DTLR Building Regulations Division Project Report :

External fire spread via windows - Analysis of the findings

Project report number 203131

Prepared for :

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Safety and Health Theme

External Fire Spread via Windows

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Task 2 Report

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Executive Summary

The object of the project, of which this report is part, is to examine the issues surrounding the phenomenon of external fire spread via windows, in order to provide comprehensive and up-to-date advice on the scale of the problem and cost-effective ways of minimising the risks. The aim of this report is to analyse and assess the survey findings of Task 1 and the current Codes and Guidance as highlighted in Task 3 reports.

There are relatively few documented cases of extensive external vertical fire spread involving combustible claddings or glazed facades, and there are even fewer cases where such spread has significantly compromised life safety.

Façade fires do not generally threaten building occupants, but the concern is that fire spread through the openings into upper levels may result in secondary fires, which can threaten occupants.

It is clear from the earlier reports (Nos. 203130 and 203132), and from that stated here, that there is insufficient guidance provided by national regulation within England and Wales, or codes of practice to effectively address the particular problems of fire spread via windows.

Where requirements for vertical separation of openings are given, consideration should be given to the removal of the requirement for 900mm high spandrels in favour of horizontal projections or sprinkler protection.

However, it is very likely that this change would be unacceptable to most building developers and architects due to the aesthetic implications, or potentially large expense of a building wide sprinkler installation.

A number of mitigatory or protective measures have been identified within the body of this report and include:

- *Spandrel panels*
- *Horizontal projections*
- *Window orientation and size*
- *Sprinklers*
- *Limited combustibility of claddings*
- *Fire resistant glazing and facades*
- *Sterile zones*
- *Staggering the window layouts*

The UK guidance given in Approved Document B Fire Safety, deals with the issue of life safety for different occupancies by application of building construction and limits on performance of material. It is the Insurance Industry which is leading the risk assessment of buildings with fully or partially glazed installations, however this is with a view to effects of business interruption and replacement costs.

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1 Introduction

The object of the project, of which this report is part, is to examine the issues surrounding the phenomenon of external fire spread via windows, in order to provide comprehensive and up-to-date advice on the scale of the problem and cost-effective ways of minimising the risks.

The aim of this report is to analyse and assess the survey findings of Task 1 and the current Codes and Guidance as highlighted in Task 3 reports.

Additional surveys have been carried out on regulatory codes and guidance from overseas to supplement that found and reported in Task 3.

Assessment of the risks posed will also be assessed and guidance offered.

2 Findings

There have been a relatively low number, yet high profile fires in high-rise buildings over the recent years involving domestic apartment/residential buildings and commercial office buildings. There are approximately 3500 residential tower blocks of greater than ten storeys in height in the UK with approximately 500 of these fitted with external cladding (1).

The fire mechanisms by which exterior cladding systems may ignite and contribute to vertical fire spread include:

- Flames projecting from broken windows in the room of origin, exposing the façade and any windows above, thus allowing for the upper windows to fail and allow flames & hot gases to enter the floor above
- Inadequate fire stopping of the gap between the edge of the floor slab and the exterior wall allowing for flames and hot gases to pass directly to the floor above. This is especially notable with curtain wall construction.
- Heat induced distortion of supporting frameworks causing the fire-stopping to become inadequate or collapse
- Direct contribution of the external cladding material to vertical fire spread. Ignition may occur following exposure to flames projecting from window openings.

Some of the more notable and international fire incidents include:

- a 31-storey department store and office building – Andraus Building, Sao Paulo, Brazil 1972 – *no fatalities*
- a 25-storey office building – Joelma Building, Sao Paulo, Brazil 1974 – *179 deaths*
- a 30-storey hotel – Las Vegas Hilton Hotel, 1981 – *eight deaths in various locations*
- 62-stoery tower – First Interstate Bank Building, Los Angeles, California 1988 – *no fatalities*
- a 12-storey office block – Mercantile Credit Building, Basingstoke 1991 – *no fatalities*
- a 38-storey bank building – One Meridian Plaza Building, Philadelphia 1991 – *no fatalities*
- a 11-storey residential tower block, Knowsley Heights, Liverpool, 1991 – *no fatalities*
- a 37-storey retail, commercial office and hotel development - President Tower, Bangkok 1997 – *no fatalities* , and
- 13-storey residential tower block, Irvine, Scotland, 1999 – *one death in the flat of fire origin*

All those incidents mentioned above directly involved exterior fire spread via the curtain walling façade or non-combustible spandrel material. None of the buildings had sprinklers installed and/or available and they were difficult to extinguish. Fire fighters were forced to tackle the fires on the upper floor levels from outside the building, as it was unsafe for them to enter floors above the fire zone.

There is no information held by BRE's historical records of fire incidents, which indicate the number of deaths in the room of origin.

To supplement that noted in Task 3 report, further investigation was carried out on the regulatory codes and guidance available covering Sweden, Malaysia, USA, New Zealand, Australia and Canada. The findings are discussed below.

2.1 Regulations and codes

2.1.1 Canada

The National Building Code of Canada [2], provides prescriptive guidance on the use of combustible components for exterior walls with or without sprinklers, however it does offer additional guidance on exposure protection of openings. Section 3.2.3.16 deals with canopy protection from vertically separated openings:

1. If a storey is required to be separated from the storey above by a fire separation,

(a) every opening in the exterior wall of the lower storey that is located vertically below an opening in the storey above shall be separated from the storey above by a canopy projecting not less than 1m from the face of the building at the intervening floor level, and

(b) the canopy required by Clause (a) shall have a fire-resistance not less than that required for the floor assembly but need not be more than 1 hour.

2. Except as permitted by Sentence (3), the canopy required by Sentence (1) is permitted to be omitted if the exterior wall of the upper storey is recessed not less than 1m behind the exterior wall containing the opening in the lower storey.

3. The requirements of Sentences (1) and (2) are permitted to be waived if the building is sprinklered throughout.

However, the above guidance relates only to Group E or F occupancies. Group E is 'Mercantile Occupancies' used for the displaying or selling of retail goods, wares or merchandise, ie. department stores and for use in unsprinklered occupancies only. Group F is for high and medium hazard occupancies such as industrial occupancies or factories. There is no specific guidance for Group C Residential, or Group D Business Occupancies.

Part 9 of the Code deals with Housing and Small Buildings. Small buildings are classed as those of 3 storeys or less in building height and having a building area not exceeding $600m^2$. Section 9.10.12 Prevention of Fire Spread at Exterior Walls and Between Storeys states for separation of exterior openings:

1. In buildings or mercantile or medium hazard industrial occupancy, exterior openings in one storey shall be separated from exterior openings in an adjacent storey by

(a) a wall not less than 1m in vertical dimension, or

(b) a canopy or balcony not less than 1m in width.

Again the canopy, wall or balcony must have a fire resistance rating comparable to that of the floor, but not greater than 1hour.

Elsewhere, the guidance relates only to the limits on distance between building facades.

Sprinklers are required in all buildings greater than three storeys in building height, subject to constraints on building area.

2.1.2 USA

The Uniform Building Code [3] refers to office buildings as Group B and residential occupancies as Group R.

Section 403 states that all occupancies of Group B and R type shall be sprinkler protected throughout, where the building height exceeds 75 feet (22.86m) above the lowest level of fire department access.

Guidance in Section 709 for Walls and Partitions addresses the problem of vertical fire spread at external walls:

709.3.2.3 Exterior

When openings in an exterior wall are above and within 5 feet (1524mm) laterally of an opening in the storey below, such openings shall be separated by an approved flame barrier extending 30 inches (762mm) beyond the exterior wall in the plane of the floor, or by approved vertical flame barriers not less than 3 feet (914mm) high measured vertically above the top of the lower opening. Flame barriers shall have a fire resistance of not less than 3/4 hour.

Exceptions:

1. Flame barriers are not required in buildings equipped with an approved sprinkler system throughout.

2. This section shall not apply to buildings of three storeys or less in height.

Further passive fire protection is required at any gap between the edge of the floor assembly and an external wall.

2.1.3 Australia

Further information has been found from the Building Code of Australia [4], which supplements that stated in the Task 3 report 203132. The Deemed to Satisfy Provision C2 - Compartmentation and Separation, sets out specific guidance directly relevant to vertical fire spread:

C2.6 Vertical separation of openings in external walls

(a) If in a building of Type A construction, any part of a window or other opening in an external wall is above another opening in the storey below and its vertical projection falls no further than 450mm outside the lower opening (measured horizontally), the openings must be separated by -

i) a spandrel which -

A) is not less than 900mm in height; and

B) extends not less than 600mm above the upper surface of the intervening floor; and

C) is of non-combustible material having an FRL of not less than 60/60/60;

OR

ii) part of a curtain wall or panel wall that complies with (i); or

iii) construction that complies with (i) behind a curtain wall or panel wall and has any gaps packed with a non-combustible material that will withstand thermal expansion and structural movement of the walling without the loss of seal against fire and smoke; or

iv) a slab or other horizontal construction that -

A) projects outwards from the external face of the wall not less than 1100mm; and

B) extends along the wall not less than 450mm beyond the openings concerned; and

C) is non-combustible and has an FRL of not less than 60/60/60.

(b) The requirements of (a) do not apply to - ....

iii) a building which has a sprinkler system complying with Specification E1.5 installed throughout

Subject to the type of construction, the above requirements would apply to buildings typically between three and eight storeys in height. Below this, provision for vertical separation is not required and above which buildings are required to be sprinklered.

2.1.4 New Zealand

The New Zealand Building Code (NZBC 1992) [(5)] deals with the fire performance of external walls through Clause 3.3.5, which states:

External walls and roofs shall have resistance to the spread of fire, appropriate to the fire load within the building and to the proximity of other household units and other property.

The Acceptable Solution C3/AS1 of the New Zealand Building Industry Authority (BIA 1992) Approved Documents, provides one approved means of complying with this clause. C3/AS1 seeks to reduce the likelihood of fire propagating vertically up a combustible façade either as a result of direct flame impingement from an adjacent building on fire, or as a result of flames projecting through openings at a lower level in the same building and igniting the façade in the vicinity of the opening. The requirements seek to control either the ignitability or the contribution of the cladding to fire development and thereby indirectly influence the rate of vertical flame spread, by use of standard test methods.

For external walls, the acceptable properties of exterior surface finishes depend on the purpose groups exposed to the fire hazard, the building height and distance from the relevant boundary.

New Zealand currently has requirements for aprons of 0.6m wide or spandrels of 2.5m high to be provided in unsprinklered buildings containing sleeping accommodation on upper floors. However, the minimum spandrel height is likely to be reduced to 1.5m. There are no requirements for aprons or spandrels in office buildings (sprinklers are required when the building height is above 25m).

2.1.5 Sweden

There are two documents available relating to building construction and fire spread.

The Swedish Building Code SBN 1980, Chapter 37, Fire Protection deals with external walls in Section 423. However, this is limited to specifying that external walls in fire resistant buildings shall be constructed in such a way that the risk of fire spread along or through the walls is limited and constructed of incombustible materials. There is no specific guidance to fire spread via windows here.

An alternative document is the Swedish Regulations for New Construction [6], which makes reference to the problems of external fire, spread via windows. Section 8.43 states that for external walls and windows, the materials used in the façade cladding shall have a very high ignition temperature. The external walls themselves shall be constructed so that 'the risk of fire spread via windows is limited' but does not quantify that statement.

However, it does venture further to state ' between windows in different fire compartments, the vertical distance should not be less than 1.2m unless the windows inside this distance are constructed to not less than Class F15'.

2.1.6 Malaysia

Guidance presented in the Uniform Building By-Laws [7] is minimal, however Section 149 of the document makes specific reference to protection of openings in an external wall:

Horizontal and vertical barriers of the external wall:

Openings in external walls located vertically above one another shall be protected by approved flame barriers either extending 750mm beyond the exterior wall in the plane of the floor or by vertical panels not less than 90mm in height.

(It should be noted here that it is the author's belief that the 90mm-height requirement stated above should read 900mm, and is a translation error in the original text.)

Section 142 Part 3 requires the external wall of a building, which exceeds 15m in height to be constructed wholly of non-combustible material. The test methods stated for evaluation are generally not deemed adequate for evaluation of the end-use performance of exterior cladding materials and systems.

Countries such as Malaysia tend to look towards USA and Europe and readily adopt controls and test methods developed and tested there.

2.2 Analysis of the findings

It is clear from the earlier reports (Nos. 203130 and 203132), and from that stated above, that the guidance provided by national regulation within England and Wales, or codes of practice does not effectively address the particular problems of fire spread via windows.

Out of the nine international countries reviewed here and previously, over half (Canada, USA, Australia, New Zealand and Malaysia), offer guidance on use of both spandrel or apron applications, although the restrictions to building occupancy type and height do vary across the board. Hong Kong makes reference to spandrel height only. Only three countries Canada, USA and Australia state that requirements for spandrel height and/or apron projections can be waived if the building is sprinklered throughout. The UK regulations notably lack guidance on either, however it does have a requirement for sprinkler protection in buildings over 30m in height, however this would not apply to any Purpose Group 1(a) (flats) part of a mixed use building.

International research has shown that the requirements for setting minimal spandrel heights (set out by those countries that attempt to address this problem), is an option that remains largely ineffective. Research, particularly that carried out by the National Research Council of Canada, has shown that spandrel walls need to be of an impractical height (>2.5m) to be effective for controlling vertical fire spread. The Canadian results show that by using an 1100mm wide apron, the exposure to the wall face was reduced to approximately 10% of that experienced by the 900mm spandrel height.

In order to overcome the problem of excessive spandrel height, consideration could be offered to the use of staggered window positions within a façade. This would serve to increase the spandrel height without having an implication on the slab to slab distances per storey. Careful planning of residential tower blocks could position window openings to accommodate the suggested 2.5m separation distance.

Igor Oleszkiewicz from the National Fire Laboratory, National Research Council, Canada carried out a substantial amount of research work into this area including vertical separation distances of spandrel panels and horizontal projections and the effects of flame spread on combustible cladding.

His research [8] suggested that the equal weighting usually given by building regulations and codes with respect to spandrel height and apron width needed to be re-examined. A series of tests were carried out on a three storey high enclosure with a 2.6m-wide x 1.37m-high window opening. Two different heat release rates were used which were typical for the size of compartment, window dimension and fire load. Horizontal projections were located immediately above the window and were 1.0m, 0.6m and 0.3m in depth. The experiments combined the use of each heat release rate with and without a projection. It was found that without the use of the projection, the maximum flame heights above the top of the opening were approximately 2m and 3m for the low and high heat release rates, respectively.

The experimental data showed that the level of protection afforded to the wall increased with the depth of projection. The 0.6m projection reduced the exposure by approximately 60%. At 1m above the opening, the 1m projection reduced the exposure by 85% when compared to readings without any projection.

In the same experiments it was found that in order to achieve a 50% reduction in exposure to the wall above the window opening, a 2.5m high spandrel would be required. It is interesting to note that the same level of protection offered by the 2.5m spandrel was afforded by the 0.3m deep projection at 1m above the opening and less than 0.5m above the opening when using the 0.6m projection.

Further work was undertaken by Oleszkiewicz, which included the effects of window orientation and dimension [9]. A similar test apparatus as discussed above was used. Four levels of fire load were assumed ranging from a room furnished with traditional wood furniture (low range of fire intensity) up to a fire involving a large quantity of thermoplastics or thin combustible panelling, representing the higher fire intensities. Three windows of different dimension were used, 2.6m-wide x 2.7m-high, 0.94m-wide x 2.70m-high and 2.6m-wide x 1.37m-high. Measurements of heat intensity were taken at 0.5m above the top of the window opening.

The data showed that the fire exposure to the exterior wall depends greatly upon both the window dimensions and heat release rate from the room. The wide and shallow window opening (2.6m x 1.37m) provided the highest thermal exposure on the façade. This is due to the velocity of the gases exiting the compartment. Gases are driven by buoyancy, which increases with the height of the window opening. The velocity is kept lower with this window dimension; the flames remain better attached to the wall above the window and so transfer more heat to the wall than did the flames issuing from the taller windows. Tall windows tend to project the flame plume away from the wall decreasing the thermal coupling of flames with the wall and cause relatively lower thermal exposure. The lowest heat release rates measured were from the more square shaped window, 2.6m x 2.7m.

Another factor found to influence the window fire plume, is the shape of the façade. Features such as 'sun shades' and deep mullions can either protect the façade from the plume, or cause greater fire exposure.

A test carried out using vertical projections channelled the flame plume up and caused a 50% increase in the heat intensity measured above the window opening. This means that locating windows in a vertical recess or providing vertical shades or privacy screens would increase the fire exposure to the wall above the venting window as well as to the window in the storey above.

Certain combustible claddings can support unlimited vertical flame spread. However, some do not, if the combustibility of the cladding is not significant. Factors such as the amount of combustibles per unit area, their heat of combustion, the ignition temperature of the combustible components, composition of the cladding and preservation of integrity when exposed to fire determine the propensity for vertical flame spread and hence its contribution to the window flame plume.

It is very difficult to identify whether a façade fire directly influences the occurrence of casualties during the incident. Information from various databases is limited, as was seen in the previous reports, and the ability to decipher the recorded statistics is somewhat masked by the method of reporting on the UK FDR1 fire reports. Information has been taken from the FDR1 statistics for the year 1998 and is shown below in Tables 1 –5. The data below refers to the number of fires in buildings by total number of floors in the building, number and type of casualty. The data also only relates to the classification of 'Other Buildings' and hence does not include for domestic fires in homes. Although generally based on a weighted sample of 20% of UK incidents, all fires are recorded where a fatality has occurred. The number of casualties also includes the Brigade personnel. In 1998, there were 681 non-fatal Brigade casualties, but no fatalities.

Tables 1 – 4 look at the casualties over a range of building heights. This data does not identify which floor is the floor of 'fire origin', merely the total number of floors in any particular building. It does, however, highlight the location of the casualty with respect to the fire location. It can be seen that the majority of casualties are found in the room of fire origin and as such, cannot be directly attributed to the effects of external fire spread.

Table 1 Fatal casualties injured by burns an/or scalds and location of casualty relative to fire

Total number of floors in building	Number of Fatalities – Burns and/or Scalds					
	Room of origin	Floor of origin	Floor +1	≥ Floor + 2	Floor - 1	≥ Floor - 2
1	18	1				
2	52	5	1			
3	16	1	1			
4	2					
5	2					
6-10	3					

11-15						
16-20	1	1				
21+	1					

Table 2 Non-fatal casualties injured by burns an/or scalds and location of casualty relative to fire

Total number of floors in building	Number of Non-Fatal Injuries – Burns and/or Scalds					
	Room of origin	Floor of origin	Floor +1	≥ Floor + 2	Floor - 1	≥ Floor - 2
1	241	20			1	
2	844	114	32		17	
3	228	34	10	1	5	1
4	62	9	1	1		
5	15	3		3		
6-10	22	1			1	
11-15	19	9	1			
16-20	6	2				
21+	1					

Comparing the range of injury type, it is clear that there are a greater number of injuries caused by inhalation of smoke and toxic fumes than actual burns or scalds. As the spread is also wider for the non-fatal injury (Table 4), this can be attributed to smoke spread through the building compartments and floors. Surprisingly, we also see a number exposed to smoke spread on floors below the floor of fire origin.

Table 3 Fatal casualties injured by smoke and/or gas inhalation and location of casualty relative to fire

Total number of floors in building	Number of Fatalities – Smoke and/or gas					
	Room of origin	Floor of origin	Floor +1	≥ Floor + 2	Floor - 1	≥ Floor - 2
1	15	12	1			
2	75	48	45		4	
3	20	21	13	1		
4	5	2	4			
5		4				
6-10	3	4				
11-15	2		2			
16-20		1				
21+		2				

Table 4 Non-fatal casualties injured by smoke and/or gas inhalation and location of casualty relative to fire

Total number of floors in building	Number of Non-Fatal Injuries – Smoke and/or Gas					
	Room of origin	Floor of origin	Floor +1	≥ Floor + 2	Floor - 1	≥ Floor - 2
1	235	189	8	1		
2	1277	1246	699	6	122	2
3	379	484	182	71	31	6
4	147	213	66	43	8	1
5	38	45	21	28		
6-10	34	61	15	1		4
11-15	37	75	3	7	4	3
16-20	16	39	1	6		
21+	4	18	1			1

From Tables 1-4, we see that the majority of injuries and fatalities occur within relatively low rise buildings which can be easily accessible by the Brigade. Within the lower rise buildings, the spread of smoke and toxic gases appears to enter the majority of floors within the building. This would most likely be due to occupants or Brigade personnel opening doors for means of escape and to gain access.

Table 5 below looks at two specific building heights, 12 and 10-storeys. Clearly, the majority of fires occur on the ground floor level, with a relatively even distribution over the remainder of the floors. This would tend to imply deliberately set fires, possibly through the setting of rubbish fires.

Table 5 Number of fires in buildings by floor of origin for a 12 and 10-storey building

12-Storey Building			10-Storey Building		
Floor Number	Number of Fires	Percentage Number of Fires	Floor Number	Number of Fires	Percentage Number of Fires
	16.3	30.			
-1	7.3	1.3	-1	5.8	1.2
0 (GROUND)	132.3	24.3	0 (GROUND)	150.9	32.0
1	46.6	8.6	1	42.0	8.9
2	32.8	6.0	2	36.5	7.7
3	32.3	5.9	3	42.7	9.1
4	32.9	6.0	4	37.1	7.9
5	37.6	6.9	5	26.2	5.6
6	46.5	8.5	6	34.0	7.2
7	37.8	6.9	7	26.6	5.7
8	37.8	6.9	8	31.4	6.7

9	19.9	3.6	9	38.3	8.1
10	16.3	3.0			
11	48.6	8.9			
Total	**545**	**100 %**	**Total**	**433.1**	**100 %**

2.3 Assessment of risk

There are relatively few documented cases of extensive external vertical fire spread involving combustible claddings or glazed facades, and there are even fewer cases where such spread has significantly compromised life safety.

Façade fires do not generally threaten building occupants, but the concern is that fire spread through the openings into upper levels may result in secondary fires, which can threaten occupants. It has been suggested that 'sterile zones' could be employed in regions close to windows, with managed policies of no combustibles near windows. This however is difficult to enforce in a domestic (or indeed many other) installations.

The UK guidance given in Approved Document B Fire Safety, deals with the issue of life safety for different occupancies by application of building construction and limits on performance of material. It is the Insurance Industry which is leading the risk assessment of buildings with fully or partially glazed installations, however this is with a view to effects of business interruption and replacement costs.

Building fires result in damage to the fabric and contents of the building and often extensive business interruption. The impact of fire, flame smoke and extinguishing water on a building is dependent upon the fire severity. In 90% of fires, damage is limited to a single compartment or room. However, this means that in 10% of fires, they continue to spread and hence fire damage goes beyond the original enclosure. As a result of experimental work carried out by the Loss Prevention Council, the Association of British Insurers (ABI) published guidance for their members, concerning the estimated maximum loss (EML) in high-rise and multi-storey buildings. Here a fire risk assessment was made of the façade [(10)] to determine the

- associated fire hazards (occupancy, building design and construction)
- fire protection (management, sprinklers, fire brigade operations)
- type of façade employed (design, key features and construction materials)

The Fire Risk Assessment Form [(10)] looks at the construction of the façade including types of structure, fixings, window, cavity etc. Information is given as to the design and material performance with an assessment as to the relative fire performance on a scale of 0 to 2. An example of such for cladding panels would be:

- 0 non-combustible and fire resistant or adequately protected eg. By an approved drencher system;
- 1 limited combustibility (Class O and full-scale testing), some inherent strength and/or obstruction preventing direct flame impingement on susceptible parts;
- 2 combustible, poor fire resistance and exposed to direct flame impingement

Finally recommendations are made as to the provision of additional protection requirement or further testing.

A figure for the total fire performance of the system is calculated from the sum of the individual components. This figure is input into an assessment of the extent of damage for a particular façade.

The extent of damage incurred will depend on the characteristics of the fire, enclosure and façade. Extent of damage can be divided up into two components, enclosures (number of floors above the fire enclosure that could be damaged due to fire spread) and façade (extent of damage over the façade in terms of number of floors above the fire enclosure). The estimated number of damaged storeys is always assumed to be the minimum, with indication made as to where the fire could involve more than one floor or multiple floors.

More floors are likely to be damaged when:

- the façade is constructed from materials that have a weak performance in fire ie. glass
- combustible products form part of the façade
- a combustible cavity exists (between structural elements and the façade)

Damage to multiple storeys is more likely to occur with façades that have a continuous cavity between the backing wall and façade or containing combustibles. However, this does also depend upon the fire severity and fire-fighting availability.

The ABI's EML definitions for extent of damage are:

- an enclosure rating 2+ (façade fire performance rating >7) to be equivalent to a 4-floor fire zone and 20% damage on other floors;
- an enclosure rating of 1-1+ (façade fire performance <7) to be equivalent to a 2-floor fire zone and 10% damage on other floors

The size of the floor area and fire load will determine the extent of damage per floor and the length of the façade within the enclosure area will determine the extent of damage per façade width.

The possible extent of damage will then lead on to consideration of cost of replacement. Damage due to fire will require the replacement of sections of the façade or individual panels. Where the construction of a particular type of façade does not enable the replacement of sections of the system, the building owners and/or insurers may incur excessive costs for replacing the whole system. A number of factors will influence the cost of replacement. The factors include: type and design of the façade system, type and colour of the original cladding panels, weathering, age, cost of original system and access to the façade.

The cost of the original system per unit area will give some guidance as to the cost of replacing a damaged façade. However, the cost of replacement of small sections will undoubtedly incur greater costs due to lack of bulk purchasing capacity and installation practicalities. Indicative costs for new systems are shown below:

Façade Type	Cost £/m^2
Facings	35-640
Concrete Panels	275-750
Rainscreen – flat wall	85-400
Rainscreen type – composite wall panels	30-300
Curtain walling	250-1000+

In addition to the above, where the performance of a component of a façade system is not well established, the building owner is advised to seek test reports from appropriate standard tests. Similarly, where a complete wall façade system performance is not well established, tests on full scale system should be carried out following standards such as BRE Fire Note 9 (11) or LPR 11(12), as appropriate.

3 Conclusion and recommendations

For fire to spread up a building, the fire must break out of a window from a fully involved compartment (i.e. a flashed over fire). Fires on stairways and other escape routes are unlikely (thought not impossibly) to contain sufficient fuel to allow for a fully developed fire.

In general, although not invariably, the layout of a building will result in a stairway window being above another stairway window (usually the same shaft). Similarly, a room (compartment) window will usually be above another compartment window. It follows that a fire from a stairway window would most probably spread to another stairway window, and a fire from a compartment window would most probably spread to another compartment window. Escape routes (except for stairways and stairway lobbies) are usually on the interior of the building. If an exterior fire attacks a compartment (as a result of fire spread up the outside of the building) this will not compromise escape.

Compartment fires do not instantly go to flash-over; there will nearly always be a time delay. It is quite unlikely then that a fire in a large building can reach flashover without the occupants being aware that an incident is in progress.

For these reasons it might be expected that the numbers of people killed or injured as a result of this particular mechanism for fire spread would be quite low.

There are relatively few documented cases of extensive external vertical fire spread involving combustible claddings or glazed facades, and there are even fewer cases where such spread has significantly compromised life safety.

However, there have been incidents where fire has spread up the outside of a building and where there has been a fire fatality from the same incident (Irving, 1999). It is notable that this fatality was not as a result of the fire spread.

Where requirements for vertical separation of openings are given, consideration should be given to the removal of the requirement for 900mm high spandrels in favour of horizontal projections or sprinkler protection.

However, it is very likely that this change would be unacceptable to most building developers and architects due to the aesthetic implications, or potentially large expense of a building wide sprinkler installation.

International research (particularly that carried out by the National Research Council of Canada) has shown that spandrel walls need to be of impractical height (>2.5m) to be effective for controlling vertical fire spread. It was shown that horizontal projections are far more effective than spandrel walls. The Canadian results show that by using an

1100mm wide apron, the exposure to the wall face was reduced to approximately 10% of that experienced by the 900mm spandrel height.

Curtain wall constructions have particular problems of fire spread via the void junctions between the floor slab edge and the façade itself. Distortion of the wall panels can lead to collapse of the passive protection at the floor slab.

Horizontal applications would be incompatible with curtain wall constructions. Here, the only real means of limiting or preventing the risk of vertical fire spread would be the use of sprinkler systems or fire resistant glazing. Work undertaken by the LPC has shown that a fire resisting façade was able to survive elevated temperatures during a fire and prevent breakout and subsequent spread up the system.

A number of mitigatory or protective measures have been identified within the body of this report and include:

- *Spandrel panels* – although not always an appropriate solution, they still perform an important task and could be critical in some buildings and occupancies. Buildings of particular concern are the high-rise buildings with slow evacuation times such as apartment blocks, hospitals, or where phased evacuation is undertaken.
- *Horizontal projections* – more effective than spandrel panel system in reducing the heat exposure to the upper floor level. Does have an aesthetic implication for building design. Impractical for large glazed areas.
- *Window orientation and size* – the heat exposure can be influenced and to a point controlled by the use of tall and thin window dimension, low and wide orientation results in a much higher heat intensity on the above façade.
- *Sprinklers* – the most effective and accessible control method. Reduces the gas temperature to levels that are not threatening to the non-fire resisting façade. Especially useful with curtain walling systems. Favoured by the international community over the use of spandrel and/or apron projection.
- *Limited combustibility of claddings* – submit all cladding materials to appropriate test methods available. BRE cladding test – Fire Note 9 outlines such a test. Additional full size testing should be carried out for applications of glazed façades.
- *Fire resistant glazing and facades* – windows or openings introduce a weakness to the façade. Use of fire resistant materials provides improved integrity of glazed systems. Full scale tests allow for assessment of the whole system performance.
- *Sterile zones* – for combustible products so use non-combustible curtains, blinds etc. Limits fire load adjacent to window openings and hence the risk of exposure from external flaming.
- *Staggering the window layouts* – to increase spandrel height in a façade.

The relatively low number of deaths or injuries is supported by the Brigade statistics identified here. It has not been possible to identify any incidents in the UK where death or injury has resulted from fire spread up the outside of a building where the fire has broken out of one window and re-entered at another. Indeed, very few people are killed or injured from fire who are elsewhere than on the fire floor. Most deaths or injuries on floors other than the fire floor are as a result of smoke.

It therefore may be concluded that fire spread up the outside of buildings via the windows is not a significant threat to life compared with the other risks from fire in tall buildings. The UK guidance given in Approved Document B Fire Safety, deals with the issue of life safety for different occupancies by application of building construction and limits on performance of material. It is the Insurance Industry which is leading the risk assessment of buildings with fully or partially glazed installations, however this is with a view to effects of business interruption and replacement costs. For buildings that are seen as being at particular risk from this process (for example, for property or contents) then the various methods given above could be applied.

Those that are most effective are the ones that have the greatest impact on the design of the building. The optimum response to this particular risk is sprinkler protection, to limit the probability of a large fire and to limit its spread. Sprinklers are already a requirement for buildings over 30m in England and Wales, except for residential.

The evidence acquired for this project therefore leads to the conclusion that the measures currently called upon in England and Wales through AD B are still commensurate with the risk. An assessment needs to be made, on an individual basis, as to the incorporation of additional measures that may be required. Buildings with potentially high risk occupancies ie. intensive care wards in a multi-storey structure, would be one such example.

Only in exceptional circumstances should special measures be applied.

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Appendix A – List of previous reports, with references, for this project

BRE output/ milestone reference	Title	Date submitted
203137	Quarterly progress report	June 2001
203130	Task 1 - A survey of available information on incidents of flame spread through windows	August 2001
203132	Task 3 – A review of codes and standards relating to fire spread through windows	August 2001

Appendix B – Historical fires involving claddings and façades

1. Andraus Building, Sao Paulo, Brazil 1972 (5)

This was a 31-storey department store and office building. The fire developed on four floors of the department store and then spread externally up the side of the building, involving another 24 floors. Wind velocity and combustible interior finishes and contents were contributing factors to the fire spread. The building construction was reinforced concrete. The building façade had extensive floor to ceiling glazed areas, with a spandrel of only 350mm in height and projecting 305mm from the face of the building. After the fire broke through windows they formed a front exposing the three to four floors above the department tore. Radiant heat then ignited combustible ceiling tiles and wood partitions on each floor. The flame front then increased in height as more floors became involved. At its peak the mass of flame over the external façade was 40m-wide and 100m-high and projecting at least 15m into the street.

2. Joelma Building, Sao Paulo, Brazil 1974 (5)

This was a 25-storey office building of reinforced concrete structure (beams, columns, floor slab) and an exterior curtain wall with hollow tiles rendered with cement plaster on both sides and windows with aluminium framing. The floor slabs were poured in situ and provided a 900mm projection on the north wall and a 600mm projection on the south wall. Fire started on the 12th floor near a window. The fire spread externally up two of the façades to the top of the building, readily igniting combustible finishes inside the windows of the floors above which allowed vertical spread to continue.

There were 179 deaths.

3. Las Vegas Hilton Hotel, 1981 (5)

This was a 30-storey hotel of reinforced concrete construction. Glass windows between floors were separated vertically by a 1m spandrel prefabricated of masonry, plaster and plasterboard on steel studs.

Fire occurred on the eighth floor of the East tower lift lobby, where the fire involved curtains, carpeting on the walls, ceiling and floor and furniture. The plate glass window to the exterior shattered allowing a flame front to extend upwards on the exterior of the building. It apparently took 20-25 minutes for exterior fire spread from the eighth floor to the top of the building (about 20 floors). Two mechanisms were identified for the vertical fire spread:

- Flames outside the upper windows radiated heat through the windows and ignited curtains, timber benches with polyurethane foam padding, which then ignited carpeting on room surfaces.

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- Flames contacted the plate glass windows. It is believed that the triangular shape of the spandrels and recessed plate glass caused additional turbulence, which rolled the flames onto the windows resulting in early failure.

There were eighth deaths in this fire. Three were in the eighth floor lift lobby, one by jumping/falling from the 12th floor and four in hotel rooms in the East tower. The doors to the hotel rooms where the deaths occurred were open or had been opened during the fire. There were no fatalities in rooms where the door had been kept closed. This suggests that internal rather than external fire spread was the main reason for the deaths.

4. First Interstate Bank Building, Los Angeles, California 1988 (5)

The bank was a 62-storey tower with sprinkler protection only in the basement, garage and underground pedestrian tunnel. An automatic sprinkler system was being installed in the building at the time of the fire. The building had a structural steel frame with spray-on fire proofing with steel floor pans and lightweight concrete decking. The exterior curtain walls were glass and aluminium with a 100mm gap between the curtain wall and the floor slab, where the fire stopping, comprised 15mm gypsum board and fibreglass caulking. The fire started on the 12th floor and extended to the floors above primarily via the outer walls of the building. Flames also penetrated behind the spandrel panels around the ends of the floor slab where there was sufficient deformation of the aluminium mullions to weaken the fire stopping, allowing the flames to pass through even before the windows and mullions had failed. Flames were estimated to be lapping 9m up the face of the building. The curtain walls including windows, spandrel panels and mullions were almost completely destroyed by the fire. The upward extension stopped at the 26th floor level.

5. Mercantile Credit Building, Basingstoke 1991 (5)

This was a 12-storey office block. Fire on the eighth floor spread up the building and broke out on the eight floor. Flame spread externally behind glass curtain walling to the tenth floor, fanned by strong winds.

6. One Meridian Plaza Building, Philadelphia 1991 (5)

This fire occurred on the 22nd floor of a 38-storey bank building. The building frame was structural steel with concrete floors poured over metal decks and protected with spray-on fireproofing materials. The exterior of the building was covered by granite curtain wall panels with glass windows attached to perimeter floor girders and spandrels. At the time of construction only the blow ground service floors were fitted with sprinklers and since then they had been added to the 30th, 31st, 34th and 35th floors and parts of floors 11 to 15. Fire broke through windows on the 22nd floor and heat exposure from the window plumes ignited items on the floor above. The fire was stopped when it reached the 30th floor which was sprinklered.

7. Knowsley Heights, Liverpool, 1991 (5)

This was an 11-storey residential tower block. The fire was started deliberately in the rubbish compound outside the building. Fire spread up through a 90mm gap between the building's rubberised paint-covered concrete outer wall and a recently installed rain screen cladding. The rapid spread of fire was thought to have been caused by the lack of fire barriers in the cavity gap passing all eleven floors and providing a flue for hot gases to rise. The fire destroyed the rubbish compound and severely damaged the ground floor lobby, outer walls and windows of all the upper floors. No smoke or fire penetrated into the flats and the building was reoccupied by tenants later the same day. The rain screen cladding material was a Class 0 rated product. Building Regulations were changed as a result of this fire.

8. President Tower, Bangkok 1997 (5)

This was a 37-storey retail, commercial office and hotel development. A sprinkler system was not yet operational as the interior fir out was not fully completed. An explosion and fire started on level seven causing the destruction of the aluminium framed curtain walling system. The effectiveness of fire stopping at the floor edge was compromised by floor to floor cabling. Window and spandrel glass shattered and collapsed before structural silicone sealant bonds between the glass and aluminium were destroyed. Many heat strengthened glass panels sustained elevated temperatures but fractured and collapsed as they cooled. The vertical fire spread extended up to level ten.

9. Residential tower block, Irvine, Scotland, 1999 (5)

The fire, which started in a flat on the fifth floor of a 13-storey block of flats, broke out through the window and quickly spread vertically up the exterior face of the building, engulfing the upper nine floors within minutes. The building was of concrete construction but had full height composite window units comprising a GRP panel below the window and u-PVC window frames. The fire ignited the GRP panels and spread vertically.

There was one death in the incident and that was in the flat of fire origin. Therefore the combustible window components were unlikely to have contributed to the death.