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# Department for Communities and Local Government Final Work Stream Report:

BD 2887

Compartment sizes, resistance to fire and fire safety project

Work stream 4 – Fire protection of basements and basement car parks

286858 (D26V1)

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**FIRE**

**BD 2887**

## Compartment sizes, resistance to fire and fire safety project

## Final Work Stream Report for Work Stream 4 - Fire protection of basements and basement car parks

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## Executive Summary


Building Regulations Division, Department for Communities and Local Government (DCLG) commissioned BRE to carry out a project titled “Compartment sizes, resistance to fire and fire safety”. The main aim of this project was to produce robust evidence and data based on research, experimental fire testing, computer modelling and laboratory testing, where necessary, on a number of linked work streams in relation to fire safety and associated provisions in Schedule 1 of Part B of the Building Regulations 2010.

This Final work stream report describes the findings of the research for Work stream 4 – Fire protection of basements and basement car parks. The principal aim of this work stream was to produce robust evidence and data to explore the options for fire protection of basements generally and basement car parks specifically.

The work conducted under this work stream has considered the background to the current guidance in relation to basements and basement car parks. DCLG fire statistics have been examined to assess the significance of fires in basements. Three new fire experiments have been undertaken with basement configurations. This work stream has also involved the participation of an industry Steering Group.

The provisions in Approved Document B for basements and basement car parks relate to protecting structures supporting the higher levels of the building during a fire, means of escape and provision of access and facilities for fire fighters.

The conclusions of this work stream are as follows:

- Approved Document B currently includes recommendations for features intended to assist fire fighters which cannot be used operationally due to uncertainties in their safe method of use. This project has reinforced and complemented the findings of previous work in this area.
- The review of the current fire statistics shows that there are a relatively small number of fires in basements and a low number of associated injuries.
- There is limited published data for basement fires that can be used to validate the fire modelling as part of a fire engineered design solution. This project has provided additional data and guidance on any further work, examining specifically the impact of increased insulation levels in buildings and to a limited extent, the size and location of openings at ceiling level.
- There is a growing trend to build downwards and to turn existing basements into habitable spaces, some of which are quite complex. The development of some simple solutions for inclusion in Approved Document B requires some further work and demonstration of performance in a range of different fire scenarios.

Content

# 1 Introduction and Objectives

This Final work stream Report is delivered as part of the Department for Communities and Local Government (DCLG) project BD 2887, titled “Compartment sizes, resistance to fire and fire safety”, DCLG Contract reference CPD/04/102/010. The main aim of this project was to produce robust evidence and data based on research, experimental fire testing, computer modelling and laboratory testing (where necessary) on a number of linked work streams in relation to fire safety and associated provisions in Schedule 1 of Part B of the Building Regulations 2010. The project has been broken down into specific work streams.

This report describes the findings of the research for Work stream 4 – Fire protection of basements and basement car parks.

Fires in basements present a number of challenges in fire safety design due to the inherent nature of buoyant smoke to rise and flow upwards via the access routes to the basement. These routes may be used for evacuation, for fire fighter access and as an air inlet; the presence of a flow of smoke hampers all three of these functions.

In principle, basement car parks do not present any further issues to the problems of basement fires. However, the potential high fire loads and low ceilings could lead to rapid fire and smoke spread so that the fire quickly becomes under ventilated, increasing the hazard to occupants (from toxicity, reduced visibility, high temperature) and potentially creating conditions for a backdraught to occur if the basement ventilation changes.

Approved Document B [1, 2] currently makes provision for protecting means of escape for occupants and for fire fighters’ access so that tenability conditions in a basement can be improved by the ventilation of the smoke and heat. This involves the provision of smoke outlets (vents), which may be either naturally (buoyancy) or mechanically driven. In the context of smoke ventilation, AD B recommends the same ventilation requirements for basement car parks as any other enclosed car park.

There are specific areas of basement ventilation design that cause difficulties for building designers and building control, such as the location of vents to achieve cross ventilation, mechanical extract rates, inlet air provision, pressurised stairs and smoke shafts.

The issue of basement smoke ventilation is further complicated by the wind conditions around the ventilation inlets and outlets.

The aim of this work stream was to produce robust evidence and data to explore the options for fire protection of basements generally and basement car parks specifically.

The specific objectives were to examine alternative options other than those detailed in Approved Document B and to identify the costs and benefits and any risks that are associated with them.

The Work stream 4 tasks were:

- Task 4.1 Establishment and meetings of Satellite Steering Group
- Task 4.2 Literature review and full project scoping
- Task 4.3 Experimental work
- Task 4.3 Changes and additions to Approved Document B
- Task 4.4 Data analysis, cost benefit analysis and risk analysis
- Task 4.5 Reporting.

# 2 Programme of work

## 2.1 Identification and engagement of stakeholders

This work stream has involved the participation of an industry Steering Group, Satellite Steering Group B. This group provided input during the course of the work, giving feedback on the research methodology as well as key deliverables and milestones. This group met three times.

The organisations represented at the Steering Group were as follows.

| **Organisations represented on the Steering Group** |
|---|
| • Building Regulations and Standards Division, Department for Communities and Local Government (DCLG)<br>• BRE Project team<br>• Association of Specialist Fire Protection (ASFP)<br>• Association of Building Engineers (ABE)<br>• British Automatic Fire Sprinkler Association (BAFSA)<br>• British Parking Association<br>• British Standards Committee FSH/25/3 Smoke ventilation in car parks<br>• Business Sprinkler Alliance (BSA)<br>• Chief Fire Officers Association (CFOA)<br>• The Chartered Institute of Building (CIOB)<br>• Fire Brigades Union (FBU)<br>• Fire Industry Association (FIA)<br>• Institution of Fire Engineers (IFE)<br>• LABC<br>• National Fire Sprinkler Association (NFSN)<br>• National Register of Access Consultants (NRAC)<br>• Passive Fire Protection Federation (PFPF)<br>• RICS Building Control Professional Group (RICS)<br>• RISC Authority<br>• Scottish Building Standards (SBS)<br>• Shore Engineering<br>• Smoke Control Association<br>• Water UK<br>• Welsh Government (WG) |

## 2.2 Review of background to existing AD B requirements

The inherent challenge of basement fires is that smoke and hot gases from a fire will typically travel upwards, following routes used for escape of occupants or access for fire fighters. If either a natural or mechanical smoke ventilation system is installed, the design for the provision of make up air is difficult, as for effective ventilation, make up air should be provided at low level. Typically, ventilation inlets and outlets are provided around the perimeter of the building so that the effective floor area of the building is not reduced. This leads to inlet and outlet grilles (or pavement lights) at ground level where their performance may be influenced by wind conditions.

Situations where compartments may contain under ventilated fires raise special issues for fire fighters. Firstly, by their very nature, the compartment will be closed and it can be difficult for a fire fighter to assess the conditions in the compartment from the outside. Entering the compartment requires making an opening which will also allow air to enter the compartment which could, potentially, lead to a backdraught.

The situation is further complicated by the wind flow across the ventilation inlets and outlets. Wind-induced air flows around buildings, especially in an urban environment, are complex and cannot be reliably characterised by simple generic data. It may not be clear which combination of wind speeds and local topography would provide the best or worst ventilation conditions at basement level.

Guidance in Approved Document B (AD B) [1, 2] regarding fire safety requirements for basements are mainly focussed on means of escape, fire fighter access and smoke ventilation, although there are a few requirements for fire resistance (see AD B Table A2) and compartmentation. Basement car parks are only referred to explicitly in the context of mechanical ventilation.

British Standards BS 9999 [3] and BS 9991 [4] draw on the recommendations in AD B.

British Standard BS 7346-7 [5] describes smoke control systems that can be applied to basement car parks.

In 2005, DCLG conducted a literature review of fire fighting in under ventilated compartments [6] which identified some of the issues with basement fires. This was followed in 2007 by a review by BRE of fire fighting provisions in basements [7] and in 2008 by some computer modelling and experimental studies by Kingston University [8].

The study by Kingston University concluded that ventilating basements using pavement lights could not be used reliably as successful operation was too dependent on wind and pressure conditions at the vent location. This conclusion was circulated to Fire and Rescue Services in England and Wales [9] and Scotland [10].

### 2.2.1 Approved Document B (Volume 1) recommendations relating to basements

Approved Document B (Volume 1) Dwellinghouses [1] includes the following definition of a basement storey in Appendix E (Definitions):

> ***Basement Storey:*** *A storey with a floor which at some point if more than 1200mm below the highest level of the ground adjacent to the outside walls.*

Table 1 lists the paragraphs in AD B Volume 1 that refer to basements.

**Table 1 - Paragraphs in AD B volume 1 relating to basements**

| Requirement | Section | Paragraph | Heading | Subheading | Text |
|---|---|---|---|---|---|
| B1 | 2 | 2.13 | General provisions | Basements | Because of the risk that a single stairway may be blocked by smoke from a fire in a basement or ground storey, if the basement storey contains any habitable room, the dwelling house should provide either:<br>An external door or window suitable for egress from the basement (see paragraph 2.8); or<br>A protected stairway leading from the basement to a final exit. |
| B3 | 4 | 4.3 | Fire resistance standard | Application of the fire resistance standards for loadbearing elements | The measures set out in Appendix A include provisions to ensure that where one element of structure supports or gives stability to another element of structure, the supporting element has no less fire resistance than the other element (see notes to Table A2). The measures also provide for elements of structure that are common to more than one building or compartment, to be constructed to the standard of the greater of the relevant provisions. Special provisions about fire resistance of elements of structure in single storey buildings are also given and there are concessions in respect of fire resistance of elements of structure in basements where at least one side of the basement is open at ground level |

### 2.2.2 Approved Document B (Volume 2) recommendations relating to basements

Approved Document B (Volume 2) – Buildings other than Dwellinghouses [2] includes the following definition of a basement storey in Appendix E (Definitions):

*"Basement Storey: A storey with a floor which at some point if more than 1200mm below the highest level of the ground adjacent to the outside walls. (However, see appendix A, Table A2, for situations where the storey is considered to be a basement only because of a sloping site).*

*Table A2 Note c: Where one side of a basement is (due to the slope of the ground) open at ground level, giving an opportunity for smoke venting and access for firefighting, it may be appropriate to adopt the standard of fire resistance applicable to above-ground structures for elements of structure in that storey."*

Table 2 lists the paragraphs in AD B Volume 2 that refer to basements.

**Table 2 - Paragraphs in AD B volume 2 relating to basements**

| Requirement | Section | Paragraph | Heading | Subheading | Text |
|---|---|---|---|---|---|
| B1 | 2 | 2.43 | Common stairs | Basement stairs | Because of their situation, basement stairways are more likely to be filled with smoke and heat than stairs in ground and upper storeys.<br><br>Special measures are therefore needed in order to prevent a basement fire endangering upper storeys. These are set out in the following two paragraphs (2.44, 2.55). |
| B1 | 2 | 2.44 | Common stairs | Basement stairs | If an escape stair forms part of the only escape route from an upper storey of a building (or part of a building) which is not a small building (see paragraphs 2.20) it should not continue down to serve any basement storey. The basement should be served by a separate stair. |
| yB1 | 2 | 2.45 | Common stairs | Basement Stairs | If there is more than one escape stair from an upper storey of a building (or part of a building), only one of the stairs serving the upper storeys of the building (or part) need to be terminated at ground level. Other stairs may connect with the basement storey(s) if there is a protected lobby, or a protected corridor between the stairs(s) and accommodation at each basement level |
| B1 | 2 | 2.6 | Introduction | Basements | Because of the risk that a single stairway may be blocked by smoke from a fire in the basement or ground storey, if the basement storey contains any habitable room, either provide:<br><br>An external door or window suitable for egress from the basement (see paragraph 2.9); or<br><br>A protected stairway leading from the basement to the final exit. |
| B1 | 4 | 4.23 | Calculation of minimum stair width | Simultaneous evacuation | Escape based on simultaneous evacuation should be used for:<br><br>All stairs serving basements<br><br>All stairs serving buildings with open spatial |

| Requirement | Section | Paragraph | Heading | Subheading | Text |
|---|---|---|---|---|---|
| | | | | | planning; and<br><br>All stairs serving Other Residential or Assembly and Recreation buildings.<br><br>Note BS 5588-7 1997 [11] includes designs based on simultaneous evacuation. |
| B1 | 4 | 4.34 | Protection of escape stairs | Access lobbies and corridors | There are situations where an escape stair needs added protection of a protected lobby or protected corridor. These are:<br><br>Where the stair is the only one serving a building (or part or a building) which has more than one storey above or below the ground storey (except for small premises covered in paragraph 4.6a; or<br><br>Height<br><br>Phased evacuation<br><br>In these cases protected lobbies or protected corridors are needed at all levels except the top storey and at all basement levels; or<br><br>Where the stair is a firefighting stair.<br><br>Lobbies are also needed where the option in paragraph 4.21(b) has been used so as not to discount one stairway when calculating stair widths.<br><br>An alternative that may be considered in (a) to (c) above is to use a smoke control system as described in paragraph 4.21(s) *{pressurisation}.* |
| | 4 | 4.41 | Basement stairs | | Because of their situation, basement stairways are more likely to be filled with smoke and heat than stairs in ground and upper storeys.<br><br>Special measures are therefore needed in order to prevent a basement fire endangering upper storeys. These are set out in the following two paragraphs (4.42, 4.43). |

| Requirement | Section | Paragraph | Heading | Subheading | Text |
|---|---|---|---|---|---|
| | 4 | 4.42 | Basement stairs | | If an escape stair forms part of the only escape route from an upper storey of a building (or part of a building) it should not continue down to serve any basement storey. The basement should be served by a separate stair. |
| B1 | 4 | 4.43 | Basement stairs | | If there is more than one escape stair from an upper storey of a building (or part of a building), only one of the stairs serving the upper storeys of the building (or part) need to be terminated at ground level. Other stairs may connect with the basement storey(s) if there is a protected lobby, or a protected corridor between the stairs(s) and accommodation at each basement level. |
| B1 | 4 | 4.5 | Introduction | Single escape stairs | Provided that independent escape routes are not necessary from areas in different purpose groups in accordance with paragraphs 2.50 or 44 the situations where a building (or part of a building) may also be served by a single escape stair are:<br><br>From a basement which is allowed to have a single escape route in accordance with paragraph 3.5b and Table 2;<br><br>From a building (other than small premises, see 4.5c) which has no storey with a floor level more than 11 m above ground level and in which every storey is allowed to have a single escape route in accordance with paragraph 3.5b and Table 2;<br><br>In the case of small premises (see paragraph 3.32), in situations where the guidance in paragraph 4.6 is followed. |
| B1 | 5 | 5.19 | Stairs | Construction of escape stairs | The flights and landings of every escape stair should be constructed of materials of limited combustibility in the following situations:<br><br>If it is the only stair serving the building, or part of the building, unless the building is of two or |

| Requirement | Section | Paragraph | Heading | Subheading | Text |
|---|---|---|---|---|---|
| | | | | | three storeys and is in Purpose Group 1(a) or Purpose Group 3;<br><br>If it is within a basement storey (this does not apply to a private stair in a flat);<br><br>If it serves any storey having a floor level more than 18m above ground or access level;<br><br>If it is external, except in the case of a stair that connects the ground floor or paving level with a floor or flat roof not more than 6 m above or below ground level. There is further guidance on external escape stairs in paragraph 5.25); or<br><br>If it is a firefighting stair (see section 17).<br><br>Note: In satisfying the above conditions combustible materials may be added to the horizontal surface of the stairs (except in the case of firefighting stairs). |
| B1 | 5 | 5.34 | General | Final exits | Final exits should be sited so that they are clear of any risk from fire or smoke in a basement (such as outlets from basement smoke vents, see Section 18), or from openings to transformer chambers, refuse chambers, boiler rooms and similar risks. |
| B1 | 5 | 5.43 | Lifts | Fire protection of lift installations | In basements and enclosed (non open-sided) car parks the lift should be approached only by a protected lobby (or protected corridor), unless it is within the enclosure of a protected stairway.<br><br>This is also the case in any storey that contains high fire risk areas, if the lift also delivers directly into corridors serving sleeping accommodation. Examples of fire risk areas in this context are kitchens, communal lounges and stores. |
| B1 | 5 | 5.44 | Lifts | Fire protection of lift installations | A lift shaft should not continue down to serve any basement if it is:<br><br>In a building (or part of a building) served by only |

| Requirement | Section | Paragraph | Heading | Subheading | Text |
|---|---|---|---|---|---|
| | | | | | one escape stair and smoke from a basement fire would be able to prejudice the escape routes from the upper storeys; or<br><br>Within the enclosure to an escape stair which is terminated at ground level. |
| B3 | 7 | 7.3 | Fire resistance standard | Application of the fire resistance standards for load bearing elements | The measures set out in Appendix A include provisions to ensure that where one element of structure supports or gives stability to another element of structure, the supporting element has no less fire resistance than the other element (see notes to Table 2). The measures also provide for elements of structure that are common to more than one building compartment, to be constructed to the standard of the greater of the relevant provisions. Special provisions about fire resistance of elements of structure in single storey buildings are also given and there are concessions in respect of the element structure in basements where at least one side is open at ground level. |
| B3 | 8 | 8.18 | Provision for compartmentation | Non-residential buildings | The following walls and floors should be constructed as compartment walls and compartment floors in buildings of a non-residential purpose group (i.e. Office, Shop and Commercial, Assembly and Recreation, Industrial Storage or Other non-residential:<br><br>every wall needed to sub-divide the building to observe the size limits on compartments given in table 12 (see Diagram 28a);<br><br>The floor of the ground storey if the building has one or more basements (see Diagram 28c), with the exception of small premises (see paragraph 3.1)<br><br>The floor of every basement storey (except the lowest floor) if the building, or separated part (see paragraph 8.19), has a basement at a depth of more than 10m below ground level |

| Requirement | Section | Paragraph | Heading | Subheading | Text |
|---|---|---|---|---|---|
| | | | | | (Diagram 28d); |
| B3 | 11 | 11.3 | Car parks | Open-sided car parks | a. there should be not be any basement storeys; |
| B3 | 11 | 11.6 | Car parks | Mechanical Ventilation | In most basement car parks and in enclosed car parks, it may not be possible to obtain the minimum standard of natural ventilation openings set out in paragraph 11.5. In such cases a system of mechanical ventilation should be provided as follows:<br><br>The system should be independent of any other ventilation system (other than any system providing normal ventilation to the car park) and be designed to operate at 10 air changes per hour in a fire condition (see AD F [12] for guidance on normal ventilation of car parks);<br><br>the system should be designed to run in two parts, each capable of extracting 50% of the rates set out in (a) above and designed so that each part may operate singly or simultaneously;<br><br>each part of the system should have an independent power supply which should operate in the event of failure of the main supply;<br><br>extract points should be arranged so that 50% of the outlets are at high level and 50% at low level; and<br><br>the fans should be rated to run at 300°C for a minimum of 60 minutes and the ductwork and fixings should be constructed of materials having a melting point of not less than 800°C.<br><br>For further information on equipment for removing hot smoke, refer to BS EN 12101-3:2002 [13].<br><br>An alternative method of providing smoke ventilation from enclosed car parks is given in |

| Requirement | Section | Paragraph | Heading | Subheading | Text |
|---|---|---|---|---|---|
| | | | | | BS 7346-7:2006 [5] |
| B5 | 17 | 17.1 | Introduction | | In low-rise buildings without deep basements fire and rescue service personnel access requirements will be met by a combination of the normal means of escape and measures for vehicle access in Section 16, which facilitate ladder access to upper stories. In other buildings, the problems of reaching the fire and working inside near the fire necessitate the provision of additional facilities to avoid delay and to provide a sufficiently secure operating base to allow effective action to be taken.<br><br>These additional facilities include firefighting lifts, firefighting stairs and firefighting lobbies, which are combined in a protected shaft known as a firefighting shaft (Diagram 52).<br><br>Guidance for protected shafts in general is given in Section 8.<br><br>Note: Because of the high degree of compartmentation in blocks of flats, the provisions for the design and construction of firefighting shafts is different to other buildings. |
| B5 | 17 | 17.2 | Provision of firefighting shafts | | Buildings with a floor at more than 18m above fire and rescue access level, or with a basement more than 10m below fire and rescue access level, should be provided with firefighting shafts containing firefighting lifts (see Diagram 51). |
| B5 | 17 | 17.4 | Provision of firefighting shafts | | Buildings with two or more basement storeys, each exceeding 90m$^2$ in area, should be provided with firefighting shaft(s), which need not include firefighting lifts. |
| B5 | 17 | 17.5 | Provision of firefighting shafts | | If a firefighting shaft is required to serve a basement it need not also serve the upper floors unless they also qualify because of the height or size of the building. Similarly a shaft serving upper floors need not serve a basement which is |

| Requirement | Section | Paragraph | Heading | Subheading | Text |
|---|---|---|---|---|---|
| | | | | | large enough or deep enough to qualify in its own right. However a firefighting stair and any firefighting lift should serve all intermediate storeys between the highest and lowest storeys that they serve. |
| B5 | 18 | 18.1 | Introduction | | The build-up of smoke and heat as a result of a fire can seriously inhibit the ability of the fire and rescue service to carry out rescue and firefighting operations in a basement. The problem can be reduced by providing facilities to make conditions tenable for fire fighters. |
| B5 | 18 | 18.10 | | | If the outlet terminates at a point that is not readily accessible, it should be kept unobstructed and should be covered with a non-combustible grille or louvre. |
| B5 | 18 | 18.11 | | | If the outlet terminates in a readily accessible position, it may be covered by a panel, stall board or pavement light that can be broken out or opened. The position of such covered outlets should be suitably indicated. |
| B5 | 18 | 18.12 | | | Outlets should not be placed where they would prevent the use of escape routes from the building. |
| B5 | 18 | 18.13 | | | A system of mechanical extraction may be provided as an alternative to natural venting to remove smoke and heat from basements, provided the basement storey(s) are fitted with a sprinkler system in accordance with paragraph 0.16 (It is not considered necessary in this particular case to install sprinklers on the storeys other than the basement(s) unless they are needed for other reasons.)<br><br>Note: Car parks are not normally expected to be fitted with sprinklers (see paragraph 11.2) |
| B5 | 18 | 18.14 | | | The air extraction system should give at least 10 air changes per hour and should be capable of |

| Requirement | Section | Paragraph | Heading | Subheading | Text |
|---|---|---|---|---|---|
| | | | | | handling gas temperatures of 300°C for not less than one hour. It should come into operation automatically on activation of the sprinkler system; alternatively activation may be by an automatic fire detection system which conforms to BS 5839-1:2002 [14] (at least L3 standard). For further information for removing hot smoke refer to BS EN 12101-2:2002 [15]. |
| B5 | 18 | 18.15 | Construction of outlet ducts or shafts | | Outlet ducts or shaft, including any bulkheads over them (see Diagram 53), should be enclosed in non-combustible construction having not less fire resistance than the element through which they pass. |
| B5 | 18 | 18.16 | | | Where there are natural smoke outlet shafts from different compartments of the same basement storey, or from different basement storeys, they should be separated from each other by non-combustible construction having not less fire resistance than the storey(s) they serve. |
| B5 | 18 | 18.17 | Basement car parks | | The provisions for ventilation of basement car parks in section 11 may be taken as satisfying the requirements in respect of the need for smoke venting from any basement that is used as a car park. |
| B5 | 18 | 18.2 | Introduction | | Smoke outlets (also referred to as smoke vents) provide a route for heat and smoke to escape to the open air from the basement level(s). They can also be used by the fire and rescue service to let in cooler air to the basement(s) (See Diagram 53). |
| B5 | 18 | 18.3 | Provision of smoke outlets | | Where practicable each basement space should have one or more smoke outlets, but it is not always possible to do this where, for example, the plan is deep and the amount of external wall is restricted by adjoining buildings. It is therefore acceptable to vent spaces on the perimeter and allow other spaces to be vented indirectly by |

| Requirement | Section | Paragraph | Heading | Subheading | Text |
|---|---|---|---|---|---|
| | | | | | connecting doors. However if a basement is compartmented, each compartment should have direct access to venting without having to open doors etc. into another compartment. |
| B5 | 18 | 18.4 | | | Smoke outlets, connected directly to the open air, should be provided from every basement storey, except for any basement that has:<br><br>A floor area of not more than 200m$^2$ and<br><br>A floor not more than 3m below the adjacent ground level. |
| B5 | 18 | 18.5 | | | Strong rooms need not be provided with smoke outlets. |
| B5 | 18 | 18.6 | | | Where basements have external doors or windows, the compartments containing the rooms with doors or windows do not need smoke outlets. It is common for basements to be open to the air on one or more elevations. This may be the result of different ground levels on different sides of the building. It is also common in 18$^{th}$ and 19$^{th}$ century terraced housing where an area below street level is extended at the front and/or rear of the terrace so that the lowest storey has ordinary windows and sometimes an external door. |
| B5 | 18 | 18.7 | Natural smoke outlets | | Smoke outlets should be sited at high level, either in the ceiling or in the wall of the space they serve. They should be evenly distributed around the perimeter to discharge in the open air outside the building. |
| B5 | 18 | 18.8 | | | The combined clear cross sectional area of all the smoke outlets should be not less than 1/40$^{th}$ of the floor area of the floor they serve. |

### 2.2.3 Summary of provisions in Approved Document B

In summary, the specific recommendations for basements in AD B consider:

- Means of escape for building occupants
- Provision of exits, protected shafts
- A basement fire compromising means of escape from other parts of a building
- Fire resistance to prevent spread of fire and maintain integrity to maintain support of structure above
- Smoke control and access for fire fighters.

### 2.2.4 Approved Document B (Volume 2) recommendations relating to basement car parks

The paragraphs in Approved Document B Volume 2 that are relevant to basement car parks are as follows.

**Sprinklers in basement car parks**
AD B volume 2, 2006 with 2010 and 2013 amendments [2]

**Section 18: Venting of heat and smoke from basements**

**Mechanical smoke extract**

18.13 A system of mechanical extraction may be provided as an alternative to natural venting to remove smoke and heat from **basements**, provided the **basement storey(s)** are fitted with a sprinkler system in accordance with paragraph 0.16 (It is not considered necessary in this particular case to install sprinklers on the storeys other than the **basement(s)** unless they are needed for other reasons).

**Note:** Car parks are not normally expected to be fitted with sprinklers (see paragraph 11.2)

**Section 11: Special provisions for car parks and shopping complexes**

**General principles**

11.2 Buildings or parts of buildings used as parking for cars or other light vehicles are unlike other buildings in certain respects which merit some departures from the usual measures to restrict fire spread within buildings. Those are:

a. The fire load is well defined; and

b. Where the car park is well ventilated, there is a low probability of fire spread from one storey to another. Ventilation is the important factor and, as heat and smoke cannot be dissipated so readily from a car park that is not open sided fewer concessions are made. The guidance in paragraphs 11.3 to 11.6 is concerned with three ventilation methods: open-sided (high level of natural ventilation), natural ventilation and mechanical ventilation.

In the 2000 with 2002 amendments paragraph 11.2 in also includes

Note: Because of the above, car parks are not normally expected to be fitted with sprinklers.

A study for DCLG by BRE on car park fires has provided data on fire growth in modern cars [16]. This report included the use of stackers (which may be used in underground car parks) [17] and a computer modelling analysis of a fire incident involving a partially underground car park [18]. This identified an issue with combustible material applied to the car park ceiling as insulation.

### 2.2.5 Related parts of other Approved Documents

Approved Document F: Ventilation [12] includes recommendations for basements that cross refer to Approved Document B, see Table 3.

**Table 3 - Paragraphs in AD F volume 2 relating to ventilation of car parks**

| Requirement | Paragraph | Heading | Text |
|---|---|---|---|
| F6 | 6.18 | Ventilation of car parks | The requirement will be satisfied for car parks **below ground level**, for enclosed-type car parks and for multi storey car parks if the mean predicted pollutant levels are calculated, the ventilation rate is designed and equipment is installed to limit the carbon monoxide to:<br>An average concentration of not more than 30 ppm over an eight hour period; and<br>Peak concentrations such as by ramps and exits, of not more than 90 ppm for periods not exceeding 15 minutes. |
| F6 | 6.19 | | Note that Approved Document B also includes provision for ventilation of car parks for the purpose of fire risk management. |
| F6 | 6.20 | Alternative approaches for ventilation of car parks | As an alternative to paragraph 6.18 the following guidance would satisfy the requirement:<br>Naturally ventilated car parks. The provision of well distributed permanent natural ventilation e.g. openings at each car parking level with an aggregate equivalent area equal to at least 1/20$^{th}$ of the floor area at that level, of which 25% should be on each of two opposing walls.<br>Mechanically ventilated car parks<br>Either the provision of both permanent natural ventilation openings of equivalent area of not less than 1/40$^{th}$ of the floor area and a mechanical ventilation system capable of at least 3 air changes per hour; or<br>For **basement car parks**, the provision of a mechanical system capable of at least 6 air changes per hour.<br>And for exits and ramps where cars queue inside the building with engines running, provisions should be made to ensure a local ventilation of at least 10 air changes per hour. |
| F6 | 6.21 | | Further guidance can be found in APEA publication Code of practice for ground floor, multi-storey and **underground car parks** [19]; CIBSE guide B: 2005 [20] 2.3.23.3 and Health and Safety publication EH40 [21]. Fire safety issues are considered in Approved Document B. |

## 2.3 Fires in basements

There have been many theoretical and experimental studies of fires in compartments with wall openings such as doors and windows. In general, the behaviour of these fires is well understood although some variables (e.g. insulation, ventilation, compartment sizes) need to be explored further to determine whether these will create practical issues in the context of new building technology (such as the development of travelling fires). There is a large amount of literature that can be drawn on to help investigate the behaviour of “simple” compartments with wall openings.

If the compartment only has openings in the ceiling (e.g. cellar with a stair to the level above), then there is little information to draw on to determine either the qualitative or quantitative behaviour of a fire.

If a fire occurs in a compartment with an open door, then a simple flow pattern is quickly established. A plume of hot gases develops above the fire; this draws in surrounding air that mixes with the hot fire gases and forms a layer at ceiling level. This layer deepens as the fire develops and when it reaches the bottom of the soffit above the door opening, the smoke and hot gases can leave the compartment. Fresh air enters at the bottom of the door opening, replacing the hot gases leaving with the compartment and providing a supply of oxygen to sustain the fire. This is illustrated in Figure 1.

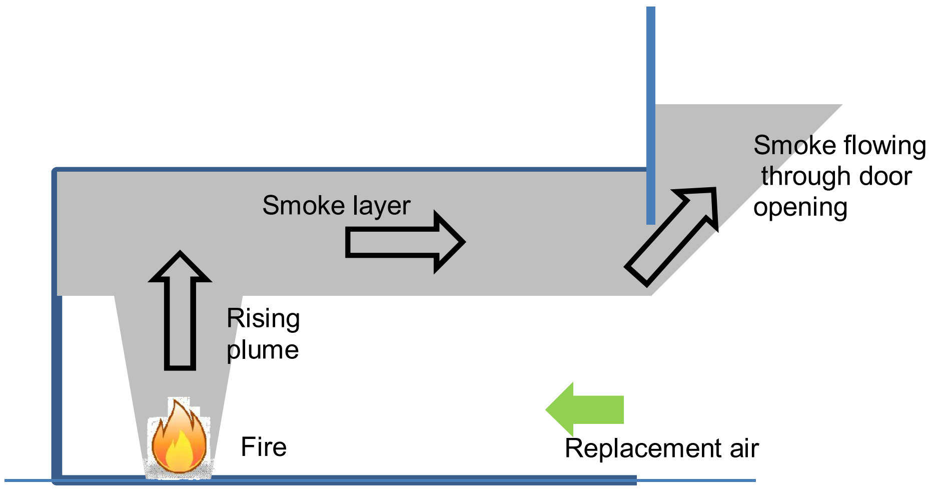



**Figure 1 - Schematic showing features of a fire in a compartment with an open door**

However, if there is only an opening in the top of the compartment, then the flow pattern is more complex. Figure 2 shows a situation with a very large (with respect to the fire size) opening.

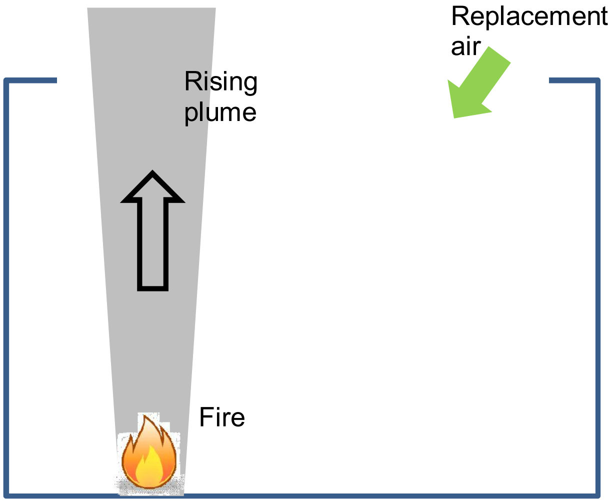



**Figure 2 - Large roof opening (or small fire)**

In the situation shown by Figure 2, the opening is large enough to allow the smoke plume to leave without interfering with the flow of replacement air and would not be strongly affected by the compartment. If the opening is smaller, then the outflow of smoke and inflow of replacement air will interfere with each other. This results either in a counter flow where there is a simultaneous inflow and outflow or a pulsing flow when there are alternate periods of inflow and outflow. The problem can be encountered in many situations where a vessel (compartment) contains a fluid with a density that is different to the external fluid density (for example when pouring a liquid from a bottle). This can either result in a smooth (laminar) flow or pulses as the flow “glugs” as the liquid flows out of the bottle and is replaced by air.

Epstein [22] has examined this scenario experimentally using brine solutions and developed a theoretical analysis that identifies four flow regimes, identified in terms of a characteristic opening diameter D and the opening thickness L, see Figure 3.

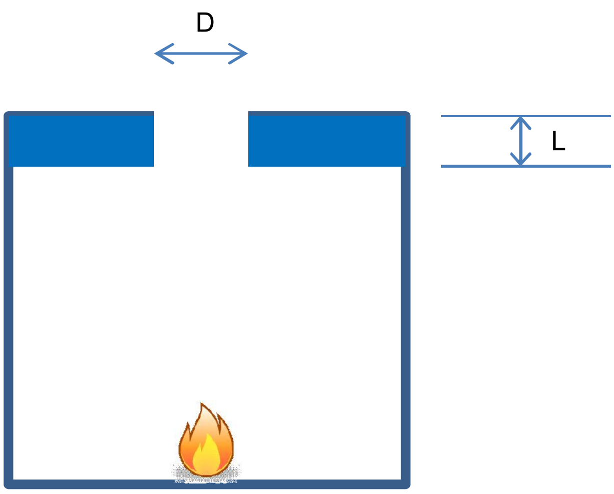



**Figure 3 - Dimensions D and L**

The flow regimes are identified in Table 4.

**Table 4 - Epstein's flow regimens**

| Regime | Description | Condition |
|---|---|---|
| 1 | Oscillation (pulsing) | L/D < 0.15 |
| 2 | Counter current flow | 0.15 < L/D < 0.4 |
| 3 | Transition from counter current - turbulent diffusion flows | 0.4 < L/D < 3.25 |
| 4 | Turbulent diffusion | 3.25 < L/D < 10.0 |

These flows can be illustrated with CFD (computational fluid dynamics) models using a box with an opening in the top and walls at a fixed temperature, e.g. Figure 4.

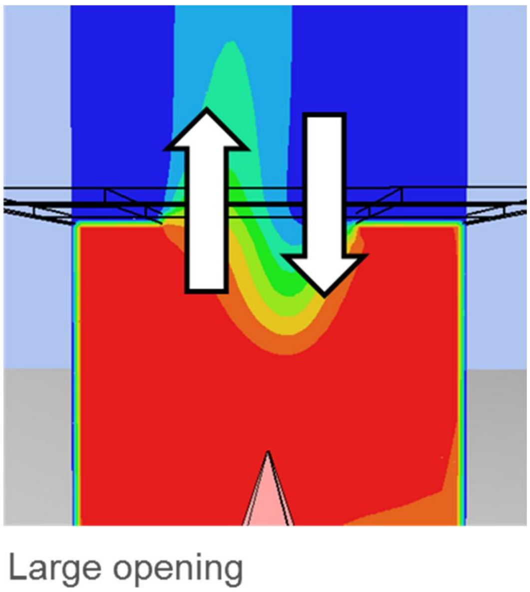



**Figure 4 - Counter flow simulated with a CFD model**

Epstein and others have considered fire problems [23, 24], notably roof mounted smoke vents, based on this analysis. However, this requires an examination of the interaction between the fire and the conditions in the compartment.

Initially, there is sufficient oxygen in the compartment for the fire to burn freely, but as the space fills with smoke and while the flow of replacement air is blocked by the outflow of smoke and hot gases, the fire can become oxygen starved and the heat release rate of the fire will be reduced. This will lead to the compartment temperature and pressure reducing and the flow will switch to become predominantly inflow, replenishing the oxygen in the compartment and allowing the heat release rate of the fire to increase. The cycle then repeats.

The interaction of the fire heat release rate with the compartment conditions presents a challenge to the analysis of basement fires and there is little experimental data to validate any attempt. One of the objectives of this work stream has been to provide a new data set from the Experimental Programme that can be used as validation for a realistic scenario for the built environment. This is presented in section 2.6.

## 2.4 Car park ventilation

The recommendations for car park ventilation are based on an analysis in the Post War Building Studies Report No 28 ‘Precautions against fire and explosion in underground car parks’ [25].

Three objectives were considered at that time:

- Ventilation to prevent/mitigate explosions from petrol vapour
- Ventilation to keep exhaust gases in tolerable limits for occupants
- Ventilation to prevent ignition of exhaust gases.

The analysis indicated that the ventilation required for maintaining a tolerable atmosphere for occupants would also meet the requirements for preventing ignition of petrol vapour and exhaust gases.

### 2.4.1 Recommendations in Approved Documents B and F

The recommendations for car park ventilation in AD B and AD F are given in Table 5.

**Table 5 - Ventilation requirements in Approved Documents**

| Configuration | AD B | | AD F |
|---|---|---|---|
| Natural ventilation | Open-sided<br>(Note 1) | 1/20th of floor area at least 25% on opposing walls. | Vent area equal to 1/20th of floor area at least 25% on opposing walls. |
| | Not open-sided<br>(Note 1) | 1/40th of floor area at least 25% on opposing walls. | |
| Mechanical | 10 air changes/hour split into two parts that can operate singly or simultaneously. Extract points 50% high level, 50% low level. There are temperature requirements for fans and ductwork. | | Ventilation openings of 1/40th of floor area AND mechanical ventilation of 3 air changes/hour.<br>6 air changes/hour for basements. |
| | | | If cars queue on exit ramps local ventilation should be at least 10 air changes per hour. |
| Note 1. Open sided car parks have lower requirements for fire resistance then non open sided car parks as lower fire temperatures would be expected in the better ventilated open sided car parks due to increased ventilation of the hot gases from the fire. | | | |

**AD B 1985** – 5% venting may need “mechanical boost” if separation requirements limit the maximum possible size of openings (9 m separation cut-off).

**AD B 1992** – Document now in the current form and recommends six air changes per hour for petrol vapour extraction and ten air changes per hour for fire conditions. The value of six air changes per hour is justified in the Post War Building Studies based on carbon monoxide (CO) concentrations using a threshold of 0.01 per cent concentration. This concentration is below the maximum exposure concentration for CO given in PD 7974-6 [26] Table G2 of 0.0275% for 1 hour, therefore the ventilation rates in AD B may be considered to be conservative.

## 2.5 Fire statistics

So that the significance of fire in basements could be assessed, fire statistics from the IRS database, covering the period 1.4.2009 – 31.3.2013 [27] have been examined.

Note. The statistical analysis presented in this report has been performed by BRE using raw statistical data supplied by DCLG.

### 2.5.1 Dwelling fires in deep basements

There were no dwelling fires originating three or more floors below ground level. There were just 16 fires in the four years where the fire origin was two floors below ground level. These fires resulted in three people receiving first aid, two being rescued, and two other casualties where the nature was unspecified.

BRE has defined "Equivalent fatalities" (EF) as follows[1]:

- Each actual fatality = 1 equivalent fatality
- Each severe injury = 0.1 equivalent fatality
- Each slight injury = 0.01 equivalent fatality
- Each injury treated by first aid = 0.003 equivalent fatality
- Each recommended precautionary check = 0.001 equivalent fatality
- Each person rescued (uninjured) = 0.001 equivalent fatality
- Each unspecified injury = 0.0003 equivalent fatality.

On this basis, the dwelling fires originating on level -2 had 0.725 EF per thousand fires. By way of comparison, 115,400 dwelling fires where the origin was on the ground or first floor had about 10 EF per thousand fires.

### 2.5.2 Other residential fires in deep basements

There were three residential fires occurring on level -3, which resulted in no casualties. There were 10 fires originating on level -2, which resulted in one slight injury. This converts to 1 EF per thousand fires, using the scheme above. By way of comparison, 8,050 residential fires where the origin was on the ground or first floor had about 3 EF per thousand fires.

### 2.5.3 Non-residential fires in deep basements

In the four-year period examined (1.4.2009 – 31.3.2013), the following fires occurred:

- One fire on level -8, causing no casualties
- Four fires on level -4, causing no casualties
- Fifteen fires on level -3, causing one severe and one slight injury (7.33 EF per thousand fires)

Note. The Bethnal Green fire (20th July 2004), which claimed the lives of two fire fighters, did not occur during the period covered by the statistics in addition the statistics only cover England and Wales so a fire-fighter fatality at the "Balmoral Bar" in Edinburgh on 12 July 2009 was not included.

[1] The rationale behind this definition is the relative value (approximate) of preventing a death, serious injury etc. Note. The concept of "Equivalent Fatalities" has previously been used by the International Maritime Organisation (IMO, MSC/Circ 1023) – BRE has refined the concept to include all injury classes, and rescues, recorded in the fire statistics.

Overall, for the 20 fires listed above, the risk was 5.5 EF per thousand fires. By way of comparison, 59,000 non-residential fires where the origin was on the ground or first floor had about 1 – 1.5 EF per thousand fires.

The 59,000 ground or first floor fires had the following probabilities of casualties:

- 46 fatalities = probability per fire of 0.000779
- 227 severe injuries = probability per fire of 0.003843
- 865 slight injuries = probability per fire of 0.014644
- 904 injuries treated by first aid = probability per fire of 0.015305
- 504 recommended precautionary checks = probability per fire of 0.008533
- 481 persons rescued (uninjured) = probability per fire of 0.009836
- 527 unspecified injuries = probability per fire of 0.008922

If the consequences of fires in the deep basements were no different to the fires on the ground or first floor, then there is a possibility that 20 fires, randomly selected from the 59,000 ground or first floor fires, would imply a risk of 5.5 EF per thousand fires or more.

A simple Monte-Carlo simulation was constructed, and in 11 out of 500 cases of 20 fires, the risk exceeded 5.5 EF per thousand fires. Therefore, there is evidence that deep basements have a statistically significant (98% confidence) higher risk than ground or first floor fires, for non-residential buildings.

### 2.5.4 Conclusions from fire statistics

There are very few fires that occur in deep basements (and in dwellings, none). This is presumably because deep basements are rare, rather than the probability of fire starting being less in deep basements.

There is some evidence for increased risk to life from fires originating in deep basements, in non-residential buildings.

## 2.6 Experimental programme

### 2.6.1 Experimental compartment and fire load

For the experimental programme, a compartment was constructed inside the BRE Burn Hall with internal dimensions of 3.6 m long, 3.6 m deep and 2.4 m high with provision for a 2.0 m high, 2.0 m wide opening in one wall. The compartment was built from medium density load bearing concrete blocks 100 mm thick (density 1400 kg/m$^3$) and precast concrete roof slabs. The floor of the laboratory was protected by plasterboard sheets and sand. This compartment was used for seven experiments and serviced the needs of four work streams; three of these experimental fires were with a basement configuration to support Work stream 4, designated Experiments 4, 5 and 6. The basement configuration is discussed here.

Figure 5 shows a schematic plan of the compartment showing the location of four wood cribs in red and the ceiling vent in blue. The wall opening was used for access and blocked with panels constructed from plasterboard sheet and ceramic fibre blanket immediately after ignition of each experiment. A view of the compartment (prior to Experiment 4) is shown in Figure 6.

The walls and roof of the compartment were lined with ceramic blanket as in the highly insulated compartment fire (Experiment 1). The thermal properties of the compartment are given in Table 6.

**Table 6 - Compartment thermal properties**

| Level | Relative degree of insulation | Construction | Thermal properties |
|---|---|---|---|
| 3 | Very high | Walls: Block work lined with ceramic blanket | Conductivity 0.02 W/mK<br>Thermal inertia 54 $J/m^2s^{1/2}K$ |
| | | Roof: Precast concrete beam and block floor lined with ceramic blanket | Conductivity 0.02 W/mK<br>Thermal inertia 54 $J/m^2s^{1/2}K$ |

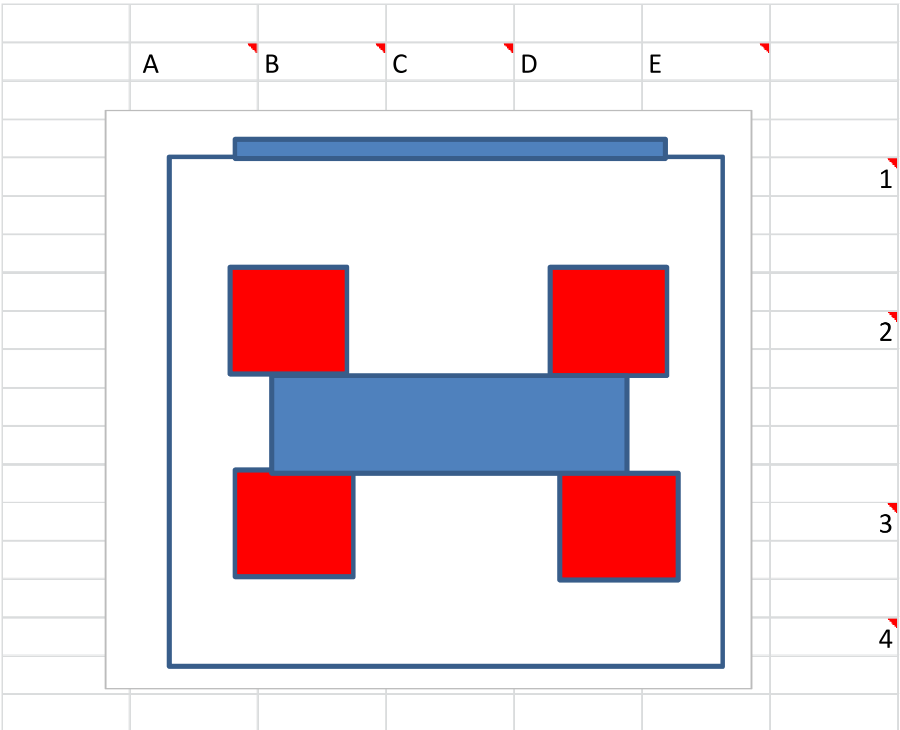



**Figure 5 - Plan of rig showing reference grid and the location of cribs (red) and vents (blue)**

**Figure 6 – Front of rig showing cribs before front opening is sealed prior to Experiment 4**

For each experiment, a fire load of 570 MJ/$m^2$ (averaged over the entire floor area) was used.

For Experiments 4, 5 and 6 (Basement fires), the fuel load was distributed over four cribs to provide a more symmetric configuration, see Figure 7. The sticks were arranged in 10 layers of ten sticks.

**Figure 7 - Crib configuration for Experiment 6**

To ignite the fuel, fibreboard strips soaked in approximately 2 litres of paraffin were inserted into the lower sections of each crib and ignited using a hand held gas burner. The objective was to provide a rapid and uniform ignition of each crib.

The compartment was ventilated by a single opening in the roof. The size of this opening was varied for each experiment as shown in Table 7. Due to the construction of the roof, the vents had to be divided in to two sections separated by a structural beam protected by ceramic fibre.

**Table 7 - Ceiling vent dimensions**

| Experiment | Nominal vent size | Actual vent opening |
|---|---|---|
| 4 | 2 m by 1.0 m | 2 x 2.0 m x 0.4 m |
| 5 | 1.5 m by 1.0 m | 2 x 1.5 m x 0.4 m |
| 6 | 1.0 m by 1.0 m | 2 x 1.0 m x 0.4 m |

Figure 8 shows a view of the vent prior to Experiment 4.

**Figure 8 – Top of rig showing roof vent and instrumentation prior to Experiment 4**

### 2.6.2 Instrumentation

The instrumentation for Experiments 4 to 6 was as follows:

- Four thermocouple columns at locations B2, D2, B3 and D3. Each column was made up of sheathed 1 mm diameter type K thermocouples at distances of 100, 400, 600, 1000 and 1400 mm from the ceiling.

- For Experiment 6, an additional column was included at location C2 with thermocouples at heights of 500, 1000 and 1500 mm above the floor.
- Two sets of three thermocouples (sheathed 1 mm diameter Type K) were embedded in the wall (exposed side, middle, unexposed side) at grid lines A and 4.
- Four to six velocity probes and associated thermocouples (0.5 mm bare wire, Type K) over the roof opening.
- Gas analysers were used to measure oxygen, carbon monoxide and carbon dioxide concentrations 1.2 m above floor level 0.3 m from the back wall of the compartment on grid line E (Figure 6).
- Video camera recording view of vent.
- During Experiment 6, an additional (sacrificial) video camera was located inside the compartment.

### 2.6.3 Experiment 4 - Details and observations

**Date:** 23rd January 2014

**Ventilation:** Roof opening nominally 2 m by 1 m

Due to the construction of the roof, the opening was two slots 2 m long and 400 mm wide, approximately 80 mm apart

**Insulation:** High, thermal inertia, b = 660 $J/m^2s^{1/2}K$

**Fire load:** Four wood cribs, fire load = 570 $MJ/m^2$

**Observations:** Due to the enclosed nature of the experimental rig, visual observations were limited.

| **Time**<br><br>**(mins: secs)** | **Observation** |
|---|---|
| 2:30 | Glow from fire can be seen inside rig |
| 4:30 | Black smoke starts to obscure glow |
| 7:00 | Flames seen inside rig |
| 9:00 | Increased flaming inside rig |
| 15:00 | First flames from vent |
| 17:00 | Increased external flaming, brighter glow |
| 23:00 | Flames stabilise at vent |

**Results:**

Figure 9 shows the temperature-time profiles at the front and the back of the experimental rig

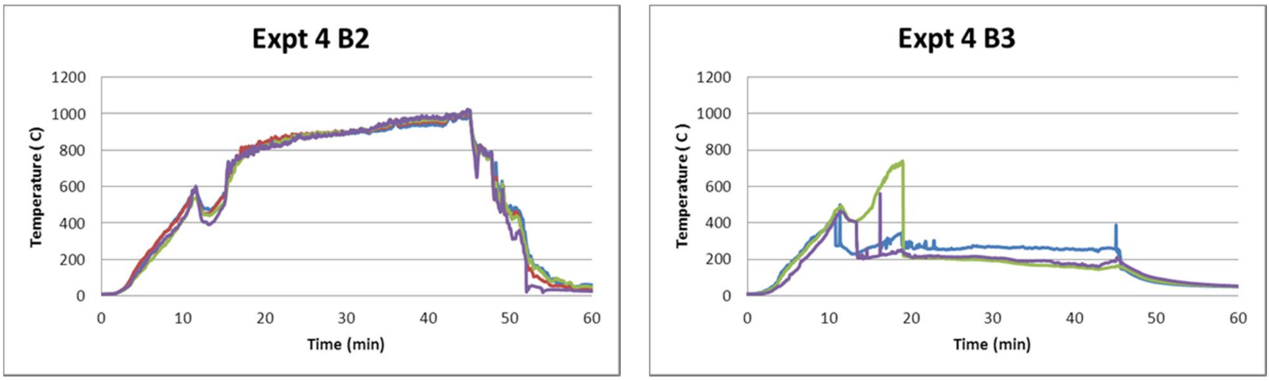



**Figure 9 - Temperatures at the front (B3) and back (B2) of the experimental rig**

Figure 10 shows the measured gas (oxygen, carbon monoxide (CO) and carbon dioxide ($CO_2$) volume concentrations during the experiment. Note. The CO and $CO_2$ analysers reach limiting values at 30000 ppm and 10%, respectively.

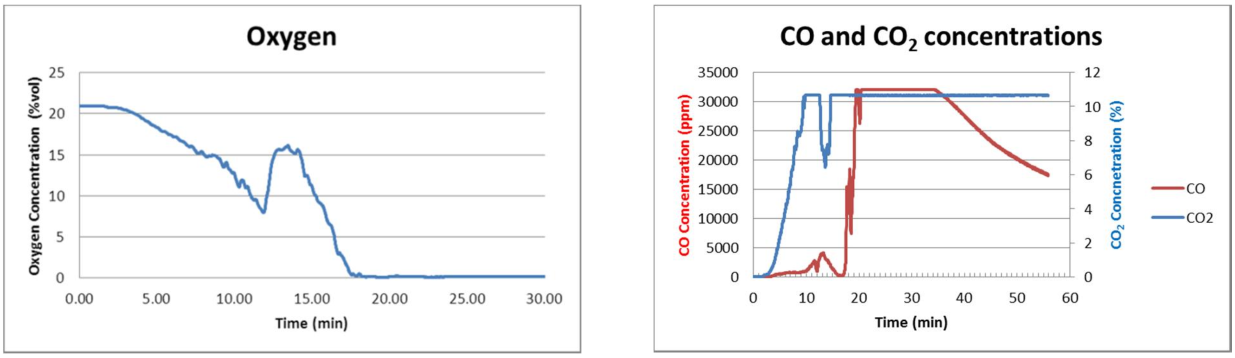
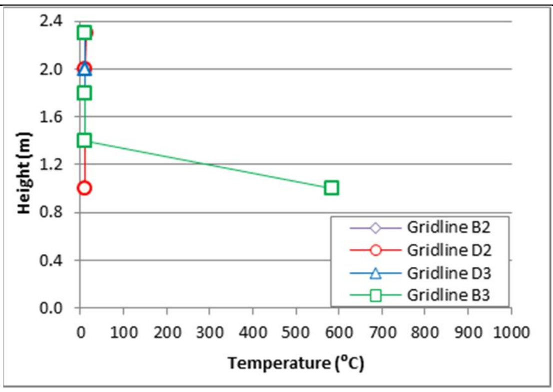
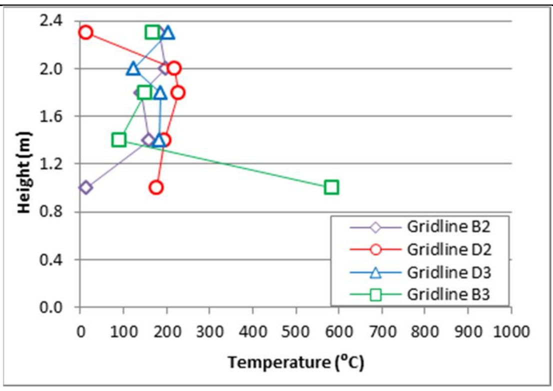
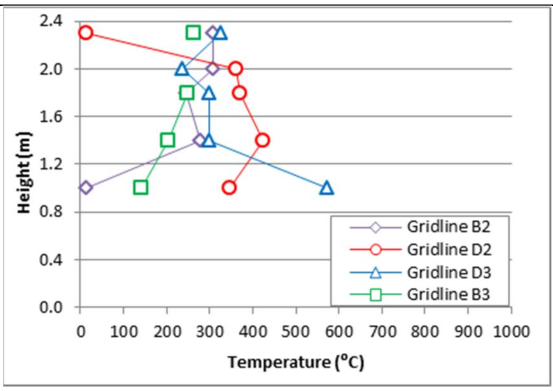
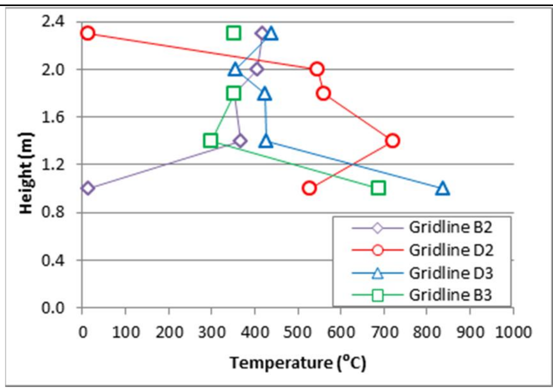


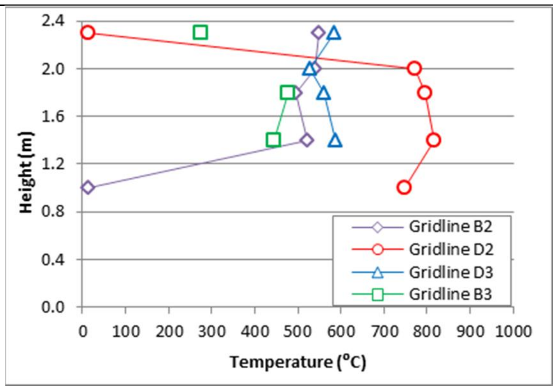

**Figure 10 – Gas concentrations (by volume) for Experiment 4**

Figure 11 shows vertical temperature profiles at loations B2, B3, D2, D3 (see Figure 5) at 5 minute intervals during the experiment, additional plots have beein incuded to show the profiles between 10 and 20 minutes around the time flames were first seen from the vent.

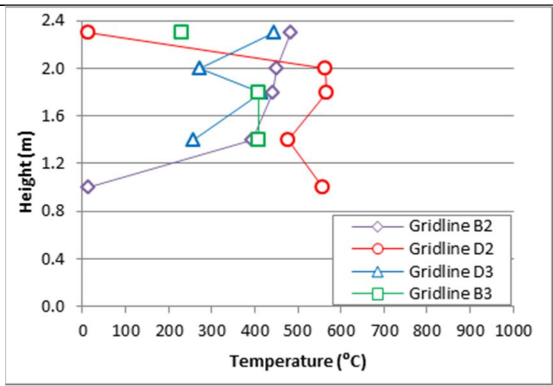
| **Photograph** | **Graph** | **Time from ignition** |
| --- | --- | --- |
|  |  | 5 minutes |
| |  | 10 minutes |
| |  | 12 minutes |



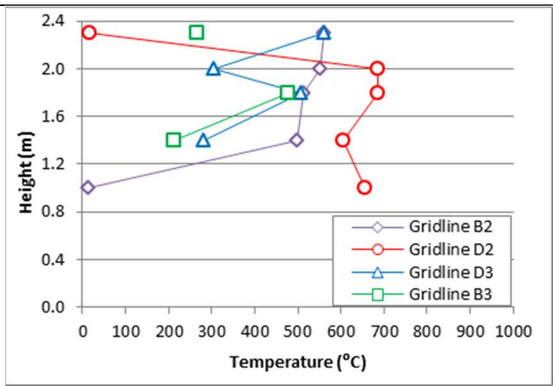

14 minutes




16 minutes




18 minutes




20 minutes

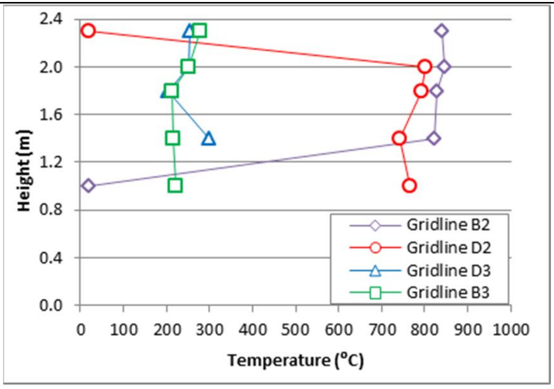
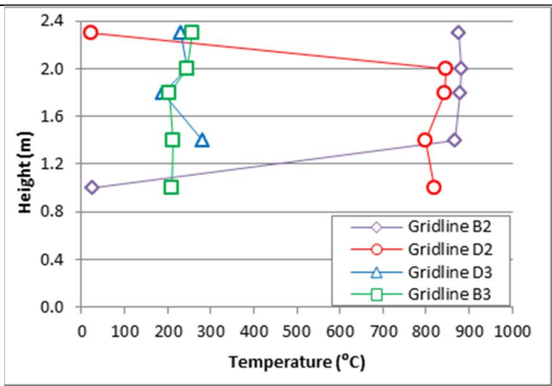
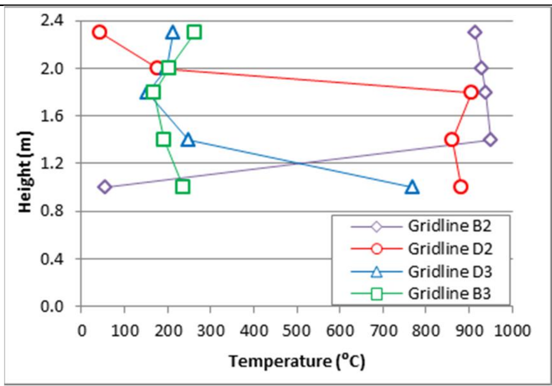
| | | |
|---|---|---|
| |   | 25 minutes |
| |   | 30 minutes |
| |   | 40 minutes |

**Figure 11 - Temperature data recorded during Experiment 4**

### 2.6.4 Experiment 5 - details and observations

**Date:** 5th February 2014

**Ventilation**: Roof opening nominally 1.5 m by 1 m

Due to the construction of the roof, the opening was two slots 1.5 m long and 400 mm wide, approximately 80 mm apart.

**Insulation:** High, thermal inertia, b = 660 $J/m^2s^{1/2}K$

**Fire load**: Four wood cribs, fire load = 570 $MJ/m^2$

**Observations:** Due to the enclosed nature of the experimental rig, visual observations were limited.

The sequence of events was similar to those observed during Experiment 4; however, these occurred over a longer timescale, with external flaming not stabilising until about 30 minutes.

**Results:**

Figure 12 shows the temperature profiles at the front and the back of the experimental rig.

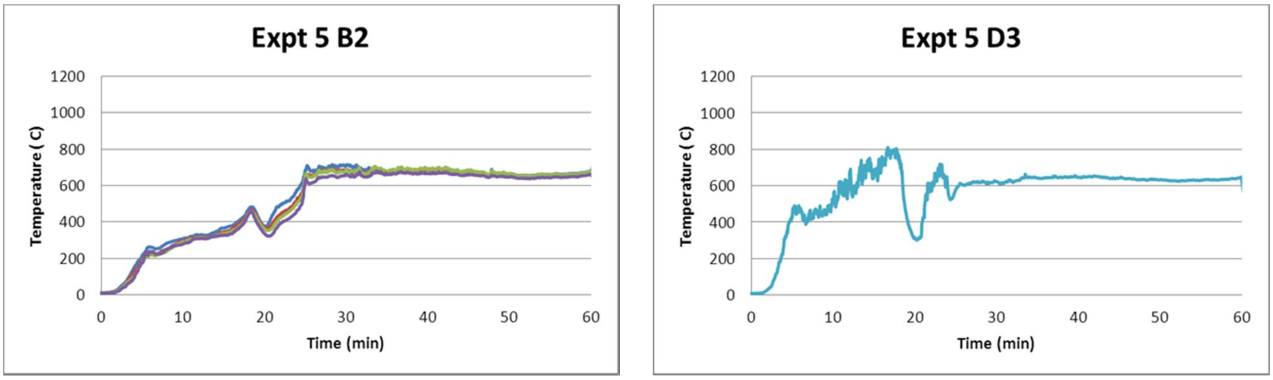



**Figure 12 - Temperatures at the front (B3) and back (B2) of the experimental rig for Experiment 5**

Figure 13 shows the measured gas (oxygen, carbon monoxide and carbon dioxide) concentrations during the experiment. Note the CO and $CO_2$ analysers reach limiting values at 30000ppm and 10%, respectively.

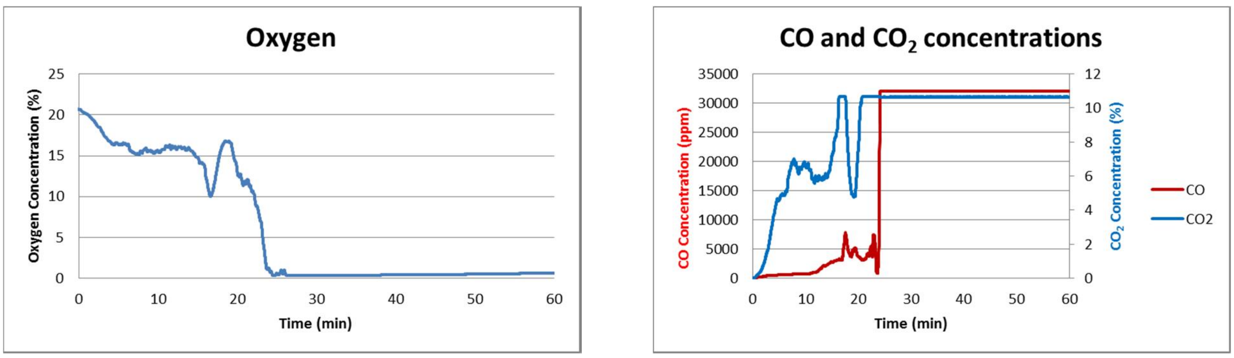
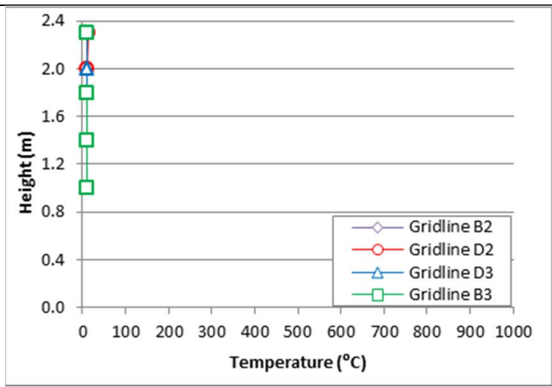



**Figure 13 – Gas concentrations (by volume) for Experiment 5**

Figure 14 shows vertical temperature profiles at loations B2, B3, D2, D3 (see Figure 5) firstly at 5 minute intervals and then at 2 minute intervals and then at 10 and 24 minutes around the time flames were first seen from the vent. When the conditions are relatively stable the profiles are shown at 10 minute intervals.

<table>
<tr><th>Photograph</th><th>Graph</th><th>Time from ignition</th></tr>
<tr><td></td><td>
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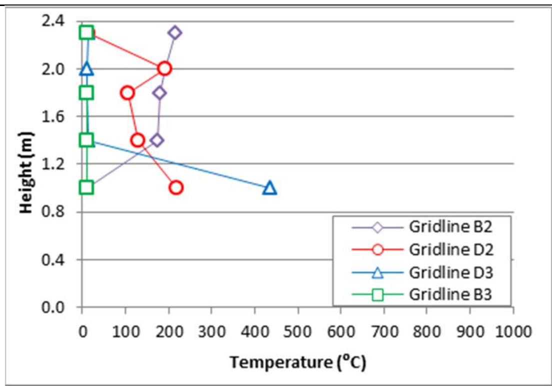
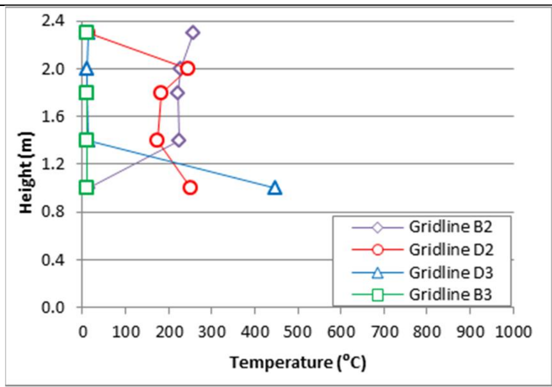
<tr><td></td><td>
</td><td>10 minutes</td></tr>
<tr><td></td><td>
</td><td>12 minutes</td></tr>
</table>

| | | |
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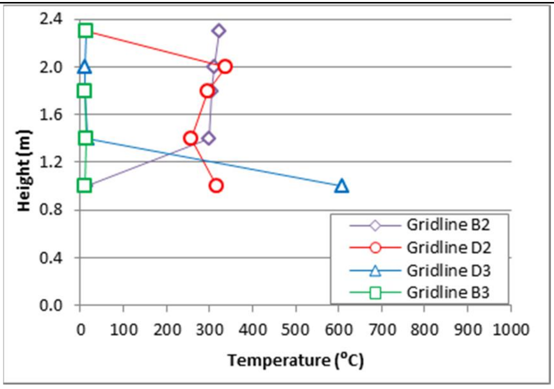
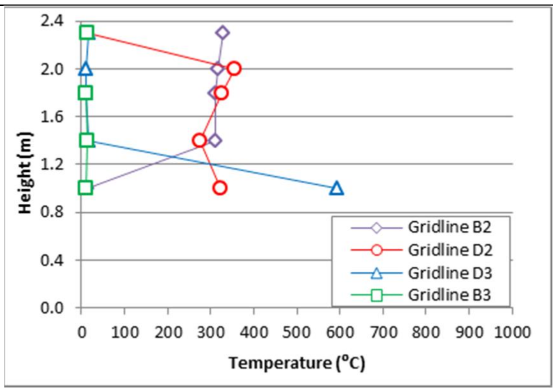
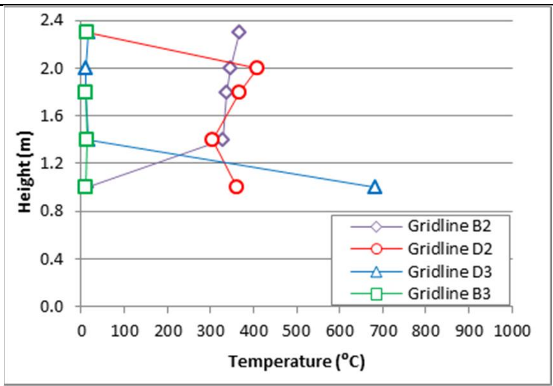
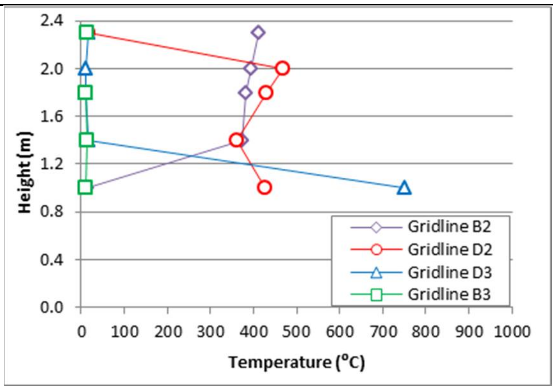
| |  | 16 minutes |
| |  | 18 minutes |
| |  | 20 minutes |
| |  | 22 minutes |

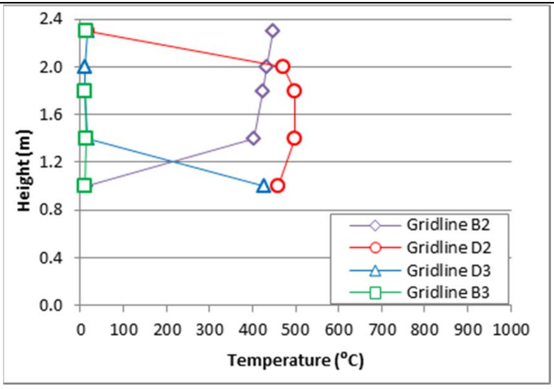
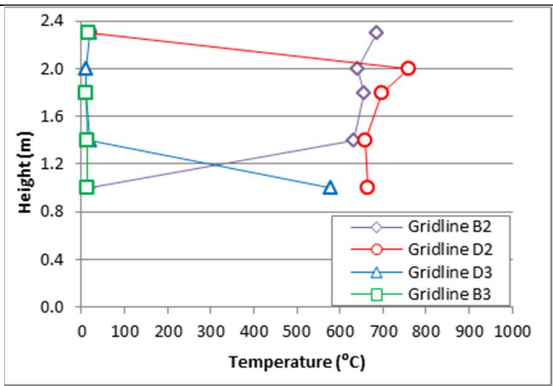
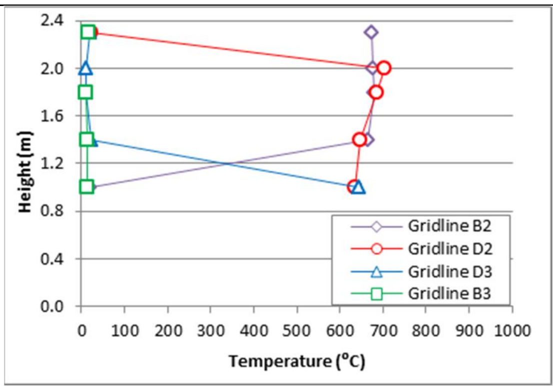
| | | |
|---|---|---|
| |  | 24 minutes |
| |  | 30 minutes |
| |  | 40 minutes |

**Figure 14 - Temperature data recorded during Experiment 5**

### 2.6.5 Experiment 6 - Details and observations

**Date:** 20th February 2014

**Ventilation:** Roof opening nominally 1 m by 1 m

Due to the construction of the roof, the opening was two slots 1 m long and 400 mm wide, approximately 80 mm apart.

**Insulation:** High, thermal inertia, b = 660 $J/m^2s^{1/2}K$

**Fire load:** Four wood cribs, fire load = 570 MJ/m$^2$

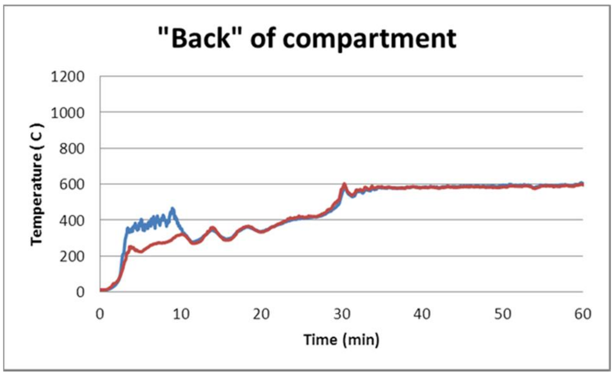
**Observations**: Due to the enclosed nature of the experimental rig, visual observations were limited.

During this experiment, there was no external flaming; however, late in the experiment, flames were observed inside the rig around the edge of the edge of the plasterboard used to close the rig opening.

The test was terminated after 60 minutes by removing the board over the opening and applying water. When the boards were removed there was a "whooshing" sound and the fire developed rapidly with a fireball coming from the roof vent.

**Results:**

Figure 15 shows the temperature profiles at the front and the back of the experimental rig.



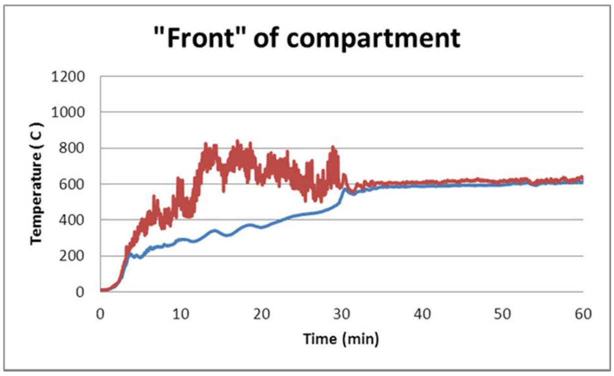
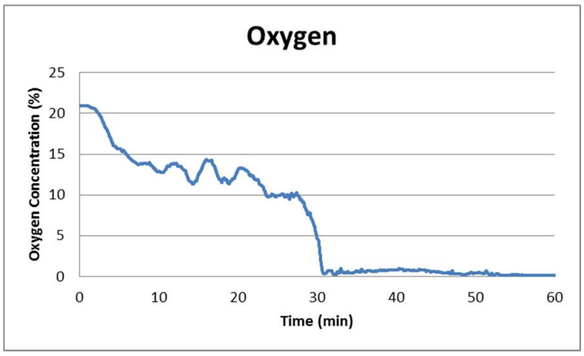




**Figure 15 - Temperatures at the front (B3) and back (B2) of the experimental rig for Experiment 6**

Figure 16 shows the measured oxygen concentration during the experiment. Note the CO and $CO_2$ analysers reach limiting values at 30000ppm and 10%, respectively.



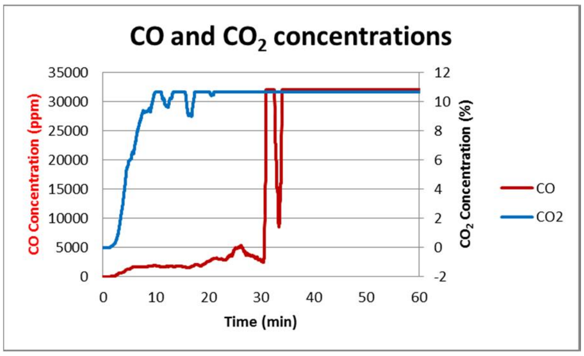
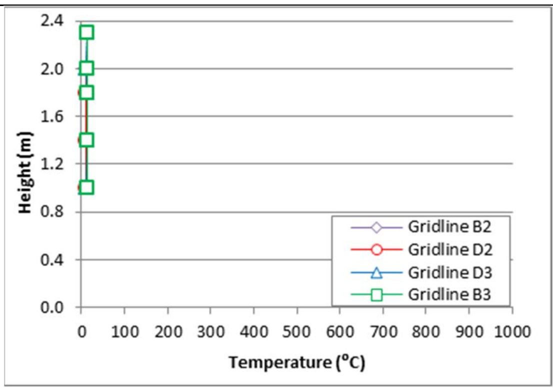
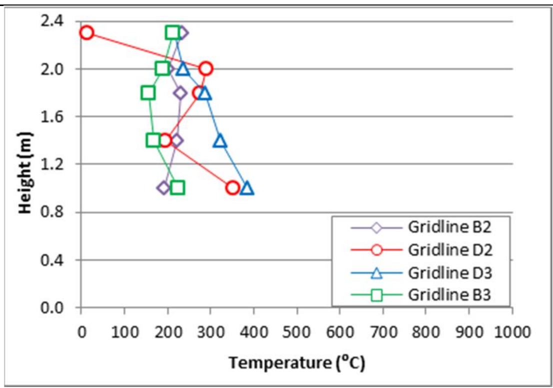
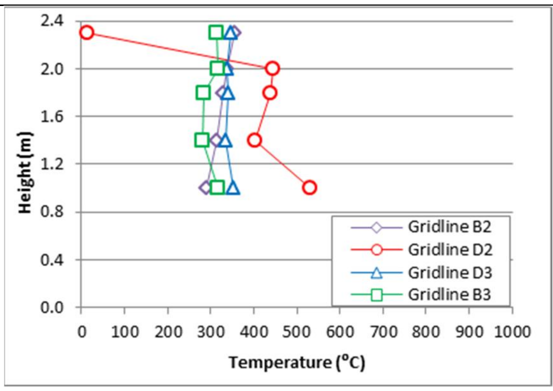
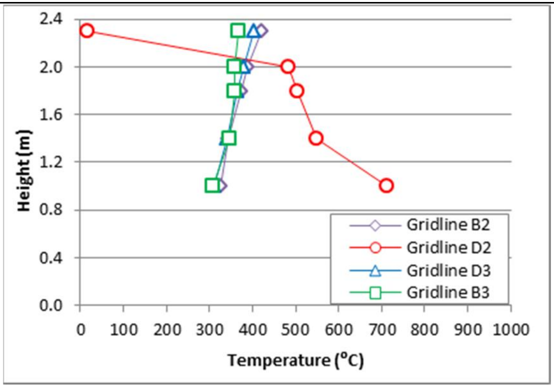
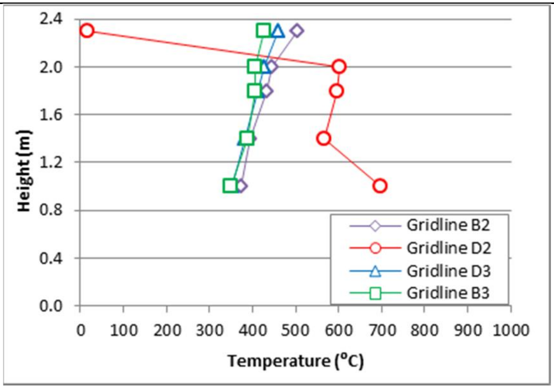
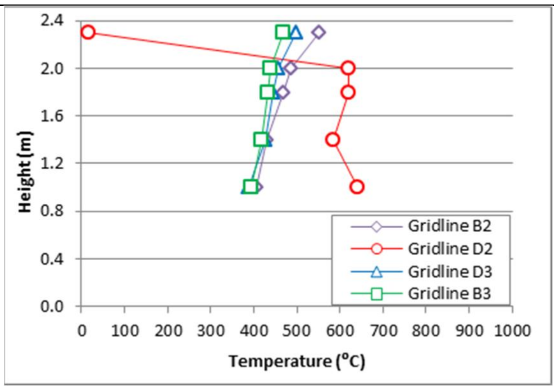
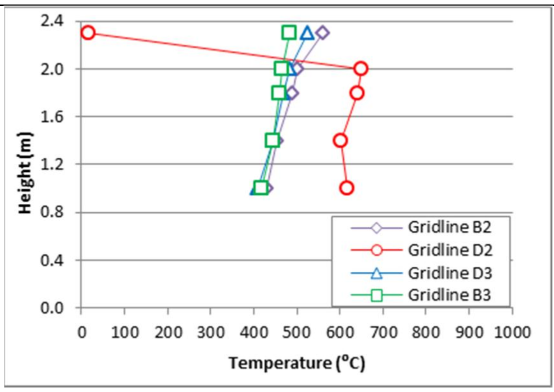




**Figure 16 – Gas concentrations (by volume) for Experiment 6**

Figure 17 shows vertical temperature profiles at loations B2, B3, D2, D3 (see Figure 5) fistly at 5 minute intervals and then at 2 minute intervals and then at 26 and 34 minutes around the time flames were first seen from the vent. A final profile is shown at 40 minutes when the flow is relatively stable.

| Photograph | Graph | Time from ignition |
|---|---|---|
|  |  | 5 minutes |
| |  | 10 minutes |
| |  | 15 minutes |

| | | |
|---|---|---|
| |  | 20 minutes |
| |  | 26 minutes |
| |  | 28 minutes |
| |  | 30 minutes |

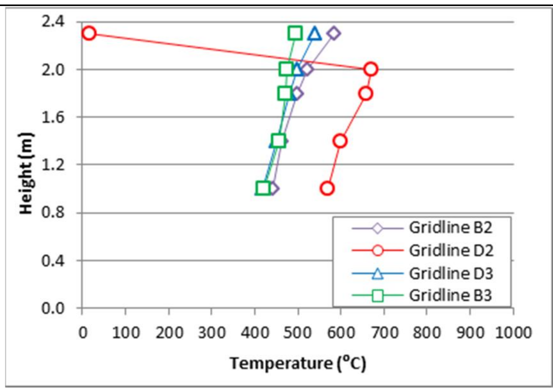
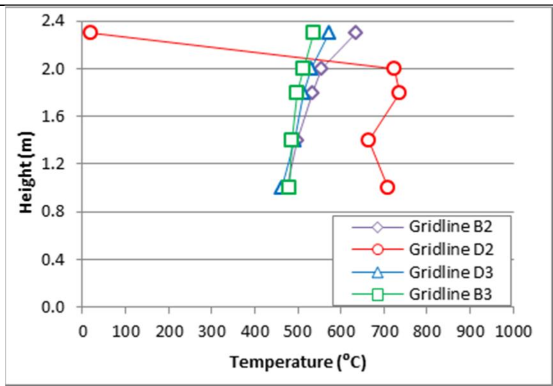
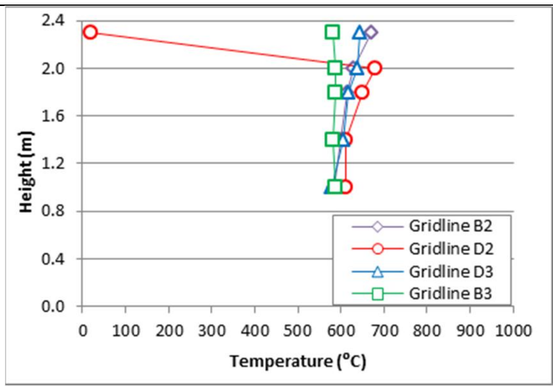
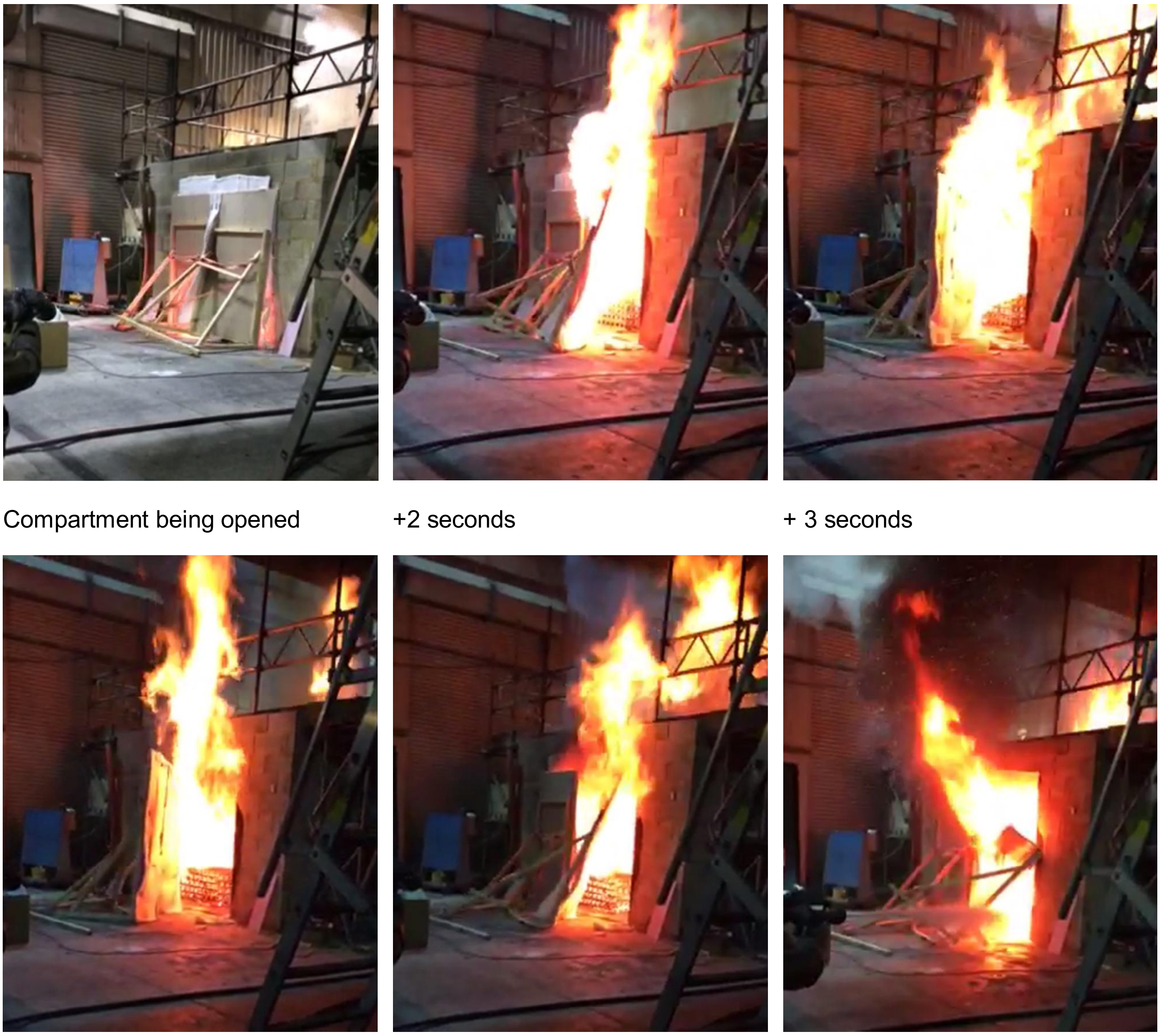
<table>
<tr><td></td><td>
</td><td>32 minutes</td></tr>
<tr><td></td><td>
</td><td>34 minutes</td></tr>
<tr><td></td><td>
</td><td>40 minutes</td></tr>
</table>

**Figure 17 - Temperature data recorded during Experiment 6**

Figure 18 shows a sequence of images as the compartment was opened at the termination of Experiment 6. It should be noted that in addition to the rapid development of external flames at the front of the compartment there was also significant flaming at the roof vent.



Compartment being opened | +2 seconds | + 3 seconds

+4 seconds | +5 seconds | +9 seconds

**Figure 18 - Opening the compartment at the termination of Experiment 6**

### 2.6.6 Discussion of the experimental results

These data are difficult to interpret, especially the temperature data shown in Figures 11, 14 and 17, due to the complex flow inside the compartment.

The highest temperatures are over the front cribs B2 and D2 for most of the experiments; this was confirmed with a camera inside the compartment during Experiment 6 that showed the fire was predominantly over the D2 crib. The low temperature recorded by the top thermocouple on column D2 during all the experiments is probably an instrumentation fault (a short circuit in the wiring outside the compartment creating a junction that recorded ambient temperature).

Observations during the experiments also indicated that the air was entering at the edge of the access opening. The predominant flow is thought to be as shown in Figure 19; however, this was not stable and there would also have been rotation in the horizontal plane.

### 2.6.7 Additional data

Bi-directional probes were used to take measurements to allow the calculation of velocity in the openings which has been used to estimate the mass flow rate through the vents. These data show significant fluctuations due to the characteristics of the air flow at the openings.

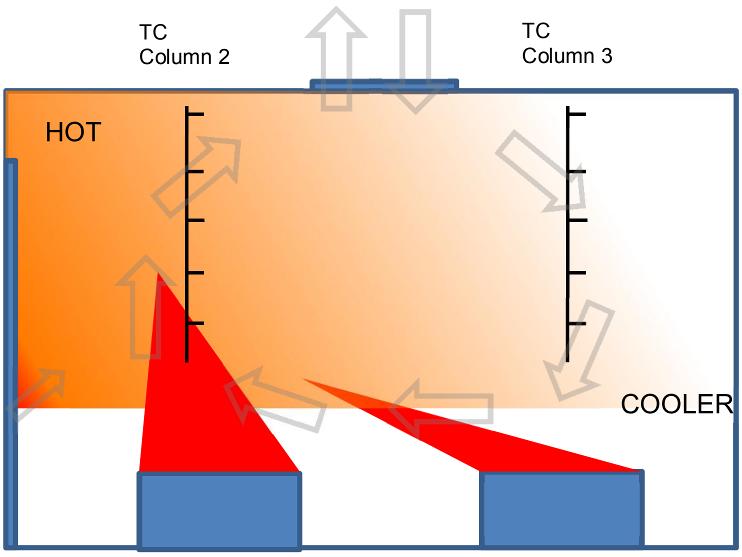



**Figure 19 - Suggested dominant flow inside basement compartment experiments**

### 2.6.8 Considerations for further experimental investigations

The design of experimental programme did not have any previous work to draw on to give guidance on the measurements that might be required or the useful locations of instruments. Resource constraints prevented a “blitz” approach where very large number of sensors would be used to record “everything”. Consequently, the experimental team used their best judgement, based on extensive experience of instrumenting and conducting fire experiments.

For the benefit of those conducting similar investigations in the future, with the benefit of hindsight, the following would be recommended:

- Using a roof design with a simple opening
- Ensuring an airtight seal on any access openings in vertical walls
- Mass loss measurements for individual fuel items
- Capability to view inside the compartment during experiments
- Including floor to ceiling temperature measurements
- Additional gas analysis locations
- Consideration of different fuels to isolate the link between compartment environment and burning rate.

In addition, the design of any experimental study of basement fires should consider difficulties that may occur controlling the fire, as shown in Figure 19.

### 2.7 Analysis and cost benefit analysis

There are no specific changes proposed to either the guidance or the regulations at this time. Therefore, a cost benefit analysis is not required for this work stream.

## 3 Discussion

There are specific areas of basement design that cause difficulties for building designers and building control, such as the location of vents to achieve cross ventilation, mechanical extract rates, inlet air provision, pressurised stairs and smoke shafts. However, most of these difficulties are due to the inherent nature of basements, in that the basement has to include the supporting structure of the building above and that access to the external environment is usually limited to the edge of the building which, in turn, may be restricted by roads or other buildings.

Approved Document B currently provides recommendations to:

- protect the foundations/supports of the building above,
- provide means of escape that do not compromise, or could be compromised by, the building above and
- provide a means of ventilating smoke to assist egress and fire fighter access.

The provisions for basement ventilation in AD B (e.g. the openings in the roof of a basement to the external environment such as pavement lights) have been investigated in previous research [7, 8] programmes which have shown that operation of these vents could be ineffective or possibly unsafe to use in practice. This is due to factors that may be unknown to fire fighters, such as the internal configuration of the basement and external wind effects.

The study by Kingston University [8] concluded that venting should be kept to a minimum and that natural (buoyancy driven) vents should not be used until the fire is fully extinguished, and then only if extinguishing media were available to attack any re-ignition. Kingston University also considered the use of PPV (positive pressure ventilation) and found, while clearance could be effective for a single compartment, it was possible to create pockets of “trapped” hot gases in more complex spaces.

Fire and Rescue Services in England and Wales [9] and Scotland [10] are aware of this conclusion. Consequently, AD B currently includes recommendations for features intended to assist fire fighters which cannot be used operationally, due to uncertainties in their safe method of use.

BRE has been informed [28] that Greater Manchester Fire and Rescue Service (GMFRS) is equipped with high pressure water lances that can be used to cut though solid structures (including pavement lights or stall boards) and apply water into a burning compartment providing an initial attack on a fire without entering the compartment. GMFRS note that single pavement lights would usually be considered as a "restricted outlet" for tactical ventilation and may be of little value (AD B recommends that the total area of natural ventilation to a basement, that may include pavement lights, should be 1/40$^{th}$ of the floor area), but the availability of large outlets would be of considerable benefit.

Approved Document F also includes recommendations for basement ventilation. While AD F refers to AD B and other documents, there is no cross reference in AD B. It should be noted that the ventilation described in AD F is for day to day use, whereas the systems described in AD B are for smoke control and have an additional requirement to operate at high (300°C) temperature; this would have an impact on systems designed to fulfil both requirements.

In the context of the trend towards more deep complex basements, AD B may not provide enough alternatives to cope with the range of site restrictions that may be encountered and the effects of changes to the ventilation paths (internal and external) during normal use. As a consequence, designers would need to consider fire engineering solutions to meet the requirements of the Building Regulations, especially for means of escape and for fire fighter access; these may involve forms of smoke shaft and mechanical extraction which have not been systematically investigated in the context of basements. In particular, the design of the shafts and location and sizing of vents and internal ventilation pathways will all be of relevance to the actual performance of a system in a fire.

An additional observation by GMFRS [28] is that basement ventilation may be required after the fire has been controlled to clear the residual, possibly untenable atmosphere and to facilitate the rescue of occupants who may have found a (relatively) safe refuge in a part of the basement.

Basement car parks tend to be unobstructed spaces which are required to have a level of ventilation to prevent the accumulation of fuel and exhaust gases and that would be sufficient to prevent a fire becoming ventilation controlled in its early development. There would also be good access routes to each level and a smoke control system based on SHEVS (Smoke and Heat Exhaust Systems) or jet fans. Consequently, the issues relating to pavement lights (e.g. backdraught/re-ignition) are unlikely to occur unless a very large fire is able to develop.

Where designers need to demonstrate some alternative measure or a relaxation of an AD B recommendation (such as an extended travel distance), there is very little published data for basement fires that can be used to validate the use of fire modelling for justifying fire engineering solutions. This research has provided further full-scale data for model validations as previous studies have mainly considered small scale or pre-flashover fires and considered the effect of variation in ceiling vent size and high insulation levels. This complements the previous experimental work conducted by BRE and used by Kingston University. The experimental work described here also provides guidance to those conducting further experimental programmes.

## 4 Conclusions

The conclusions for this work stream are as follows:

- AD B currently includes recommendations for features intended to assist fire fighters which cannot be used operationally due to uncertainties in their safe method of use. This project has reinforced and complemented the findings of previous work in this area.
- The review of the current fire statistics shows that there are a relatively small number of fires in basements and a low number of associated injuries.
- There is limited published data for basement fires that can be used to validate the fire modelling as part of a fire engineered design solution. This project has provided additional data and guidance on any further work, examining specifically the impact of increased insulation levels in buildings and to a limited extent, the size and location of openings at ceiling level.
- There is a growing trend to build downwards and to turn existing basements into habitable spaces, some of which are quite complex. The development of some simple solutions for inclusion in AD B requires some further work and demonstration of performance in a range of different fire scenarios.

## 5 Acknowledgements

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- BRE colleagues: Corinne Williams and Koo Sung-Han
- BRE experimental team for Experiments 1 to 6: Tom Lennon, Phil Clark, Simon Barrow, Harry Granados.
- Steering Group member companies who contributed materials for construction, rig linings and indicative test specimens for BRE Experiments 1 to 6: The Concrete industry, beam and block floor and blocks for walls, ASFP, plasterboard for linings, insulation blanket, indicative specimens.
- Steering Group members who provided specialist advice in relation to the construction of the experimental rig.

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## Appendix A – Summary of the Research

Building Regulations Division, Department for Communities and Local Government (DCLG) commissioned BRE to carry out a project titled “Compartment sizes, resistance to fire and fire safety”. The main aim of this project was to produce robust evidence and data based on research, experimental fire testing, computer modelling and laboratory testing, where necessary, on a number of linked work streams in relation to fire safety and associated provisions in Schedule 1 of Part B of the Building Regulations 2010.

This Final work stream report describes the findings of the research for Work stream 4 – Fire protection of basements and basement car parks.

The conclusions of this work stream are as follows:

- Approved Document B currently includes recommendations for features intended to assist fire fighters which cannot be used operationally due to uncertainties in their safe method of use. This project has reinforced and complemented the findings of previous work in this area.
- The review of the current fire statistics shows that there are a relatively small number of fires in basements and a low number of associated injuries.
- There is limited published data for basement fires that can be used to validate the fire modelling as part of a fire engineered design solution. This project has provided additional data and guidance on any further work, examining specifically the impact of increased insulation levels in buildings and to a limited extent, the size and location of openings at ceiling level.
- There is a growing trend to build downwards and to turn existing basements into habitable spaces, some of which are quite complex. The development of some simple solutions for inclusion in Approved Document B requires some further work and demonstration of performance in a range of different fire scenarios.