimensions 925 mm high x 2440 mm wide x 9 mm thick. A 400 mm wide section was cut from a second panel to fill the frame width and these sections were joined together using fire cement. It was anticipated that the reaction to fire performance would be Class 3 (National class), assuming a density greater than 400 kg/m^3.
    - NOTE: There was no available evidence of the fire rating of this panel, hence Class 3 is assumed based upon guidance provided in Approved Document B [9]. For the purposes of reporting, this panel will be referred to herein as "Class 3".
- A compressed stone-fibre spandrel panel with an organic binding agent of dimensions 925 mm high x 2900 mm wide x 8 mm thick. This panel, as part of a specific system for external facades, demonstrates a reaction to fire performance of Class B-s2,d0, according to EN 13501-1:2007 [6].
    - NOTE: For the purposes of this experiment, only the spandrel panel (a single component part of the system), and not the complete system was used. Therefore, the reaction to fire performance for this panel has been assumed as "Class B-s2,d0" but this was not confirmed as part of this programme of work.

- Six non-toughened non-fire resisting double-glazed units were manufactured by a glazing supplier using 4 mm float glass with a 10 mm cavity filled with argon. This gave a complete thickness of 18 mm. The dimensions of the glazing panels were 1420 mm wide x 1350 mm high.

Instrumentation

Temperature and heat flux were measured.

The experimental rig was instrumented with twelve 1.5 mm diameter Type K steel sheathed thermocouples. The thermocouples were arranged as shown in Figure 3. Thermocouples measuring temperatures at the glazing level were placed equidistantly. The thermocouples measuring temperatures at the spandrel panel were placed in similar locations, horizontally, to the thermocouples at the glazing level.

Thermocouples at the front of the rig were intended to record the gas/flame temperatures that the panels and glazing were exposed to, rather than solid surface temperatures. The thermocouples at the rear of the rig were approximately 300 mm from the spandrel and glazing and 1550 mm from the base of the frame; this was to record temperatures likely to be achieved within a room, hence they were not fitted to the rear side of the panels.

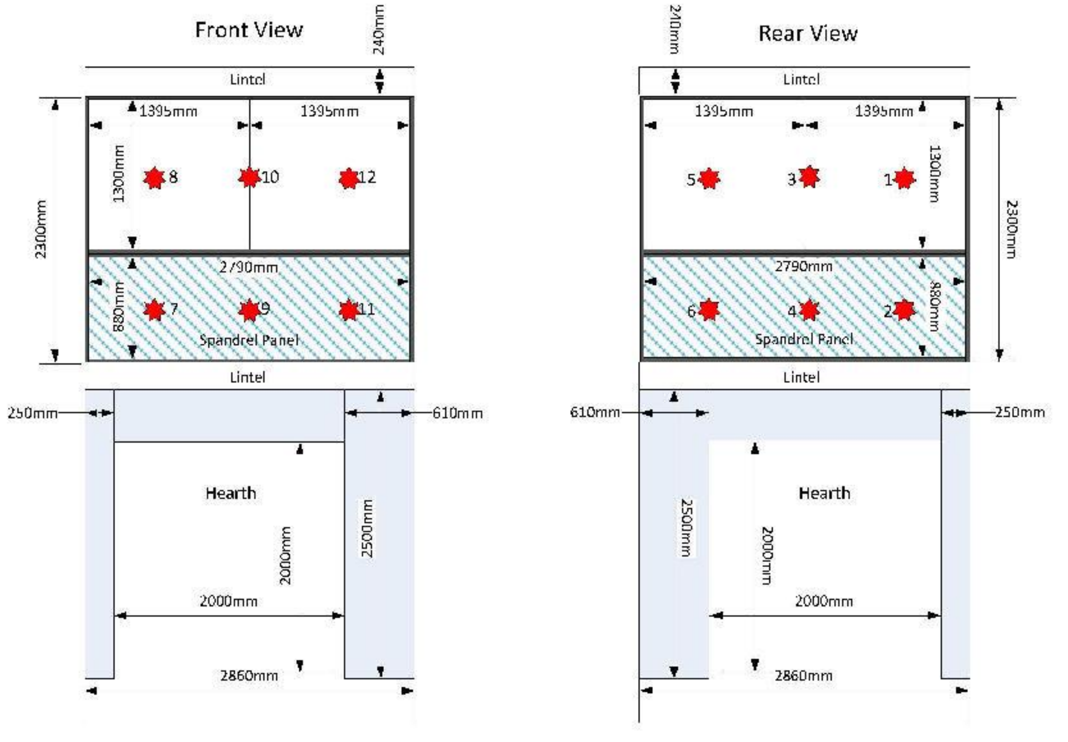

Figure 3 – Approximate locations of thermocouples in the structure

Three water-cooled heat flux transducers (heat flux meters) were also fitted at various locations on the rig to measure targeted heat fluxes and to aid the assessment of the severity of the fire (Figure 1 and Figure 2). The locations were as follows:

- One Schmidt-Boelter thermopile type sensor, mounted in the return wing of the BRE Global BS 8414-2 test rig, was located approximately 365 mm from the base of the spandrel panel and approximately 245 mm from the corner of the test rig, flush with the wall surface, with a side-on view of the fire plume. The meter was calibrated to 100 kW/m^2.

- One Gardon type sensor was located approximately 180 mm behind the spandrel panel and approximately 365 mm from the base of the frame, approximately central to the frame, protruding out approximately 10 mm, from the plasterboard (used for positioning), with a face-on view of the fire plume. The meter was calibrated to 20 kW/m^2.

- One Gardon type sensor was located approximately 300 mm behind the double-glazing unit and approximately 1550 mm from the base of the frame, approximately central, flush with the plasterboard (used for positioning), with a face-on view of the fire plume. The meter was calibrated to 50 kW/m^2.

Experimental method

Three experiments were carried out to assess the performance of the spandrel panel and glazing unit when exposed to a fire from an opening below. The fire source was a wooden crib as described in the BS 8414-2 [3] test method to be representative of a fully flashed-over fire in a compartment breaking out of a window and impinging on the external façade above. The following experiments were carried out:

- Experiment 1 – "Fire resisting" panel and non-fire resisting double-glazing unit.
- Experiment 2 – "Class 3" (plywood) spandrel panel and non-fire resisting double-glazing unit.
- Experiment 3 – "Class B-s2,d0" (stone fibreboard) spandrel panel and non-fire resisting double-glazing unit.

Each experiment was continued until the experimental rig was thought to be at risk of damage.

Findings

Observations made for all three experiments are summarised in Table 1.

The maximum flame length for all three experiments was estimated at 3.3 metres from the underside of the hearth i.e. to the top of the glazing (Figure 4). The glazing failed in all three experiments.

NOTE: Failure of glazing was defined as both panes of glass (i.e. full thickness of a double-glazed panel) falling out of the frame allowing flames through to the back of the rig.

Table 1 - Summary of observations

Experiment Number	Time (minutes:seconds)						
	Duration of fire	Flaming at 2 metres	Flaming at maximum length	Failure of first glazing panel	Failure of full glazing system	Involvement of spandrel panel	Burn through of spandrel panel
1	15:00	02:38	04:30	06:15	08:40	N/a	N/a
2	11:54	02:57	10:30	04:54	08:08	03:08	11:04
3	26:40	06:30	04:00	13:40	20:30	N/a	N/a

N/a = not applicable

Figure 4 – Image showing maximum achieved flame length of approximately 3.3 m

The severity of the fire to which each system was exposed was similar as shown by the measured data presented in Table 2 and Figure 5. It should be noted that the moisture content of the crib wood was not measured prior to the experiments which is a possible explanation for the differences in fire growth in the three experiments. The growth of the fire for Experiment 3 was slower than that of Experiments 1 and 2 but ultimately, a similar peak heat flux at the return wall was achieved.

The slower growth rate, for Experiment 3, explains the differences in failure times of glazing and time to reaching maximum flame lengths.

The peak heat flux at the return wall for Experiment 2 was lower than that for Experiments 1 and 3; this was due to the shorter duration of the fire due to the failure of the spandrel panel and also the failure of the panel resulted in a change of air flow which impacted on the position of the fire plume relative the heat flux meter.

Table 2 – Summary of peak heat flux and temperatures for all three experiments

Experiment Number	Peak heat flux (kW/m^2)			Peak temperature (°C)			
	Return Wall	Glazing	Spandrel	Front Spandrel	Front Glazing	Rear Spandrel	Rear Glazing
1	120	25	7	848	746	17	112
2	82	27	N/a	729	759	28	486
3	140	17	10	850	698	29	116

N/a – Heat flux meter was damaged during the experiment rendering the data unusable.

Table 3 compares the severity of the fire at the time of failure of the first glazing panel in each experiment. The heat flux quoted is from the return wall of the rig with a side view of the fire plume and has not been corrected for the view factor. It is only indicative of the heat flux to which the glazing was exposed and not an accurate measurement of the direct heat flux on the glazing at that time.

Table 3 – Comparison of the heat flux measured at the return wall fire at the time of the failure of the first glazing panel for each experiment

Experiment Number	Heat flux (kW/m^2)	Time (mins)
1	51	6.8
2	22	4.9
3	47	13.7

This comparison shows that there are similarities to be drawn between the failure of the glazing with Experiments 1, the "fire resisting" spandrel and Experiment 3, the "Class B-s2,d0" spandrel.

As shown in Table 2, the glazing in Experiment 2 failed earlier than in the other experiments. Given that, as shown in Figure 5, the rate of fire growth for Experiments 1 and 2 are comparable, the reason for this earlier failure of the glazing is, in our opinion, due to the involvement of and eventual burn through of the "Class 3" spandrel panel contributing to and changing the local dynamics of the fire. That is, the involvement of the spandrel panel in Experiment 2 may have changed the angle of trajectory of the fire plume relative to location of the heat flux meter in the return wall resulting in the difference of recorded data.

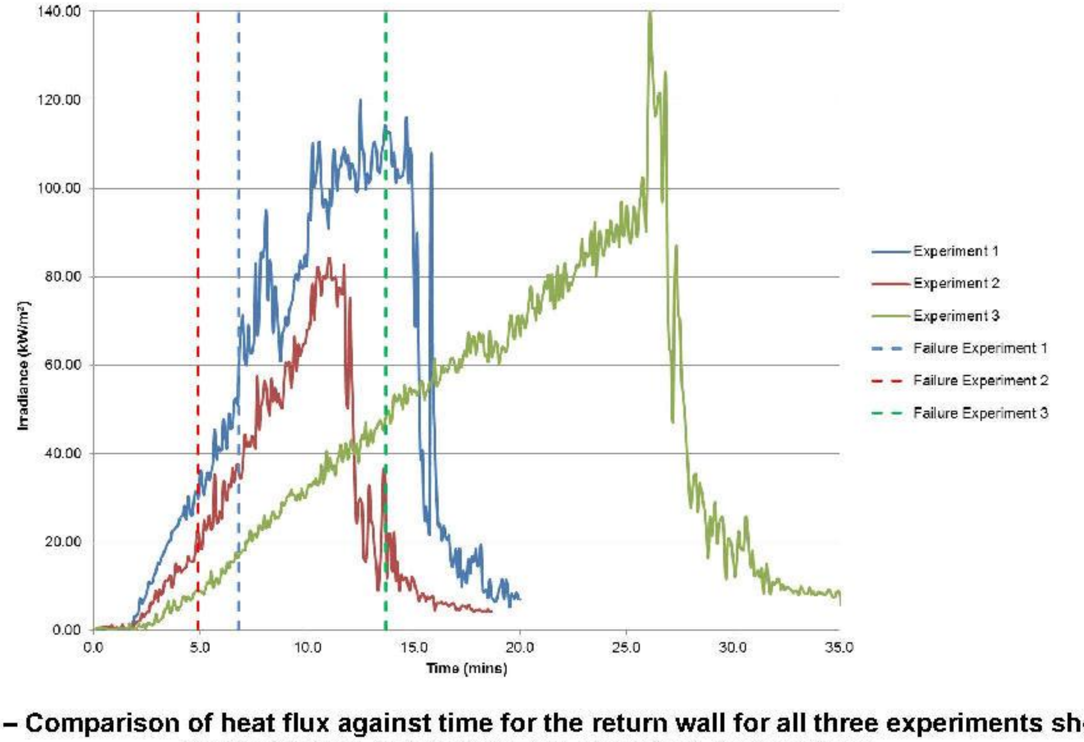

Figure 5 – Comparison of heat flux against time for the return wall for all three experiments showing the first failure point of glazing at vertical dashed lines

The highest measured temperature behind the panel system was recorded for Experiment 2. This was due to the failure of the spandrel panel allowing flames into the space behind, whereas, in Experiments 1 and 3 the panels remained intact and hence the temperatures recorded, due only to failure of the glazing, were significantly lower.

Conclusions

A limited series of three fire experiments was carried out to assess the performance of three different external facades including non-fire rated double glazing when exposed to a fire from below.

The conclusions are:

- In all three experiments the double-glazing panels failed. Failures in glazing, such as those which occurred during these experiments, provide a potential route for external fire spread from one flat to another regardless of the design of the external façade.
- The "fire resisting" and "Class B-s2,d0" panels performed in similar manner; in both experiments the glazing failed but the panels remained intact for the duration of the fire.
- The non-fire rated, "Class 3" panel became involved in the fire before the failure of the glazing and later burnt through. This early involvement of the panel appears to have contributed to the severity of conditions imposed on the glazing by introducing a flame source directly beneath it and in direct contact with it. This increased severity then caused the glazing to fail under conditions which appeared less severe than would otherwise have been the case.

It should be noted that there were several limitations to this programme of work namely:

- Only spandrel panels i.e. single components of a system and not entire systems were assessed.
- Only one type of non-fire rated double glazing was assessed and it is recognised that there are several different types of glazing used in multi-storey buildings. This would need to be addressed by separate experimental work.
- The experiments were carried out under laboratory controlled conditions. Environmental factors such as wind conditions were not part of this work and these can change the dynamics of a fire.

Overall, the findings from this research show that there is a clear and demonstrable need to ensure that buildings are designed and constructed so that the fire spread across the external surface and within the external façade is inhibited, as required by the Building Regulations. There is adequate guidance available in the public domain to allow this to be achieved.

References

[1] Holland, C; Shipp, M and Crowder, D. External fire spread – Part 1 Background research. To be published.

[2] BS 8414-1:2002 Fire performance of external cladding systems. Test methods for non-loadbearing external cladding systems applied to the face of a building. British Standards Institution, 2002. Note Current version of this standard is dated 2015.

[3] BS 8414-2:2005 Fire performance of external cladding systems. Test method for non-loadbearing external cladding systems fixed to and supported by a structural steel frame, British Standards Institution, 2005. Note Current version of this standard is dated 2015.

[4] Ashton, L. A. and Malhotra, H. L., F.R. Note No.436. Department of Scientific And Industrial Research and Fire Offices' Committee, Joint Fire Research Organization. External Walls of Buildings - Part I. The Protection of Openings Against Spread of Fire from Storey to Storey. Fire Research Station, Boreham Wood, Herts, July 1960.

[5] Colwell, S. and Baker, T., BRE Report BR 135 Fire performance of external thermal insulation for walls of multistorey buildings. Third edition, IHS BRE Press, 2013.

[6] BS EN 13501-1:2007+A1:2009 Fire classification of construction products and building elements. Classification using test data from reaction to fire tests, British Standards Institution, 2007.

[7] BS 476-20:1987. Fire tests on building materials and structures. Method for determination of the fire resistance of elements of construction (general principles), British Standards Institution, 1987 [and others in the series].

[8] BS 476-21:1987. Fire tests on building materials and structures. Methods for determination of the fire resistance of loadbearing elements of construction. British Standards Institution, 1987.

[9] HM Government. The Building Regulations 2010. Fire safety. Approved Document B Volume 2 – Buildings other than dwellinghouses. London. DCLG, 2006 edition incorporating 2007, 2010 and 2013 amendments, Crown Copyright 2006.

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