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Department for Communities and Local Government Project Report:

BD 2887

Compartment sizes, resistance to fire and fire safety project

Work stream 3 – Construction details – roof voids, cavity barriers and fire/smoke dampers

Final publishable guidance

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FIRE

BD 2887

Compartment sizes, resistance to fire and fire safety project

Interim Report – Final publishable guidance for Work stream 3

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Fire spread in concealed spaces and the provision of compartmentation in roof voids, cavity barriers and fire rated ducts and dampers

Final version (taking into account Satellite Steering Group A and Project Steering Group comments)

1 Introduction

This draft publication has been prepared as part of a research project funded by the Department for Communities and Local Government 'Compartment sizes, resistance to fire and fire safety', BD 2887, under Work stream 3, Construction details – roof voids, cavity barriers and fire/smoke dampers.

This draft publication is primarily concerned with the unseen spread of fire and smoke within concealed spaces in buildings and the provision of construction details, in particular compartmentation in roof voids, cavity barriers and fire rated ducts and dampers.

The purpose of this draft document is to provide a review of the issues of fire (and smoke) spread in concealed spaces, to explain the principles that underpin existing guidance, and to seek to reinforce the importance of the proper application of the measures that are available to prevent or limit such fire spread.

Information is provided on the relevant Regulatory requirements, Approved Document B (AD B)[1] and other guidance, methods of test and assessment, previous research, issues highlighted from real fires, fire statistics of hidden fire spread, alternative solutions not covered by AD B, and third party certification. Real fires and existing research have highlighted situations where the compartmentation has been effective and situations where the detail has failed to provide the requisite performance.

In addition, the relevant findings from the experimental research programme that is part of the current programme are reported.

This draft guide is primarily intended for designers, specifiers, inspectors, installers, approvers, and risk assessors of fire safety measures in buildings.

2 Background

Fire and smoke spread in concealed spaces within buildings can present both a life risk to occupants and fire-fighters, and cause widespread damage with extensive, difficult, and expensive clean-up and re-instatement. Indeed, in some cases, smoke deposits (and their resulting odour) can never be adequately removed, and buildings have had to be demolished. Also, as new and innovative methods of construction introduce additional voids, cavities, and shafts into buildings[2,] there are identified issues associated with the provision and quality of installation of fire protection products and systems in concealed spaces.

The issue is not new. Concerns during the 1990s and 2000s led to a joint government/industry research project part funded under the "Partners in Innovation" programme to review the issues and produce guidance. The report is produced by the Association of Specialist Fire Protection, 'Ensuring Best Practice for Passive Fire Protection in Buildings' [3].

However, despite these concerns, there are very few deaths that can be associated with fire (or smoke) spread in concealed spaces (although there are cases of smoke inhalation). Indeed, to date, only three specific cases of fatal fires have been identified by BRE: the Aviemore hotel fire in 1995, the Rosepark care home fire in 2004[4, 5] and the Lakanal block of flats fire in 2009[6].

3 Regulatory requirements

The Building Regulations 2010[7] have five requirements with respect to fire. These are:

- B1 Means of warning and escape
- B2 Internal fire spread (linings)
- B3 Internal fire spread (structure)
- B4 External fire spread
- B5 Access and facilities for the fire service

With respect to concealed spaces, the relevant parts of the Requirement B3 Internal fire spread (structure) from Part B of Schedule 1 to the Building Regulations 2010[7] are B3(3) and B3(4).

B3(3) states:

"Where reasonably necessary to inhibit the spread of fire within the building, measures shall be taken, to an extent appropriate to the size and intended use of the building, comprising either or both of the following –

(a) Subdivision of the building with fire resisting construction;"

(b) [Installation of suitable automatic fire suppression systems].

B3(4) states:

"The building shall be designed and constructed so that the unseen spread of fire and smoke within concealed spaces within its structure and fabric is inhibited".

The actual means by which these (functional) requirements of B3 are met are chosen by the designer, architect or fire engineer and, ultimately, ratified by the Building Control Authority. However, by way of overarching guidance, Approved Document B[1] states that:

"In the Secretary of State's view the Requirements of B3 will be met:

a. if the loadbearing elements of structure of the building are capable of withstanding the effects of fire for an appropriate period without loss of stability;

b. if the building is sub-divided by elements of fire-resisting construction into compartments;

c. if any openings in fire-separating elements [….] are suitably protected in order to maintain the integrity of the element (i.e. the continuity of the fire separation); and

d. if any hidden voids in the construction are sealed and sub-divided to inhibit the unseen spread of fire and products of combustion, in order to reduce the risk of structural failure and the spread of fire, in so far as they pose a threat to the safety of people in and around the building. The extent to which any of these measures are necessary is dependent on the use of the building and, in some cases, its size and on the location of the element of construction."

Standard details are provided within Approved Document B to ensure compartmentation is maintained for a reasonable period in compliance with requirement B3 of the Building Regulations[1].

4 Compartmentation in roof voids

4.1 Principles

The principle of protecting roofs is to ensure that the volume of the roof void in which the fire may develop is limited in extent, and that any barriers to the spread of fire are imperforate. Therefore, in order to prevent roof spaces from providing a means of bypassing existing compartmentation in the event of a fire, it is necessary to extend compartment walls up to meet the underside of the roof covering or deck with fire stopping at the roof/wall junction, if required.

Alternatively, the compartment wall may be extended up through the roof.

The intention is that there must be complete separation in the plane of the separating wall between dwellings which cannot be by-passed by fire.

4.2 Existing guidance on compartmentation in roof voids

4.2.1 Approved Document B and standard details

Guidance is presented in Section 8 of Approved Document B (AD B)[1] on the means of satisfying the compartmentation requirement at the junction of a compartment wall with the roof. The guidance may appear to be complicated but, broadly speaking, involves

- Either fire stopping up to the underside of the roof covering or deck and restricting flame spread in the area around the junction or
- Continuing the compartment wall up through the roof extending beyond the top surface of the roof covering.

A typical detail from AD B is shown in Figure 1.

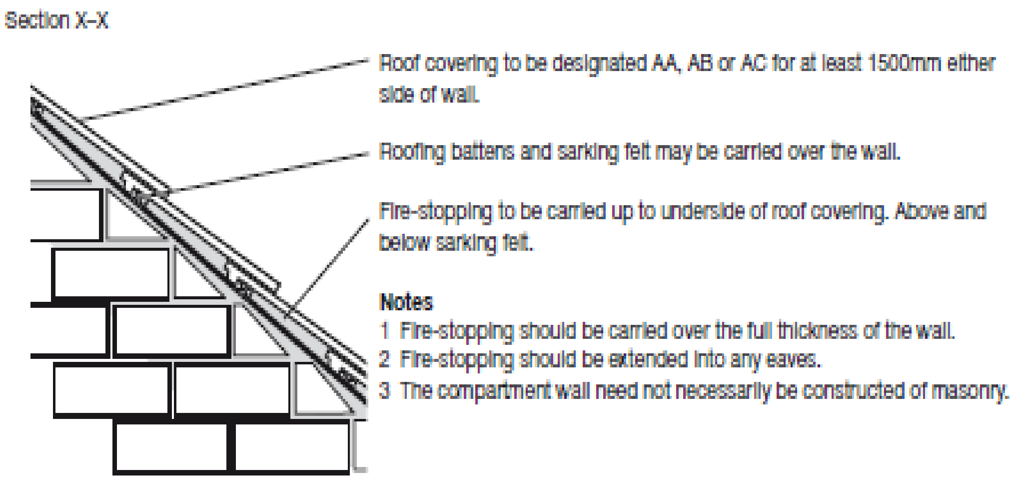

Figure 1 - Section showing typical detailing for fire stopping between compartment wall and roof covering (from Diagram 30 of Approved Document B)

4.2.2 Other guidance

Further guidance is available from the NHBC[8] to resist fire spread at the junction between roofs and compartment or separating walls. This guidance requires the junction to be fire stopped to prevent fire, smoke and fire spread from one compartment to the next across the wall. Mineral wool fire stopping is specified to allow for movement of the roof timber and avoid hogging of the roof associated with mortar fire stopping. A typical detail from the guidance is shown in Figure 2.

As with the AD B detail (Figure 1), it is emphasised that fire stopping is required both below the underlay (sarking felt) and above the underlay, between the battens and under the roof tiles. Both AD B and the NHBC guidance also emphasise the need to provide fire stopping within the eaves detail and to close off the external wall cavity where it meets the eaves. It is important to note that the compartment wall need not necessarily be constructed of masonry. A number of standard details are provided[8] available for timber frame spandrel panels (a timber frame triangular panel forming a gable wall above the ceiling line).

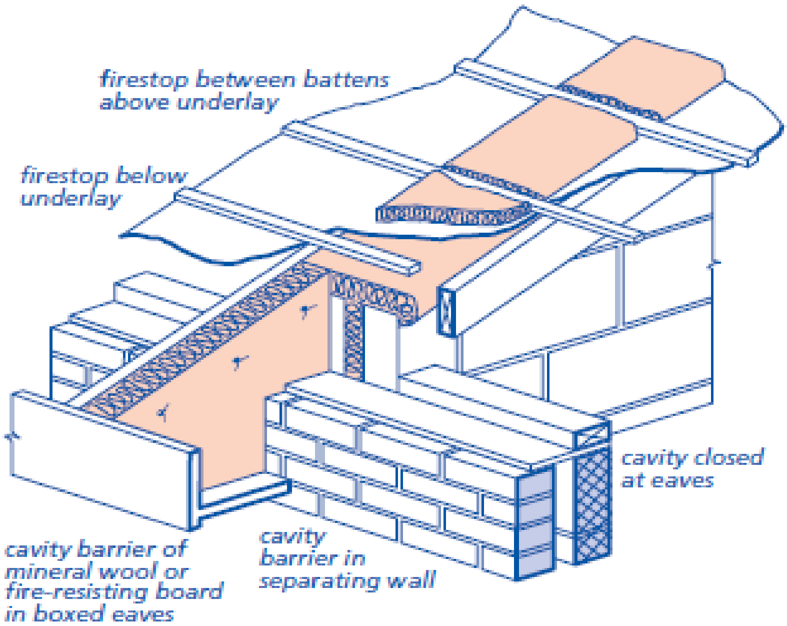

Figure 2 - Detail of fire stopping at wall/floor junction (From NHBC Design standard Part 7 Roofs Chapter 7.2 Pitched roofs[8])

Although specialist information on fire stopping is available through the Association for Specialist Fire Protection (ASFP) website (www.asfp.org), the particular detailing of compartmentation within the roof spaces of residential buildings is often left to non-specialist construction staff. Standard details, such as spandrel panels used in timber frame construction, provide a simple means of achieving the required level of fire resistance but do not account for fire stopping around any eaves cavity or the difficulties of providing fire stopping to the underside of the roof covering. The current guidance in Approved Document B is the main source of information for those involved in specifying and providing compartmentation within roof voids. The particular issue of the detail at the junction between a separating wall and the roof in relation to preventing fire spread between dwellings was covered by the BRE Housing Defects Prevention Unit in Defect Action Sheets 7[9] and 8[10]. Further information was provided on cavity barriers and fire stops including cavities within roof spaces, in BRE Digests 214[11] and 215[12].

BS 9999[13] is the fire safety code of practice for building design, management and use. The standard outlines ways to meet fire safety legislation through a more flexible approach to design. The standard can be used in and around existing buildings, at design stage for new buildings or extensions, and also applies to alterations, extensions and changes of use of an existing building. It also provides an assessment tool to ensure fire safety strategy remains robust.

Concealed spaces are discussed in Section 34 of the British Standard, and this includes guidance on cavity barriers (Section 34.2) and extensive cavities (Section 34.3).

In some existing buildings, such as historic buildings undergoing conversion for change of use, it may be difficult to fit adequate compartmentation in roof voids for a variety of reasons, including restriction of ventilation. In such cases alternative approaches might be considered, including fitting sprinklers into the roof void.

4.3 Methods of test and assessment of compartmentation in roof voids

There are many different ways of providing the required level of compartmentation within roof voids, depending on the size and nature of the occupancy and the level of fire resistance required. In general, the barrier will be assessed in the same way as internal compartment walls, i.e. through standard fire tests for load bearing or non-loadbearing walls.

This will provide an effective measure of the fire resistance of the wall, be it constructed from masonry, timber frame with plasterboard, light steel frame with plasterboard or any other specific form of construction. However, it will not provide an assessment of the system actually installed and will not take into account critical detailing aspects such as fire stopping between the top of the separating wall and the underside of the roof covering and within any boxed eaves detail. Consequently, any such test results can provide only limited assurance that the element will perform as required in a realistic fire scenario.

4.4 Previous research on compartmentation in roof voids

The Department for Communities and Local Government commissioned a research study BD 2846 ‘Compartmentation in roof voids’ published in 2010[14] to investigate a number of specific issues with respect to fire compartmentation in roof voids.

The research was instigated following a number of fires in relatively modern apartment buildings which resulted in fires in roof voids which spread quickly throughout the roof and affected all of the top floor flats. This was despite the provisions in the Building Regulations and supporting guidance intended to ensure that the fire resisting separation between individual flats is maintained.

The resulting publication[14] described the findings from an investigation into two specific issues:

- Whether recent and current building practice followed the guidance in Approved Document B, and
- To research actual fires within roof voids.

The project focussed specifically on pitched roofs in apartment buildings.

Four potential mechanisms of fire spread were identified:

a) Combustible materials spanning beneath the non-combustible roof covering, (i.e. on the underside of the roof covering),

b) Absent or poor installation of cavity barriers/compartmentation,

c) Fire spread along the soffit,

d) Heat transfer through penetrations.

These mechanisms are broadly in line with the findings in the case studies discussed later.

The principal conclusions from the project were:

- The design details which are submitted for Building Regulations approval often do not contain adequate information to prove compliance with Building Regulations.
- Fire-stopping was identified as a particular issue.
- Errors often arise due to misunderstandings between a “cavity barrier” and a “compartment wall”.
- A review of real fire incidents appear to indicate that the construction methods adopted over many years can provide the levels of compartmentation required by the regulations.
- The quality of installation is variable with many systems providing inadequate levels of compartmentation.

4.5 Issues from fire investigations – fire spread in roof voids

A number of incidents in recent years have involved fire spread within roof voids. BRE, through its contract with DCLG to attend fires of special interest, investigate issues that may impact on Building Regulations and through contacts with the Fire and Rescue Service and other agencies has access to fire scenes. The BRE database has been reviewed to identify those areas where compartmentation in roof voids played a role (either positively or negatively) in fire development and the nature and extent of fire spread.

To ensure confidentiality, no mention is made here of specific locations and all incidents are referred to with reference to the type of structure involved.

4.5.1 Case study 1 – Residential development (four- and five-storey apartment blocks)

The fire started in a small section of a flat roof of one apartment block, ignited the sarking felt on the adjacent pitched roof and spread into the roof void. The fire spread within the roof space over three flats, bypassing two compartment walls. Eventually, the fire spread into the roof void of an adjacent block, again involving three apartments and bypassing two compartment walls. The compartment walls were constructed from concrete building blocks. However, it was clear from the scene that no attempt had been made to firestop the junction between the walls and the roof as detailed in AD B (see Figure 3).

Figure 3 - Lack of fire stopping between compartment wall and roof covering

4.5.2 Case study 2 – Three-storey block of flats

It is likely that the fire was initiated as a result of hot work being carried out on pipes penetrating the exterior wall of the three-storey block of flats. Initial fire spread was through the external wall cavity breaking out at roof level some distance from the point of origin. Once in the roof area, the fire spread rapidly, leading to collapse of the roof trusses and break out back into the floors below. It is clear from the speed and extent of the fire spread that compartmentation within the roof space was ineffective. Figure 4 shows the point of fire origin and the area where the fire broke out from the roof.

Figure 4 - Arrow A indicates point of fire origin. Arrow B indicates point of break out at roof level

4.5.3 Case study 3 – Four-storey residential building

The fire is believed to have started on the landing of the second floor of a four-storey residential building. The fire spread from here to involve the third floor landing and ultimately, to the roof structure, most probably via an external wall cavity accessed through a window opening. Compartmentation was breached as the fire traversed the roof structure over a number of compartment walls. The compartment walls were constructed from concrete blocks clad in plasterboard with a plaster skim coat. The walls were continued up through the ceiling to the underside of the roof covering. The seal between the top of the wall and the roof covering seems to have been made from mineral wool. It is believed that the fire spread due to a combustible membrane between the tiles and the roof structure. Figure 5 shows the roof collapse into the apartment below.

Figure 5 - Roof collapse through ceiling into compartment below

4.5.4 Case study 4 – Four-storey apartment block

Fire broke out in one of the flats on the third floor of a four-storey apartment block. The fire broke out of the window and into the roof void through the roof eaves soffit and spread to destroy the entire roof area. The roof was a new pitched roof over an existing flat roof formed from a concrete slab. For this reason, the roof void could be considered to be a single compartment and separation would be necessary to maintain the maximum distances of cavities rather than specifically to maintain compartmentation. Separation was provided in the roof space at approximately 15m intervals, comprising mineral wool and chicken wire curtains held in place with metal bars fixed to the timber trusses. The separation in the roof space clearly did not perform as intended. The poor state of the compartmentation in the roof space had been highlighted in a previous report following a fire on the same estate. The condition of the fire stopping in the roof space in a similar block is illustrated in Figure 6.

Figure 6 - Fire stopping in poor condition (Image courtesy of London Fire Brigade)

4.5.5 Case study 5 – Three-storey block of flats

The fire occurred in a flat on the top floor of a three-storey block of flats and spread into the roof space. The fire developed to involve the roof space over all three flats on the top floor. Fire spread over the compartment walls in the roof area appears to have been due to a combination of poor fire stopping in the compartment walls above ceiling level, poor fire stopping where the curved sections of the roof crossed the compartment walls, and fire bridging the compartment walls due to the presence of combustible materials within the make-up of the roof covering. Figure 7 shows the attempt made to provide fire stopping where the curved section of the roof crossed the compartment wall.

Figure 7 - Attempt to follow roof profile over compartment wall

4.5.6 Case study 6 – Two- and three-storey blocks of flats

The fire started in a first floor flat of a block of flats, broke out of the room of origin through a window, and entered the roof through the eaves. Fire spread rapidly throughout the structure of the roof. The roof was constructed from lightweight timber truss rafters. The roof covering was ceramic tiles under which a bitumen impregnated sarking felt had been fixed. Fire separation within the roof space was completed using a mixture of blockwork and cavity barriers. The cavity barriers were constructed from mineral wool fixed to a wire mesh. The barriers were fixed to timber trusses using clamping plates. The fixing of the fire barrier to the timber trusses does not appear to have been in accordance with manufacturer's guidance since the barriers did not press up against the underside of the sarking felt so the fire was able to spread along the sarking felt over the top of the cavity barriers (see Figure 8).

Figure 8 - Fire stopping against underside of sarking felt but not pushed up against underside of roof tiles

4.5.7 Case study 7 – Three-storey block of flats

The fire is believed to have been started by a cigarette discarded in wood chippings in flower beds arranged around the outside of a three-storey block of flats and in contact with the external wall. The fire spread from the wood chippings into the cavity of the external wall via a plastic air brick providing ventilation to the cavity situated beneath the suspended ground floor. Cavity barriers in the external wall cavity were either missing or poorly fitted. The fire spread up the cavity to the roof of the building, causing significant structural damage to the roof and accommodation storeys. A combination of fire-fighting and effective compartmentation, both between compartments and within the roof space, prevented more extensive fire spread within the building. Figure 9 is an aerial view of the building showing the damage at roof level.

Figure 9 - Aerial view showing damage to roof structure

4.5.8 Case study 8 – Two-storey residential care home

Fire started within a first floor bedroom of a two-storey residential care home. Smoke entered a wall cavity and found its way into the roof void where a detector was activated. Due to early activation and the prompt action of the Fire and Rescue Service, the fire was prevented from spreading into the roof void. However, there was inadequate separation within the roof space. The junction between the external wall cavity and the roof space is shown in Figure 10.

Figure 10 - Close up of fire damage to pitch roof (arrow showing direction of fire spread from wall cavity)

4.5.9 Case study 9 – Three-storey timber-frame terraced house

The fire was started within an upper floor bedroom of a three-storey timber-frame terraced house and flames spread into an external wall cavity through failure of a uPVC window frame. From there, it spread into a compartment wall separating dwellings. In this case, the quality of the compartmentation in the roof space prevented more widespread damage as can be seen from the undamaged roof trusses in figure 11. The compartmentation was formed from two layers of plasterboard either side of the timber frame compartment wall, with all joints fully taped and sealed.

Figure 11 - Undamaged roof trusses above seat of fire

4.5.10 Case study 10 - Mixed residential timber-frame development

The fire started within a ground floor flat and spread via the external façade into the compartment wall between occupancies. As with the incident in case 9, the quality of compartmentation in the roof space, as shown in Figure 12, restricted the amount of damage from the fire.

Figure 12 - Sealing between compartment wall and roof construction

4.6 New fire experiment on compartmentation in roof voids

As part of the research project commissioned by the Department for Communities and Local Government ‘Compartment sizes, resistance to fire and fire safety’, BD 2887, BRE has undertaken a series of full-scale fire experiments within a purpose-built fire compartment. The experimental programme encompassed fully developed post-flashover fires focussed on investigating the influence of high levels of thermal insulation on fire growth, development and space separation between buildings and a number of fires within an enclosure representative of a basement fire with limited ventilation provided via horizontal openings in the ceiling.

The final experiment in the series utilised the fire compartment to provide a room on which a trussed rafter roof was constructed incorporating a compartment wall typical of a standard spandrel panel detail used in timber frame construction.

The roof fire experiment differed from the previous six experiments in that this was primarily a demonstration of performance rather than an attempt to generate fundamental data for subsequent analysis. The initial condition consisted of a compartment lined on the walls and ceiling with two layers of fire rated plasterboard. The trussed rafter roof was built on top of the existing floor screed over a beam and block floor from rafters provided by the Truss Rafter Association (see Figure 13).

Figure 13 - Trussed rafters used for compartmentation in roof voids experiment

The gable ends and the intermediate compartmentation within the roof space were formed from spandrel panels (see Figure 14) constructed to a specification prepared by the Structural Timber Association.

Figure 14 - Timber used to form spandrel panels

The gable end spandrel panels were protected with two layers of fire rated plasterboard on the internal face only (see Figure 15) while the intermediate spandrel panel forming the internal compartmentation within the roof space was protected with two layers of 12.5mm fire rated plasterboard on either side (see Figure 16).

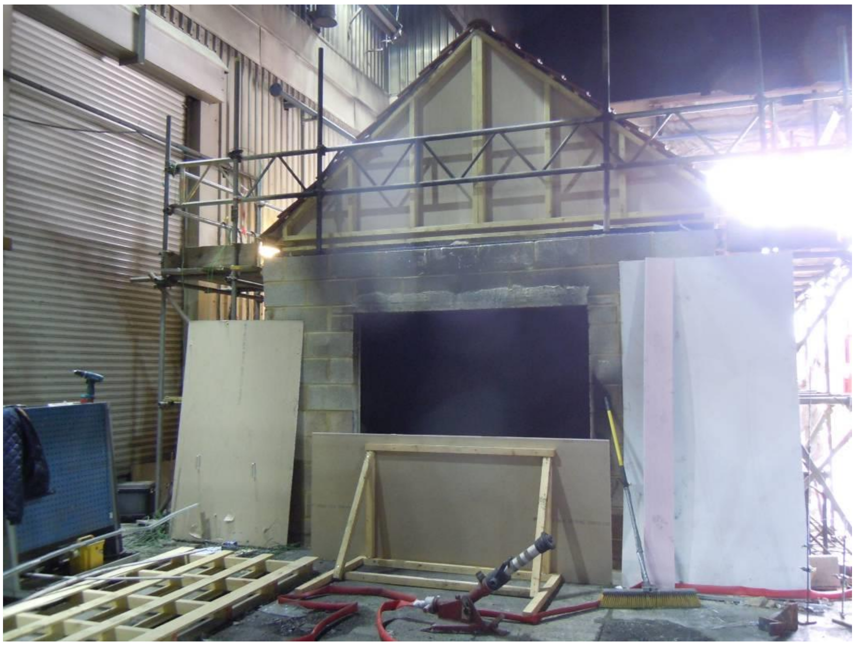

Figure 15 - (Northern) Gable end showing plasterboard to internal face of spandrel panel

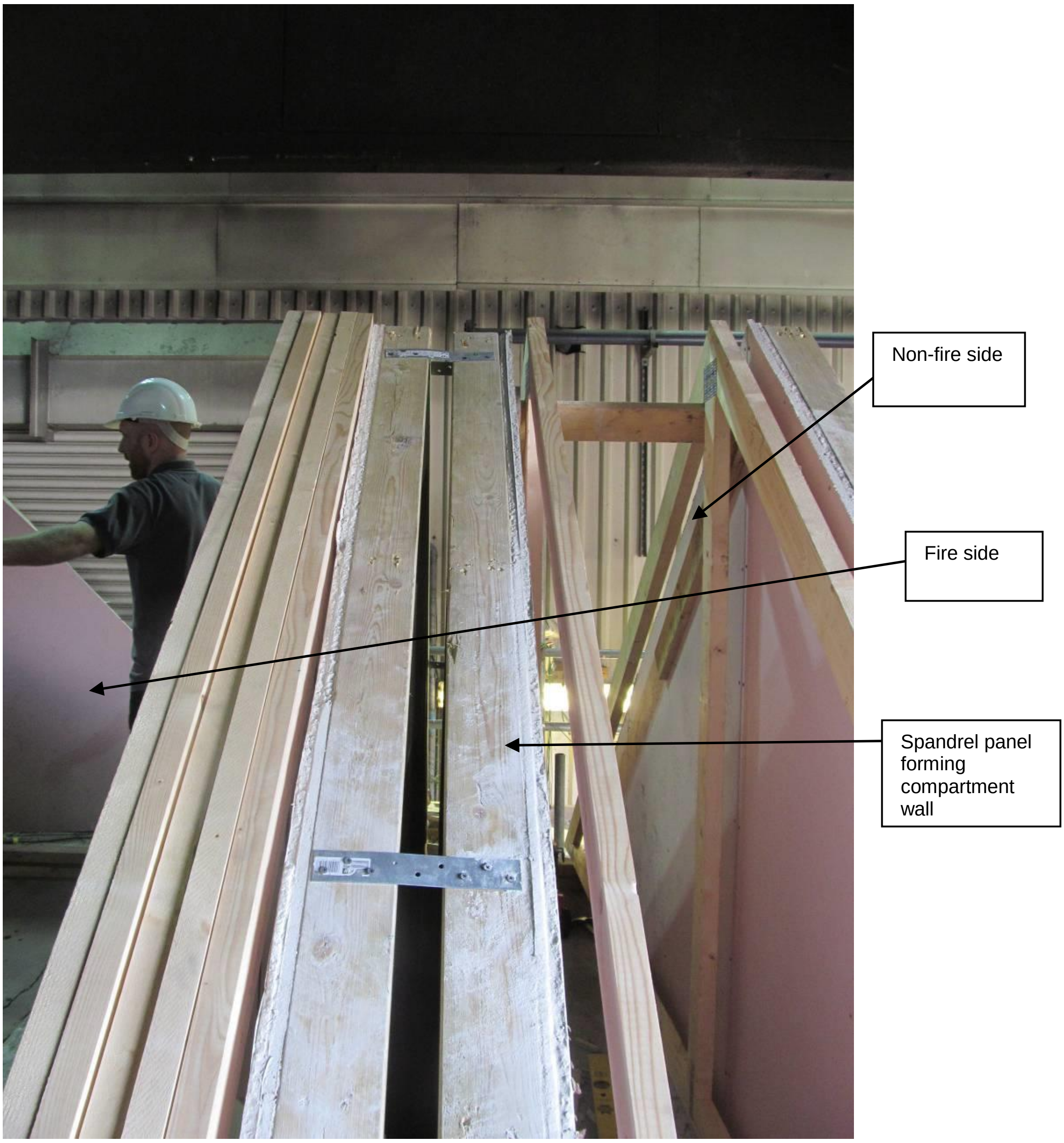

Figure 16 - Intermediate spandrel panel showing double layer plasterboard protection

The spandrel panels were cut approximately 25mm below the level of the trusses and the gap between the top of the panel and the roofing membrane was filled with a 30mm thick rock fibre slab (RWA45 grade material) as specified through the ASFP and supplied through the Structural Timber Association. The same insulation was used to cover the space between the tile battens to fill the gap between the roofing membrane and the clay tiles (see Figure 17). The battens were continuous over the spandrel panel.

Figure 17 - Insulation between tiling battens prior to fixing roof tiles

Four 60mm diameter holes were drilled through the ceiling towards the centre of the compartment and the plasterboard at this point locally weakened by a saw cut (see Figure 18) to provide a means by which the fire could enter the roof space without subjecting the roof to the immediate effects of a fully developed post-flashover fire.

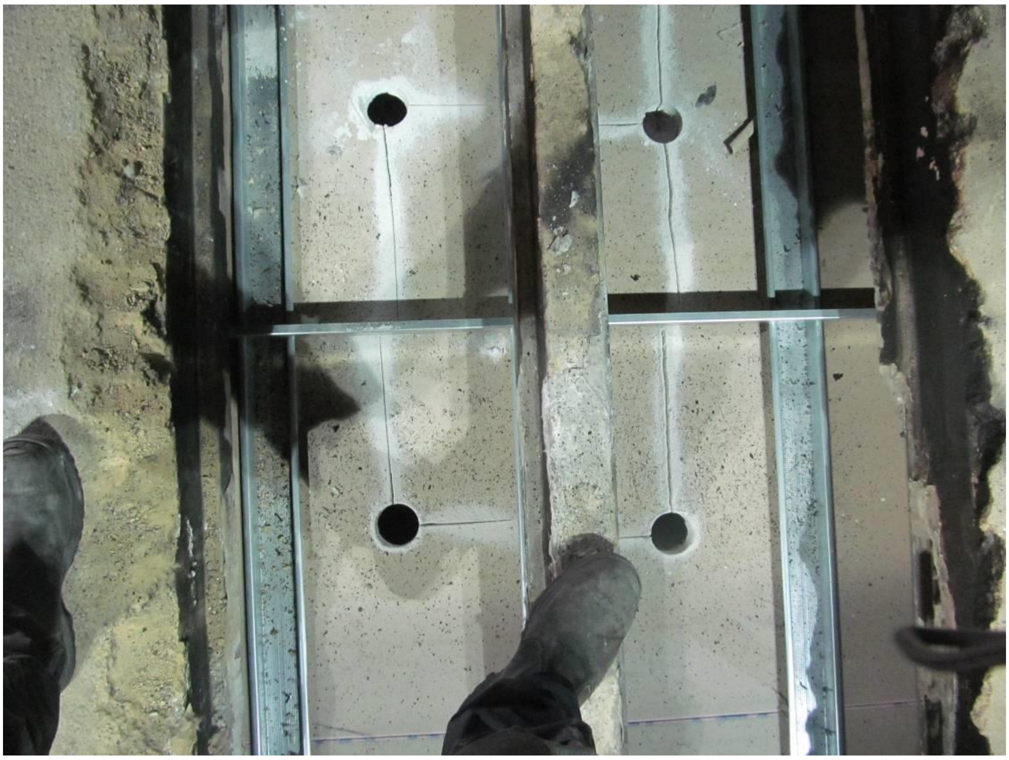

Figure 18 - Holes drilled through plasterboard in centre of fire compartment (The finished roof with the location of the intermediate spandrel panel indicated by yellow paint is shown in Figure 19)

Figure 19 - Completed roof structure with spandrel panel location indicated by yellow paint

4.6.1 Observations and results

The key observations are summarised in Table 1.

Approximate time from ignition (minutes: seconds)	**Observation**
0:00	Ignition
1:20	Board fitted over horizontal opening following ignition
7:00	Flashover (external flaming and compartment temperatures > 500°C)
40:00	Compartment fire extinguished
80:00	Additional fuel put into compartment
90:00	Roof collapse

Table 1 - Key observations from roof fire test

The key events are highlighted in the graphs showing compartment temperatures and temperatures within the roof space either side of the compartment wall (see Figures 20 and 21).

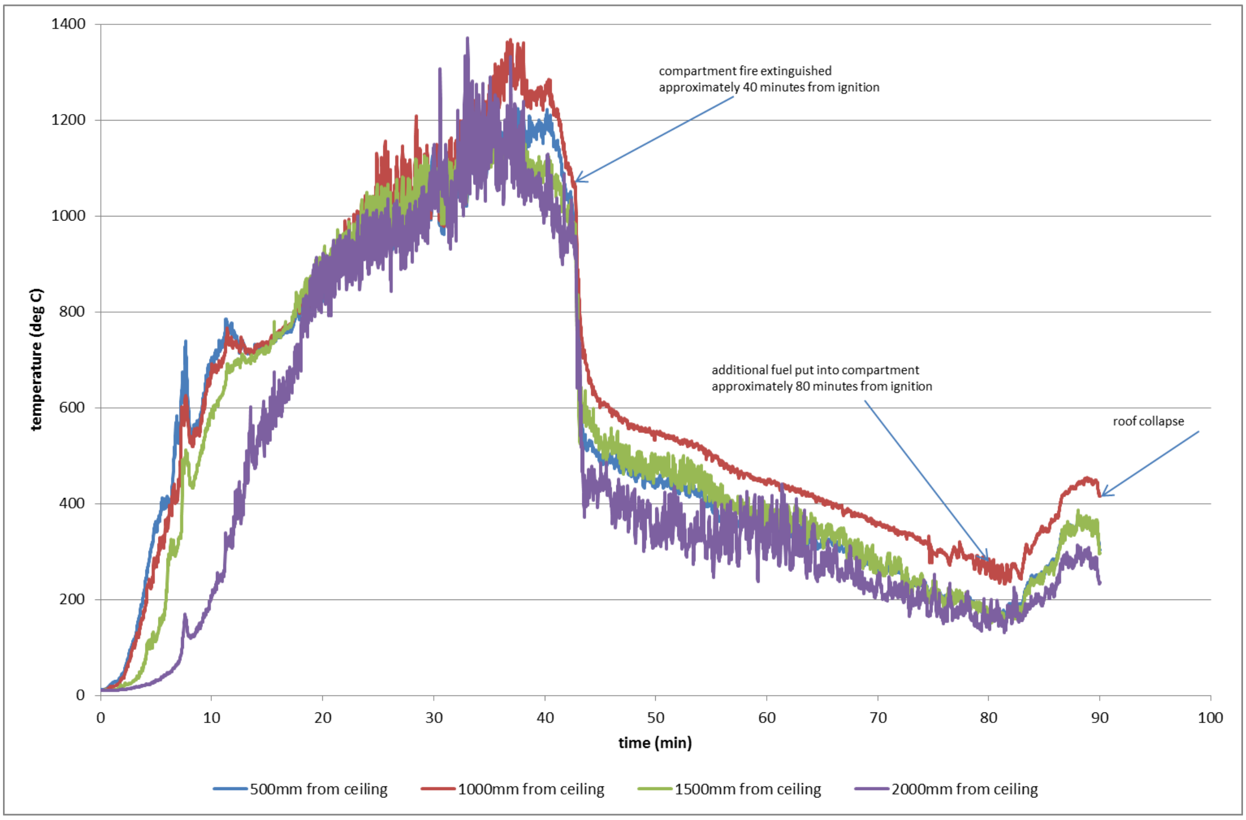

Figure 20 - Compartment temperatures (North West corner)

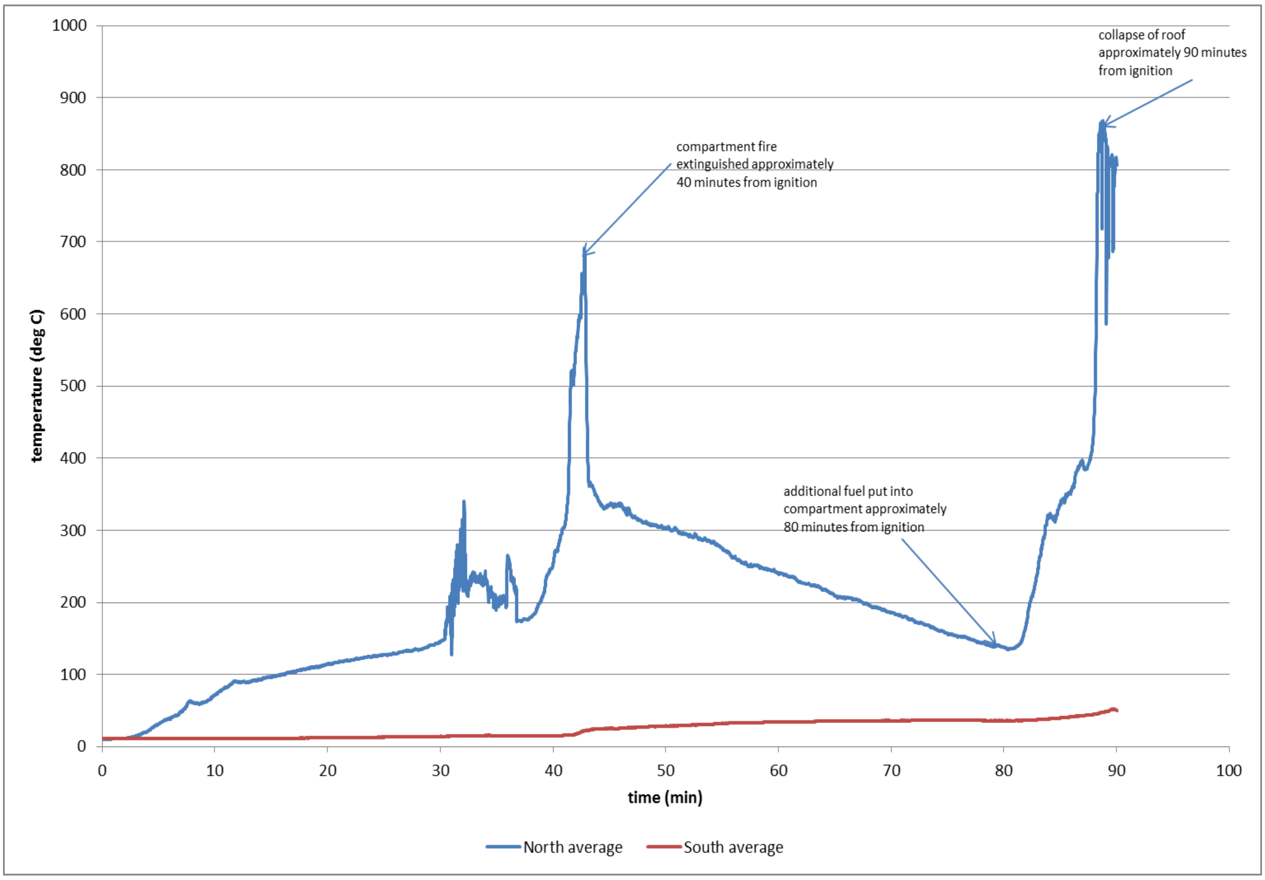

Figure 21 - Average temperatures in roof void either side of compartment wall

The results clearly indicate that the compartmentation has prevented any significant rise in temperature on the non-fire side of the roof space. The performance was clearly borne out through observations with the spandrel panel remaining intact despite a collapse of the roof structure on the fire side (see Figure 22).

Figure 22 - Collapse of roof structure with compartmentation intact

5 Cavity barriers

5.1 Principles

As with roof voids, the principle behind cavity barriers is to ensure that the volume of the void (cavity) in which the fire may develop is limited in extent, and that any barriers to the spread of fire are imperforate.

5.2 Existing guidance on cavity barriers

5.2.1 Approved Document B

Cavity barriers are used to meet the Building Regulations requirement B3 to inhibit the unseen spread of fire and smoke within concealed spaces in the structure and fabric of a building. The requirement will be met if any hidden voids in the construction are sealed and sub-divided to inhibit the unseen spread of fire and products of combustion.

The particular nature of the risk posed by concealed spaces or cavities in the construction of a building is highlighted in AD B[1] where smoke or flame spread may be concealed and therefore presents a greater danger than would a more obvious weakness in the fabric of the building. Cavities are found in walls (both internal and external), floors, ceilings and roofs.

The provisions for cavity barriers aim to avoid cavities forming a route around fire separating elements and provide limits on the maximum size of cavities within buildings. The provisions for cavity barriers are summarised in Diagram 33 of AD B[1], reproduced as Figure 23 here. This diagram is very useful in that it also highlights where fire stopping is required.

There is an important distinction between cavity barriers and fire stopping which is often misunderstood: fire stopping is intended to maintain the fire resistance of an element of structure (e.g. a compartment wall) and therefore needs to have at least the same fire resistance as the element of structure of which it is a part; cavity barriers do not necessarily need the same level of fire resistance as the element of structure in which they are located since the cavity barrier is not expected to be immediately exposed directly to a fire (since it is contained within the structure of the cavity).

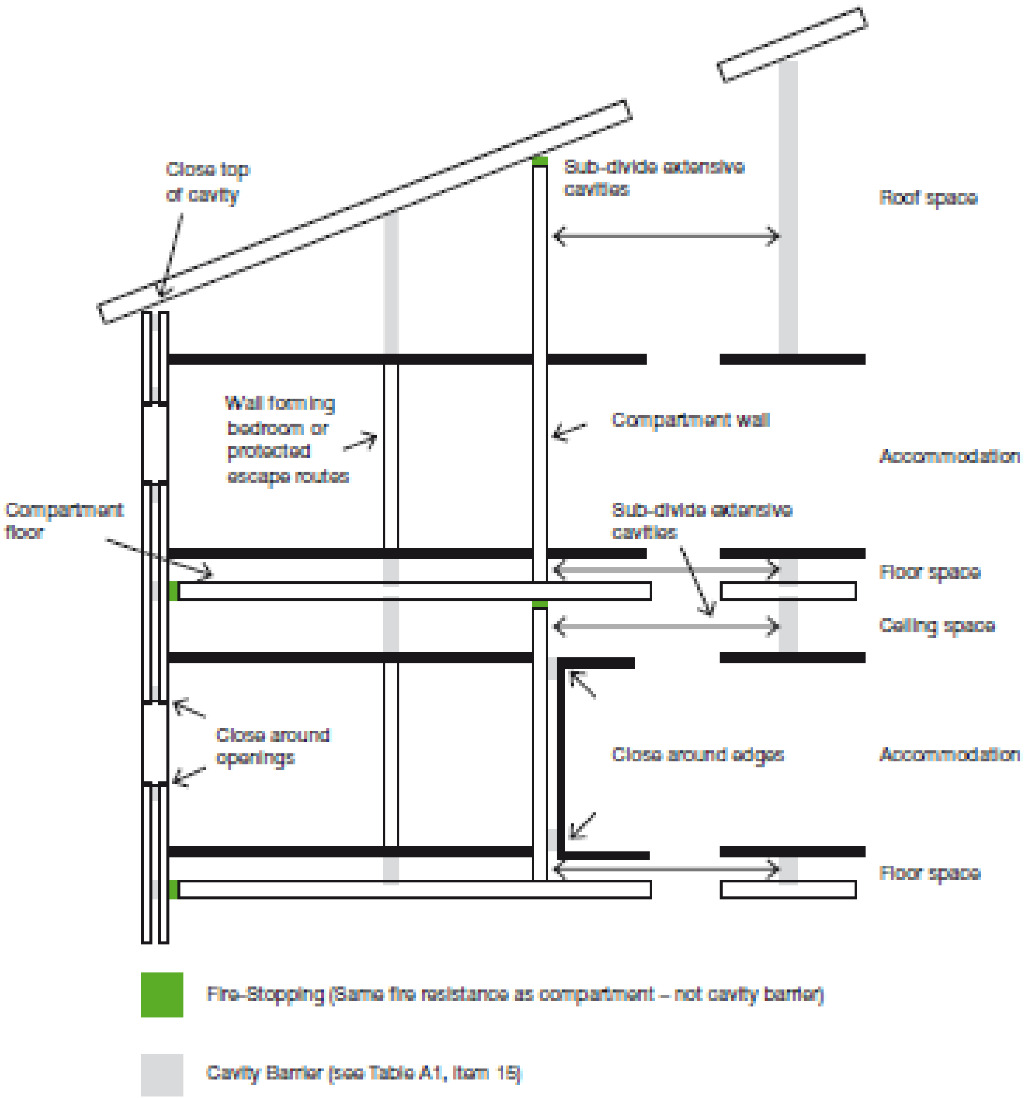

Figure 23 - Provisions for cavity barriers (Diagram 33 of Approved Document B[1])

The principal areas where cavity barriers are required are:

- At the junction between an external cavity wall and every compartment floor and compartment wall (apart from masonry or concrete cavity walls complying with Diagram 34 of AD B[1]). This effectively creates a box around the lines of compartmentation within a building incorporating both vertical cavity barriers (to inhibit horizontal fire and smoke spread from room to room) and horizontal cavity barriers (to inhibit vertical fire and smoke spread from floor to floor).
- At the top of a cavity wall i.e. at the junction with the eaves.
- Around any openings in the external wall of a building.
- Around any openings (such as doorways) in an element forming a fire-resisting barrier.
- Within large floor, ceiling or wall cavities, regardless of whether they incorporate compartment floors or walls, see Table 2.

Location of cavity	**Class of surface/product exposed in cavity**		**Maximum dimension in any direction (m)**
	National class	**European class**	
Between roof and a ceiling	Any	Any	20
Any other cavity	Class 0 or Class 1	Class A1 or Class A2-s3, d2 or Class B-s3, d2 or Class C-s3, d2	20
	Not Class 0 or Class 1	Not any of the above classes	10

Table 2 - Maximum dimensions of cavities in non-domestic buildings (from Table 13 of AD B[1])

The performance requirements for cavity barriers in terms of fire resistance are set out in Table A1 of Appendix A of AD B1 and are summarised in Table 3.

Minimum provisions when tested to the relevant part of BS 476 (minutes)			**Minimum provisions when tested to the relevant European standard (minutes)**	**Method of exposure**
Loadbearing capacity	Integrity	Insulation		
Not applicable	30	15	E30 and EI15	Each side separately

Table 3 - Specific provisions of test for fire resistance of cavity barriers (from Table A1 of AD B[1])

AD B recognises the importance of maintaining cavity barriers in place so they are effective when required. Cavity barriers should, wherever possible, be tightly fitted to a rigid construction and mechanically fixed in position. They should be fixed so that their performance is unlikely to be made ineffective by:

- Movement of the building due to subsidence, shrinkage or temperature change and movement of the external envelope due to wind.
- Collapse in a fire of any services penetrating cavities.
- Failure in a fire of fixings or elements to which the cavity barrier may be fixed.

5.2.2 Other guidance

Manufacturer's data sheets and manuals contain detailed information on specification and installation of cavity barriers for specific systems.

There is little generic information available, possibly reflecting the diversity of the potential design solutions to cavity fire protection.

The Structural Timber Association (STA) (formerly the UKTFA) has produced generic guidance on the installation of cavity barriers in timber-frame construction[15].

Guidance on installation and specification of cavity barriers is available through the published output from the NHBC Foundation/BRE Trust research project[16].

Recent guidance from the ASFP[17] on fire stopping systems includes some limited information on small cavity barriers including some useful practical guidance notes in Appendix D of that document which highlights the need to verify that the in service dimensions of the system being installed are correct and that any splices/joints are correctly installed in accordance with manufacturers' instructions and at the correct centres.

The issue of where, when and how to provide cavity barriers within buildings was covered in some detail in BRE Digests 214[11] and 215[12] published in 1978. Much of this information is still relevant although specific materials such as asbestos insulation board are no longer applicable.

Although general guidance is available from the passive fire protection industry through the Association of Specialist Fire Protection (ASFP) on the installation of cavity barriers, there is no dedicated publication covering this important area of fire protection.

BS 9999[13] is the fire safety code of practice for building design, management and use. The standard outlines ways to meet fire safety legislation through a more flexible approach to design.

Concealed spaces are discussed in Section 34, and this includes guidance on cavity barriers (Section 34.2) and extensive cavities (Section 34.3). Fire stopping is discussed in Section 33.5.

5.3 Methods of test and assessment of the performance of cavity barriers

Given the nature of the performance requirements described above, it is not surprising that the performance of cavity barriers is generally assessed with reference to standard fire tests. However, the conditions within a cavity during a fire incident may be markedly different from that of an element of construction exposed to a fully developed post-flashover compartment fire and it is worth considering the extent to which current test procedures reflect the likely conditions in service.

Table 3 makes reference to fire performance in British and European standard tests but does not provide specific information on which test standard should be used. Cavity barriers have traditionally been tested either as part of an overall element of structure (such as a wall or floor) in accordance with the provisions of BS 476 Part 20[18] or BS EN 1363-1[19] or as linear gap seals in accordance with BS EN 1366-4[20]. In the former case, the wall or floor system would in general be protected by a layer of plasterboard or similar so the barrier would not necessarily be subjected to a significant rise in temperature or direct exposure to flames.

When tested as a linear gap seal, it is important that the supporting construction is representative of the end use application. For example, a horizontal cavity barrier, intended for use in a timber frame building with an external masonry wall forming the outer leaf, should be connected to a form of construction representative of the end use application (generally an Oriented Strand Board (OSB)).

There is no specific harmonised test standard covering cavity barriers.

A European Technical Approval Guideline (EOTA) ETAG 026[21] includes cavity barriers but specifically excludes testing of cavity barriers in external cladding systems which should be considered when using a façade fire test.

TR31[22], also published by EOTA, specifies fire resistance tests for cavity barriers. However, TR31 explicitly states that “This method is not applicable to horizontal barriers in e.g. rain screen cladding because it is difficult if not impossible to model the correct thermal exposure and boundary condition in a fire resistance type test, such tests should be considered as part of a facades test.”

5.4 Previous research on cavity barriers

The performance of cavity barriers and mechanisms of fire spread within cavities have been topics for research and discussion for many years with particular attention focussed on issues relating to the performance of cavity barriers in internal and external walls incorporating combustible materials.

In 1983, BRE published *Timber-Framed Housing – A Technical Appraisal*[23]. The report made the following recommendations in relation to fire performance and fire protection:

- To develop a set of recommended details of fire stops and cavity barriers of proven efficacy which are realistic for simple implementation on site, education of site staff on the importance of these details.
- To assess the effect of introducing new materials, such as readily combustible sheathing boards, on fire performance.
- To emphasise in the site inspection, the importance of proper installation of cavity barriers and fire stops.

- To carry out research to resolve the potential conflict between the need for cavity barriers (to improve performance in fire) and the need for ventilation of the cavity (to reduce the risk from interstitial condensation).
- To introduce performance criteria for sheathing materials and breather papers, including development of appropriate test methods.

5.4.1 The TF2000 project cavity fire incident

Fires in cavities containing combustible materials became a focus of attention following a compartment fire test within the six-storey timber-frame residential building at BRE's large building test facility at Cardington undertaken as part of the TF2000 project[24].

Following a compartment fire test on the second floor of the TF2000 building, a seat of smouldering combustion led to fire spread in the external wall cavity between the timber frame and the external masonry façade. The cavity barriers within the external wall failed to provide the anticipated level of performance, resulting in extensive fire spread within the cavity. Several horizontal cavity barriers at floor compartment boundaries were ineffective although vertical cavity barriers remained intact and prevented extensive horizontal fire spread within the cavity. The incident highlighted issues around fighting fires in concealed spaces with particular problems encountered in identifying the seat of the fire and accessing the area most directly involved.

Following this TF2000 cavity fire incident, a collaborative research project 'Understanding Fire Risks in Combustible Cavities' was carried out by Chiltern International Fire, with BRE as project partners, to investigate a number of the issues around fires in cavities[25].

5.4.2 Understanding fire risks in combustible cavities project

The TF2000 cavity fire incident demonstrated that a relatively small ignition source could lead to extensive fire spread which was very difficult to detect and difficult to extinguish once external indications were visible. This is a conclusion supported by a number of real fire incidents investigated in recent years.

The 'Understanding fire risks in combustible cavities' project[25] involved a number of distinct tasks including fire initiation testing on the TF2000 building, fire testing of sheathing board and vapour membrane, testing of different types of cavity barrier incorporating the effect of discontinuities, site surveys and training schemes for the Fire and Rescue Service. A summary of this project is provided in "Fires in cavities in residential buildings – The performance of cavity barriers in external walls with combustible materials"[16].

The TF2000 cavity fire incident had demonstrated that there were issues around identifying the seat of a cavity fire in the early stages. The only indication during the initial smouldering phase is the presence of odours and/or smoke emanating from gaps in the building.

An experimental training exercise for the Fire and Rescue Service was undertaken on the TF2000 building involving three local crews. The intention was to simulate a smouldering fire in the cavity that had been burning slowly for approximately two hours. An area of the external wall of the building was accessed by removing the plasterboard linings and cutting through sections of OSB. Two heaters were installed in the cavity space producing a localised temperature of approximately 110°C together with heated tubing connected to a smoke generator concealed in the flat below. The heaters and copper tubing are shown in Figure 24 prior to replacing the internal linings.

Figure 24 - Internal view of gable end wall with plasterboard linings removed and equipment installed

Three exercises were conducted each using a different crew. Prior to commencing the exercise, each crew was briefed on the purpose of the exercise but no information was provided on the location of the simulated fire source. The results of the Fire and Rescue Service exercises are summarised in Table 4.

Crew	Tools available	Results and observations
1	Thermal imaging cameras	Fire source located within 27 minutes. The initial search was conducted internally but the seat of the fire was eventually located from the outside of the building.
2	Infrared thermometer	Fire source was located within 34 minutes. The initial search was conducted internally but the seat of the fire was eventually located from the outside of the building.
3	Traditional hand tools	Fire source was not located within 40 minutes of the initial search of the building. After 40 minutes the crew were presented with a thermal imaging camera. The fire source was located within two minutes from the outside of the building.

Table 4 - Summary of Fire and Rescue Service training exercises conducted on the TF2000 building[25]

5.4.3 BRE experimental programme on cavity barriers

As part of an overall review of the guidance provided in Approved Document B[1] an experimental programme on behalf of ODPM was undertaken by BRE on cavity barriers in 2005[28]. The focus of the experimental work was on floor voids, plenum spaces and cavity closures, although some fire resistance testing was undertaken to assist in the development of an appropriate fire resistance test for assessing the performance of cavity barrier systems. The scenario adopted for the fire resistance tests was designed to consider the influence of installation details on the performance of the systems. The results from this work raised issues regarding performance in service and the ease of installation and associated workmanship in relation to the end use of the system.

The key findings from the programme were:

- Confirmation that cavity barriers when appropriately designed and installed, offer a means by which the unseen spread of fire and smoke can be mitigated.
- The issues of installation design and methods must be considered in the application and end use of these systems.
- Modelling of these types of systems may offer potential options for expansion of current design solutions.

The work was split into five different sections covering:

- Floor voids.
- Plenum spaces.
- Cavity closures.
- Computer modelling.
- Fire resistance testing.

The results of each section are discussed individually below. For more detailed information, see reference 28.

5.4.3.1 Floor voids

A series of fire experiments was undertaken utilising a commercially designed and installed suspended floor system. Work was also undertaken to look at potential fire risks from standard timber floor systems and potential transmission routes for fire spread from radiated heat from the room of fire origin into the floor void.

Seven tests were undertaken on an 8.4m square grid, formed from steel encapsulated chipboard panels screwed to pedestals to give the required height. The principal variables were: the height of the floor; the presence and position of the 50mm foil faced mineral wool cavity barrier and the position of the 200kW ignition source. The results from the tests on the commercial floor system (Tests 1 to 7) and a single test (Test 8) on a chipboard sheet forming the exposed surface are summarised in Table 5.

Test	Void depth (mm)	Burner position	Barrier position	Floor size (m²), material	Test duration (mins:sec)
1	300	Centre of ½ floor	No barrier	8.4, steel & chipboard	8:31
2	300	Centre of ½ floor	Centre of floor	8.4, steel & chipboard	30:00
3	300	600mm from barrier	Centre of floor	8.4, steel & chipboard	30:00
4	300	600mm from centre of floor	No barrier	8.4, steel & chipboard	30:00
5	150	Centre of ½ floor	No barrier	8.4, steel & chipboard	20:00
6	150	Centre of ½ floor	Edge of floor	8.4, steel & chipboard	30:00
7	150	Centre of ½ floor	Centre & edge of floor	8.4, steel & chipboard	30:00
8	300	Centre of ½ floor	600mm from edge of floor	8.4, steel & chipboard	20:00

Table 5 - Summary of burner tests on raised floor systems[29]

To investigate the potential for radiated heat from a compartment fire to ignite the floor void below, a section of the floor was subjected to heating from a radiant source for a period of 30 minutes. The sample was exposed to a radiant exposure of between 12 and 15 kW/m² at a distance of 500mm from the burner surface. There was no ignition during the exposure period.

5.4.3.2 Plenum spaces

In the current context, a plenum space may be defined as a ceiling void that can be used to carry building services such as communication and power cabling. A series of fire tests was undertaken to investigate the conditions that arise inside a ceiling void when a fire occurs in the room below and to measure the effectiveness of a cavity barrier installed in the ceiling void.

Three scenarios were considered:

- Test 1 – Control test with no cavity barrier installed.
- Test 2 – Cavity barrier installed with cables running through the barrier but no fire stopping.
- Test 3 – Cavity barrier installed with fire stopping.

The work demonstrated that, in order to prevent fire spread along a potentially combustible route, such as cabling, fire stopping around any penetration through a cavity barrier will be required.

5.4.3.3 Cavity closures

The objectives of this part of the project were to investigate the effectiveness of different types of window frame construction at mitigating the entry of fire into a timber-frame cavity. The experimental scenario selected for this study was based around a post-flashover fire within an enclosure breaking out of a window opening set within a timber frame cavity wall construction.

Four systems were investigated. The findings suggest that the interface detail between the cavity closure and the primary substrate is as critical to the overall performance of the system as the ability of the material involved to withstand the fire exposure.

The main variable was the material used to construct the window frames. The results are summarised in Table 6.

No.	Frame type	Entry time into cavity (mins:secs)	Cavity breach
1	PVCu with timber head	23:03	Head of window frame
2	PVCu without timber head	05:51	Head of window frame
3	Aluminium with timber head	13:40	Side of timber head
4	Aluminium without timber head	07:26	Head of window frame
5	Hardwood with timber head	23:23	Inside enclosure*
6	Hardwood without timber head	16:56	Inside enclosure*
7	Softwood with timber head	27:41	Inside enclosure*
8	Softwood without timber head	14:40	Inside enclosure*

* Post-test inspection suggests that the frame system was still intact and the breach may be due to failure of the joint system between the enclosure and the frame

Table 6 - Summary of results from fire tests of different closure systems[28]

5.4.3.4 Computer modelling of cavity barriers in floor voids and plenum spaces

The BRE Computational Fluid Dynamics (CFD) models JASMINE and SOFIE were used to assess the performance of cavity barriers in floor voids and plenum spaces. Floor Test 3 and Floor Test 4 discussed above were modelled with temperature dependent material properties used for the principal components (floor tiles and mineral wool cavity barriers). For the plenum space model Test 3 discussed above, incorporating a cavity barrier and fire stopping, typical values for the cavity barrier and cable thermal properties were used. The results confirmed the potential for numerical modelling to be used to determine fire spread within concealed floor and ceiling voids.

5.4.3.5 Fire resistance testing of cavity barrier systems

In order to assist in the development of an appropriate fire resistance test for assessing the performance of cavity barrier systems, four typical cavity closure systems were subjected to an ad-hoc fire resistance test. The four systems tested were:

- Test 1 – Foil faced stone mineral wool.
- Test 2 – Plastic coated stone mineral wool.
- Test 3 – Extruded PVCu cavity closure.
- Test 4 – PVCu coated stone mineral wool cavity closure.

The systems were built into a single skin block wall and therefore the materials which formed the linings of the “cavity” were non-combustible. As no method of assessing performance criteria for failure under integrity and insulation of these systems exist; those used for partitions in BS 476 Part 22[29] were adopted. Table 7 is a summary of the performance in minutes of the various products against the specific failure criteria of insulation and integrity. Each specimen was installed in three different configurations representing a vertical, horizontal and combined (both vertical and horizontal connected together) position.

Test	Vertical element		Horizontal element		Double element	
	Insulation (mins)	**Integrity (mins)**	**Insulation (mins)**	**Integrity (mins)**	**Insulation (mins)**	**Integrity (mins)**
1	Failure criteria not met during exposure	Failure criteria not met during exposure	Failure criteria not met during exposure	Failure criteria not met during exposure	38	Failure criteria not met during exposure
2	11.5	12	7	20	5.5	10
3	7.5	7.5	7.5	10.5	5	5
4	11	21.5	9	15.5	11	17.5

Table 7 - Summary of performance based on failure criteria from BS 476: Part 22[29]

The ad-hoc standard fire resistance tests showed that the performance of the systems assessed was related primarily to the installation of the system with the corner configuration (junction of a vertical and horizontal cavity barrier) being particularly difficult to install correctly. The research highlighted the importance of specifying the appropriate cavity barrier system depending on the end use application taking into account potential difficulties in installation.

5.4.4 NHBC Foundation/BRE Trust research into fires in cavities

Further details relating to the information discussed above is presented in a 2013 publication[16] published by the IHS BRE Press on behalf of the NHBC Foundation and jointly funded by the NHBC Foundation and the BRE Trust. This publication also summarises the results from an extensive programme of large-scale fire experiments looking at the performance of various generic types of cavity barrier used in the ventilated cavity between a timber frame building and an external masonry façade.

The work built on the earlier work undertaken at BRE Cardington. The experimental set up was similar to that shown in Figure 25. The tests were undertaken against a masonry wall usually used to assess the performance of cladding systems to BS 8414-1:2002[30]. In this case, two timber-frame panels representing a ground and first floor internal room were fixed back to the masonry wall and separated by a header/ring beam to simulate modern forms of timber frame construction. The cavity barrier test sample was fixed in position and installed in the cavity formed between the timber frame and the masonry wall. The experimental set up is illustrated in Figure 25.

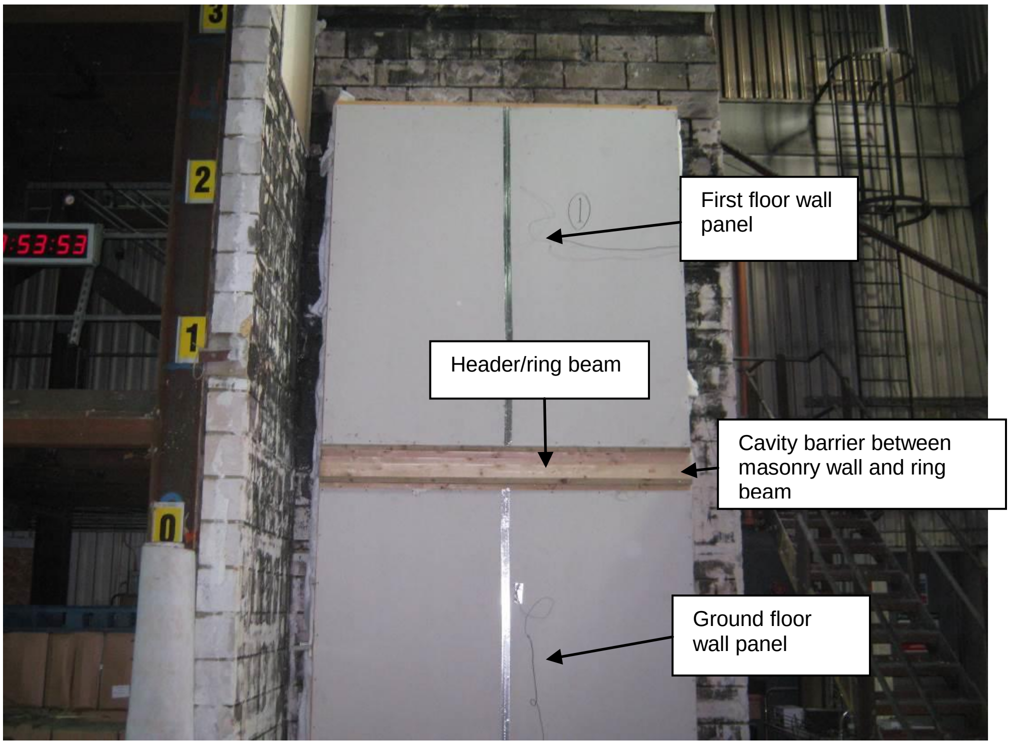

Figure 25 - Experimental set up for cavity barrier fire tests

The ventilation openings were sized to simulate typical conditions within a ventilated cavity and the initial fire source (see Figure 26) consisted of a number of small timber cribs to provide a repeatable fire scenario consistent with the types of ignition sources found in real fire incidents.

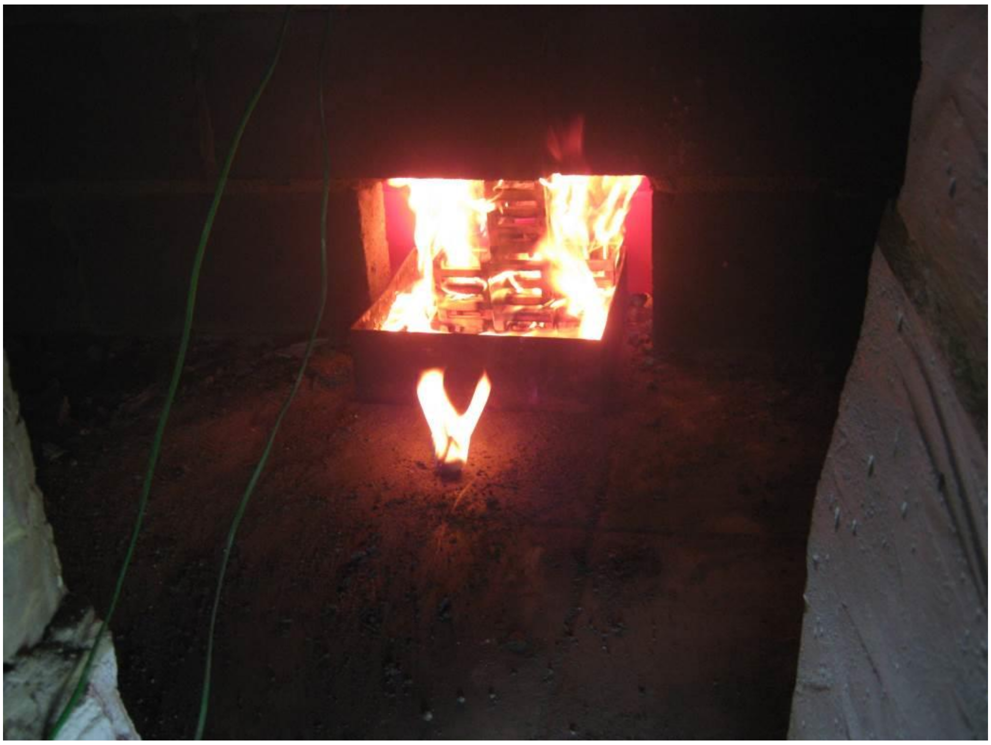

Figure 26 - Ignition source and ventilation opening at low level

The experimental programme is summarised in Table 8.

The conclusions from the experimental programme were:

- All generic forms of cavity barrier are capable of inhibiting the spread of fire and smoke when installed in accordance with manufacturer's instructions.
- There was no fire spread away from the initial ignition source in any of the experiments incorporating non-combustible sheathing board (magnesium oxide board).
- The presence of discontinuities was shown to have a marked effect on the ability of all generic forms of cavity barrier other than intumescent barriers to inhibit the spread of fire for a reasonable period when present alongside a combustible sheathing board.
- The performance of solid timber battens used as cavity barriers is particularly sensitive to discontinuities. In particular, solid timber battens are unable to accommodate dimensional variations in cavity widths leading to rapid fire spread above the level of the barrier in the event of a cavity fire.

Test	Sheathing[1 or 2]	Cavity barrier			Vent area (mm²)	
		Generic type	Cavity width (mm)	Discontinuity	Bottom	Top
1	OSB	None	50	Not applicable	8125	8125
2	OSB	Stone wool 65mm x 65mm	50	No	8125	8125
3	OSB	Glass wool 100mm x 100mm	50	No	8125	8125
4	OSB	Timber 50mm x 50mm	50	No	8125	8125
5	OSB	Intumescent 25mm x 75mm (type 1)	50	No	8125	8125
6	OSB	Intumescent 25mm x 75mm (type 2)	50	No	8125	8125
7	OSB	Stone wool 65mm x 65mm	50	No	4550	4550
8	OSB	Timber 50mm x 50mm	50	No	4550	4550
9	OSB	Intumescent 25mm x 75mm (type 1)	50	No	4550	4550
10	MgO	Stone wool 65mm x 65mm	50	13mm gap in centre	8125	8125
11	MgO	Glass wool 100mm x 100mm	50	13mm gap in centre	8125	8125
12	MgO	Timber 50mm x 50mm	50	13mm gap in centre	8125	8125
13	MgO	Intumescent 25mm x 75mm (type 2)	50	13mm gap in centre	8125	8125
14	OSB	Glass wool 100mm x 100mm	50	13mm gap in centre	8125	8125
15	OSB	Stone wool 65mm x 65mm	50	13mm gap in centre	8125	8125
16	OSB	Stone wool 65mm x 65mm	55	13mm gap in centre	8125	8125
17	OSB	Timber 50mm x 50mm	55	13mm gap in centre	8125	8125
18	OSB	Intumescent 25mm x 75mm (type 2)	55	13mm gap in centre	8125	8125
19	OSB	Stone wool 65mm x 65mm	55	13mm gap in centre	8125	8125
20	OSB	Timber 50mm x 50mm	55	13mm gap in centre	8125	8125
21	OSB	Intumescent 25mm x 75mm (type 2)	55	13mm gap in centre	8125	8125

[1]MgO = Magnesium oxide, [2]OSB = Oriented Strand Board

Table 8 - Experimental programme for NHBC Foundation/BRE Trust Research Project[14]

5.5 Issues from fire investigations – fire spread in wall and floor cavities

The specification and performance of cavity barriers has been the focus of attention in a number of real fire incidents in recent years. BRE through its contracts with DCLG to attend fires of special interest to investigate issues that may impact on Building Regulations and through contacts with the Fire and Rescue Service and other agencies has access to fire scenes. The BRE database has been reviewed to identify those areas where cavity barriers have played a role (either positively or negatively) in fire development and the nature and extent of fire spread.

For confidentiality and sensitivity reasons, no mention is made in this document of specific locations and all incidents are referred to with reference to the type of structure involved.

The BRE Trust/NHBC Foundation report[16] included information on a number of recent fire incidents in which fire initiation and/or development was influenced by the ignition of materials within the cavity and included four case studies based on fires which BRE had attended as part of the DCLG fire investigation contract. This current document includes an additional three case studies, two of which have been investigated since the previous BRE Trust/NHBC Foundation report was published.

5.5.1 Case study 1: Three-storey timber-framed residential building

The fire started within the external wall void of a three-storey timber-framed residential building due to a nail penetrating a lighting cable. The external façade was an insulated cladding system. Fire spread up the building through the internal cavities and the external cladding. However, vertical cavity barriers were effective in limiting the extent of horizontal fire spread. The nature of the construction and the damage to the external façade is shown in Figure 27.

Figure 27 - Damage to front elevation of building

5.5.2 Case study 2: Five-storey modular timber-framed residential building

Fire started in an electrical consumer unit within one of the flats on the first floor of a five-storey, modular timber-framed residential building and spread through cavities between modules where it involved the combustible linings (OSB) of the cavity. The fire spread laterally to affect two flats via two cavity walls. This caused further spread into the floor void supporting the first floor leading to extensive damage to the supporting engineered timber beams (see Figure 28) and solid timber studs. The fire also spread upwards to the walls on the second, third and fourth floors.

The fire spread through cavities in compartment walls resulting in fire damage within twelve different fire compartments (two flats and one corridor on four floors). The ignition source was an electrical fault and the fire did not involve any fuel load other than the fabric of the building itself. The external walls were not involved in the fire.

Figure 28 - Damage to engineered floor joists

5.5.3 Case study 3: Three-storey timber-framed block of flats

See case study 2 under the section on compartmentation in roof voids for details.

The fire spread initially through the cavities and up and along the front face of the three-storey timber-framed block of flats. Compression fitted cavity barriers were present although evidence from areas remote from the fire indicate slippage of the barriers and gaps between the frame and the external wall similar to issues discussed in relation to the ‘Understanding fire risks in combustible cavities’ project[7]. The fire spread up to the roof space, then downwards internally and laterally through the roof area. The fire spread led to the collapse of roof trusses and subsequent failure of the ceiling between the top floor and the roof space.

Cavity barriers within the external walls did not perform adequately. Figure 29 shows the remains of a vertical cavity barrier with the sheathing board completely burnt away. Observations and ad-hoc fire tests carried out by BRE indicated that the breather membrane and the plastic wrapping on the cavity barrier may have contributed to fire spread within the cavity in the early stages. Bituminous material spanning the roof beneath the tiles appears to have contributed to fire spread within the roof space.

Re-ignition of fire within the cavity occurred during the demolition operations six days after the first fire started.

Figure 29 Remains of cavity barrier on external wall

5.5.4 Case study 4: Four-storey timber-framed block of flats

The fire occurred within one of the ground floor flats of a four-storey timber-framed block of flats. The fire was attended by the Fire and Rescue Service who extinguished the fire and, before leaving the scene, checked the area with a thermal imaging camera to ensure there were no hidden hot spots. However, the Fire and Rescue Service was recalled approximately one to one and a half hours after leaving the scene. The fire had taken hold within the external wall cavity and eventually spread into the roof space. From there, it spread back down into the unaffected areas of the external wall cavity leading ultimately to collapse of the building (see Figure 30).

Timber battens were used to bridge the cavity in line with the compartment floor levels. These barriers were wrapped in a bituminous damp proof material to prevent moisture ingress. The sheathing layer appeared to be a low density bitumen impregnated fibre board similar to that identified as the worst performing product of those tested in the small flame test (BS EN ISO 11925-2[27]) conducted as part of the collaborative 'Understanding fire risks in combustible cavities' research project[25].

Figure 30 - Structural collapse following fire spread through roof

5.5.5 Case study 5: Three- and four-storey timber-framed block of flats

The fire is thought to have started by a carelessly discarded cigarette being thrown into a pile of wood/bark chippings laid in the flower beds in contact with the external wall of a timber-framed block of flats. A number of plastic openings were present at low level on the external wall and some were completely covered by the bark/wood chippings. An initial external fire was reported. Approximately 40 minutes later, the Fire and Rescue Service was called to attend as smoke could be seen issuing from the roof of the building and out of openings in the cavity at various levels. A decision was taken to evacuate the building and to adopt a defensive fire-fighting approach because of the extent of the fire spread and based on experience of similar fires. The fire led to the collapse of a large area of the development (see Figure 31).

Figure 31 - Partial collapse of development due to extent of fire spread

5.5.6 Case study 6: Three-storey timber-framed block of flats

See case study 7 under the section on compartmentation in roof voids for details.

The fire spread from wood chippings into the cavity of the external wall of a three-storey timber-framed block of flats via a plastic air brick providing ventilation to the cavity situated beneath the suspended ground floor. Cavity barriers were either missing or poorly fitted. The fire spread up the cavity to the roof of the building, causing significant structural damage to the roof and accommodation storeys. One compartment wall was rendered ineffective due to an apparent absence of a cavity barrier at the junction with the external wall. However, another compartment wall prevented further spread through the roof space. The Fire and Rescue Service adopted a defensive fire-fighting strategy when it became apparent there was unseen fire spread which had the potential to affect the structural stability of the building.

5.5.7 Case study 7: Three-storey timber-frame terraced house

See case study 9 under the section on compartmentation in roof voids for details.

Vertical cavity barriers were absent in some locations providing a route for fire spread from the external wall back into the three-storey timber-frame terraced house. There was extensive downward fire spread in the cavities within the compartment walls separating the property from adjacent occupancies.

The fire caused extensive damage to the loadbearing ring beams supporting the wall panels at both second and first floor levels. There was very little damage to the roof area and the compartmentation between dwellings in the roof void area was of very good quality with all joints between plasterboard taped and sealed.

5.5.8 Case study 8: Mixed residential timber-frame development

See case study 10 under the section on compartmentation in roof voids for details.

Due to an absence of cavity barriers at the junction between the internal compartment wall and compartment floor, the fire was able to spread upwards to the roof area via the internal wall void.

A combination of Fire and Rescue Service intervention and effective compartmentation in the roof void prevented more extensive fire spread.

6 Fire rated ducts and dampers

6.1 Principles

A critical potential weakness in the fire safety precautions of any building can be the penetration of fire compartment walls and floors by building services such as cables, pipes and ductwork, including dampers.

Potential fire spread via a ductwork system is of particular concern as it is designed to distribute air throughout the building. A fire attacking such a system that is not designed and installed correctly has the potential to spread fire, smoke and toxic gases to parts of the building remote from the initial fire source and within a very short period of time.

A fire resisting duct is a system of enclosures (for the distribution or extraction of air) which is designed to provide a level of fire resistance when tested to the appropriate standard.

A fire damper is a mechanical or intumescent device within a duct or ventilation opening usually through a compartment wall or floor which is designed to close in the event of a fire to prevent the passage of fire.

A fire and smoke damper is a mechanical or intumescent device within a duct or ventilation opening which is designed to close in the event of a fire and prevent the passage of fire and smoke.

6.2 Existing guidance on fire rated ducts and dampers

6.2.1 Approved Document B

The guidance in Approved Document B[1] relates to mechanical ventilation and air conditioning systems, protected shafts, pipes for oil or gas and ventilating ducts in protected shafts, dampers and ducts, ventilation, flues and basement car parks. Guidance is provided in Section 10.9 of AD B covering ventilation ducts, flues etc. Three methods are presented to maintain the integrity of air handling ducts passing through fire separating elements:

- Protection using fire dampers
- Protection using fire-resisting enclosures
- Protection using fire-resisting ductwork

AD B makes reference to a number of guidance documents covering specific areas of fire resisting ducts and dampers as described below.

6.2.2 Other guidance

The primary source of advice on the fire protection of ducted air distribution systems within the UK is BS 5588 Part 9[31]. A number of specialist publications have been produced by industry bodies[32,33], the fire protection industry[34-36] and research organisations[37] dealing with specification, installation and third party approval schemes for fire rated ducts and dampers.

BS 9999[13] is the fire safety code of practice for building design, management and use. The standard outlines ways to meet fire safety legislation through a more flexible approach to design.

Service ducts, pipes and shafts are discussed in Section 33.4, and this includes guidance on methods for the protection of ductwork (Section 33.4.3) and fire dampers (Section 33.4.5).

6.3 Methods of test and assessment of fire rated ducts and dampers

Performance of fire rated ducts and dampers is assessed using standard fire resistance test furnaces to either national[38] or European[39, 40] fire test standards. For the European test, classification is carried out in accordance with BS EN 13501-3[41].

6.4 Previous research into fire rated ducts and dampers

6.4.1 ODPM research on the fire resistance of ducts and the effectiveness of dampers

Research in this area is largely restricted to performance under standard fire conditions. As part of an overall review of Part B of the Building Regulations, a research project was conducted by BRE for ODPM looking at the fire resistance of ducts and the effectiveness of dampers[42]. The research incorporated an analysis of fire statistics provided by London Fire Brigade and case studies from the USA provided by the National Fire Protection Association. The fire statistics data suggest that fires in kitchen extract ducts appear to be a particular problem particularly in relation to property loss. This is due to the build-up of combustible residues (grease) that adhere to the internal surfaces of ducts which may in turn adversely affect the performance of a damper.

Many fire rated dampers rely on activation of a fusible link to shut off in the event of a fire. A number of experiments were undertaken to ascertain activation times for such systems. The results from the project suggest that the design of the damper, particularly in relation to the location of the fusible link, will be a key factor in determining performance in the event of a fire and current test methods do not include the complete damper exposed to a realistic developing fire situation. The results show that dampers vary in terms of their activation characteristics. In the early stages of a developing fire the project has indicated that dampers relying solely on a fusible link may not shut in a fan-off situation because the gas temperatures at the position of the fusible link may be below the operating temperature of 70°C. In some cases, it has also been shown that dampers may not close in the fan-on position, depending on the location of the fusible link within the duct. If the link is sited low down in the duct it will be exposed to lower gas temperatures and may not reach its activation temperature. It should also be noted that intumescent dampers are, in general, designed to activate at higher temperatures than fusible links.

Fire resistance tests designed to assess the performance of three different damper/duct/wall installations were carried out. The tests demonstrated the ability of the systems to provide the required fire resistance. The tests demonstrated the importance of providing adequate support to the ductwork and highlighted the advantages of utilising aluminium cased steel mandrel rivets allowing for collapse of the ductwork within the fire compartment without adversely affecting the damper location at the compartment boundary.

6.4.2 Research on the Rosepark care home fire

The Rosepark care home fire in Scotland in January 2004 was one of the worst fires in a care home in the UK with fourteen fatalities[4]. The fire started in a cupboard and smoke spread into the adjoining corridor, and hence into occupied bedrooms where doors had been left open. But smoke also travelled into an adjoining corridor and bedrooms. One of the routes for smoke travel was via a ventilation duct within the false ceiling of the corridor which had no fire or smoke damper where the duct passed above the intermediate, self-closing, fire door.

Amongst other work conducted by BRE in connection with this incident, a programme of laboratory research was carried out during July 2006 by BRE which was commissioned by the Crown Office and Procurator Fiscal Service (COPFS)[5]. This included an examination of the ventilation system, which had been implicated in some of the deaths.

The objectives of the examination of the ventilation system were to determine how Corridors 2 and 3 (the corridors beyond Corridor 4, where the fire started) became smoke logged and the explanations for the timescale. Specific issues to be addressed included:

- The possibility of smoke passing through the ventilation ducts into Corridors 2 and 3,
- Whether the volume of smoke passing through the ventilation system into Corridor 3 had presented any hazard to the safety of the residents in the bedrooms there,
- Whether a fire damper in the duct at the wall between Corridors 4 and 3 would have had any effect on the flow of smoke into the Corridors 3 or 2, and
- How long would it have taken before a fire damper between Corridors 4 and 3 would have activated.

It is considered that fire dampers most likely to have been fitted in Rosepark care home (had any been fitted) would operate on a “fusible link” (or similar release device), typically at a nominal operating (gas) temperature of 72^0C. (Noting that due to thermal inertia the device will usually operate at a higher gas temperature than this, e.g. 100^0C).

The dynamics of the fire and the proximity of a damper (if fitted) to the duct from the cupboard meant that a damper would be expected to have operated within a few minutes of ignition. It follows that during these first few minutes, smoke could have passed through a duct before the damper would have closed.

A practical test involving a replica of the ventilation system would have assisted in demonstrating if and how the smoke may have passed through the ventilation system, how quickly, and the effect of a damper when fitted. However, a full-size test rig was not appropriate for reasons of both time and cost and so a more limited test programme was agreed with COPFS (Figure 32).

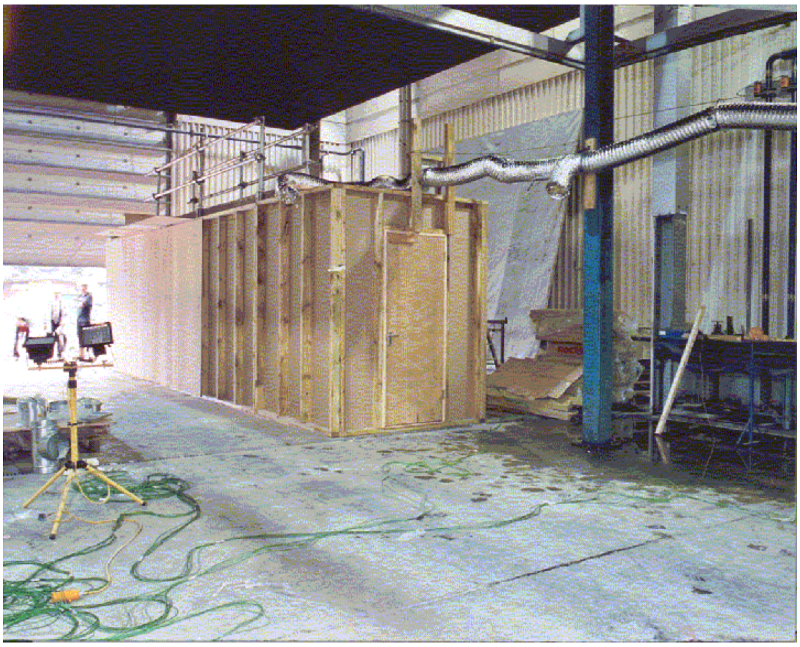

Figure 32 - The ducting test rig

The key findings from the programme of work were as follows:

- The tests demonstrated that smoke is very likely to have travelled from the initial cupboard in Corridor 4 to Corridor 2 via the ventilation ducting. Depending upon the extraction rate of the fan, most of the smoke would have travelled into Corridor 2 only after the ventilation system fan (in the roof) failed.
- The tests demonstrated that smoke is very likely to have travelled from the initial cupboard in Corridor 4 to Corridor 3 via the ventilation ducting. Again, depending upon the extraction rate of the fan, most of the smoke would have travelled into Corridor 3 only after the ventilation system fan (in the roof) failed.
- The results from the tests indicated that the volume of smoke that is likely to have travelled from the initial cupboard in Corridor 4 to Corridor 3 via the ventilation ducting may not, by itself, have been hazardous, i.e. noting that fatalities occurred in rooms off Corridor 3, the quantity of smoke that passed through the ventilation ducting was probably supplemented by smoke that travelled by another or other routes, most probably via the Corridor 4/3 fire door.

- Test 2 demonstrated that a fire damper located in the duct between Corridors 4 and 3 would, after a few minutes from ignition, have significantly reduced the quantity of smoke that is likely to have travelled from the initial cupboard in Corridor 4 to Corridors 3 and 2 via the ventilation ducting. Prior to activation of the damper some smoke would have travelled into Corridor 2, probably in quantities sufficient to alert residents or staff, again depending upon the operation of the fan.
- In Test 1 the fire damper located in the duct between Corridors 4 and 3 operated after 3 minutes 58 seconds from ignition, in Test 2, in 4 minutes 13 seconds and in Test 3 after 7 minutes 58 seconds. In Test 4 the fire damper operated after 10 minutes 40 seconds minutes from ignition. In Tests 3 (and 4) the extract fan was operating for the first 6 minutes, which would have reduced or prevented any spread of hot gases towards the damper during this time.
- The tests demonstrated that smoke is likely to have travelled from the initial cupboard in Corridor 4 to Corridor 2 and Corridor 3 via the ventilation ducting within 3 or 4 minutes of ignition. If the fan had been operating then this may have stopped smoke travelling into Corridor 2 and Corridor 3 and smoke would only have travelled into Corridor 2 after the ventilation system fan (in the roof) failed.
- In Tests 1, 2, 3 and 4, the fire damper located in the duct between Corridors 4 and 3 operated when the duct temperature was around 150 - 200^{0}C. Temperatures in the duct near a fire damper located between Corridors 3 and 2 did not reach these values in any of the tests.

6.5 Issues from fire investigations – fire rated ducts and dampers

A number of incidents in recent years have involved the spread of fire and/or smoke and products of combustion through ventilation systems. BRE, through their contract with DCLG to attend fires of special interest, investigate issues that may impact on Building Regulations and through contacts with the Fire and Rescue Service have access to fire scenes. The BRE database has been reviewed to identify those areas where ducts and dampers have played a role (either positively or negatively) in fire and smoke development and the nature and extent of fire spread. To ensure confidentiality no mention is made of specific locations and all incidents are referred to with reference to the type of structure involved. Some incidents are included that do not specifically involve fire rated ducts and dampers but do involve smoke movement within a building or penetrations through compartment walls or floors.

6.5.1 Case study 1 – Multi-storey office block

This incident did not directly involve fire rated ducts and dampers but is included here as an example of service penetrations through compartment floors. The fire started in a ground floor service riser and progressed up to the fourth floor of a multi-storey office block. The service riser was separated from the accommodation areas by fire resisting construction and accessed through fire rated doors. The existing fire precautions prevented fire spread away from the service riser and maintained tenability conditions within the occupied area of the building to enable safe evacuation. Fire stopping around services penetrating the fourth floor prevented more extensive fire and smoke damage above this level (see Figure 33).

Figure 33 - Effective fire stopping on floor above fire damaged floor

6.5.2 Case study 2 – Eight-storey block of flats

The fire originated in a bin/storage area on the ground floor. Although the fire did not break out of the area of origin, there was extensive smoke spread throughout the block with about 20 out of 40 flats affected. The area above the fire contained pipework and other services which penetrated compartment walls and floors. There was inadequate fire stopping in place leading to the problems with smoke spread during the incident (see Figure 34).

Figure 34 - Inadequate fire stopping around soil pipe penetrating compartment floor

6.5.3 Case study 3 – Fifteen-storey mixed use building

The fire occurred within an underground car park of a fifteen-storey mixed use building, spreading from the car of origin to involve the two cars parked either side. The car park was fitted with a detector operated impulse jet fan system designed to clear smoke away from the entrance to allow for emergency access and to direct the smoke towards an extraction point in a plenum space before passing up through the floor slab to the ground floor and then out to fresh air. However, since installation of the smoke extract system, a large amount of HVAC equipment including extensive ductwork had been installed. The new ductwork had blocked off much of the opening through the floor slab through which the smoke was to be extracted from the building. The fire rapidly overwhelmed the ventilation system, smoke logging the entire car park. The smoke impeded the actions of the emergency services and led to smoke spread into a number of staircases via leaky seals around doors and poor fire stopping around ducts and cables. The scene examination indicated that the HVAC ducting throughout the car park was obstructing the flow of smoke out of the jet fans (see Figure 35).

Figure 35 - Flow from impulse jet fan obstructed by HVAC ducting

6.5.4 Case study 4 – Twenty one-storey block of flats

The fire started at first floor level of a twenty one-storey block of flats on a canopy structure built over the flat entrance door. The fire spread from the roof of the canopy to one of the flats on the first floor through the window. From this flat, smoke entered the communal corridor and smoke logged the stairwell and communal areas for the full height of the building. Permanently open vents and smoke shafts meant that all of the common corridors adjoined each of the smoke shafts into a single smoke compartment.

7 Fire statistics of hidden fire spread

The final report produced for the collaborative research project 'Understanding fire risks in combustible cavities'[25] included a review undertaken by BRE of available fire statistics relating to cavity fire incidents. The review found that of the 566 incident records reviewed, only eight were identified as cavity fire events. It is acknowledged that some fires involving cavities may not have been recognised as such, particularly in severe compartment fires that have penetrated and spread within the cavity, where the material first ignited or most responsible for fire growth may not have been in the cavity. The review identified careless or incorrect use of hot working appliances such as blow torches and hot air guns as the most likely ignition sources. Although relatively few incidents were identified as cavity fires, the extent of damage sustained from such incidents may be considerable both from the fire itself and from fire-fighting operations due to difficulties in identifying the seat of the fire and in fire-fighting once the seat of the fire has been located.

Of the eight fires identified in the BRE review as cavity fire incidents, four were in timber frame construction.

8 Alternative solutions not covered by AD B

The guidance in Approved Document B does not specify prescriptive solutions but it provides performance requirements in relation to compartmentation and fire stopping. The compartment wall specification and the specific detail around the junction between the compartment wall and the roof described in Section 4.6 is one example of a construction detail which has been shown to be effective in contributing to meeting the requirements of B3 of the Building Regulations. Similarly the cavity barriers incorporated within the NHBC Foundation/BRE Trust experimental programme[16] were examples of products capable of contributing to meeting the requirements of B3 with respect to inhibiting the spread of fire and smoke within concealed spaces.

The list of materials and construction products set out in section 9.13 and in section 10.19 in relation to fire stopping materials does not cover the full range of product types available in the market and which have been shown to provide a high level of integrity in terms of fire performance in realistic scenarios. It is therefore important that designers and specifiers remember that Approved Document B is guidance and give consideration to the full range of products available to ensure that they select the product and/or solution most appropriate for their required application.

9 Third party certification schemes

Inadequate supervision, inspection and installation of fire protection measures have a significant impact on measures intended to maintain the effectiveness of compartmentation within a building in the event of a fire. Certification schemes provide third party verification that a tested product is properly manufactured and/or installed in accordance with a specification agreed between the manufacturer/installer and the certification body.

The guidance to the Building Regulations[1] covering fire safety states that third party certification schemes for fire protection products and related services provide an effective means of providing the fullest possible assurances, offering a level of quality, reliability and safety. It is further stated that third party accreditation of installers of systems, materials or products provides a means of ensuring that installations have been carried out by contractors that understand the products, their intended purpose and the appropriate installation requirements, thereby increasing the reliability of the anticipated performance in fire.

The idea behind third party approval/certification schemes is to drive up standards and to ensure that best practice is followed wherever possible. The basic principle of a third party approval scheme is that the certification body is entirely independent from the manufacturer/installer and has the necessary technical expertise to evaluate product performance, conformity with regulatory requirements and the quality of procedures and methodologies related to manufacture or installation of products or systems.

Product approval schemes carry out regular audits on the factory production control for the product and review the supporting test and assessment evidence for the products and systems being marketed to ensure they continue to meet appropriate standards. In the absence of such schemes, there will be some doubt as to whether the product tested is the same as the product/system currently marketed. Such schemes normally operate in tandem with an ISO 9000 quality system covering design, manufacture and/or installation of products. The schemes also incorporate a process for dealing with modifications to the product or proposed changes to the method of installation so that an agreed plan of action can be put in place before any changes are implemented.

Most certification schemes incorporate a marking or labelling system, which indicates that the product and/or the installation is covered by a third party scheme. Whilst third party certification schemes exist for both approval of cavity barrier products and installers of them, cavity barrier installation is rarely carried out by third party approved installers/contractors. The use of third party approved installers is currently on a voluntary basis. Given that fire protection products and in this case, specifically cavity barriers, are specialist products for which the performance in fire is very dependent on correct installation, should a non-specialist contractor with no training be expected to carry out the installation correctly.

Another approach that would contribute to improvements on the issues of poor workmanship would be improved inspection and quality control during the construction process. The options to achieve this would currently be the responsibility of the building contractor.

10 Discussion and conclusions

As new and innovative methods of construction introduce additional voids, cavities and shafts into buildings as part of the construction process, there are identified issues associated with the provision of and quality of installation of fire protection products and systems in concealed spaces. It is important to ensure that such fire protection is properly designed, specified, procured, installed, inspected and maintained.

The biggest issue with fire protection in concealed spaces is that of quality of construction. The research presented here, and the case studies, shows that poor workmanship, with inappropriate materials, resulting in the inadequate protection of concealed spaces, are the main reasons for fire (and smoke) spread via these routes.

Quality control on site remains an issue to be resolved. What is required is firstly education on how to carry out an installation correctly and why it matters through the impact of omissions on levels of fire safety so that operatives involved in the installation of fire safety measures are aware of the importance of preventing fire spread in concealed spaces. Regular inspection is an essential part of this process particularly given the difficulties in inspecting fire safety measures once they have been covered up by the building process.

Building Control officers and Approved Inspectors should be aware of the requirements of Regulation 7 in ensuring materials are fit for purpose and installed in a workmanlike manner. The requirements of Regulation 38 with respect to information relating to fire precautions and fire safety products is of great benefit to those involved in Fire Risk Assessments and should help improve overall levels of fire safety within buildings covered by the Fire Safety Order.

Whilst, historically, there have been only a limited number of fatalities that can be directly associated with fire or smoke spread in concealed spaces, those (high profile) cases that there are demonstrate that the potential risks and the potential losses remain high.

Some general conclusions from this study are as follows:

- The biggest issue remains that of quality of construction. The research presented here and supported by the case studies shows that poor workmanship with inappropriate materials are the main reasons for the inadequate protection of concealed spaces.
- The increasing use of innovative construction methods, materials, and building designs (often in response to the need for energy efficiency) is resulting in an increase in concealed voids and an increase in combustible material within these voids.
- The fire protection of concealed spaces is of prime importance because any deficiencies in installation and materials are not readily apparent and may quickly be covered over. Any inadequacies in such fire protection cannot be observed by the building users and, unlike other engineering provisions within the building, will not be apparent by its impact on everyday life. Any inadequacies in the fire protection of concealed spaces will only become apparent during the very time that their effectiveness is required – during a fire.
- There is a clear and demonstrable need to ensure that buildings are designed and constructed so that the unseen spread of fire and smoke within concealed spaces within its structure and fabric is inhibited, as required by the Regulations.
- There is adequate guidance available in the public domain to allow this requirement to be achieved.

- A number of UKAS accredited certification schemes exist to seek to ensure that the products used, and the installation of these products, is carried out properly. Given the current guidance in AD B and the potential benefits, the use of third party approved installers of cavity barriers would be advantageous.
- The fire safety information required under Regulation 38 is of proven value to those carrying out a fire risk assessment (under the Fire Safety Order), in particular with respect to the identification of concealed spaces. It is important that this information is made available when required.
- Provisions for greater on-site inspection of cavity barrier installations by Building Control bodies or other independent professionals should be actively considered.
- The case studies have highlighted the potential for plastic vents in masonry walls to act as a potential route for fire spread. Specifiers should consider the risks associated with the location and selection of materials for any products that penetrate through the external building envelope.

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