bre

www.bre.co.uk

Health and Safety Executive
Final Report

Structural Fire Resistance and Fire Separating Elements – Main Summary Report

Prepared for:	**The Building Safety Regulator**
Prepared by:	**Tom Lennon, Neal Butterworth, Grunde Jomaas, Octavian Lalu, Weimiao Lu, Stuart Martin, Stephen Welch, Adeyanju Teslim-Balogun, Martina Manes, Corinne Williams**
Approved by:	**Tony Baker on behalf of BRE Global**
Date:	**15th September 2025**
HSE Contract:	**1.11.4.4436 (previously MHCLG Contract: CPD/004/120/206)**
Report Number:	**P118139-1015 (M11D9V3)**

BRE Global Ltd
Watford, Herts
WD25 9XX

Customer Services 0333 321 8811

From outside the UK:
T + 44 (0) 1923 664000
E enquiries@bregroup.com
www.bregroup.com

This report is made on behalf of BRE Global and may only be distributed in its entirety, without amendment, and with attribution to BRE Global Ltd to the extent permitted by the terms and conditions of the contract.

BRE Global's liability in respect of this report and reliance thereupon shall be as per the terms and conditions of contract with the client and BRE Global shall have no liability to third parties to the extent permitted in law.

This project was initiated by the Ministry of Housing, Communities and Local Government (MHCLG) and then completed and published by Health and Safety Executive (HSE) as the Building Safety Regulator (BSR). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect MHCLG or HSE policy.

Queries on this report should be sent to bsrcorrespondence@hse.gov.uk.

© Crown copyright, 2025 Copyright in the typographical arrangement rests with the Crown. If you wish to reuse this information visit www.hse.gov.uk/copyright.htm for details.

Some images and illustrations may not be owned by the Crown so cannot be reproduced without permission of the copyright owner.

If you have any enquiries regarding this document/publication, email bsrcorrespondence@hse.gov.uk or write to us at: Building Safety Regulator, Health and Safety Executive, Redgrave Court, Merton Road, Bootle, Merseyside, L20 7HS.

Executive Summary

The work reported in this report was carried out by a BRE Global Project team under a Contract placed by the Ministry of Housing, Communities and Local Government (MHCLG) which was novated to the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect MHCLG or HSE policy.

This Final report is delivered as part of the Ministry of Housing, Communities and Local Government (MHCLG) (formerly the Department for Levelling Up, Housing and Communities (DLUHC)) project titled "Structural Fire Resistance and Fire Separating Elements", MHCLG Contract reference CPD/004/120/206. This project was novated from DLUHC to the Building Safety Regulator of the Health and Safety Executive (BSR HSE), HSE contract reference 1.11.4.4436, effective date 1st April 2023.

The aims of the project were to assess the current provisions in Approved Document B (AD B) regarding structural fire resistance and fire separating elements, by establishing the latest knowledge and reviewing this against the underpinning basis and provisions in AD B, to ensure that AD B provides adequate guidance to meet the minimum requirements under Schedule 1 Part B of the Building Regulations 2010.

It should be noted that the edition of Approved Document B referred to throughout this project (unless otherwise stated) is the 2019 edition (incorporating 2020 amendments). Where reference is made to current provisions within this report it is with reference to this edition of AD B.

This project had the following objectives:

- Objective A - Undertake a scoping study to provide information on modern buildings, the current state of knowledge, and the basis for the current provisions.
- Objective B - Review the current provisions to provide information to consider whether current policy/guidance is adequate.
- Objective C - Provide evidence for future policy consideration.

Objectives A and B identified issues and problems with the current approach and guidance and identified issues requiring a more detailed consideration as part of Objective C. The outcome of Objectives A and B informed the work required to develop robust evidence to consider future policy options, based on assessment, analysis and experimental research.

The objectives applied to three sub-workstreams:

- Workstream 1 - Structural Fire Resistance
- Workstream 2 - Fire Separating Elements
- Workstream 3 - Resilience.

Workstream 3 is related to both Workstreams 1 and 2, rather than a standalone subject. When reviewing and assessing guidance and requirements related to structural performance in fire and compartmentation, the issue of resilience cannot be separated from performance but is an integral part of the work carried out.

To meet the project objectives, the project was divided into main Tasks, as follows:

- Develop a research methodology
- Establish expert Technical Steering Group
- Undertake a scoping study (Objective A)
- Review the current provisions (Objective B)
- Provide evidence for future policy consideration (Objective C)
- Produce Final report.

Following completion of Objectives A and B, DLUHC gave consideration to the future research direction and consulted with a Working Group of the Building Regulations Advisory Committee. DLUHC issued a research instruction that gave the direction to the Objective C research.

In summary, the six research sub-tasks taken forward as parts of Objective C were:

- Task C1 AD B Clarification - combustible structures and modular construction
- Task C2 Generate knowledge around mass timber construction
- Task C3 Generate knowledge around modern forms of construction including modular systems
- Task C4 Inform the development of a test methodology (MMC and timber)
- Task C5 Cavity barriers
- Task C6 Car parks

The research was led by BRE Global with contributions from Project Partners Design Fire Consultants, Buro Happold and the University of Edinburgh.

The work also involved the active participation of a Project Technical Steering Group.

This Final report contains the findings of the project for Objectives A, B and C. It comprises a Main summary report and supporting Appendices. The Main summary report provides an overview of the whole project and summarises the work conducted, conclusions and recommendations for future work. The Appendices contain the full technical details of the project.

© BRE Global Ltd 2025

Table of Contents

1 Acknowledgements

BRE Global authors would like to acknowledge the contributions of project partners, Neal Butterworth, Weimiao Lu and Adeyanju Teslim-Balogun, Design Fire Consultants, Stuart Martin and Florian Block, Buro Happold and Grunde Jomaas, Stephen Welch and Martina Manes, University of Edinburgh. The various contributions of the Project Partners are detailed in the individual Appendices of this report.

The authors would also like to acknowledge the contributions of the Project Technical Steering Group members. The Technical Steering Group was established at the start of the project to support MHCLG officials. This Group assisted the project where necessary and appropriate, guided the research programme and provided comments and advice on the research methodology, key deliverables and milestones over the course of the project.

The Group has met eight times by video conference. Meetings were held on 4th November 2020, 11th June 2021, 18th March 2022, 21st October 2022, 12th April 2023, 26th January 2024, 25th September 2024 and 27th February 2025:

- At the first introductory meeting, the proposed research approach was presented and discussed. As this was a wide-ranging and complex research project, the primary project objectives, the considered scope of the project, scope of buildings were also discussed.
- At the second meeting, the findings of the scoping study (Objective A) and the review of current provisions (Objective B) were presented and discussed.
- At the third meeting, the DLUHC research direction summary and the methodologies for each of the six research (Objective C) tasks were presented and discussed.
- At the fourth meeting, the Task C1 AD B clarification findings were presented and discussed. The Task C2 and Task C3 experimental programme updated matrix and the findings from the initial control experiment (precast concrete roof panels and masonry walls) were presented and discussed.
- At the fifth meeting, the Task C6 car park findings were presented and discussed. Task C2 and Task C3 experimental programme report update following receipt of the BSR HSE and Steering Group members' comments and findings from the second experiment involving a modular steel frame system with hot rolled corner posts and a concrete floor slab were presented and discussed.
- At the sixth meeting, the update made to the Task C6 car parks report, following receipt of the BSR HSE and Steering Group members' comments, was verbally outlined. Task C2 and Task C3 experimental programme report update and findings from the third experiment involving a cross laminated timber (CLT) compartment were presented and discussed.
- At the seventh meeting, an update on the Task C2 and Task C3 experimental programme was presented and discussed, focussing on the findings of the fourth experiment involving a panelised light steel frame system. A presentation on Task C2 smouldering combustion issues and implications was presented and discussed. Task C5 cavity barriers which had recently started was outlined.
- At the eighth and final meeting, an update on the Task C2 and Task C3 experimental programme was presented and discussed, focussing on the findings of the fifth experiment involving a timber frame compartment and the Task C4 draft test methodology. A presentation on Task C5 cavity barriers was presented and discussed.

 © BRE Global Ltd 2025

Individuals from the following organisations were members of the Project Technical Steering Group:

- Building Safety Regulator, Health and Safety Executive
- Ministry of Housing, Communities and Local Government (formerly Department for Levelling Up, Housing and Communities)
- The Office for Zero Emission Vehicles
- BRE Global
- Building Regulations Advisory Group (BRAC) Working Group representative
- Association for Specialist Fire Protection
- B/525/-/32 (BSI committee)
- British Constructional Steelwork Association
- British Parking Association
- Buro Happold
- Design Fire Consultants
- Fire Industry Association (MMC Group)
- Institution of Fire Engineers
- Institution of Structural Engineers
- Local Authority Building Control
- National Fire Chiefs Council
- NHBC
- RISCAuthority
- Royal Institute of British Architects
- Steel Construction Institute
- Structural Timber Association
- The Concrete Centre
- University of Edinburgh.

BRE Global authors would like to acknowledge the Industrial Collaboration Group for providing programme assistance and expertise in defining and facilitating (through the provision of experimental samples) the experimental programme.

BRE Global authors would like to acknowledge the contributions to the experimental programme of the following:

- The BRE Global experimental team.
- The Concrete Centre for arranging the provision of materials for the construction of the control fire compartment for the first experiment.

- Supplier 1 for supply, delivery and removal of the module for the second experiment.
- The industry group for the design, supply and construction of the CLT compartment for the third experiment, coordinated through the Structural Timber Association.
- Supplier 2 for supply, delivery and removal of the panellised steel system for the fourth experiment.
- The industry group for the design, supply and construction of the timber frame compartment for the fifth experiment, coordinated through the Structural Timber Association.

The authors would also like to thank the participants of the Car Parks Focus Group for their insights and valuable contributions to the open discussion at the virtual Focus Group meeting held on 29th July 2022.

This Car Parks Focus Group comprised representatives from: DLUHC, the Project team (University of Edinburgh and BRE Global) and invited participants from the Office for Zero Emission Vehicles (OZEV), the British Parking Association, the National Fire Chiefs Council (NFCC) and consultants from OFR Consultants and Arup with expertise in relation to fires in car parks.

The authors would like to thank the participants of the Smouldering Combustion Focus Group for providing additional input to the project on the Fire and Rescue Service experience of post-fire smouldering combustion in timber structures at the virtual Focus Group meeting held on 3rd July 2024.

This Smouldering Combustion Focus Group comprised members from: BSR HSE, BRE Global, the National Fire Chiefs Council (NFCC) and the Structural Timber Association. BRE Global presented a summary of the CLT experiment post-fire findings and the Focus Group members were asked to contribute to an open discussion.

© BRE Global Ltd 2025

2 Introduction

The work reported in this report was carried out by a BRE Global Project team under a Contract placed by the Ministry of Housing, Communities and Local Government (MHCLG) which was novated to the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect MHCLG or HSE policy.

It should be noted that the edition of Approved Document B referred to throughout this project (unless otherwise stated) is the 2019 edition (incorporating 2020 amendments)[1, 2]. Where reference is made to current provisions within this report it is with reference to this edition of AD B.

This Final report is delivered as part of the Ministry of Housing, Communities and Local Government (MHCLG) (formerly the Department for Levelling Up, Housing and Communities (DLUHC)) project titled "Structural Fire Resistance and Fire Separating Elements", MHCLG Contract reference CPD/004/120/206. This project was novated from DLUHC to the Building Safety Regulator of the Health and Safety Executive (BSR HSE), HSE contract reference 1.11.4.4436, effective date 1st April 2023.

The aims of the project were to assess the current provisions in Approved Document B (AD B) regarding structural fire resistance and fire separating elements, by establishing the latest knowledge and reviewing this against the underpinning basis and provisions in AD B, to ensure that AD B provides adequate guidance to meet the minimum requirements under Schedule 1 Part B of the Building Regulations 2010.

This project had the following objectives:

- Objective A - Undertake a scoping study to provide information on modern buildings, the current state of knowledge, and the basis for the current provisions.
- Objective B - Review the current provisions to provide information to consider whether current policy/guidance is adequate.
- Objective C - Provide evidence for future policy consideration.

Objectives A and B identified issues and problems with the current approach and guidance and identified issues requiring a more detailed consideration as part of Objective C. The outcome of Objectives A and B informed the work required to develop robust evidence to consider future policy options, based on assessment, analysis and experimental research.

The objectives applied to three sub-workstreams:

- Workstream 1 - Structural Fire Resistance
- Workstream 2 - Fire Separating Elements
- Workstream 3 - Resilience.

Workstream 3 is related to both Workstreams 1 and 2, rather than a standalone subject. When reviewing and assessing guidance and requirements related to structural performance in fire and compartmentation, the issue of resilience cannot be separated from performance but is an integral part of the work carried out.

To meet the project objectives, the project was divided into main Tasks, as follows:

- Develop a research methodology
- Establish expert Technical Steering Group
- Undertake a scoping study (Objective A)
- Review the current provisions (Objective B)
- Provide evidence for future policy consideration (Objective C)
- Produce Final report.

Following completion of Objectives A and B, DLUHC gave consideration to the future research direction and consulted with a Working Group of the Building Regulations Advisory Committee. DLUHC issued a research instruction that gave the direction to the Objective C research.

In summary, the six research sub-tasks taken forward as parts of Objective C were:

- Task C1 AD B Clarification - combustible structures and modular construction
- Task C2 Generate knowledge around mass timber construction
- Task C3 Generate knowledge around modern forms of construction including modular systems
- Task C4 Inform the development of a test methodology (MMC and timber)
- Task C5 Cavity barriers
- Task C6 Car parks.

This Final report contains the findings of the project for Objectives A, B and C. It comprises a Main summary report and supporting Appendices. The Main summary report provides an overview of the whole project and summarises the work conducted, conclusions and recommendations for future work. The Appendices contain the full technical details of the project.

To assist the reader, Table 1 (below) relates the supporting Appendices to the related Objectives and sub-tasks.

Table 1 – Appendices and related Objectives and sub-tasks

Objective and sub-task	Title	Appendix	Appendix title
A	Undertake a scoping study	A	Scoping study
B	Review the current provisions	B	Summary of scoping study and review of current provisions
C1	AD B Clarification - Combustible structures and modular construction	C	AD B clarification
C2	Generate knowledge around mass timber construction	D1 D2	Experimental programme and development of a test methodology Smouldering combustion issues and implications
C3	Generate knowledge around modern forms of construction including modular systems	D1	Experimental programme and development of a test methodology
C4	Inform the development of a test methodology (MMC and timber)	D1	Experimental programme and development of a test methodology
C5	Cavity barriers	E	Cavity barriers
C6	Car parks	F	Car parks

© BRE Global Ltd 2025

3 Project summary

3.1 Scoping study (Objective A)

A scoping study on the review and collection of evidence on Structural Fire Resistance, Fire Separating Elements and Compartmentation was undertaken.

The work in this area was reviewed based on the outputs from a previous research project completed in 2015, BD 2887 dealing with Compartment Sizes, Resistance to Fire and Fire Safety[3].

The methodology undertaken for Objective A was as follows:

- 136+ responses submitted to the MHCLG Call for Evidence on AD B that related to “Compartmentation”, “Other B3 issues” and Car parks and Fire tests considered under “Other issues” were reviewed (and areas have been identified for focus in Objective B);
- The background to the current guidance in relation to the specification and assessment of performance in fire in relation to structural fire resistance were presented;
- Alternative approaches to the specification of performance in Approved Document B (BS 9999[4], BS 9991[5], the Travelling fires approach, Structural Eurocodes) were identified (for subsequent review in Objective B);
- Issues relating to Modern Methods of Construction were identified (for subsequent review in Objective B);
- The relevant Fire Statistics (for England) were identified (for further investigation in Objective B);
- The test standards related to fire resistance and compartmentation (including extended application documents) were identified (for a subsequent review of current test methods and classification criteria in Objective B);
- From the above, additional references were identified (for subsequent review in Objective B).

Details of the Objective A scoping study can be found in Appendix A.

3.2 Review of current provisions (Objective B)

The methodology undertaken for the Objective B review of current provisions was as follows.

Information relating to the areas identified during the Objective A scoping study was reviewed in Objective B against the underpinning basis and provisions in AD B, to determine whether AD B provides adequate guidance to meet the minimum requirements under Schedule 1 Part B of the Building Regulations 2010.

Based on the initial scoping study and review, a number of specific topics were identified as the primary focus of the current research project. The specific areas where further evidence was considered to be required were:

- Modern Methods of Construction
- Mass timber construction
- Timber frame construction*
- Cavity barriers

- Car parks
- Alternative approaches to defining the performance required
- Deemed to Satisfy solution
- Maximum compartment sizes

* The original intention was for the project to focus on mass timber. However, at the request of BSR HSE and following discussions with the timber frame industry, additional work was undertaken to investigate the performance of timber frame construction.

A summary of the Objective A scoping study and details of the Objective B review of current provisions can be found in Appendix B.

3.3 Provision of evidence for future policy consideration (Objective C)

Following completion of Objectives A and B, DLUHC gave consideration to the future research direction and consulted with a Working Group of the Building Regulations Advisory Committee (BRAC). DLUHC subsequently issued a research instruction that gave the direction to the Objective C research.

In summary, the six research tasks taken forward as parts of Objective C were:

- AD B Clarification - combustible structures and modular construction
- Generate knowledge around mass timber construction
- Generate knowledge around modern forms of construction including modular systems
- Inform the development of a test methodology (MMC and timber)
- Cavity barriers
- Car parks

Research on maximum compartment sizes in relation to large single-storey buildings and on Deemed to Satisfy solutions were not taken forward to the Objective C research stage of this project.

3.3.1 AD B Clarification - Combustible structures and modular construction (Objective C1)

Details of Objective C1 AD B Clarification (Combustible structures and modular construction) can be found in Appendix C.

In order to provide clarification in relation to combustible structures and modular construction (and other uncommon building types), the authors of Appendix C1 summarised the findings from the Objective A and B studies in relation to the current recommended guidance in terms of exposure to a specified period in a standard fire test. The main findings of Objectives A and B in relation to AD B clarification are:

- The regulatory requirement for fire resistance is functional but the functional intent is not specifically identified in the current guidance.
- AD B should be explicit as to the type of structures covered by the guidance and make clear reference to other guidance for alternative routes for compliance or determine appropriate performance requirements.

© BRE Global Ltd 2025

Appendix C focuses specifically on the Intention sections which, to be effective, must:

- Be sufficiently clear to ensure that guidance can be interpreted correctly where there is the potential for ambiguity or insufficient detail available.
- Be sufficiently clear to ensure that alternative methods (to the recommendations of the guidance) meet the requirements.
- Ensure (current) implicit assumptions within AD B regarding its scope in relation to “common building situations” are explicitly stated.

Appendix C provides proposed clarification to the Intention sections of AD B in relation to requirement B3 (1). The intention of the proposed clarification is to make the Intention sections applicable not only to “common building situations” but to all buildings.

The overall intention is to identify implicit assumptions within AD B and to make them explicit.

3.3.2 Experimental programme (Objectives C2 and C3)

Details of the Objective C2 experimental programme can be found in Appendices D1 and D2.

The approach to developing knowledge of the behaviour in fire of mass timber structures and other modern forms of construction including modular (both volumetric and panellised) systems is intrinsically linked to the development of a methodology for test and assessment that takes into account aspects of system behaviour that cannot be considered in standard fire testing. Therefore, Research Tasks C2, C3 and C4 were considered together.

The experimental methodology that formed the basis of the experimental programme undertaken is summarised in section 3.3.5 (below).

A programme of experimental fires was conducted, as summarised in Table 2.

The first fire experiment was a control sample intended to be representative of “traditional” forms of construction.

The experimental programme covered a range of different systems representative from “traditional” forms of construction to volumetric steel framed modules, panellised steel frame systems, mass timber systems and timber frame systems. Fire resistance periods of 60, 90 and 120 minutes were covered. The details of the construction and the findings from the experiments can be found in Appendix D1.

Table 2 − Experimental programme

Ref.	System Description	Applied height	Relevant sector(s)	Recommended structural fire resistance requirement (minutes)	AD A Consequence Class	Floor loaded (Yes/No)
1	Traditional (precast concrete roof panels and masonry walls) Control experiment	Under 18 m	Residential, student accommodation	60	2a or 2b	No
2	Volumetric with SHS corner posts and concrete slab	8-50 storeys	Residential	120	3	No
3	Panellised Cross Laminated Timber (CLT) walls and floors	Under 18 m	Residential, hotels, student accommodation	60	1, 2a and up to 2b	Yes (1.14 kN/m²)
4	Panellised light steel frame with concrete slab	Above 18 m	Residential, hotels, student accommodation	90	Up to 2b	Yes (1.5 kN/m²)
5	Timber frame	Under 18 m	Residential, hotels, student accommodation	60	1, 2a and up to 2b	Yes (1.2 kN/m²)

3.3.3 Generate knowledge around timber construction (Objective C2)

Details of the Objective C2 experimental programme can be found in Appendix D1.

As part of the overall experimental programme, two large-scale fire experiments were conducted on compartments constructed from Cross Laminated Timber (CLT) (Experiment 3) and timber frame (Experiment 5) to consider issues around the potential contribution of the structure itself to fire growth and development.

3.3.3.1 Experiment 3 Panellised Cross Laminated Timber compartment

The third fire experiment carried out as part of the current research project consisted of a Cross Laminated Timber (CLT) compartment constructed from wall and roof panels. The details of the construction and the findings from the experiment can be found in Appendix D1.

Based on the results from the fire experiment involving the CLT compartment with a design fire resistance of 60 minutes, the following conclusions can be drawn:

- The compartment survived complete burn out of the moveable fire load while maintaining overall stability. There were no signs of any integrity failure during the course of the crib fire and no evidence of any external flaming away from the ventilation opening.
- There was no evidence of any insulation failure during the fire exposure from the moveable fire load, based on the criterion adopted in standard fire testing.

However, some hours after completion of the fire experiment, localised areas of smouldering combustion were present, eventually leading to reignition of the CLT in localised areas. Despite persistent attempts to deal with this, the smouldering continued over a period of several days with damage extending to three of the wall panels and spreading through to the roof panel.

The post-experimental smouldering issue is considered in a separate Appendix, based on observations and data collected for an extensive period following the end of the fire experiment.

Details of Objective C2 Smouldering combustion issues and implications can be found in Appendix D2.

3.3.3.2 Experiment 5 Timber frame compartment

Following discussions with BSR HSE, suppliers and key stakeholders, the fifth large-scale fire experiment was undertaken on a timber frame compartment formed from timber frame wall panels and engineered floor joists with a design fire resistance of 60 minutes. The details of the construction and the findings from the experiment can be found in Appendix D1.

Based on the results from the fifth large-scale fire experiment, the following conclusions can be drawn:

- The compartment survived complete burn out of the moveable fire load while maintaining overall stability. There were no signs of any integrity failure during the course of the crib fire and no evidence of any external flaming away from the ventilation opening.
- There was no evidence of any insulation failure during the fire exposure from the moveable fire load, based on the criterion adopted in standard fire testing.

3.3.4 Generate knowledge around modular forms of construction including modular systems (Objective C3)

The experimental programme included a modular compartment with a design fire resistance of 120 minutes (Experiment 2) and a panellised system with a design fire resistance of 90 minutes (Experiment 4). The detailed observations can be found in Appendix D1, but in each case the following conclusions can be drawn:

3.3.4.1 Experiment 2 Modular steel frame system

Based on the results from the second fire experiment of a modular system with a design fire resistance of 120 minutes, the following conclusions can be drawn:

- The compartment survived complete burn out of all combustible material while maintaining overall stability. There were no signs of any integrity failure during the course of the fire and no evidence of external flaming away from the ventilation opening.
- There was no evidence of any insulation failure during the fire exposure based on the criterion adopted in standard fire testing.

3.3.4.2 Experiment 4 Panellised light steel frame system

Based on the results from the fourth fire experiment of a panellised steel system with a design fire resistance of 90 minutes, the following conclusions can be drawn:

- The compartment survived complete burn out of all combustible material while maintaining overall stability. There were no signs of any integrity failure during the course of the fire and no evidence of external flaming away from the ventilation opening.
- There was no evidence of any insulation failure during the fire exposure based on the criterion adopted in standard fire testing.

3.3.5 Inform the development of a test methodology (MMC and timber) (Objective C4)

Details of the draft test methodology can be found in Appendix D1.

The experimental methodology that forms the basis of the experimental programme undertaken is based on that set out in Loss Prevention Standard LPS 1501 *Fire test and performance requirements for innovative methods of building construction*[6] and subsequently modified to form Annex B of the BRE Product Standard BPS 7014 *Standard for Modular Systems for Dwellings* (withdrawn)[7]. The BRE Global Project team believes this Annex represents the most rational and logical approach to the assessment of modern forms of construction currently available.

The primary purpose of the experimental programme was twofold:

1. To assess those aspects of system behaviour that cannot be evaluated using a standard fire test procedure predicated on isolated elements and with no cooling phase.
2. To provide a means of assessment that is consistent and reproducible for all systems where, for whatever reason, reliance on the results from standard fire testing is insufficient to demonstrate compliance with the mandatory requirements of the Building Regulations in relation to performance in fire.

The performance criteria adopted are those of the standard fire test system (loadbearing capacity (stability), integrity and insulation) and the fire design is related to an equivalent severity to the level of fire resistance appropriate to the specific system under consideration. In this way, performance can be assessed and understood by a range of construction professionals in a language with which they are already familiar. It also means that the individual experiment can be tailored to the specific application in terms of the required minimum recommended period of fire resistance from Table B4 of AD B. The large-scale methodology also allows assessment of other non-standard performance characteristics such as the potential for smouldering combustion, connection details and the interaction between wall and ceiling details which would generally not be determined during a standard fire resistance test.

For practical purposes, the maximum module size that can be accommodated is approximately 6 m wide by 4 m long. To aid comparative assessment and promote reliability and repeatability a number of parameters will be fixed. As far as possible, the ventilation conditions will be standardised, and the primary variable will be the fire load density. The other variables are the compartment geometry and ventilation.

The choice of the appropriate fire load density was based on the intended end use application provided by the manufacturer which will be related to both the recommended minimum fire resistance period and the required consequence class. The manufacturer/supplier is the only party who can provide information on the intended end use application, based on the markets in which they operate.

The concept of time equivalence as set out in the fire part of the Eurocode for Actions[8] was used to relate severity to an equivalent period of exposure to the standard fire test. In this way, performance can be related to a metric familiar to many construction professionals. Part of what the BRE Global Project team is trying to assess is whether there is anything specific to the system (such as sensitivity to the rate of heating) that may make reliance on standard fire test results potentially inappropriate.

Where appropriate, the incorporation of active suppression systems can be taken into account through a reduction in the design fire load density within the overall methodology. Sprinkler systems were not incorporated in any of the experiments used to develop the test methodology.

 © BRE Global Ltd 2025

3.3.6 Cavity barriers (Objective C5)

Details of Objective C5 cavity barriers can be found in Appendix E.

The methodology for Objective C5 cavity barriers was as follows.

The current means of test and assessment for open and closed state fire cavity barriers does not necessarily reflect the end use application. Evidence from standard fire testing was investigated. Alternative approaches to standard fire testing were also reviewed, such as the Association for Specialist Fire Protection (ASFP) Technical Guidance Document TGD 19 *Fire resistance test for 'open-state' cavity barriers used in the external envelope or fabric of buildings*[9] which will form the basis of a new harmonised test standard and research undertaken in this area was looked at to try and identify the areas where additional information was required.

It was hoped that the experimental work covered under Tasks C2, C3 and C4 above would also provide an opportunity to assess the performance of cavity barriers when used in conjunction with modern forms of construction. Cavity barriers were included in the final timber frame experiment within party wall and external wall details. The experimental methodology developed during this project makes allowance for the incorporation of cavity barriers, if required.

For modular systems, cavity barriers are often used between modules and fixed to substrates that may differ significantly from those used to determine their performance as linear gap seals in a standard fire test configuration. This leads to some confusion as to the difference between a cavity barrier and a linear gap seal. The impact of movements between modules on the performance of cavity barriers including differential thermal expansion can be evaluated as part of the assessment of performance of realistic structural configurations. This approach will also enable an assessment of service penetrations under realistic conditions of installation and assessed against a realistic thermal exposure.

The justification and background for the recommendations in Approved Document B relating to cavity barriers and cavity closures for masonry walls constructed in accordance with Diagram 5.3 of AD B Volume 1 and Diagram 9.2 of AD B Volume 2, were considered, in particular, the relaxation in the provisions for cavity barriers alongside the stated performance that "do not necessarily achieve the performance specified in paragraph 5.20 (AD B Volume 1)", i.e. do not necessarily achieve 30 minutes integrity and 15 minutes insulation in a fire resistance test. The recommendations were assessed in relation to uninsulated cavities and insulated cavities including partial fill and, where possible, evidence was drawn from real fire incidents.

3.3.7 Car parks (Objective C6)

Details of Objective C6 car parks can be found in Appendix F.

A Focus Group including representatives from BSR HSE, the BRE Global Project Team and invited participants from the Office for Zero Emission Vehicles (OZEV), the British Parking Association (BPA), the National Fire Chiefs Council (NFCC) and consultants from OFR and Arup with expertise in relation to fires in car parks was set up. A virtual meeting was held on 29th June 2022 to define research priorities in relation to car parks.

The principal issue identified in the meeting was the justification for the specification in AD B of a recommended period of fire resistance of 15 minutes for open sided car parks up to 30 m high. This issue has been investigated in relation to the original research used in support of the change and, in the light of recent high profile fire incidents and recent research into the changing nature of vehicles and car park design.

© BRE Global Ltd 2025

Appendix F includes a critical review of the underpinning research behind the 15 minutes recommendation which, for open sided car parks, was based on an assumption that the number of cars involved varies between 0 and 3. Recent fires such as the Echo Arena fire in Liverpool[10] and the fire at Luton Airport[11] have shown that, under certain circumstances, fires in open sided car parks can involve multiple vehicles on multiple floors simultaneously. Reports following these fires have suggested that multi-storey car parks designed for a fire resistance rating of 15 minutes may not satisfy the functional requirement of the Building Regulations.

Recent research has established that the rate of heat release for modern vehicles is greater than that typically used for fire engineering design purposes. This is in part due to a greater use of plastics and increased vehicle size rather than any specific differences between electric vehicles and vehicles relying on internal combustion. There is also evidence that parking spaces have reduced in size with a resulting decrease in separation distances between cars and an associated increase in incident heat flux from one car to another should ignition take place.

In terms of an international perspective, England has the lowest recommended level of fire resistance for open sided car parks with the least restrictive definition of what constitutes an open sided car park. Based on the review undertaken, the research evidence underpinning the current recommendation for open sided car parks is akin to a fire in the open with no restrictions on ventilation and large heat losses to the external environment while a number of recent fire incidents are more representative of a fire within an internal compartment or a closed car park.

The review concluded that the current recommendations with respect to the fire resistance of open sided car parks up to 30 m can no longer be justified. Further work is required to look at the sensitivity of fire growth based on a variation in the relationship between the open area and the overall geometry of the car park including the ratio between open area and floor area and the minimum distance between any area within the car park where a fire might be initiated and the closest opening.

The current situation where 15 minutes fire resistance is used to design open sided car parks up to 30 m in height should be revisited. Based on the review conducted of the current guidance related to the fire resistance of open sided car parks and based on published information and real fire incidents, it is the BRE Project Team's understanding that the following tasks are required:

a) A study to relate assumed heat release rates to an equivalent period of fire severity. In this way more recent data on fire growth can be used to provide input to structural calculations (see bullet point b) below) as design in England is generally not based on structural fire engineering from first principles but on prescribed periods of fire resistance.

b) A parametric study to consider the response of typical structural members (generally composite beams and steel columns) to a variation in fire severity related to either specific design fire scenarios or specified periods of exposure to the standard fire curve. The study should be informed by those responsible for the design of car parks to ensure the structural elements are representative of current practice.

c) Consideration should be given to the use of automatic sprinkler systems as a potential compensatory measure for existing structures.

 © BRE Global Ltd 2025

4 Summary of conclusions and potential further work

A summary of the general conclusions and potential further work from the Research Tasks covered under Objective C are as follows. Full detailed conclusions and potential further work are included in the Appendices of this report.

4.1 Research Task C1 AD B Clarification – Combustible structures and modular construction

The principal output from this part of the project was clarification of AD B guidance to identify implicit assumptions and make these explicit to allow the intent section to be applicable not only to "common building situations" but to all buildings.

It is recommended that BSR HSE review the findings from Research Task C1 to see if any specific changes to the guidance are required to achieve greater clarity in relation to "uncommon building systems".

4.2 Research Task C2 Generate knowledge around mass timber construction

The original intention was for the project to focus on mass timber. However, at the request of BSR HSE and following discussions with the timber frame industry, additional work was undertaken to investigate the performance of timber frame construction. The results from the large-scale fire experiments involving Cross Laminated Timber and timber frame have demonstrated that:

- It is possible to design a fire protection system to ensure that the construction can survive burn out of the moveable fire load for the specific design fire resistance period without any impact on the fire dynamics within the compartment.
- Even where the fire protection has demonstrated the ability of the compartment to survive burn out, this does not guarantee that there will not be reignition at a later period. The issue of smouldering combustion and potential reignition, such as occurred following the CLT experiment, cannot be accounted for in standard fire resistance tests. In the absence of an analytical approach, such issues can only be evaluated through a large-scale test methodology such as that provided under Research Task C4.

4.3 Research Task C3 Generate knowledge around modern forms of construction including modular systems

The results from the large-scale fire experiments involving volumetric and panellised steel systems have demonstrated that:

- The construction can survive burn out of the moveable fire load for the specific design fire resistance.
- The behaviour of the specific systems provided by the suppliers can be conservatively predicted based on the results from standard fire resistance tests.
- However, the experiments carried out did not include some features that are now part of the proposed test methodology.

4.4 Research Task C4 Inform the development of a test methodology (MMC and timber)

The results from Research Tasks C2 and C3 have demonstrated that:

- There is a benefit in a large-scale experimental approach to the assessment of performance in fire where for whatever reason, the results from standard fire tests may be inappropriate or insufficient.
- The methodology developed is robust enough to meet the requirements of a standard test (i.e. it is reliable, repeatable and reproduceable).

It is recommended that BSR HSE reviews the draft test methodology provided which may form the basis of a future standardised test method capable of providing additional assurance that modern systems of construction can meet the functional requirements of the Building Regulations in terms of structural fire resistance.

4.5 Research Task C5 Cavity barriers

Based on the research undertaken as part of this project and a review of related data from previous research projects, the following conclusions can be drawn:

- The current guidance in AD B in relation to the deemed to satisfy provisions for cavity barriers in a stud wall or partition or provided around openings should be reviewed.
- The findings from Research Task C5 in relation to the correct specification and installation of cavity barriers should be widely disseminated. The impact of gaps and discontinuities should be communicated across the industry.
- The development of a specific harmonised European standard for cavity barriers is a welcome development and will enable the use of open state cavity barriers where required. These products are capable of inhibiting fire and smoke spread within cavities even where gaps and discontinuities may be present.
- It is recommended that consideration be given to mandatory checks of life-safety critical aspects of building construction such as the correct installation of cavity barriers, particularly in high risk buildings.

4.6 Research Task C6 Car parks

The review undertaken as part of Objective B of this project established that the underpinning basis for 15 minutes fire resistance for open sided car parks up to 30 m high is no longer valid for modern car park designs.

The work undertaken in Research Task C6 found that the HRR (Heat Release Rate) is similar for ICEV (Internal Combustion Engine Vehicles) and EV (Electric Vehicles) although the heat release rate in the early stages may be faster for the latter. Of more concern, in terms of vehicle design and car park design, is the size and amount of plastic materials present in modern cars (including plastic fuel tanks) and the reduced size of spaces between cars. These issues together result in an increase in the total heat release for an individual vehicle and a reduced time to achieve peak HRR leading to faster spread between cars and an increased probability of multiple cars being involved in a fire incident.

The assumption of a localised fire with a limited number of vehicles involved at any one time can no longer be maintained. This was the basis for the reduction in the recommended fire resistance rating in the guidance based on outdated research.

© BRE Global Ltd 2025

The research concluded that in international terms England has one of the lowest requirements for fire resistance in open car parks, combined with the least restrictive constraints on what constitutes an “open sided” car park.

It is recommended that the current periods in the AD B guidance to the Building Regulations for England for a fire resistance of 15 minutes in open sided car parks up to 30 m in height should be revisited.

Based on the review conducted of the current guidance related to the fire resistance of open sided car parks and based on published information and real fire incidents, it is recommended that the following activities are undertaken:

- A study to relate assumed heat release rates to an equivalent period of fire severity. In this way more recent data on fire growth can be used to provide input data to structural calculations as design in England is generally not based on design from first principles but on prescribed periods of fire resistance from the guidance.
- A parametric study is required to consider the response of typical structural members (generally composite beams and steel columns) to a variation in fire severity related to either specific design fire scenarios or specified periods of exposure to the standard fire curve. This study should be informed by those involved in the design of car parks to ensure the structural elements are representative of current practice.
- Consideration should be given to the use of automatic sprinkler systems as a potential compensatory measure for existing structures.

© BRE Global Ltd 2025

5 References

1. HM Government. Approved Document B (fire safety) Volume 1: Dwellings, 2019 edition incorporating 2020 amendments (for use in England).

2. HM Government. Approved Document B (fire safety) Volume 2: Buildings other than dwellings, 2019 edition incorporating 2020 amendments (for use in England).

3. BRE Global (various authors). BD 2887 Compartment sizes, resistance to fire and fire safety project. Seven workstreams, Final workstream reports for Department for Communities and Local Government, published 2019. Available from https://www.gov.uk/government/publications/compartment-size-resistance-to-fire-and-fire-safety-research. Last accessed 5th March 2025.

4. British Standards Institution, BS 9999:2017 Fire safety in the design, management and use of buildings – Code of practice, BSI, London, 2017.

5. British Standards Institution, BS 9991:2015 Fire safety in the design, management and use of residential buildings, BSI, London, 2015.

6. Loss Prevention Standard LPS 1501 Issue 1.1 Fire test and performance requirements for innovative methods of building construction, BRE Global Limited 2014.

7. BRE Product Standard BPS 7014 Standard for Modular Systems for Dwellings Issue 1.0 Annex B Fire test and performance requirements for whole modules, BRE Global Limited 2021 (withdrawn).

8. Association for Specialist Fire Protection, Technical Guidance Document TGD 019 Fire resistance test for 'open state' cavity barriers used in the external envelope or fabric of buildings, ASFP, 2017.

9. British Standards Institution, BS EN 1991-1-2, Eurocode 1: Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire, BSI, London, 2002.

10. Merseyside Fire & Rescue Service, Kings Dock car park fire - Protection Report, April 2018. Available from: kings-dock-car-park-fire-protection.pdf (merseyfire.gov.uk). Last accessed 5th March 2025.

11. Bedfordshire Fire & Rescue Service, Significant Incident Report: London Luton Airport Terminal Car Park 2, 10/10/2023, Terminal Car Park 2, Easy Way, Luton, Bedfordshire, GB-040100-2023, published 9th October 2024. Available from: Significant Incident Report LLA Car Park 2 fire.pdf. Last accessed 5th March 2025.

© BRE Global Ltd 2025

Report Ends

www.bre.co.uk

Health and Safety Executive
Final Report

Structural Fire Resistance and Fire Separating Elements – Appendix A: Scoping Study

Prepared for:	**The Building Safety Regulator**
Prepared by:	**Tom Lennon**
Approved by:	**Dr Debbie Smith (Original report approval 22nd March 2021) and Tony Baker (Final amendments March 2025), on behalf of BRE Global**
Date:	**22nd March 2021**
HSE Contract:	**1.11.4.4436 (previously MHCLG Contract: CPD/004/120/206)**
Report Number:	**P118139-1015 (M11D9V3) Appendix A**

BRE Global Ltd
Watford, Herts
WD25 9XX

Customer Services 0333 321 8811

From outside the UK:
T + 44 (0) 1923 664000
E enquiries@bregroup.com
www.bregroup.com

This report is made on behalf of BRE Global and may only be distributed in its entirety, without amendment, and with attribution to BRE Global Ltd to the extent permitted by the terms and conditions of the contract.

BRE Global's liability in respect of this report and reliance thereupon shall be as per the terms and conditions of contract with the client and BRE Global shall have no liability to third parties to the extent permitted in law.

Table of Contents

 © BRE Global Ltd 2025

1 Introduction

This Appendix contains the findings of Objective A scoping study.

This report takes into account comments from MHCLG and the Technical Steering Group. Some of the comments on the Objective A report were addressed in the Appendix B report.

2 Methodology for scoping study

A scoping study on the review and collection of evidence on Structural Fire Resistance, Fire Separating Elements and Compartmentation was undertaken.

The work in this area was reviewed based on the outputs from a previous research project completed in 2015, BD 2887 dealing with Compartment Sizes, Resistance to Fire and Fire Safety[1].

The methodology for Objective A was as follows:

- 136+ responses submitted to the MHCLG Call for Evidence on AD B that related to "Compartmentation", "Other B3 issues" and Car parks and Fire tests considered under "Other issues" have been reviewed (and areas have been identified for focus in Objective B);
- The background to the current guidance in relation to the specification and assessment of performance in fire in relation to structural fire resistance has been presented;
- Alternative approaches to the specification of performance in Approved Document B (BS 9999, BS 9991, the Travelling fires approach, Structural Eurocodes) have been identified (for subsequent review in Objective B);
- Issues relating to Modern Methods of Construction have been identified (for subsequent review in Objective B);
- The Fire Statistics (for England) have been identified (for further investigation in Objective B);
- The fire test standards related to fire resistance and compartmentation (including extended application documents) have been identified (for a subsequent review of current test methods and classification criteria in Objective B);
- From the above, additional references have been identified (for subsequent review in Objective B).

bre

3 Review of responses from MHCLG Call for Evidence

3.1 Introduction

It is our understanding that MHCLG is moving forward with a full technical review of the fire safety aspects of the Building Regulations. The MHCLG Call for Evidence, sought views to help set the agenda, terms of reference and programme for the technical review and closed on 15th March 2019. 140 individuals/organisations responded to the consultation, submitting a total of 1,342 separate responses on all subjects. MHCLG supplied BRE Global with a spreadsheet containing the collated comments which had been classified according to the main topic areas. The current research project cuts across a number of topic areas within the technical review. The most significant areas are those dealing with "Compartmentation" (including issues around cavity barriers), "Other B3 issues" as well as Car parks and Fire tests considered under "Other issues". There were 136 responses classified as "Compartmentation" plus additional comments under other sections that related to the subjects covered by the current project.

3.2 Findings

A number of the comments assigned to compartmentation were actually dealing with issues related to external walls and will be considered as part of another ongoing MHCLG research project. Many of the comments related to the very specific concerns of particular sectors. Others are of a general nature and in many cases relate to subjects outside the scope of AD B covering issues such as quality of workmanship and site supervision. Other comments such as the potential confusion between the recommendations of the old Table A1 and Table A2 of AD B 2006 edition (Table B1 and B3 in AD B 2019 edition) relate to the older versions and have been addressed in the latest edition. This is also the case in relation to comments concerning the requirement for sprinklers in blocks of flats below 30m.

However, in reviewing the responses. a number of common issues and concerns were identified. These are summarised below.

3.2.1 Modern Methods of Construction (MMC)

A number of submissions suggested that the guidance was based on "traditional" construction and is therefore inappropriate for modern innovative forms of construction. This is a recurring theme and one that will also presumably be considered in the current MHCLG Construction Technologies research project.

Many of the comments suggest that the guidance needs to be updated to provide a route to demonstrate compliance for MMC and diagrams should be updated to reflect modern construction. One of the respondents makes the assertion that MMC is an ideological term with no basis in Building Science. The important issue here is not whether some particular material, product, system, module or building conforms to some nebulous definition of a category that does not really exist, but whether the guidance as it exists is applicable or not to that particular material, product, system, module or building. If it is not applicable or not wholly applicable, then additional performance requirements should be stipulated. One of the respondents makes the point that the application of new technology and materials must be controlled by a rigorous testing and certification regime prior to use.

The review of the background to the recommended periods of fire resistance will consider the issue of the extent to which the existing recommendations are based on traditional materials. At this stage, it seems reasonable to assume that the recommendations in the guidance were based on an ability to survive burn out and the assumption that the structure was effectively inert. In such cases, the recommendations were based on the anticipated fire load modified as appropriate to take into account issues such as the ease of escape in the event of a fire, issues of intervention and firefighting, consequence of failure and property protection.

If it is accepted that the recommendations are applicable to "traditional" forms of construction, then it follows that the current system of assessing performance (i.e. standard fire resistance tests) is somehow inappropriate for any other form of construction. It therefore follows that additional guidance is required to cover those products, systems, panels, modules or complete buildings that do not conform to the concept of traditional construction.

It is not the purpose of the guidance to provide solutions (in the form of standard details that "conform"). The primary purpose of the guidance is to set levels of performance in a technologically neutral way that will ensure that the finished construction is capable of meeting the (functional) requirements of the Building Regulations. Any attempt to try and keep up with changes to construction methods or practices will be flawed. This is accepted by one of the respondents who identifies the difficulties in such an approach even with regular revisions of AD B. The solution is not to try to change the guidance to keep up with changes to materials, systems and products but to modify the levels of performance required based on the perceived risk.

For those forms of construction that, for one reason or another, cannot be classed as "in scope", then additional requirements are needed in order to demonstrate compliance. The format that any additional requirements might take will be covered as part of Objective B. One area identified by respondents is through reliance on the results from large-scale tests.

3.2.2 BRE Report BR 128 and "Deemed to Satisfy solutions"

One of the respondents mentioned the need for an updated version of BRE Report BR 128 *Guidelines for the construction of fire-resisting structural elements*[2]. This document, which was referenced in previous versions of AD B as providing an appropriate specification for a wide range of different materials and different types of loadbearing and non-loadbearing structural elements, has been archived by BRE and is no longer referenced in the latest version of AD B. According to the BRE Bookshop, although the document can still be purchased, some of the information (in the document) has been superseded by more recent research and standards. The Call for Evidence indicated that this has left a large space within the construction industry with there being no readily available source of approved details.

There are many instances where details previously incorporated within BR 128 and approved as fit for purpose over many years are no longer accepted on the basis that it is no longer referenced in AD B. The absence of readily available generic solutions has placed a greater reliance on desktop assessments based on existing test reports or advanced design methods.

The publication of BR 128 was a partnership between the UK government and the construction industry based on a consideration of current test data and information. Much of the information within the document was incorporated (or taken from) British Standards which, themselves have been withdrawn or are no longer maintained and have largely been superseded by the development of the fire parts of the Structural Eurocodes. Different sectors of the industry have attempted to bridge the gap with the publication of sector-based guidance[3,4]. However, BR 128, in covering a wider scope, served a very useful purpose and there remains a need for a document that can be used to specify simple conservative solutions to achieve specified periods of fire resistance based on a combination of calculation procedures from European standards supported by fire test results. The approach to achieving this would require careful consideration. Such a document could also be used to provide supplementary information related to modern forms of construction.

3.2.3 Maximum compartment sizes

A number of respondents (principally those representing the insurance industry, the sprinkler industry and the Fire and Rescue Service) identified the issue of the lack of any restrictions for large single-storey industrial buildings or warehouses. The focus of many of the comments was financial losses backed up by reference to potential environmental damage and difficulties faced by the Fire and Rescue Service. As long as the primary focus of the regulations is the health and safety of people in and around buildings and there are adequate means of escape in the early stages of a fire and the primary aim of the Fire and Rescue Service is to minimise the spread based on external fire-fighting, there is unlikely to be sufficient justification to either restrict the size of compartments in such buildings or to require sprinkler systems to be installed. The discussion on the need to incorporate property protection as an explicit objective of the Building Regulations is outside the scope of this project.

Maximum compartment sizes were an issue addressed previously as part of the project titled “Compartment sizes, resistance to fire and fire safety”, BD 2887[5]. The work considered the background to the current guidance in relation to maximum compartment sizes. A review of existing fire databases was undertaken primarily to consider the relationship between compartment size and life safety with particular reference to single-storey industrial and storage buildings. A review was undertaken of alternative approaches used to derive maximum compartment sizes for single-storey industrial and storage buildings to provide an international perspective in relation to regulatory requirements. The overall conclusion of the work stream was that a review of statistical data showed no clear correlation between compartment size and life safety for compartments with floor areas larger than 500m² for large, single-storey industrial and storage buildings. This information will be further reviewed as part of Objective B of the current project.

3.2.4 Timber frame construction

A number of respondents cited timber frame structures as being of concern in relation to fire performance and the number and nature of incidents. Sometimes the reference to timber frame was related to MMC, highlighting the confusion in relation to definitions of MMC.

In addition to the concerns raised by respondents from other parts of the construction industry and fire safety community, some issues were raised from within the timber construction industry, notably the issue of how to build compliant spandrel panels. In this case, the term ‘spandrel panel’ means something particular in relation to timber frame construction, notably the continuation of compartment walls within a roof space. This was an issue covered in a previous government-funded research project. The output from this research project[6] will be reviewed as part of Objective B of the current project.

The Project Team is aware of the work conducted by the timber frame industry in collaboration with key stakeholders to provide guidance in relation to issues around fire performance of timber structures during both the construction and as built phase. The Project Team will continue to liaise with representatives from the timber frame industry through the Project Steering Group to ensure all relevant information is included in the review.

3.2.5 Mass timber construction

Most references to this subject in the responses to the Call for Evidence refer directly to Cross Laminated Timber (CLT) although the issues are also of relevance to other forms of mass timber. Again, this form of construction is often lumped into the general term MMC, which is undoubtedly a source of confusion.

As with the issues around light timber frame construction discussed above, the timber industry is well aware of the issues around the fire performance of mass timber and have been at the forefront of discussions into approaches to enable the safe use of the technology through the publication of guidance and consultation with a range of key stakeholders most notably through the Structural Timber Working Group initially set up to deal with issues around construction site fires. The outputs arising from this area including the draft industry guidance[7] and guidance prepared for Building Control professionals[8] will be reviewed as part of Objective B of the current project.

3.2.6 Cavity barriers

A number of respondents made specific reference to both cavity barriers and fire stopping in relation to the guidance. Specific mention was made of open state cavity barriers. Work has been undertaken in this area in relation to timber frame as detailed in the NHBC publication NF 51 *Fires in cavities in residential buildings - the performance of cavity barriers in external walls with combustible materials*[9]. This document and other sources of information and research will be reviewed as part of Objective B of the current project. The review of test standards related to fire resistance and compartmentation will also consider the applicability of a standard fire exposure to the performance requirements for cavity barriers to ensure the assessment of performance is related to the anticipated exposure and to the requirements in relation to life safety. The Association for Specialist Fire Protection (ASFP) has produced a test standard specifically for open state cavity barriers[10]. It is understood that the intention is to develop the methodology as a harmonised European test standard. The approach will be investigated as part of the review of fire test standards and a review of specific issues related to cavity barriers and the reference to same in the guidance.

3.2.7 Car parks

Respondents raised the issue of both fire resistance and compartmentation in relation to the existing guidance on car parks. Reference was made to a project “Fire spread in car parks” undertaken for DCLG, BD 2552[11] which pointed to the effectiveness of sprinklers in limiting fire spread in car parks.

The issue of the structural fire resistance requirements/recommendations for open-sided car parks was raised. The guidance recommends a fire resistance of 15 minutes for open-sided car parks for buildings up to 30m in height. There is some acknowledgement that this level of performance may be appropriate for small car park structures but not for multi-storey structures. The respondent also points to a conflict between the guidance in AD B and that in the most recent version of BS 9999[12] which restricts the use of the 15-minute fire resistance period to open-sided car parks up to 18m high.

There has been a great deal of debate over the current recommendations following the Echo Arena car park fire in Liverpool[13]. The Project Team is familiar with the issues raised. The author of this report attended a meeting with representatives of a Working Group of the British Parking Association (BPA) to discuss issues of common concern and the potential for collaboration/information exchange. The BPA provided input to the Call for Evidence and have made their submissions available to the Project Team. The BPA commissioned OFR Consultants to provide a review[14] of various UK and international codes in relation to the fire safety design of car parks, and to identify research that has been used to underpin the codes, as well as other relevant research that is directly applicable to car parks. This report will form the initial basis of the review to be undertaken in support of Objective B of the current project.

3.2.8 Other issues

The response to the Call for Evidence was very wide ranging. Based on an initial review and informed by discussions with MHCLG and the input provided during the initial Steering Group meeting, the topics above are proposed as the primary focus of the current project. Other issues such as guidance specific to particular sectors including fire rated ducts and dampers and fire door specifications may be better dealt with through industry groups. As previously mentioned, other important areas including issues related to external walls and the role of property protection within the guidance will be dealt with in other MHCLG research projects.

Other specific areas covered in the Call for Evidence include:

- Fire resistance requirements for mezzanine floors
- Compartment and non-compartment floors
- Conflict and inconsistencies between different guidance documents (e.g. AD B and BS 9999)

One of the most important aspects to come from a review of the submissions to the Call for Evidence is the various interpretations of the objective of the guidance. There is a clear need to set out the scope and intent of AD B to state what it covers and what it does not cover. Clarity in this area will help to steer the future course of this project and will be of great help to the UK construction industry.

3.3 Documents cited as supporting evidence

There were a number of documents cited as supporting evidence in the MHCLG Consultation responses, see section 11.

4 Background to recommended periods of fire resistance

The background to the specification of fire resistance periods and the development of standard fire testing has been the focus of academic interest in recent years[15]. For information on the derivation of the standard fire test and the associated performance characteristics, recourse should be made to the paper by Law and Bisby. They conclude that the pioneers of the concept of fire resistance did not attempt to "*set performance requirements but only devised the framework within which performance might be assessed, and against which requirements could subsequently be set*".

For current purposes, it is sufficient to note that the standard fire curve used worldwide as the means of assessing performance in relation to fire resistance and compartmentation has remained largely unchanged since its inception and incorporation into ASTM 119[16] in 1917. The first edition of BS 476[17] was published in 1932 and set out the three principal performance criteria associated with the maintenance of loadbearing capacity and satisfying the requirements related to fire spread associated with insulation and integrity performance.

The process of assessment, of measuring performance, while very important, is not the main purpose of this scoping study. The specification of requirements and how they relate to specific types of occupancy, specific sizes and heights of buildings and specific forms of construction or types of material is the primary focus. As far as the situation in the UK is concerned, there is a general consensus that the basic principles underlying the current system are based on the recommendations of the Joint Committee of the Building Research Board of the Department of Scientific and Industrial Research and of the Fire Offices' Committee as set out in the Post-War Building Studies Report No. 20 on the Fire Grading of Buildings[18] published in1946. In relation to the rationale behind the specification of fire resistance periods for different occupancies and buildings of different sizes, the most important document is Part 1 of the Fire Grading of Buildings dealing with General Principles and Structural Precautions[18]. This document set out a proposed grading of occupancies on the basis of damage and exposure hazard in relation to "fire load". Another important document forming part of the Post-War Building Studies went on to consider grading of occupancies in relation to grading on the basis of personal hazard. This is the Post-War Building Studies Report No. 29[19] published in 1952. In particular, that part focussed on personal safety.

Prior to the publication of the Post-War Building Studies Report No. 20, a similar process of providing recommended Fire Resistance classifications had been undertaken in the United States[20] and recommended a similar approach to that put forward in the Fire Grading of Buildings report.

One of the underlying principles of both the Post-War Building Studies and the US Building Materials and Structures reports is that where there is a requirement for a compartment to resist a complete burn out of all combustible material without failure, then such a compartment should be built using "*fully protected construction*". This term, which was effectively the equivalent to the "*Fireproof*" classification, provided in the US Building Materials and Structures report is related to the performance requirements associated with the standard fire test procedure i.e. resistance to collapse (load bearing function), limiting the temperature rise on the unexposed surfaces of the fire compartment (insulation function) and preventing the passage of flames or hot gases from passing through the compartment construction (integrity function).

Identifying those scenarios that require the construction to survive a complete burn out of all combustible material will be an important aspect of this work in the following stages. Those structures where some form of fire resistance was required but did not necessarily need to survive complete burn out of all combustibles were classified as "*partially protected*". The reports noted that even though some forms of combustible construction were capable of providing a high level of fire resistance they were not appropriate for the construction of buildings designed to withstand complete burn out without failure. This distinction between different forms of construction or different construction materials represents a different approach to the functional requirements of the current regulations and the performance-based approach to compliance designed to encourage innovation and provide a more rational basis for the design of structures in fire.

When considering structural fire resistance and compartmentation, it is important to appreciate both the different requirements concerning damage and personal safety and the interaction between the two sets of requirements. The requirements related to survival of burn out of all combustible materials within a fire compartment are predicated on information concerning the fire load density. For those occupancies (such as residential buildings and offices) considered to represent a low fire load, then, according to the Fire Grading of Buildings reports, a fire resistance of one hour would be sufficient to survive complete burn out of all combustible materials on the basis of a grading determined according to the damage hazard. This approach is principally concerned with structural behaviour.

A grading predicated on personal hazard would need to consider issues related to both egress and tenability. This covers not only the need to maintain overall stability but also to ensure that sufficient time is available to either ensure that building occupants can remain within a place of relative safety while firefighting activities are undertaken (or until the fire has burnt out) or occupants can be safely evacuated. In such cases, the prescribed or recommended periods of fire resistance must take into account not only issues related to the performance of construction materials and elements of structure but also the characteristics of the occupants and the time taken to either extinguish a fire or to facilitate a safe evacuation. It is here that issues other than structural fire resistance and compartmentation come into play, such as the need to minimize the spread of flame on wall and ceiling linings, preventing or restricting the movement of smoke and hot gases (including toxic products of combustion) through the building.

4.1 Compartment sizes, resistance to fire and fire safety project BD 2887

The Building Regulations and Standards Division of what was then the 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 the 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 Part B of the Building Regulations. As part of Workstream 1 Periods of fire resistance, a review was undertaken of the background to the existing AD B requirements[21]. The results are relevant to the current project and are summarised below.

A review was undertaken of the principal document underpinning the current regulatory guidance with respect to fire resistance to understand the methodology and background to the current guidance. The review concluded that the current guidance in AD B is based largely on the findings from the *Post War Building Studies No. 20 Fire Grading of Buildings Part 1 General Principles and Structural Precautions*[18] published in 1946 initially via the technical requirements in the Model Byelaws issued by the Ministry of Housing in 1952 and ultimately on the enactment of the Building Regulations firstly in Scotland followed shortly after by similar provisions for the rest of the UK. The current provisions are largely based on this pioneering document with fire load density (i.e. fire load divided by floor area) forming the principal hazard categories set alongside the type of construction requiring elements of structure to achieve a specified period of fire resistance. Three hazard categories are identified corresponding to ‘low’, ‘moderate’ and ‘high’ fire loads. The values corresponding to these categories are significantly higher than the corresponding figures used for the performance-based design of buildings, suggesting that performance-based approaches are based on more recent information such as the fire load densities tabulated in the CIB W14 design guide for structural fire safety[22].

In the Post-War Building Studies No. 20 report, three categories of occupancy are identified principally on the basis of the fire load expected in each case as illustrated in Table 1.

Table 1 − Occupancy characteristics from Post-War Building Studies No. 20

Category	Fire load density (BTU/ft²)	Fire load density (MJ/m²)	Example occupancies
Low fire load	≤ 100000	≤ 1134	Flats, offices, hotels etc.
Moderate fire load	100000 ≤ 200000	1134 ≤ 2269	Shops, factories etc.
High fire load	200000 ≤ 400000	2269 ≤ 4538	Warehouses and storage
Note. For conversion from BTU/ft² to MJ/m² x 0.001054/0.092903			

The concept of 'normal' and 'abnormal' fire loads is used to quantify the additional risk related to ignitability, burning rate and products of combustion of certain materials as well as the impact that certain activities may have on the risk of fire initiation. This concept recognises that situations involving identical fire loads may create additional risks in relation to fire initiation and propagation.

Those familiar with the values of characteristic fire load densities used for modern performance-based fire engineering design solutions would be surprised to see that fire load densities up to 1134MJ/m² are classified as low fire load. Typical design values for offices and residential buildings would be of the order of 570 and 780MJ/m², respectively.

The relationship between fire load density and fire resistance period for cellulosic fires was identified based on USA data as shown in Table 2.

Table 2 − Relationship between fire load density and fire resistance period

Weight (lb/ft²)	Weight (kg/m²)	Fire load (BTU/ft²)	Fire load (MJ/m²)	Equivalent fire severity (hours)
10	48.8	80000	907.6	1
15	73.2	120000	1361.4	1.5
20	97.6	160000	1815.2	2
30	146.4	240000	2722.8	3
40	195.2	320000	3630.4	4.5
50	244	380000	4538	6
60	292.8	43200	5445.6	7
Note. For conversion from lb/ft² to kg/m² x 0.453592/0.092903.				

The relationship in Table 2 was used to develop the categories used in the Fire Grading of Buildings Report, as shown in Table 3.

Table 3 − Categorisation in Fire Grading of Buildings Report

Fire load (BTU/ft²)	Fire load (MJ/m²)	Category	Equivalent fire severity (hours)
< 100000	< 1134	Low fire load	1
100000 – 200000	1134 – 2269	Moderate fire load	2
200000 - 400000	2269 – 4538	High fire load	4

The concept of 'fully protected' construction was developed to cover those buildings designed to withstand a complete burn out, i.e. the protection provided equals the severity anticipated.

Special requirements are included in relation to separating and division walls. It is recommended that separating walls i.e. walls which separate different buildings should provide at least four hours fire resistance regardless of the fire load. Division walls separating different fire risks within the same building should be related to the fire load category although it is recommended that at least two hours fire resistance is provided even where a low fire load is present. External walls of one-hour fire resistance are restricted to buildings of up to 15m (50ft). Above this height, external walls should be of at least two hours fire resistance and four hours in the case of high fire loads.

Other categories were defined with a fire resistance less than that required to survive complete burn out as shown in Table 4. Seven categories of construction are identified, ranging from fully protected structures designed to survive a complete burn out of all combustible material through to combustible materials without any specific fire resistance requirement.

Table 4 − Categories of construction from Post-War Building Studies Report

Type of construction	Fire resistance required (hours)	Description	Examples
1	≥ 4	Fully protected	Large warehouses, large shops, factories, office blocks, blocks of flats
2	≥ 2	Fully protected	
3	≥ 1	Fully protected	
4	≥ 0.5	Partially protected	Small shops or factories, apartment houses
5	≥ 2 (external walls only)	Externally protected	
6	0 but incombustible materials	Unprotected incombustible	Single-storey factories, garages
7	0	Combustible	Timber houses, factories etc.

Strict restrictions on the use of combustible material apply for Types 1 to 3. With the exception of fire-rated timber doors, it is recommended that all structural parts of fully protected buildings requiring fire resistance should be of incombustible material. This has important implications when considering limitations in relation to allowable heights of buildings. The criteria in relation to fire resistance for each type of construction is summarised in Table 5.

Table 5 − Relationship between fire resistance performance and form of construction

Type of building		
Fully protected	Design for burn out based on fire load density	Type 1, 2 and 3
Partially protected construction	Not capable of surviving a complete burn out	Type 4
Externally protected	Internal construction has no specified fire resistance but external walls have ≥ 2 hours	Type 5
Unprotected incombustible construction	No specified fire resistance (other than separating walls) but incombustible material e.g. portal frames	Type 6
Combustible construction	No fire resistance	Type 7

© BRE Global Ltd 2025

A summary of the grading recommendations giving the fire resistance requirements of the various elements of structure for each type of construction is summarised in Table 6.

Table 6 − Summary of grading recommendations

Grading	**Minimum fire resistance for elements of structure (hours)**				
	Walls and columns or beams supporting walls				Floors and roofs and columns and beams supporting floors and roofs
	External	Separating	Division	Other fire resisting or loadbearing	
Type 1	4	4	4	4	4
Type 2	2	4	2/4+	2	2
Type 3	2/1*	4	2/4+	1	1
Type 4	2/1*	4	2/4+	1	0.5
Type 5	2	4	2/4+	1	-
Type 6	-	4	2/4+	-	-
Type 7	-	4	2/4+	-	-
* 1 hour for low fire load occupancies in framed buildings below 50ft (15m) + if occupancy is of high fire load					

Restrictions on maximum height/floor area/cubic capacity apply depending on the type of occupancy as defined by the nature of the anticipated fire load and the accessibility of the building or compartment. The restrictions on maximum compartment size in relation to height, floor area or cubic capacity were defined based on a study of existing requirements.

The principle of establishing an appropriate fire resistance period for a particular occupancy and height of building is the same in the current guidance as the approach used in the 1946 document. The fire severity is assumed to be a function principally of the type and magnitude of the fire load. The size of the building in terms of height, floor area and cubic capacity is related to the consequences of failure and the accessibility for means of escape and fire-fighter access.

The basic methodology underpinning the fire grading of buildings is summarised in Figure 1. There is an acknowledged acceptance that there may be cases where buildings will need to exceed the proposed limits on floor area, cubic capacity and height. It is therefore clear that the recommendations were never intended to cover all forms of construction just as the guidance in AD B does not cover all types of building.

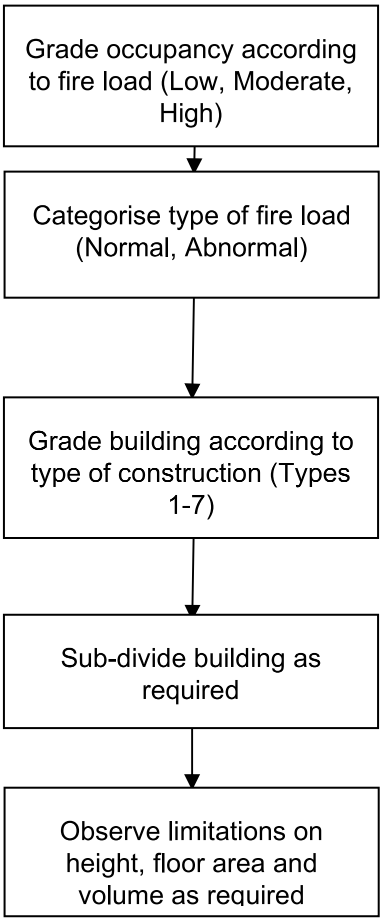


Figure 1 − Methodology underpinning Fire Grading of Buildings

To illustrate the similarities between the approach adopted in the Post-War Building Studies Report and the current guidance, a fire resistance period will be derived using both the recommendations of the Post-War Building Studies and the current guidance in relation to the following cases:

- Case A, an eight-storey office building 32m high
- Case B, a five-storey block of flats 15m high

Case A, an office building with a 'normal' fire load type and distribution, would be classed as low fire load. Assuming the building will need to be fully protected (i.e. protected to withstand a burn out) then the structure (excluding external walls) could be designed using incombustible material to provide a fire resistance of one hour (Type 3). However, the external walls and any internal compartment walls would require two hours fire resistance.

Using Approved Document B guidance, the required period of fire resistance for such a building would be two hours but the building would require an automatic sprinkler system. Elements not forming part of the structural frame would only require 90 minutes fire resistance. The results are summarised in Table 7.

Table 7 − Comparison between Fire Grading of Buildings approach and AD B guidance for Case A

Design approach	Minimum fire resistance of elements of structure for 32m office building (hours)				
	Walls and columns or beams supporting walls				Floors and roofs and columns and beams supporting floors and roofs
	External	Separating	Division	Other fire resisting or loadbearing	
Fire Grading of buildings Type 3	2	4	2	1	1
AD B	2	2	1.5	2	0

Case B, a 15m block of flats with a 'normal' fire load type and distribution, would be classed as low fire load. Assuming that the building will need to be fully protected i.e. protected to withstand a burn out, then the structure (excluding external walls) could be designed using incombustible material to provide a fire resistance of one hour (Type 3). However, the external walls and any internal compartment walls would require two hours fire resistance.

There is also a possibility to construct the building from Type 4 or Type 5 construction. Where Type 4 construction is used, then fire resisting construction is required but it does not need to be incombustible. Where Type 5 construction is used, the external walls need to be incombustible, but the internal construction may be combustible.

Using AD B guidance, the required period of fire resistance for such a building would be one hour. The results are summarised in Table 8.

Table 8 − Comparison between Fire Grading of Buildings approach and AD B Guidance for Case B

Design approach	Minimum fire resistance of elements of structure for 15m residential building (hours)				
	Walls and columns or beams supporting walls				Floors and roofs and columns and beams supporting floors and roofs
	External	Separating	Division	Other fire resisting or loadbearing	
Fire grading of buildings Type 3	2	4	2	1	1
Fire grading of buildings Type 4	1	4	2	1	0.5
Fire Grading of buildings Type 5	2	4	2	1	-
AD B	1	1	1	1	-

© BRE Global Ltd 2025

The review has established that the guidance in the Approved Document in relation to periods of fire resistance is strongly influenced by the recommendations of the Post-War Building Studies research. The current values are a combination of statistical data (fire loads), experimental data (calorific values), engineering calculations supported by empirical observations (time equivalence) and engineering judgement influenced by experience of real fires, commercial considerations and political decisions[22].

One area which is completely absent in the work of the Post-War Building Studies research, is the impact of ventilation on fire growth and development. Fire severity is assumed to be purely a function of the fire load and the floor area of the compartment. This is clearly a major simplification of real fire behaviour.

Malhotra[23] called for a new approach to fire safety in buildings which drew on the research undertaken since the publication of the Post-War Building Studies notes. His report, published in 1987, represented an examination and consolidation of the practical information developed since the publication of the Fire Grading reports with the aim of proposing changes to the technical content of the guidance that would not have an adverse impact on the existing levels of fire safety. The proposals represented an initial move away from a prescriptive approach towards a more rational methodology based on the principles of fire safety engineering.

In considering the historical perspective, Malhotra alludes to the fact that legislative changes are often understandably enacted in response to specific incidents. He mentions that occasionally demands for action intended to prevent a re-occurrence of a given incident have led to hasty reactions when provisions have been introduced which, in the long term, prove too onerous and prejudicial to good design.

Malhotra provides an interesting historical perspective on the development of legislative provisions for the protection of life and property against fire in the UK. This subject is also covered in Aspects of fire precautions in buildings by Read and Morris[24]. These documents cover similar ground to that covered in the recent paper by Law and Bisby[15]. Although of general interest, the current study is focussed principally on the background to the current recommendations set out in Approved Document B. The first set of national building standards was introduced in 1965. Prior to this, regulatory requirements were primarily the responsibility of local government with the result that requirements varied from one location to another. The publication of the Approved Documents providing practical guidance to meeting the requirements covering various aspects of the Building Regulations has been instrumental in specifying minimum levels of performance whilst encouraging innovation in construction. For Approved Document B the specification of performance in relation to structural fire resistance and fire separating elements through reference to survival under standard fire test conditions has proved remarkably resilient and, it could well be argued, remarkably successful.

In this review, it is important to try and focus on the motivation behind the statutory requirements and particularly on the specification of performance as set out in Approved Document B. It is also important to understand the conflicting requirements of the various sectors impacted by regulatory control. There has always been some resistance to change associated with increased regulation or, conversely, the introduction of the principle of maximum self-regulation and minimum Government interference[25]. In order to understand the development of the regulations, it is important to understand the competing requirements and vested interests of key stakeholders.

This conflict between minimum requirements to achieve an acceptable level of safety and the financial implications of compliance is at the heart of the discussion as to how we arrived at the current values. The current recommendations need to be seen as a result of the work undertaken by research institutes often publicly-funded and conducted by scientific experts with little or no appreciation of the financial consequences of compliance. The simple comparison between the level of performance obtained by following the recommendations of the Fire Grading Report and the values derived using the recommendations based on the version of Approved Document B in place at the time of BD 2887 project illustrate a general reduction in the requirements when compared with those predicated on a requirement to survive burn out of all combustibles. The reasons for this may in part be explained by the publication in

1985 (the same year as the publication of the first version of AD B) of the Government white paper “Lifting the Burden”. Malhotra in summarising the white paper issued jointly in the name of six major ministries concerned with regulations points out that compliance with regulation (in general) was considered to be the main burden on industry. According to Malhotra “*In the field of fire safety the issue of the simplified regulations is considered as the first step followed by a detailed examination of the requirements of the regulations to see how far they can be reduced or dropped altogether*”.

Aside from the conflict between safety and economy there is also the move away from a prescriptive approach to structural design (including fire safety) and towards performance-based solutions. The latter would in general not differentiate requirements according to the nature of the construction material (as in the Fire Grading approach) but simply specify performance requirements. A performance-based approach to design is encouraged by a functionally-based regulatory framework. The two together would explain why there is no longer, except in exceptional circumstances, any major prohibitions on the use of combustible materials for use as structural elements or fire separating elements, other than the recently introduced requirements related to the construction of external walls for specific types of building.

For many years, the emphasis has been on removing barriers to innovation and encouraging alternative approaches to achieve the requirements of the regulations. In the scientific and research community, there has long been a consensus that a performance-based approach to design is preferable to a blind reliance on prescription. While there are many arguments to support a performance-based methodology (enabled through a functional approach to regulatory requirements) there are not too many who have questioned whether such an approach has, in all cases, resulted in improved design solutions which have achieved the requirements of the Building Regulations.

Although strictly outside the scope of the current project, there is little doubt that solutions designed to achieve an improved performance with regard to one aspect of the Building Regulations have had an adverse impact on levels of safety in another area. An example is the increased use of combustible products exhibiting a high level of insulation designed to enhance the thermal performance of buildings having a potentially adverse impact on fire safety.

According to Malhotra “*the aim is that the regulations should be reduced to the minimum required to secure their essential function, which is the preservation of public health and safety*”. If this is true, then the starting point would be to know what level of safety this minimum represents. There are statistical approaches to reliability that may be able to provide answers to this question. Such a methodology is adopted in design codes through the use of a target reliability and is the basis of the target reliability index set out in the Eurocode dealing with the Basis of Design[26]. However, EN 1990 acknowledges “*The actual frequency of failure is significantly dependent upon human error, which are not considered in partial factor design. Thus β (target reliability index) does not necessarily provide an indication of the actual frequency of structural failure*”.

Malhotra identifies an issue which has already been discussed at the first Steering Group meeting for this project and that is the need to define not only the level of performance required but also the objective to be achieved – “*In order to formulate a rational approach to fire safety and to define precise fire protection requirements it is necessary to have clearly stated objectives or goals of fire protection*”. For our purposes this could be restated as:

“In order to formulate a rational approach to fire safety for buildings and to define the required levels of structural fire performance and compartmentation, it is necessary to have clearly stated objectives for the building fire strategy.”

These objectives will be revisited over the course of this project but need to be addressed not only as a technical question but also a political one. The original objectives of the Fire Grading Report were to safeguard both life and property and the means by which this is achieved depends on the relative importance of each and what level of “failure” is deemed to be acceptable. This is not a straightforward question. The current version of the guidance states that:

"The Building Regulations are intended to ensure a reasonable standard of life safety in fire."

Furthermore:

"The fire safety aspects of the Building Regulations aim to achieve reasonable standards of health and safety for people in an around buildings."

Malhotra considered the objectives of "fire protection" in buildings to be life safety, prevention of conflagrations and property protection. In terms of the current objectives of the guidance, the first of these are clearly the primary function and the latter two are important only to the extent that they help to achieve the primary objective.

In terms of maintaining reasonable standards of health and safety for people in and around buildings, the primary purpose of structural fire resistance is to maintain the stability of elements of construction to avoid collapse for a period commensurate with the primary objective of the Building Regulations, to prevent extensive fire spread and to maintain the structural integrity of compartmentation and means of escape for a period related to the primary objective of the guidance and the Regulations.

It is acknowledged that the primary risk to life in the event of a fire is due to exposure to toxic gases, smoke inhalation and exposure to heat. Loss of life due to structural instability or collapse is a rare occurrence[23].

What is also of great importance, but rarely acknowledged, is that the resulting guidance needs to be simple and transparent. Many of the criticisms of a fire safety system based on reliance on standard fire testing are promulgated by experts who specialise in fire dynamics, fire safety engineering or structural fire engineering. Those charged with the design, specification, installation, assessment and approval of structural elements or fire separating elements do not, in general, have the time or expertise to assess performance-based on fundamental principles but need to ensure that construction is undertaken in a manner that does not constitute an unacceptable risk to those in and around buildings.

5 Alternative Guidance

5.1 BS 9999 and BS 9991

The specifications from the Fire Safety British Standards BS 9999[12] and BS 9991[27] are often used in the design of buildings as an alternative or in addition to the recommendations of Approved Document B. Sections of both documents are referenced in AD B, with BS 9999 referenced extensively.

Both standards are widely used as the basis for Fire Strategies for new buildings and therefore, the approach to the specification of structural fire resistance and compartmentation is relevant to the current discussion.

Both documents may be viewed as a half-way house between the “prescriptive” recommendations of AD B and the more detailed Fire Safety Engineering approach set out in the BS 7974 series consisting of the main standard[28] and the series of Published Documents that support the approach[29-34].

In terms of a review of fire resistance and compartmentation, the most important aspect of BS 9999 is the incorporation in Section 7 of BS 9999 dealing with Design of the Building Structure and Section 4 of BS 9991 dealing with Design for construction of an alternative approach to the specification of fire resistance. This alternative is based on the concept of time equivalence and, as such, takes into consideration not only the assumed fire load densities which are the basis of the AD B approach but also the impact of ventilation on fire growth and development. The background, methodology and justification for this is set out in a paper published in the Structural Engineer in 2004[35]. The approach will be reviewed as part of Objective B of the current project.

5.2 Travelling fires approach

The most recent version of Part 1 of the PD 7974[29] suite of published documents supporting the development of an alternative fire engineering approach to the protection of people, property and the environment from fire includes a new section related to Travelling fire frameworks.

The concept was originally proposed through two papers published in the Fire Safety Journal in 2012[36,37] based on the work undertaken by Stern-Gottfried for his PhD study completed in 2011[38]. The methodology is based on observations from real fires and large-scale experiments that fires in large enclosures do not burn in a uniform manner but travel across the floor space. The concept has been modified in a more recent paper which considers the application to concrete and steel structures[39] and has recently formed the basis for a collaborative research project TRAFIR (Characterisation of Travelling Fires in Large Compartments) funded by the European Research Fund for Coal and Steel. These papers and the outputs produced from the research projects will be critically reviewed as part of Objective B of the current project.

5.3 Structural Eurocodes

Appendix A of the 2006 edition of Approved Document B guidance sets out a number of methods by which the performance of materials, products and structures can be assessed and verified. These included a reliance on the results from standard fire tests either directly or through conforming to a specification or design that has been shown to achieve the required level of performance. Alternatively, assessment either from test evidence or relevant design guides was allowed. For fire resisting elements, a direct reference was made to a specification provided in BR 128 (see section 5.2.2 above) or the elements could be designed in accordance with a relevant British Standard or Eurocode.

In the current version of the guidance, the relevant Appendix (Appendix B) makes no direct reference to design to British or European Standards. It is unclear at this stage whether this is a deliberate omission or an oversight.

The structural Eurocodes are a set of harmonised technical rules for the design of construction works. They provide a means to prove compliance of building and civil engineering works with the essential requirements of Council Directives covering both *Mechanical resistance and stability* and *Safety in case of fire*. The fire design aspects are covered in (BS) EN 1991-1-2[40] which is the fire part of the Eurocode for Actions while the fire parts of the material codes (EN 1992-1-2[41], EN 1993-1-2[42], EN 1994-1-2[43], EN 1995-1-2[44], EN 1996-1-2[45] and EN 1999-1-2[46]) cover the fire design of concrete, steel, composite steel and concrete, timber, masonry and aluminium structures, respectively. These documents incorporate a combination of tabulated design data, simple design methods and advanced design methods to determine the response of structures in fire which can be used to determine compliance with the tables of notional fire resistance periods set out in the guidance. Alternatively, in addition to deriving performance-based on nominal fire exposures (such as the standard fire curve), a number of the approaches set out in the fire parts of the Eurocodes can also be used to determine performance under more realistic (physically-based) fire exposures. This approach will be considered as part of Objective B of the current project.

5.3.1 The Natural Fire Safety Concept

The fire part of Eurocode 1 contains an Annex (Annex E) setting out a methodology for the calculation of fire load densities to be used in subsequent structural fire engineering calculation methods. This approach was based on a collaborative European research project undertaken in the 1990s known as the Natural Fire Safety Concept (NFSC)[47]. Funding was provided by the European Coal and Steel Community (ECSC) and the principal objective was to provide a more realistic and more credible approach to analysis of structural safety in case of fire. It was an expressed aim of the project to implement the findings of the research into the Structural Eurocodes. In this regard, the project team led by a steel manufacturer (later merged with two other steel manufacturers in 2002) were very successful. The concept will be reviewed as part of Objective B of the current project.

6 Issues related to Modern Methods of Construction (MMC)

In 2008, a report[48] was published by Communities and Local Government looking at Innovative Construction Products and Techniques (ICPT) with a particular focus on the fire safety and robustness of new and emerging products and systems. The principal objective of the project was to develop and prioritise a programme of further work in relation to ICPT. This list is reproduced in Table 8 and will be reviewed as part of Objective B of the current project.

Table 8 − Prioritised topics for further research work[47]

Topic	Comments	Ranking
The performance in fire of structural insulated panels (SIPS)	Large-scale testing required to ascertain residual strength, possibility of disproportionate collapse and effect of different filler materials and adhesives. Industry support required.	1
Database of real fire incidents	Information required related to form of construction and individual products. Require input from all key stakeholders. Web-based system preferred. Would have to manage the interests of insurers, manufacturers and avoid impinging on legal cases.	2
Cavity barriers/cavity fires/fire stopping	Experimental study required to investigate relative performance of materials/products/systems where seat of fire is within the cavity. Reference to Regulation 7. Some inherent fire performance required.	3
Fires in the construction stage	Guidance is required on measures to minimise the risk of a serious fire occurring during the construction phase. Many of the real fire incidents brought to the attention of the project team during the course of the study have involved fires during the construction phase. The risk of fire initiation is often very high at a time when the building has little or no inherent fire protection. This often leads to substantial economic losses, particularly where ICPT are involved. In terms of life safety, the issue of partial occupation of incomplete residential schemes should also be addressed.	4
Performance of modern concrete materials	Experimental programme to investigate the performance of a range of modern concretes, including cement replacement materials, in relation to long-term durability, strength and fire performance.	5
Performance of engineered timber products.	This could be extended to cover long span beams in general. Structural performance likely to be very different to conventional floor joists.	6
System performance in fire	Series of large-scale fire tests undertaken with industrial support to demonstrate best practice in relation to the design of connections and fire stopping.	7

7 Codes and standards related to fire resistance

The number of standards related to fire resistance tests, classification and extended application has increased dramatically over recent years. The continuing use of national test standards alongside European standards has led to a great deal of confusion as to which is the most appropriate standard for any particular case. Under the British Standards scheme, the approach was relatively straightforward with different standards for loadbearing and non-loadbearing elements of construction. The early European standards were differentiated by the nature of the structural or non-structural element with different standards for walls and ceilings, floors and roofs and beams and columns. In recent years, new standards have been developed based on the type of passive fire protection product rather than the structural element.

The British Standards and European Standards directly related to fire resistance and compartmentation issues are listed in Tables 9 to 12. The British standards are current but have been at “standstill” since the development of the European standards began. Therefore, the reference is to the most recent version. Given the pace of development of the European standards, only the reference is provided. The reader should consult the British Standards Institution website for the most up to date version. These standards will be reviewed as part of Objective B.

Table 9 − British Standards fire resistance test standards

Standard reference	Title/scope
BS 476-20: 1987	Fire tests on building materials and structures. Method for the determination of the fire resistance of elements of construction (general principles)
BS 476-21: 1987	Fire tests on building materials and structures. Methods for the determination of the fire resistance of loadbearing elements of construction
BS 476-22: 1987	Fire tests on building materials and structures. Methods for the determination of the fire resistance of non-loadbearing elements of construction
BS 476-23: 1987	Fire tests on building materials and structures. Method for the determination of the contribution of components to the fire resistance of a structure.
BS 476-24: 1987, ISO 6944: 1985	Fire test on building materials and structures. Method for the determination of the fire resistance of ventilation ducts.

© BRE Global Ltd 2025

Table 10 − Current European fire resistance test standards

Standard reference	Title/scope
EN 1363-1	Fire resistance tests – Part 1: General requirements
EN 1363-2	Fire resistance tests – Part 2: Alternative and additional procedures
EN 1364-1	Fire resistance tests for non-loadbearing elements – Part 1: Walls
EN 1364-2	Fire resistance tests for non-loadbearing elements – Part 2: Ceilings
EN 1364-3	Fire resistance tests for non-loadbearing elements – Part 3: Curtain walling – Full configuration
EN 1364-4	Fire resistance tests for non-loadbearing elements – Part 4: Curtain walling – Part configuration
EN 1364-5	Fire resistance tests for non-loadbearing elements – Part 5: Air transfer grilles
EN 1365-1	Fire resistance tests for loadbearing elements – Part 1: Walls
EN 1365-2	Fire resistance tests for loadbearing elements – Part 2: Floors and roofs
EN 1365-3	Fire resistance tests for loadbearing elements – Part 3: Beams
EN 1365-4	Fire resistance tests for loadbearing elements – Part 4: Columns
EN 1365-5	Fire resistance tests for loadbearing elements – Part 5: Balconies and walkways
EN 1365-6	Fire resistance tests for loadbearing elements – Part 6: Stairs
EN 1366-1	Fire resistance tests for service installations – Part 1: Ventilation ducts
EN 1366-2	Fire resistance tests for service installations – Part 2: Fire dampers
EN 1366-3	Fire resistance tests for service installations – Part 3: Penetration seals
EN 1366-4	Fire resistance tests for service installations – Part 4: Linear joint seals
EN 1366-5	Fire resistance tests for service installations – Part 5: Service ducts and shafts

Standard reference	Title/scope
EN 1366-6	Fire resistance tests for service installations – Part 6: Raised access and hollow core floors
EN 1366-7	Fire resistance tests for service installations – Part 7: Conveyor systems and their closures
EN 1366-8	Fire resistance tests for service installations – Part 8: Smoke extraction ducts
EN 1366-9	Fire resistance tests for service installations – Part 9: Single compartment smoke extraction ducts
EN 1366-10	Fire resistance tests for service installations – Part 10: Smoke control dampers
EN 1366-11	Fire resistance tests for service installations – Part 11: Fire protective systems for cable systems and associated components
EN 1366-12	Fire resistance tests for service installations – Part 12: Non-mechanical fire barrier for ventilation ductwork
EN 1366-13	Fire resistance tests for service installations – Part 13: Chimneys
EN 1634-1	Fire resistance and smoke control tests for door and shutter assemblies, openable windows and elements of building hardware – Part 1: Fire resistance test for door and shutter assemblies and openable windows
EN 1364-2	Fire resistance and smoke control tests for door and shutter assemblies, openable windows and elements of building hardware – Part 2: Fire resistance characterisation test for elements of building hardware
EN 1364-3	Fire resistance and smoke control tests for door and shutter assemblies, openable windows and elements of building hardware – Part 3: Smoke control test for door and shutter assemblies
EN 13381-1	Test methods for determining the contribution to the fire resistance of structural members – Part 1: Horizontal protective membranes
EN 13381-2	Test methods for determining the contribution to the fire resistance of structural members – Part 2: Vertical protective membranes
EN 13381-3	Test methods for determining the contribution to the fire resistance of structural members – Part 3: Applied protection to concrete members
EN 13381-4	Test methods for determining the contribution to the fire resistance of structural members – Part 4: Applied passive protection to steel members

© BRE Global Ltd 2025

Standard reference	Title/scope
EN 13381-5	Test methods for determining the contribution to the fire resistance of structural members – Part 5: Applied protection to concrete/profiled sheet steel composite member
EN 13381-6	Test methods for determining the contribution to the fire resistance of structural members – Part 6: Applied protection to concrete filled hollow steel columns
EN 13381-7	Test methods for determining the contribution to the fire resistance of structural members – Part 7: Applied protection to timber members
EN 13381-8	Test methods for determining the contribution to the fire resistance of structural members – Part 8: Applied reactive protection to steel members
EN 13381-9	Test methods for determining the contribution to the fire resistance of structural members – Part 9: Applied fire protection systems to steel beams with web openings
EN 13381-10	Test methods for determining the contribution to the fire resistance of structural members – Part 10: Applied protection to solid steel bars in tension

Table 11 − Current European classification standards related to fire resistance

Standard reference	Title/scope
EN 13501-2	Fire classification of construction products and building elements – Part 2: Classification using data from fire resistance tests, excluding ventilation services
EN 13501-3	Fire classification of construction products and building elements – Part 3: Classification using data from fire resistance tests on products and elements used in building service installations: fire resisting ducts and dampers
EN 13501-4	Fire classification of construction products and building elements – Part 4: Classification using data from fire resistance tests on components of smoke control systems

Table 12 − Current European Extended Application (EXAP) standards related to fire resistance

Standard reference	Title/scope
EN 15080-8	Extended application of results from fire resistance tests – Part 8: Beams
EN 15080-12	Extended application of results from fire resistance tests – Part 12: Loadbearing masonry walls
EN 15254-2	Extended application of results from fire resistance tests – Non-loadbearing walls – Part 2: Masonry and Gypsum blocks
EN 15254-3	Extended application of results from fire resistance tests – Non-loadbearing walls – Part 3: Lightweight partitions
EN 15254-4	Extended application of results from fire resistance tests – Non-loadbearing walls – Part 4: Glazed constructions
EN 15254-5	Extended application of results from fire resistance test – Non-loadbearing walls – Part 5: Metal sandwich panel construction
EN 15254-6	Extended application of results from fire resistance tests – Non-loadbearing walls – Part 6: Curtain walling
EN 15254-7	Extended application of results from fire resistance tests – Non-loadbearing ceilings – Part 7: Metal sandwich panel construction
EN 15269-1	Extended application of test results for fire resistance and/or smoke control for door, shutter and openable window assemblies, including their elements of building hardware – Part 1: General requirements
EN 15269-2	Extended application of test results for fire resistance and/or smoke control for door, shutter and openable window assemblies, including their elements of building hardware – Part 2: Fire resistance of hinged and pivoted steel doorsets
EN 15269-3	Extended application of test results for fire resistance and/or smoke control for door, shutter and openable window assemblies, including their elements of building hardware – Part 3: Fire resistance of hinged and pivoted timber doorsets and openable timber framed windows
EN 15269-5	Extended application of test results for fire resistance and/or smoke control for door, shutter and openable window assemblies, including their elements of building hardware – Part 5: Fire resistance of hinged and pivoted metal framed glazed doorsets and openable windows

© BRE Global Ltd 2025

Standard reference	Title/scope
EN 15269-7	Extended application of test results for fire resistance and/or smoke control for door, shutter and openable window assemblies, including their elements of building hardware – Part 7: Fire resistance for steel sliding doorsets
EN 15269-10	Extended application of test results for fire resistance and/or smoke control for door, shutter and openable window assemblies, including their elements of building hardware – Part 10: Fire resistance of steel rolling shutter assemblies
EN 15269-11	Extended application of test results for fire resistance and/or smoke control for door, shutter and openable window assemblies, including their elements of building hardware – Part 11: Fire resistance for operable fabric curtains
EN 15269-20	Extended application of test results for fire resistance and/or smoke control for door, shutter and openable window assemblies, including their elements of building hardware – Part 20: Smoke control for doors, shutters, operable fabric curtains and openable windows
EN 15882-1	Extended application of results from fire resistance tests for service installations – Part 1 Ducts
EN 15882-2	Extended application of results from fire resistance tests for service installations – Part 2: Fire dampers
EN 15882-3	Extended application of results from fire resistance tests for service installations – Part 3: Penetration seals
EN 15882-4	Extended application of results from fire resistance tests for service installations – Part 4: Linear joint seals

A number of these standards are under revision within European Standards Technical committee CEN/TC 127 (Fire Safety in Buildings) and there are a number of new work items related to fire resistance. These documents will be reviewed as part of Objective B.

8 Fire statistics for England

The Home Office collates and publishes detailed information on incidents attended by the Fire and Rescue Services. The most recent information covers the year ending June 2020[49,50]. The primary focus of the statistics as far as this project is concerned is Primary fires with a particular focus on dwelling fires and fires in purpose-built flats and potential differences between high rise (10+ storeys), medium rise (four to nine storeys) and low rise (one to three storeys).

In terms of the focus of this project and the stated aim of the Building Regulations (and associated guidance), to ensure a reasonable standard of life safety in a fire, the most obvious metric is to consider the number of fatalities and non-fatal casualties. It is reasonable to assume that any major issues with the functionality of the guidance in relation to modern forms of construction would be reflected in an increase in either the number of primary fires in buildings and/or the numbers of deaths and injuries resulting from fire incidents.

The statistics will be reviewed as part of Objective B. Although there has been a general decrease in the number of primary fires over the last decade, the number of dwelling fires has remained fairly constant. There were more than 28,000 primary dwelling fires in the year ending 2020 of which approximately three-quarters were in houses, bungalows, converted flats and other properties and just over a quarter were in purpose-built flats.

Approximately 65% of all fires in purpose-built flats were in the low-rise (one to three storeys) category (17% of the total number of dwelling fires), approximately 27% of all fires in purpose-built flats were in the medium-rise (four to nine storeys) category with the remainder assigned to the high-rise (10+ storeys) category. In terms of the number of primary fires over the last decade or the number of dwelling fires there is no evidence to show any increase in incidents attended.

In terms of the primary objective of the Building Regulations, the more significant data is that related to fire-related fatalities and casualties. The most recently available information shows a decrease in the number of fire-related fatalities on the previous year and the lowest figure since quarterly data became available in 2001/2002. There was a corresponding decrease in the number of fire-related fatalities in dwelling fires and a decrease in the number of non-fatal casualties.

The number of fire-related fatalities (and non-fatal casualties) has been on a general downward trend from 1981/1982, when comparable figures first became available. There was an exceptionally high figure for fire-related fatalities for the year ending June 2017, due to the Grenfell Tower fire.

© BRE Global Ltd 2025

9 Next steps

Based on an initial review of the response to the Call for Evidence informed by discussions with MHCLG and the input provided during the initial Steering Group meeting, the following topics are proposed as the primary focus of the current project:

- Modern Methods of Construction
- Generic "Deemed to Satisfy" Solutions
- Timber Frame Construction
- Mass Timber Construction
- Cavity Barriers
- Car Parks

10 References

1. BRE Global (various authors), BD 2887 Compartment sizes, resistance to fire and fire safety project. Seven workstreams, Final workstream reports for Department for Communities and Local Government, published 2019. Available from: https://www.gov.uk/government/publications/compartment-size-resistance-to-fire-and-fire-safety-research. Last accessed 23rd September 2020.
2. Morris W A, Read R E H and Cooke G M E, Guidelines for the construction of fire-resisting structural elements, Building Research Establishment Report BR 128, Crown Copyright, 1988.
3. Structural Timber Association, Structural timber buildings fire safety in use guidance Volume 1 Pattern book systems, STA fire safety research and guidance project Revision V1.1, March 2020.
4. Lawson R M and Way A G J, Fire resistance of light steel framing, SCI Publication P 424, 2020.
5. Lennon T and Fraser-Mitchell J, BD 2887 Compartment sizes, resistance to fire and fire safety project, Final Work Stream Report for Work Stream 2 – Maximum fire compartment sizes, BRE Output ref. 286856 (D24V1), March 2015.
6. Lennon T, Holland C and Shipp M, BD 2887 Compartment sizes, resistance to fire and fire safety project, Final Work Stream Report for Work Stream 3 – Construction details – roof voids, cavity barriers and fire/smoke dampers, BRE Output ref. 286857 (D25V2), March 2015.
7. Structural Timber Association, Structural timber buildings fire safety in use guidance Volume 6 – Mass timber structures Building Regulation compliance B3(1) STA fire safety research and guidance project version v1.1, October 2020.
8. Building Control Alliance, BCA Technical Guidance Note 29 (Draft), London, BCA GN 29, 2019.
9. Lennon T, Fires in cavities in residential buildings, The performance of cavity barriers in external walls with combustible materials, NHBC Foundation Publication NF 51, 2013.
10. Association for Specialist Fire Protection, Technical Guidance Document TGD 019 Fire resistance test for ‘open state’ cavity barriers used in the external envelope or fabric of buildings, ASFP, 2017.
11. Department for Communities and Local Government, BD 2552 Fire spread in car parks, 2010. Available from: https://webarchive.nationalarchives.gov.uk/20120919204054/http://www.communities.gov.uk/documents/planningandbuilding/pdf/1795610.pdf. Last accessed 23rd September 2020.
12. British Standards Institution, BS 9999:2017 Fire safety in the design, management and use of buildings – Code of practice, BSI, London, 2017.
13. Structural Safety Alert, Standing Committee on Structural Safety (SCOSS) Alert Fires in Multi-Storey Car Parks, February 2018.
14. OFR Fire and Risk Consultants, Review of fire precautions for car parks in building codes, Revision R02, 28th February 2019.
15. Law A and Bisby L, The rise and rise of fire resistance, Fire Safety Journal, 116, 103188, 2020.

16. ASTM International, ASTM E119-19, Standard Test Methods for Fire Tests of Building Construction and Materials, 2019.

17. British Standards Institution, BS 476 Resistance, Incombustibility and Non-inflammability of Building Materials and Structures (Including Methods of Test), BSI, London, 1932.

18. Joint Committee of the Building Research Board of the Department of Scientific and Industrial Research and of the Fire Offices' Committee, Post-War Building Studies No. 20 Fire Grading of Buildings Part 1 General Principles and Structural Precautions, Published for the Ministry of Works by His Majesty's Stationery Office, London, 1946.

19. Joint Committee of the Building Research Board of the Department of Scientific and Industrial Research and of the Fire Offices' Committee, Post-War Building Studies No. 29 Fire Grading of Buildings Part II Fire Fighting Equipment Part III Personal Safety Part IV Chimneys and Flues, Published for the Ministry of Works by Her Majesty's Stationery Office, London, 1952.

20. United States Department of Commerce, National Bureau of Standards, Building Materials and Structures, Report BMS92 Fire-Resistance Classifications of the Central Housing Committee on Research, Design, and Construction, United States Government Printing Office, Washington, 1942.

21. Lennon T and Chitty R, BD 2887 Compartment sizes, resistance to fire and fire safety project, Final Work Stream Report for Work Stream 1 – Periods of fire resistance, BRE Output ref. 286855 (D23V2), March 2015.

22. CIB W14 Workshop Report, Design Guide: Structural Fire Safety, Fire Safety Journal, Volume 10, No. 1, pp 77-154, 1986.

23. Malhotra H L, Fire safety in buildings, Building Research Establishment Report, BR 96, Building Research Establishment, IHS BRE Press, 1987.

24. Read R E H and Morris W A, Aspects of fire precautions in buildings, Building Research Establishment, Department of the Environment, HMSO, 1983.

25. Ley A J, Building Control UK – An Historical Review, Session: CIB T5 Performance Based Buildings and Regulatory Systems, CIB, 1989.

26. British Standards Institution, BS EN 1990:2002 Eurocode – Basis of structural design, BSI, London, 2002.

27. British Standards Institution, BS 9991:2015 Fire safety in the design, management and use of residential buildings, BSI, London, 2015.

28. British Standards Institution, BS 7974:2019 Application of fire safety engineering principles to the design of buildings – Code of practice, BSI, London, 2019.

29. British Standards Institution, PD 7974-1:2019 Application of fire safety engineering principles to the design of buildings, Part 1: Initiation and development of fire within the enclosure of origin (Sub-system 1), BSI, London, 2019.

30. British Standards Institution, PD 7974-2:2019 Application of fire safety engineering principles to the design of buildings, Part 2: Spread of smoke and toxic gases within and beyond the enclosure of origin (Sub-system 2), BSI, London, 2019.

31. British Standards Institution, PD 7974-3:2019 Application of fire safety engineering principles to the design of buildings, Part 3: Structural response to fire and fire spread beyond the enclosure of origin (Sub-system 3), BSI, London, 2019.

32. British Standards Institution, PD 7974-5:2014 +A1 2020 Application of fire safety engineering principles to the design of buildings, Part 5: Fire and rescue service intervention (Sub-system 5), BSI, London, 2020.

33. British Standards Institution, PD 7974-6:2019 Application of fire safety engineering principles to the design of buildings, Part 6: Human factors: Life safety strategies – Occupant evacuation, behaviour and condition (Sub-system 6), BSI, London, 2019.

34. British Standards Institution, PD 7974-7:2019 + A1:2021 Application of fire safety engineering principles to the design of buildings, Part 7: Probabilistic risk assessment, BSI, London, 2021.

35. Kirby B R, Newman G M, Butterworth N, Pagan J and English C, A new approach to specifying fire resistance periods, The Structural Engineer, pp. 34-37, 5 October 2004.

36. Stern-Gottfried J and Rein G, Travelling fires for structural design – Part I: Literature Review, Fire Safety Journal, 54, pp. 74-85, 2012.

37. Stern-Gottfried J and Rein G, Travelling fires for structural design – Part II: Design methodology. Fire Safety Journal, 54, pp. 96-112, 2012.

38. Stern-Gottfried J, Travelling Fires for Structural Design, A thesis submitted for the degree of Doctor of Philosophy, The University of Edinburgh, 2011.

39. Rackauskaite E, Hamel C, Law A and Rein G, Improved Formulation of Travelling Fires and Application to Concrete and Steel Structures, Structures, 3, pp. 250-260, 2015.

40. British Standards Institution BS EN 1991-1-2:2002 Eurocode 1. Actions on structures. General actions. Actions on structures exposed to fire, BSI, London, 2002.

41. British Standards Institution, BS EN 1992-1-2:2004 Eurocode 2. Design of concrete structures. General rules. Structural fire design, BSI, London, 2004.

42. British Standards Institution, BS EN 1993-1-2:2005 Eurocode 3. Design of steel structures. General rules. Structural fire design, BSI, London, 2005.

43. British Standards Institution, BS EN 1994-1-2:2005 Eurocode 4. Design of composite steel and concrete structures. General rules. Structural fire design, BSI, London, 2005.

44. British Standards Institution, BS EN 1995-1-2:2004 Eurocode 5. Design of timber structures. General. Structural fire design, BSI, London, 2004.

45. British Standards Institution, BS EN 1996-1-2:2005 Eurocode 6. Design of masonry structures. General rules. Structural fire design, BSI, London, 2005.

46. British Standards Institution, BS EN 1999-1-2:2007 Eurocode 9. Design of aluminium structures. Structural fire design, BSI, London, 2007.

47. Cajot L-G, Schleich J-B, Pierre M, Profilarbed-Research and also 11 European project partners, Valorisation Project, Natural Fire Safety Concept, ECSC Research Project, 20th August 2001.

48. Department for Communities and Local Government, BD 2503 Innovative Construction Products and Techniques, 2008. Available from: http://webarchive.nationalarchives.gov.uk/20121030191133/http://www.communities.gov.uk/documents/planningandbuilding/pdf/628281.pdf. Last accessed 23rd September 2020.

49. Home Office, Fire and rescue incident statistics England, year ending June 2020, Fire statistics - GOV.UK (www.gov.uk). Last accessed 22nd February 2021.

50. Home Office, Detailed analysis of fires attended by fire and rescue services, England, April 2019 to March 2020.

11 Documents cited as supporting evidence in MHCLG Consultation Responses

There were a number of documents cited as supporting evidence in the MHCLG Consultation responses, including:

Compartmentation

- Association of Specialist Fire Protection (ASFP) 'Red book' Fire-stopping: linear joint seals, penetration seals and cavity barriers.
- Birtles B, Greater Manchester FRS and Sibert D, Fire Brigades Union, Analysis of warehouse fires and fire-fighting requirements to assess the adequacy of current AD B provisions.
- Bisby L, Report to Grenfell Tower Inquiry, 2018. Available from: Homepage | Grenfell Tower Inquiry.
- BRE, BD 2552 Fire spread in car parks, Report for the Department for Communities and Local Government, 2010.
- British Standards Institution, BS 5588-7 Fire precautions in the design, construction and use of buildings. Code of practice for the incorporation of atria in buildings, BSI, 1997.
- British Standards Institution, BS 6375 Performance of windows and doors. Classification for weathertightness and guidance on selection and specification, BSI, 2016.
- British Standards Institution, BS 8214 Timber-based fire door assemblies. Code of practice, BSI, 1990.
- British Standards Institution, BS 8414 Fire Performance of external cladding systems. Part 1: Test method for loadbearing external cladding systems applied to the masonry face of a building. Part 2: Test method for non-loadbearing external cladding systems fixed to and supported by a structural steel frame, BSI, 2015.
- British Standards Institution, BS 9414 Fire performance of external cladding systems. The application of results from BS 8414-1 and BS 8414-2 tests, BSI, 2019.
- British Standards Institution, BS 9999 Fire safety in the design, management and use of buildings. Code of practice, BSI, 2017.
- British Standards Institution, BS EN ISO 1716 Reaction to fire tests for products. Determination of the gross heat of combustion (calorific value), BSI, 2010.
- Building Control Alliance Technical Guidance Note 10: Installation of boiler flues and ventilation perforations in external timber framed walls and other such structures, 2011.
- Building Control Alliance Technical Guidance Note 26: Service Penetrations through External Wall Constructions of Residential Buildings, 2017.
- Building Disaster Assessment Group, Research, Various Reports. Available from: https://webarchive.nationalarchives.gov.uk/20100408020132/http://www.communities.gov.uk/fire/researchandstatistics/fireresearch/buildingdisasterassessment/. Accessed 1st March 2021.
- Business Sprinkler Alliance evidence of the losses in large uncompartmented buildings.

© BRE Global Ltd 2025

- Case studies, Grenfell Tower, Lakanal House, Harrow Court, Shirley Towers, etc.
- Centre for Economics and Business Research, The Financial and Economic Impact of Warehouse fires. An evidence-based assessment of the direct and indirect economic impacts in England and Wales of fires in warehouse buildings without automatic fire sprinkler systems (AFSS), Report for the Business Sprinkler Alliance, 2014. Available from: Downloads | BSA | Business Sprinkler Alliance
- Chitty R, BR 187: External Fire Spread, Building Separation and Boundary Distances Second Edition, BRE, 2014. Section 13 based in BR 187 is founded on the research by Margaret Law in the 1960s regarding the risk of conflagration.
- Chitty R and Fraser-Mitchell J F, BD 2887 Compartment sizes, resistance to fire and fire safety project Work stream 4 – Fire protection of basements and basement car parks, 2015. Available from: Compartment size, resistance to fire and fire safety research - GOV.UK. Accessed 1st March 2021.
- Croner-I, Extracts from Fire Safety and Timber-Frame Building Guidance, 2012. Available from: Fire safety and timber-frame building guidance | Croner-i – Members only
- Crowder D. Potential Perils of Modern Building Construction – A short introduction, Presentation given on 20th September 2011. Available from: https://www.bre.co.uk/filelibrary/events/Awareness%20day%20for%20members%20of%20the%20AIS/Methods_of_modern_construction_potential_perils_David_Crowhurst.pdf. Accessed 1st March 2021.
- Fraser-Mitchell J, Owen A and Williams C, An Environmental Impact and Cost benefit Analysis of Fire Sprinklers in Warehouse Buildings – Final report, BRE Global Client Report for The Business Sprinkler Alliance. BRE Global 2013. Available from: Downloads | BSA | Business Sprinkler Alliance.
- Hackitt J, Building a safer future, Independent Review of Building Regulations and Fire Safety: Final Report, 2018. Available from: https://www.gov.uk/government/publications/independent-review-of-building-regulations-and-fire-safety-final-report. Accessed 1st March 2021.
- IAL Consultants, Study on the Market for Thermal Insulation in Europe.
- Investment Property Forum, The Size and Structure of the UK Property Market: End-2017 Update, 2018. Available from: The Size & Structure of the UK Property Market: Year-End 2017 Update (December 2018) Full Report. Accessed 1st March 2021.
- Lane B, Report to Grenfell Tower Inquiry, 2018. Available from: Homepage | Grenfell Tower Inquiry.
- Lennon T and Chitty R, BD 2887 Compartment sizes, resistance to fire and fire safety project Work stream 1 – Periods of fire resistance, 2015. Available from: Compartment size, resistance to fire and fire safety research - GOV.UK. Accessed 1st March 2021.
- Lennon T and Fraser-Mitchell J F, BD 2887 Compartment sizes, resistance to fire and fire safety project Workstream 2 - Maximum fire compartment sizes, 2015. Available from: Compartment size, resistance to fire and fire safety research - GOV.UK. Accessed 1st March 2021.
- Lennon T, Holland C and Shipp M, BD 2887 Compartment sizes, resistance to fire and fire safety project Work stream 3 – Construction details – roof voids, cavity barriers and fire/smoke dampers, 2015. Available from: Compartment size, resistance to fire and fire safety research - GOV.UK. Accessed 1st March 2021.

- Local Government and Social Care Ombudsman, Decision, Planning , Building Control 17-107-556. Available from: https://www.lgo.org.uk/decisions/planning/building-control/17-017-556. Accessed 1st March 2021.
- National Fire Chiefs Council, Automatic Water Suppression Systems Position Statement, 2018.
- National Fire Chiefs Council, Efficiency and Effectiveness of Sprinkler Systems in the United Kingdom, Supplementary Report, 2019.
- NHS Property Services, Weybridge Fire Incident Report: NHS Property Services - Version 3.1, 2018. Available from: NHS-Property-Services-Weybridge-Hospital-Fire-Investigation-Report.pdf
- Property Industry Alliance, Property Data Report, Facts and figures about the UK commercial property industry to year-end 2016, 2017.
- Tenos Report into a Fire at RA Wood Adhesive Tapes. Report for Kingspan Ltd, 2009.
- Tenos Report into a Fire on 30 July 2004 at Clifton Comprehensive School Rotherham, Report for Kingspan, 2004. Available from: https://www.kingspan.com/gb/en-gb/products/insulated-panel-systems/fire-performance-of-kingspan-insulated-panels/real-fire-case-studies/clifton-comprehensive-school. Accessed 1st March 2021.
- WHO Mortality Database. Available from: WHO Mortality Database - WHO.

© BRE Global Ltd 2025

Report Ends

bre

www.bre.co.uk

Health and Safety Executive
Final Report

Structural Fire Resistance and Fire Separating Elements –
Appendix B: Summary of scoping study and review of current provisions

Prepared for: The Building Safety Regulator

Prepared by: Tom Lennon, Neal Butterworth, Adeyanju Teslim-Balogun, Grunde Jomaas, Martina Manes, Stephen Welch, Stuart Martin

Approved by: Dr Roger Harrison (original report approval 21st December 2021) and Tony Baker (final amendments March and September 2025) on behalf of BRE Global

Date: 21st December 2021

HSE Contract: 1.11.4.4436 (previously MHCLG Contract: CPD/004/120/206)

Report Number: P118139-1015 (M11D9V3) Appendix B

BRE Global Ltd
Watford, Herts
WD25 9XX

Customer Services 0333 321 8811

From outside the UK:
T + 44 (0) 1923 664000
E enquiries@bregroup.com
www.bregroup.com

This report is made on behalf of BRE Global and may only be distributed in its entirety, without amendment, and with attribution to BRE Global Ltd to the extent permitted by the terms and conditions of the contract.

BRE Global's liability in respect of this report and reliance thereupon shall be as per the terms and conditions of contract with the client and BRE Global shall have no liability to third parties to the extent permitted in law.

Table of Contents

 © BRE Global Ltd 2025

1 Introduction

This Appendix contains a summary of the findings of Objective A the scoping study and the outcome of Objective B the review of current provisions and takes into account MHCLG and Technical Steering Group comments.

2 Methodology for scoping study and review

A scoping study on the review and collection of evidence on Structural Fire Resistance, Fire Separating Elements and Compartmentation was undertaken and the outcome was reported in Appendix A. The work in this area was reviewed based on the outputs from a previous research project completed in 2015, BD 2887 dealing with Compartment Sizes, Resistance to Fire and Fire Safety[1]. The methodology for Objective A was as follows:

- 136+ responses submitted to the MHCLG Call for Evidence on AD B that related to "Compartmentation", "Other B3 issues" and Car parks and Fire tests considered under "Other issues" have been reviewed (and areas have been identified for focus in Objective B);
- The background to the current guidance in relation to the specification and assessment of performance in fire in relation to structural fire resistance and compartmentation has been presented;
- Alternative approaches to the specification of performance in Approved Document B (BS 9999, BS 9991, the Travelling fires approach, Structural Eurocodes) have been identified;
- Issues relating to Modern Methods of Construction have been identified;
- The relevant Fire Statistics (for England) have been identified;
- The test standards related to fire resistance and compartmentation (including extended application documents) have been identified;
- From the above, additional references have been identified.

The areas identified during the scoping study have been reviewed against the underpinning basis and provisions in AD B, to determine whether AD B provides adequate guidance to meet the minimum requirements under Schedule 1 Part B of the Building Regulations 2010.

This report builds on the initial information presented in the scoping study, taking into account comments received by MHCLG and the Project Technical Steering Group.

3 Scope of the review of responses from MHCLG Call for Evidence

The responses received to the MHCLG Call for Evidence undertaken as part of a full technical review of the fire safety aspects of the Building Regulations were considered as part of the initial scoping study of this project. In particular, those comments classified as related to "Compartmentation" were reviewed by the Project Team and used, in conjunction with the instructions in the original specification of requirements for this project, together with additional comments under other sections but related to the objectives of this project, to produce a number of themes which, it is proposed, are taken forward as part of this project. Other workstreams or projects such as the MHCLG Construction Technologies workstream or the Arup MOD (Ministry of Defence) project on offsite volumetric construction will cover other issues identified in the Call for Evidence.

The specific areas to be considered are listed, but not prioritised, below:

- Modern Methods of Construction (MMC)
- Timber frame construction
- Mass timber construction
- Cavity barriers
- Car parks
- Deemed to Satisfy solutions
- Maximum compartment sizes
- Alternative (to AD B) methods of specifying structural fire performance

All these areas were raised in the Call for Evidence. However, the final choice of which areas to take forward was also influenced by the findings of the initial literature review, the expertise of the Technical Steering Group and the experience of the Project Team. The reason why some areas were not taken forward was explained in the report covering the initial review which identified those areas deemed to be of narrow sectorial interest or outside the scope of AD B. It is the intention that these broad subjects will form the primary focus for this research project. The initial specification discussed a number of other issues and there were other areas referenced in the Call for Evidence which are not covered above. It was recognised from the beginning of the project, that it would not be possible to comprehensively cover every single area relevant to the subject of structural fire resistance and fire separating elements due largely to constraints in time and resources. The intention is to focus on those issues related to structural fire resistance and fire separating elements which are seen to be the most significant and to try and make real progress in these areas. The focus is to identify areas where adherence to the recommendations of the guidance is potentially insufficient to demonstrate compliance with the mandatory requirements of the Building Regulations. Such an approach will cover concerns around both MMC and mass timber which are among the most common areas highlighted in the Call for Evidence, in discussions with the Technical Steering Group and in the wider construction industry.

The scoping study identified those areas where the comments related to either a misunderstanding of the purpose of the guidance (specifically in relation to property protection issues), areas to be covered by complementary research projects (such as issues related to the performance in fire of external walls) or sector-specific issues (e.g. fire rated ducts and dampers and fire doors) which will not be covered by the current project.

Other areas raised in the Call for Evidence or mentioned by MHCLG in the specification of requirements may be better dealt with as part of one of the ongoing related research projects. For example, the issues of electric vehicles (EVs) in relation to car parks and appropriate designation of places of special fire hazard in modern construction, may be partly addressed as part of the MHCLG Construction Technologies, Design and Usage project. In relation to car parks, it is unlikely that the different design fire models to be assumed in each case will have a significant bearing on the specification of structural fire resistance. It is the number of vehicles involved rather than the specific characteristics of each individual vehicle that will have the biggest impact on the required level of performance. This is covered in more detail in Section 6.7. In relation to designation and fire separation for places of special fire hazard, the MHCLG Construction Technologies project is examining modern building usage trends that could provide evidence to support informed policy decisions.

One particular area not covered explicitly by the comments received in the Call for Evidence but evidenced implicitly in the assumptions of a number of respondents, is confusion over the purpose of AD B. There is a clear need for a more explicit statement of the aims and objectives of AD B to avoid confusion and to ensure that the document is performing the function for which it was designed. This will form a cornerstone of the research project going forward as it will dictate how the other topics are dealt with. Central to this is the need for clarity in relation to the circumstances where the expectation is that a building or fire compartment will be designed so as to survive burn out of all combustible materials.

 © BRE Global Ltd 2025

4 Summary of background to recommended periods of fire resistance

A comprehensive review of the background to recommended periods of fire resistance was provided in Appendix A. What is clear from that review is that:

- The basic principles underlying the current system are based on the recommendations of the Joint Committee of the Building Research Board of the Department of Scientific and Industrial Research and of the Fire Offices' Committee as set out in the Post-War Building Studies Report No. 20 on the Fire Grading of Buildings[2], published in 1946.
- One of the underlying principles of both the Post-War Building Studies (and the US Building Materials and Structures reports) is that where there is a requirement for a compartment to resist a complete burn out of all combustible material without failure, then such a compartment should be built using "*fully protected construction*".
- Those structures where some form of fire resistance was required but did not necessarily need to survive complete burn out of all combustibles were classified as "*partially protected*".
- The reports noted that even though some forms of combustible construction were capable of providing a high level of fire resistance they were not appropriate for the construction of buildings designed to withstand complete burn out without failure.
- This distinction between different forms of construction or different construction materials represents a different approach to the functional requirements of the current regulations and the technologically neutral performance-based approach to compliance designed to encourage innovation and provide a more rational basis for the design of structures in fire.
- For those occupancies (such as residential buildings and offices) considered to represent a low fire load, then, according to the Fire Grading of Buildings reports, a fire resistance of one hour would be sufficient to survive complete burn out of all combustible materials on the basis of a grading determined according to the damage hazard. This approach is principally concerned with structural behaviour and a grading system predicated on the basis of "Damage Hazard".
- The concept of "Damage Hazard" and "Personal Hazard" and the relationship between the two go a long way to explaining the current system. The initial recommendations in the Fire Grading Report were based on the concept of "Damage Hazard" which included an implicit allowance for property protection. The current system is more closely aligned to an approach based on "Personal Hazard" relating to life safety.
- A grading predicated on personal hazard (such as the current approach to Building Regulations) needs to consider issues related to both egress and tenability. This covers not only the need to maintain overall stability but also to ensure that sufficient time is available to either ensure that building occupants can remain within a place of relative safety while fire-fighting activities are undertaken (or until the fire has burnt out) or occupants can be safely evacuated. In such cases, the prescribed or recommended periods of fire resistance must take into account not only issues related to the performance of construction materials and elements of structure but also the characteristics of the occupants and the time taken to either extinguish a fire or to facilitate a safe evacuation. It is here that issues other than structural fire resistance and compartmentation come into play, such as the need to minimise the spread of flame on wall and ceiling linings and preventing or restricting the movement of smoke and hot gases (including toxic products of combustion) through the building.

 © BRE Global Ltd 2025

- A high rise building (such as residential buildings and offices) classified as low risk within a grading system predicated on “Damage Hazard” on the basis of the anticipated fire load may represent a high risk when considered in relation to “Personal Hazard” due to difficulties in facilitating means of escape. Conversely, a building (such as a large single-storey warehouse) which may represent a high risk when considered on the basis of a “Damage Hazard” system may be considered low risk in relation to a “Personal Hazard” approach.
- The appropriate level of performance (fire resistance) in the current system will depend on the specific relationship between personal and damage hazard. In recent years, this approach has been widened to encompass what might be termed “Environmental Hazard” to encompass incidents that may be deemed unacceptable due to the impact on the environment such as contamination of watercourses or an unacceptable impact on air quality.

4.1 Compartment sizes, resistance to fire and fire safety project BD 2887

The Building Regulations and Standards Division of what was then the 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 the 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 workstreams in relation to fire safety and associated provisions in Part B of the Building Regulations. As part of Workstream 1 Periods of fire resistance, a review was undertaken of the background to the existing AD B requirements[1]. The results are relevant to the current project and are summarised below:

- The review concluded that the current guidance in AD B is based largely on the findings from the Post-War Building Studies No. 20 Fire Grading of Buildings Part 1 General Principles and Structural Precautions[2] published in 1946.
- Three hazard categories are identified corresponding to ‘low’, ‘moderate’ and ‘high’ fire loads. The values (see Appendix A scoping study for details) corresponding to these categories are significantly higher than the corresponding figures used for the performance-based design of buildings, suggesting that performance-based approaches are based on information such as the fire load densities tabulated in the CIB W14 design guide for structural fire safety[3]. The concept of ‘fully protected’ construction was developed to cover those buildings designed to withstand a complete burn out, i.e. the protection provided equals the severity anticipated.
- Other categories are defined with a fire resistance less than that required to survive complete burn out. Seven categories of construction are identified, ranging from fully protected structures designed to survive a complete burn out of all combustible material through to structural materials without any specific fire resistance requirement.
- The principle of establishing an appropriate fire resistance period for a particular occupancy and height of building is the same in the current guidance as the approach used in the 1946 document. The fire severity is assumed to be a function principally of the type and magnitude of the fire load. The size of the building in terms of height, floor area and cubic capacity is related to the consequences of failure and the accessibility for means of escape and fire-fighter access (i.e. the “personal hazard”).
- The recommendations of the Post-War Building Studies were never intended to cover all forms of construction just as the guidance in AD B does not cover all types of building. The background to the guidance (and the concept of design to survive burnout) was based initially on the concept of “damage hazard”. The current system in AD B is based on the concept of “personal hazard” or life safety. This may be one of the principal reasons for the departure (in AD B) from some of the recommended values in the Post-War Building Studies.

The scoping study for this project expanded on the review of the background to the current provisions to incorporate research and knowledge derived since the publication of the Fire Grading report. Malhotra[4] called for a new approach to fire safety in buildings which drew on the research undertaken since the publication of the Post-War Building Studies notes. His report, published in 1987, represented an examination and consolidation of the practical information developed since the publication of the Fire Grading reports with the aim of proposing changes to the technical content of the guidance that would not have an adverse impact on the existing levels of fire safety. The proposals represented an initial move away from a prescriptive approach towards a more rational methodology based on the principles of fire safety engineering.

© BRE Global Ltd 2025

5 Alternative methods for specifying periods of fire resistance

The specifications from the Fire Safety British Standards BS 9999[5] and BS 9991[6] are often used in the design of buildings as an alternative or in addition to the recommendations of Approved Document B. Sections of both documents are referenced in AD B, with BS 9999 referenced extensively.

Both BS 9999 and BS 9991 are used widely as the basis for Fire Strategies for new buildings and therefore, the approach to the specification of structural fire resistance and compartmentation is relevant to the current discussion.

Both BS 9999 and BS 9991 may be viewed as a 'half-way house' between the "prescriptive" recommendations of AD B and the more detailed Fire Safety Engineering approach set out in the BS 7974 series consisting of the main standard[7] and the series of Published Documents that support the approach[8 to 13].

In terms of a review of fire resistance and compartmentation, the most important aspect of BS 9999 is the incorporation in Section 7 of BS 9999 dealing with Design of the Building Structure and Section 4 of BS 9991 dealing with Design for construction of an alternative approach to the specification of fire resistance. This alternative is based on the concept of time equivalence and, as such, takes into consideration not only the assumed fire load densities which are the basis of the AD B approach, but also the impact of ventilation on fire growth and development. The background, methodology and justification for this is set out in a paper published in the Structural Engineer in 2004[14].

5.1 Historical background

In the late nineteenth century, attempts were being made to standardise fire resistance testing so that different buildings materials and systems could be compared against each other[15]. This led to the development of what is now commonly known as the "standard fire" (e.g. the time-temperature relationship set out in BS 476-20[16] and BS EN 1363-1[17]).

The time equivalence concept originated in the 1920s with Ingberg[18], where he used the Equal Area Concept to correlate fuel load in experimental tests with an 'equivalent' duration of exposure to the standard fire. The tests replicated the highly compartmentalised building stock of the time and the construction was largely non-combustible.

The fire resistance standards specified in Table B4 of AD B can be traced back (Malhotra[4]) to Ingberg. The Fire Grading of Buildings report[2] recommended fire resistance standards for different building uses as a function of the associated fire hazards or fire load. The fire resistance standard is the duration of exposure in the standard fire curve that would result in an equivalent 'severity' to that of the 'real' fire for the given fire load (i.e. time equivalence). The intent of the fire resistance standard was to ensure that structures would withstand the burnout of the fire load in a real building. In defining the link between burnout and time equivalence, Ingberg[19] recognised that where sprinklers were provided, the combined effect of sprinklers and fire resistance could be deemed adequate to prevent collapse.

The Building Regulations 1965[20] adopted this concept and stipulated fire resistance standards as a function of purpose group and height. Since then, the values of minimum fire resistance standards have changed (generally increased – for reasons unknown), but the fundamental concept has remained the same: they are based on time equivalence with a purpose to withstand the burnout of a reasonable, worst-case fire that could occur in real buildings (see Malhotra[4]).

 © BRE Global Ltd 2025

Ingberg and the Fire Grading of Buildings report (and subsequently the Building Regulations) determined the time equivalent period as a function of the fire load. Since then, several methods for calculating the time equivalent period have been developed (Law[21]). All of these methods attempt to equate the severity of a real enclosure fire to an equivalent duration in standard fire tests. They consider the expected fire severity of 'real' fires as a function of enclosure properties and fuel loads. Law concluded that while many of the formulae for time equivalence provided a good fit for small compartments, the formulae did not adequately consider the effect of large or deep compartments.

Modern codified implementations (e.g. BS EN 1991-1-2[22] and PD 7974-3[10]) of time equivalent calculations are often vague on the actual value of fire load that should be used (e.g. 80%, 90%, 95% fractiles) and include factors to account for the likelihood of fires and the consequences of those fires. The derivation of these factors is not always well documented, but typically they are derived from calibration against prevailing norms such as AD B.

5.2 BS 9999 Fire safety in the design, management and use of buildings – Code of practice

5.2.1 Principles of BS 9999

BS 9999[5] specifies fire resistance requirements for elements of structure as a function of risk profile (as opposed to purpose group) and storey height. The risk profile is a concatenation of occupancy profile (i.e. awake and familiar, awake and unfamiliar and sleeping risks) and expected fire severity (low, medium, high and very high).

To account for buildings having many different enclosures and the likelihood of different fire severities within an enclosure, the fire resistance standards specified in Table 26 of BS 9999 are based on Monte Carlo calculations and a concept of 'equivalent reliability' (see Kirby et. al[14] for more information).

The method uses the parametric fires defined in BS EN 1991-2[22] to approximate fire severity as a function of occupancy fuel load distributions and expected geometric configurations.

For generic building types (e.g. office, residential, school, hotel, etc.) assessments of thousands of potential room enclosures and fire load were conducted to generate cumulative distribution/exceedance curves for time equivalent periods; thereby, addressing the multitude of different enclosures that could exist in a real building and selection of fire loads.

Instead of modifying the time equivalent period by frequency and consequence factors (as is the approach in BS EN 1991-1-2 and PD 6688), the BS 9999 methodology determines the fractile (of the cumulative distribution of fire severity) from the Monte Carlo analysis at which risk is the same for different heights of building. In each case, the fire severity was characterised in terms of the equivalent temperature of a protected steel section when subjected to a standard heating regime. The detail is provided in reference 14. The main point is that there are alternative values in BS 9999 to the minimum recommendations in AD B but they can only be used where ventilation conditions allow.

The results were calibrated against AD B such that in some instances (e.g. tall retail buildings) fire resistance standards are higher than AD B and in others (e.g. office) they are lower.

5.2.2 Trigger heights

BS 9999 introduces two additional trigger heights for fire resistance standards: 11m and 60m. This was to increase fidelity between 5m and 18m heights and to account for an increasing prevalence of taller buildings.

5.2.3 Sprinklers

BS 9999 differs from AD B in the way in which automatic suppression systems are considered. BS 9999 applies reductions to the fire resistance standard across most risk profiles and building heights, whereas AD B reductions are more limited across purpose groups and height ranges. However, recent changes to Table B4 of AD B have increased the number of cases where sprinkler provision is mandatory and increased the scope for reducing minimum requirements where an approved sprinkler system is present.

5.2.4 Ventilation options

BS 9999 provides two options for fire resistances requirements: where ventilation (window area) is unknown, and where ventilation is within certain bounds.

5.2.5 Use of BS 9999 Risk Profiles

The fire resistance standards are expressed (as per AD B) as being in accordance with BS EN 13501-2[23] or BS 476[16].

Risk is a widely accepted approach to ensuring adequate safety. The intent of the BS 9999 methodology was to ensure risk of failure is consistent across buildings (as a function of Risk Profile and storey height). This is effectively ensuring an equivalent reliability against risk of structural failure.

Risk of structural failure from fire is a function of frequency of fires, probability of fire causing structural failure(s) and the consequences of such structural failure, where:

- Frequency is influenced by the BS 9999 occupancy profile, but not BS 9999 occupancy profile alone. For example, offices and factories would both be BS 9999 occupancy profile A, but their different uses and different activities that take place are such that the frequency of fires in similar sized buildings might be different. Even with similar occupancies (such as factories) there will be significant differences in frequency depending on the nature of the operations undertaken within the premises. Frequency of fires may also be related to social issues and may lead to differences in nominally identical occupancy types such as blocks of flats.

- Probability of structural failure is influenced by the severity of fire that would occur and the fire resistance of the structure. Severity is influenced by fuel load, enclosure fire dynamics and any active measures such as sprinklers and smoke control.

- Consequence of failure in a Building Regulations context is largely about the number of people that would be impacted by structural failure.

Using Risk Profile and height to specify fire resistance standards is partially justifiable because there is likely to be some correlation between: Risk Profile and frequency; Risk Profile and probability of structural failure; and Occupancy Characteristic and height and consequence of failure.

However, the above correlations are also likely to be weak because there is significant variation in risk within Risk Profiles and height is a crude approximation of consequences of failure.

5.2.6 Tolerable Risk

Typically, society is more tolerant to multiple low consequence events (e.g. car accidents per year) than single high consequence events (e.g. aircraft crashes). The same is true for fire where society would be more tolerant of say 100 single fatalities per year than one incident with 100 fatalities. Therefore, risk of failure should not be consistent across buildings; instead, risk should reduce with increasing consequence of failure.

© BRE Global Ltd 2025

Part A of the Building Regulations already includes the concept of acceptable risk of failure as a function of different consequent classes. At the time of the Post-War Building Studies, Parts A and B were more closely (if not explicitly) linked, but over time the linkage had weakened to an extent that it is almost non-existent.

Given that Part A is explicitly about structural stability, AD B should include an explicit linkage between Part B and Part A.

5.2.7 Accuracy of BS 9999 versus AD B

The use of parametric fire curves as opposed to correlating against fuel load is a more accurate approach. However, it remains crude and does not account for non-homogeneous fires (a.k.a. travelling fires).

The BS 9999 calculations used the parametric fire equations in BS EN 1991-1-2, which inherently assume a single zone homogeneous fire and have been validated for enclosure sizes of up to approximately 100m^2 in plan area. Therefore, they are not necessarily appropriate for fires that might occur in compartments greater than 100m^2.

More recently, travelling fire concepts (Stern-Gottfried[24]) have been recognised as offering a better representation of fire in larger enclosures. The fire is approximated as a near field zone (the area of enclosure where fire load is burning) and a far field zone (the area of the enclosure where fire load is not burning). There is also more recent work being completed in this arena.

That said, the import of parametric fires versus travelling fires or similar in the BS 9999 methodology is diminished by the calibration with AD B (see below).

Regardless of the appropriateness of the calculation method, the fire resistance standards are calibrated against AD B (due to uncertainty associated with the calculation method). Therefore, in practice, the BS 9999 methodology is no more “accurate” than the AD B method because it is fundamentally linked back to AD B through the calibration.

However, the BS 9999 methodology is a risk-based method and can be adapted and improved more readily than the implicit AD B method.

The 11m height was introduced to correlate with other 11m triggers within BS 9999 (and AD B). The 11m category is now included in Table B4 of AD B.

5.2.8 Discussion and recommendations

The introduction of the 60m height is potentially sensible given that taller buildings are more common and the consequences of failure of taller buildings are greater than shorter buildings. However, an implicit assumption is that risk of structural failure does increase with increasing heights above 30m. This is theoretically true, but not necessarily in practice – it could be that the measures required for buildings more than 30m (sprinklers, compartment floors and a high fire resistance) are sufficient to make the risk of the probability of structural failure sufficiently small that additional risk reduction is not required to mitigate potential consequences.

The principle of using sprinklers to reduce the required fire resistance standard is well founded.

When generating cumulative distribution curves for sprinklered buildings, the BS 9999 method factored the fire load by 0.61 as per BS EN 1991-1-2. This approach is not conceptually correct (in that sprinklers do not reduce the amount of fire load), nor is the justification for the value of 0.61 thoroughly documented.

A more conceptually accurate approach is to assume that the required reliability is a combination of the sprinkler reliability and the reliability of the fire resistance of the structure. This means if the sprinklers fail, the structure is subject to the full fire severity associated with the appropriate fuel load.

That said, given that fire resistance standards in AD B are somewhat arbitrary, it is not necessarily inappropriate to include an equally arbitrary reduction in fire resistance standards where sprinklers are installed.

The BS 9999 methodology resulted in the fire resistance standards quoted in BS 9999 Table 24. The method already accounted for different ventilation conditions in the Monte Carlo analysis, and it was never intended that Table 23 (fire resistance standards that do not account for ventilation and are in effect a replication of what was AD B Table A2) be included. Table 23 was included as a drafting decision to create closer linkage to AD B. Table 23 is a reproduction of what was Table A2 in the version of AD B current at the time of drafting.

The fire resistance standards are expressed (as per AD B) as being in accordance with the standard time-temperature relationship as set out in BS EN 13501-2 or BS 476. These tests are limited by the imposed heating regime, furnace sizes, and structural restraint and load configuration options. As such, they can only test the thermo-mechanical performance of building components (or sub-assemblies), not whole structures. Therefore, BS 9999 inherits the same implicit and explicit assumptions associated with the specification of fire resistance standards as for AD B.

BS 9999 compartmentation requirements are similar to AD B except that they are expressed as a function of Occupancy Profile as opposed to Purpose Group.

There are four potential options as to how AD B responds to BS 9999 (the recommended option is included in Section 7):

- No Change: Accept that AD B fire resistance standards are sufficiently adequate and require no change simply because of BS 9999.
- Selected Change: Assess which principles of BS 9999 are appropriate to incorporated into AD B.
- Adopt BS 9999: Adopt BS 9999 in its entirety (this would require changes elsewhere in AD B to reflect Risk Profiles as opposed to Purpose Groups).
- Change Philosophy: BS 9999 identified shortfalls in the AD B implicit assumptions and derivation of fire resistance standards. However, BS 9999 inherits similar assumptions and has others that are questionable. If change is to be made to AD B, consideration should be given to linking more closely with Part A and incorporating new knowledge and approaches that have been developed since BS 9999 was published.

5.3 Recent research

Recent research[25] has built on the initial work used to develop the alternative approach to assess the required fire resistance rating for elements of structure as set out in BS 9999. This proposed new approach uses a reliability-based methodology that incorporates elements from the time equivalent approach adopted by Kirby et al[14], the incorporation of the travelling fires methodology (see below), probabilistic applications using Monte Carlo Simulations (MCS), Consequence Classes (CC) from Approved Document A[26], a reliability index (β) based on the Joint Committee for Structural Safety (JCSS) model code and the probability based approach to defining the likelihood of a (structurally significant) fire occurring from the Natural Fire Safety Concept[27] to derive fire resistance periods for specific types of occupancy and specific heights and floor areas and compare the results with the requirements of BS 9999 (not the AD B recommendations).

Such an approach needs to be considered in the light of the comment by Malhotra[4] that guidance needs to be simple and transparent. The implications of replacing the current system with an approach that very few construction professionals would be capable of understanding needs to be clearly understood. Those charged with ensuring compliance with the regulations in the field of fire engineering are already faced with a system where designs may be based on advanced computational analysis that can only be readily interrogated through some form of external expert third party review. There is no evidence, based on an analysis of data from real fires, that the current system, based on the minimum recommended periods of fire resistance provided by AD B, is failing to deliver an acceptable level of safety. The statistics show a general reduction in fire related fatalities and injuries. There may be issues with the way the regulations are being applied or with the ongoing maintenance of fire protection measures, but there does not seem to be any evidence to suggest that the current performance requirements are inadequate. It is also unclear to what extent the provisions for structural fire resistance and the maintenance of compartmentation impact directly on life safety. Over the last few decades, many millions of pounds have been spent on research into structural performance in fire focused largely on the maintenance of structural stability in offices where there is no significant body of evidence suggesting there is a problem with life safety. The primary motivation for much of the work undertaken in this area appears to be economic and focused on reducing the cost of fire protection measures within buildings.

Within the Eurocode system, it has long been recognised that what constitutes an acceptable level of safety is a matter for national choice. This is one of the reasons why the methodology set out in Annex E of the fire part of the Eurocode for Actions (see below) is not used for design in the UK as it uses detection, suppression and fire service intervention to specify the design fire load density. These parameters will vary from country to country and from location to location within individual countries, depending on the nature of the society and availability of local resources.

The current regulatory system in England allows for flexibility in the approach to ensuring adequate levels of fire safety whether through compliance with prescriptive rules, through advanced calculation procedures or reliance on the results from fire tests.

Structural fire engineering is a relatively new discipline. The direct involvement of (structural) engineers and even statisticians in the process of ensuring fire engineering design submissions are fit for purpose is welcome and should be an integral part of the fire engineering design framework. Engineers will always be looking to provide more exact solutions to meet the requirements of their clients without undue expenditure.

Structural engineering and fire dynamics are both topics governed by physical phenomena that can be studied, analysed and predicted. Material behaviour at elevated temperatures, while complicated for certain materials and combination of materials, is reasonably well understood and, in many cases, is predictable and relatively easy to model. Similarly, fire dynamics is governed by fundamental equations of energy transfer, whereby mass balance can be used to determine temperature distributions within structural elements based on combustion behaviour and gains and losses dependent on the compartment geometry, ventilation conditions and constituent materials of the compartment.

However, structural fire engineering deals with the interactions between fire development, structural performance (in relation to both maintenance of structural integrity and maintenance of compartmentation) and human behaviour and cannot be so easily calculated as some believe. The current framework has been developed over many years, based on establishing a simple relationship between fire load density and floor area but always taking into account factors that could not be directly calculated such as ease of access and egress, occupant familiarity and mobility and the importance of maintaining adequate tenability conditions.

Empiricism and the lessons learnt from real events has played a significant part in the development of the recommendations in AD B and should not be easily set aside in favour of an academic approach to predict complex interactions, not based on deterministic methods proven over time, but on statistical distributions each one of which comes with its own uncertainties. Although the approach to specifying levels of performance may appear more objective than the current system, the selection of parameters for inclusion and the range over which those parameters should vary is a subjective choice reliant on the accuracy of the information available.

 © BRE Global Ltd 2025

Anyone familiar with structural engineering design approaches will know that there is, in general, a hierarchy of complexity and a consequent decrease in conservatism as more effort is put into providing an “exact” solution. This is the basis of the delineation between tabulated design values, simplified design methods and advanced design methods set out in the structural Eurocodes.

There is nothing to stop advanced approaches being used to demonstrate compliance provided the approach can be understood by those responsible for ensuring the designs comply with the requirements of the regulations. This is the basis of structural fire engineering design. It is an approach that is permitted within the UK regulatory framework and one that is widely used to justify departures from the recommended values not just for structural performance but across the entire range of fire design scenarios.

If an individual designer wants to provide an approach which is tailor-made to the specific characteristics of the project for which he or she is involved then, provided they have the competency and can provide a justification for their approach, they are free to do so. This does not provide a justification to change the means by which performance is specified for all other parts of the industry. The recommended values for fire resistance set out in AD B should be conservative. If there are cases where complying with the guidance does not produce conservative results then it may be necessary to require additional evidence, but that does not require a wholesale change to the current values unless they can be shown, on the basis of evidence from natural fires, to provide a level of performance which is unacceptable to society.

There should, however, be a difference between the methods deemed acceptable to demonstrate compliance with the requirements and a framework where the requirements themselves are the subject of alternative and competing approaches. It is important to ensure that not only are those responsible for the structural fire engineering design competent to carry out the task but that the means by which the design is undertaken is understood by those responsible for approval and that any new methodology related to the specification of performance is robust and transparent.

5.4 Travelling fires

The most recent version of Part 1 of the PD 7974[8] suite of published documents supporting the development of an alternative fire engineering approach to the protection of people, property and the environment from fire includes a new section related to Travelling fire frameworks.

The concept was originally proposed through two papers published in the Fire Safety Journal in 2012[24,28] based on the work undertaken by Stern-Gottfried for his PhD study completed in 2011[29]. The methodology is based on observations from real fires and large-scale experiments that fires in large enclosures do not burn in a uniform manner but travel across the floor space. The concept has been modified in a more recent paper which considers the application to concrete and steel structures[30] and has recently formed the basis for a collaborative research project TRAFIR (Characterisation of Travelling Fires in Large Compartments) funded by the European Research Fund for Coal and Steel.

Recent years have seen much interest in the concept of “travelling fires” which aim to bridge the gap between fully-developed compartment fires and localised fires, establishing representations of the overlapping remote and local heating of structural elements. The need for such representations was recognised by Charles Clifton in the early 1990s, inspired by observations of non-uniform heating in full-scale compartment fire tests, in particular the “natural fires in large compartments” series carried out by British Steel Technical in collaboration with the Fire Research Station undertaken at BRE Cardington[31]. Clifton proposed a treatment based on a subdivision into large “firecells”, each being subject to a modified parametric fire curve which thereby progressed over the floor plan, providing sequential phases of pre-heating, fully-developed fire and cooling. The utility of the model was also assessed against the BHP large office tests conducted in Australia[32].

An alternative approach, a prototype of the Travelling Fires Methodology (TFM) was proposed by Rein et al. in 2007, discriminating near and far field heating and describing the latter via a family of temperature curves for different assumed travelling fire areas and heat release rates. Further work by Stern-Gottfried et al.[33] simplified and refined this methodology, utilising a ceiling jet correlation to generate the far field temperatures. Stern-Gottfried and Rein later developed the methodology further and published a pair of papers which reviewed the literature on travelling fires and provided a definitive description of their model[24,28]. The methodology was subsequently improved to take better account of fire dynamics, the so called "improved Travelling Fire Methodology" (iTFM)[30], and has been applied to the analysis of concrete and steel structures[34].

Dai et al. later put forward an alternative framework, the Extended Travelling Fire Methodology (ETFM), which additionally seeks to ensure mass and energy conservation in the compartment by adoption of a zone model for the representation of the far field (hot layer) temperatures. This open-source model also adopts Hasemi's localised fire model for the near field and has been applied to analysis of the thermal and structural response of steel and composite structures, spanning extensive parametric studies of fire and structural parameters[35,36].

The original review by Stern-Gottfried and Rein identified three main experimental programmes, the British Steel Technical/Fire Research Station in 1993[31], the small rectangular enclosure tests of Thomas and Bennetts[32] and the Dalmarnock fire tests in 2006[37], together with anecdotal evidence garnered from a number of large accidental fires. Dai et al.[36] provide a further review of travelling fires, adding three further large-scale travelling fire test programmes, i.e. the Veselí test in 2011[38], the Edinburgh Tall Building Tests (ETFT) in 2013[39] and the Tisova fire test in 2015[40]. A number of further travelling fire experiments have been performed and documented since, including the Malveira fire test in 2014[41], x-ONE in 2017 and x-TWO in 2019[42] and the TRAFIR RISE Guttasjön large elongated compartment series[43,44] and TRAFIR Ulster large compartment test series[45]. Table 1 provides a summary of the main tests (series) performed to date.

 © BRE Global Ltd 2025

Table 1 − Overview of main parameters for some key experiments relevant to travelling fires
(PT = Plate Thermometer; TSC = Thin Skin Calorimeter, a simple heat flux measurement device)

Categories Experiments	Dimensions (length x breadth x height) (m)	Fuel load	Thermal response	Structural response	Mass loss measurement	Tests
BST/FRS Natural fires in large scale compartments, 1993	22.8 × 5.6 × 2.75	Wood cribs	Gas and steel temperatures	None	Yes	9
LBTF – Demonstration Furniture, BRE Cardington, 1995-1996	135 m^2	Furniture	Gas and steel temperatures	Strain and deflections	No	1
ECSC NFSC II, BRE Cardington, 1999-2000	12 × 12 × 3	Wood cribs only, or 80% wood cribs + 20% plastic	Gas and steel temperatures	None	Yes	8
Thomas and Bennetts, 2000	8 × 2 × 0.6	Commercial grade methylated spirits (97% ethanol)	Gas and steel temperatures	None	Yes	187
St. Lawrence Burn project, 1958	11.2 × 12.8; 13 × 9	Wood waste	Gas temperatures	None	No	2
Veselí Travelling Fire Test, 2011	10.4 × 13.4 × 4	Wood cribs	Gas, steel, and concrete temperatures	Strain and deflections	No	1
Edinburgh Tall Building Test, 2013	5 × 18 × 2	Wood cribs, or gas burners	Gas temperatures, TSC	None	Yes	2+25
Tisová Travelling Fire Test, 2015	230m^2 × 4.4	Wood cribs + hydrocarbon accelerant	Gas and concrete temperatures	Deflections	No	1
Malveira Fire Test, 2014	4.7 × 21.0 × 2.85	Wood cribs (continuous)	Gas temperatures, TSC	None	Yes	1
x-ONE, 2017	10.8 × 35.5 × 3.24	Wood cribs (continuous)	Gas and concrete temperatures	None	No	1
x-TWO, 2019	10.8 × 35.5 × 3.24	Wood cribs (continuous)	Gas and concrete temperatures	None	No	2
TRAFIR RISE Guttasjön large elongated compartment series, 2018	18 × 6 × 3	Wood cribs, or diesel pool	Gas, steel and concrete temperatures, PT, TSC	None	Yes	6
TRAFIR Ulster large compartment series, 2019	15 × 9 × 2.9	Wood cribs (continuous)	Gas, steel and concrete temperatures, TSC	None	Yes	3

The last mentioned test series was conducted within the scope of a recently concluded collaborative research project, TRAFIR (Characterization of TRAvelling FIRes in Large Compartments), funded by the Research Fund for Coal and Steel (European Commission). In addition to the full-scale experiments, the project explored the conditions supporting development of travelling fires, undertook extensive parametric analysis of conditions in travelling fires using Computational Fluid Dynamics (CFD) methods (with the Fire Dynamics Simulator (FDS)) and developed an analytical procedure to facilitate the analysis of fire structure coupling, which was also implemented into two Finite Element Method (FEM) software frameworks (SAFIR and OpenSees).

Parallel theoretical works have been progressed by a research team in the School of Civil Engineering at the University of Queensland, Australia, based upon detailed analysis of the ETFT and Malveira fire tests[46,47,48]. These studies have established the characteristic parameters associated with different fire spread regimes and make the significant observation that more intense momentum-driven flows may be found in some compartments with large openings and limited smoke layer accumulation, resulting in higher convective heat transfer, which may result in equivalent or sometimes greater thermal severities than with more constrained conditions[46], challenging some of the perceived wisdom in this area. They develop theoretical treatments for coupling crib burning processes to compartment conditions, establishing a division into fuel-bed-controlled and momentum-controlled regimes. They note that burning behaviours of non-charring plastics tend to diverge significantly from those of wood cribs, which provides a strong caution about attempting to extrapolate some of the findings from the classical studies of the problem which were nearly all performed with wood crib fuels.

In terms of implementation of the new travelling fire methodologies into design codes, the most recent version of part one of the PD 7974 suite of published documents, supporting the development of an alternative fire engineering approach to the protection of people, property and the environment from fire, includes a short section related to Travelling fire frameworks. TRAFIR project outcomes have been reported to and approved by the European Commission, via the Technical Group relevant to Steel TGS8 (Steel products and applications for building, construction and industry), and provided to members of technical committees responsible for the revision of the Eurocodes.

5.5 Structural Eurocodes

Appendix A of the 2006 edition of Approved Document B guidance sets out a number of methods by which the performance of materials, products and structures can be assessed and verified. These included a reliance on the results from standard fire tests either directly or through conforming to a specification or design that has been shown to achieve the required level of performance. Alternatively, assessment either from test evidence or relevant design guides was allowed. For fire resisting elements, a direct reference was made to a specification provided in BR 128 (see section 6.2) or the elements could be designed in accordance with a relevant British Standard or Eurocode.

In the current version of the guidance, the relevant Appendix (Appendix B) makes no direct reference to design to British or European Standards. The only reference to the structural Eurocodes is in relation to the classification of steel elements suitable for providing 15 minutes fire resistance dependent on the ratio of the heated perimeter to the cross-sectional area (H_p/A) where mention is made of EN 1993-1-2[49]. It is recommended that MHCLG review the guidance to make it clear whether this is a deliberate omission or an oversight.

The structural Eurocodes are a set of harmonised technical rules for the design of construction works. They provide a means to prove compliance of building and civil engineering works with the essential requirements of Council Directives covering both *Mechanical resistance and stability* and *Safety in case of fire*. The fire design aspects are covered in (BS) EN 1991-1-2[22] which is the fire part of the Eurocode for Actions while the fire parts of the material codes (EN 1992-1-2[50], EN 1993-1-2[49], EN 1994-1-2[51], EN 1995-1-2[52], EN 1996-1-2[53] and EN 1999-1-2[54]) cover the fire design of concrete, steel, composite steel and concrete, timber, masonry and aluminium structures, respectively. These documents incorporate a combination of tabulated design data, simple design methods and advanced design methods to determine the response of structures in fire which can be used to determine compliance with the tables of notional fire resistance periods set out in the guidance. Alternatively, in addition to deriving performance based on nominal fire exposures (such as the standard fire curve), a number of the approaches set out in the fire parts of the Eurocodes can also be used to determine performance under more realistic (physically based) fire exposures.

As a response to the European Commission Mandate M/515, the European standards organisation responsible for the development and maintenance of the structural Eurocodes, prepared a detailed work programme split into four phases leading to the development of the second generation of the EN Eurocodes. This process is nearing completion and has involved significant changes to all the fire parts of the Eurocodes mentioned above.

It is unclear how these changes will impact on the specification, assessment and approval of structural fire engineering design approaches and solutions. It is recommended that this issue is considered further in the next phase of this research project (Objective C) or outside of this project through liaison with the BSI structural fire Eurocodes group (B525/-/32). The new fire parts will need to be reviewed by the national standards bodies and a new National Annex will need to be developed for each part. It is unclear if the capability and resource is available within the UK to make informed decisions on what the UK position should be on specific changes to the fire parts of the European standards. Most of the changes will be assessed, reviewed and monitored by the construction material sector (concrete, steel, timber etc.) most directly associated with each standard. However, some of the Eurocodes deal with issues such as the fire design procedures set out in EN 1991-1-2[22] which are material independent and deal with the specification of performance in fire in relation to structural stability and compartmentation.

5.5.1 The Natural Fire Safety Concept

The fire part of Eurocode 1 contains an Annex (Annex E) setting out a methodology for the calculation of fire load densities to be used in subsequent structural fire engineering calculation methods. This approach was based on a collaborative European research project undertaken in the 1990's known as the Natural Fire Safety Concept (NFSC)[27]. Funding was provided by the European Coal and Steel Community (ECSC) and the principal objective was to provide a more realistic and more credible approach to analysis of structural safety in case of fire. It was an expressed aim of the project to implement the findings of the research into the Structural Eurocodes. In this regard, the project team led by a steel manufacturer (later merged with two other steel manufacturers in 2002) was very successful.

In developing the UK National Annex for use with the fire part of Eurocode 1, the project team felt that it could not support the use of this approach. There was general agreement that the specification of structural performance should not be reliant on active detection or intervention by the Fire and Rescue Service. There was scope provided in the UK National Annex and associated guidance to make allowance for the use of suppression systems when using performance-based structural fire engineering approaches by allowing for a reduction in the design fire load density.

New probabilistic approaches to the specification of performance have been and are being developed where the concept of time equivalence is used to relate thermal exposure derived on the basis of statistical analysis to a time equivalent value which can be compared with existing recommended values. The approach in Annex E of EN 1991-1-2 is set out in the Valorisation document for the Natural Fire Safety Concept[27]. The approach evaluates the probability of a structurally significant fire occurring based on a combination of the probability of ignition and the effect of potential interventions prior to the fire progressing to the extent that it would impact on structural performance (generally by progressing through flashover). The impact of sprinklers is taken into account as part of this approach based on statistics related to sprinkler reliability.

The availability of computers capable of running extensive Monte Carlo Simulations has promoted this form of analysis by taking a range of parameters that impact on fire growth and development and randomly varying each to produce cumulative density functions of the equivalent time of fire exposure.

The accuracy of the output will be dependent on the range of the parameters selected and how closely they reflect reality. Where sprinklers are used, then the values of reliability need to be very carefully interrogated in terms of what is and what is not counted as a failure. Although current guidance does make allowance for sprinklers in terms of a reduction in recommended periods of fire resistance in specific circumstances and does make their use mandatory in other cases, they are generally used as an addition and have not been seen as the primary means of providing structural fire resistance. In a real fire scenario, sprinklers either work or do not work. If through a generalised approach, the impact of sprinklers is such that the structure cannot achieve the requirements of the regulations in their absence, then this is a potential problem.

5.6 Summary

Alternative methods for the specification of structural fire resistance and compartmentation are available and have been used extensively by specialist structural fire engineers for many years.

A number of new approaches have been developed based on reliability theory. The approaches discussed above are complex and would be beyond the understanding of many key stakeholders involved in the procurement, regulation and approval of structural fire engineering projects.

There are difficulties with non-specialists being able to understand the relative level of performance being assessed. For travelling fire scenarios, the relative severity is very much dependent on what initial assumptions are adopted with regard to near field and far field temperatures, flame front and fire spread rates etc. The practical application of alternative methodologies is rarely used to derive a more onerous design case than would be derived from adherence to the recommended values. In general, the additional design effort needs to be offset by some reduction in the required level of performance.

There is no evidence (see Section 6.9) that the current system of specification and assessment is resulting in a level of safety which is deemed unacceptable (by society).

If a specialist designer wishes to adopt alternative procedures on a project specific basis, they are free to do so, but they must demonstrate that the proposed methodology is achieving compliance with the mandatory requirements of the regulations.

 © BRE Global Ltd 2025

6 Prioritised areas for review

6.1 Modern Methods of Construction

The construction industry is ever evolving with innovative materials and new construction practices being introduced into the market regularly. The rate of innovation is quicker than the evolution of AD B and the variety of different forms of construction is beyond the scope of generic documents such as AD B.

This results in two challenges with regard to fire safety:

1. In its current drafting (as a hybrid between guidance and prescription) AD B is open to interpretation and can be exploited (accidentally or deliberately) resulting in constructions that might not comply with Part B.

2. It can become a struggle to achieve/ensure Part B compliance, as AD B does not necessarily account for these types of construction.

According to the MHCLG MMC Cross Industry Working Group, Modern Methods of Construction (MMC) typically fall under one of the following seven categories:

- Pre-Manufacturing - 3D primary structural systems
- Pre-Manufacturing - 2D primary structural systems
- Pre-Manufacturing - Non systemised structural components
- Pre-Manufacturing - Additive manufacturing
- Pre-Manufacturing - Non-structural assemblies and sub-assemblies
- Traditional building product led site labour reduction/productivity improvements
- Site process led labour reduction/productivity improvements

The list above shows that MMC encompasses a wide variety of construction types, and rather than trying to analyse them all, it is more efficient and sensible to consider if and when such forms of construction fall within the scope of AD B (i.e. whether they are more common building situations in the context of the advice that is given in AD B) because evolving AD B (in its current format) to provide guidance would be impracticable. Whilst excluding some forms of MMC from the scope of AD B protects against accidental failure to comply with Part B through AD B compliance, it would also result in a void in the guidance for such forms of construction unless AD B was more explicit on performance expectations and MMC specific guidance was developed by industry.

The objective and aims of AD B will be addressed as the project progresses. However, the specification of recommended minimum levels of performance (fire resistance) is not based, and never has been based, on specific forms of construction, traditional or otherwise.

The values are related to the perceived risk and consequence of fire, but it is the way that performance is assessed that may need to change depending on the material, system or product used, the database available on performance in (real) fires and potential issues with interaction between the structure and compartment fire dynamics.

In general, the recommended minimum values are appropriate and demonstrably conservative. In certain specific cases the means of assessment is not providing sufficient information to ensure compliance with the regulations. In these specific cases something over and above (not instead of) reliance on results from standard fire tests is required.

The evolution of AD B guidance is derived from and for "traditional" forms of construction and is for "more common building situations". Therefore, the guidance is unlikely to be appropriate or relevant for all MMC. For example:

- Load bearing elements of structure. AD B states minimum fire resistance standards in accordance with BS EN 13501-2[23] (or BS 476-20[16]) for elements of structure and separating elements as a function of purpose group and storey height. The fire resistance standards implicitly assumed that the construction is not combustible, and that loadbearing capacity can be adequately or conservatively represented in standard fire tests. These assumptions (and hence specifications of BS EN 13501-2) are not necessarily appropriate for some forms of MMC, particularly given that some MMC include combustible components (e.g. CLT) or cannot be represented as interconnected simple elements such as beams and columns (e.g. modular construction). Conceptually, this is not necessarily a problem because AD B is for more common building situations, but because the assumptions are not explicit, it is possible to "comply" with AD B but fail to meet the intended performance and potentially fail to comply with Part B.

- Junctions of compartments. Provisions for protection of junctions (e.g. walls with floors) are based on traditional forms of construction because the fire tests are representative of traditional construction details such as brick walls or concrete floors. For some forms of MMC or non-traditional construction, the testing might not be sufficient to ensure adequate performance for example where materials might deteriorate, char or deform in fire. The integrity of the junction between a floor and wall could be impacted by charring of the surfaces or opening up of gaps due to deformations. This is not the same as connections (see below) which have a greater impact on loadbearing capacity and overall stability.

- Concealed spaces:

  – Cavities. It is typically assumed that fire spread within cavities is likely to a present a risk to health and safety. However, there are forms of MMC (e.g. modular construction or precast cladding where cavities are encapsulated in concrete) where cavities are encapsulated in fire resisting construction, and as such, may not present a risk to health and safety. Many of the issues of concern in relation to cavities and cavity barriers are a function of workmanship issues. Some prefabricated modular systems are better placed to minimise the effects of workmanship and installation problems through effective prefabrication and monitoring quality control procedures under factory production conditions

  – Cavity barriers. The traditional cavity barriers are the closed state cavity barriers which will be the system implied in the AD B. The construction industry has seen the rise of open state cavity barriers which allow drainage and ventilation in the cavity. These can typically take the form of an intumescent strip which will seal the cavity on activation by heat. This type of cavity barrier system is not mentioned in the current guidance (see below).

  – Cavity barrier testing. The performance of cavity barriers is assessed through test methods and configurations that are unlikely to be appropriate for certain MMC (or even for some forms of traditional construction). The test often involves placing a cavity barrier in a cavity surrounded by masonry or concrete and does not account for movement, warping or degradation of cavity surfaces. The use of standard fire testing and the standard fire curve to assess the performance of cavity barriers, whilst convenient, is unlikely to be representative of a real fire scenario within a cavity.

- Protection of openings. Means of protection of openings or penetrations (such as dampers, pipe collars and fire stopping) are tested in "more common" building configurations and the performance as demonstrated by testing might not be applicable to certain forms of MMC. An example would be assessing cavity barriers to be used in a timber frame external wall by carrying out a standard fire resistance test with the barrier placed between two leaves of concrete or masonry. The same issue applies to fire stopping details and penetration seals.

There are three conceptual approaches for addressing the issue:

- Expand and/or clarify AD B guidance to include MMC. This is unlikely to be practical or resilient because there are already multiple forms and examples of MMC and many more likely to be in development. AD B would be unlikely to be able to keep pace and would become unnecessarily cumbersome.

- Be explicit about the scope of AD B. On its own, this is not desirable because there would be an absence of guidance or control on MMC that fall outside the scope of AD B, which could in turn create a situation where the lack of guidance precludes forms of construction for which there is no evidence of any problems in relation to performance in fire.

- Be explicit about the performance expectation of relevant parts of AD B to allow interpretation and/or development of alternative methods. This would allow bespoke solutions (and guidance) to be developed by industry for MMC. This is not unprecedented (for instance, for buildings with atria, AD B refers to BS 9999 – previously BS 5588-7[55]) and is in keeping with recommendations made by Dame Judith Hackitt. For example, loadbearing performance objectives could be expressed in terms of ensuring escape or surviving burnout (see Section 8) and the purpose of cavity barriers and the reasons for incorporating them in specific locations could be explained.

A number of respondents to the Call for Evidence suggested that the guidance was based on "traditional" construction and is therefore inappropriate for modern innovative forms of construction. The suggestion is that the guidance should be updated to reflect modern construction. This goes to the heart of what is the purpose of AD B. In the opinion of the Project Team, it is not the purpose of the guidance to provide solutions. If there is a need for this then this should be the role of "deemed to satisfy" guidance or reference to appropriate forms of test and assessment that can be referenced within the Approved Document.

The primary purpose of AD B is to set levels of performance in a technologically neutral way that will ensure the finished construction is capable of meeting the (functional) requirements of the Building Regulations. Any attempt to try and keep up with changes to construction methods or practices will be flawed. The solution is not to try and change the guidance to keep up with changes to materials, systems and products but to modify the levels of performance required and the means by which the level of performance is assessed, based on the perceived risk.

The approach is related to the definition of those forms of construction considered as "common building types" and therefore classed as "in scope". If for whatever reason, a form of construction or the application of a specific form of construction is seen as "out of scope" then additional or alternative requirements are needed in order to demonstrate compliance with the mandatory requirements of the Building Regulations.

Two questions follow from this. Firstly, what defines whether a construction system is "in scope" or "out of scope" and secondly, what form may the additional or alternative requirements take.

There are a number of reasons why a particular form or system of construction may be classified as out of scope. The most obvious is in relation to the construction/structure because Part B relates to structural performance of buildings falling outside the scope of the purpose groups as set out in Table 0.1 of the 2019 version of AD B. This would include the construction of complex structures such as airport terminals and large stadiums or convention centres. AD B provides additional guidance and references to additional

 © BRE Global Ltd 2025

sources of information to cover some of the areas outside the purpose group classification system such as health care premises, unsupervised group homes, shopping complexes, assembly buildings, schools, prisons, buildings containing one or more atria and buildings of special architectural or historic interest. The Manual to the Building Regulations, a code of practice for use in England[56] provides further clarification and would be a useful starting point for classification. Chapter 7 of the document sets out the following:

"The approved documents provide guidance for common building situations. They may not provide appropriate guidance if the case is unusual in terms of its design, setting, use, scale or technology. Non-standard conditions may include any of the following:

a) Difficult ground conditions

b) Buildings with unusual occupancies or high levels of complexity

c) Very large or very tall buildings

d) Large timber buildings

e) Some buildings that incorporate modern construction methods"

It is clear that AD B would benefit from a clearer definition of what constitutes a "common building situation". In relation to structural fire resistance and what is generally termed Modern Methods of Construction, there are at least two situations where a particular system may be inappropriate and compliance with the recommended levels of fire resistance set out in AD B may be either inappropriate or insufficient.

The first situation is those systems where the component materials are such that there is the potential for a substantial interaction between the structure itself and the fire dynamics within a compartment such that the resulting fire severity may be increased compared to "traditional" forms of construction. The most obvious example of such a system would be a compartment constructed from mass timber but could include any system where a substantial portion of the construction and particularly the loadbearing components are formed from combustible material.

The specific cases of (light) timber frame construction and mass timber are covered elsewhere in this document, but the main issue is the potential contribution to fire severity and fire duration of the structure itself. A reliance on the results from standard fire tests alone may not be sufficient in such situations. Standard fire resistance testing is effectively a comparative test method whereby different types of structural element, products and systems are assessed against a common thermal exposure and their performance ranked accordingly.

The background to the standard fire test and the thermal exposure universally used to assess performance has been the subject of much debate in recent years[57] but the issue here is that the standard fire test under certain circumstances is different for different materials. This issue is covered in the Compliance Roadmap for mass timber developed by OFR Consultants[58] and included as an Appendix to the STA guide on mass timber construction in fire[59].

In a standard furnace test the atmosphere temperature in the vicinity of the test sample is controlled to give the standard fire exposure as set out in national and international standards. The history of the standard fire exposure has been covered elsewhere but it is a crude representation of a post-flashover fire scenario where all the combustible contents of the compartment are contributing to the fire development. In order to maintain the same gas temperature-time curve for a non-combustible as compared to a combustible component it is necessary to reduce the amount of energy in the latter case compared to the former to account for the contribution to the gas temperature provided by combustion of the material. So, when comparing the thermal input for a concrete floor slab compared to a CLT floor slab, for example, then the energy needed to follow the curve is different in the two cases. If both forms of construction are subject to a standard fire exposure for a duration of 60 minutes and the time-temperature curve is meant to represent the combustible fire load within a compartment, then the concrete slab is effectively evaluated against a higher fire load density than the CLT slab. There are two ways in which this can be addressed. Firstly, a higher level of fire resistance (or a higher level of thermal exposure) could be specified for the CLT slab or secondly, additional requirements could be specified.

The other area where the current approach (i.e. a reliance on the results from standard fire testing) may be inappropriate or insufficient is where member interaction and system behaviour play an important role in maintaining overall stability in the event of a fire. The most obvious example of this is the interaction between floors and walls and the crucial role played by connections in maintaining stability at the fire limit state. In relation to structural performance there are, for both ambient temperature situations and under the extreme conditions of a post-flashover fire, a number of potential failure mechanisms. Standard fire testing for evaluating structural stability and the maintenance of compartmentation considers three performance criteria related to the maintenance of loadbearing capacity (evaluated through controls on the amount and rate of displacement), integrity and insulation. It does not and cannot take into account alternative modes of failure (or alternative load paths) that are a function of the system behaviour rather than that of isolated elements.

Here there are again two main options. Firstly, modify the existing test standards so they take account of system behaviour or secondly, specify additional performance requirements. The former is not practical as it would require a complete overhaul of the existing system of test and assessment used across the world and therefore the latter is the most sensible course of action where it is concluded that the existing system does not provide the evidence (of compliance) required. The identification of such cases will be a focus of the project in the latter stages.

There is general agreement within the Project Team and the Technical Steering Group of the need for an additional (rather than alternative) approach to be adopted in specific circumstances but some debate as to what format the additional approach should take. The current system already allows for the development of alternative performance-based solutions and indeed makes special reference to such approaches. There is currently no mention of any alternative to standard fire resistance test procedures. What is required is the option of an assessment approach based on a realistic fire scenario that considers the specific circumstances of the end use application and can take into account potential systemic modes of failure characteristic of modular systems, the impact of service penetrations, fire stopping and the interaction between components. As mentioned above, the option to adopt a performance-based design solution exists now and has existed for many years. However, there are a limited number of specialist designers capable of undertaking the advanced analysis required to demonstrate compliance with the regulations and to justify departure from the recommended guidance. There is a need to provide a means of assessment the results of which can be clearly understood and presented in a manner that can be debated by the wide range of construction professionals involved in both the design process and regulatory control of that process. The development of a large-scale natural fire assessment process would be capable of providing the additional information required to ensure compliance with the requirements of the regulations.

Concerns were expressed among the Technical Steering Group with regard to the potential cost of a large-scale test methodology and the availability of facilities to undertake this type of activity. Based on experience, it is the opinion of the Project Team that both the costs and the scale of the work required can be controlled to enable the feasibility of the approach. Such an approach would not be generally required and would only be needed where the standard routes to compliance are insufficient or inappropriate. The intention is not to replace either standard fire testing or numerical modelling but to complement such approaches and provide information that cannot currently be provided by either of these methods.

 © BRE Global Ltd 2025

6.2 Deemed to Satisfy solutions

In the scoping study and in the Call for Evidence, reference was made to the impact of removing reference to specific guidance documents. The comments related specifically to the status of BR 128[60] and the role it played in providing (conservative) generic solutions that could be specified with confidence. It was mentioned previously that different sectors of the industry have recently attempted to provide alternative guidance[61,62] to fill the vacuum left by the decision to no longer reference the guidance in BR 128.

BR 128 as a partnership between the UK government and the construction industry served a very useful purpose. The publication of tables based on the results from standard fire resistance tests is very much in line with the methodology of the structural Eurocodes where tabulated design data is available to provide the most conservative and least time consuming approach to the specification of structural fire resistance. MHCLG should give consideration not only to the status of the structural Eurocodes in providing acceptable solutions to regulatory requirements but also the benefits of bringing together publicly available information across a range of different industries to provide a convenient and robust set of solutions to achieve specified levels of fire performance.

The important issue in referencing any particular document or approach is to be aware of the special status that this confers. Any guidance document referenced within the Approved Document must be independently reviewed to ensure that the solutions are not only robust but also are based on test data which clearly demonstrates a level of conservatism that will ensure there are no problems with implementing the guidance in real buildings. In this area, as in many others, there is a clear need for MHCLG to have access to independent, impartial, expert advice. As a minimum, any industry guidance document referred to should have been subject to an independent third-party review. Prescriptive or deemed to satisfy solutions which are demonstrably conservative have an important role to play and have done so for many years. The construction industry faces problems in providing evidence of compliance for forms of construction that have been safely used for many years. There are also problems in demonstrating compliance of standard details where there is a very minor change from tested solutions. It is not practical to provide test evidence for every detail and for every conceivable variation from a standard detail.

6.3 Maximum compartment sizes

The scoping study drew on the evidence of the “Compartment sizes, resistance to fire and fire safety” project[1] in relation to maximum compartment sizes. The overall conclusion was that a review of statistical data showed no clear correlation between compartment size and life safety for compartments with floor areas greater than 500m² for large, single-storey industrial and storage buildings.

The focus of the research was on large single-storey industrial and storage buildings and it is this category of buildings that was identified in the Call for Evidence as presenting difficulties for firefighters due to the lack of internal compartmentation. Although there is currently no limit on compartment sizes for multi-storey office buildings there tends to be a practical limit imposed on inner city developments. This is not the case with large out of town storage or industrial buildings. The design of large open plan compartments within multi-storey office buildings is the subject of a number of new initiatives looking at travelling fires (see above).

At the time of the original research reported in reference 1 the guidance to the building regulations for England in Approved Document B[63] was reviewed in relation to work stream 2 which focused specifically on maximum compartment sizes. The guidance sets out limits on the maximum dimensions of fire compartments based on the type of occupancy and the height of the building. In common with the periods of fire resistance discussed above many of the current provisions are based on the recommendations set out in Post-War Building Studies No. 20 Fire Grading of Buildings. Tables 7a to 7c in that document specify restrictions in relation to both maximum floor areas and maximum cubic capacities dependent on the nature of the construction and the nature of the fire hazard. From the outset, there was recognition that any recommendations on limiting floor areas, heights or cubic capacity to reduce the extent of loss of contents and reduce the risk of a fire developing into a conflagration should take into account commercial considerations and should not impose significant barriers to trade. Original bye laws were applicable only to buildings constructed in full or in part from combustible materials. For other forms of construction, only in London and Liverpool were there restrictions in relation to the height or cubic capacity of buildings. Subsequent revisions to the guidance have removed the distinction between combustible and non-combustible materials with performance based functional requirements applied to all forms of building. In the past, there may have been specific issues in relation to both height and cubic capacity in relation to bonded warehouses that led to specific restrictions within certain metropolitan districts. However, it is acknowledged that there was no general demand for greater heights in industrial buildings. If that were true in the immediate post-war period it is even more so now when for industrial and storage facilities the trend has been for increasing floor area rather than increasing height, while for office buildings there has been an increase in the number of very tall buildings within city centres which looks likely to continue for the foreseeable future.

The principal factors which influence the maximum size of fire compartments are:

a) the type of construction

b) the nature of the occupancy

c) the location and particularly the proximity of other buildings and

d) the nature of fire precautions including the provision of an automatic sprinkler system.

Provided “fire proof” construction was used, the recommendations of the Post-War Building Studies report did not propose a restriction on maximum height. Current restrictions on maximum height are addressed by means of performance requirements related to periods of fire resistance and there does not seem to be any reason to change this approach.

The critical issue is in relation to maximum floor area or maximum cubic capacity, particularly in relation to very large single-storey warehouse or storage buildings which may house very large amounts of combustible material. Many such buildings may incorporate significant amounts of combustible material within the fabric of the building itself in the form of insulated cladding panels forming the external envelope of the building. The definition of the building may itself be a source of confusion particularly as AD B does not set any limit on compartment size for single-storey industrial buildings but does provide a limit for unsprinklered storage buildings. In some cases, the borderline between the two may become blurred.

One of the most significant aspects of the guidance in the version of Approved Document B effective at the time of the 2015 review (and the current guidance) is that there is no limitation on compartment floor area for single-storey industrial buildings. The original recommendations of the Post-War Building Studies proposed a similar solution for single-storey buildings of Construction Type 1, 2 or 3 (protected or partially protected for low fire load occupancies) but did impose restrictions on cubic capacity in relation to other types of construction or higher fire load hazards.

The fact that single-storey industrial buildings which are not subject to issues around boundary conditions and where the structural elements only support a roof do not require any specific level of fire resistance and are not subject to any restrictions in terms of compartmentation has enabled the development of very large industrial and storage buildings. The comments received as part of the Call for Evidence indicate some concern from firefighters and from the insurance industry. The 2015 research[1] reported that Steering Group members felt that where compartment sizes greater than the limitations in the then Table 12 (Table 8.1 in the 2019 version) are constructed, it is important to realise that the access and facilities for the Fire and Rescue Service may be inadequate. It was recommended that where large compartments are constructed using alternative fire engineering approaches, the Fire and Rescue Service are consulted at as early a stage as possible.

Although the regulatory guidance does not specify any limitation in maximum compartment size for such buildings, insurance industry requirements do[64]. For single-storey buildings belonging to the industrial group where no limit on compartment floor area is specified in the Approved Document, the property protection requirements limit the maximum compartment floor area to 7,000m² where there is no approved sprinkler system installed and 14,000m² where an approved automatic sprinkler system is installed.

The research published in 2015 reported on the views of the Steering Group that there was a need to include a limitation on compartment sizes for single-storey buildings in Approved Document B. However, such a limitation would not mean that large compartments could not be constructed, simply that they would not be covered by the simplified guidance within Approved Document B. A designer wishing to go outside the limits would need to carry out a fire engineered design in accordance with BS 9999[5] or BS 7974[7] as appropriate. This then is another potential area to be identified as out of scope within AD B.

As part of the 2015 research project, BRE Global looked at the available statistics to determine the impact of increased compartment size on life safety. The data from the DCLG's Incident Reporting System (IRS) records[65] were analysed to generate statistics that illustrate the effect of compartment size. The records reviewed covered the four year period 1st April 2009 to 31st March 2013.

The conclusions are as follows.

- The DCLG fire statistics show a clear trend for the average area damaged by fire to increase as the area of the room of origin increases up to a certain size. However, where life safety is concerned, there is no trend for the risk to increase as the area of the room of fire origin increases. This suggests that the measures currently recommended by AD B, to mitigate against (perceived) increase in risk for larger compartments, are having the intended impact i.e. the residual risk is no higher for large compartments than for smaller ones.

- Generally, sprinklers are shown to reduce the life safety risks in non-residential buildings. (For dwellings and other residential buildings, the statistics are too sparse to draw meaningful conclusions). However, as the life safety risks are low to begin with, the primary benefits of sprinklers remain the economic ones (property protection of building and contents, reduced business interruption, etc.)

- Based on the analysis of DCLG data from the UK between 2009 and 2013, there is no obvious statistical evidence for an increase in risk to life safety as compartment sizes increase.

As part of the 2015 research project, a review was undertaken of alternative approaches used to derive maximum compartment sizes to provide an international perspective in relation to regulatory requirements. The results from the study are summarised in Table 2. The review concluded that the provisions within the regulatory guidance in relation to maximum compartment sizes for single-storey industrial and storage buildings for England are the least onerous of all the countries investigated.

Table 2 – International requirements for maximum compartment sizes for single-storey industrial and storage buildings (excluding car parks)[2]

Country	Code/ Guidance/ Regulation	Single-storey industrial				Single-storey storage			
		Unsprinklered		Sprinklered		Unsprinklered		Sprinklered	
		High risk	Low risk	High risk	Low risk	High risk	Low risk	High risk	Low risk
England	AD B	No limit	No limit	No limit	No limit	20000	20000	No limit	No limit
England	AD B (property protection)	7000	7000	14000	14000	2000	8000	2000**	8000**
Wales	AD B (Wales)	No limit	No limit	No limit	No limit	20000	20000	No limit	No limit
Scotland	NDTGD	33000	93000	66000	186000	1000	14000	2000	28000
Republic of Ireland*	TGDB	33000	93000	66000	186000	14000	No limit	28000	No limit
Australia*	BCA	2000	2000	2000	2000	2000	2000	2000	2000
Hong Kong*	HKCPFSB	10500	10500	10500	10500	10500	10500	10500	10500
South Africa	SANS 10400	5000	5000	No limit	No limit	No limit	No limit	No limit	No limit
Greece		5000	2000	12500	4000	3000	3000	3000	3000
China	GB 50016-2006	2500	2500	5000	5000	2500	2500	5000	5000
Holland	DBR	2500	2500	No limit	No limit	1000	1000	No limit	No limit
India	NBCI	1125	1125	No limit	No limit	1125	1125	No limit	No limit
Denmark		2000	5000	10000	10000	2000	5000	10000	10000

* Restrictions on volume also apply
** Recommended floor areas may be increased if a suitable automatic extinguishing system is provided.
AD B = Approved Document B
NDTGD = Non-Domestic Technical Guidance Document
TGDB = Technical Guidance Document B
BCA = Building Code of Australia
HKCPFSB = Hong Kong Code of Practice for Fire Safety in Buildings
SANS = South African National Standards
GB = Guobiao Standards
DBR = Dutch Building Regulations
NBCI = National Building Code of India

6.4 Timber frame construction

The scoping study referenced comments received in the Call for Evidence concerning timber frame and the potential confusion between timber frame and MMC and, to a certain extent, between mass timber construction and light timber frame.

In recent years, the timber construction industry in the UK, initially through the UK Timber Frame Association and, in recent years, through the Structural Timber Association, has been active in providing guidance and conducting research related to the performance of timber structures in fire. The industry has worked closely with a range of key stakeholders including representatives from the Fire and Rescue Service, regulatory bodies, insurers, fire engineers and academic experts to produce guidance covering specific aspects of fire safety including during the construction phase and the as built situation[59, 61].

Regulatory requirements and guidance in relation to the use of timber in construction varies significantly from country to country. It is important to realise the distinction between the requirements of the regulations and the means by which compliance is demonstrated. Safety in case of fire is one of the seven Basic Requirements of Construction Works as set out in the European Construction Products Regulation (CPR) which replaced the Construction Products Directive. In accordance with the CPR, construction works must be designed and built in such a way that in the event of a fire:

a) The load-bearing capacity of the construction can be assumed for a specific period of time;

b) The generation and spread of fire and smoke within the construction works are limited;

c) The spread of fire to neighbouring construction works is limited;

d) Occupants can leave the construction works or be rescued by other means;

e) The safety of rescue teams is taken into consideration.

There are clear parallels here with the functional requirements of the Building Regulations. In a European context CEN TC127 (fire safety in buildings) is responsible for the development of standards for testing and classification and CEN TC250 is responsible for the development of design standards that provide alternative (to testing) means of demonstrating compliance with the requirements.

There is a clear distinction here between European standards on the technical level (whether test and classification or design standards) where harmonisation of standards has taken place across Europe and regulatory requirements applicable to different types of buildings which remain a subject for national choice. Acceptable levels of fire safety within individual member states are assessed on a political level and not purely on a technical level. One consequence of this is that there are major differences between countries within Europe (and outside Europe) with regard to the application of timber construction in buildings. Some countries (such as England) adopt a performance-based approach whereby the functional requirement is specified in general terms and the recommended values are set in relation to a level of performance and not (in general) restricted by material or technology. Klippel et al[66] provide a summary of restrictions across international regulatory systems to the use of products with a similar Reaction to Fire classification as timber in terms of allowable number of storeys or height of building based on investigations undertaken as part of COST ACTION FP1404 (Fire safe use of bio-based building products). The situation is summarised in Table 3. The information is currently being reviewed and updated through the European Fire Safe Use of Wood network and the current situation will be included in subsequent outputs for this project.

Table 3 − Regulatory limitations and possibilities for D and D_{FL} reaction to fire class products reproduced from reference 62, first 6 columns only.

Country	Allowed number of storeys (or height of building in m) for D class products				
	Load-bearing structures			External cladding	
	Prescribed rules	Performance based (PB)	Protection required	No sprinklers	With sprinklers
Austria	6	No limit	No	6	6
Belgium	See PB	No limit	No	3 (10 m)	3 (10 m)
Czech Republic	3-4 (12 m)			3-4 (12 m)	3-4 (12 m)
Denmark	3-4	No limit		3-4	3-4
Estonia	4	No limit	No	8	8
Finland	2 / 8[b]	No limit	K_210/K_230	2/4	8
France	No limit	No limit	No	4 or 50 m[c]	
Germany	4-5	> 5	K_260	3 (7 m)	3 (7 m)
Greece	No limit	No limit	No	No limit	No limit
Ireland	3 (10m)	No limit		≥ 5	≥ 5
Italy	See PB	No limit	No	(12 m)	(12 m)
Latvia	4	Not used	B-s1,d0	4	4
Macedonia	2			2	
Netherlands	13 m	No limit		3-4	≥ 5
Norway	4	No limit	EI30/EI60,K_210	4	4
Poland	3-4 (12 m)		B-s1, d0	(25 m)	(25 m)
Portugal	(9 m/single family)			(28 m)	(28 m)
Slovakia	2-4	Not permitted	EI	(12 m)	(12 m)
Slovenia	3 / 5[b]	No limit	EI30/EI60	3 (10 m)	3 (10 m)
Spain	See PB	No limit	EI30-EI120	6 (18 m)	6 (18 m)
Sweden	See PB	No limit	No	2	≥ 5
Switzerland	(30 m)	No limit	No	(30 m)	(30 m)
Turkey	3	No limit	F30B2/F60AB	3	3
United Kingdom	See PB	No limit		≥ 5	≥ 5

[b] With sprinklers

[c] Applicable for dwellings; more than 4 storeys requires compliance with French façade test

6.5 Mass timber construction

The discussion above in relation to MMC and timber frame construction has already made reference to mass timber construction and specific issues in relation to Cross Laminated Timber. This is clearly a very important development in the construction industry worldwide and has been the focus of extensive research throughout the world.

The use of mass timber construction especially Cross Laminated Timber (CLT) is now on the rise as architects and building owners have found it to be more aesthetically pleasing and more sustainable.

© BRE Global Ltd 2025

In such construction, the building structure (beams, columns, floors, walls, etc.) include mass timber components, which are combustible.

6.5.1 Fire resistance

Provision B3(1) of the Building Regulations requires that, “The building shall be designed and constructed so that, in the event of fire, its stability will be maintained for a reasonable period.” There is no definition of “stability” or “reasonable period”.

The Intent Section of AD B states that, “For defined periods, loadbearing elements of structure withstand the effects of fire without loss of stability.”

The AD B active recommendations are:

“Elements such as structural frames, beams, columns, loadbearing walls (internal and external), floor structures and gallery structures should have, as a minimum, the fire resistance given in Appendix B, Table B3.

Appendix B includes guidance on all of the following.

a) Provisions to ensure that where one element of structure supports or stabilises another element of structure, the supporting element has no less fire resistance than the other element (see Table B4).

b) Measures so that elements common to more than one building or compartment are constructed to the standard of the more onerous of the relevant provisions.

c) Special provisions about fire resistance of elements of structure in single-storey buildings.

d) Concessions in respect of fire resistance of elements of structure in basements where one or more sides of the basement are open at ground level.

AD B Table B3 refers to AD B Table B4 and provides minimum fire resistance standards in accordance with BS EN 13501-2[23] or BS 476-20[16] for elements of structure as a function of purpose group and storey height.

The AD B specifications implicitly assume that:

- The elements of construction do not contribute to the total fuel load within a building/compartment, and
- For certain purpose groups and heights, the intent of the fire resistance standard is to ensure an adequate likelihood of the structure maintaining its stability until all the combustible contents have been burned and beyond. This is commonly referred to as “surviving burnout”.

The above is not explicitly stated within AD B. However, where the construction of a building is combustible:

- The construction itself can burn and as such contributes to the total fuel load within a building or compartment, and
- If ignited, the structure of the building could continue to burn and ‘fail’ after any combustible contents have been burned or extinguished (i.e. it would not necessarily survive burnout).

Therefore, where the construction of a building is combustible, it is possible that it would not comply with the implicit assumptions of AD B, would not comply with the intent of AD B, and would not achieve the same fire resistance as an equivalent non-combustible construction.

Additionally, BS EN 1995-1-2[52] provides methods for calculating the fire resistance of timber construction. The methods in BS EN 1995-1-2 do not account for any additional fuel load associated with combustible construction, nor does BS EN 1995-1-2 provide a requirement or any advice to ensure survival of burnout.

Therefore, as it is currently drafted, compliance with the explicit AD B recommendations does not necessarily result in compliance with the implicit intent of those recommendations because compliance with BS EN 1995-1-2 does not necessarily ensure stability is maintained for the implicit reasonable period associated with surviving burnout.

Therefore, to address this situation, an appropriate combination of the following is required:

1. Provide explicit guidance within AD B on the performance requirements for elements of structure to achieve the functional requirements of Part B3(1) by interpreting the B3(1) functional objective to define common building situations. This interpretation is already in Approved Document A to some extent by virtue of consequence classes and similar concepts could be included in AD B (for example, for consequence class 1 and 2A a reasonable period might be that currently specified). Specifically, provide guidance on 'stability' and 'reasonable period':
    a. Stability: Part B3(1) requires building stability to be maintained. For common building situations it may be the most appropriate way to ensure stability is maintained is to ensure that all loadbearing elements retain adequate capacity in fire. Alternatively, it could be accepted that individual loadbearing elements do not need to retain capacity provided overall building stability is maintained.
    b. Reasonable period: Currently AD B contains two implicit periods. Firstly, a 30 minute standard or less is based on the need to ensure stability is maintained for a duration sufficient to ensure occupants can escape and the Fire and Rescue Service have some chance of preventing overall collapse. Secondly, a 60 minute or greater standard is to ensure an acceptable probability of surviving burnout. 90 and 120 minute standards were derived for higher risk buildings but still relate to burnout. This concept could be retained for more common building situations, but made explicit within the document. Being explicit would also set a benchmark against which "non-AD B compliant" designs could be assessed. Alternatively, the duration could be linked to the fire strategy in that the duration should be sufficient to allow for escape, prevent fire spread between buildings and ensure adequate fire service access. Such an approach would allow flexibility to increase requirements under specific circumstances taking into account for example occupancy mobility and impairment issues in care homes.
2. Make any implicit assumptions explicit. For example:
    a. Fuel load. Be explicit that the fire resistance standards assume that the construction does not contribute to the overall fuel load (and therefore, either the combustible construction must be prevented from burning, or fire resistance standards must be increased to account for combustible construction).
    b. Burnout. Be explicit for which purpose groups and storey heights surviving burnout is required.
    c. Sub-assemblies. Be explicit that AD B assumes that the connections between any sub-assemblies (e.g. connections between beams and columns) will maintain the fire resistance of each component. This is to be clear that connections between mass timber elements must also be shown to perform adequately.
3. Make reference to the Structural Timber Association[59] (STA) guide for achieving compliance with Part B3(1) for mass timber structures. It established the consequence of failure for different building types and recommended the route to compliance which could be either performance-based or guidance based. This guide explains the impact of fire safety on timber structures and provides possible solutions.

4. Provide explicit context on what constitutes a ‘more common building situation’ in respect of fire resistance standards. For example, the fire resistance standards are only applicable to the following:

   a. Buildings where elements of structure are not combustible, and

   b. Structures where the thermodynamics and associated heat transfer can be adequately or conservatively represented by the standard fire (i.e. a constantly increasing temperature applied to the whole compartment with no cooling phase). Examples of structures that might fall outside the scope include:

   - Structures where fire resistance is sensitive to the rate of heating (e.g. where the relative temperature between components would change as a function of heating rate such as steel structures with a combination of protected and unprotected beams or structures susceptible to spalling).

   - Structures where heating might not be the same throughout a compartment (e.g. travelling fires) and where fire resistance is sensitive to differential heating (e.g. restrained thermal expansion). Such situations may be rare.

   - Structures where fire resistance can deteriorate during cooling (e.g. thermally brittle structures such as steel structures where connections might rupture or structures that continue to deteriorate beyond the heating period such as thermally thick structures where the thermal wave takes time to progress through the structure or combustible structures).

   c. Structures where the thermo-mechanical response can be adequately or conservatively represented by standard fire tests. Examples of structures that might fall outside of this scope include:

   - Structures where the overall performance is reduced by interactions between sub-components (e.g. restrained thermal expansion).

   - Structures where expansion of structural elements could lead to loss of stability (e.g. tensioned structures such as post tensioned concrete with unbonded tensioning cables).

6.5.2 Compartmentation

Provision B3(3) of the Building Regulations requires that, “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 [. . .] sub-division of the building with fire-resisting construction [or sprinklers].”

Therefore, as well as a stability function, mass timber elements (e.g. CLT floors or walls) are also likely to be used in situations where they are required to achieve a subdivision (compartmentation) function.

AD B specifies fire resistance recommendations for sub-dividing elements in accordance with AD B Table B3. Therefore, the implicit and explicit assumptions are the same as for fire resistance, and the same recommendations apply.

6.5.3 External fire spread

Although not a specific concern of this project the potential impact of mass timber on external fire spread has been considered. Provision B4(1) of the Building Regulation requires that, “The external walls of the building shall adequately resist the spread of fire over the walls and from one building to another, having regard to the height, use and position of the building.”

AD B recommendations in respect of Part B(1), particularly with respect to allowable unprotected areas, are predicated on the assumption that the construction does not contribute to the total fuel load within the building.

 © BRE Global Ltd 2025

Therefore, AD B should either:

- Provide a methodology for accounting for additional fuel load from burning combustible construction, or
- Recommend that combustible construction should be adequately encapsulated such that it does not contribute to the overall fuel load with respect to determination of allowable unprotected areas.

6.5.4 CROSS Report 966

A report has been submitted and published on the CROSS UK website entitled "The risk of collapse of multi-storey CLT buildings during a fire" (CROSS Report 966[67]). CROSS stands for Collaborative Reporting for Safer Structures and provides a forum for confidential reports to be submitted covering issues of structural (and now fire) safety. Given the relevance of this subject to the current research, the report and the views of the CROSS Expert Panel and feedback provided as it appears on the website has been reviewed.

The report focuses specifically on buildings designed to achieve 60 minutes fire resistance. Presumably this relates to the recommendations in AD B and therefore only covers buildings where the height from lowest ground level to the uppermost occupied storey is less than or equal to 18m. There is nothing to prevent CLT being used for applications where a 90 or 120 minute requirement would be appropriate. The concerns raised in relation to multi-storey buildings where sleeping accommodation is provided would certainly include buildings where the "design intent" is to achieve more than 60 minutes.

The concept of design for burnout and its relationship with the mandatory requirement to maintain stability for a reasonable period is more complex than assumed in the CROSS report. The original concept of design to withstand burnout of all combustible material within a fire compartment was predicated on a concept of a "Damage Hazard" which considers principally the effect of a fire on the structure and its contents and incorporates an element of property protection in the original recommendations. The current regulatory requirement is based on a concept of "Personal Hazard" which considers the effect of a fire on the occupants of the building, those in the immediate vicinity and firefighters. This means that not all buildings are necessarily designed to survive burnout of all combustibles. The requirement is dependent on the specific circumstances and the relationship between the "Damage Hazard" and the "Personal Hazard". However, it is accepted that for the majority of high-rise buildings designed on the basis of compartmentation and particularly for high rise buildings providing sleeping accommodation then design for burnout is a reasonable expectation.

It is stated that the concept of design for burnout is the basis for the longer fire resistance requirements in AD B. As discussed above, these values were again influenced by issues such as means of escape and access for fire-fighters which are more closely related to the concept of "Personal Hazard". It is therefore not clear that "the aim of the regulations for longer fire resistance durations is… to ensure that a building's design is suitable to withstand burnout without collapse". The aim is to ensure a reasonable standard of life safety in a fire. In some cases, this may be achieved through a design to resist burnout in other situations a lower level of performance may be acceptable.

It is stated that there is considerable academic research indicating that CLT does not reliably self-extinguish. It is not clear that this is true. The majority of "academic" research available (see below) has been looking to demonstrate the exact opposite and in most cases has been supported by the CLT industry or designers wishing to utilise CLT so it is not clear how academic (or independent) such research is.

The issue of delamination is discussed, and it is clear that this may occur under specific circumstances. This is a complex area and depends on the nature and performance of the bond between lamellas. The uncertainties in this area highlight the need for independent research. Research is being undertaken but again the issue of independence and impartiality needs to be addressed.

© BRE Global Ltd 2025

The CROSS reporter suggests two ways in which CLT could be adopted. These are along the lines suggested in the STA Guidance[58] and are:

- Demonstration of self-extinguishing behaviour should be provided for the particular CLT construction used, or
- The CLT should be fully encapsulated in fire resistant plasterboard (or similar material) to limit the risk of it becoming involved in fire in the first place.

Neither of these solutions adequately address the concerns raised. The CROSS reporter has already stated that CLT does not reliably self-extinguish and there is no guidance on how self-extinguishing behaviour should be demonstrated. This area is complex, and knowledge is required not only by the designers but also by the regulatory bodies charged with approving such designs. The question remains who is going to demonstrate this behaviour and how is it going to be achieved. Full encapsulation will undoubtedly enable the construction to achieve a specified performance in a standard fire test. This could even be achieved without any form of encapsulation, but it will not guarantee that the construction is capable of withstanding burnout unless there is some relationship between the fall off time of the protection (known) and the severity of the fire (unknown).

The assertion that Part B guidance should only be applied in buildings where the structure is not anticipated to burn and contribute additional fuel would suggest that it is inappropriate for light timber frame. The requirement depends on the application and the level of "Personal Hazard" associated in each case.

It is stated that the phenomenon of char formation and the insulation provided leads to eventual self-extinguishment of the timber. This is dependent on the severity of the fire and may just as easily end up in collapse of the structure as self-extinguishment of the timber. It is true that a simple reliance on charring rates may be inappropriate for mass timber construction. Again, this is an area where independent impartial research is required.

The CROSS reporter recommends that Eurocode and/or Part B guidance be explicitly changed to identify and mitigate specific fire safety risks of using exposed CLT in construction. There has been very little active participation in the development of the Structural Eurocodes and no UK involvement in the Project Team responsible for updating the fire part of the Eurocode for the fire design of timber structures which includes rules for the design of mass timber construction. It is recommended that this issue should be dealt with in relation to the guidance in AD B within the current MHCLG project.

In the response of the CROSS Expert Panel it is stated that "This (the use of CLT in conformity with the minimum requirements of the regulatory guidance) could potentially lead to the construction of buildings that may not satisfy the functional requirements of the regulations or the expectations of the owners and their insurers. Some of these buildings might allow fire development that could endanger the occupants, neighbours and firefighters." This is the primary focus of the current MHCLG research project although the scope is wider than just mass timber construction as this is not the only example of where following the recommendations in the guidance may not be sufficient to meet the mandatory requirement of the Building Regulations.

The CROSS Expert Panel states that "Whilst the Approved Documents are not explicit about the assumptions that sit behind the guidance, there is a wealth of industry and academic literature that details the principles of design for burnout." Again, this is one of the areas identified in the scoping study and review currently underway as part of this research project. This demonstrates the need for a more open and explicit statement of the aims of the guidance in AD B.

There is some recognition that the issue may be wider than that of CLT construction in the reference to "innovative construction materials" and that "commonly applied design assumptions" may be invalidated by the chosen material or system. Again, this is a primary focus of the current MHCLG research.

The CROSS Expert Panel seems to hold great store in “guidance from specialists”. It is not desirable to rely on a small core of “experts” who will judge the merits of specific design solutions. What is required is a robust means of demonstrating compliance which is independent, impartial and can be understood by all those with an interest in maintaining acceptable levels of fire safety in construction.

The STA guidance referred to is helpful in filling the gap in knowledge by providing hopefully conservative solutions to the application of mass timber construction but it is not a replacement for genuine independent and impartial research in this area and it still relies to a certain extent on the expertise of a small number of “specialists” to demonstrate compliance with the requirements of the Regulations.

The reference to Approved Document A in the CROSS report is confusing. The robustness rules were established in response to accidental load cases not generally covered by structural design procedures. Approved Document A requires a systematic risk assessment for higher consequence structures. This risk assessment should include the risk of disproportionate collapse due to fire. However, acceptable mitigation may be as straightforward as ensuring the design complies with the requirements in AD B. The risk assessment may be one place where the relevance of the AD B guidance, to the building in question, is checked. The fact that the Eurocodes deal with fire as an accidental action in the same way as other extreme events does not mean that this is a more suitable frame of reference for performance in fire than that currently used and developed over many years on the basis of experience of real fires.

The Project Team has reviewed feedback received since the CROSS Report 966 was published, available on their website. It is not at all surprising that the feedback focuses on the fact that compliance with the guidance in Approved Documents does not guarantee compliance with Building Regulations. There is a generally held view within the profession that reliance on the guidance does demonstrate compliance and that this would be supported by the legal system. This goes to the heart of what the guidance is intended to cover and what is meant by “common building situations”. Again, this is an issue which has been raised in the current MHCLG research project and recommendations will likely be provided for the government to consider a more explicit explanation of the objectives of the guidance and what is covered and what is not covered or not wholly covered.

The comments related to burnout are understandable and, to a certain extent, correct. It is certainly true that not all buildings are designed to withstand burnout and it was never the intention for this to be the case. The problem comes in defining those that should be and those that do not need to be. Again, this is an issue with which we will be dealing with in the MHCLG project.

The report and the subsequent feedback have provided further evidence of the need for fundamental independent, impartial research to be undertaken in relation to the performance of CLT buildings in fire. It also provides further evidence of the confusion that exists in relation to the nature and purpose of the regulatory guidance documents for fire and the need to provide further clarification in this area.

6.5.5 Review of mass timber fire experiments

There is a great deal of work being undertaken at this time into the behaviour of mass timber and specifically CLT in fire. OFR Consultants have been appointed by CLT suppliers Stora Enso, BinderHolz and KLH to undertake research in support of establishing a defensible fire safety design envelope for mass timber buildings, with an emphasis on commercial and residential medium to high rise buildings. This work is clearly of direct relevance to the current project. The CLT research project constitutes six primary work packages as set out below:

- WP1 Compliance framework;
- WP2 Continuing Professional Development presentations to stakeholders;
- WP3 Large-scale experiment literature review;
- WP4 Guidance on an encapsulated (protected) route to compliance;

© BRE Global Ltd 2025

- WP5 Large scale experiments for residential buildings; and
- WP6 Large scale experiments for commercial buildings

The work is ongoing and is being disseminated through the Structural Timber Association website. Those responsible for funding and coordinating the work have engaged with a range of key stakeholders through the existing network established by the timber frame industry and coordinated initially through the Chief Fire Officers Association and latterly through the Fire Sector Federation. Many of the organisations involved in the Technical Steering Group for this project will have been part of the consultation exercise organised through the STA.

The information reviewed here is focused on WP3 above to identify the scope and nature of experimental fire research conducted in this area both here in the UK and internationally. The information produced as part of WP1 and included as an annex to the STA Guide to Mass Timber Construction in Fire[58] effectively forms another strand of the alternative methods for specifying periods of fire resistance covered in Section 5 above.

The output from WP3 available as a free download from the STA website[68] provides more detailed information on each of the fire tests/experiments undertaken. Table 4 and Table 5 are a brief summary of the work referenced based on the tables provided in the summary to the WP3 output. The report splits the review into those experiments focused on unexposed CLT which, in the report, are confined to exposed floor/ceiling panels, partially exposed CLT, unexposed CLT and external fire spread on CLT external walls.

The work of Mindeguia et al[69] is particularly important here as it focused on the comparative performance of combustible (CLT) and non-combustible (reinforced concrete) floor slabs under identical conditions in both standard furnace and natural fire tests. The output from WP3 is focused purely on the performance of the CLT and does not provide any indication of comparative performance. It is interesting to note that for the four scenarios under which the CLT slab was tested, collapse occurred in the cooling phase in all but one scenario (natural fire scenario with relatively high levels of ventilation). In the other cases, collapse occurred at times ranging from 108 minutes to 29 hours from the start of the tests. The natural fire tests utilised fire load densities consistent with values adopted for structural engineering design calculations for residential buildings.

The tests reported by Medina Hevia[70] provide some justification for partial encapsulation although of the three tests undertaken two had to be manually extinguished while the third which demonstrated self-extinguishment was that with the lowest percentage of exposed timber and only involved a single wall.

Su et al[71] reported the results from six compartment tests in an enclosure with plan dimensions of 9.1m x 4.6m and a height of 2.7m. In all tests, the CLT surfaces were either completely or partially encapsulated. In two cases, the fire had to be manually extinguished and in one case where only a single wall was left exposed, secondary flashover occurred as a consequence of delamination which resulted in the full involvement of all panels initially encapsulated.

Although not a specific focus of the current project, Bartlett et al[72] used data derived from the tests described in reference 69 and concluded that the inclusion of the CLT ceiling (when compared with the same scenario and a reinforced concrete ceiling) resulted in a considerably greater heat flux to the external façade, increased temperatures in the external plume and an increased hazard with regard to external fire spread to neighbouring buildings.

Many of the large-scale fire tests described have identified delamination as a potential issue impacting on charring rates, fire severity and sometimes leading to secondary flashovers. Dagenais et al[73] investigated the behaviour of different types of adhesives used in the manufacture of CLT. Brandon et al[74] highlighted the need to prevent glue line integrity failure and made reference to the implicit requirements in performance based regulations for buildings above a certain height to be able to survive burnout.

The OFR review is contemporary and comprehensive. However, it is a sign of the activity within this area of research that important work has been released in the public domain since the publication of the WP3 output. Arup have recently published a brief summary of a series of full-scale fire experiments in a very large purpose-built compartment with a floor area of 380m² [75]. The work is being undertaken at CERIB in France. Preliminary results from the first experiment involving a CLT ceiling have shown the initial fire spread across the exposed CLT ceiling was faster than expected. Smouldering behaviour in the cooling phase was observed that led to breaches in the CLT thickness in a number of places. The results confirmed the observations of reference 72 in relation to substantial external flame extension.

It is clear from the above that a large amount of research has been undertaken into the behaviour in fire of compartments constructed from CLT. This activity shows no sign of abating and the work currently supported by Arup in France and the ongoing activities of the industry-funded research coordinated by OFR will improve knowledge in this area.

What is clear from a study of the results from the large-scale fire tests undertaken to date is that there is very little definitive information on the means by which it can reliably be demonstrated that self-extinguishment will occur in any specific credible fire scenario where significant amounts of exposed timber are present. There is some evidence that supports this as a phenomenon that can occur and important evidence on the level of critical heat flux that is not to be exceeded for this to happen. There is certainly evidence that encapsulation is a potential solution provided it is specified and installed correctly. In this way, mass timber is no different to light timber frame, but additional care is required because of the potential impact on fire dynamics should the protection be removed before the critical flux is reached. The current guidance provided by the STA is the most effective way to deal with this issue in the short term until more definitive information is available and accepted within the industry.

While it is clear that a great deal has been done, it would appear that the majority of the work has been supported by the CLT industry with the stated aim[68] of increasing the market share of this innovative form of construction particularly in relation to high rise commercial and residential buildings. There remains a need to undertake independent, impartial research in this area where the main input parameters are clearly defined and related to realistic design fire scenarios. The Project Team will aim to learn from and build on the work conducted to date and summarised in the tables below. Although the intention is to collaborate with the mass timber industry it is important that the Project Team retains commercial independence.

There remains a need to provide a critical review of the design processes put forward in the latest draft of the Eurocode for the design of timber structures in fire. It is understood that the design method proposed is now to be included in the main “normative” part of the code rather than an informative Annex where national choice on how it is applied within each member state is allowed.

Table 4 − Summary of key information from the different studies on CLT compartments (Table 13 from reference 64)

Author/s	CLT exposure	Properties of the CLT members	Glue type	Thickness of the CLT build-up (mm)	Type of test	Size of opening/ opening factor	Fire load density (MJ/m^2)	Peak HRR (MW)	Peak room temperature (°C)	Time to delamination[1] (min)	Charring rate[2]
Friquin et al. (2010)	Fully exposed	Species: Norwegian spruce Moisture content: 8-9.3% Density: 440 kg/m^3	Melamine formaldehyde	Refer to Table 1	Furnace test following the parametric curve of a fictitious 4.08 m x 3.08 m x 3.00 m compartment Standard fire test	Not mentioned	511	Not mentioned	1050	No delamination	Parametric: 0.68- 0.95 Standard: 0.31-0.71 Swedish: 0.46-0.63
Klippel et al. (2014)	Fully exposed	Species: spruce-pine-fir Moisture content: 12%	Polyurethane	34-34-34 34-24-24-24-34	Standard fire test	N/A	N/A	Not mentioned	Not mentioned	No delamination	Wall: 0.72 Floor: 0.79
Lineham et al. (2016)	Fully exposed	Species: spruce/pine Moisture content: 10% Density: 457 kg/m^3	Melamine formaldehyde	20-20-20-20-20 33-34-33	Four-point loading test with an incident heat flux of 27.7 ± 2.5 kW/m^2 on the underside of the beam	N/A	N/A	Not mentioned	Not mentioned	No delamination	Initial: 1.4-2.0 Quasi-steady: 0.3-0.5
Mindeguia et al. (2019)	Fully exposed	Species: spruce	Polyurethane	33-33-33-33-33	Natural fire experiment using 6 m x 4 m x 2.52 m compartment Standard fire test	Natural fire test Scenario 1: 0.14 $m^{1/2}$ Scenario 2:0.05 $m^{1/2}$ Scenario 3: 0.03 $m^{1/2}$ Standard fire test: N/A	891	Not mentioned	Standard: 1050 Scenario 1: 1250 Scenario 2: 1210 Scenario 3: 1220	Standard: 55-70 Scenario 1: 40-60 Scenario 2: 45-65 Scenario 3: 65-85	Refer to Table 3

Author/s	CLT exposure	Properties of the CLT members	Glue type	Thickness of the CLT build-up (mm)	Type of test	Size of opening/ opening factor	Fire load density (MJ/m^2)	Peak HRR (MW)	Peak room temperature (°C)	Time to delamination[1] (min)	Charring rate[2]
Dagenais et al. (2019)	Fully exposed	Species: Douglas fir, spruce-pine-fir	Polyurethane Improved polyurethane Melamine formaldehyde Phenolic-resorcinol-formaldehyde	35-35-35-35-35	CSA O177 Annex A.2 flame test Furnace tests	N/A	N/A	Not mentioned	Furnace: 1060	Polyurethane specimens: 1st layer: 70 2nd layer: 112 3rd layer: 155 4th layer: 173 Other specimens: Not reported	Refer to Table 5
Medina Hevia (2014)	Partially exposed Test 1: 52.8% Test 2: 59.4% Test 3: 29.7%	Species: spruce-pine-fir Moisture content: 10.7%	Polyurethane	35-35-35	Natural fire experiment using 4.5 m x 3.5 m x 2.5 m compartment	1.07 m x 2.00 m	531.6	Test 1: 4.8 Test 2: 6.3 Test 3: 4.4	Test 1: 1200 Test 2: 1200 Test 3: 800	Test 1: 68 Test 2: 40 Test 3: No delamination	Test 1: 0.69 Test 2: 0.77 Test 3: 0.71
Li et al. (2016)	Fully exposed Tests 1 & 3 Partially exposed Tests 5-7 Unexposed Tests 2 & 4	Species: spruce-pine-fir	Not mentioned	35-35-35	Natural fire experiment using 3.71 m x 4.71 m x 2.71 m compartment	1.1 m x 2.0 m	753	Tests 1 & 2: not mentioned Test 3: 7.7 Test 4: 5.1 Test 5: 4.8 Test 6: 6.4 Test 7: 4.4	Tests 1 & 2: not mentioned Test 3: 1190 Test 4: 1100 Test 5: 1210 Test 6: 1190 Test 7: 1090	Delamination was observed in Test 3, 5, & 6. However, the time to delamination was not reported.	Test 1: 0.81 over the first 6 mm, 0.51 over the next 6 mm, 0.63 average over these 2 depths combined, 0.69 overall average Test 2:0.77 overall average Test 3: 1 over a 60-M

Author/s	CLT exposure	Properties of the CLT members	Glue type	Thickness of the CLT build-up (mm)	Type of test	Size of opening/ opening factor	Fire load density (MJ/m²)	Peak HRR (MW)	Peak room temperature (°C)	Time to delamination[1] (min)	Charring rate[2]
											in. period, 0.71 overall average Test 5:0.6 initial, 1.1 max. alter 15 min Test 6:0.6 initial, 1.0 max; Test 7: no reported value
Emberley et al. (2017)[3]	Partially exposed ceiling and one side wall	Species: radiata pina Density: 425 kg/m³	Not mentioned	45-20-20-20-45	Natural fire experiment using 3.5 m x 3.5 m x 2.7 m compartment	0.85 m x 2.10 m	100	Not mentioned	1000	30 (based on small-scale test)	Ceiling: 0.5-2.3 Wall: 0.4-1.1
Hadden et al. (2017)	Partially exposed Alpha: back wall and side wall Beta: back wall and ceiling Gamma: Back wall, ceiling, and side wall	Species: spruce Moisture content: 12% Density: 548 kg/m³	Polyurethane	20-20-20-20-20	Natural fire experiment using 2.72 m x 2.72 m x 2.72 m compartment	0.76 m x 1.84 m	132	Alpha-1: 5.3 Alpha-2: 4.7 Beta-1: 6.2 Beta-2: 5.2 Gamma-1: 6.7	Alpha-1: 1250 Alpha-2: 1150 Beta-1: 1150 Beta-2: 1100 Gamma-1: 1190	Alpha: not relevant as per the authors Beta-1 and Gamma-1: no delamination Beta-2 1st layer: 20 2nd layer: 40	Beta-1 Peak: 5.6 Quasi-steady: 0.5 Beta-2 Peak: 7 Quasi-steady: 0.6 Gamma-1 Peak: 7 Quasi-steady: 0.7
Su et al. (2018)	Partially exposed Tests 1-3 to 1-6	Species: spruce-pine-fir	Polyurethane	35-35-35-35-35	Natural fire experiment using 9.1 m x 4.6 m x	1.8 m x 2.0 m in four tests	550	Test 1-1: 9.5 Test 1-2: 12.4	1200	Test 1-3 1st layer: 80 2nd layer: 210	Test 1-3: 0.31-0.63 Test 1-4: 0.42-0.60

Author/s	CLT exposure	Properties of the CLT members	Glue type	Thickness of the CLT build-up (mm)	Type of test	Size of opening/ opening factor	Fire load density (MJ/m^2)	Peak HRR (MW)	Peak room temperature (°C)	Time to delamination[1] (min)	Charring rate[2]
	Unexposed Tests 1-1 & 1-2	Moisture content: 7.7%			2.7 m compartment	3.6 m x 2.0 m in two tests		Test 1-3: 14.2 Test 1-4: 13.1 Test 1-5: 10.0 Test 1-6: 12.9		Test 1-4 1st layer: 58 2nd layer: 150 Test 1-5 1st layer: 52-75 2nd layer: 140-154 Test 1-6 1st layer: 52-68 2nd layer: 88-101	Test 1-5: 0.47-0.63 Test 1-6: 0.45-0.77
Wiesner et al. (2019)[4]	See Hadden et al. (2017)	Species: spruce Moisture content: 13 3% Density: 420 kg/m^3	Polyurethane	20-20-20-20-20	See Hadden et al. (2017)	See Hadden et al. (2017)	132	See Hadden et al. (2017)	See Hadden et al. (2017)	Alpha: not relevant as per the authors Beta-1 and Gamma-1: no delamination Beta-2 1st layer: 20 2nd layer: 40	Beta-1 Peak: 5.6 Quasi-steady: 0.5 Beta-2 Peak: 7 Quasi-steady: 0.6 Gamma-1 Peak: 7 Quasi-steady: 0.7
Frangi et al. (2008)	Unexposed	Species: spruce	Not mentioned	5-ply 85 mm-thick external walls 6-ply 142 mm-thick slabs and internal wall (no mention of lamella thickness)	Natural fire experiment using 3.34 m x 3.34 m x 2.95 m compartment	1 m x 1 m window 0.9 m x 2.1 m door	790	Not mentioned	1168.9	No delamination	Not mentioned

Author/s	CLT exposure	Properties of the CLT members	Glue type	Thickness of the CLT build-up (mm)	Type of test	Size of opening/ opening factor	Fire load density (MJ/m²)	Peak HRR (MW)	Peak room temperature (°C)	Time to delamination[1] (min)	Charring rate[2]
McGregor (2013)	Unexposed Tests 1, 2, & 4 Fully exposed Tests 3 & 5	Species: spruce-pine-fir	Not mentioned	35-35-35	Natural fire experiment using 3.5 m x 4.5 m x 2.5 m compartment	1.07 m x 2.00 m	534	Test 1: 4.59 Test 2: 5.49 Test 3:8.75 Test 4: 5.70 Test 5: 7.64	Test 1: 1304 Test 2: 1100 Test 3: 1140 Test 4: 1109 Test 5: 1170	Test 1: 105 Tests 2, 3, & 4: No delamination Test 5:39	Test 1: 1.27-1.67 Test 3: 0.63 Test 5: 0.85 Tests 2 & 4: no charring
Su & Lougheed (2014)	Unexposed	Not mentioned	Not mentioned	Walls: 35-35-35 Ceiling: 35-35-35-35-35	Natural fire experiment using a 6.3 m x 8.3 m x 2.4 m compartment	1.5 m x 1.5 m	Furnitures (equivalent fire load not mentioned)	8.4	1200	No delamination	Not mentioned
Kolaitis et al. (2014)	Unexposed	Not mentioned	Not mentioned	19-19-19-19-19	Natural fire experiment using a 2.22 m x 2.22 m x 2.11 m compartment	0.43 m x 0.98 m	420	Not mentioned	830	No delamination	No charring
Su & Muradori (2015)	Unexposed	Not mentioned	Not mentioned	35-35-35-35-35	Natural fire experiment using a 4.64 m x 2.45 m x 8.83 m lift shaft connected to a 4.58 m x 5.18 m x 2.70 m compartment	2.50 m x 1.88 m	790	Not mentioned	1100	60	Not mentioned
Janssens et al. (2016)	Unexposed	Species: spruce-pine-fir	Not mentioned	35-35-35-35-35	Natural fire experiment using a 4.11 m x 3.60 m x 2.38 m & 4.46 m x 3.25 m x 2.38 m compartments	1.87 m x 2.07 m	90th percentile for living rooms in Canada (equivalent fire load not mentioned)	Test 1: 5.5 Test 2: 4.9	Not mentioned	Not mentioned	Not mentioned

NOTES:

1. Measured from the onset of ignition.
2. Single value means average charring rate.

3. Instead of charring rate, the pyrolysis rate was reported which is deemed comparable.
4. Hadden et al. (2017) and Wiesner et al. (2019) reported different moisture content and density despite being part of the same experiment.

Table 5 − Summary of key information from the different studies on external fire spread on CLT walls (Table 14 from reference 64)

Study	Properties of the CLT members	Glue type	Thickness of the CLT build-up	Compartment size	Size of opening	Fuel	Test label/Ref	Max. flame spread height (m)	Temperature on the wall (°C)	Incident heat flux on the facade (kW/m^2)	Incident heat flux opposite the facade (kW/m^2)
Su & Lougheed (2014)	Not mentioned	Not mentioned	38 mm (outer layer of the CLT simulated walls)	Natural fire experiment using 5.0 m x 9.9 m wall assembly	2.50 m x 1.45 m	Propane burner	CLT with regular gypsum plasterboard	3.0	Refer to Table 8	Refer to Table 8	Refer to Table 8
							CLT with interior FLT plywood	5.5			
Su et al. (2018)	Species: spruce- pine-fir Moisture content: 7.7%	Polyurethane	35-35-35-35-35	Natural fire experiment using 9.1 m x 4.6 m x 2.7 m compartment	1.8 m x 2.0 m in four tests 3.6 m x 2.0 m in two tests	891 MJ/m^2	Refer to Table 9	Not mentioned	Not mentioned	Refer to Table 9	Refer to Table 9
Gorska (2019)[1]	Species: Radiata pine Density:425 kg/m^3	Not mentioned	45-20-20-20-45	Natural fire experiment using 0.50 m x 0.50 m x 0.37 m compartment	0.30 m x 0.28 m	9 cm diameter kerosene pan	Baseline	0.58	900 @ 0 m above ceiling level	30 @ 0 m above ceiling level	Not mentioned
									150 @ 1 m above ceiling level	5 @ 1 m above ceiling level	
							Exposed ALL	1.26	800 @ 0 m above ceiling level	160 @ 0 m above ceiling level	
									450 @ 1 m above ceiling level	25 @ 1 m above ceiling level	
Bartlett et al. (2019)	Species: spruce	Polyurethane	33-33-33-33-33	Natural fire experiment using 6 m x 4 m x 2.52 m compartment; standard fire test	Scenario 1: 0.14 $m^{1/2}$ Scenario 2: 0.05 $m^{1/2}$ Scenario 3: 0.03 $m^{1/2}$	891 MJ/m^2	Scenario 1: Concrete ceiling	Not mentioned	No measurement	No measurement	23
							Scenario 1: CLT ceiling				44
							Scenario 2: Concrete ceiling		760 @ 0.2 m above the top of compartment	27 @ 0.2 m above the top of compartment	15

							Scenario 2: CLT ceiling		900 @ 0.2 m above the top of compartment	48 @ 0.2 m above the top of compartment	25
							Scenario 3: Concrete ceiling		350 @ 1.2 m above the top of compartment	17 @ 1.2 m above the top of compartment	20
							Scenario 3: CLT ceiling		750 @ 1.2 m above the top of compartment	59 @ 1.2 m above the top of compartment	32

NOTE:

1) Only the baseline and case with the highest percentage of exposed percentage are presented for simplicity. Refer to Section 5.3 of reference 64 for the graphs showing the experimental results.

 © BRE Global Ltd 2025

6.6 Cavity barriers

The issue of cavity barriers was discussed in the scoping study in relation to open state cavity barriers and the relevance of the current methods of test and assessment to the end use condition of cavity barriers. Cavity barriers are primarily located within two parts of the building: internal walls, floors, ceilings and roofs, and within the external wall. The guidance provided within AD B for the internal parts of the building allows designers to consider the appropriate solutions for the subdivision of hidden, connecting and extensive cavities. Diagram 9.1 of the 2019 edition of AD B Volume 2 (and diagram 8.1 of Volume 1) has evolved over many years and presents a simplistic approach to building forms in order to identify the locations for cavity barriers and fire stops to be considered by building designers and to show the important distinction between the two.

Associated with Diagram 9.1 (and diagram 8.1) Clause 9.14 of AD B Volume 2 provides guidance notes on materials that may be suitable to act as cavity barriers in certain limited situations inside stud or partition walls but notes that those materials may not achieve the required standards of fire resistance (that is the fire resistance required by the cavity barrier). A similar statement is made with regard to cavity closers which are only intended to relate to masonry wall constructions. Is it therefore appropriate to retain a reference to materials (i.e. timber elements and steel in the limited forms of construction) that do not meet the required fire resistance, or should the guidance simply refer to fire test evidence of proprietary products for all cavity barrier locations?

The main challenges are cavities associated with the external walls and how the guidance should be applied to framed, cladding and rainscreen systems.

Cavity barriers are fire resistance tested as a linear gap seal and the harmonised standard approach provides a broader explanation for the orientation and testing of cavity barriers to assess a products fire performance when compared to British Standards. When carrying out the fire resistance tests of proprietary materials they are tested in a simplistic arrangement and are positioned between fire resisting construction. Whilst these are not representative of the end use application it does provide a standardised way of assessing comparative products. Introducing other materials and components to reflect abutments of cavity barriers with cladding systems and inner wall constructions will reflect reality to investigate if these influence the performance of the cavity barriers. Consideration should be given to testing cavity barriers along with the same substrates (cavity linings) used in practice.

Other aspects of the Building Regulations have an influence on external wall cavity barrier designs. For example, preventing condensation and allowing drainage of rainscreen systems requires horizontal barriers which are open to allow ventilation through. The common approach to address this is to adopt cavity barriers which incorporate an intumescent material on their front face to close and seal the cavity in the event of a fire. These open state cavity barriers will permit the passage of flame and smoke until such time as the intumescent activates to close the gap. This initial passage of fire and smoke could be seen as being in contravention of Regulation B3(4) and such barriers are only permissible in relation to compliance with those Regulations by adopting the harmonised standard and ASFP guidance on variations to those standards. Therefore, should the Approved Document be amended to provide a clear set of functions for external wall cavity barriers so that this type of barrier can continue to be used in buildings? The fire test evidence of these materials would suggest that they are more resilient than full fill closed state cavity barriers particularly where they are required to interface with façade elements that are not linear flat faces[76].

The fire tests are also not representative of the horizontal width of cavities into which such cavity barriers are installed in buildings. For example, the cavity may be 20m wide across the face of the building and many storeys in height yet only a few metres are tested. This means that in zones beyond the cavity barriers intumescent activation point smoke spread is still possible within an external wall cavity contrary to the Building Regulations requirements. Consideration should be given to how this contradiction can be addressed by providing relevant guidance to designers on the risks and consequences to be addressed

It is not clear whether or not the supporting construction for a cavity barrier requires fire resistance to ensure that the barrier remains in place for the prescribed periods. Where barriers align with elements of structure such as concrete and steel which are predominantly fire protected the issue is less severe as these tend to be fire protected. Turning to external walls where the inner leaf is of framed construction (i.e. timber or light gauge steel clad with timber, cementitious boards, etc.) these walls are not fire resisting from the cavity side particularly where a wall can be 100% unprotected when considering fire spread between buildings. Therefore, cavity barriers at floor levels (i.e. aligned with concrete and steel) have a higher resilience than vertical barriers provided to sub divide the lateral extent of a cavity. Similarly, cavity barriers around openings such as windows, ventilation and service penetrations are fixed on the cavity side to non fire resisting elements. If the walls are not fire resisting in the installed situation, how can it be demonstrated that the cavity barrier will not fail as required by 9.16(b) AD B Volume 2 2019 edition (and the corresponding section in Volume 1). This may be addressed by providing more clarity on the objectives of cavity barriers in such cavities.

Numerous tests of external walls following the principles of BS 8414 do not appear to have demonstrated that the internal walls require a fire resistance from the cavity face to retain the vertical barriers in in place. If this is the accepted case the guidance within AD B and other standards such as BS 9991 and BS 9999 should be updated to distinguish between the fixity of cavity barriers within external walls and those placed in other locations inside the building.

In modern built up rainscreen systems, cladding supporting bracketry often interferes with the placement of cavity barriers around openings such that the barriers may need to be positioned away from actual openings in the external wall. There is no guidance at present on how close to any opening or penetration through the external wall cavity a cavity barrier should be placed, and designers are able to place barriers where they can fit them in to the construction. Where this becomes an additional design challenge is at floor levels where space for two cavity barriers (i.e. above an opening and at floor level) may not exist. At present, there is no guidance on how to address this conflict and one approach taken is to provide one cavity barrier with a higher standard of fire resistance of not less than two cavity barriers. None of the current guidance in AD B, BS 9991, BS 9999 considers this situation. It is left to the designers and approvers to agree on the appropriate solution. Providing some guidance on the approach or parameters to consider would help to reduce the conflicting views that exist.

We have potential contradictions and points which may be exploited whereby for external walls the requirements for fire resisting cavity barriers is undermined by recommending materials that do not achieve the required fire resisting standards (9.14 of AD B). If there is an intention to limit these recommendations to particular types of construction this should be made clear or the text adjusted to set out the fire performances to be met by products which have been assessed by undertaking a relevant test.

Other cavities are created within external walls. One example is the extruded sections of aluminium framing systems of glazed curtain wall facades. These routes are cavities within the external wall construction and by virtue of interpretations of the term cavities now being applied, these parts of a building’s façade are considered as relevant cavities. It is possible to design buildings up to 30m in height as a single compartment meaning that the framing should be sub divided to limit the extent of cavities. Proprietary fire protection products for insertion into the non fire resisting framing are available but as with other cavity barriers they are not tested in an end use condition. The necessity for cavity barriers in these locations should be investigated such that further guidance can be provided. This research could also address the fire stopping requirements of the interfaces of compartment structure with abutting curtain walled façade mullions and transoms.

The intention going forward is to review the available evidence particularly that underpinning the publication of NF 51[76] to investigate the time taken for the intumescent strip on the open state barriers to operate under realistic conditions representing a fire in the external wall cavity. The relevance of current methods of test and assessment for cavity barriers has been mentioned above and is discussed in relation to the review of the codes and standards related to fire resistance below.

6.7 Car parks

The scoping study and the Call for Evidence both identified the issue of the structural fire resistance requirements/recommendations for open-sided car parks for buildings up to 30m in height as a potential issue. The current guidance in AD B recommends a fire resistance of 15 minutes for such buildings.

Large car parks fires (Liverpool Echo and the Sola Airport) have led to an increased concern about the fire risk in such premises. Traditionally, the fire risk (i.e. the product of the fire probability and the fire consequence) have been reported as minimal. This has mainly been related to the very low fire probability, but also due to very low probability of injuries and fatalities (Table 6).

Table 6 − Total number of non-fatal and fatal casualties in fires in car park buildings, England 2010-2020 (from Alimzhanova, 2021[77])

	Multi-Storey Car Park	Underground	Other	Total
Hospital treatment – severe	0	0	1	**1**
Hospital treatment – slight	3	4	2	**9**
First aid treatment	3	0	0	**3**
Precautionary checks	4	3	0	**7**
Total non-fatal casualties	10	7	3	**20**
Fire-related fatalities	1	0	0	**1**

The low fire risk has resulted in approaches with lower fire protection costs, such as car parks with unprotected steel construction with as low fire resistance rating as 15 minutes, or sometimes even less (10 minutes). Also, sprinkler systems have not been incorporated based on cost arguments, and sometimes on cost-benefit arguments. Such arguments have also been supported by the relative low damage in most car park fires (Table 7).

Table 7 − Average extent of damage (m^2) in car park fires attended by Fire and Rescue Services, England 2010-2020 (from Alimzhanova, 2021[77])

	Multi-Storey Car Park		Underground		Other	
Financial year	**Number of fires**	**Average area of fire damage, m^2**	**Number of fires**	**Average area of fire damage, m^2**	**Number of fires**	**Average area of fire damage, m^2**
2010/11	43	12.2	26	23.8	16	1257.8
2011/12	30	10.9	16	20.8	19	31.6
2012/13	29	59.6	16	9.2	10	19.6
2013/14	34	62.6	18	34.9	19	11.8
2014/15	26	12.1	23	351.0	20	30.2
2015/16	41	4.2	20	92.8	16	16.8
2016/17	52	56.1	24	46.6	22	10.4
2017/18	59	370.9	19	13.6	13	20.1
2018/19	51	35.7	23	4.3	17	14.6
2019/20	43	31.3	27	41.4	21	9.6
Average		**66**		**64**		**142**

Such solutions have been highlighted as problematic based on fires such as the Sola Airport (Stavanger, Norway) fire in January 2020, which led to partial collapse. The collapse was in the new part with this type of solution (unprotected steel, no sprinklers), whereas the old part consisting of a heavier concrete structure remained standing. A detailed analysis of this fire was undertaken by RISE FR in Norway[78].

This type of solution is often argued to be based on early arrival of the fire brigade, but this is a problematic assumption, as the arrival time can vary, and so can the time to first water on the fire, especially now that many fire brigades are reluctant to enter buildings with electric cars on fire. The Sola Airport fire supports how wrong the design assumption of early arrival of the fire brigade can be, as the airport even had its own, local ‘fire brigade unit’.

Another argument that is used is that the fire will be relatively small, and the design fire used for the calculations assumes that the initial fire will spread to no more than a couple of vehicles. This assumption has been proven wrong by previous studies and multiple recent fires worldwide (Table 8). Actually, reports have established that there is a faster fire development (peak Heat Release Rate (HRR) occurring earlier) for newer cars, which in turn results in faster fire spread, and thus also a higher probability of spread to more cars. Figure 1 shows the data reported in a recent report by NFPA[79]. The fire spread is also facilitated by the fact that cars have become larger and parking spaces have become smaller, thus decreasing the separation distance between cars in car parks.

It has also been argued that the car park will not be full, and that this can be used for design calculations. This is a significant misconception, because one cannot use probabilistic input for the magnitude of the consequence. A full risk analysis would have to be carried out, and the probability of different scenarios could then be based on statistics of how many cars are present at a given time. However, one scenario should be that the car park is fully occupied with cars, and the consequences should thus also be calculated based on this.

Table 8 − Examples of car park fires with several cars burning simultaneously (from Hertz et al. 2021[80])

Date	Location	Burned cars	Construction type	Notes
2001-09-16	Fasanvænget, Kokkedal, Denmark	30	Open	30 cars at fire at the same time 70 people evacuated
2002-10-13	Schiphol airport, Netherlands	51	Open	30 cars at fire at the same time
2004-04-06	Jacob Hansensvej Odense, Denmark	10	Open	Collapse of the steel shelter structure
2010-08-30	Stansted airport, UK	24	Open air	High wind reported
2013-10-14	Olympic Park Aquatic Center, Sydney, Australia	80	Open air	1500 people evacuated
2016-03-25	Nygaards Plads Brøndby, Denmark	19	Open	Fire started in one car Steel shelter repaired
2017-04-16	Von Lingens Väg Malmö, Sweden	35	Closed	Probably ignited on purpose
2018-01-01	Echo Arena, Liverpool UK	1400	Open	Fully developed fire started in one car Concrete building demolished
2019-08-31	Douglas Shopping Centre Cork, Ireland	60	Open	Fully developed fire started in one car Steel building demolished
2019-10-14	Münster-Osnabrück Airport, Germany	73	Closed	Fire started in one car Concrete building repaired
2020-01-07	Sola Airport Stavanger, Norway	300	Open	Fully developed fire started in one car. Steel building collapsed in fire

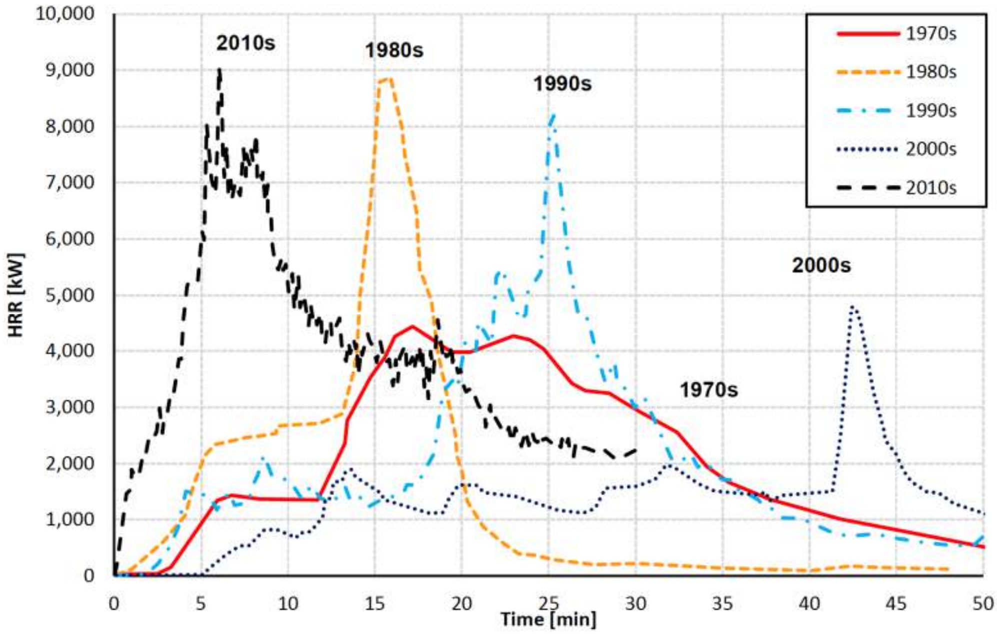


Figure 1 − HRR curves for vehicles from each decade (NFPA report, 2020[79])

With respect to sprinklers, several studies have shown that they are not cost-effective for car parks, and this result is predominantly based on low fire occurrence and a very low probability of injuries and fatalities (Table 9). However, these may have focused too much on injuries and fatalities, and they may have underestimated the property losses for modern car parks. As mentioned, the latter number needs revisiting after the very large fires (Liverpool Echo and Sola Airport), which might be related to the changes associated with modern car parks (e.g. more compact parking, electric vehicles, larger fire load and faster fire development).

In summary, the current trend where low fire resistance in car parks is used for designs is recommended to be revisited, and so are the scenarios and input values used for design fire calculations in car parks. This could also be used to further upgrade the numerous recent studies that have focused on the predictive capability of CFD models used in support of design calculations.

Table 9 − Fire occurrence, fatalities and injuries without sprinklers installed (from Alimzhanova, 2021[77])

Place and type (range of years considered)	Annual fire occurrence rate	Probability of fatality	Probability of person having a severe injury	Probability of person having a slight injury
	λ_{ig}, fires/year/car park	$N\lambda_{f,0}$, fatalities/fire	$N\lambda_{Si,0}$ injuries/fire	$N\lambda_{si,0}$ injuries/fire
UK All (1994/2005)	0.0105	0.0006	0.0029	0.0252
UK Multi-Story Car Park (1994/2005)	0.0484	0.0009	N/A	0.0183
England All (2010/2020)	0.0036	0.0013	0.0013	0.0114
England Multi-Storey Car Park (2010/2020)	0.0128	0.0025	N/A	0.0074
England Underground (2010/2020)	0.0353	0	N/A	0.0189
England Other (2010/2020)	0.0009	0	0.0058	0.0116
Scotland All (2009/2020)	0.0050	0	N/A	0.0106
Wales All (2009/2020)	0.0046	0	N/A	0.0401

It is interesting to note that the reduction in the fire resistance requirements for open-sided car parks up to 30m tall was in part a function of research undertaken in France and sponsored by the European steel industry[81]. Although the relaxation was authorised in the UK, it is not the same situation in France where the underlying research and corresponding demonstration tests were carried out. In France, the typical requirement from the regulations is for R60 or R90 fire resistance for open-sided car parks when the car park is higher than ground floor plus two levels.

It is recommended that this issue of an appropriate specification for fire resistance is taken through to the next phase of the project. The appropriateness of the 15 minute recommendation and hence the ability to construct car parks from unprotected steel should take into account issues including:

- Evidence from recent fires in the UK and elsewhere.
- The definition of open-sided car parks in relation to ventilation conditions within the floor plates of typical car parks.
- The effect of height on fire spread.
- The impact of service ducts and drainage systems in spreading fire in car parks.
- The proximity of the open-sided car park to other buildings, including residential premises.

- The effect on fire growth and fire spread of changing technologies (such as electric vehicles (EVs) and the provision of charging points)

6.8 Codes and standards related to fire resistance

The scoping study provided a list of national and European standards directly related to fire resistance and compartmentation. The principal objective in listing these standards covering fire testing, classification and extended application rules was to highlight the proliferation and growth of standards in this area in recent years.

At the request of MHCLG the tables are reproduced in Appendix B1 of this report. However, in this case those standards directly referenced in AD B are specifically identified. Many of the European test standards are not referenced in AD B although all the equivalent British Standards are. The most obvious reason for this is that the test and classification process is contained within the individual national test standard where in the European system there is a separation between the test standard and the classification standard and it is the European classification standards that are referenced in AD B.

The discussion regarding cavity barriers above identified that current methods of test and assessment are not suitably representative of the end use application. The use of either an ad-hoc test system based on BS 476 testing or testing to EN 1366-4[82] designed for linear joint seals did not and does not address the particular characteristics of a fire within a cavity. The current approach appears to be a means of matching the requirements to the availability of existing test facilities rather than giving consideration to a more appropriate means of test and assessment. Existing research[76] has provided a potential framework for a means of test and assessment that takes into account the specific characteristics of a cavity fire particularly in relation to cavities within external walls.

The current approach to developing a test and assessment methodology appropriate for cavity barriers has been focused on adapting the requirements of the standard procedures to enable the adoption of open state cavity barriers rather than considering the intent of the regulatory requirement, the end use condition and likely thermal exposure for a cavity barrier.

However, the current means of test and assessment for cavity barriers is not the only example where a test procedure seems to have been developed to enable fire tests to be undertaken in standard fire test facilities using the standard fire curve. EN 1365-5[83] covering balconies and walkways and EN 1365-6[84] covering stairs both specify a thermal exposure corresponding to the heating curve set out in EN 1363-1[17] i.e. the standard fire curve. As discussed above the standard fire curve is representative of (the heating phase) of a post-flashover fire within a compartment and is not an appropriate model for a thermal exposure characterised by external flaming (balconies and walkways) or a comparatively sterile area such as a staircase or stairwell. In the former case, a more appropriate fire scenario would be either an external fire curve such as that specified in EN 1991-1-2[22] or a realistic fire scenario representative of a post-flashover compartment fire venting through a window and impacting on the external façade (such as that used in BS 8414[85]). For a stair, a more relevant fire exposure and corresponding means of assessment was developed following the work undertaken as part of the Timber Frame 2000 project at Cardington and subsequently developed into a test and assessment methodology as part of a collaborative research project funded by the UK government and supported by the wood construction industry[86].

In both national and European test standards for all structural elements there is an explicit acknowledgement that the test scenario should, as far as possible, reflect the end use condition in relation to the boundary and support conditions. If this is meant to be the case, then the current review has highlighted a number of instances where this is not so. MHCLG may wish to consider alternative means of test and assessment that more closely reflect the end use application for specific systems, products and materials.

 © BRE Global Ltd 2025

6.9 Fire statistics

The scoping study considered the evidence provided by the Home Office fire statistics for England[87,88] who publish detailed information on incidents attended by the Fire and Rescue Services. The initial review concluded that, apart from an exceptionally high figure for fire-related fatalities for the year ending June 2017, due to the Grenfell Tower fire:

- There has been a general decrease in the number of primary fires over the last decade.
- The number of dwelling fires has remained fairly constant over the same period.
- There were more than 28,000 primary dwelling fires in the year ending 2020.
- Just over a quarter of this total were in purpose-built flats.
- Approximately 65% of all fires in purpose-built flats were classed as low-rise (1-3 storeys), approximately 27% of all fires in purpose-built flats were classed as medium-rise (4-9 storeys) and the remainder (8% of all fires in purpose-built flats) classed as high rise (10+ storeys).
- There is no evidence to show any increase in the number of primary fires or the number of dwelling fires over the last 10 years.
- The most recently available data shows a decrease in the number of fire-related fatalities on the previous year and the lowest figure since quarterly data became available in 2001/2002.
- There was a corresponding decrease in the number of fire-related fatalities in dwelling fires and a decrease in the number of non-fatal casualties.

The current fire statistics for England between 2010 and 2020 have been reviewed. Recent investigations of fire statistics have demonstrated the need for updates and renewal of the data available in the relevant British Standards. This is supported by the recent updates of PD 7974-7:2003 which previously presented data from 1966 to 1987. The new version, published in 2019[13], has recommendations based on current fire statistics from the USA[89] and England[90]. Fire statistics have been investigated in European countries to understand the available data of building fires[91].

Despite the decreasing trends in the number of fire incidents, fatalities and casualties recorded over the last years, new fire hazards and building performances appeared in current fire scenarios. Therefore, the challenge for designers is represented by the fire resistance framework not explicitly providing a definition of a usual building, nor suggesting the fire conditions when a building is considered unusual or "uncommon"[57]. It is in this light that fire statistics are considered as a powerful tool of analysis able to describe real fire incidents, provide pre and post-fire conditions, represent the performance of buildings when exposed to fires and link the dichotomy between fire resistance testing and real performance.

Structural fire resistance is difficult to capture in the fire statistical datasets due to the complexity of the building characteristics and the interaction of multiple variables. However, fire statistical data provide useful information about the building constructions, consequences of fires in several property types in terms of fire spread, fire damage and total damage. Moreover, when fire damage is examined, this appears linked to the response time of the fire brigades in reaching the scene and the fire duration.

In line with the above considerations, this section will examine the fire statistics of Dwellings published by the Home Office for what concerns the evolution of fire incidents, fatalities and casualties from 2010/2011 to 2019/2020, fire response of the fire brigades, fire duration, incidents in several building construction types and fire consequences such as fire spread and area damage. These factors could support the evaluations related to the fire scenarios that structural elements face during fire incidents.

Data on fire incidents are usually recorded by the Fire and Rescue Service in the aftermath of an event filling an online form. The Incident Recording System (IRS)[92] is adopted for the collection of the information in England, and the Home Office applies a monthly quality assurance process to guarantee that the data is fit-for-purpose and published with the highest accuracy[93].

Fire incidents are classified into primary, secondary and chimney fires. Primary fires are "those that meet at least one of the following criteria – occurred in a (non-derelict) building, vehicle or outdoor structure or involved a fatality, casualty or were attended by five or more pumping appliances"[94], while secondary fires are usually outdoor fires not involving properties. Within the available primary fires, the analysis will be focused on Dwellings, which are defined as "fires in properties that are a place of residence i.e. places occupied by households such as houses and flats, excluding hotels/hostels and residential institutions. Dwellings also include "non-permanent structures used solely as a dwelling, such as houseboats and caravans". The latest Dwelling fires dataset was published in August 2020[95] and present 319,150 fire incidents from 2010/11 to 2019/20 (year ending in March).

Table 10 – Examined variables of the Dwelling fire datasets

Dwelling type	Building special construction
House - single occupancy	Atria
Converted Flat/Maisonette - single occupancy	Cladding
Dwelling - Multiple occupancy	Sandwich panels
Purpose Built Low Rise (1-3) Flats/Maisonettes	Thatch
Purpose Built Medium Rise (4-9) Flats	Timber framed
Purpose Built High Rise (10+) Flats	Other
Bungalow - single occupancy	None
Other dwelling	Not known

The variables considered in this research are related to the Dwelling types and building special constructions (Table 10). Moreover, fatalities and casualties are collected as a unique value that records whether the incident involved at least one fire-related fatality or one casualty. Due to data protection considerations, no other information is provided, and a separate fatality/casualty dataset is available.

Considering the evolution of the number of fire incidents from 2010/2011 to 2019/2020 (Table 11), the frequency appears to slightly decrease for all the property types considered, except for House – single occupancy and Purpose Built Low Rise (1-3) Flats/Maisonettes, which have a more significant decrease, as they were reduced from 19,387 to 14,553 and from 6,300 to 4,840 fires, respectively. Similar considerations apply to the presence of fatalities/casualties in fire incidents (Table 12), which also show a small reduction over the period considered with a bigger decrease recorded for House – single occupancy (28%) and Purpose Built Low Rise (1-3) Flats/Maisonettes (33%).

Table 11 − Evolution of the number of fires from 2010/2011 to 2019/2020 in various dwelling types[95]

	From 2010/11 to 2019/20									
	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20
A	19387	18678	17384	16995	16512	16557	16194	16245	15363	14553
B	2195	2132	2360	2271	2315	2261	2071	2153	2148	2046
C	1052	994	743	673	639	663	610	630	610	628
D	6300	6088	5473	5038	5016	5098	4907	5013	4958	4840
E	2088	2075	2011	1935	1892	1878	1848	1957	1889	1902
F	999	1060	845	801	773	760	713	800	821	775
G	1862	1787	1794	1723	1698	1743	1713	1690	1657	1575
H	2728	2603	2690	2474	2489	2412	2289	2331	2149	2128
A. House - single occupancy; B. Converted Flat/Maisonette - single occupancy; C. Dwelling - Multiple occupancy; D. Purpose Built Low Rise (1-3) Flats/Maisonettes; E. Purpose Built Medium Rise (4-9) Flats; F. Purpose Built High Rise (10+) Flats; G. Bungalow - single occupancy; H. Other dwelling										

Table 12 − Evolution of the presence of fatalities/casualties from 2010/2011 to 2019/2020 in various dwelling types[95]

	From 2010/11 to 2019/20									
	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20
A	2740	2759	2605	2363	2274	2262	2113	1976	1978	1970
B	340	339	312	322	341	314	304	295	290	258
C	198	180	133	121	97	98	98	112	93	121
D	1155	1084	962	837	857	858	772	794	794	777
E	293	263	245	234	244	228	226	217	222	224
F	177	167	132	107	112	100	106	108	116	110
G	376	377	365	341	351	350	354	311	312	326
H	453	461	493	419	411	382	319	352	332	310
A. House - single occupancy; B. Converted Flat/Maisonette - single occupancy; C. Dwelling - Multiple occupancy; D. Purpose Built Low Rise (1-3) Flats/Maisonettes; E. Purpose Built Medium Rise (4-9) Flats; F. Purpose Built High Rise (10+) Flats; G. Bungalow - single occupancy; H. Other dwelling										

Having looked at the overall fire statistics, the following analyses will focus more on structural fire resistance investigating influencing factors. Normally, for structural fire resistance and fire separating elements, the objective is to maintain the stability of the elements for a defined period avoiding building collapse. It also involves limiting the fire spread and guaranteeing occupant evacuation as stated in the objective of the Building Regulations. In terms of the statistics, the fire duration in several building types and fire brigade attendance time can be determined. Moreover, based on the investigation of fires in different building construction types, the structural material involved in the fire incidents can also be determined. Finally, in fire statistics, it is possible to evaluate fire consequences in terms of fire spread, fire damage and total damage extent. Fire damage extent is the total horizontal area damaged (in m^2) by the flame and heat at the end of the fire, while total damage extent is the total horizontal area damaged (in m^2) by the flame, heat, smoke and water. The variables mentioned above will be studied in the following analysis.

The response time of the fire brigades from the notification of the incidents to the arrival at the fire scene is composed of preparation, dispatch and travel time and is influenced by the position of fire stations, number of available fire crews and traffic conditions. According to the information provided by the Home Office, the response time to primary fires in Dwellings in 2019/20 is 7 minutes 45 seconds, which presents a decrease of 2s from 2018/2019 and 4s from 2014/2015[96].

The following analyses are obtained examining the Dwellings fires dataset[95], which presents 319,150 fire incidents from 2010/2011 to 2019/2020. The time at scene is defined as 'the time between the first fire vehicle attending the scene and the incident being closed'[94]. Several Dwelling types present three peaks for fires between 15 to 30 minutes, 1 to 2h and more than 4h (Figure 2). Therefore, the fire scenarios should be designed considering those time ranges.

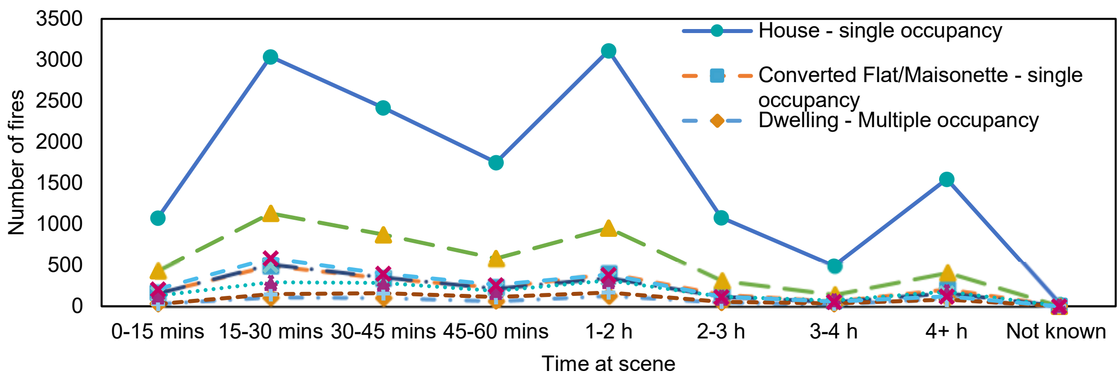


Figure *2* − Time at the scene for Dwellings in 2019/2020[95]

The analysis is now focused on the evolution of the number of fires according to modern forms of construction. Data presented are absolute values of fires that have occurred. The analysis does not provide a comparison of the probability/risk of fire occurring in dwellings with different forms of construction, as that would require information on the number of existing dwellings with each form of construction, that was not considered here. The construction types are those listed in Table 10. However, the majority of fires appears to be recorded for the class of 'None' or 'Not known'. Removing the above-mentioned classes and 'Bungalow' from the elaboration, a total of 5,823 fire incidents was investigated.

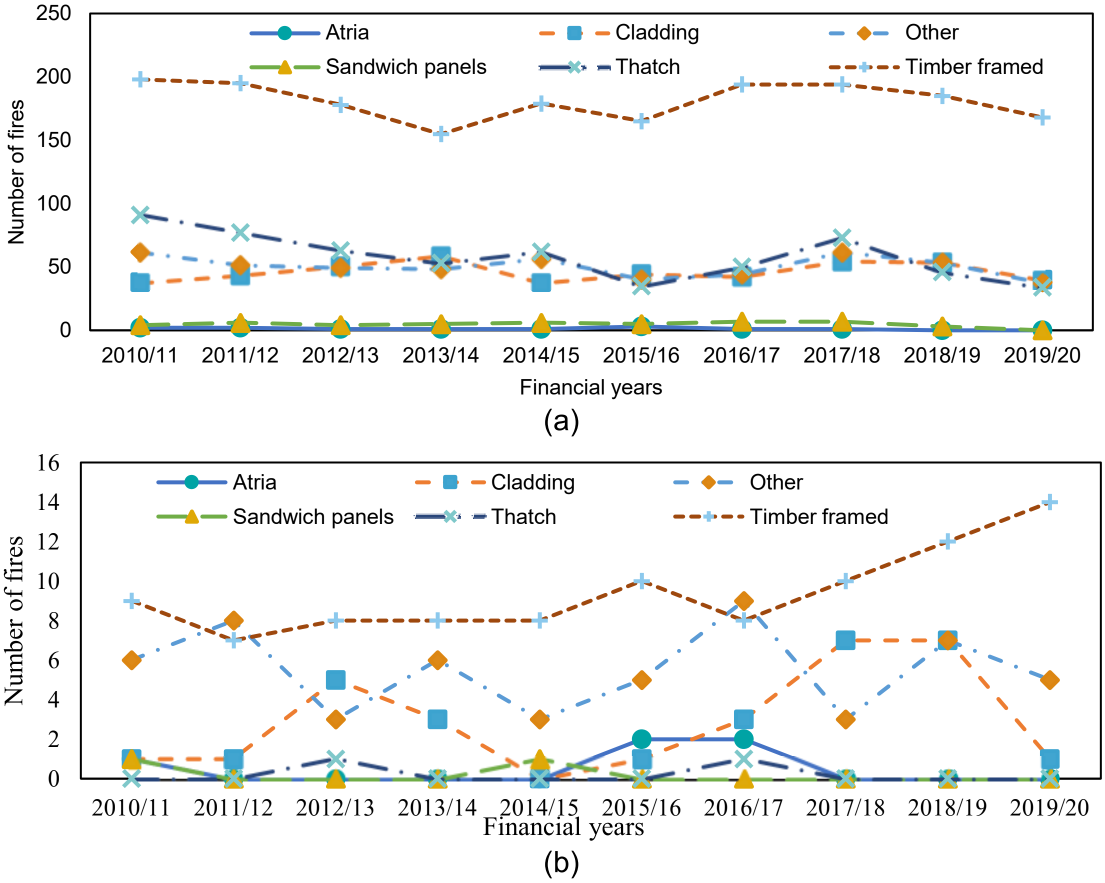


Figure 3 − Evolution of the number of fires from 2010/2011 to 2019/2020 considering various building constructions in (a) House single occupancy and (b) Converted Flat/Maisonette – single occupancy[95]

The property types of House single occupancy and Converted Flat/Maisonette - single occupancy are shown in Figure 3 while Dwelling - Multiple occupancy and Other dwelling are shown in in Figure 4. In these four property types for the period considered, the construction type related to the highest number of fire incidents is Timber frame where in House single occupancy appears to fluctuate around 200 fires, in Converted Flat/Maisonette - single occupancy has an increase of 56%, in Dwelling - Multiple occupancy and Other dwelling has a decrease of 50% and 43%, respectively. In House single occupancy (Figure 3 (a)), the other forms of constructions that appear relevant are Cladding, Thatch and Other around 50 fire incidents. In Converted Flat/Maisonette - single occupancy (Figure 3 (b)), Cladding has peaks of 5 incidents in 2012/13 and 7 fire incidents in 2017/18 and 2018/19. In Dwelling – Multiple occupancy (Figure 4 (a)), the trends never exceed 4 fire incidents for Cladding, and the data appear too limited in number.

bre

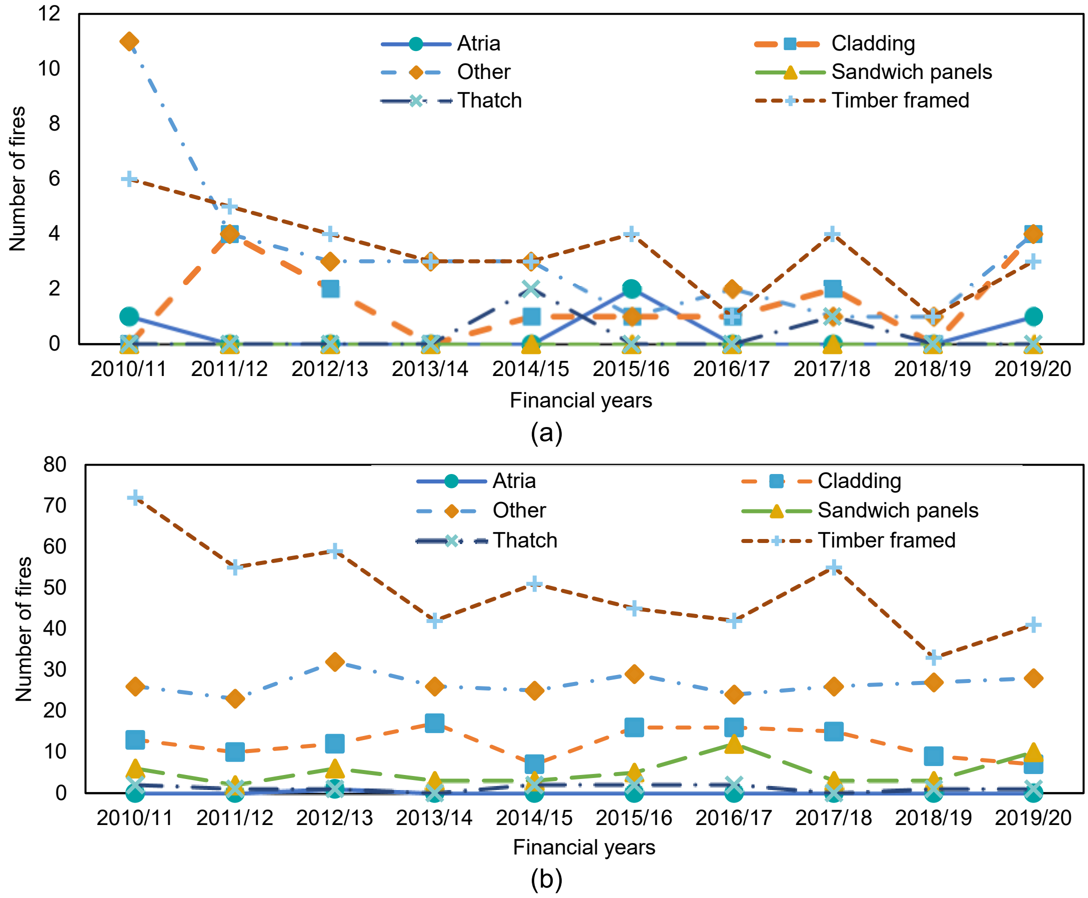
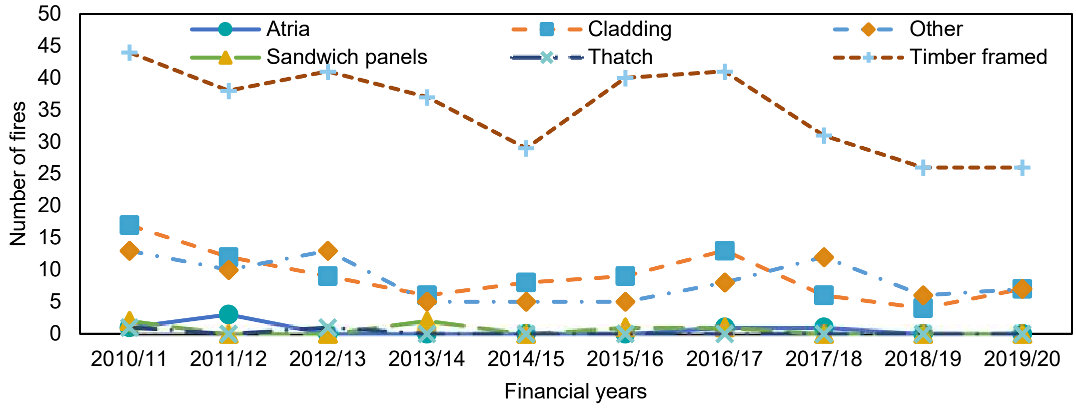
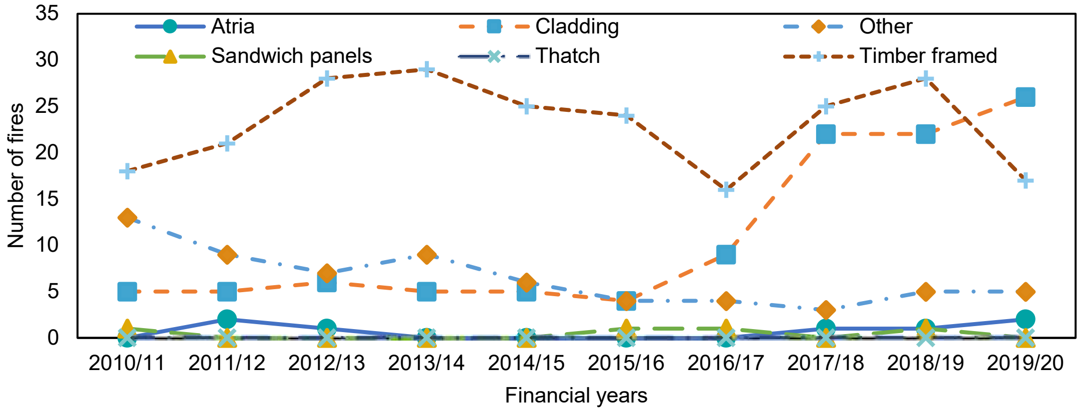


Figure 4 − Evolution of the number of fires from 2010/2011 to 2019/2020 considering various building constructions in (a) Dwellings – Multiple occupancy and (b) Other dwelling[95]

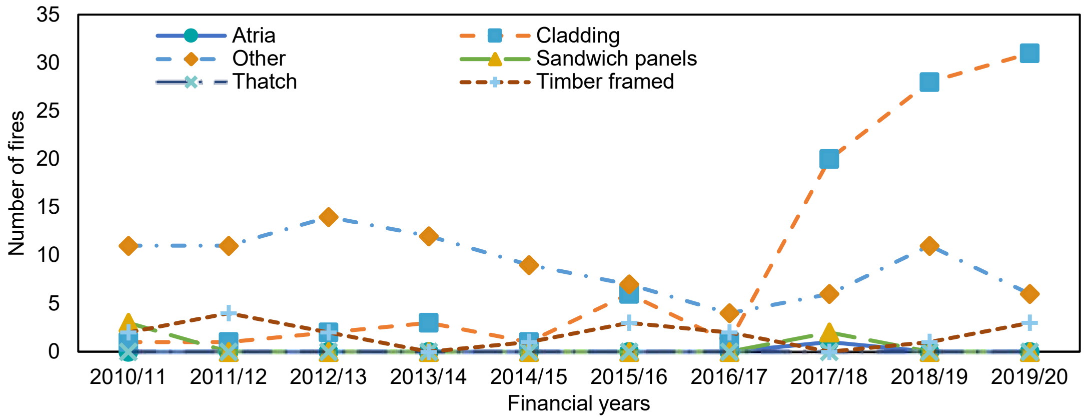
In Purpose Built Low Rise (1-3) Flats/Maisonettes (Figure 5 (a)) and Purpose Built Medium Rise (4-9) Flats (Figure 5 (b)), the highest number of fire incidents is recorded for Timber framed constructions with an average of 35 and 23 fire incidents in the examined period. This is likely due to the number of existing dwellings with timber frame construction being greater than those with other forms of construction, hence, the absolute number of fires occurring is likely to be greater. In Figure 5, for Purpose Built Low Rise (1-3) Flats/Maisonettes, Purpose Built Medium Rise (4-9) Flats and Purpose Built High Rise (10+) the second most relevant construction type is recorded as Other while all the other construction types never exceed 5 fire incidents except for Cladding. One aspect that could be investigated further is the number of fire incidents recorded for the construction type of Cladding that from 2016/2017 to 2019/2020 that for Purpose Built Medium Rise (4-9) Flats rises from 4 to 26 (Figure 5 (b)) and for Purpose Built High Rise (10+) from 2 to 31 (Figure 5 (c)). The main question is related to the potential connection that the increase from 2016 has to the major fire incidents that happened in the UK related to the presence of cladding in high-rise buildings.



(a)



(b)

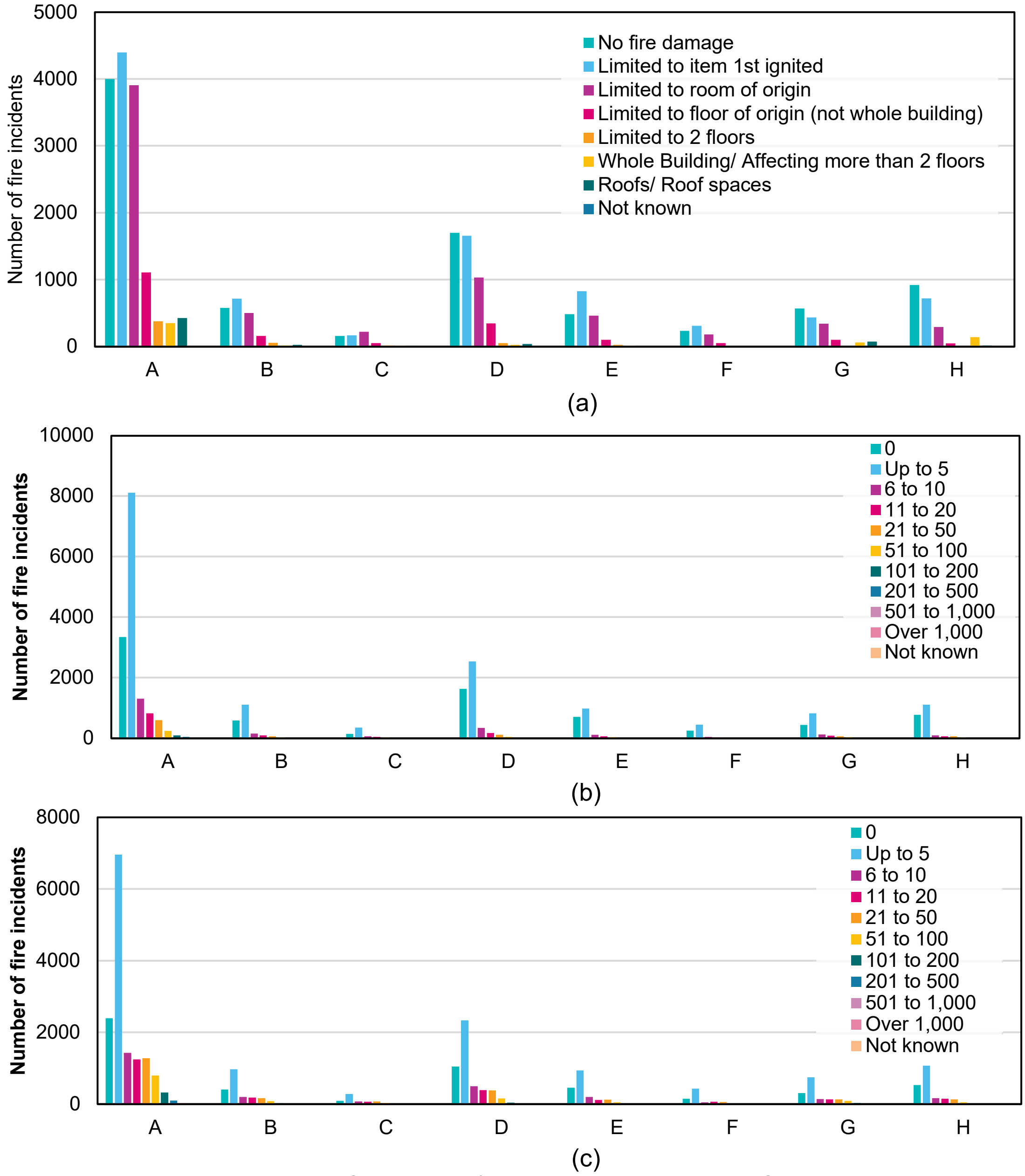


(c)

Figure 5 − Evolution of the number of fires from 2010/11 to 2019/20 considering various building constructions in (a) Purpose Built Low Rise (1-3) Flats/Maisonettes, (b) Purpose Built Low Rise (4-9) Flats and (c) Purpose Built Low Rise (10+) Flats[95]

© BRE Global Ltd 2025

When fire incidents in 2019/2020 in several Dwellings types are examined for what concerns the fire consequences, a total of 28,447 incidents are present with a high number of small fires and a small number of large fires recorded. As shown in Figure 6 (a), for the eight Dwellings types analysed, no fire damage generally is recorded and if fire spread is present, this is usually confined to the item first ignited or room of origin. In House - single occupancy, more than 300 fire incidents have fire spread limited to two floors or affecting the whole building (more than two floors). Fire damage (Figure 6 (b)) and total damage (Figure 6 (c)) are usually recorded as 0 or up to 5m^2. Again, House - single occupancy has more than approximately 600 incidents for fire damage and more than 1,200 incidents for total damage in which the area damage is recorded between 6 and 50m^2.



A. House - single occupancy; B. Converted Flat/Maisonette - single occupancy; C. Dwelling - Multiple occupancy; D. Purpose Built Low Rise (1-3) Flats/Maisonettes; E. Purpose Built Medium Rise (4-9) Flats; F. Purpose Built High Rise (10+) Flats; G. Bungalow - single occupancy; H. Other dwelling

Figure 6 − Evaluation of (a) fire spread, (b) fire damage and (c) total damage in Dwellings types in 2019/20

A decreasing number of fires is recorded in Dwellings characterised by a response time of approximately 7 minutes and a fire duration between 15 and 30 minutes, 1 to 2h and more than 4h. If special building constructions are examined, timber-framed are related to the highest number of fires with particular attention to the rising number of incidents related to claddings in high-rise buildings. Fire spread is generally within the room of origin and when fire consequences are quantified in terms of fire and total damage, there are several fire incidents causing damage between 6 and 50m^2.

Fire statistics presents data of fire incidents able to close the gaps between the testing and the evaluation of real building performance. Even though not all the necessary fields are recorded, it provides useful variables able to describe factors influencing fire developments and describing fire scenarios.

The statistics currently available show no increase in fatalities or serious injuries in recent years. The general trend is for fewer fires. Although this is not necessarily because of the existing recommended minimum periods of fire resistance it does not suggest that the existing system is failing to deliver the level of performance required.

 © BRE Global Ltd 2025

7 Interim conclusions

Based on the initial scoping study, a number of specific topics were identified as the primary focus of the current research project. Information related to these general areas has been reviewed and the intention is that the review will highlight those areas where further action is needed to ensure that Approved Document B provides adequate guidance to meet the minimum requirements under Schedule 1 of the Building Regulations 2010. The specific areas where further evidence is required are:

- Modern Methods of Construction
- Mass timber construction
- Timber frame construction
- Cavity barriers
- Car parks
- Alternative approaches to defining the performance required
- Deemed to Satisfy solution
- Maximum compartment sizes

What is clear from a review of the relevant information is that there is a need to provide simple, transparent information on the purpose of the Approved Document. Without this clarity there can be no means of measuring adequacy. It is therefore recommended that the Project Team, in consultation with the Technical Steering Group and MHCLG, consider how this can best be achieved for example by an appropriate combination of definition, more detailed performance expectations for elements of structure, making implicit assumptions within AD B explicit and/or providing additional context as to what constitutes common building situations in respect of fire resistance.

Recommendations and decisions need to be taken based on evidence. Statistical information from real fires plays a crucial role in providing data to inform decisions on potential changes to the guidance and, as we have seen recently, to the regulations themselves. A review of the available statistics related to real fire incidents in England in recent years shows no evidence that the current system is failing to achieve the requirements of the Building Regulations in relation to structural performance in fire and the maintenance of compartmentation. In the absence of any such data, there is no evidence that would justify a root and branch reform of the current system and a departure from the current reliance on standard fire resistance as the principal means of assessment.

The review has highlighted a number of areas where implementation of the guidance in AD B may be insufficient to demonstrate compliance with the minimum requirements of the Building Regulations. This may be due to the potential interaction between compartment fire dynamics and structural performance (mass timber construction, timber frame, highly insulated buildings) or due to potential mechanisms of failure which are a function of system behaviour rather than that of individual elements (modular construction, connection behaviour). Consideration should be given to identifying means of assessment over and above (not instead of) that specified in AD B that can be used to demonstrate compliance with the requirements of the Building Regulations in relation to structural fire resistance and the maintenance of compartmentation. Such an approach may provide a route to dealing with the first four topics identified above.

 © BRE Global Ltd 2025

The validity of the specification for fire resistance for open-sided car parks has emerged as an area where further work is required to establish the basis for the relaxation. Changes to the design of car parks, real fire incidents and changes in technology should be investigated to see if the current recommendation is still justified.

The review of alternative methods of specifying fire resistance has highlighted a number of methods which differ significantly from the current system. These include an approach to link the requirements for robustness with fire resistance and attempts to utilise probabilistic methods to determine an appropriate level of performance for specific circumstances. The new methods are still based on a specification of performance related to standard fire resistance and are therefore incapable of dealing with the issues described above where a demonstration of fire resistance related to a standard fire test on isolated elements does not necessarily address the critical behaviour in terms of response to a real fire situation. A review of the alternative approaches to the specification of structural fire performance and compartmentation set out in BS 9999 has been conducted. The review set out a number of potential options going forward. The preferred option is to assess which, if any, of the principles of BS 9999 are appropriate to be incorporated into AD B.

The withdrawal of the reference to BR 128 and the removal of any reference to the fire part of the structural Eurocodes has reduced the options available to designers to demonstrate compliance using some form of conservative “deemed to satisfy” solutions. MHCLG may wish to consider their position with regard to references to other forms of guidance related to demonstrating compliance with the requirements of the Building Regulations.

A previous study looking at the implications for the design of large industrial and storage buildings found that there was no obvious statistical evidence for an increased risk to life safety as compartment size increases. The analysis should be reviewed in the light of the most recent data to see if this conclusion still holds.

 © BRE Global Ltd 2025

8 Proposed next steps

A draft list of prioritised research topics was prepared in response to a request arising from discussions with MHCLG, to potentially be taken forward in Objective C of the current research project which was prepared and sent out to BRE Global project partners and Technical Steering Group members for comment. The prioritised list is shown in Table 13.

Table 13 − Draft prioritised list of research topics to potentially be taken forward in Objective C

Priority	Description	Nature of work required
1	Improved clarity on purpose of the Approved Document B	Revised text to provide an unambiguous statement on the purpose of AD B and to provide information on what is and what is not covered by the guidance.
2	Development of an additional methodology for assessment of structural fire resistance and compartmentation over and above the standard fire testing regime	Development of a large-scale experimental testing methodology capable of dealing with complex fire dynamics and interaction of members and components.
3	Impartial, independent fire testing of mass timber compartments subject to realistic design fire scenarios	Large-scale fire tests/experiments to evaluate anticipated performance of mass timber buildings designed in accordance with standard fire testing requirements (60/90/120).
4	Review and assessment of fire test procedures for cavity barriers. Consider scope for development of means of test and assessment that more closely reflect the end use condition.	Desk based review and potential large-scale fire tests.
5	Fire resistance of open-sided car parks	Review of evidence underpinning relaxation in guidance to allow 15 minutes for open-sided car parks up to 30m in height. Desk based review but consider potential for collaborative programme of work with the British Parking Association (BPA).
6	Need for revised “deemed to satisfy” guidance	The archiving of BR 128 by BRE and the removal of the reference to the document in the current version of the guidance has highlighted the need for simple, conservative solutions to common fire resistance periods across the construction industry. Consideration should be given to providing updated, demonstrably conservative solutions based on tabulated data from modern codes and standards and, where available, standard fire test data from industry.

7	Fire resistance recommendations for large single-storey buildings	A review of the current recommendations related to maximum compartment sizes to take account of concerns from key stakeholders to see if there is any evidence to provide restrictions on compartment size for large single-storey storage and warehouse buildings.

It is understood that the list of research topics was presented with a briefing note prepared by MHCLG at a meeting of the Building Regulations Advisory Committee (BRAC) Fire Safety Working Group held on 6th October 2021.

The number of policy areas taken forward into the research stage will depend on the project timeline and budget and therefore will be selected by MHCLG, considering the proposals of the BRE Global Project Team, the comments from the Project Technical Steering Group and the feedback from the BRAC Working Group members.

© BRE Global Ltd 2025

9 Acknowledgements

It should be noted that the views of the individual sections of this report are the views of the author of that section and are not necessarily the views of all the authors.

University of Edinburgh were the primary authors of the fire statistics, travelling fires and car parks sections.

Buro Happold were the primary authors of the cavity barriers section.

Design Fire Consultants were the primary authors of the mass timber construction, Modern Methods of Construction and BS 9999 sections.

© BRE Global Ltd 2025

10 References

1. BRE Global (various authors), BD 2887 Compartment sizes, resistance to fire and fire safety project. Seven workstreams, Final workstream reports for Department for Communities and Local Government, published 2019. Available from https://www.gov.uk/government/publications/compartment-size-resistance-to-fire-and-fire-safety-research. Last accessed 23rd September 2020.

2. Joint Committee of the Building Research Board of the Department of Scientific and Industrial Research and of the Fire Offices' Committee, Post-War Building Studies No. 20 Fire Grading of Buildings Part 1 General Principles and Structural Precautions, Published for the Ministry of Works by His Majesty's Stationery Office, London, 1946.

3. CIB W14 Workshop Report, Design Guide: Structural Fire Safety, Fire Safety Journal, Volume 10, No. 1, pp 77-154, 1986.

4. Malhotra H L, Fire safety in buildings, Building Research Establishment Report, BR 96, Building Research Establishment, IHS BRE Press, 1987.

5. British Standards Institution, BS 9999 Fire safety in the design, management and use of buildings – Code of practice, BSI, London, 2017.

6. British Standards Institution, BS 9991 Fire safety in the design, management and use of residential buildings, BSI, London, 2015.

7. British Standards Institution, BS 7974 Application of fire safety engineering principles to the design of buildings – Code of practice, BSI, London, 2019.

8. British Standards Institution, PD 7974-1 Application of fire safety engineering principles to the design of buildings, Part 1: Initiation and development of fire within the enclosure of origin (Sub-system 1), BSI, London, 2019.

9. British Standards Institution, PD 7974-2 Application of fire safety engineering principles to the design of buildings, Part 2: Spread of smoke and toxic gases within and beyond the enclosure of origin (Sub-system 2), BSI, London, 2019.

10. British Standards Institution, PD 7974-3 Application of fire safety engineering principles to the design of buildings, Part 3: Structural response to fire and fire spread beyond the enclosure of origin (Sub-system 3), BSI, London, 2019.

11. British Standards Institution, PD 7974-5:2014 +A1 2020 Application of fire safety engineering principles to the design of buildings, Part 5: Fire and rescue service intervention (Sub-system 5), BSI, London, 2020.

12. British Standards Institution, PD 7974-6 Application of fire safety engineering principles to the design of buildings, Part 6: Human factors: Life safety strategies – Occupant evacuation, behaviour and condition (Sub-system 6), BSI, London, 2019.

13. British Standards Institution, PD 7974-7:2019 + A1:2021 Application of fire safety engineering principles to the design of buildings, Part 7: Probabilistic risk assessment, BSI, London, 2021.

14. Kirby B R, Newman G M, Butterworth N, Pagan J and English C, A new approach to specifying fire resistance periods, The Structural Engineer, pp 34-37, October 2004.

© BRE Global Ltd 2025

15. Gales J, Maluk C and Bisby L, Large-scale Structural Fire Testing – How did we get here, where are we, and where are we going? 15th International conference on experimental mechanics: Fire symposium, 22 to 27 July 2012, 22pp.

16. British Standards Institution, BS 476: Part 20 Fire tests on building materials and structures. Method for determination of fire resistance of elements of construction (general principles), BSI, London,1987.

17. British Standards Institution, BS EN 1363 Part 1, Fire resistance tests. General Requirements, BSI, London, 2012.

18. Ingberg S H, Tests on the severity of building fires, National Fire Protection Association, 22(1) pp 43-61, 1928.

19. Ingberg S H, Fire resistance classifications of building materials, 1942.

20. Statutory Instruments, 1965 No. 1373 Building and Buildings, The Building Regulations 1965, HMSO, 1965.

21. Law M, A review of formulae for t-equivalent, Fire Safety Science – Proceedings of the fifth international symposium, International Association for Fire Safety Science, pp 985-996, 1997.

22. British Standards Institution, BS EN 1991-1-2 Eurocode 1. Actions on structures. General actions. Actions on structures exposed to fire, BSI, London, 2002.

23. British Standards Institution, BS EN 13501-2 Fire classification of construction products and building elements – Part 2: Classification using data from fire resistance tests, excluding ventilation services, BSI, London, 2016.

24. Stern-Gottfried J and Rein G, Travelling fires for structural design – Part I: Literature review, Fire Safety Journal, Volume 54, pp 74-85, 2012.

25. Fu I, Rickard I and Hopkin D, An improved reliability-based approach to specifying fire resistance periods for buildings in England, Applications of Structural Fire Engineering, Ljubljana, Slovenia, 9 to 11 June 2021.

26. HM Government, The Building Regulations 2010, Approved Document A (Structure), 2013.

27. Schleich J-B and Cajot L-G, Valorisation Project – Natural Fire Safety Concept, Profil Arbed Researches, 2001.

28. Stern-Gottfried J and Rein G, Travelling fires for structural design – Part II: Design methodology. Fire Safety Journal, Volume 54, pp 96-112, 2012.

29. Stern-Gottfried J, Travelling Fires for Structural Design, A thesis submitted for the degree of Doctor of Philosophy, The University of Edinburgh, 2011.

30. Rackauskaite E, Hamel C, Law A and Rein G, Improved Formulation of Travelling Fires and Application to Concrete and Steel Structures, Structures, Volume 3, pp 250-260, 2015.

31. Kirby B R, Wainman D E, Tomlinson L N , Kay T R and Peacock B N, Natural Fires in Large Scale Compartments, British Steel Technical, Fire Research Station Collaborative Project Report, Rotherham, UK, 1994.

32. Thomas I R et al., Fire tests of the 140 William Street Office Building, BHP Co. Ltd., Melbourne, Australia, 1993.

33. Stern-Gottfried J, Rein G, Lane B and Torero J L, An innovative approach to design fires for structural analysis of non-conventional buildings: a case study, Application of Structural Fire Engineering, Prague, Czech Republic, 2009.

34. Rackauskaite E, Kotsovinos P, Jeffers A and Rein G, Structural analysis of multi-storey steel frames exposed to travelling fires and traditional design fires, Engineering Structures, pp 271-288, 2017. doi: 10.1016/j.engstruct.2017.06.055

35. Dai X, Welch S and Usmani A, A critical review of 'travelling fire' scenarios for performance-based structural engineering, Fire Safety Journal, Volume 91, pp 568–578, 2017. doi:10.1016/j.firesaf.2017.04.001

36. Nan Z, Dai X, Chen H, Welch S and Usmani A, A numerical investigation of 3D structural behavior for steel-composite structures under various travelling fire scenarios, Proceedings of the 11th International Conference on Structures in Fire, SiF 2020, University of Queensland, Brisbane, Australia, 30 November to 2 December 2020, 2020. doi:10.14264/a1068ab

37. Rein G, Abecassis-Empis C and Carvel R, The Dalmarnock Fire Tests: Experiments and Modelling, the School of Engineering and Electronics, University of Edinburgh, Edinburgh, UK, 2007. ISBN 978-0-9557497-0-4

38. Horová K, Jána T and Wald F, Temperature heterogeneity during travelling fire on experimental building, Advances in Engineering Software, Volumes 62–63, pp 119–130, 2013. ISSN 0965-9978, doi: 10.1016/j.advengsoft.2013.05.001

39. Hidalgo J P, Cowlard A, Abecassis-Empis C, Maluk C, Majdalani A H, Kahrmann S, Hilditch R, Krajcovic M and Torero J L, An experimental study of full-scale open floor plan enclosure fires, Fire Safety Journal, Volume 89, pp 22-40, 2017. doi:10.1016/j.firesaf.2017.02.002

40. Rush D, Dai X, Lange D, Tisova Fire Test – fire behaviours and lessons learnt, Fire Safety Journal, Volume 121, 103261, 2020, doi:10.1016/j.firesaf.2020.103261

41. Hidalgo J P, Goode T, Gupta V, Cowlard A, Abecassis-Empis C, Maclean J, Bartlett A I, Maluk, C, Montalvá J M, Osorio A F and Torero J L, The Malveira fire test: full-scale demonstration of fire modes in open-plan compartments, Fire Safety Journal, Volume 108, 102827, 2019. https://doi.org/10.1016/j.firesaf.2019.102827

42. Heidari M, Rackauskaite E, Christensen E, Bonner M, Morat S, Mitchell H, Kotsovinos P, Turkowski P, Węgrzyński W, Tofilo P and Rein G, Fire experiments inside a very large and open-plan compartment: x-TWO, Proceedings 11th International Conference Structures in Fire, SiF 2020, University of Queensland, Brisbane, Australia, 30 November to 2 December 2020.

43. Sjöström J, Hallberg E, Kahl F, Temple A, Anderson J, Welch S, Dai X, Krajcovic M, Gupta V, Lange D and Hidalgo J, TRAFIR Characterization of TRAvelling FIRes in large compartments, Work Package 2, Deliverable 2.2 (unpublished), 2019.

44. Anderson J, Sjöström J, Temple A, Dai X, Welch S, Rush D, Charlier M and Anderson J, FDS simulations and modelling efforts of travelling fires in a large elongated compartment, Proceedings of the 15th International Conference and Exhibition on Fire Science and Engineering, Interflam 2019, Royal Holloway College, Nr Windsor, UK, 1-3 July 2019.

45. Nadjai A, Alam N, Charlier M, Vassart O, Dai X, Franssen J -M and Sjöström J, Travelling fire in full scale experimental building subjected to open ventilation conditions, Proceeding of the 11th International Conference Structures in Fire, SiF 2020, University of Queensland, Brisbane, Australia, 30 November to 2 December 2020. doi:10.14264/987a305

46. Gupta V, Hidalgo J P, Cowlard A, Abecassis-Empis C, Majdalani A H, Maluk C and Torero J L, Ventilation effects on the thermal characteristics of fire spread modes in open-plan compartment fires, Fire Safety Journal, Volume 120, 103072, 2020. doi:10.1016/j.firesaf.2020.103072

47. Gupta V, Osorio A F, Torero J L and Hidalgo J P, Mechanisms of flame spread and burnout in large enclosure fires, Proceedings of the Combustion Institute, Brisbane, Australia, Volume 38, pp 24-29, January 2021 doi:10.1016/j.proci.2020.07.074

48. Gupta V, Torero J L and Hidalgo J P, Burning dynamics and in-depth flame spread of wood cribs in large compartment fires, Combustion and Flame, Volume 228, pp 42-56, 2021. doi:10.1016/j.combustflame.2021.01.031

49. British Standards Institution, BS EN 1993-1-2 Eurocode 3. Design of steel structures. General rules. Structural fire design, BSI, London, 2005.

50. British Standards Institution, BS EN 1992-1-2 Eurocode 2. Design of concrete structures. General rules. Structural fire design, BSI, London, 2004.

51. British Standards Institution, BS EN 1994-1-2 Eurocode 4. Design of composite steel and concrete structures. General rules. Structural fire design, BSI, London, 2005.

52. British Standards Institution, BS EN 1995-1-2 Eurocode 5. Design of timber structures. General. Structural fire design, BSI, London, 2004.

53. British Standards Institution, BS EN 1996-1-2 Eurocode 6. Design of masonry structures. General rules. Structural fire design, BSI, London, 2005.

54. British Standards Institution, BS EN 1999-1-2 Eurocode 9. Design of aluminium structures. Structural fire design, BSI, London, 2007.

55. British Standards Institution, BS 5588-7 Fire precautions in the design, construction and use of buildings. Code of practice for the incorporation of atria in buildings, BSI, London, 1997.

56. HM Government, Manual to the Building Regulations, A code of practice for use in England, Crown Copyright, July 2020.

57. Law A and Bisby L, The rise and rise of fire resistance, Fire Safety Journal, Volume 116, 103188, 2020.

58. OFR Compliance Roadmap for CLT projects in England Regulation B3 (1), OFR Consultants, 2020.

59. Structural Timber Association, Structural timber buildings fire safety in use guidance Volume 6 – Mass timber structures Building Regulation compliance B3(1) STA fire safety research and guidance project version v1.1, October 2020.

60. Morris W A, Read R E H and Cooke G M E, Guidelines for the construction of fire-resisting structural elements, Building Research Establishment Report BR 128, Crown Copyright, 1988.

61. Structural Timber Association, Structural timber buildings fire safety in use guidance Volume 1 Pattern book systems, STA fire safety research and guidance project Revision V1.1, March 2020.

62. Lawson R M and Way A G J, Fire resistance of light steel framing, SCI Publication P 424, 2020.

63. Department for Communities and Local Government. The Building Regulations 2010 (England) Approved Document B. Fire safety Volume 2: Buildings other then dwellinghouses (2006 edition incorporating 2010 and 2013 amendments).

64. The Fire Protection Association, The Building Regulations 2000 (England). Approved Document B Fire safety Volume 2: Buildings other than dwellinghouses. AD B incorporating insurers' requirements for property protection 2008 edition (under revision).

65. Department for Communities and Local Government – Fire Statistics – Great Britain.

66. Klippel M, Leyder C, Frangi A, Fontana M, Lam F and Cecotti A, Fire tests on loaded Cross Laminated timber wall and floor elements, Fire Safety Science, Volume 11, pp 626-639, 2014.

67. CROSS UK, The risk of collapse of multi-storey CLT buildings during a fire, CROSS Safety Report 966, published 29th March 2021. Available from: Collaborative Reporting for Safer Structures UK (CROSS-UK). Last accessed 27th May 2021.

68. OFR Fire and Risk Consultants Design Note Literature Review of Large-scale Fire Experiments on Cross-laminated Timber, 28/7/2020, 2020.

69. Mindeguia J-C, Mohaine S, Bisby L A, Robert F, McNamee R and Bartlett A I, Thermo-mechanical behaviour of cross-laminated timber slabs under standard and natural fires, Interflam 2019, 15th International Conference and Exhibition on Fire Science and Engineering, London, 2019.

70. Medina Hevia A R, Fire resistance of partially protected cross-laminated timber rooms, Carleton University, 2014.

71. Su J Z, Lafrance P-S, Hoehler M and Bundy M, Fire safety challenges of tall wood buildings – Phase 2: Tasks 2 and 3 – Cross-laminated timber compartment fire tests, 2018.

72. Bartlett A, Law A, McNamee R J, Zehfuss J, Mohaine S, Tessier C and Bisby L, Heat fluxes to a façade resulting from compartment fires with combustible and non-combustible ceilings, 3rd International Symposium on Fire Safety of Facades, Paris, 2019.

73. Dagnesais C, Ranger L and Benichou N, Fire performance of cross-laminated timber with adhesives conforming to 2018 edition of ANSI/APA PRG-320 (No. 301013085; Solutions for Upper Mid-Rise and High-Rise Mass Timber Construction), National Resources of Canada, 2019.

74. Brandon D, Temple A, Sjostrom J, Klippel M and Schmid J, Standard test development for fire performance characterisation of CLT glue lines, Smart Housing Smaland.

75. Mass timber fire safety experiment, Arup see Arup explores the safe use of cross laminated timber in construction - Arup. Last accessed 28th May 2021.

76. Lennon T, Fires in cavities in residential buildings, The performance of cavity barriers in external walls with combustible materials, NHBC Foundation Publication NF 51, 2013.

77. Alimzhanova M, J-Value Assessment of Sprinkler Systems in Car Parks, IMFSE Thesis, University of Edinburgh, 2021.

78. Storesund K, Sesseng C, Mikalsen R F, Holmvaag O and Steen-Hansen A, Evaluation of fire in Stavanger airport car park 7 January 2020, RISE Research Institutes of Sweden, RISE-report 2020:91, September 2020. doi: 10.13140/RG.2.2.24520.14080.

79. Boehmer H, Klassen M, and Olenick S, Modern Vehicle Hazards in Parking Structures and Vehicle Carriers, Fire Protection Research Foundation, FPRF-2020-07, July 2020. Available from: https://www.nfpa.org/News-and-Research/Data-research-and-tools/Building-and-Life-Safety/Modern-Vehicle-Hazards-in-Parking-Garages-Vehicle-Carriers. Last accessed 27th May 2021.

 © BRE Global Ltd 2025

80. Hertz K D, Sørensen L S and Giuliani L, Structural design of car parks, Journal of Structural Fire Engineering, under review, 2021.

81. Joyeux D, Kruppa J, Cajot L, Schleich J, Van de Leur P and Twilt L, Demonstration of real fire tests in car parks and high buildings, European Commission, 2002.

82. British Standards Institution, BS EN 1366-4, Fire resistance tests for service installations – Part 4: Linear joint seals, BSI, London, 2010.

83. British Standards Institution, BS EN 1365-5, Fire resistance tests for loadbearing elements – Part 5: Balconies and walkways, BSI, London, 2004.

84. British Standards Institution, BS EN 1365-6, Fire resistance tests for loadbearing elements – Part 6: Stairs, BSI, London, 2004.

85. British Standards Institution, BS 8414-1, Fire performance of external cladding systems. Test method for non-loadbearing external cladding systems fixed to and supported by a masonry substrate, BSI, London, 2020.

86. Communities and Local Government, BD 2569, Fire Performance of Escape Stairs, October 2009.

87. Home Office, Fire and rescue incident statistics England, year ending June 2020, Fire statistics - GOV.UK (www.gov.uk). Last accessed 22nd February 2021.

88. Home Office, Detailed analysis of fires attended by fire and rescue services, England, April 2019 to March 2020.

89. Manes M and Rush D, A Critical Evaluation of BS PD 7974-7 Structural Fire Response Data Based on USA Fire Statistics, Fire Technology, Volume 55, pp 1243–1293, October 2018.

90. Manes M and Rush D, Assessing fire frequency and structural fire behaviour of England statistics according to BS PD 7974-7, Fire Safety Journal, Volume 120, 103030, 2021.

91. EU FireStat, First Progress Report: EU FireStat - Closing data gaps and paving the way for pan-European Fire Safety Efforts, 2021. Available from: https://eufirestat-efectis.com/. Last accessed 27th May 2021.

92. Department for Communities and Local Government, Incident Recording System - Questions and lists Version 1.6, 2012.

93. Home Office, Fire and rescue incident statistics. Methodology and quality report, 2020.

94. Home Office, Fire Statistics definitions, 2020.

95. Home Office, Fire statistics team, Publishing Incident Recording System data on the fire and rescue service at an incident level: Dwelling Fires Dataset and Guidance, 2020.

96. Home Office, Response times to fires attended by fire and rescue services, England, April 2019 to March 2020, 2020.

Appendix B1 National and European standards directly related to fire resistance

Table B1 − British Standards fire resistance test standards and whether referenced in AD B (Volume 1 and 2)

Standard reference	Title/scope	AD B (Volume 1 and 2)
BS 476-20: 1987	Fire tests on building materials and structures. Method for the determination of the fire resistance of elements of construction (general principles)	Yes
BS 476-21: 1987	Fire tests on building materials and structures. Methods for the determination of the fire resistance of loadbearing elements of construction	Yes
BS 476-22: 1987	Fire tests on building materials and structures. Methods for the determination of the fire resistance of non-loadbearing elements of construction	Yes
BS 476-23: 1987	Fire tests on building materials and structures. Method for the determination of the contribution of components to the fire resistance of a structure.	Yes
BS 476-24: 1987, ISO 6944: 1985	Fire test on building materials and structures. Method for the determination of the fire resistance of ventilation ducts.	Yes ISO 6944: 1985 not referenced

Table B2 − Current European fire resistance test standards and whether referenced in AD B (Volume 1 and 2)

Standard reference	Title/scope	AD B (Volumes 1 and 2)
EN 1363-1	Fire resistance tests – Part 1: General requirements	No
EN 1363-2	Fire resistance tests – Part 2: Alternative and additional procedures	No
EN 1364-1	Fire resistance tests for non-loadbearing elements – Part 1: Walls	No
EN 1364-2	Fire resistance tests for non-loadbearing elements – Part 2: Ceilings	No
EN 1364-3	Fire resistance tests for non-loadbearing elements – Part 3: Curtain walling – Full configuration	No
EN 1364-4	Fire resistance tests for non-loadbearing elements – Part 4: Curtain walling – Part configuration	No
EN 1364-5	Fire resistance tests for non-loadbearing elements – Part 5: Air transfer grilles	No
EN 1365-1	Fire resistance tests for loadbearing elements – Part 1: Walls	No
EN 1365-2	Fire resistance tests for loadbearing elements – Part 2: Floors and roofs	No
EN 1365-3	Fire resistance tests for loadbearing elements – Part 3: Beams	No
EN 1365-4	Fire resistance tests for loadbearing elements – Part 4: Columns	No
EN 1365-5	Fire resistance tests for loadbearing elements – Part 5: Balconies and walkways	No
EN 1365-6	Fire resistance tests for loadbearing elements – Part 6: Stairs	No
EN 1366-1	Fire resistance tests for service installations – Part 1: Ventilation ducts	No
EN 1366-2	Fire resistance tests for service installations – Part 2: Fire dampers	Yes

Standard reference	Title/scope	AD B (Volumes 1 and 2)
EN 1366-3	Fire resistance tests for service installations – Part 3: Penetration seals	No
EN 1366-4	Fire resistance tests for service installations – Part 4: Linear joint seals	No
EN 1366-5	Fire resistance tests for service installations – Part 5: Service ducts and shafts	No
EN 1366-6	Fire resistance tests for service installations – Part 6: Raised access and hollow core floors	No
EN 1366-7	Fire resistance tests for service installations – Part 7: Conveyor systems and their closures	No
EN 1366-8	Fire resistance tests for service installations – Part 8: Smoke extraction ducts	Yes
EN 1366-9	Fire resistance tests for service installations – Part 9: Single compartment smoke extraction ducts	No
EN 1366-10	Fire resistance tests for service installations – Part 10: Smoke control dampers	No
EN 1366-11	Fire resistance tests for service installations – Part 11: Fire protective systems for cable systems and associated components	No
EN 1366-12	Fire resistance tests for service installations – Part 12: Non-mechanical fire barrier for ventilation ductwork	No
EN 1366-13	Fire resistance tests for service installations – Part 13: Chimneys	No
EN 1634-1	Fire resistance and smoke control tests for door and shutter assemblies, openable windows and elements of building hardware – Part 1: Fire resistance test for door and shutter assemblies and openable windows	Yes
EN 1364-2	Fire resistance and smoke control tests for door and shutter assemblies, openable windows and elements of building hardware – Part 2: Fire resistance characterisation test for elements of building hardware	Yes

© BRE Global Ltd 2025

Standard reference	Title/scope	AD B (Volumes 1 and 2)
EN 1364-3	Fire resistance and smoke control tests for door and shutter assemblies, openable windows and elements of building hardware – Part 3: Smoke control test for door and shutter assemblies	Yes
EN 13381-1	Test methods for determining the contribution to the fire resistance of structural members – Part 1: Horizontal protective membranes	No
EN 13381-2	Test methods for determining the contribution to the fire resistance of structural members – Part 2: Vertical protective membranes	No
EN 13381-3	Test methods for determining the contribution to the fire resistance of structural members – Part 3: Applied protection to concrete members	No
EN 13381-4	Test methods for determining the contribution to the fire resistance of structural members – Part 4: Applied passive protection to steel members	No
EN 13381-5	Test methods for determining the contribution to the fire resistance of structural members – Part 5: Applied protection to concrete/profiled sheet steel composite member	No
EN 13381-6	Test methods for determining the contribution to the fire resistance of structural members – Part 6: Applied protection to concrete filled hollow steel columns	No
EN 13381-7	Test methods for determining the contribution to the fire resistance of structural members – Part 7: Applied protection to timber members	No
EN 13381-8	Test methods for determining the contribution to the fire resistance of structural members – Part 8: Applied reactive protection to steel members	No
EN 13381-9	Test methods for determining the contribution to the fire resistance of structural members – Part 9: Applied fire protection systems to steel beams with web openings	No
EN 13381-10	Test methods for determining the contribution to the fire resistance of structural members – Part 10: Applied protection to solid steel bars in tension	No

© BRE Global Ltd 2025

Table B3 − Current European classification standards related to fire resistance and whether referenced in AD B (Volume 1 and 2)

Standard reference	Title/scope	AD B (Volumes 1 and 2)
EN 13501-2	Fire classification of construction products and building elements – Part 2: Classification using data from fire resistance tests, excluding ventilation services	Yes
EN 13501-3	Fire classification of construction products and building elements – Part 3: Classification using data from fire resistance tests on products and elements used in building service installations: fire resisting ducts and dampers	Yes
EN 13501-4	Fire classification of construction products and building elements – Part 4: Classification using data from fire resistance tests on components of smoke control systems	Yes

Table B4 − Current European Extended Application (EXAP) standards related to fire resistance and whether referenced in AD B (Volume 1 and 2)

Standard reference	Title/scope	AD B (Volumes 1 and 2)
EN 15080-8	Extended application of results from fire resistance tests – Part 8: Beams	No
EN 15080-12	Extended application of results from fire resistance tests – Part 12: Loadbearing masonry walls	No
EN 15254-2	Extended application of results from fire resistance tests – Non-loadbearing walls – Part 2: Masonry and Gypsum blocks	No
EN 15254-3	Extended application of results from fire resistance tests – Non-loadbearing walls – Part 3: Lightweight partitions	No
EN 15254-4	Extended application of results from fire resistance tests – Non-loadbearing walls – Part 4: Glazed constructions	No
EN 15254-5	Extended application of results from fire resistance test – Non-loadbearing walls – Part 5: Metal sandwich panel construction	No
EN 15254-6	Extended application of results from fire resistance tests – Non-loadbearing walls – Part 6: Curtain walling	No
EN 15254-7	Extended application of results from fire resistance tests – Non-loadbearing ceilings – Part 7: Metal sandwich panel construction	No
EN 15269-1	Extended application of test results for fire resistance and/or smoke control for door, shutter and openable window assemblies, including their elements of building hardware – Part 1: General requirements	No
EN 15269-2	Extended application of test results for fire resistance and/or smoke control for door, shutter and openable window assemblies, including their elements of building hardware – Part 2: Fire resistance of hinged and pivoted steel doorsets	No
EN 15269-3	Extended application of test results for fire resistance and/or smoke control for door, shutter and openable window assemblies, including their elements of building hardware – Part 3: Fire resistance of hinged and pivoted timber doorsets and openable timber framed windows	No

Standard reference	Title/scope	AD B (Volumes 1 and 2)
EN 15269-5	Extended application of test results for fire resistance and/or smoke control for door, shutter and openable window assemblies, including their elements of building hardware – Part 5: Fire resistance of hinged and pivoted metal framed glazed doorsets and openable windows	No
EN 15269-7	Extended application of test results for fire resistance and/or smoke control for door, shutter and openable window assemblies, including their elements of building hardware – Part 7: Fire resistance for steel sliding doorsets	No
EN 15269-10	Extended application of test results for fire resistance and/or smoke control for door, shutter and openable window assemblies, including their elements of building hardware – Part 10: Fire resistance of steel rolling shutter assemblies	No
EN 15269-11	Extended application of test results for fire resistance and/or smoke control for door, shutter and openable window assemblies, including their elements of building hardware – Part 11: Fire resistance for operable fabric curtains	No
EN 15269-20	Extended application of test results for fire resistance and/or smoke control for door, shutter and openable window assemblies, including their elements of building hardware – Part 20: Smoke control for doors, shutters, operable fabric curtains and openable windows	No
EN 15882-1	Extended application of results from fire resistance tests for service installations – Part 1 Ducts	No
EN 15882-2	Extended application of results from fire resistance tests for service installations – Part 2: Fire dampers	No
EN 15882-3	Extended application of results from fire resistance tests for service installations – Part 3: Penetration seals	No
EN 15882-4	Extended application of results from fire resistance tests for service installations – Part 4: Linear joint seals	No

© BRE Global Ltd 2025

Report Ends

www.bre.co.uk

Health and Safety Executive
Final Report

Structural Fire Resistance and Fire Separating Elements – Appendix C: AD B Clarification

Prepared for: The Building Safety Regulator

Prepared by: Neal Butterworth and Weimiao Lu

Approved by: Dr Roger Harrison (original report approval 27 May 2023) and Tony Baker (final amendments March 2025) on behalf of BRE Global

Date: 27 May 2023

HSE Contract: 1.11.4.4436 (previously MHCLG Contract: CPD/004/120/206)

Report Number: P118139-1015 (M11D9V3) Appendix C

BRE Global Ltd
Watford, Herts
WD25 9XX

Customer Services 0333 321 8811

From outside the UK:
T + 44 (0) 1923 664000
E enquiries@bregroup.com
www.bregroup.com

This report is made on behalf of BRE Global and may only be distributed in its entirety, without amendment, and with attribution to BRE Global Ltd to the extent permitted by the terms and conditions of the contract.

BRE Global's liability in respect of this report and reliance thereupon shall be as per the terms and conditions of contract with the client and BRE Global shall have no liability to third parties to the extent permitted in law.

Table of Contents

© BRE Global Ltd 2025

 © BRE Global Ltd 2025

1 Introduction

This Appendix contains the findings of Task C1 AD B Clarification and takes into account comments from DLUHC, the Technical Steering Group and the BRAC Part B working party.

 © BRE Global Ltd 2025

2 Introduction to Objective C Task 1

2.1 Summary of Objective A and B findings

Objectives A and B have been completed and a summary of the findings is provided in this section.

Objective A identified that:

- Fire resistance requirements in AD B are expressed as an exposure period in a standard fire test.
- The intent of the fire resistance recommendations in AD B Table B4 can be summarised as:
  - 30 minutes: sufficient fire resistance to allow occupants to evacuate and fire service to have some impact from outside.
  - 60 minutes: sufficient fire resistance to withstand burnout of 'low fire load' combustible contents.
  - 90 minutes: sufficient fire resistance to withstand burnout of 'low fire load' combustible contents with a factor of safety of 1.5.
  - 120 minutes: sufficient fire resistance to withstand burnout of 'moderate fire load' combustible contents or sufficient fire resistance to withstand burnout of 'low fire load' combustible contents with a factor of safety of 2.0.
- Building Regulations 1965 prescribed fire resistance standards as a function of purpose group (a proxy for fire load) and height (a proxy for increasing fire load and a required factor of safety).
- Building Regulations 1985 onwards defined a functional requirement (i.e. stability for a reasonable period), but guidance in Approved Documents still referred to 30, 60, 90 and 120 minute fire resistance standard in accordance with standard fire tests.

Objective B identified that:

- The current guidance does not take into account the potential of the extra fire load from combustible structures such as mass timber, timber frame or SIP panels.
- The current guidance is more generally suited to traditional forms of construction and may not be applicable to modern methods of construction.
- There are some conflicting performance requirements to AD B and BS 9999/BS 9991.

Therefore, the findings of Objective A and B show that:

- The legislative requirement for fire resistance is functional, but the functional intent is lost in AD B.
- AD B needs to be explicit on the type of structures that the guidance is applicable to and make clear reference to other guidance for routes of compliance or to determine the appropriate performance requirements.

2.2 Purpose of report

The structure of legislation and AD B is such that:

- Part B includes fire safety provisions for compliance with Regulations 4 and 7 of the Building Regulations. The provisions are functional and undefined.
- The Building Act 1984 refers to approving and issuing documents for the purpose of providing practical guidance with respect to the requirements of any provision of building regulations. By definition, AD B is one of such approved documents and approved under Regulation 6. Therefore, according to the Building Act 1984, AD B is meant to provide government approved practical guidance for compliance with Part B, and according to its own stated scope, the guidance in AD B is limited to more common building situations.
- For each Part B provision, AD B includes an Intention Section, which by definition is to provide additional clarification on the intention of the functional provision.
- Finally, as stated in AD B, there are other means by which compliance with Part B can be evidenced and in fact, in some situations due to limitations on the scope of AD B, alternative approaches ("Alternatives") might be the only option.

This results in the hierarchy shown in Figure 1.

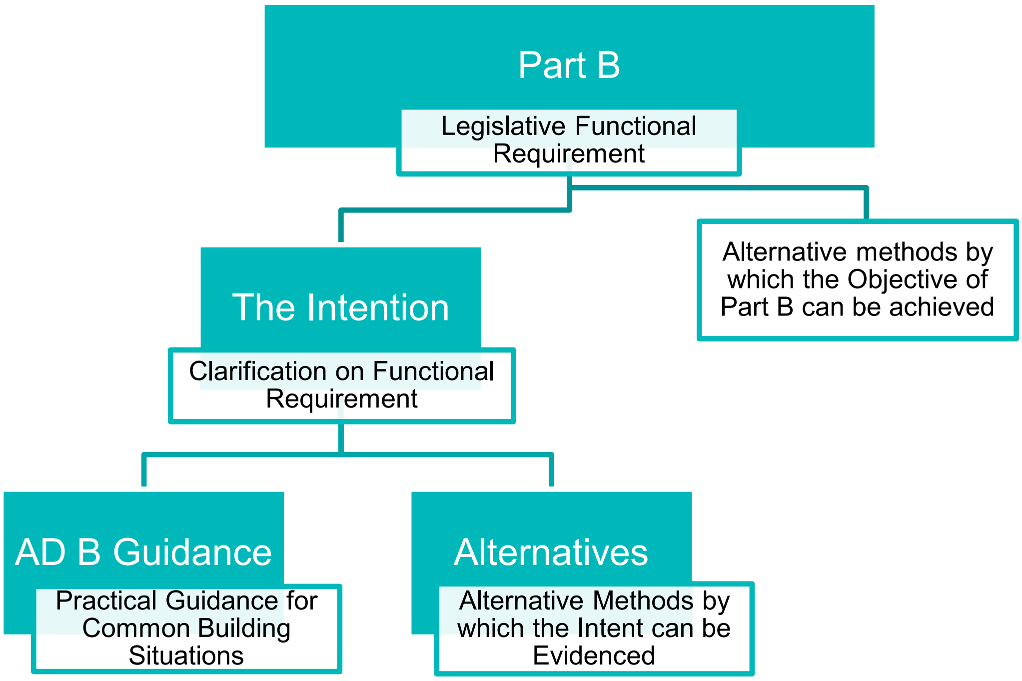


Figure 1 – Hierarchy of options in satisfying Part B of the Building Regulations

Under this hierarchy, it becomes clear how important the Intent Section is because it provides clarity on how Part B is to be met and consequently whether AD B Guidance and/or Alternatives result in compliance with Part B.

Therefore, to be successful, the following must exist:

1. The Intention Section must be sufficiently clear to ensure that AD B Guidance can be interpreted correctly where there is ambiguity or insufficient detail (which is inevitable for a guidance document).
2. The Intention Section must be sufficiently clear to ensure that Alternative Methods deliver on the requirements of Part B.
3. Implicit assumptions within AD B regarding its scope in the context of ‘common building situations’ must be made explicit.

Therefore, Objective C, Task 1 sets out to provide clarification and future policy consideration to the guidance in AD B Provision B3, with a view to help avoid the misapplication of AD B guidance on the fire resistance for unsuitable buildings or structural forms. This is to be achieved by considering:

- Proposed clarification to the Intention Section to improve clarity on the requirements of provision B3(1) – i.e. items 1 and 2 above. The objective of the proposed clarification is to make the Intent Section applicable to not only “common building situations”, but also to all building situations.
- Identifying implicit assumptions within AD B and making them explicit – i.e. item 3 above.

© BRE Global Ltd 2025

3 The Intent

3.1 Functional requirement

Provision B3(1) of the Building Regulations requires that:

"B3. (1) The building shall be designed and constructed so that, in the event of fire, its stability will be maintained for a reasonable period."

This functional objective includes three components; event of fire, building stability and reasonable period, none of which is defined or quantified.

The lack of definition or quantification is common across all Part B provisions, and indeed all provisions within Schedule 1 of the Building Regulations. This is deliberate and acknowledged within the Building Act which empowers government to provide practical guidance (in this case AD B) for compliance with Part B.

For context, the Building Act 1984 states the following intent on Approved Documents for purpose of building regulations:

"For the purpose of providing practical guidance with respect to the requirements of any provision of building regulations, the Secretary of State or a body designated by him for the purposes of this section may—

(a) approve and issue any document (whether or not prepared by him or by the body concerned), or

(b) approve any document issued or proposed to be issued otherwise than by him or by the body concerned,

if in the opinion of the Secretary of State or, as the case may be, the body concerned the document is suitable for that purpose."

Therefore, it can be concluded that the Secretary of State's view is paramount to the correct interpretation of Building Regulations.

3.2 Current Intention Section (as stated within AD B)

Each provision of Part B of AD B includes a section entitled, "Intention", which is meant to describe how the provision would be met.

In the case of provision B1, the Intention Section provides useful expansion on the provision.

Provision B1 requires that:

"B1. The building shall be designed and constructed so that there are appropriate provisions for the early warning of fire, and appropriate means of escape in case of fire from the building to a place of safety outside the building capable of being safely and effectively used at all material times."

The intention confirms that appropriate means of escape must consider location, number and capacity of escape routes and to be safe they must be protected from the effect of smoke and fire and be adequately lit, as shown in the extract from the Intention Section below.

"In the Secretary of State's view, requirement B1 is met by achieving all of the following.

a. There are sufficient means for giving early warning of fire to people in the building.

© BRE Global Ltd 2025

b. *All people can escape to a place of safety without external assistance.*

c. *Escape routes are suitably located, sufficient in number and of adequate capacity.*

d. *Where necessary, escape routes are sufficiently protected from the effects of fire and smoke.*

e. *Escape routes are adequately lit and exits are suitably signed.*

f. *There are appropriate provisions to limit the ingress of smoke to the escape routes, or to restrict the spread of fire and remove smoke.*

The extent to which any of these measures are necessary is dependent on the use of the building, its size and its height.

Building work and material changes of use subject to requirement B1 include both new and existing buildings."

Another such example is provision B5 where the Intention Section also provides elaboration on the requirements.

Provision B5 requires that:

"B5. (1) The building shall be designed and constructed so as to provide reasonable facilities to assist fire fighters in the protection of life; (2) Reasonable provision shall be made within the site of the building to enable fire appliances to gain access to the building."

The Intention Section then provides more details on what "reasonable facilities" and "reasonable provision" entail. It gives recommendation on providing provisions such as external access, internal access and ventilation of heat and smoke from a fire in a basement by stating the following in the Intention Section of B5:

"*Provisions covering access and facilities for the fire service are to safeguard the health and safety of people in and around the building. Their extent depends on the size and use of the building. Most firefighting is carried out within the building. In the Secretary of State's view, requirement B5 is met by achieving all of the following.*

a) *External access enabling fire appliances to be used near the building.*

b) *Access into and within the building for firefighting personnel to both:*

    i. *search for and rescue people*

    ii. *fight fire.*

c) *Provision for internal fire facilities for firefighters to complete their tasks.*

d) *Ventilation of heat and smoke from a fire in a basement.*

If an alternative approach is taken to providing the means of escape, outside the scope of this approved document, additional provisions for firefighting access may be required. Where deviating from the general guidance, it is advisable to seek advice from the fire and rescue service as early as possible (even if there is no statutory duty to consult)."

However, for provision B3(1), the Intention Section includes no such clarification.

In the Intent Section for provision B3(1), the Secretary of State's view states that "*(a). For defined periods, loadbearing elements of structure withstand the effects of fire without loss of stability*".

The wording does not give clear guidance on the required duration of stability in a fire nor on the definition of structural stability; instead, it is simply a rephrasing of the provision itself.

Therefore, for consistency and to have any benefit, the Intention Section should be changed so that it provides at least some expansion or clarification of the provision. Such change would need to elaborate on the three components of the provision (i.e. what fire event, what is meant by stability and what constitutes a reasonable period).

3.3 Proposed changes to the Intent Section

This section provides insight on the functional objective requirement by clarification of the three components; event of fire, building stability and reasonable period.

3.3.1 Event of fire

By adopting the fire resistance standards of AD B Table B4, it has been shown from the Objective A and B findings that the AD B specification implicitly assumes a compartment fire, where all combustible contents have been burned and no account is taken of any fire service intervention.

If this is an intended definition of "event of fire", then the Intention Section should include a statement that compliance with provision B3(1) must be based on assumptions that an accidental fire occurs and that its growth and development is not affected by first-aid or fire service intervention.

3.3.2 Building stability and reasonable period

Objective A and B work traced the origins of provision B3(1) and associated AD B Guidance and concluded that the periods of fire resistance in AD B Table B4 are as follows:

- 30 minutes: sufficient fire resistance to allow occupants to evacuate and fire service to have some impact from outside.
- 60 minutes: sufficient fire resistance to withstand burnout of 'low fire load' combustible contents.
- 90 minutes: sufficient fire resistance to withstand burnout of 'low to moderate fire load' combustible contents or sufficient fire resistance to withstand burnout of 'low fire load' combustible contents with a factor of safety of 1.5.
- 120 minutes: sufficient fire resistance to withstand burnout of 'moderate fire load' combustible contents or sufficient fire resistance to withstand burnout of 'low fire load' combustible contents with a factor of safety of 2.0.

© BRE Global Ltd 2025

Table 1 is reproduced from Post-war building studies[1] which defines the fire load in terms of calorific values.

Table 1 – Categories of fire load as per Post-war building studies[1]

Category	Fire load density (BTU/ft^2)	Fire load density (MJ/m^2)	Example occupancies
Low fire load	≤100,000	≤1134	Flats, offices, hotels etc.
Moderate fire load	100,000 to 200,000	1134 to 2269	Shops, factories etc.
High fire load	200,000 to 400,000	2269 to 4538	Warehouses and storage

In this context, "low fire load" refers to Post-war building studies and may be considered as "normal fire load" in the current built environment.

Therefore, it is implicitly inherent that the duration for which stability must be maintained for different building situations is interlinked with achieving compliance with the other provisions of Part B. In other words:

- For buildings where safety is dominated by means of escape, a sufficient period of stability must be maintained for the evacuation period (with a factor of safety).
- For buildings where safety requires internal fire service access, a sufficient period of stability must be maintained to allow the fire service to access the opportunity to complete search and rescue, attempt offensive fire fighting and retreat if necessary.
- For some buildings the consequences of loss of stability might be considered so high that stability should be maintained indefinitely.

The above principle is akin to recommendation by BS EN 1991-1-7, which states that "*The minimum period that a building needs to survive following accident should be that period needed to facilitate the safe evacuation and rescue of personnel from the building and its surroundings*".

With these building categories in mind, the following intention for provision B3(1) is inferred:

1. To ensure adequate means of escape;
   a. Stability should be maintained in so far as is necessary to allow occupants to get to protected means of escape and to maintain the tenability and functionality of protected means of escape routes.
   b. The period of stability should be the time required to enter protected means of escape routes and evacuate the building with a reasonable margin of safety.
2. To protect subdivision provision;
   a. Stability should be maintained in so far as is necessary to maintain the function of any subdividing elements.
   b. The period of stability should be the duration for which the integrity of subdividing elements needs to be maintained.

3. To prevent external fire spread;

   a. Stability should be maintained in so far as is necessary to prevent fire spread between buildings.

   b. The period of stability should be indefinite or of sufficient time to allow the fire service to prevent fire spread (where fire service intervention is possible).

4. To protect fire service access;

   a. Stability should be maintained in so far as is necessary to enable the fire service access strategy.

   b. The period of stability should be sufficient to enable the fire service access strategy, which might be indefinite where there is an internal fire service access strategy.

In addition, it can be inferred that provision A3 imposes requirements on provision B3(1) such that collapse should not be disproportionate to the cause should fire occur (see Section 5.1). Therefore, it might also be necessary to include an additional item to the Intention Section that acknowledges (perhaps simply by reference) provision A3. For example, Item 5 could be added to the Intention Section to read:

5. To comply with provision A3 such that damage is not disproportionate to the fire event.

Including the above clarification within the Intention Section would re-establish a connection between provision B3(1) and the intended structural performance required to comply with provision B3(1). Additionally:

- It would be clear to users what AD B recommendations are trying to achieve.
- There would some context as to the scope of AD B in respect of ‘more common building situations’.
- Where Alternatives are adopted, it would clarify what performance needs to be achieved.

© BRE Global Ltd 2025

4 Approved Document B Guidance

4.1 AD B referencing

All references to AD B paragraphs and tables are based on AD B Volume 2. Similar provisions are also available in AD B Volume 1.

4.2 Common building situations

The scope of AD B is common building situations. Therefore, AD B Guidance is only relevant to common building situations. AD B includes no definition of a common building situation; therefore, whether a specific building constitutes a common building situation needs to be inferred.

AD B Guidance (and any associated assumptions) with respect to fire resistance can be interpreted to identify what constitutes more common building situations, and results in one of the following:

- AD B Guidance is appropriate for common building situations, and for common building situations, AD B provides guidance on how to meet Building Regulations including compliance with provision B3(1).
- AD B Guidance is not necessarily appropriate for buildings that do not constitute common building situations, and for such buildings, compliance with AD B Guidance would either:
  - Not be adequate for compliance with provision B3(1), or
  - Be adequate for compliance with provision B3(1) but using an Alternative might yield a more optimal construction.

In the following sections, the relevant AD B recommendations are assessed respectively to provide contextualisation where common building situations are inferred within the guidance.

4.3 AD B Section 7

AD B Section 7 heading “Loadbearing elements of structures” indicates that the provisions in Section 7 only cover loadbearing element of structures. This is not necessarily the case, as AD B paragraph 7.2 (a) provides provisions on elements that provide the function of support or stabilisation of another element of structure. An example of this might be the restraint beams which reduce the effective length of a long column that span multi storeys, but are not loadbearing elements.

Therefore, it is suggested that consideration be given to changing AD B Section 7 heading to “Elements of structures” to avoid confusion.

4.3.1 AD B paragraph 7.1

AD B paragraph 7.1 states that “*Elements such as structural frames, beams, columns, loadbearing walls (internal and external), floor structures and gallery structures should have, as a minimum, the fire resistance given in Appendix B Table B3*”.

This recommendation assumes implicitly that the building’s structural stability system comprises only structural frames, beams, columns, loadbearing walls, floor structures and gallery structures. This assumption is also inherent in the fire resistance requirements of AD B Table B3.

© BRE Global Ltd 2025

Accordingly, AD B paragraph 7.1 assumes implicitly that the stability systems of common building situations are limited to structural frames, beams, columns, loadbearing walls, floor structures and gallery structures. Similarly, and buildings with stability systems comprising items other than those listed in AD B paragraph 7.1 (e.g. suspended/hung structures, geodesic structures, some volumetric systems or panelised systems) cannot be considered common building situations.

It is suggested that AD B paragraph 7.1 could be amended to clarify that this provision is related to "loadbearing elements and any elements needed for structural stability".

4.3.2 AD B paragraph 7.3

AD B paragraph 7.3 gives a list of exclusions from the provision for elements of structure.

It can be inferred from the assumed function of the items listed (in the context of building stability) and the note to paragraph 7.3 that they are listed because in common building situations they do not contribute to the building's stability.

If this interpretation is correct, it is suggested that the current note could be amended to clarify that in instances where items listed in paragraph 7.3 may be essential for the stability system of the building, the elements must demonstrate the relevant fire resistance for the building as required by paragraph 7.2a.

4.4 AD B Appendix B (Fire resistance)

4.4.1 Principles

AD B Paragraph B19 to B25 define the principles of fire resistance for compliance with AD B as follows:

- B19: Fire resistance is a measure of one or more of resistance to collapse (loadbearing), resistance to fire penetration (integrity) and resistance to transfer of excessive heat (insulation).
- B20: The standards of fire resistance necessary are based on assumptions about the severity of fires and consequences should an element fail. AD B uses purpose group as a proxy for fire severity and storey height as a proxy for consequences of failure.
- B22: Performance in terms of fire resistance achieved by elements of structure is classified in accordance with BS EN 13501-2.
- B23: For the purposes of AD B, fire resistance periods relate to time elapsed in a standard test as opposed to real time.
- Table B3 gives requirements in accordance with BS EN 13501-2 or BS 476-20 for each element of structure either directly and/or by reference to Table B4.
- Table B4 sets out minimum fire resistance periods in accordance with BS EN 13501-2 or BS 476-20 by purpose group and storey height.
- Table B5 is related to uninsulated glazing and is not discussed herein.

It is recognised that the evolution of AD B Guidance is derived from and for "traditional" forms of construction and is for "more common building situations". As a result, simply following the guidance in AD B (including the minimum fire resistance periods and the standard test methods), may not be sufficient to meet the requirements of provision B3(1). This is particularly so in case where the structure is combustible, and fire induced structural failure is more significant.

Therefore, the objective of the following clarifications is to ensure that compliance with AD B can be explicitly achieved and that implicit assumptions are not invalidated by constructions that do not fall within the implicit scope of Tables B3 and B4.

4.4.2 Tables B3 and B4

4.4.2.1 Inherited limitations and assumptions

Tables B3 and B4 express fire resistance requirements in terms of testing in accordance with European standards or BS 476. Therefore, AD B inherits any explicit and implicit limitations and/or assumptions of the test methodologies, which in turn defines more common building situations for the purposes of provision B3(1). In other words, structural systems that can be adequately or conservatively represented by standard tests constitute common building situations and are within the scope of AD B.

Similarly, any structural systems that cannot be adequately or conservatively represented by standard tests are not within the scope of AD B and do not constitute common building situations. In such situations either AD B Guidance must be amended to increase its scope (and widen the definition of common building situations) or Alternatives must be used to demonstrate compliance with the Intent Section and hence provision B3(1).

As Part of the Objective C work, the following testing standards have been reviewed to identify the relevant underpinning assumptions of AD B fire resistance table:

- BS EN 1363-1:2012[2]
- BS EN 1363-2:1999[3]
- BS EN 1364-1:2015[4]
- BS EN 1365-1:2012[5]
- BS EN 1365-2:2014[6]
- BS EN 1365-3:2000[7]
- BS EN 1365-4:1999[8]
- BS 476-20:1987[9]
- BS 476-21:1987[10]
- BS 476-22:1987[11]
- BS EN 13501-2: 2009[12]

The findings are summarised below.

Combustible construction

From the review, it is identified that the relevant test standards include the following types of heating curves:

- Standard heating curve;
- Hydrocarbon curve;
- External fire exposure curve;
- Slow heating curve.

The curves define the gas temperature of the furnace with respect to time.

The standard heating curve includes tolerance of a deviation in excess of 100K above the specified temperature/time curve for less than 10 minutes, this is to account for test specimens which burn rapidly with sudden ignition of significant quantities of combustible materials increasing the gas temperature in the furnace.

However, regardless of the above provision, as discussed in Section 3.3.1, the duration of exposure in the furnace was derived to give an equivalent severity of exposure that would result from the combustible contents of a building if they were to burn out (i.e. burnout of all combustible contents). These 'equivalent' periods are only valid for buildings where the fabric of the building does not contribute to the fire severity (i.e. the construction is either not combustible, or combustible materials are adequately encapsulated so that they do not pyrolyze).

An alternative way of thinking of this is that the standard curves are simply a means of defining the rate at which gas must be burned in the furnace. The gas is a proxy for combustible contents of the 'building'. To have adequate resistance to fire from the combustible contents of a building non-combustible elements of structure should be exposed to the same fire load (furnace gas) as combustible elements of structure. However, when a combustible element burns in a furnace, the amount of gas (fire load) required to maintain the furnace temperature is lower than for a non-combustible element of structure (i.e. the fire load exposure (amount of gas) differs) and a combustible element would not achieve the same fire resistance in practice as a non-combustible element.

Therefore, standard fire testing, and consequently Tables B3 and B4, are only applicable to buildings where the structure and fabric of the building are not combustible or where any combustible materials are adequately encapsulated (both in the building and in the test).

Rate of heating

Fire resistance testing requires structures to be tested to a single fire exposure (i.e. a single fire curve, e.g. standard, hydrocarbon, etc.). Because the test is limited to a single heating curve, the methodology implicitly assumes that the fire resistance of the structural system is not sensitive to the time-temperature history (i.e. rate of heating), but is solely governed by the maximum temperature to which elements are elevated by the fire.

Therefore, for compliance with provision B3(1), AD B Guidance implicitly assumes that common building situations means structures that are not sensitive to the rate of heating in a fire.

Conversely, the standard fire testing method (and hence AD B Guidance) might not be applicable to structural systems that are sensitive to the rate of heating (e.g. thermally brittle structures such as steel structures where connections might rupture, or thermally thick structures where thermal wave and load induced thermal strain might take time to incur a negative impact on the strength and stiffness of structures).

In addition, intumescent paint is typically sensitive to the rate of heating, and as a result it might not activate properly under slow heating in the initial stage of fire.

It is understood that the performance of plasterboards depends on the chemicals within the plasterboard and may fail prematurely due to rapid heating rate. However, there is not sufficient evidence that suggests that testing under standard fire curve will result in non-safe design solutions of plasterboard.

Other examples of structural materials or forms which may be sensitive to the rate of heating might include (but are not limited to):

- Spalling of concrete structures, particularly high-strength concrete;
- Hollow core slabs with pre-stressed wires that could be susceptible to rate of heating;

Homogeneous heating

Standard test furnace sizes and configurations are such that all elements are heated homogeneously on the exposed faces. Therefore, it is an implicit assumption in AD B Guidance that all elements within a structural system are subject to uniform heating or that uniform heating of all structural elements is more onerous than differential heating.

However, there are building situations (e.g. large compartments) where heating of the structural system might not be homogenous (e.g. because of uneven fire load distribution or the fire travels through the compartment as opposed to having a homogenous compartment fire).

As such, this single zone homogeneous fire may not be a conservative assumption for structural system that might be sensitive to differential heating (e.g. systems where restrained thermal expansion might induce instability).

However, there is no known evidence of failures of structures that comply with the AD B guidance as a result of non-homogeneous heating. Therefore, for common building situations, it is likely that AD B is sufficiently conservative.

Fully developed fires

As discussed in Section 3.3.1, AD B specification implicitly assumes a fully developed compartment fire, where all combustible contents have been burned. This inherent assumption does not consider travelling fires/fires that do not become fully developed.

Whilst the assumption is likely to be conservative in most situations, there are situations where the assumption becomes unduly onerous (e.g. spaces where the fire load is low relative to the volume of the space.

Residual strength after cooling

AD B and the fire resisting standards are generally applicable to structures where the thermodynamics and associated heat transfer can be adequately or conservatively represented by the standard fire (i.e. a constantly increasing temperature applied to the whole compartment with no cooling phase).

It is identified from the review that Appendix B of BS 476-20: 1987 provides recommendation of evaluation of residual loadbearing capacity. It states that a test construction may be considered to have adequate residual strength if it is capable of supporting the full test load 16 h after termination of the heating period. If a test construction collapses during the post-heating period, or if a residual strength test is not carried out, a reduction in the time for compliance with the loadbearing capacity criterion may be considered necessary. The level of reduction may be varied for example depending on the mode of failure but should not be greater than 20%. Where a structure can be shown to have adequate redundancy or where the form of construction is known to have sufficient residual loadbearing capacity, the residual strength test would normally not be required.

The above is the requirement from Appendix B of BS 476-20: 1987. It is noted that this is not commonly adopted in fire testing and this piece of recommendation is not contained within the relevant European standards (i.e. the relevant parts of BS EN 1363, BS EN 1364 and BS EN 1365).

Boundary and support conditions

The review of the testing standards shows that the typical standard fire test procedures have been developed for test specimens comprising simple elements with simplified restraint conditions. This does not adequately represent the complex interactions within real buildings including continuity, redistribution and membrane actions.

For most structural forms, the simplistic representation is conservative because most real structures perform better in fire as a system than as a collection of isolated parts.

However, in some instances, e.g. where thermal expansion of components might reduce the overall performance of the system, the simplified restraint conditions might not be conservative.

Examples of such conditions include:

- Inclined columns where loss of lateral restraints due to thermal expansion of beams could lead to column failure.
- Where a secondary beam connects to a primary beam off-centre from the column, the thermal expansion of secondary beams could lead to shear failure of the connections between primary beams and the column.
- Where the supports of a structural element are rigid, the thermal expansion of the element could lead to premature buckling failure.

Replicability

Because fire testing typically only requires one specimen to be tested for a given set of support, restraint, loading and exposure conditions, approval and certification of a product can be based on a test result of a solitary specimen with no account taken of variances where multiple specimens are tested. There is an implicit assumption that the as-built construction replicates (or is no worse than) the test specimen. The current testing regime does not provide sufficient information on whether the fire resistance achieved is disproportionately sensitive to quality of construction and installation details. As such, it is possible that the ”in-practice” fire resistance achieved by a system/product could be significantly less than that achieved in fire tests if it is not installed with a high degree of precision. This might be particularly true for some Modern Methods of Construction (MMC) which are by necessity and by definition highly optimised.

As the AD B guidance is heavily reliant on achieving adequate fire resistance standards for elements, it is important to note that the lack of replicability requirement in the current testing regime may result in inadequate “in-practice” fire resistance when structural systems are installed.

Calculation methods

Calculation methods, such as in EN 1993-1-2, are based on the assumption that fire performance is governed by residual material strength. This is not always the case, and in some situations other factors govern. Such factors include:

- Thermally induced material elongation.
- Thermally induced buckling.

Examples of situations where the above might result in premature failure are:

- Unbonded post-tensioned concrete structures where thermal elongation of the steel tendons result in loss of pre-stressing.
- Inclined columns (see discussions above).

© BRE Global Ltd 2025

4.4.3 Table B3 review

AD B Table B3 specifies the following types of exposure for certain elements of structure as outlined in Table 2.

Table 2 – Extract from AD B Table B3

Part of building	Type of exposure (AD B)
1. Structural frame, beam or column	Exposed faces
2. Loadbearing wall	Each side separately
3. Floors	From underside

It can be inferred from Table 2 that the following assumption is made within the AD B guidance:

1. In common buildings situations, it is implicitly assumed that the behaviour of structural frame, beam or column can be adequately represented by being subject to fire exposure on exposed faces. The review of the relevant test standards shows that beams are typically tested with associated construction on the top to reflect its exposure to fire in practice. Columns are fully exposed to the fire equally on all faces in the fire tests. Where columns are built into wall constructions which have the effect of partially shielding the column from full fire exposure, these columns should be evaluated as part of a wall specimen.
2. In common building situations, it is implicitly assumed that the behaviour of loadbearing walls can be adequately represented by being subject to fire exposure from one side. However, it is identified that this is not necessarily the case where loadbearing walls do not act as fire separation walls, they can be exposed from fire on both sides simultaneously. Therefore, the specified type of exposure (each side separately) may not be conservative enough for certain types of wall constructions (e.g. light gauge steel frame walls or timber framed construction).
3. In common building situations, it is implicitly assumed that floors are typically only susceptible to fire exposure from underside. This assumption may be appropriate for traditional floor constructions (e.g. concrete floors). However, it might be necessary for lightweight floor construction (e.g. CLT floors) to be tested under fire exposure from both underside and above as a worst case scenario. There is existing test data that suggests that lightweight floors can be prone to failure when subject to heating from the above.

4.4.4 Table B4 review

The principles of the assumptions of AD B Table B4 are:

- For certain purpose groups and heights, the intent of the fire resistance standard is to ensure an adequate likelihood of the structure maintaining its stability until all the combustible contents have been burned and beyond.
- Purpose Group is a proxy for fire severity. Factors that are considered also include occupant responsiveness, evacuation mode and time. This is a generalisation of typical occupancy types, but may be a conservative assumption for common building situations.
- Purpose Group and height are proxies for the consequence of failure. This may not be an accurate representation (because consequences of failure are also influenced by other factors such as size of building, number of people, etc.), but they are not unreasonable parameters.

© BRE Global Ltd 2025

bre

- The effect of sprinklers in reducing the required fire resisting standard is accounted for by an arbitrary reduction (e.g. a reduction of 30 minutes fire resistance in some instances).

4.4.5 Fire severity

Fire load survey research[13] has shown that the fire load differs between different purpose groups, for example domestic fire load is typically higher than office or hotel fire load. This is not exactly reflected in AD B Table B4, i.e. the fire load is assumed to be low for all occupancies except industrial and storage (where a 90 minutes fire resistance is recommended for buildings with a top storey more than 5 m in height to survive the burn out of the fire load). This has been recognised in BS 9999 which recommends different fire resistance standards for different risk profiles of the same height.

The origins of AD B guidance use fire load density as a proxy for fire severity. However, this is not always the case as heat release rate per unit area or ventilation conditions could have a considerable impact on the fire severity.

4.4.6 Options for AD B

There are three options available for AD B:

1. No change.
2. Adopt the considerations from BS 9999 Table 23 which assigns different fire resistance standards for different risk profiles.
3. Further study to determine the appropriate fire severity (fire load and heat release rate per unit area) for different purpose groups and adapt AD B Table B4 accordingly.

Table 3 provides a summary of the pros and cons for each of the options outlined above.

Table 3 – Pros and cons of the proposed Option 1, 2 and 3

	Change required	Conservative recommendations	More optimal building design	Currency of fire load survey data
Option 1	Zero	√[Note 1]	×	1950s
Option 2	Low	×	√	1970s
Option 3	High	√	√	Current

Notes:

1 The AD B recommendations are conservative as the fire load assumption in AD B is more onerous across purpose groups than the current research indicates.

At this juncture, we would recommend Option 1 as it requires zero change and there is no evidence of this resulting in a non-safe building design. The AD B requirements have been well accepted by industry and alternative methods are always available (e.g. BS 9999 or fire engineering approaches such as that in BS 7974 standard and published documents). In addition, the clarification provided to the Intent (see Sections 3.3.1 and 3.3.2) will enable alternative approaches to be followed to satisfy functional objectives. Therefore, AD B remains applicable for common building situations.

4.4.7 Recommendations

Notwithstanding the above, there is little evidence that the fire testing regime specified by AD B Tables B3 and B4 does not result in an adequate fire resistance standard for traditional forms of construction or

© BRE Global Ltd 2025

structures that have been common until now (although there are limited instances identified where traditional construction or structural forms may result in unsafe design when following the current AD B guidance. Refer to examples outlined in Section 4.4.2.1).

With the advancement of the construction industry in the past decades and development of innovative structural systems and forms, it cannot be assumed that Tables B3 and B4 will always result in adequate fire resistance that satisfies the functional objectives. It has already been identified in this report that they cannot be used for combustible construction that is not adequately encapsulated and it is possible that they would not be adequate for some Modern Methods of Construction (MMC).

Therefore, in order to ensure that AD B Tables B3 and B4 are appropriate for use, the explicit and implicit assumptions should be used to define explicit limitations on their application. For example, Tables B3 and B4 are only relevant for:

- Constructions that are not combustible or constructions where combustible components are fully encapsulated for the required duration.
- Situations where the rate of heating is similar to the standard fire curves or the fire resistance of structural systems and elements is governed by the maximum temperature (surface temperature of the element) and is not adversely sensitive to the rate of change of temperature.
- Situations that result in homogenous heating of the structural system or structural system that are not adversely sensitive to differential heating.
- Structural systems and elements of structure that are not unduly susceptible to failure during cooling.
- Structural systems and elements of structure that can be adequately or conservatively represented with the boundary and support conditions in standard fire tests.
- Structural systems and elements that either reliably replicate the test specimens or are not unduly sensitive to construction imperfections.

Based on the review, recommendations are made to "Type of exposure" in AD B Table B3. This is shown in Table 4.

Table 4 – Suggested change for AD B Table B3

Part of building	Type of exposure (recommendation)
1. Structural frame, beam or column	Exposed face(s)
2. Loadbearing wall	Exposed face(s)
3. Floors	Exposed face(s)

Notes:
1 Elements that would only be exposed on one face can be tested for that face only.
2 Symmetrical elements that could be exposed on multiple faces (but not simultaneously) can be tested for one face only.
3 Asymmetrical elements that could be exposed on multiple faces (but not simultaneously) must be tested for each face separately or the weakest face.
4 Elements that can be exposed on multiple faces simultaneously must be tested for the most onerous exposure (this could be a combination of exposed faces). Note that there is no harmonised test standard currently available to enable this.

The intent of the recommendation is such that AD B makes recommendation to ensure that the element is tested under conditions which are reflective of the most onerous scenario that can be reasonably foreseen as possible, although the recommendation may indicate proposed changes to the current testing standards which is outside the scope of Task C1.

Therefore, when considering exposure to "Exposed faces", it is recommended that one or a combination of the following should be adopted in the testing where appropriate:

- One side only (e.g. from underside of concrete floor);
- Each side separately (e.g. compartment wall);
- All exposed faces simultaneously (e.g. heating a timber floor, light gauge steel frame floor panels or steel modular floor panels from both underside and upper side simultaneously).

An example that a combination of the above may be required is testing of a loadbearing wall (e.g. light gauge steel frame or timber frame) that does not form a compartment wall. It is not clear whether the most onerous scenario will be fire exposure to one side or both sides simultaneously. Therefore, it is suggested this type of construction should be tested both from each side separately, and from all exposed sides simultaneously. This is to ensure that the testing method is conservative enough to represent a realistic behaviour of the element in the event of a fire. Note that further research is required in this area before deciding what (standard) tests should be specified.

Based on the review, the scope of AD B Table B4 is limited to common building situations and the fire resistance values provided are intended to achieve functional objectives rather than being reflective of real time. To help users of AD B interpret Table B4 and meet the functional objectives, the following clarification is proposed:

- Where 30 minutes is specified, this is to provide sufficient fire resistance to allow occupants to evacuate and fire service to have some impact from outside.
- Where 60 minutes is specified, this is to provide sufficient fire resistance to withstand burnout of 'low fire load' combustible contents.
- Where 90 minutes is specified, this is to provide sufficient fire resistance to withstand burnout of 'low fire load' combustible contents with a factor of safety of 1.5.
- Where 120 minutes is specified, this is to provide sufficient fire resistance to withstand burnout of 'moderate fire load' combustible contents or sufficient fire resistance to withstand burnout of 'low fire load' combustible contents with a factor of safety of 2.0.

This clarification intends to help users of AD B evaluate the impact of fire safety on a case by case basis and determine the possible routes to compliance for different types of buildings. For instance, STA (Structural Timber Association) guide[14] provides Building Regulation compliance routes for structural stability in the event of fire of mass timber buildings of different uses and sizes. Therefore, it is considered that reference can be made to the STA guide for routes of achieving compliance for mass timber structures.

It is also identified during the review that AD B puts the reliance of structural fire performance on the results from standard fire tests and does not make direct reference to design to British or European standards (e.g. EN 1991-1-2, EN 1992-1-2, EN 1993-1-2, EN 1994-1-2, EN 1995-1-2, EN 1996-1-2, EN 1999-1-2). It is perceived that there is a disconnect in the existing guidance and design approach as it is not clear whether fire safety design of common building situations can be based on the relevant fire parts of the Eurocodes or have to be solely based on fire test results. Therefore, it is recommended that clarification be provided within AD B on whether the structural Eurocodes can provide a means to prove compliance with fire resistance requirement in addition to standard fire tests.

 © BRE Global Ltd 2025

5 Part A

5.1 Relationship between provisions A3 and B3(1)

5.1.1 Provisions

Provision A3 of the Building Regulations requires that:

"A3. The building shall be constructed so that in the event of an accident the building will not suffer collapse to an extent disproportionate to the cause."

The Secretary of State's view further states that:

"The requirement of A3 will be met by an appropriate choice of measures to reduce the sensitivity of a building to disproportionate collapse should an accident occur."

Fire is an accidental loading that may occur in the building life. Therefore, provision A3 is also applicable to the fire safety design, i.e. the building should not be sensitive to disproportionate collapse should a fire occur.

Therefore, there is a clear link between provisions A3 and B3(1); the former requiring protection against disproportionate collapse from fire and the latter requiring stability to be maintained for a reasonable period in the event of fire.

However, there are two differences between provisions A3 and B3(1):

- Provision A3 is not time bound (i.e. the building should not be sensitive to disproportionate collapse from fire altogether) whereas provision B3(1) requires stability to be maintained for a reasonable period. Therefore, it is theoretically possible for a building to comply with provision B3(1) but not provision A3 (because the building could be sensitive to disproportionate collapse, but only after a reasonable period).

- Provision B3(1) requires certain parts of the building to maintain stability for certain periods (e.g. means of escape routes or fire service access routes); whereas provision A3 allows some collapse which could be parts of the building that would cause a failure to comply with Part B. Therefore, it is also theoretically possible to comply with provision A3 but not provision B3(1).

Therefore, unless the link between the provisions is explicit, there is a chance (particularly when using Alternatives) of buildings failing to comply with one or both provisions (e.g. because fire is not properly considered as an accidental load when designing for provision A3, or sensitivity to disproportionate collapse is not considered when designing for provision B3(1)).

5.1.2 Approved Document B Intention Sections

There is no explicit reference to the relationship between provisions A3 and B3(1) in the Intention Sections of the respective Approved Documents.

© BRE Global Ltd 2025

5.1.3 Approved Document guidance

There is no explicit reference to the relationship between provisions A3 and B3(1) in the guidance of the respective Approved Documents. However, as discussed below, for most common building situations, the guidance in the Approved Documents is aligned and would result in compliance with respective provisions:

- Whilst not referenced as being an accidental load in AD A, fire is referenced as an accidental load in codes and standard (e.g. BS EN 1990: 2002) that are referenced by AD A.
- The guidance in AD A paragraph 5.1 makes no additional requirement to protect against disproportionate collapse for structural Consequence Class 1 buildings. Consequence Class 1 buildings are typically low rise buildings. The guidance in Table B4 of AD B only requires low rise buildings to have achieve a 30-minute fire resistance standard (i.e. partially protected) and (implicitly) accepts that collapse can occur after a reasonable period. Therefore, the guidance is aligned.
- The guidance in AD B paragraph 5.1 makes additional recommendations to protect against disproportionate collapse for Consequence Class 2 buildings. Consequence Class 2 buildings are low to medium consequence buildings. The guidance in Table B4 of AD B implicitly requires all buildings other than low rise buildings to maintain stability for the entire duration of a fire (i.e. collapse would not occur). Therefore, the guidance is aligned.
- The guidance in AD B paragraph 5.1 requires a systematic assessment for Consequence Class 3 buildings. Consequence Class 3 buildings are high rise buildings or buildings that are not within the scope of AD B (e.g. hospitals). For high rise buildings, AD B Table B4 requires structures to be fully protected with a high factor of safety. Therefore, provided fire is included as an accidental load within that systematic assessment, the guidance is aligned.
- Therefore, for Consequence Class 3 buildings it is possible to assume that compliance with provision B3(1) is adequate for compliance with provision A3. However, this is not necessarily always the case (e.g. it is possible to have a fully protected structure, i.e. AD B compliant, that is sensitive to disproportionate collapse from fire). In other words, it cannot always be assumed that compliance with AD B is adequate for compliance with provision A3. For instance, in situations where the performance of certain elements are key to the stability of the whole structure, disproportionate collapse could occur even though the AD B guidance has been followed, if a systematic assessment has not been undertaken in accordance with AD A.

This potential loophole could be eliminated by making the relationship between provision A3 and B3(1) more explicit. This is discussed in Section 5.2.

5.2 Making relationship explicit

5.2.1 Options

As outlined in Section 5.1, there is a relationship between provisions A3 and B3(1). Currently, this relationship is not explicit: neither in the provisions themselves, nor in the Approved Document Intention Sections, nor in the Approved Document Guidance.

In respect of the Approved Documents, there are four options:

1. No change: As discussed above, there is good alignment between the guidance in the Approved documents.

2. Guidance: make a note in AD B Table B4 to state that in addition to the provisions in Table B4, a systematic assessment of the impact of fire on the structural system needs to be considered for compliance with provision A3, and/or make it clear in AD A Section 5 that fire is an accidental load and simply complying with AD B might not be sufficient.
3. Intention Sections: Add clarification to the Intention Sections of the respective Approved Documents to cross-reference the respective provisions (see Section 3.3.2).
4. Explicit integration of the consequences class concept into AD B guidance.

5.3 Merits

Table 5 provides a summary of the pros and cons for each of the options outlined above.

As shown in Table 5, adopting Option 2 along with Option 3 will require a low level of change to the Approved Documents whilst providing benefits among three areas out of four:

- Cover all consequence classes; and
- Provide clarification for uncommon building situations; and
- Provide clarification for Alternatives.

Although Option 4 (Explicit integration) may provide the most benefits in helping users interpreting AD B guidance, this would necessitate significant change in the guidance document and therefore not recommended at this stage of the work.

Table 5 − Pros and cons of Options 1, 2, 3 and 4

	Change required	Cover all consequence classes	Provide clarification for uncommon building situations	Provide clarification for Alternatives	Integrated
Option 1	Zero	×	×	×	×
Option 2	Low	√	×	×	×
Option 3	Low	×	√	√	×
Option 4	High	√	√	√	√

Based on the above, it is proposed to adopt both Option 2 and 3 to establish an explicit link between AD A and AD B.

6 Conclusion

As set out within Approved Document B, the guidance is provided for common building situations. Tall, large, complex buildings, or where the structure is able to contribute as a source of fuel during a fire, might not be common building situations.

This report has been produced with a view to clarify AD B guidance where appropriate, to allow interpretation and expansion of guidance to be explicit on the performance expectation of relevant parts of AD B. Recommendation has been made to help inform the users of AD B (e.g. designers and approvers) where appropriate.

This report documents the findings of Task C1. It was recommended that this work be revisited when the outcome of Objective C Task 2 and Task 3 was made available. The outcome from these tasks as detailed in Appendix D1 has identified issues where reliance on the results from standard fire resistance testing is insufficient to demonstrate compliance with the mandatory requirements of the Building Regulations.

7 Acknowledgements

BRE Global would like to acknowledge the contribution of project partner Design Fire Consultants, the principal authors of this report.

8 References

1. Joint Committee of the Building Research Board of the Department of Scientific and Industrial Research and of the Fire Offices' Committee, Post-War Building Studies No. 20 Fire Grading of Buildings Part 1 General Principles and Structural Precautions, Published for the Ministry of Works by His Majesty's Stationery Office, London, 1946.
2. British Standards Institution, BS EN 1363-1, Fire resistance tests. General Requirements, BSI, 2012.
3. British Standards Institution, BS EN 1363-2, Fire resistance tests – Alternative and additional procedures, BSI, 1999.
4. British Standards Institution, BS EN 1364-1, Fire resistance tests for non-loadbearing elements, Part 1: Walls, BSI, 2015.
5. British Standards Institution, BS EN 1365-1, Fire resistance tests for loadbearing elements, Part 1: Walls, BSI, 2012.
6. British Standards Institution, BS EN 1365-2, Fire resistance tests for loadbearing elements, Part 2: Floors and roofs, BSI, 2014.
7. British Standards Institution, BS EN 1365-3, Fire resistance tests for loadbearing elements, Part 3: Beams, BSI, 2000.
8. British Standards Institution, BS EN 1365-4, Fire resistance tests for loadbearing elements, Part 4: Columns, BSI, 1999.
9. British Standards Institution, BS 476-20, Fire tests on building materials and structures. Method for determination of fire resistance of elements of construction (general principles), BSI, 1987.
10. British Standards Institution, BS 476-21, Fire tests on building materials and structures. Method for determination of fire resistance of loadbearing elements of construction, BSI, 1987.
11. British Standards Institution, BS 476-22, Fire tests on building materials and structures. Method for determination of fire resistance of non-loadbearing elements of construction, BSI, 1987.
12. British Standards Institution, BS EN 13501-2 + A1, Classification using data from fire resistance tests, excluding ventilation services, BSI, 2009.
13. CIB W14 Workshop Report, Design Guide: Structural Fire Safety, Fire Safety Journal, Volume 10, No. 1, pp 77-154, 1986.
14. Structural Timber Association, Structural timber buildings fire safety in use guidance, Volume 6 – Mass timber structures; Building Regulations compliance B3(1), Version v1.1, October 2020.

Appendix C1 Approved Document A provisions

This appendix provides a summary of Approved Document A Paragraph 5.1 provisions.

Paragraph 5.1 of Approved Document A provides the following approaches for ensuring that the building is sufficiently robust to sustain a limited extent of damage or failure, depending on the consequence class of the building, without collapse:

a. Determine the building's consequence class from AD A Table 11.

b. For Consequence Class 1 buildings, design and construct in accordance with AD A, no additional measures are likely to be necessary.

c. For Consequence Class 2a buildings, in addition to the Consequence Class 1 measures, provide enhanced measures such as horizontal ties.

d. For Consequence Class 2b buildings, in addition to the Consequence Class 1 measures, provide enhance measures such as horizontal ties and vertical ties.

   Alternatively, check that upon the notional removal of each load bearing element that building remains stable and that the area of floor at any storey at risk of collapse does not exceed 15% off the floor area of that storey or 100 m^2, whichever is smaller, and does not extend further than the immediate adjacent storeys (see Figure 2).

e. For Consequence Class 3 buildings, a systematic risk assessment of the building should be undertaken taking into account all the normal hazards that may reasonably be foreseen, together with any abnormal hazards.

Figure 2 shows the extract from AD A Diagram 24, which illustrates the notional removal method as outlined above and the underlying notion of collapse should not be disproportionate to the incident.

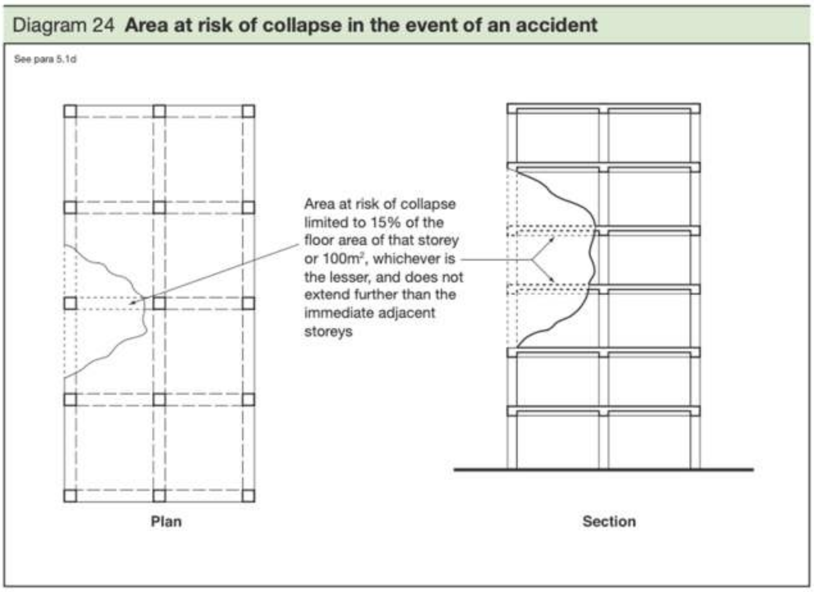


Figure 2 − Extract from AD A Diagram 24

Appendix C2 Approved Document A integration

This appendix documents the work undertaken on the explicit integration of AD A and AD B (See option 4 in Section 5.2) thus far. This is a subtask that suggests further changes and is not the focus of the current assignment.

Consequence class

As outlined in Section 5.2 for Option 4, it is identified from review that the grouping of buildings by consequences of failure in AD A Table 11 (see Figure 3) can be helpful in informing the structural performance objectives in AD B.

Table 11 **Building consequence classes**

Consequence Classes	Building type and occupancy
1	Houses not exceeding 4 storeys Agricultural buildings Buildings into which people rarely go, provided no part of the building is closer to another building, or area where people do go, than a distance of 1.5 times the building height
2a Lower Risk Group	5 storey single occupancy houses Hotels not exceeding 4 storeys Flats, apartments and other residential buildings not exceeding 4 storeys Offices not exceeding 4 storeys Industrial buildings not exceeding 3 storeys Retailing premises not exceeding 3 storeys of less than 2000m² floor area in each storey Single-storey educational buildings All buildings not exceeding 2 storeys to which members of the public are admitted and which contain floor areas not exceeding 2000m² at each storey
2b Upper Risk Group	Hotels, blocks of flats, apartments and other residential buildings greater than 4 storeys but not exceeding 15 storeys Educational buildings greater than 1 storey but not exceeding 15 storeys Retailing premises greater than 3 storeys but not exceeding 15 storeys Hospitals not exceeding 3 storeys Offices greater than 4 storeys but not exceeding 15 storeys All buildings to which members of the public are admitted which contain floor areas exceeding 2000m² but less than 5000m² at each storey Car parking not exceeding 6 storeys
3	All buildings defined above as Consequence Class 2a and 2b that exceed the limits on area and/or number of storeys Grandstands accommodating more than 5000 spectators Buildings containing hazardous substances and/or processes

Notes:

1. For buildings intended for more than one type of use the Consequence Class should be that pertaining to the most onerous type.
2. In determining the number of storeys in a building, basement storeys may be excluded provided such basement storeys fulfil the robustness requirements of Consequence Class 2b buildings.
3. BS EN 1991-1-7:2006 with its UK National Annex also provides guidance that is comparable to Table 11.

Figure 3 – Extract from AD A Table 11

Therefore, it is proposed to integrate the concept of consequence classes AD A into AD B such that different approaches for adopting fire resistance standard can be proposed based on the consequences of failure:

- For low to medium failure consequence buildings, the building can provide adequate time for means of escape.
- For medium to high failure consequence buildings, the building has an adequate high probability of withstanding burnout of combustible contents considering consequences of failure on means of escape, fire spread between buildings and fire service access.

This principle is formulated in Table 66. The consequence classes of failure depend on a number of factors, such as occupancy type, building height, number of storeys, and forms of construction. AD B adopts a combination of trigger heights and purpose groups to address the failure consequences, whilst AD A provides a consequence class system that account for the typical normal hazards and abnormal hazards group.

Such linkage has also been established in Structural Timber Association (STA) guide[14]. The STA guide provides routes for achieving compliance with Part B3(1) for mass timber structures and adopts the methodology of the consequence of failure for different building types. On this basis, this guide made recommendations on the route to compliance, which could be either performance-based or guidance based.

Table 6 – Consequence class of failure based on AD A and STA Guide and its associated functional objectives

Consequence Class	Type Building Type and Occupancy	Functional Objectives
Class 1: Low	Single occupancy houses not exceeding 4 storeys	The building should provide adequate time for means of escape
Class 2A: Low to medium (Lower risk group)	• 5-storey single occupancy houses • Hotels not exceeding 4 storeys • Flats, apartments and other residential buildings not exceeding 4 storeys • Offices not exceeding 4 storeys • Industrial buildings not exceeding 3 storeys • Retail premises not exceeding 3 storeys of less than 1000 m^2 floor area in each storey • Single storey educational buildings • All buildings not exceeding two storeys to which the	The building should have an adequate high probability of withstanding burnout

Consequence Class	Type Building Type and Occupancy	Functional Objectives
	public are admitted, and which contain floor areas not exceeding 2000 m² at each storey	
Class 2B: Medium (Upper risk group)	• Hotels, flats, apartments and other residential buildings greater than 4 storeys but not exceeding 15 storeys • Educational buildings greater than single storey but not exceeding 15 storeys • Retail premises greater than 3 storeys but not exceeding 15 storeys • Hospitals not exceeding 3 storeys • Offices greater than 4 storeys but not exceeding 15 storeys • All buildings to which the public are admitted, and which contain floor areas exceeding 2000 m² but not exceeding 5000 m² at each storey	The building should have an adequate high probability of withstanding burnout with a factor of safety
Class 3: High	• All buildings defined above as lower and upper consequences class that exceed the limits on area and number of storeys • All buildings to which members of the public are admitted in significant numbers • Stadia accommodating more than 5,000 spectators	Not in the scope of AD B

Integration approach

Risk = frequency x probability x consequence

Frequency = occupancy (small influence).

Probability = fire load, sprinklers, compartmentation

Fire load and compartmentation are amalgamated in AD B by maximum allowable compartment areas.

Consequence = B1, B4 and B5.

	Short Evacuation Low rise External Fire	**Medium Evacuation Mid Rise ?**	**Stay-put High Rise Internal Fire**
Low Fire Load	Evacuation period only	Burnout	Burnout with factor of safety
Moderate Fire Load	Evacuation period only	Burnout	Burnout with factor of safety
High Fire Load	Evacuation period only	Burnout	Burnout with factor of safety

	Short Evacuation Low rise External Fire	**Medium Evacuation Mid Rise ?**	**Stay-put High Rise Internal Fire**
Low Fire Load	30 Consequence 1	60	90
Moderate Fire Load	30	90	120
High Fire Load	30	120	240 (reduced to 120 based on other AD B provisions).

		Short Evacuation Low rise External Fire	Medium Evacuation Mid Rise ?	Stay-put High Rise Internal Fire
Low Fire Load	Houses, flats, institutional, other residential, office, assembly (some)	30	60	90
Moderate Fire Load	Shop, assembly, industrial	30	90	120
High Fire Load	storage	30	90	120

Factors = fire load, compartment floors,

Fire load – low = 60, moderate = 90, high = 120.

If not compartment floors x fire load by 2.

If means of escape only x above by 0.5.

If sprinklers x above by 0.5.

Consequence Class 1 = 30 minutes / 0 minutes if sprinkler protected.

Consequence Class 2a = 60 minutes / 30 minutes if sprinkler protected.

Consequence Class 2b and less than 30m = 90 minutes / 60 minutes if sprinkler protected.

Consequence Class 2b and more than 30m = 120 minutes / 90 minutes if sprinkler protected.

Consequence Class 3 = not in scope of AD B.

Document	Consequence 1 or up to 5 m	Consequence 2a	Consequence 2b	Consequence 3
AD A	Can fall down	60	90	120
AD B	Means of escape only	Burnout	Burnout	120

© BRE Global Ltd 2025

Purpose Group	Consequence 1 or up to 5 m	Consequence 2a	Consequence 2b	Consequence 3
1a – flats	30	60	90	120
1b – dwelling	30	60	90	120
2a – institutional	30	60	90	120
2b – other	30	60	90	120
3 – office	30	30	60	90
4 – shop and commercial	60	60	90	120
5 – assembly	60	60	90	120
6 – industrial	30	60	90	120
7 – storage	60	60	90	120
7b – car parks	30 15			120
Any other	30	30	90	120

© BRE Global Ltd 2025
Report Ends

www.bre.co.uk

Health and Safety Executive
Final Report

Structural Fire Resistance and Fire Separating Elements – Appendix D1: Experimental Programme and Development of a Test Methodology

Prepared for: The Building Safety Regulator

Prepared by: Tom Lennon

Approved by: Tony Baker on behalf of BRE Global

Date: 13th March 2025

HSE Contract: 1.11.4.4436 (previously MHCLG Contract: CPD/004/120/206)

Report Number: P118139-1015 (M11D9V3) Appendix D1

BRE Global Ltd
Watford, Herts
WD25 9XX

Customer Services 0333 321 8811

From outside the UK:
T + 44 (0) 1923 664000
E enquiries@bregroup.com
www.bregroup.com

This report is made on behalf of BRE Global and may only be distributed in its entirety, without amendment, and with attribution to BRE Global Ltd to the extent permitted by the terms and conditions of the contract.

BRE Global's liability in respect of this report and reliance thereupon shall be as per the terms and conditions of contract with the client and BRE Global shall have no liability to third parties to the extent permitted in law.

bre

Table of Contents

© BRE Global Ltd 2025

© BRE Global Ltd 2025

1 Introduction

This Appendix covers three of the research sub-tasks.

This report covers the findings of Task C2 (Generate knowledge around mass timber construction), Task C3 (Generate knowledge around modern forms of construction including modular systems) and Task C4 (Inform the development of a test methodology (MMC and timber)).

This report takes into account comments from BSR HSE and the Technical Steering Group.

© BRE Global Ltd 2025

2 Relationship between Tasks C2, C3 and C4

The approach to developing knowledge of the behaviour in fire of mass timber structures and other modern forms of construction including modular (both volumetric and panellised) systems is intrinsically linked to the development of a methodology for test and assessment that takes into account aspects of system behaviour that cannot be considered in standard fire testing.

For this reason, these three sub-tasks are considered together in this report which presents the results from the experimental programme and the development of a test methodology.

© BRE Global Ltd 2025

3 Experimental methodology

The experimental methodology that forms the basis of the experimental programme undertaken is based on that set out in Loss Prevention Standard LPS 1501 *Fire test and performance requirements for innovative methods of building construction*[1] and subsequently modified to form Annex B of the (withdrawn) BRE Product Standard BPS 7014 *Standard for Modular Systems for Dwellings*[2]. The Project team believes this Annex represents the most rational and logical approach to the assessment of modern forms of construction currently available.

The primary purpose of the experimental programme is twofold:

1. To assess those aspects of system behaviour that cannot be evaluated using a standard fire test procedure predicated on isolated elements and with no cooling phase.
2. To provide a means of assessment that is consistent and reproducible for all systems where, for whatever reason, reliance on the results from standard fire testing is insufficient to demonstrate compliance with the mandatory requirements of the Building Regulations in relation to performance in fire.

The performance criteria adopted are those of the standard fire test system (loadbearing capacity (stability), integrity and insulation) and the fire design is related to an equivalent severity to the level of fire resistance appropriate to the specific system under consideration. In this way, performance can be assessed and understood by a range of construction professionals in a language with which they are already familiar. It also means that the individual experiment can be tailored to the specific application in terms of the required minimum recommended period of fire resistance from Table B4 of AD B.

For practical purposes, the maximum module size that can be accommodated is approximately 6 m wide by 4 m long. To aid comparative assessment and promote reliability and repeatability, a number of parameters were fixed. As far as possible, the ventilation conditions were standardised, and the primary variable is the fire load density.

The choice of the appropriate fire load density was based on the intended end use application provided by the manufacturer which is related to both the recommended minimum fire resistance period and the required consequence class. The manufacturer/supplier is the only party who can provide information on the intended end use application, based on the markets in which they operate.

The concept of time equivalence as set out in the fire part of the Eurocode for Actions[3] was used to relate severity to an equivalent period of exposure to the standard fire test. In this way, performance is related to a metric familiar to many construction professionals. Part of what the Project team is trying to assess is whether there is anything specific to the system (such as sensitivity to the rate of heating) that may make reliance on standard fire test results potentially inappropriate.

Where appropriate, the incorporation of active suppression systems can be taken into account through a reduction in the design fire load density within the overall methodology. Sprinkler systems were not incorporated in any of the experiments used to develop the test methodology.

© BRE Global Ltd 2025

4 Rationale for the experimental programme

The Project team developed the initial experimental programme following consultation with potential suppliers and discussions that were held during an initial Industrial Collaboration Group meeting held on 15^{th} March 2022.

The research is focused on understanding the failure mechanisms of structures within a real fire scenario which traditional means of fire testing cannot assess due to the single element methodology or the inability of the current testing methodology to adequately represent real fire scenarios. Although there are geometrical constraints to what can be included in the experimental programme, the research focus relevant to MMC concerns are listed below:

- Systems that are volumetric are often reliant on 3D interaction for structural performance with design load paths reliant on connection stability between vertical and horizontal members.
- Both volumetric and panellised light gauge steel systems rely on connections which may be critical in a fire situation and are not assessed within a standard fire test.
- Mass timber systems could potentially contribute to the fire load should fire protection linings fail (either within the heating or cooling phase of the fire), increasing the severity of the fire and the speed and likelihood of flashover.

This research has been designed to provide answers to questions currently arising in industry and government with regard to the fire performance of innovative forms of construction. Therefore, the focus has been mindful of reflecting industry systems and building applications that are most used, serving high risk scenarios as a priority. The priority areas below are based on the consequence classes set out in Approved Document A. There is no simple way to transfer from the recommended values of fire resistance set out in Table B4 of AD B (Volume 1) to the Consequence Classes from AD A. However, generally, CC1 can equate to the requirement for a building with a top occupied floor level up to 5 m above ground level and a recommendation that elements of structure should have a minimum fire resistance of 30 minutes and CC3 can equate to the requirement for a building with a top occupied floor level greater than 30 m above ground level and a recommendation that elements of structure should have a minimum fire resistance of 120 minutes.

This classification may also help to identify those situations where there is a requirement to survive burn out of all combustible materials within the compartment (including those incorporated within the building structure) whilst maintaining overall stability and where such a requirement may not be necessary.

The priority order of system type requested, was as outlined below:

A. CC3 High rise (residential buildings > 15 storeys)

B. CC2a – CC2b Medium rise (residential buildings 4 ≥ 15 storeys)

C. CC1 Low rise (residential buildings ≤ 4 storeys)

© BRE Global Ltd 2025

High to medium rise residential buildings were identified as the highest priority sector to be incorporated within the experimental programme. However, higher risk buildings of low-rise nature, such as hospitals and care homes, have also been included as a common application for volumetric systems and representative of industry. Note that the mass timber industry does not construct above 18 m in the UK, unless of hybrid format (confirmed through discussions with the Structural Timber Association) due to regulatory changes and therefore this was discounted from the research.

The original list of samples and the risk category and associated fire resistance period assigned to each to be experimentally assessed when subjected to a realistic natural fire scenario (corresponding to the target market identified by the suppliers) is as follows:

- Sample A Control compartment of "traditional" construction (CC2a-CC2b/60 minutes)
- Sample B STA CLT construction (CC2a-CC2b/60 minutes)
- Sample C Volumetric with steel frame and concrete floors (CC3/120 minutes)
- Sample D Volumetric with steel frame and steel joisted floors (CC3/120 minutes)
- Sample E Steel (SCI Light Gauge Steel Frame Group) Panellised (To be confirmed/60 minutes)
- Sample F Steel (SCI LGSFG) Panellised with composite slab (90 minutes)
- Sample G Steel (SCI LGSFG) Modular (To be confirmed/90 minutes)
- Sample H MPBA Volumetric (To be confirmed)

This was the original schedule, but it was accepted at an early stage that this would be subject to changes and modifications dependent on discussions with the manufacturers/suppliers. In each case, the Project team has reviewed the designs submitted in part to ensure that the specifications align with the stated requirement in terms of fire resistance period. Detailed design was the responsibility of the supplier in order to replicate details of construction provided to the market.

A timber frame compartment was included in the final experimental programme at the request of BSR HSE.

4.1 Other items addressed in the research

Further experimental measurements have been proposed including the investigation of the potential impact of downward fire spread and two-sided exposure of loadbearing walls located entirely within a fire compartment. This has been introduced to act as base data validation for some industry raised concerns. Note that these are secondary items and BRE Global does not want to introduce significant additional parameters that may adversely impact the primary research aim.

4.2 Downward heat transfer (lightweight floors)

A question about the impact of heat transfer in a downward direction has been raised in industry with lightweight floors and informally raised through the work undertaken in Task C1. This issue was to be investigated in agreement with the sample suppliers. It is noted that the findings may also be useful with regard to traditional construction.

4.3 Loadbearing walls – simultaneous attack of fire from both sides

A Collaborative Reporting for Safer Structures UK (CROSS-UK) Report identified the issue of fire exposure from both sides simultaneously as a potential issue of concern. This scenario was also investigated in agreement with the sample suppliers where relevant.

© BRE Global Ltd 2025

4.4 Penetrations/fire stopping

LPS 1501[1] and Annex B of BPS 7014[2] provide a methodology for testing penetrations should the supplier wish to do so within the experimental programme. BRE Global would, where required, incorporate testing of penetrations. This was discussed with suppliers in relation to areas where there may be potential or perceived issues around service penetrations/fire stopping. Although none of the experiments included such details, their potential inclusion is provided in the test methodology outlined in Section 11.

4.5 Cavity barriers

Cavity barriers were included in the experiments where they would normally be installed to comply with the Building Regulations. The research is not concerned with attack of fire externally and will predominantly be observing cavity barrier behaviour should the structure move in real fire application, affecting the gap seal at compartment and openings.

Issues around cavity barrier testing, installation and specification are covered in Appendix E.

© BRE Global Ltd 2025

5 Experimental programme

The final experimental schedule is set out in Table 1. This differs from the original list of samples set out above. The final programme was dependent on the active participation of those involved in the Industrial Collaboration Group meeting.

Table 1 − Experimental programme

Ref.	System Description	Applied height	Relevant sector(s)	Recommended structural fire resistance requirement (minutes)	AD A Consequence Class	Floor loaded (Yes/No)
A	Traditional (precast concrete roof panels and masonry walls)	Under 18 m	Residential, student accommodation	60	2a or 2b	No
B	Volumetric with SHS corner posts and concrete slab	8-50 storeys	Residential	120	3	No
C	Panellised Cross Laminated Timber (CLT) walls and floors	Under 18 m	Residential, hotels, student accommodation	60	1, 2a and up to 2b	Yes (1.14 kN/m²)
D	Panellised light steel frame with concrete slab	Above 18 m	Residential, hotels, student accommodation	90	Up to 2b	Yes (1.5 kN/m²)
E	Timber frame	Under 18 m	Residential, hotels, student accommodation	60	1, 2a and up to 2b	Yes (1.2 kN/m²)

6 Fire experiment A – Traditional construction

As described in Table 1, the first fire experiment was a control sample intended to be representative of “traditional” forms of construction.

One of the objectives of the project, and particularly the experimental programme, is to assess whether the various systems are capable of surviving burn out of all combustibles within the fire compartment whilst maintaining overall stability. The understanding is that this is the principal starting point for the specification of fire resistance periods underpinning the current recommendations in AD B. It is therefore important to demonstrate that a “traditional” form of construction can achieve this implicit objective when subject to a real fire scenario.

The compartment was constructed from precast concrete roof planks (see Figure 1) supported on loadbearing walls formed from 100 mm thick concrete blocks. The roof planks were “stitched” together using in-situ concrete with reinforcement placed within the joints. The materials were provided through collaboration with the Concrete Centre.

The inside of the compartment is shown in Figure 2 just prior to ignition while Figure 3 shows the front elevation including the single ventilation opening during ignition. The internal dimensions were approximately 5 m long by 3.2 m wide by 2.5 m high. The compartment was built by contractors appointed and supervised by BRE Global. The compartment was lined with a single layer of Type F plasterboard on all internal surfaces to provide a realistic layout for this type of construction. The plasterboard was chosen to provide a realistic lining. The thermal properties of Type A and Type F boards are similar which means that the predicted fire development is similar. What is important in this regard is not the specification of the plasterboard but how long it stays in place. The plasterboard was simply fixed with timber battens to walls and ceiling. The timber battens to the ceiling boards failed early in the test and from that time the precast planks were directly exposed to the fire. The concrete does not rely on the plasterboard to achieve its designed fire resistance rating. For this reason, no special measures were taken to ensure that the plasterboard stayed in place for a specified duration. BRE Global does not believe its inclusion to be advantageous compared to other experiments. In general, the other systems rely to a great extent on the performance of the plasterboard linings to achieve the specified level of performance and the design and installation of these systems is vitally important to the ability of the systems to survive burn out without collapse.

No fire stopping or service penetrations were included in this experiment as BRE Global is not aware of any evidence to suggest there is a problem with fire stopping in either masonry walls or concrete floor slabs.

The single ventilation opening consists of a single doorway 1.3 m wide and 2 m high. The intention was that this layout will, wherever possible, be replicated for subsequent fire experiments. The ventilation has been chosen to represent a severe value in terms of the ratio between openings and floor area and to ensure that the ratio is within the scope of validity of both the time equivalence concept and the parametric approach used to “predict” the compartment time-temperature response. The fires were ventilation controlled.

Figure 1 − Precast planks used to form the roof of the fire compartment

Figure 2 − Internal view of the fire compartment showing the layout of the fire load

Figure 3 − Front elevation of fire compartment showing ventilation opening

6.1 Fire design

Based on information from the suppliers, the precast slabs were capable of providing a performance in relation to fire resistance of up to 60 minutes REI. Therefore, the fire design was predicated on providing a natural fire with an equivalent exposure to 60 minutes under the standard fire curve. In each case, the experiments were designed to "equate" to the required end use application in terms of fire resistance. This enables determination of one of the critical areas for evaluation namely "*can this system survive burnout without collapse*"?

The concept of time equivalence is a well-established approach incorporated in national and international codes and standards. Use of this technique enables performance in a real fire situation to be related to the results obtained from standard fire resistance testing and to provide a relationship between system performance and the minimum periods of fire resistance specified in statutory guidance.

One of the objectives of the project is to see where the boundaries of reliance on standard fire resistance testing lie. This project is not trying to confirm or calibrate the concept of time equivalence but to find out the extent to which reliance can be placed on test results from standard fire tests in a real fire situation which corresponds to a fire of equivalent severity. In this case, the input values are the fire load, the thermal properties of the compartment linings and the ventilation. No attempt is made to define an appropriate fire resistance period for the structure and therefore the approach does not rely on fitting data from standard fire tests on steel structures.

The formula for the Equivalent time of fire exposure is set out in the fire part of Eurocode 1[3] as:

$$t_{e,d} = \left(q_{f,d} \times w_f \times k_b\right) \times k_c$$

Where:

$q_{f,d}$ is the design fire load density per unit floor area (MJ/m²)

k_b is the conversion factor for the compartment thermal properties (min.m²/MJ)

w_f is the ventilation factor

k_c is a correction factor dependent on the structural material

For every structural Eurocode, there is a corresponding National Annex for use within the individual member state. Work undertaken in developing the UK National Annex[4] showed that the correction factor k_c for different materials could not be supported and that the use of the concept for unprotected steel structures should be limited to fire resistance periods up to 30 minutes. For reinforced concrete (or protected steel) the correction factor is 1.0, so using the National guidance there is no difference other than the approach is only valid for unprotected steel for periods up to 30 minutes. Therefore, the equivalent time of fire exposure is a function of the fire load density, the thermal properties of the compartment boundaries and the ventilation factor. For present purposes, the ventilation condition and the thermal properties of the compartment boundaries are fixed values, and the choice of fire load density is used to provide the required level of fire severity.

The ventilation factor w_f is derived from a consideration of the height of the compartment and the ratio of the openings to the floor area such that:

$$w_f = (6/H)^{0.3}\left[0.62 + 90\,(0.4 - \alpha_v)^4\right] \geq 0.5\ (in\ the\ absence\ of\ horizontal\ openings)$$

Where:

H is the height of the compartment (m)

$$\alpha_v = A_v/A_f$$

A_v is the area of the ventilation opening (m^2)

A_f is the floor area (m^2). In this case, the value of w_f = 1.179.

The conversion factor (k_b) for the thermal properties of the compartment linings is related to the b factor which in turn is a function of the specific heat, density and thermal conductivity values for the materials forming the lining of the compartment such that b = (ρ.c.λ)^{½}. In this case, the relevant values are given using generic properties for plasterboard as these will govern behaviour during the growth and steady state phases of fire development. The properties used in the analysis for gypsum-based plasterboard are given in Table 2. In terms of fire development, unless the lining materials are thermally thin or will not survive for any significant period, it is the thermal properties of the compartment linings that will dictate fire growth and development rather than the underlying substrate. In general, the systems tested rely on maintaining the integrity of the plasterboard lining for a significant duration of the fire exposure. It is therefore the innermost layer that will have the most significant impact on fire development in the growth and steady state phases of the fire. This may change in the cooling phase particularly where combustible materials are present.

Table 2 – Properties of gypsum-based plasterboard

Density ρ (kg/m³)	**Specific heat c (J/kgK)**	**Thermal conductivity λ (W/mK)**	**b (J/m²s½K)**
900	1000	0.25	474

The National Annex[4] sets out the appropriate values for k_b which differ from those in the informative annex. The default value for use in the UK is k_b = 0.09 and this is the appropriate value for this case.

Therefore, to achieve an equivalent time of fire exposure the required fire load density is given by:

$$q_{f,d} = 60/(1.179 * 0.09) = 565 \text{ MJ/m}^2$$

In this case, the value adopted was 570 MJ/m² giving an equivalent time of fire exposure of 60.46 minutes.

The concept of time equivalence is used to define the appropriate level of fire load density. The parametric approach set out in EN 1991-1-2 *Eurocode 1: Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire*[3] is used to predict the time-temperature relationship for the compartment.

The time-temperature curves in the heating phase are given by:

$$\theta_g = 1325\left(1 - 0.324\, e^{-0.2t^*} - 0.204\, e^{-1.7t^*} - 0.472\, e^{-19t^*}\right)$$

Where:

θ_g = temperature in the fire compartment	(°C)
$t^* = t.\Gamma$	(h)
t = time	(h)
$\Gamma = [O/b]^2/(0.04/1160)^2$	(-)

b = $\sqrt{\rho c \lambda}$ and should lie between 100 and 2200 ($J/m^2s^{½}K$)

O = opening factor ($A_v \sqrt{h}$ /A_t) ($m^{½}$)

A_v = area of ventilation openings (m^2)

H = height of ventilation openings (m)

A_t = total area of enclosure (including openings) (m^2)

ρ = density of boundary enclosure (kg/m^3)

c = specific heat of boundary enclosure (J/kgK)

λ = thermal conductivity of boundary (W/mK)

The parametric approach is an example of a physically based fire model. Although various models are available, the parametric approach is used here due to its inclusion in the fire part of Eurocode 1 and based on the amount of validation available.

The model assumes that the temperature rise is independent of fire load. In order to account for depletion of the fuel the duration of the fire must be considered. This is a complex process and depends on the rate of burning of the fuel which itself is dependent on the ventilation available and the physical characteristics and distribution of the fuel.

The parametric fire curves comprise a heating phase represented by an exponential curve up to a maximum temperature θ_{max} occurring at a corresponding time of t_{max}, followed by a linearly decreasing cooling phase.

The maximum temperature in the heating phase occurs at a time given by:

$$t_{max} = \max\left[\left(0.2 \times 10^{-3} \times q_{t,d}/O_{lim}\right); t_{lim}\right]$$

Where:

$$q_{t,d} = q_{f,d} \times A_f/A_t$$

The limiting time period for medium fire growth (residential and offices) is 20 minutes. For most practical combinations of fire load, compartment geometry and opening factor t_{max} will be in excess of these limiting values. The temperature-time curves for the cooling phase are then given by:

$$\theta_g = \theta_{max} - 625(t^* - t^*_{max})\ for\ t^*_{max} \le 0.5(h)$$

$$\theta_g = \theta_{max} - 250(3 - t^*_{max})\ (t^* - t^*_{max})\ for\ 0.5 < t^*_{max} < 2(h)$$

$$\theta_g = \theta_{max} - 250(t^* - t^*_{max})\ for\ t^*_{max} \ge 2(h)$$

Using the approach set out above, the predicted behaviour within the compartment is as shown in Figure 4 which also provides a comparison with the standard fire curve for 60 minutes.

© BRE Global Ltd 2025

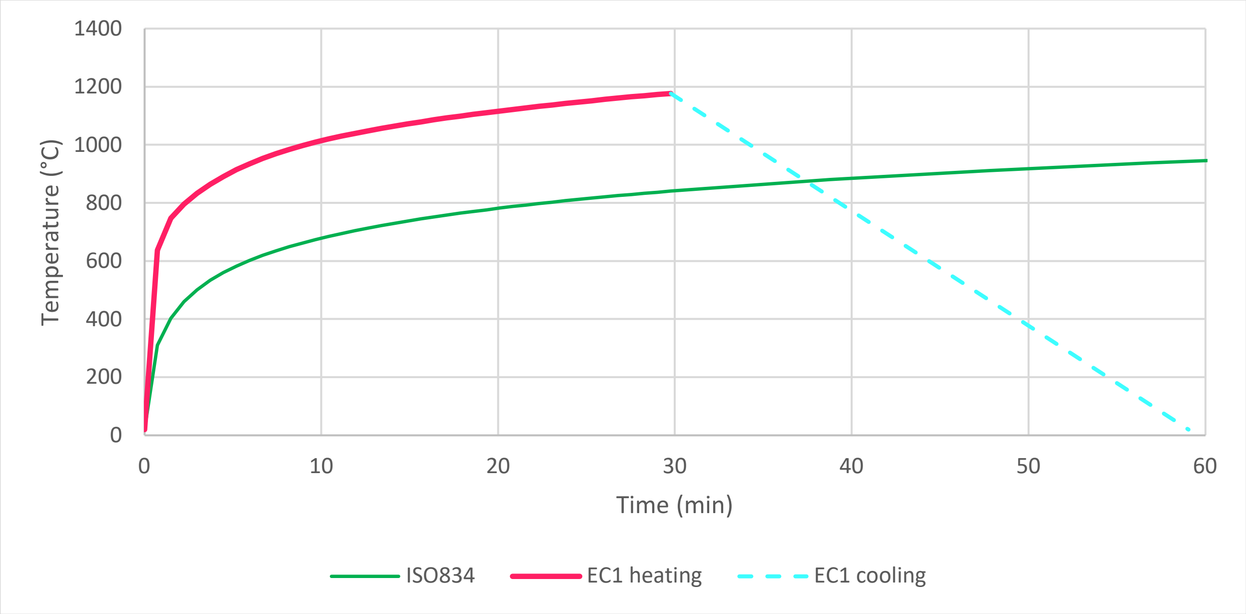


Figure 4 − Predicted compartment response compared to standard fire exposure

6.2 Instrumentation

In order to assess performance in relation to the selected performance criteria of loadbearing capacity, integrity and insulation it is necessary to utilise a combination of visual observations and direct measurement. In general, overall stability and integrity can be assessed through direct observation while insulation performance is assessed by measuring the temperature rise on the unexposed surface of the compartment boundaries.

Figure 5 shows the basic layout and orientation of the fire compartment and can be used to identify the instrumentation locations in subsequent drawings.

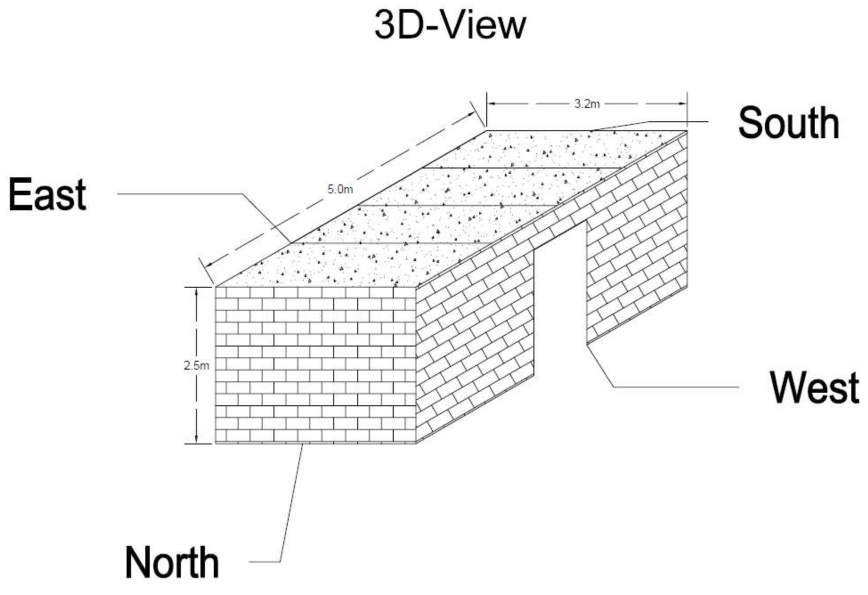


Figure 5 − Compartment layout showing orientation of the various elevations

Figure 6 shows the layout of the timber cribs used to provide the fire load inside the compartment.

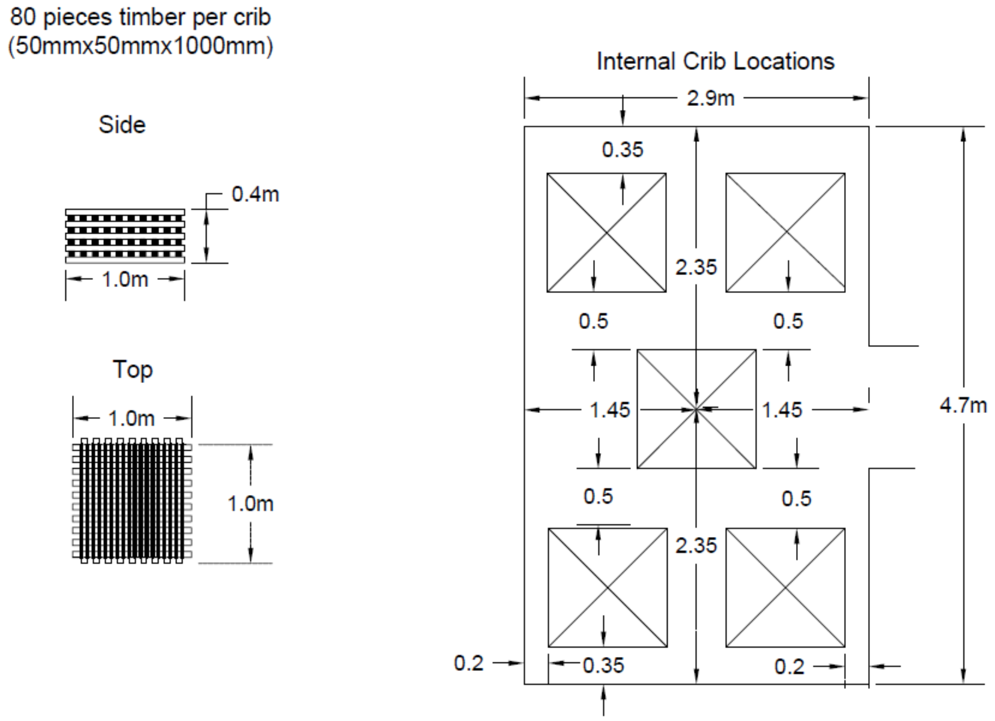
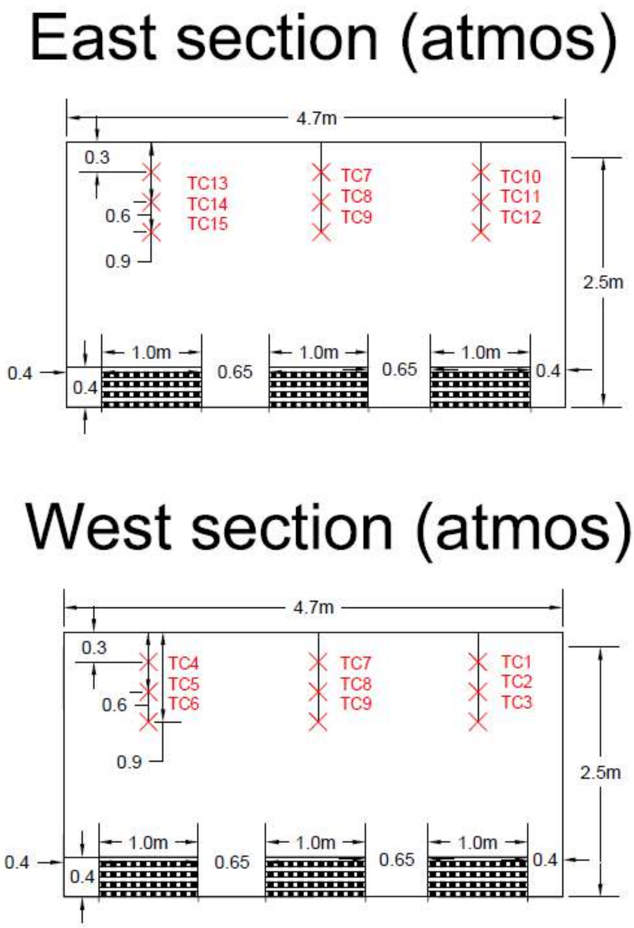


Figure 6 − Crib layout inside compartment

The atmosphere temperature measurement locations are illustrated in Figure 7 in elevation and Figure 8 in plan.

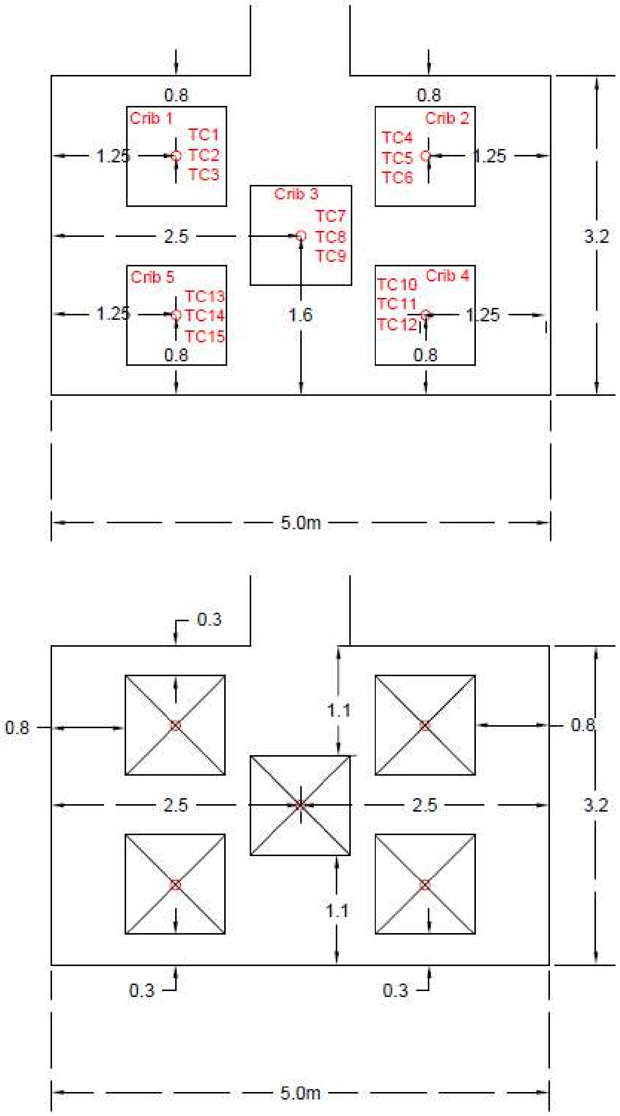


Channel	Instrument	Ident	Description	Drawing ref.
1	Type K sheathed thermocouple	1	Atmosphere t/c above Crib 1 300mm from ceiling	1,2
2	Type K sheathed thermocouple	2	Atmosphere t/c above Crib 1 600mm from ceiling	1,2
3	Type K sheathed thermocouple	3	Atmosphere t/c above Crib 1 900mm from ceiling	1,2
4	Type K sheathed thermocouple	4	Atmosphere t/c above Crib 2 300mm from ceiling	1,2
5	Type K sheathed thermocouple	5	Atmosphere t/c above Crib 2 600mm from ceiling	1,2
6	Type K sheathed thermocouple	6	Atmosphere t/c above Crib 2 900mm from ceiling	1,2
7	Type K sheathed thermocouple	7	Atmosphere t/c above Crib 3 300mm from ceiling	1,2
8	Type K sheathed thermocouple	8	Atmosphere t/c above Crib 3 600mm from ceiling	1,2
9	Type K sheathed thermocouple	9	Atmosphere t/c above Crib 3 900mm from ceiling	1,2
10	Type K sheathed thermocouple	10	Atmosphere t/c above Crib 4 300mm from ceiling	1,2
11	Type K sheathed thermocouple	11	Atmosphere t/c above Crib 4 600mm from ceiling	1,2
12	Type K sheathed thermocouple	12	Atmosphere t/c above Crib 4 900mm from ceiling	1,2
13	Type K sheathed thermocouple	13	Atmosphere t/c above Crib 5 300mm from ceiling	1,2
14	Type K sheathed thermocouple	14	Atmosphere t/c above Crib 5 600mm from ceiling	1,2
15	Type K sheathed thermocouple	15	Atmosphere t/c above Crib 5 900mm from ceiling	1,2
16	Type K sheathed thermocouple	16	Atmosphere t/c below crib 1 100mm from ffl	1,2
17	Type K sheathed thermocouple	17	Atmosphere t/c below crib 2 100mm from ffl	1,2
18	Type K sheathed thermocouple	18	Atmosphere t/c below crib 4 100mm from ffl	1,2
19	Type K sheathed thermocouple	19	Atmosphere t/c below crib 5 100mm from ffl	1,2

Figure 7 − Atmosphere thermocouples (1.5 mm Type K Inconel sheathed) locations

© BRE Global Ltd 2025

bre



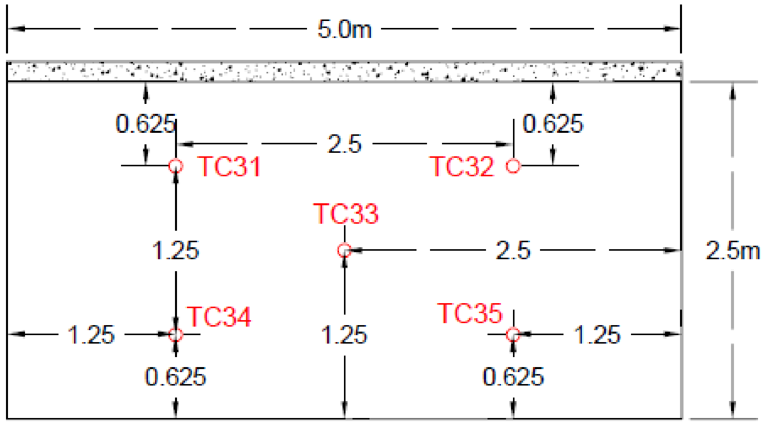
Roof A-TCs

Channel	Instrument	Ident	Description	Drawing ref.
1	Type K sheathed thermocouple	1	Atmosphere t/c above Crib 1 300mm from ceiling	1,2
2	Type K sheathed thermocouple	2	Atmosphere t/c above Crib 1 600mm from ceiling	1,2
3	Type K sheathed thermocouple	3	Atmosphere t/c above Crib 1 900mm from ceiling	1,2
4	Type K sheathed thermocouple	4	Atmosphere t/c above Crib 2 300mm from ceiling	1,2
5	Type K sheathed thermocouple	5	Atmosphere t/c above Crib 2 600mm from ceiling	1,2
6	Type K sheathed thermocouple	6	Atmosphere t/c above Crib 2 900mm from ceiling	1,2
7	Type K sheathed thermocouple	7	Atmosphere t/c above Crib 3 300mm from ceiling	1,2
8	Type K sheathed thermocouple	8	Atmosphere t/c above Crib 3 600mm from ceiling	1,2
9	Type K sheathed thermocouple	9	Atmosphere t/c above Crib 3 900mm from ceiling	1,2
10	Type K sheathed thermocouple	10	Atmosphere t/c above Crib 4 300mm from ceiling	1,2
11	Type K sheathed thermocouple	11	Atmosphere t/c above Crib 4 600mm from ceiling	1,2
12	Type K sheathed thermocouple	12	Atmosphere t/c above Crib 4 900mm from ceiling	1,2
13	Type K sheathed thermocouple	13	Atmosphere t/c above Crib 5 300mm from ceiling	1,2
14	Type K sheathed thermocouple	14	Atmosphere t/c above Crib 5 600mm from ceiling	1,2
15	Type K sheathed thermocouple	15	Atmosphere t/c above Crib 5 900mm from ceiling	1,2
16	Type K sheathed thermocouple	16	Atmosphere t/c below crib 1 100mm from ffl	1,2
17	Type K sheathed thermocouple	17	Atmosphere t/c below crib 2 100mm from ffl	1,2
18	Type K sheathed thermocouple	18	Atmosphere t/c below crib 4 100mm from ffl	1,2
19	Type K sheathed thermocouple	19	Atmosphere t/c below crib 5 100mm from ffl	1,2

Figure 8 − Atmosphere thermocouple (1.5 mm Type K Inconel sheathed) locations viewed from roof level

Figure 9 shows the location of the temperature measurements on the unexposed face of the Eastern elevation while Figures 10 and 11 show the corresponding locations for the North and South elevations, respectively. Thermocouples were fixed with aluminium tape and staples to measure the unexposed face temperature.

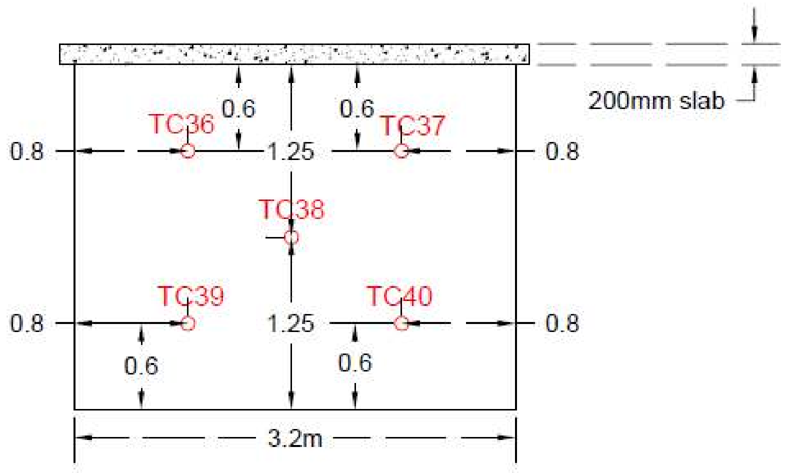
© BRE Global Ltd 2025



Channel	Instrument	Ident.	Description	Drawing ref.
31	Type K glass fibre thermocouple	31	Rear wall top S quadrant	5
32	Type K glass fibre thermocouple	32	Rear wall top N quadrant	5
33	Type K glass fibre thermocouple	33	Rear wall centre	5
34	Type K glass fibre thermocouple	34	Rear wall bottom S quadrant	5
35	Type K glass fibre thermocouple	35	Rear wall bottom N quadrant	5

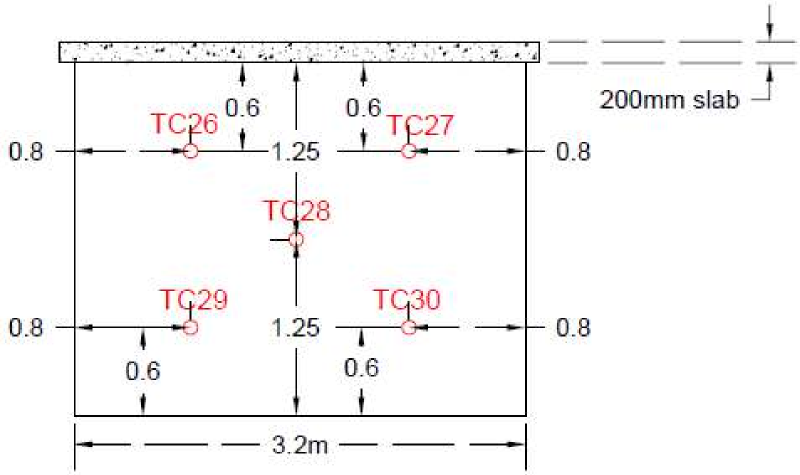
Figure 9 – Location of unexposed face temperature measurements (Glass fibre welded tip Type K) on East elevation

© BRE Global Ltd 2025



Channel	Instrument	Ident.	Description	Drawing ref.
36	Type K glass fibre thermocouple	36	North wall top E quadrant	6
37	Type K glass fibre thermocouple	37	North wall top W quadrant	6
38	Type K glass fibre thermocouple	38	North wall centre	6
39	Type K glass fibre thermocouple	39	North wall bottom E quadrant	6
40	Type K glass fibre thermocouple	40	North wall bottom W quadrant	6

Figure 10 − Location of unexposed face temperature measurements (Glass fibre welded tip Type K) North elevation

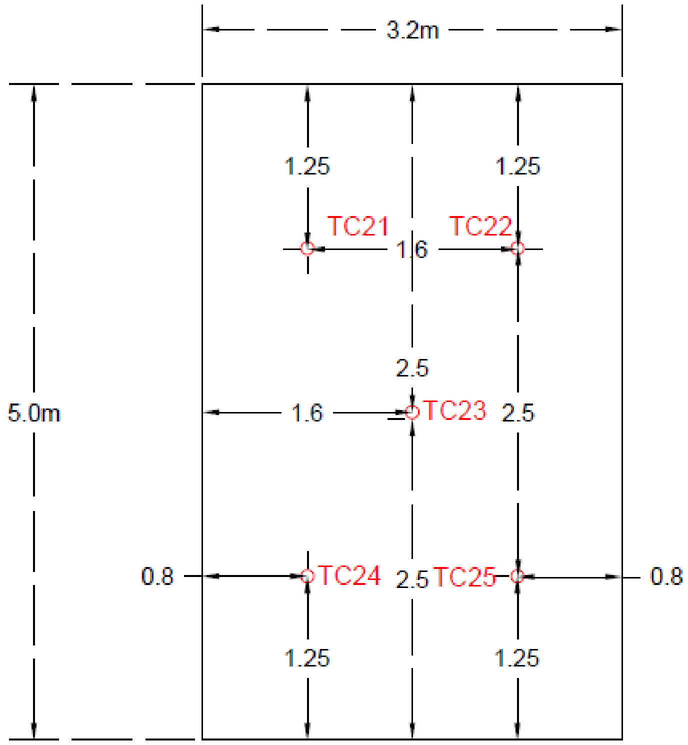


Channel	Instrument	Ident.	Description	Drawing ref.
26	Type K glass fibre thermocouple	26	South wall top W quadrant	4
27	Type K glass fibre thermocouple	27	South wall top E quadrant	4
28	Type K glass fibre thermocouple	28	South wall centre	4
29	Type K glass fibre thermocouple	29	South wall bottom W quadrant	4
30	Type K glass fibre thermocouple	30	South wall bottom E quadrant	4

Figure 11 − Location of unexposed face temperature measurements (Glass fibre welded tip Type K) South elevation

© BRE Global Ltd 2025

Figure 12 shows the location of the thermocouples on the unexposed face of the roof slabs used to determine the insulation criterion.



Channel	Instrument	Ident.	Description	Drawing ref.
21	Type K glass fibre thermocouple	21	Roof slab SE quadrant	3
22	Type K glass fibre thermocouple	22	Roof slab SW quadrant	3
23	Type K glass fibre thermocouple	23	Roof slab centre	3
24	Type K glass fibre thermocouple	24	Roof slab NE quadrant	3
25	Type K glass fibre thermocouple	25	Roof slab NW quadrant	3

Figure 12 − Location of unexposed face temperatures (Glass fibre welded tip Type K) on the roof slab (plan)

6.3 Fire development

Following ignition, the compartment quickly transitioned to flashover following the build-up of hot gases around the ceiling with flames emerging from the opening, as shown in Figure 13.

Figure 13 − External flaming shortly after flashover

The fire continued until all the combustible material was consumed. The time-temperature development based on the atmosphere thermocouples within the compartment is shown in Figure 14.

There was no insulation failure on the unexposed faces of the compartment during the fire exposure measured against the standard fire test performance criteria.

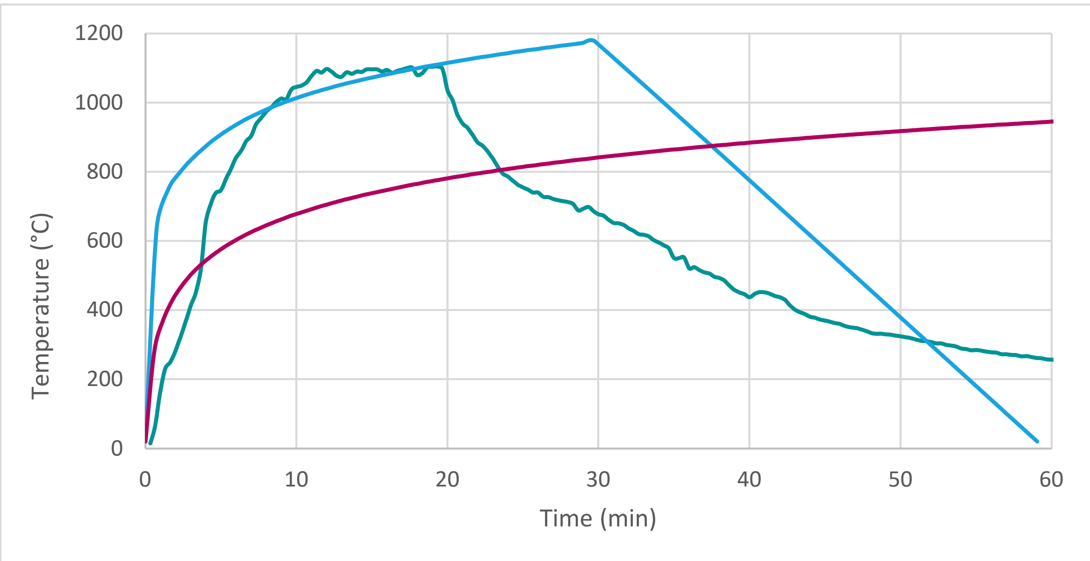


Figure 14 − Compartment time-temperature response (in green) related to standard fire exposure (in red) and predicted response from EN 1991-1-2 parametric approach (in blue)

The compartment atmosphere temperature is in excess of the standard curve for approximately the first 24 minutes. In this case, the total area under the measured curve equates approximately to the total area under the standard curve for the 60-minute exposure. The data indicates the fire achieved an equivalent output in terms of total energy to the 60-minute standard fire curve as intended. However, the time equivalent concept is not based on a comparison of gas temperatures but on structural element temperatures and the equivalent area approach is likely to break down when used for design fire resistance periods in excess of 60 minutes.

The parametric approach provides a good correlation for the maximum temperature within the compartment but overestimates the duration of the heating phase. Failure of the plasterboard had an impact on the measured temperatures in this experiment as the walls will have absorbed energy from combustion. This may be a potential issue in those cases where the linings do not stay intact for a significant period. However, this project is not looking to calibrate the parametric approach. It is looking to evaluate the performance of systems designed in accordance with standard fire testing procedures when subject to realistic fire scenarios.

6.4 Structural performance

The compartment survived complete burn out of all combustible material while maintaining overall stability. Although there was no imposed load present in this experiment, BRE Global does not believe this would have had an adverse impact on the results. Loadbearing capacity and utilisation need to be considered in different ways depending on the specifics of the system. For those modular or panellised systems reliant on critical components such as column posts, then the residual capacity can be assessed based on the measured temperature of those critical components. For other systems (such as mass timber) then the residual loadbearing capacity is more closely related to the thickness of the undamaged layer. The relevant values will be measured to determine this in future experiments. There were no signs of any integrity failure during the course of the fire and there was no evidence of external flaming away from the ventilation opening.

There was no evidence of any insulation failure during the fire exposure. Figure 15 shows the unexposed face temperatures on the upper surface of the roof slabs. This graph continues to 90 minutes rather than the 60 minutes shown for the atmosphere temperatures. This is because the compartment temperatures were decreasing after 60 minutes (and had been for some time) while the unexposed face temperatures continued to rise, with the peak value achieved well into the cooling phase of the fire. This is an important distinction and one which the change in horizontal axis values emphasises.

© BRE Global Ltd 2025

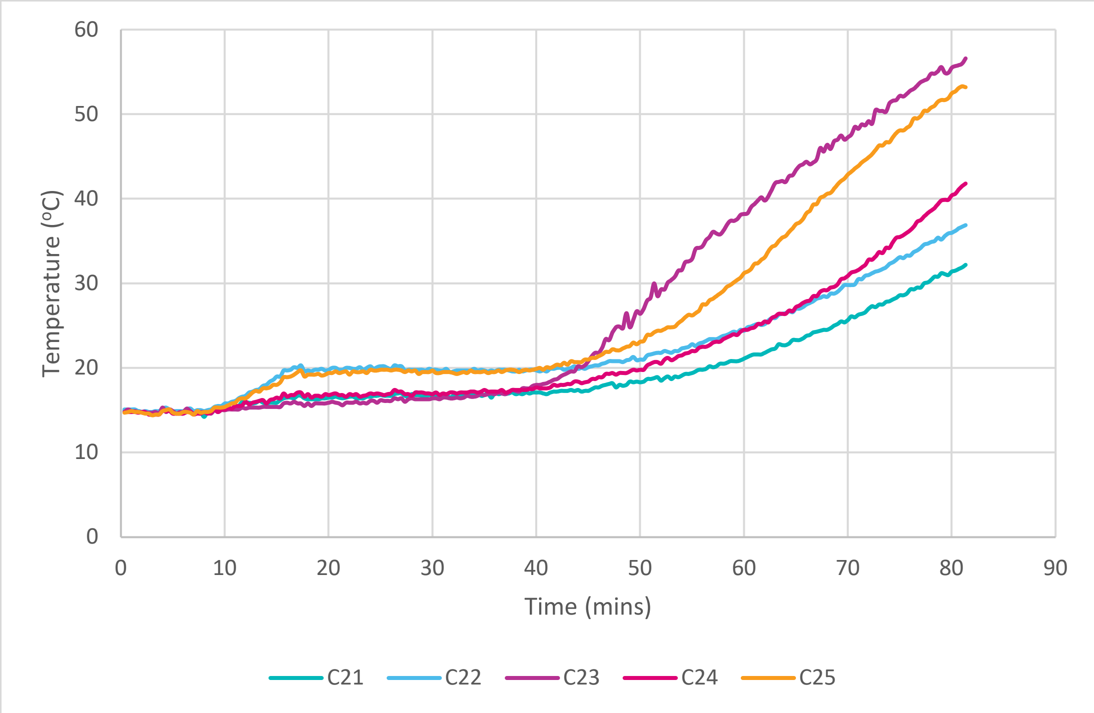


Figure 15 – Unexposed surface temperatures of the roof slab

Figure 16 shows the unexposed face temperatures of the Southern elevation while Figures 17 and 18 show the corresponding values for the East and North elevations.

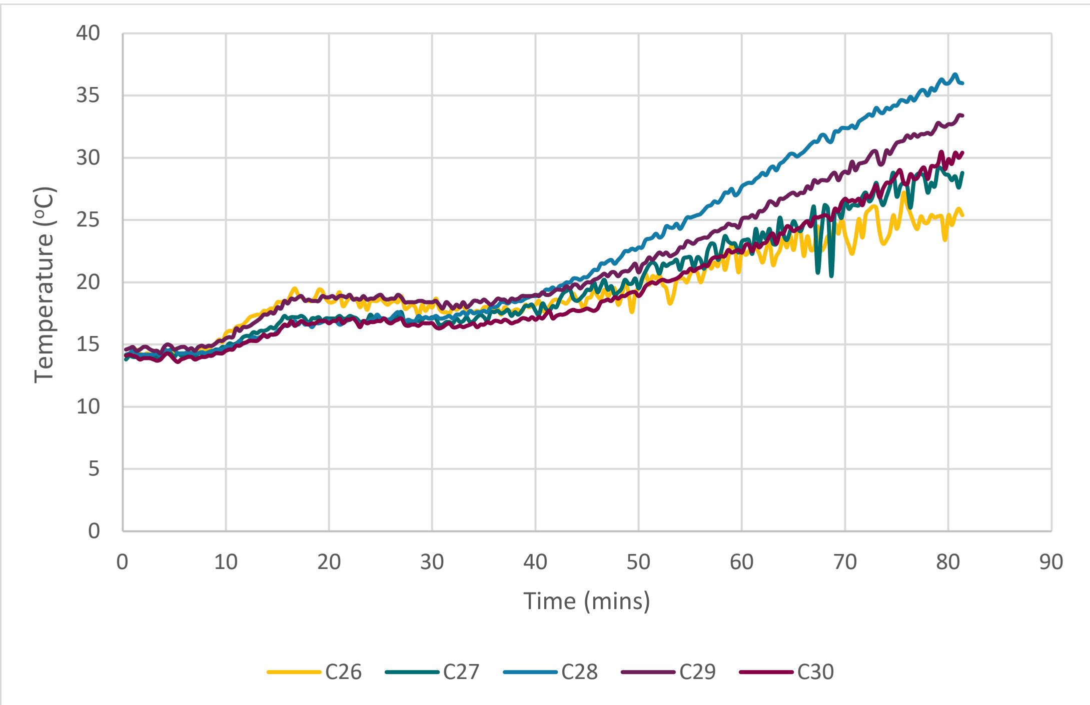


Figure 16 – Temperature of the unexposed face of South wall elevation

© BRE Global Ltd 2025

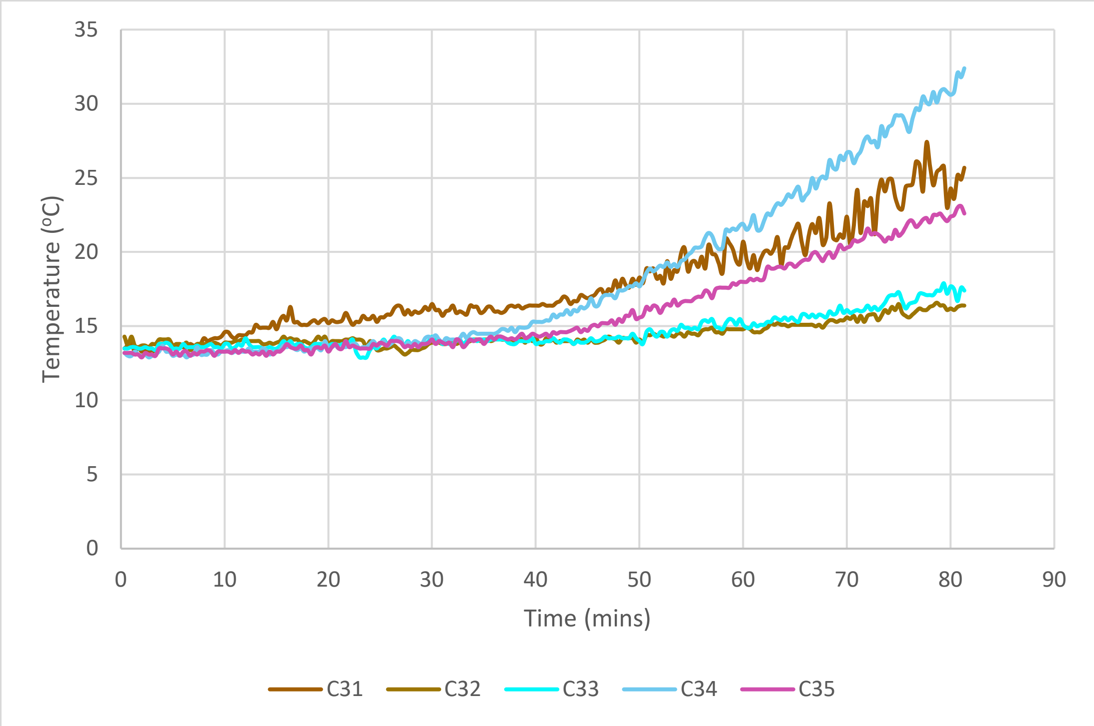


Figure 17 – Temperature of the unexposed face of East wall elevation

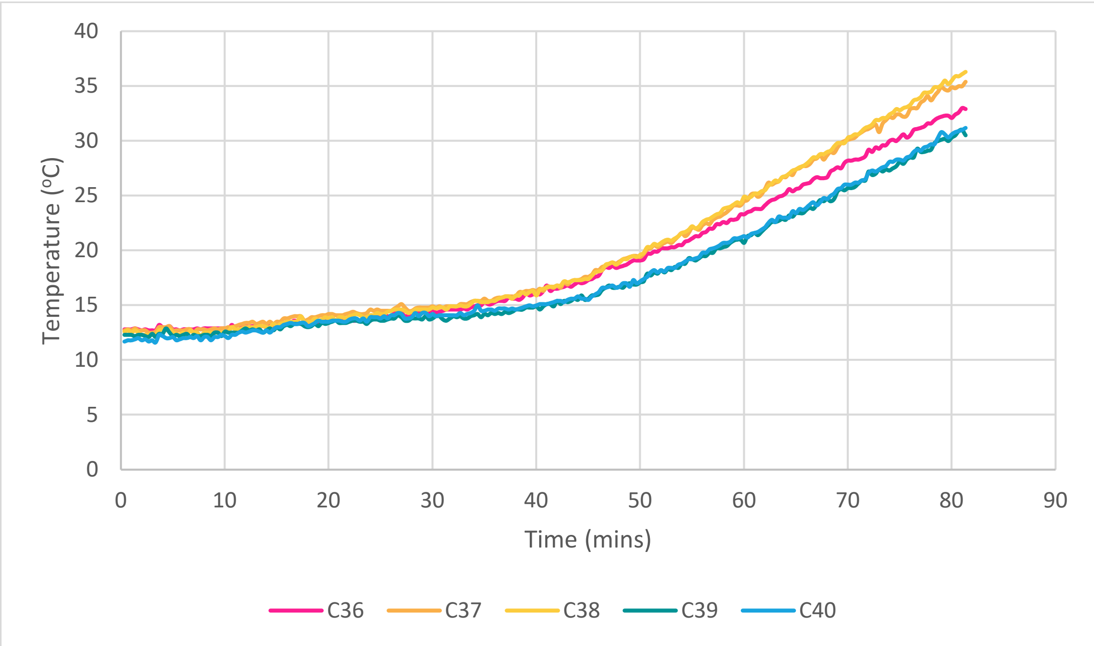


Figure 18 – Temperature of the unexposed face of North wall elevation

The plasterboard linings to the ceiling failed in the early stages of the post-flashover fire development. This led to spalling of the surface of the precast concrete planks, as shown in Figure 19. Based on observations during the fire experiment, the spalling was non-explosive and had no significant impact on the fire resistance of the floor slabs. The spalling was only a few millimetres deep and exposed the bottom layer of steel. The minimum cover to the main steel was 25 mm. As described above, it would have had some impact on the compartment temperatures but by the time the plasterboard failed the fire had already developed through flashover. The parametric approach was used as a predictive tool with no idea how long the plasterboard would remain in place. This impact would account for discrepancies between the measured and predicted values of compartment temperature. However, the correlation in terms of peak temperature is still reasonably good.

Figure 19 − Post-fire photograph showing extent of spalling to the soffit of the precast floor slabs

© BRE Global Ltd 2025

The measured heat flux 2 m away from the centre of the opening at a height of 1.8 m is shown in Figure 20. The peak occurred approximately 14 minutes from ignition with a value of approximately 40 kW/m².

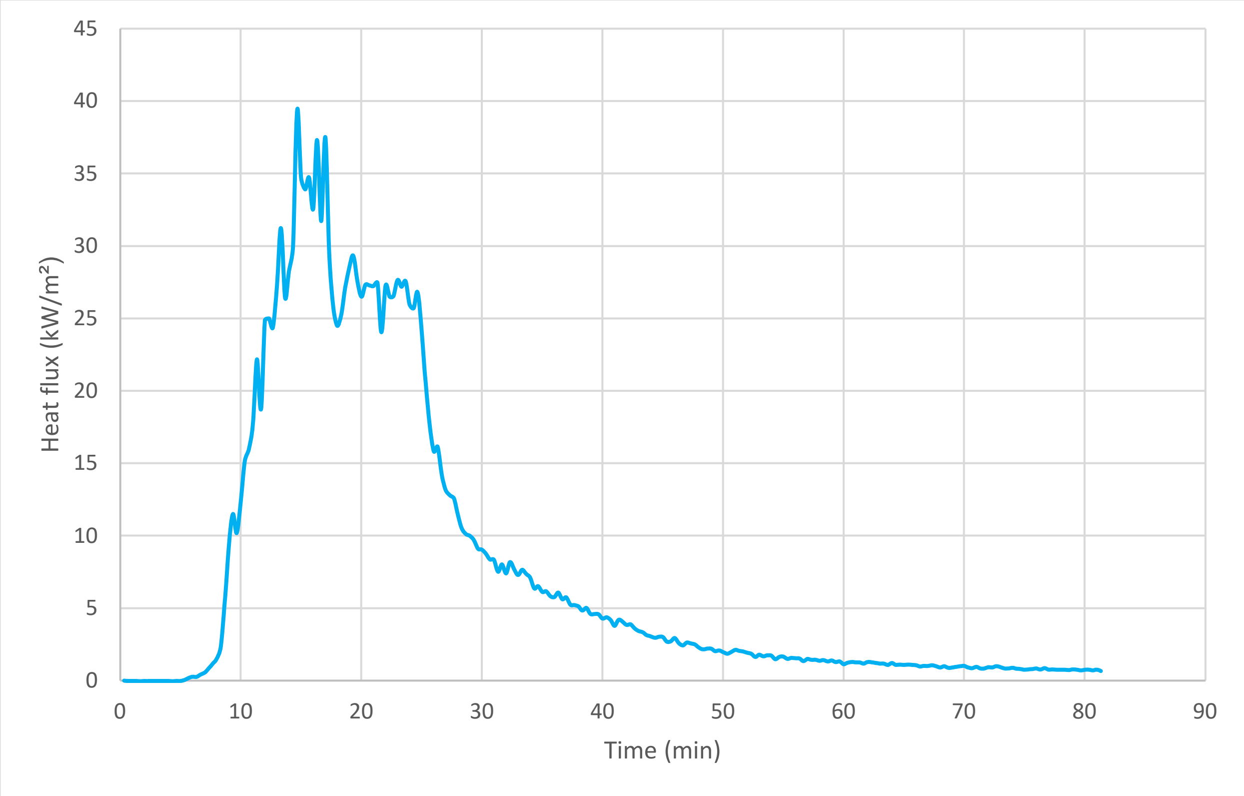


Figure 20 − Heat flux at a height of 1.8 m and a distance of 2 m from the centre of the opening

7 Fire experiment B – Volumetric construction with SHS corner posts and concrete slab

As described in Table 1, the second fire experiment incorporated a corner post modular system with solid concrete floors. All internal and perimeter walls were constructed from Square Hollow Section SHS studs typically at 600 mm centres encased in two layers of 15 mm Type F board. Columns are typically boarded with three layers of 15 mm Type F board. Although not part of this project, in practice the external walls of the modular system are of limited combustibility (A2) as defined in AD B Volume 2, 2006 edition incorporating amendments up to April 2019, in accordance with Building Regulation requirements for high rise residential buildings.

Figure 21 shows the inside of the compartment just prior to ignition, and Figure 22 shows the front elevation including the single ventilation opening. The internal dimensions were approximately 4.7 m long by 3.8 m wide by 2.4 m high. The compartment was supplied and delivered to BRE as a single module with an additional slab provided to simulate the vertical module to module condition. A detailed specification of the construction of the module and additional information related to standard fire testing was provided to BRE Global for review. This information has been forwarded to DLUHC. The compartment was lined throughout with Type F plasterboard.

No fire stopping or service penetrations were included in this experiment.

The single ventilation opening consists of a single doorway 1.3 m wide and 2 m high. The intention is that this layout will, wherever possible, be replicated for subsequent fire experiments. The ventilation has been chosen to represent a severe value in terms of the ratio between openings and floor area and to ensure that the ratio is within the scope of validity of both the time equivalence concept and the parametric approach used to “predict” the compartment time-temperature response. The fires will be ventilation controlled.

© BRE Global Ltd 2025

Figure 21 − Inside compartment prior to ignition (looking at inside of East elevation)

Figure 22 − Front elevation showing ventilation opening in West elevation

7.1 Fire design

Based on information from the suppliers, the volumetric system is capable of providing a performance in relation to fire resistance of up to 120 minutes REI. Therefore, the fire design was predicated on providing a natural fire with an equivalent exposure to 120 minutes under the standard fire curve. In each case, the experiments have been designed to “equate” to the required end use application in terms of fire resistance. This enables determination of one of the critical areas for evaluation namely “*can this system survive burnout without collapse*”?

The concept of time equivalence is a well-established approach incorporated in national and international codes and standards. Use of this technique allows performance in a real fire situation to be related to the results obtained from standard fire resistance testing and to provide a relation between system performance and the minimum periods of fire resistance specified in statutory guidance.

One of the objectives of the project is to see where the boundaries of reliance on standard fire resistance testing lie. This project is not trying to confirm or calibrate the concept of time equivalence but to find out the extent to which reliance can be placed on test results from standard fire tests in a real fire situation which corresponds to a fire of equivalent severity. In this case, the input values are the fire load, the thermal properties of the compartment linings and the ventilation. No attempt is made to define an appropriate fire resistance period for the structure and therefore, the approach does not rely on fitting data from standard fire tests on steel structures.

The formula for the Equivalent time of fire exposure is set out in the fire part of Eurocode 1[3] as:

$$t_{e,d} = (q_{f,d} \times w_f \times k_b) \times k_c$$

Where:

$q_{f,d}$ is the design fire load density per unit floor area (MJ/m²)

k_b is the conversion factor for the compartment thermal properties (min.m²/MJ)

w_f is the ventilation factor

k_c is a correction factor dependent on the structural material

For every structural Eurocode there is a corresponding National Annex for use within the individual member state. Work undertaken in developing the UK National Annex[4] showed that the correction factor k_c for different materials could not be supported and that the use of the concept for unprotected steel structures should be limited to fire resistance periods up to 30 minutes. For reinforced concrete (or protected steel), the correction factor is 1.0 so using the National guidance there is no difference other than the approach is only valid for unprotected steel for periods up to 30 minutes. Therefore, the equivalent time of fire exposure is a function of the fire load density, the thermal properties of the compartment boundaries and the ventilation factor. For present purposes, the ventilation condition and the thermal properties of the compartment boundaries are fixed values, and the choice of fire load density is used to provide the required level of fire severity.

The ventilation factor w_f is derived from a consideration of the height of the compartment and the ratio of the openings to the floor area such that:

$$w_f = (6/H)^{0.3} [0.62 + 90 (0.4 - \alpha_v)^4] \geq 0.5 \; (in\ the\ absence\ of\ horizontal\ openings)$$

Where:

H is the height of the compartment (m)

$$\alpha_v = A_v/A_f$$

A_v is the area of the ventilation opening (m^2)

A_f is the floor area (m^2). In this case, the value of w_f = 1.313.

The conversion factor (k_b) for the thermal properties of the compartment linings is related to the b factor which in turn is a function of the specific heat, density and thermal conductivity values for the materials forming the lining of the compartment such that b = $(\rho.c.\lambda)^{½}$. In this case, the relevant values are given using generic properties for plasterboard as these will govern behaviour during the growth and steady state phases of fire development. The properties used in the analysis for gypsum-based plasterboard are given in Table 2 (see section 2.1). In terms of fire development, unless the lining materials are thermally thin or will not survive for any significant period, it is the thermal properties of the compartment linings that will dictate fire growth and development rather than the underlying substrate. In general, the systems that will be tested rely on maintaining the integrity of the plasterboard lining for a significant duration of the fire exposure. It is therefore the innermost layer that will have the most significant impact on fire development in the growth and steady state phases of the fire. This may change in the cooling phase particularly where combustible materials are present.

The National Annex[4] sets out the appropriate values for k_b which differ from those in the informative annex. The default value for use in the UK is k_b = 0.09 and this is the appropriate value for this case.

Therefore, to achieve an equivalent time of fire exposure the required fire load density is given by:

$$q_{f,d} = 120/(1.313 * 0.09) = 1015 \text{ MJ/m}^2$$

In this case, the value adopted was 1025 MJ/m², giving an equivalent time of fire exposure of 121.09 minutes.

The concept of time equivalence is used to define the appropriate level of fire load density. The parametric approach set out in EN 1991-1-2 *Eurocode 1: Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire*[3] is used to predict the time-temperature relationship for the compartment.

The time-temperature curves in the heating phase are given by:

$$\theta_g = 1325\left(1 - 0.324\, e^{-0.2t^*} - 0.204\, e^{-1.7t^*} - 0.472\, e^{-19t^*}\right)$$

Where:

θ_g = temperature in the fire compartment	(°C)
$t^* = t.\Gamma$	(h)
t = time	(h)
$\Gamma = [O/b]^2 / (0.04/1160)^2$	(-)
b = $\sqrt{\rho c \lambda}$ and should lie between 100 and 2200	($J/m^2s^{½}K$)
O = opening factor ($A_v \sqrt{h} / A_t$)	($m^{½}$)
A_v = area of ventilation openings	(m^2)

H = height of ventilation openings	(m)
A_t = total area of enclosure (including openings)	(m^2)
ρ = density of boundary enclosure	(kg/m^3)
c = specific heat of boundary enclosure	(J/kgK)
λ = thermal conductivity of boundary	(W/mK)

The parametric approach is an example of a physically based fire model. Although various models are available, the parametric approach is used here due to its inclusion in the fire part of Eurocode 1 and based on the amount of validation available.

The model assumes that the temperature rise is independent of fire load. In order to account for depletion of the fuel, the duration of the fire must be considered. This is a complex process and depends on the rate of burning of the fuel, which itself is dependent on the ventilation available and the physical characteristics and distribution of the fuel.

The parametric fire curves comprise a heating phase represented by an exponential curve up to a maximum temperature θ_{max} occurring at a corresponding time of t_{max}, followed by a linearly decreasing cooling phase.

The maximum temperature in the heating phase occurs at a time given by:

$$t_{max} = \max\left[\left(0.2 \times 10^{-3} \times q_{t,d}/O_{lim}\right); t_{lim}\right]$$

Where:

$$q_{t,d} = q_{f,d} \times A_f/A_t$$

The limiting time period for medium fire growth (residential and offices) is 20 minutes. For most practical combinations of fire load, compartment geometry and opening factor t_{max} will be in excess of these limiting values. The temperature-time curves for the cooling phase are then given by:

$$\theta_g = \theta_{max} - 625(t^* - t^*_{max})\ for\ t^*_{max} \leq 0.5(h)$$

$$\theta_g = \theta_{max} - 250(3 - t^*_{max})\ (t^* - t^*_{max})\ for\ 0.5 < t^*_{max} < 2(h)$$

$$\theta_g = \theta_{max} - 250(t^* - t^*_{max})\ for\ t^*_{max} \geq 2(h)$$

© BRE Global Ltd 2025

Using the approach set out above, the predicted behaviour within the compartment is as shown in Figure 23 which also provides a comparison with the standard fire curve for 120 minutes.

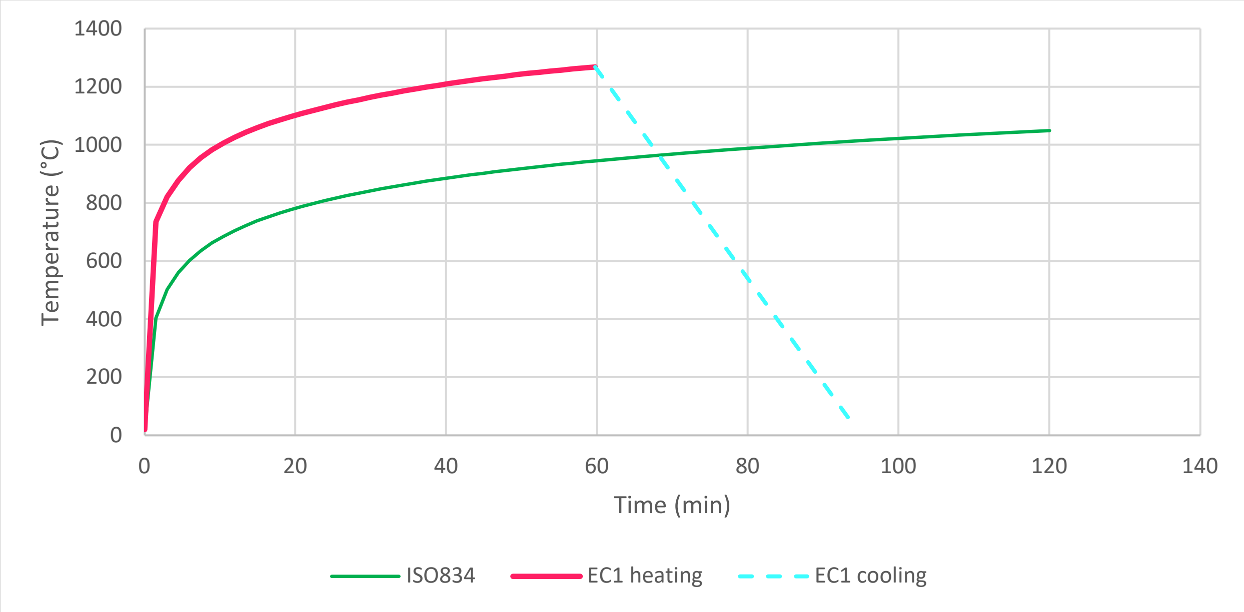


Figure 23 – Predicted compartment response compared to standard fire exposure

7.2 Instrumentation

In order to assess performance in relation to the selected performance criteria of loadbearing capacity, integrity and insulation, it is necessary to utilise a combination of visual observations and direct measurement. In general, overall stability and integrity can be assessed through direct observation while insulation performance is assessed by measuring the temperature rise on the unexposed surface of the compartment boundaries.

Figure 24 shows the basic layout and orientation of the fire compartment and can be used to identify the location of the timber cribs used to provide the fire load.

Note that the compartment included two internal walls to investigate issues around two-sided exposure of internal walls as identified in a recent CROSS report[5]. A large number of additional thermocouples were installed by the supplier. The data from these thermocouples were shared with BSR HSE for use in a separate research project.

This report focuses on the instrumentation installed by BRE Global to investigate the overall objectives of the project and to provide a direct comparison with other systems.

© BRE Global Ltd 2025

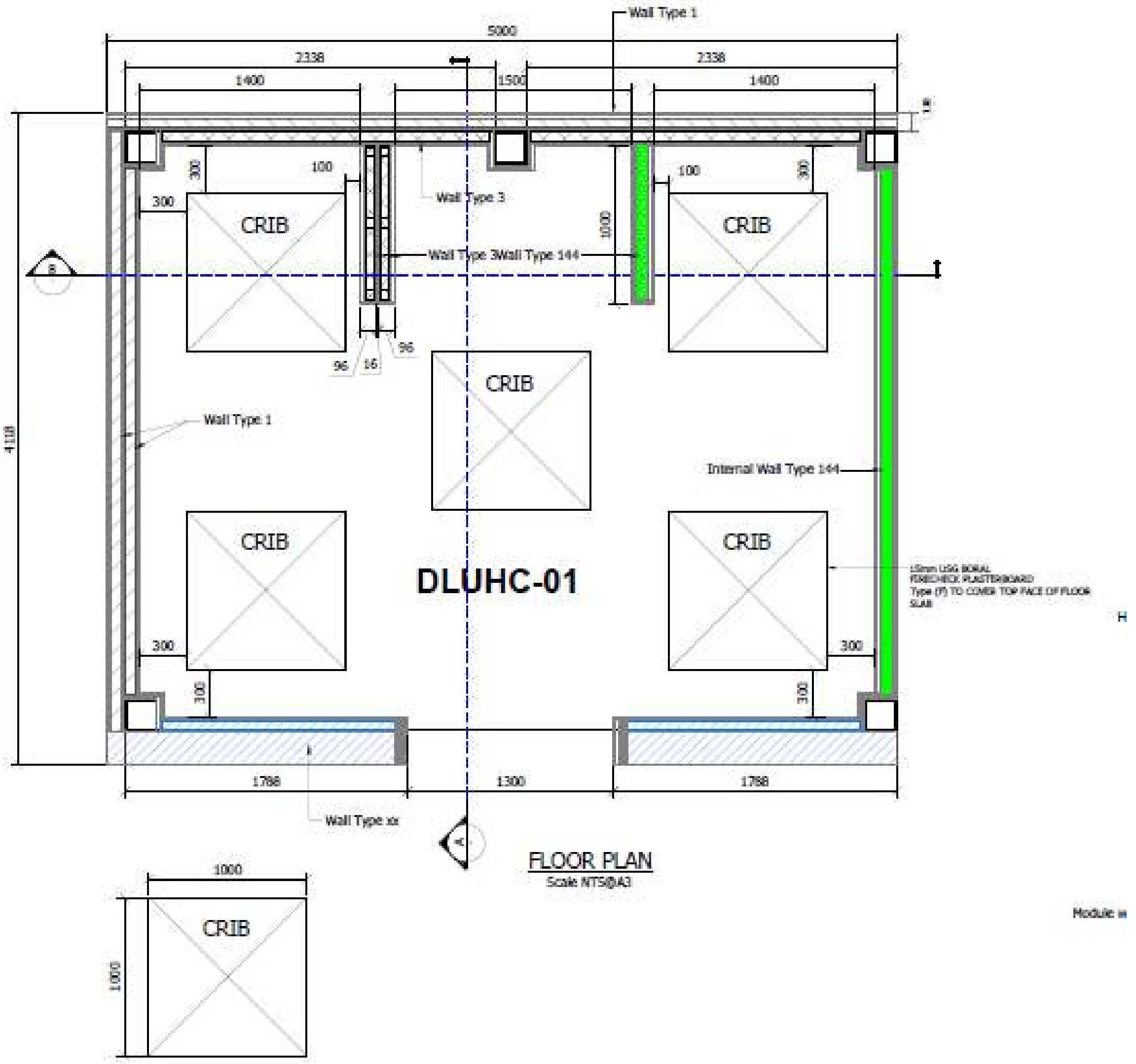
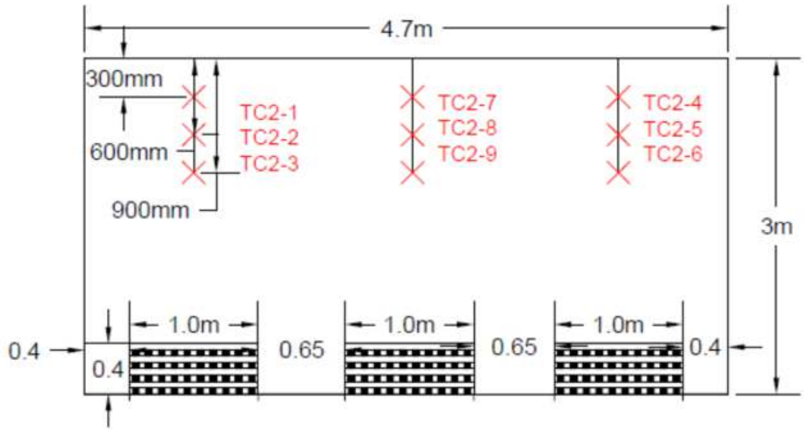


Figure 24 – General layout of the fire compartment

The locations of the atmosphere temperature thermocouples are shown in Figure 25 with a description in Table 3. At each location, three thermocouples were used corresponding to 300 mm, 600 mm and 900 mm from the underside of the ceiling.

East section



West section

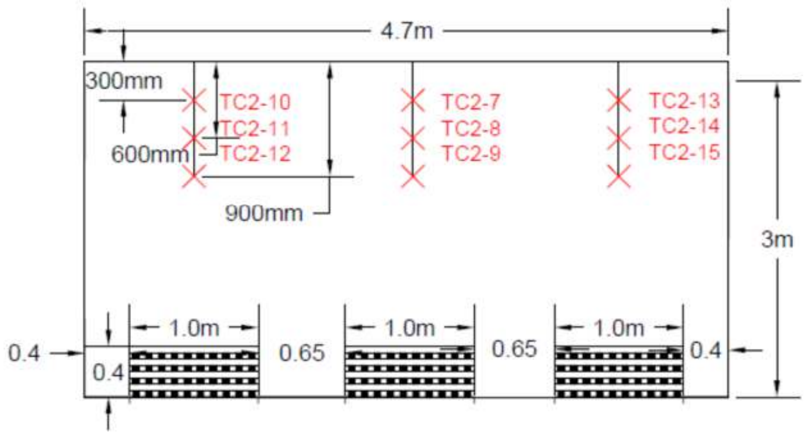


Figure 25 − Location of atmosphere thermocouples
Note that each crib is 800 mm high, not as shown

 © BRE Global Ltd 2025

Table 3 – Atmosphere thermocouple channel allocation

Channel	ID	Description	Position	Drawing ref.
1	TC2-1	Atmospheric	Back right 300	East section
2	TC2-2	Atmospheric	Back right 600	East section
3	TC2-3	Atmospheric	Back right 900	East section
4	TC2-4	Atmospheric	Back left 300	East section
5	TC2-5	Atmospheric	Back left 600	East section
6	TC2-6	Atmospheric	Back left 900	East section
7	TC2-7	Atmospheric	Middle 300	East/West
8	TC2-8	Atmospheric	Middle 600	East/West
9	TC2-9	Atmospheric	Middle 900	East/West
10	TC2-10	Atmospheric	Front left 300	West section
11	TC2-11	Atmospheric	Front left 600	West section
12	TC2-12	Atmospheric	Front left 900	West section
13	TC2-13	Atmospheric	Front right 300	West section
14	TC2-14	Atmospheric	Front right 600	West section
15	TC2-15	Atmospheric	Front right 900	West section

The location of the thermocouples on the top of the roof slab is shown in Figure 26 and the relevant section of the channel allocation is reproduced as Table 4.

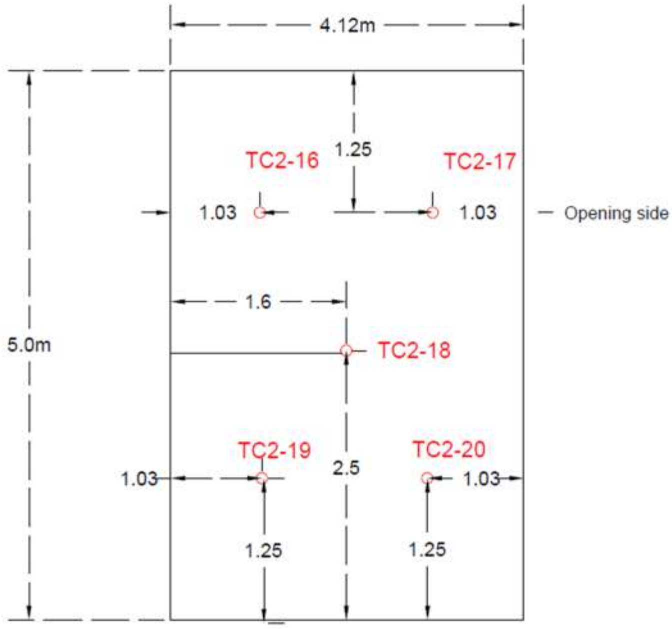


Figure 26 – Instrumentation locations on roof slab (plan view)

Table 4 – Roof slab thermocouple locations

Channel	ID	Description	Position	Drawing ref.
16	TC2-16	Roof TC	South east	Plan view
17	TC2-17	Roof TC	South west	Plan view
18	TC2-18	Roof TC	Middle	Plan view
19	TC2-19	Roof TC	North east	Plan view
20	TC2-20	Roof TC	North west	Plan view

The location of the thermocouples on the unexposed face of the South elevation is shown in Figure 27 and the relevant section of the channel allocation is reproduced as Table 5.

© BRE Global Ltd 2025

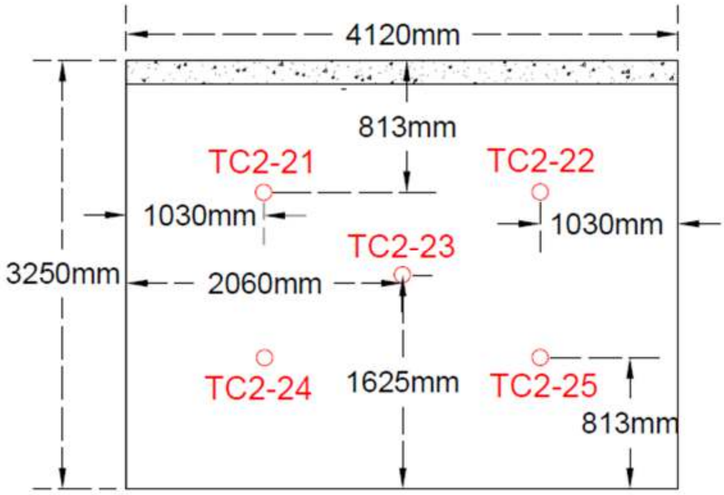


Figure 27 – Thermocouple locations on the South elevation

Table 5 – South elevation unexposed face thermocouple locations

Channel	ID	Description	Position
21	TC2-21	South	Top left
22	TC2-22	South	Top right
23	TC2-23	South	Middle
24	TC2-24	South	Bottom left
25	TC2-25	South	Bottom right

The location of the thermocouples on the unexposed face of the East elevation is shown in Figure 28 and the relevant section of the channel allocation is reproduced as Table 6.

© BRE Global Ltd 2025

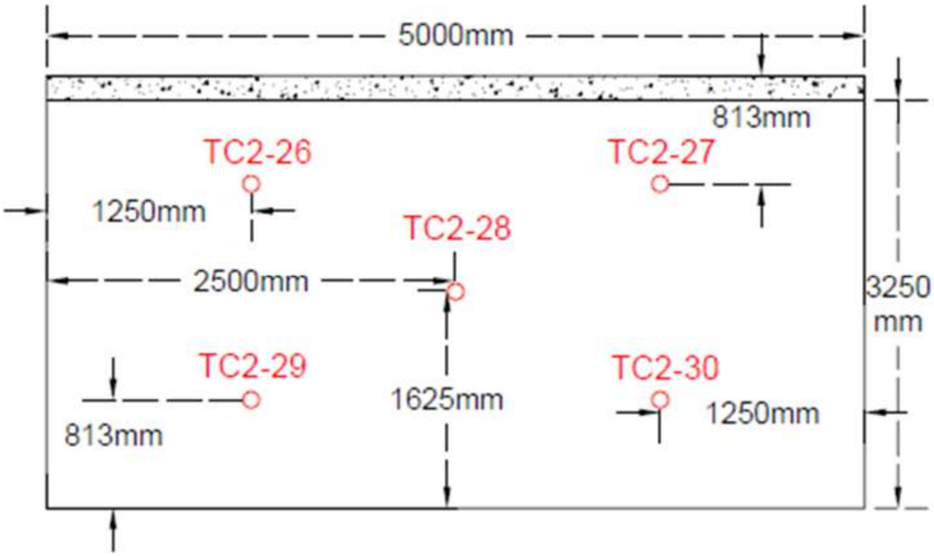


Figure 28 − Thermocouple locations on the East elevation

Table 6 − East elevation unexposed face thermocouple locations

Channel	ID	Description	Position
26	TC2-26	East	Top left
27	TC2-27	East	Top right
28	TC2-28	East	Middle
29	TC2-29	East	Bottom left
30	TC2-30	East	Bottom right

The location of the thermocouples on the unexposed face of the North elevation is shown in Figure 29 and the relevant section of the channel allocation is reproduced as Table 7.

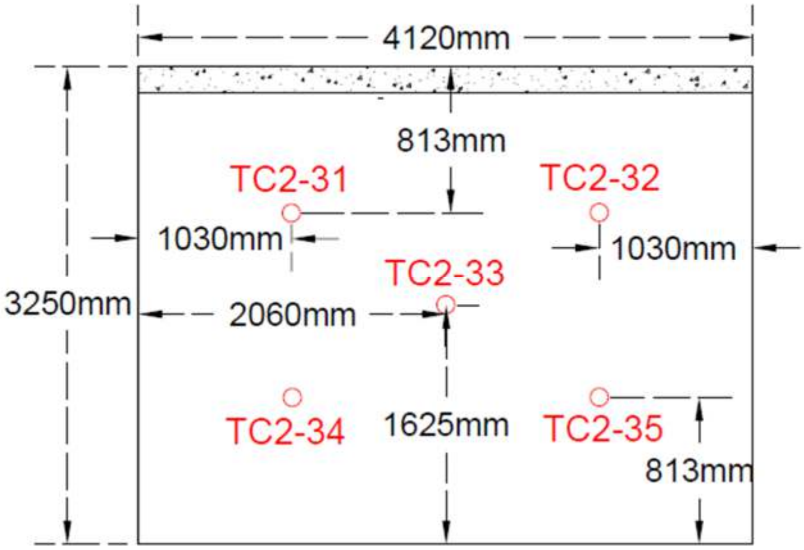


Figure 29 − Thermocouple locations on the North elevation

Table 7 − North elevation unexposed face thermocouple locations

Channel	ID	Description	Position
31	TC2-31	North	Top left
32	TC2-32	North	Top right
33	TC2-33	North	Middle
34	TC2-34	North	Bottom left
35	TC2-35	North	Bottom right

BRE Global also measured heat flux outside the opening (2 m away and 1.8 m height) and deflection at specific points on the structure (mid-span of the slab and at column heads).

7.3 Fire development

Following ignition, the compartment quickly transitioned to flashover following the build-up of hot gases around the ceiling with flames emerging from the opening (see Figure 30).

© BRE Global Ltd 2025

Figure 30 − External flaming 5 minutes from ignition

The fire continued until all the combustible material was consumed. The time-temperature development based on the atmosphere thermocouples within the compartment is shown in Figure 31.

There was no insulation failure on the unexposed faces of the compartment during the fire exposure measured against the standard fire test performance criteria.

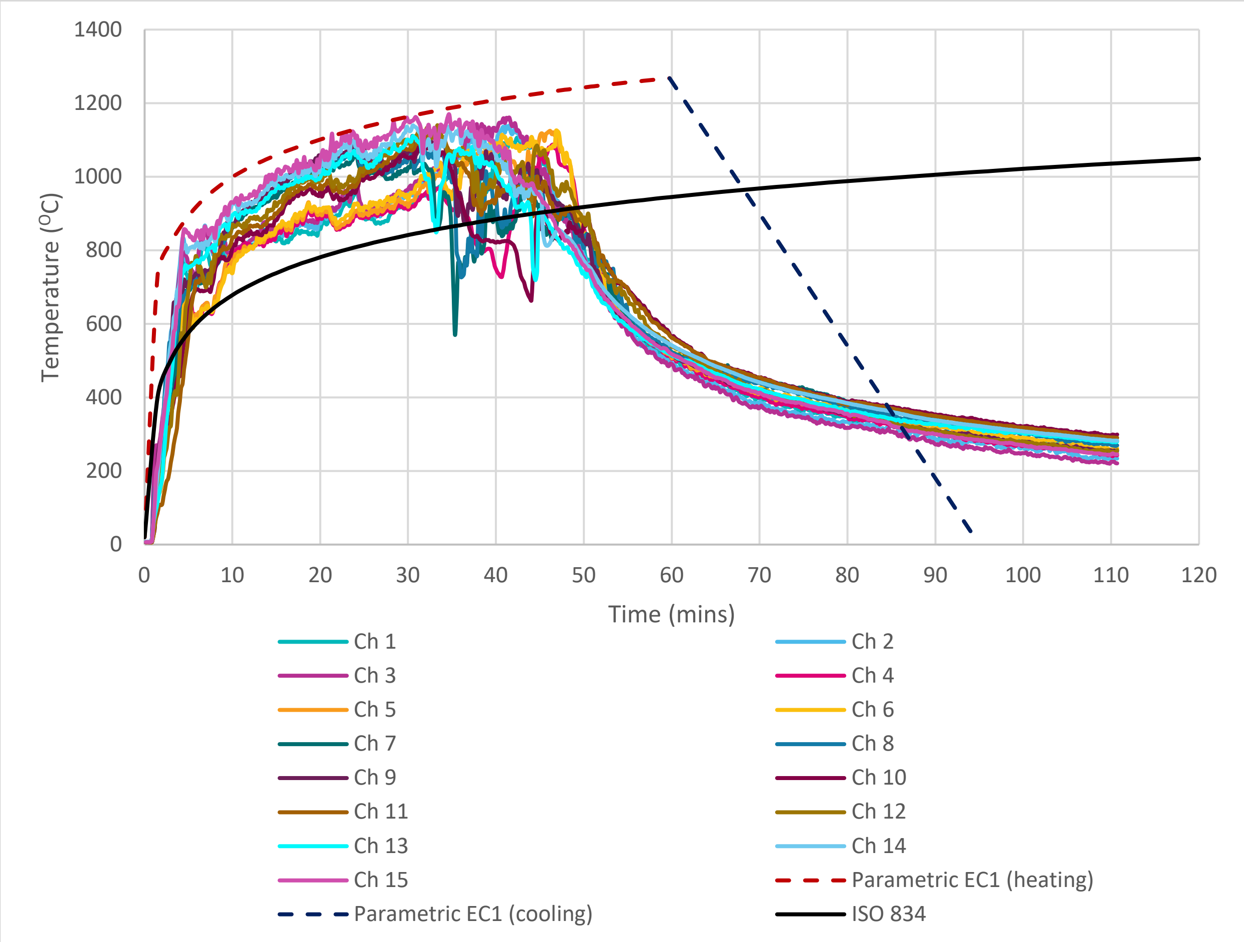


Figure 31 − Compartment time-temperature response related to standard fire exposure and predicted response from EN 1991-1-2 parametric approach

The predicted compartment atmosphere temperature is in excess of the standard curve for approximately the first 70 minutes. Although the total area under the measured curve does not equate to the total area under the standard curve for the 120-minute exposure, this issue is discussed in Section 11. The issue of equivalent severity is very much dependent on the nature of the structural element and the configuration and design of any protection system.

The parametric approach provides a good correlation for the maximum temperature within the compartment but overestimates the duration of the heating phase.

7.4 Structural performance

The compartment survived complete burn out of all combustible material while maintaining overall stability. Although there was no imposed load present in this experiment, BRE Global does not believe this would have had an adverse impact on the results. Loadbearing capacity and utilisation need to be considered in different ways, depending on the specifics of the system. For those modular or panellised systems reliant on critical components such as column posts, then the residual capacity can be assessed based on the measured temperature of those critical components. For other systems (such as mass timber), then the residual loadbearing capacity is more closely related to the thickness of the undamaged layer. In future experiments, the relevant values were measured to determine this. There were no signs of any integrity failure during the course of the fire and no evidence of external flaming away from the ventilation opening.

There was no evidence of any insulation failure during the fire exposure. Figure 32 shows the unexposed face temperatures on the upper surface of the roof slab.

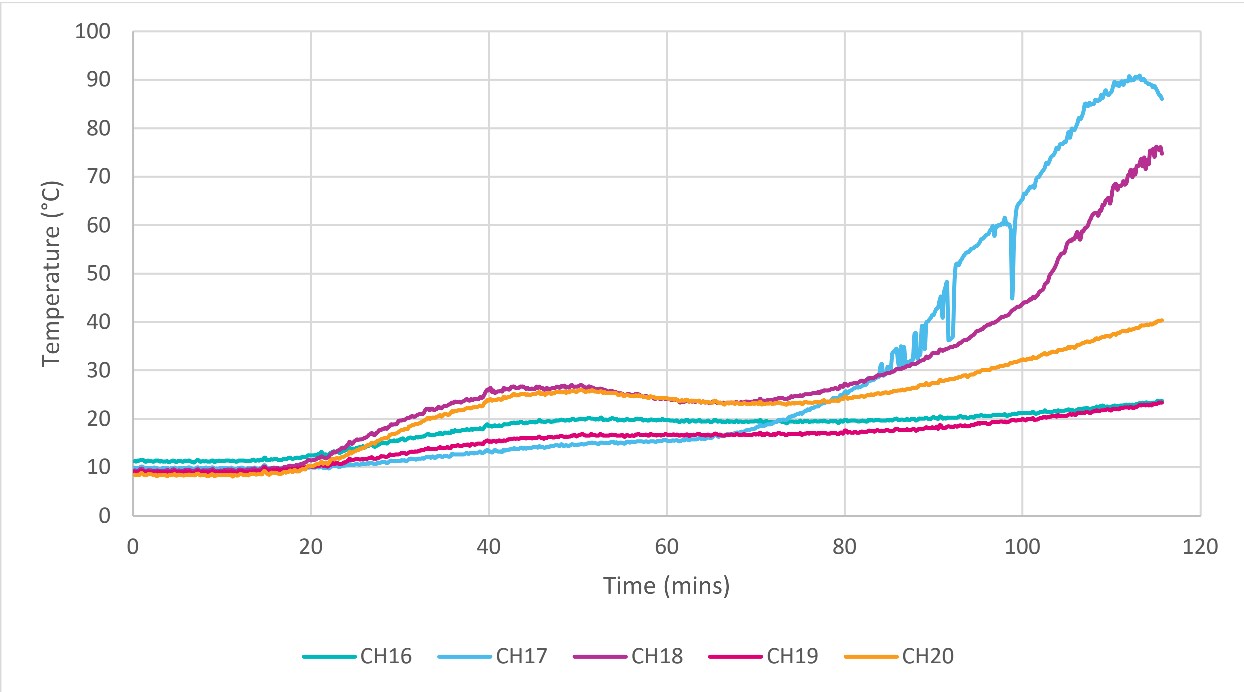


Figure 32 − Temperature of the unexposed surface of the roof slab

Figure 33 shows the unexposed face temperatures of the Southern elevation, while Figures 34 and 35 show the corresponding values for the East and North elevations.

© BRE Global Ltd 2025

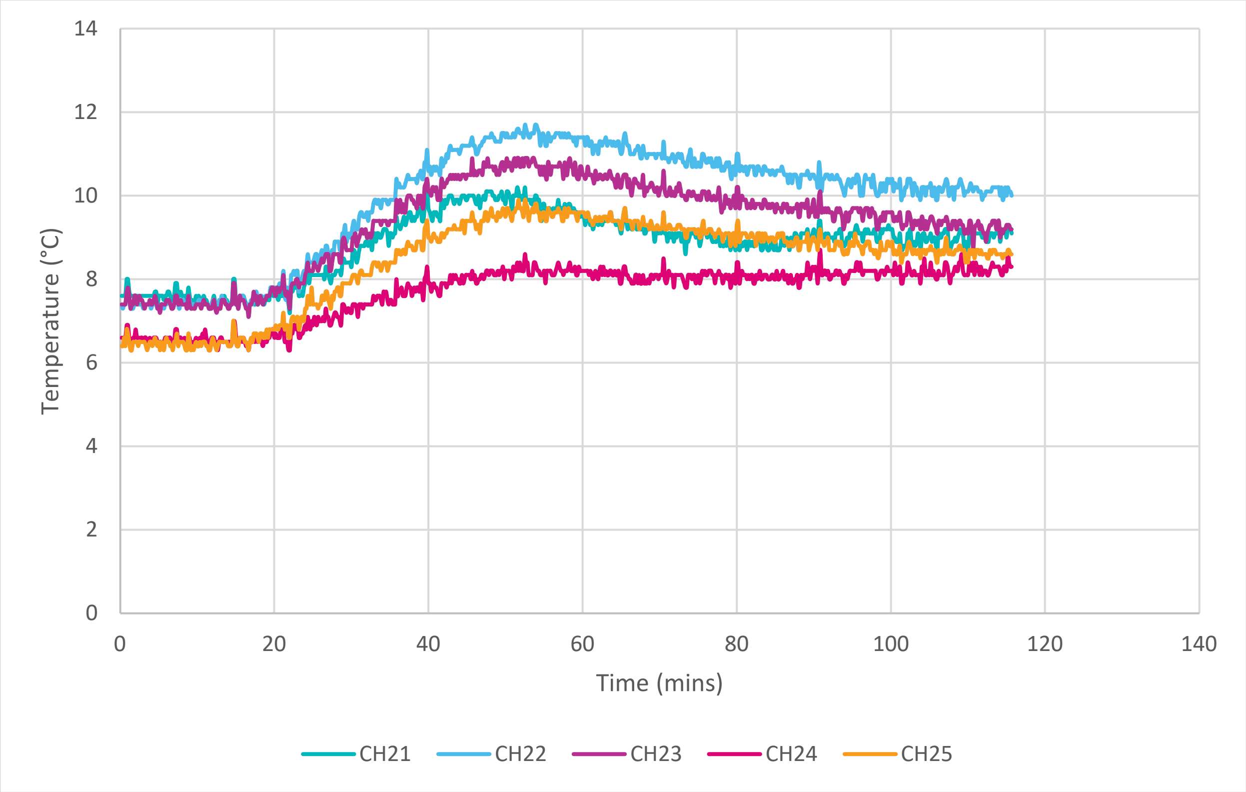


Figure 33 − Temperature of the unexposed face of South wall elevation

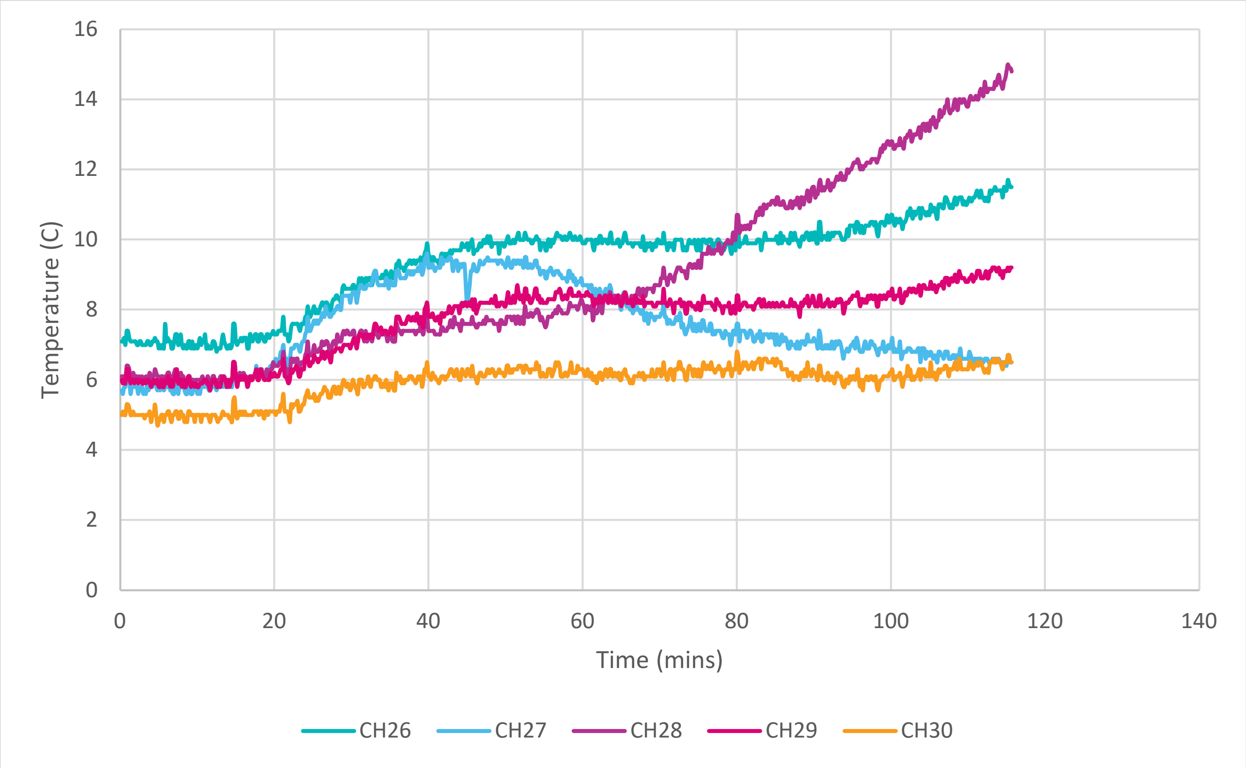


Figure 34 − Temperature of the unexposed face of East wall elevation

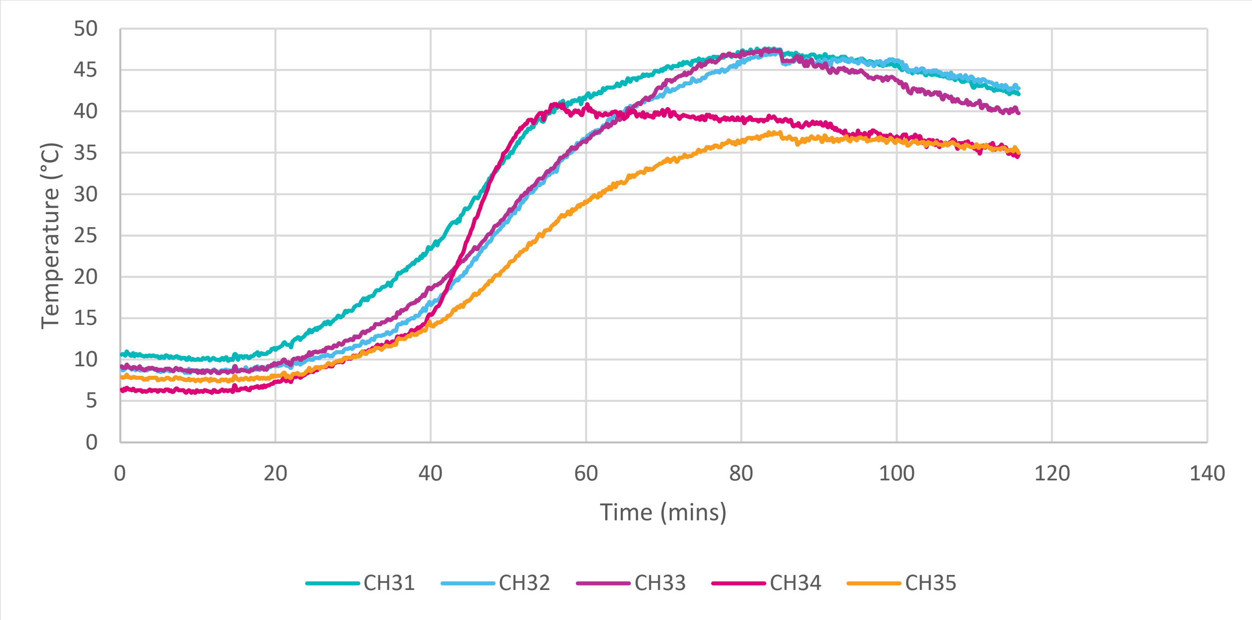


Figure 35 − Temperature of the unexposed face of the North wall elevation

In addition to the temperature measurements, displacement was measured in the centre of the slab and on the columns on the rear (East) elevation. The results are summarised in Figure 36. The measured value of heat flux 2 m from the centre of the opening is shown in Figure 37.

© BRE Global Ltd 2025

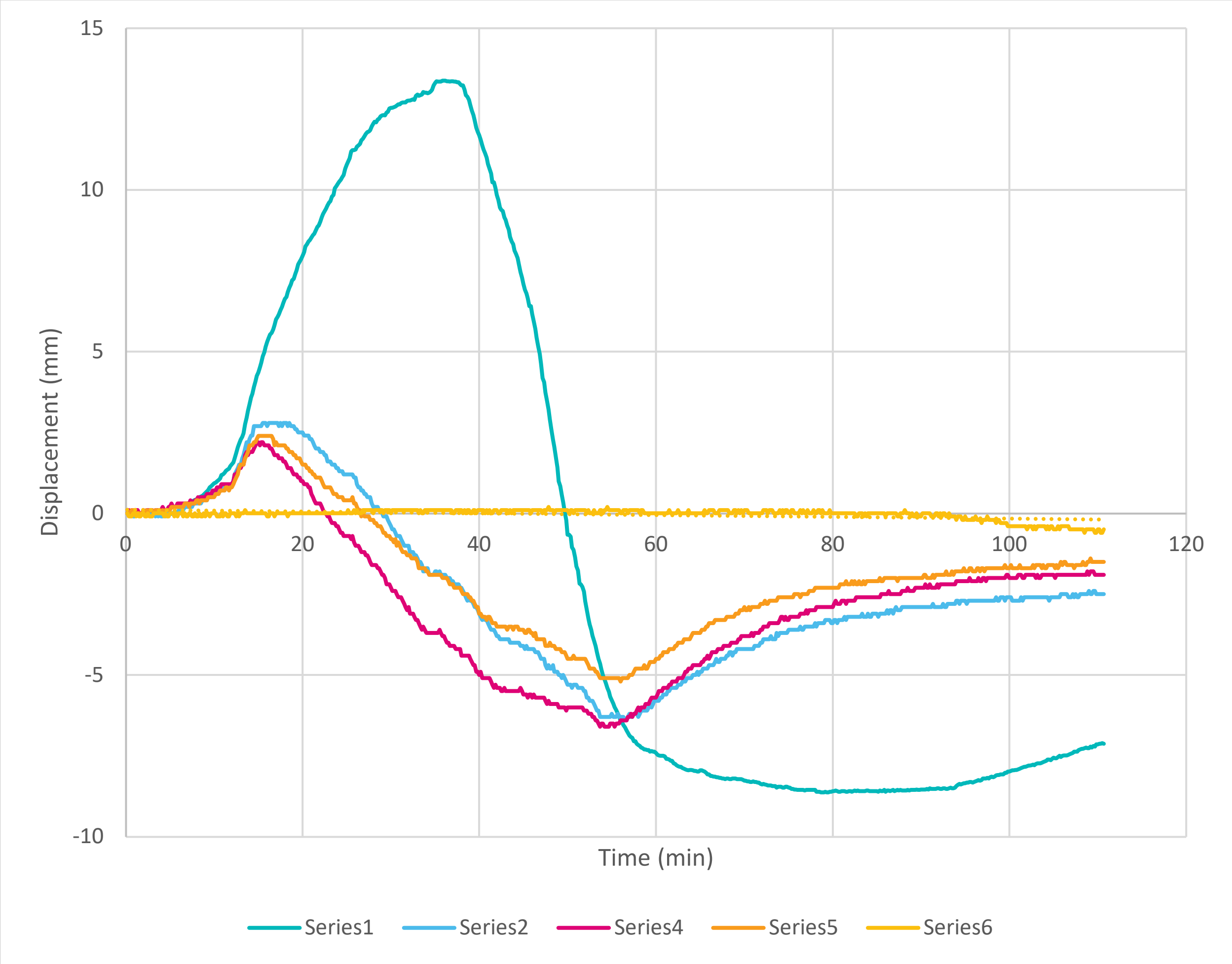


Figure 36 − Displacement readings

Series 1 is the central displacement of the slab, Series 2, 3 and 4 is the vertical displacement of the column heads on the rear elevation; Series 6 is the lateral displacement of one of the edge columns on the rear elevation. In this case, a positive reading represents upwards movement, and a negative reading represents downwards movement.

© BRE Global Ltd 2025

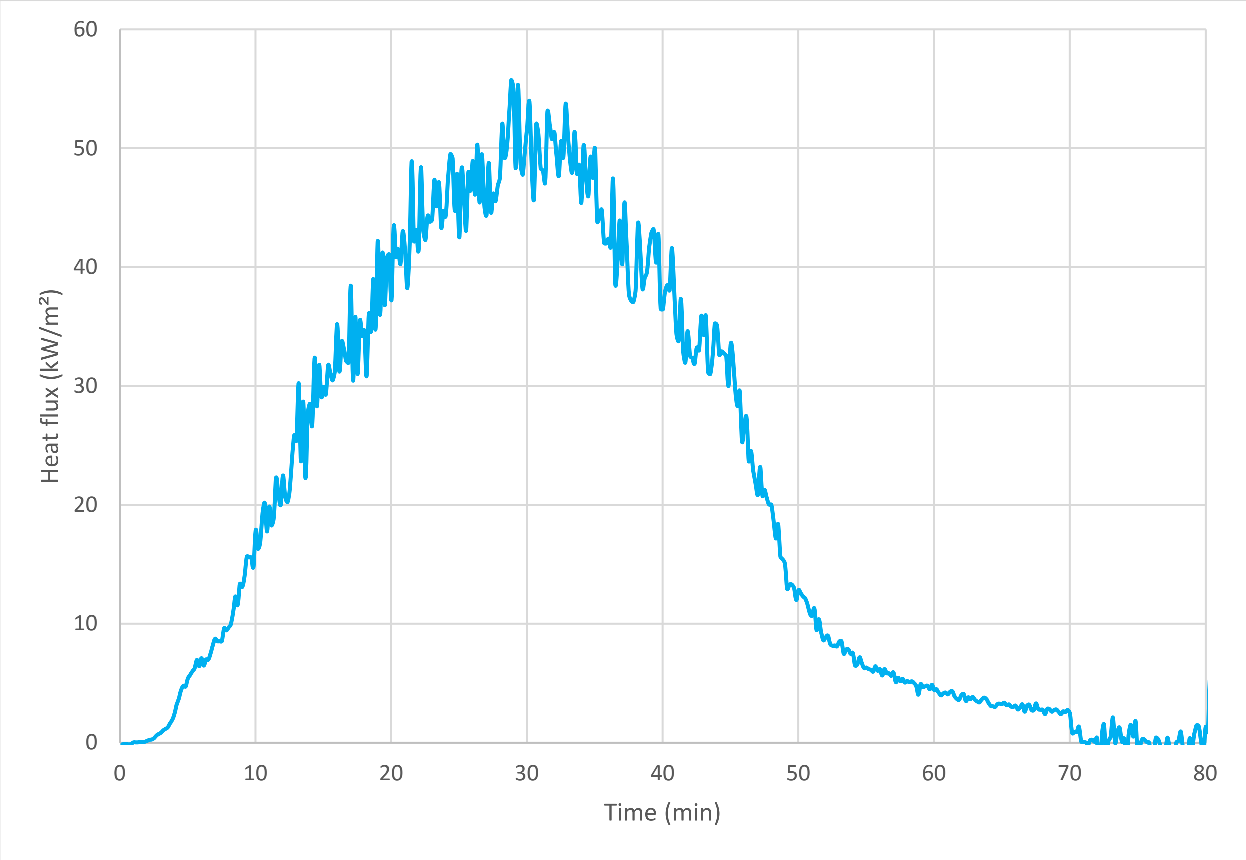


Figure 37 − Heat flux at a height of 1.8 m and a distance of 2 m from the centre of the opening

8 Fire Experiment C – Cross Laminated Timber walls and floors (CLT)

As described in Table 1, the third fire experiment consisted of a CLT compartment constructed from wall and roof panels. The design, supply and construction of the compartment was organised by an industry group coordinated through the Structural Timber Association (STA). The CLT structure was designed specifically for the fire experiment but is understood to be representative of a real design used for real buildings. The general structural form for the superstructure is a panellised load bearing wall system with CLT panels used to form the walls. In common with the other systems included in this experimental programme, there was a single opening in one of the walls. In this location, the CLT panel is used as a deep beam to span over the opening.

All floor panels were formed from CLT. The lower floor slab was raised off the ground, sitting on timber bearers.

Stability of the structure is achieved by the upper CLT floor panel acting as a diaphragm, which transfers loads to the CLT walls which act as shear walls.

Typical screwed and bracketed connections were used for the CLT-CLT connections. The CLT walls were fixed to the BRE Burn Hall ground slab using steel angle brackets and the timber bearers were nominally fixed to the BRE Burn Hall ground slab.

Figure 38 shows the inside of the compartment just prior to ignition, and Figure 39 shows the front elevation including the single ventilation opening. The internal dimensions were approximately 4.8 m long by 3 m wide by 2.7 m high. The compartment was supplied and delivered to BRE as individual panels erected on site with linings installed following erection. A detailed specification of the construction of the compartment and additional information related to the linings was provided to BRE Global for review. This information has been forwarded to BSR HSE. The compartment was lined throughout with two layers of 18 mm gypsum fibreboards. Additional boards were fixed to the external face of the compartment around the ventilation opening to prevent ignition from flames emerging from the opening. The supplier's fire protection design approach was based on encapsulation with the aim to ensure the temperature at the interface between the CLT panel and the gypsum fibre board remains below 200°C when subject to a standard fire exposure for the specified design period (60 minutes).

No fire stopping or service penetrations were included in this experiment.

The single ventilation opening consists of a single doorway 1.372 m wide and 2.085 m high. The intention is that this layout will, wherever possible, be replicated for subsequent fire experiments. The ventilation has been chosen to represent a severe value in terms of the ratio between openings and floor area and to ensure that the ratio is within the scope of validity of both the time equivalence concept and the parametric approach used to "predict" the compartment time-temperature response. The fires will be ventilation controlled.

Following completion of the fire experiment, seats of smouldering combustion were found, leading to ignition of localised areas of the CLT over a period of many hours. The issues around the post-experiment behaviour have been reviewed, analysed and reported in Appendix D2.

© BRE Global Ltd 2025

Figure 38 − Inside compartment prior to ignition (looking at inside of East elevation)

Figure 39 − Front elevation showing ventilation opening in West elevation

© BRE Global Ltd 2025

8.1 Fire design

Based on information from the supply team, the target market for CLT systems is those buildings with a requirement in relation to fire resistance of up to 60 minutes REI. Therefore, the fire design was predicated on providing a natural fire with an equivalent exposure to 60 minutes under the standard fire curve. In each case, the experiments have been designed to "equate" to the required end use application in terms of fire resistance. This enables determination of one of the critical areas for evaluation namely "*can this system survive burnout without collapse*"?

The concept of time equivalence is a well-established approach incorporated in national and international codes and standards. Use of this technique allows performance in a real fire situation to be related to the results obtained from standard fire resistance testing and to provide a relation between system performance and the minimum periods of fire resistance specified in statutory guidance.

One of the objectives of the project is to see where the boundaries of reliance on standard fire resistance testing lie. This project is not trying to confirm or calibrate the concept of time equivalence but to find out the extent to which reliance can be placed on test results from standard fire tests in a real fire situation which corresponds to a fire of equivalent severity. In this case, the input values are the fire load, the thermal properties of the compartment linings and the ventilation. No attempt is made to define an appropriate fire resistance period for the structure and therefore, the approach does not rely on fitting data from standard fire tests on steel structures.

The formula for the Equivalent time of fire exposure is set out in the fire part of Eurocode 1[3] as:

$$t_{e,d} = \left(q_{f,d} \times w_f \times k_b\right) \times k_c$$

Where:

$q_{f,d}$ is the design fire load density per unit floor area (MJ/m²)

k_b is the conversion factor for the compartment thermal properties (min.m²/MJ)

w_f is the ventilation factor

k_c is a correction factor dependent on the structural material

For every structural Eurocode there is a corresponding National Annex for use within the individual member state. Work undertaken in developing the UK National Annex[4] showed that the correction factor k_c for different materials could not be supported and that the use of the concept for unprotected steel structures should be limited to fire resistance periods up to 30 minutes. For reinforced concrete (or protected steel) the correction factor is 1.0 so using the National guidance there is no difference other than the approach is only valid for unprotected steel for periods up to 30 minutes. Therefore, the equivalent time of fire exposure is a function of the fire load density, the thermal properties of the compartment boundaries and the ventilation factor. For present purposes, the ventilation condition and the thermal properties of the compartment boundaries are fixed values, and the choice of fire load density is used to provide the required level of fire severity.

The ventilation factor w_f is derived from a consideration of the height of the compartment and the ratio of the openings to the floor area such that:

$$w_f = (6/H)^{0.3}\left[0.62 + 90\,(0.4 - \alpha_v)^4\right] \geq 0.5\ (in\ the\ absence\ of\ horizontal\ openings)$$

Where:

H is the height of the compartment (m)

$\alpha_v = A_v/A_f$

A_v is the area of the ventilation opening (m^2)

A_f is the floor area (m^2). In this case, the value of w_f = 0.976.

The conversion factor (k_b) for the thermal properties of the compartment linings is related to the b factor which in turn is a function of the specific heat, density and thermal conductivity values for the materials forming the lining of the compartment such that b = $(\rho.c.\lambda)^{½}$. In this case, the relevant values are given using generic properties for plasterboard as these will govern behaviour during the growth and steady state phases of fire development. The properties used in the analysis for gypsum-based plasterboard are given in Table 2 (see section 2.1). These were used in the absence of any specific elevated temperature thermal properties for the board used in the experiment. In terms of fire development, unless the lining materials are thermally thin or will not survive for any significant period, it is the thermal properties of the compartment linings that will dictate fire growth and development rather than the underlying substrate. In general, mass timber and modern forms of construction including modular systems rely on maintaining the integrity of the plasterboard lining for a significant duration of the fire exposure. It is therefore the innermost layer that will have the most significant impact on fire development in the growth and steady state phases of the fire. This may change in the cooling phase particularly where combustible materials are present.

The National Annex[4] sets out the appropriate values for k_b which differ from those in the informative annex. The default value for use in the UK is k_b = 0.09 and this is the appropriate value for this case.

Therefore, to achieve an equivalent time of fire exposure the required fire load density is given by:

$$q_{f,d} = 60/(0.976 * 0.09) = 683 \text{ MJ/m}^2$$

In this case, the value adopted was 690 MJ/m², giving an equivalent time of fire exposure of 60.6 minutes.

The concept of time equivalence is used to define the appropriate level of fire load density. The parametric approach set out in EN 1991-1-2 *Eurocode 1: Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire*[3] is used to predict the time-temperature relationship for the compartment.

The time-temperature curves in the heating phase are given by:

$$\theta_g = 1325\left(1 - 0.324\, e^{-0.2t^*} - 0.204\, e^{-1.7t^*} - 0.472\, e^{-19t^*}\right)$$

Where:

θ_g = temperature in the fire compartment	(°C)
$t^* = t.\Gamma$	(h)
t = time	(h)
$\Gamma = [O/b]^2/(0.04/1160)^2$	(-)
$b = \sqrt{\rho c \lambda}$ and should lie between 100 and 2200	($J/m^2s^{½}K$)
O = opening factor ($A_v \sqrt{h} / A_t$)	($m^{½}$)
A_v = area of ventilation openings	(m^2)

© BRE Global Ltd 2025

H = height of ventilation openings	(m)
A_t = total area of enclosure (including openings)	(m^2)
ρ = density of boundary enclosure	(kg/m^3)
c = specific heat of boundary enclosure	(J/kgK)
λ = thermal conductivity of boundary	(W/mK)

The parametric approach is an example of a physically based fire model. Although various models are available, the parametric approach is used here due to its inclusion in the fire part of Eurocode 1 and based on the amount of validation available.

The model assumes that the temperature rise is independent of fire load. In order to account for depletion of the fuel the duration of the fire must be considered. This is a complex process and depends on the rate of burning of the fuel which itself is dependent on the ventilation available and the physical characteristics and distribution of the fuel.

The parametric fire curves comprise a heating phase represented by an exponential curve up to a maximum temperature θ_{max} occurring at a corresponding time of t_{max}, followed by a linearly decreasing cooling phase.

The maximum temperature in the heating phase occurs at a time given by:

$$t_{max} = \max\left[(0.2 \times 10^{-3} \times q_{t,d}/O_{lim}); t_{lim}\right]$$

Where:

$$q_{t,d} = q_{f,d} \times A_f/A_t$$

The limiting time period for medium fire growth (residential and offices) is 20 minutes. For most practical combinations of fire load, compartment geometry and opening factor t_{max} will be in excess of these limiting values. The temperature-time curves for the cooling phase are then given by:

$$\theta_g = \theta_{max} - 625(t^* - t^*_{max})\ for\ t^*_{max} \leq 0.5(h)$$

$$\theta_g = \theta_{max} - 250(3 - t^*_{max})\ (t^* - t^*_{max})\ for\ 0.5 < t^*_{max} < 2(h)$$

$$\theta_g = \theta_{max} - 250(t^* - t^*_{max})\ for\ t^*_{max} \geq 2(h)$$

Using the approach set out above, the predicted behaviour within the compartment is as shown in Figure 40 which also provides a comparison with the standard fire curve for 60 minutes.

© BRE Global Ltd 2025

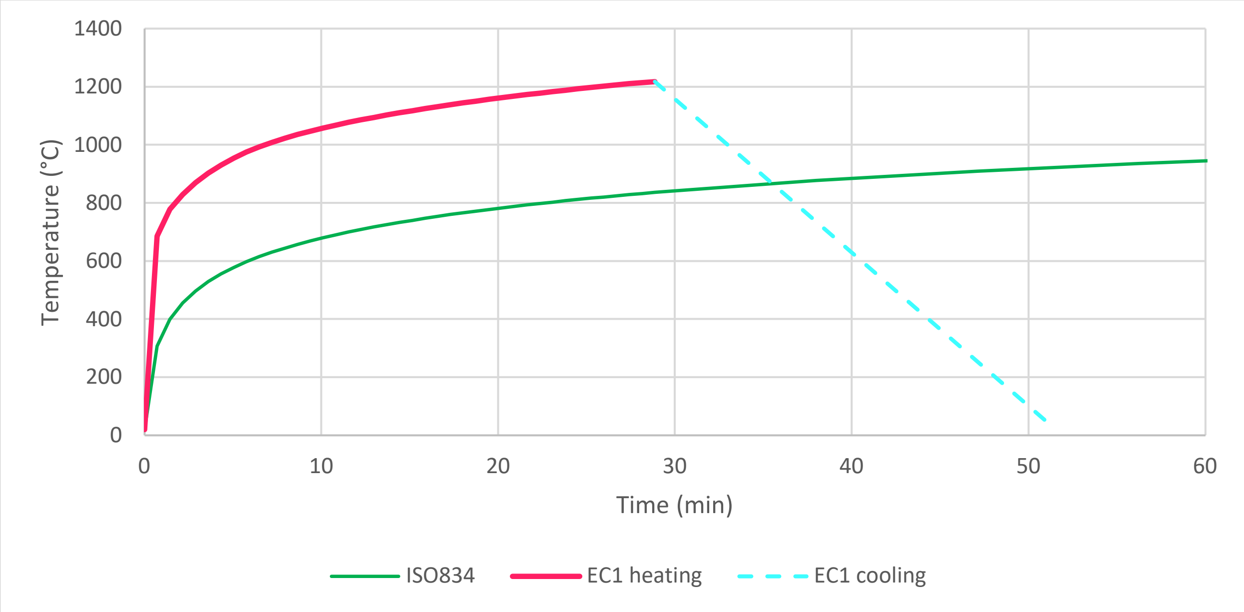


Figure 40 – Predicted compartment response compared to standard fire exposure

8.2 Instrumentation

In order to assess performance in relation to the selected performance criteria of loadbearing capacity, integrity and insulation, it is necessary to utilise a combination of visual observations and direct measurement. In general, overall stability and integrity can be assessed through direct observation while insulation performance is assessed by measuring the temperature rise on the unexposed surface of the compartment boundaries.

Figure 41 shows the basic layout and orientation of the fire compartment and can be used to identify the location of the internal wall within the compartment. The thermocouple channels illustrated relate to the atmosphere temperatures and are located above each of the five cribs.

Note that the compartment included an internal wall to investigate issues around two-sided exposure of internal walls as identified in a recent CROSS report[5]. Due to the nature of the construction additional thermocouples were installed at the interface between the unexposed face of the gypsum fibre building boards and the CLT panels.

This report focuses on the instrumentation installed by BRE Global to investigate the overall objectives of the project and to provide a direct comparison with other systems.

© BRE Global Ltd 2025

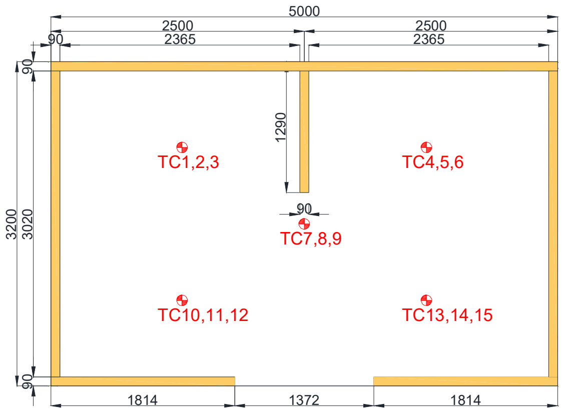


Figure 41 – General layout of the fire compartment

The channel allocation for the atmosphere thermocouples is shown in Table 8 which describes the location within the fire compartment and should be read in conjunction with Figure 41. The directions relate to the orientation of the compartment within the BRE Burn Hall test facility.

Table 8 – Atmosphere thermocouple channel allocation

Channel	ID	Description	Position	Direction
1	TC-1	Atmospheric	Atmosphere t/c above Crib 1 100 mm from ceiling	NE
2	TC-2	Atmospheric	Atmosphere t/c above Crib 1 300 mm from ceiling	NE
3	TC-3	Atmospheric	Atmosphere t/c above Crib 1 600 mm from ceiling	NE
4	TC-4	Atmospheric	Atmosphere t/c above Crib 2 100 mm from ceiling	SE
5	TC-5	Atmospheric	Atmosphere t/c above Crib 2 300 mm from ceiling	SE
6	TC-6	Atmospheric	Atmosphere t/c above Crib 2 600 mm from ceiling	SE
7	TC-7	Atmospheric	Atmosphere t/c centre of compartment 100 mm from ceiling	centre
8	TC-8	Atmospheric	Atmosphere t/c centre of compartment 300 mm from ceiling	centre
9	TC-9	Atmospheric	Atmosphere t/c centre of compartment 600 mm from ceiling	centre
10	TC-10	Atmospheric	Atmosphere t/c above Crib 3 100 mm from ceiling	NW
11	TC-11	Atmospheric	Atmosphere t/c above Crib 3 300 mm from ceiling	NW

12	TC-12	Atmospheric	Atmosphere t/c above Crib 3 600 mm from ceiling	NW
13	TC-13	Atmospheric	Atmosphere t/c above Crib 4 100 mm from ceiling	SW
14	TC-14	Atmospheric	Atmosphere t/c above Crib 4 300 mm from ceiling	SW
15	TC-15	Atmospheric	Atmosphere t/c above Crib 4 600 mm from ceiling	SW

The location of the thermocouples on the top of the roof slab including those on the unexposed surface and those at the intersection between the CLT and the board is shown in Figure 42 and the relevant section of the channel allocation is reproduced as Table 9.

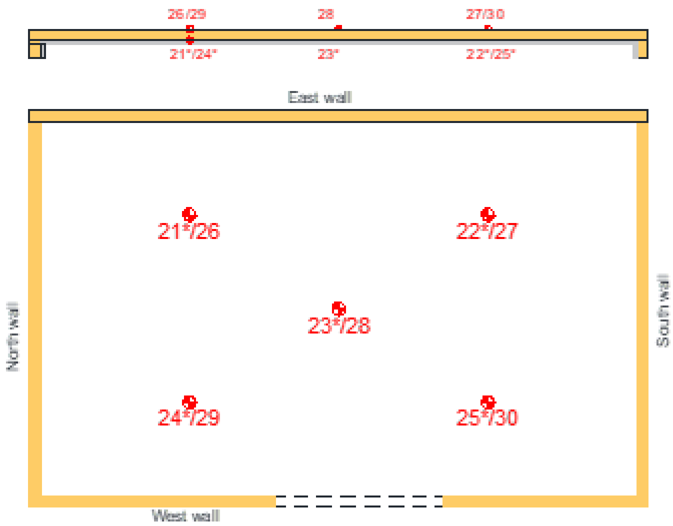


Figure 42 − Instrumentation locations on roof slab (plan view)

Table 9 – Roof slab thermocouple locations

Channel	ID	Description	Position	Location
21	TC21	Roof TC	Northeast	Interface
22	TC22	Roof TC	Southeast	Interface
23	TC23	Roof TC	Middle	Interface
24	TC24	Roof TC	Northwest	Interface
25	TC25	Roof TC	Southwest	Interface
26	TC26	Roof TC	Northeast	Unexposed
27	TC27	Roof TC	Southeast	Unexposed
28	TC28	Roof TC	Middle	Unexposed
29	TC29	Roof TC	Northwest	Unexposed
30	TC30	Roof TC	Southwest	Unexposed

The location of the thermocouples on the unexposed face of the North elevation including those on the unexposed surface and those at the intersection between the CLT and the board is shown in Figure 43 and the relevant section of the channel allocation is reproduced as Table 10.

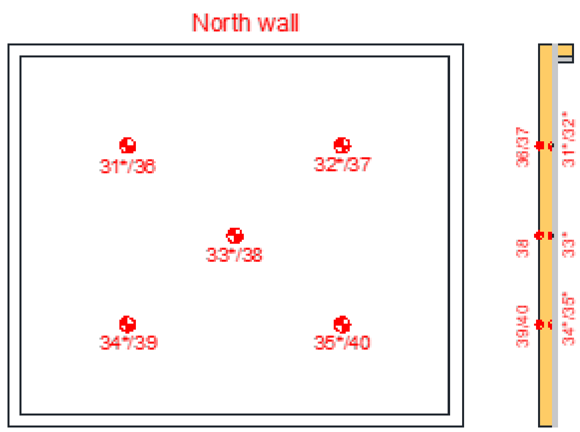


Figure 43 – Thermocouple locations on the North elevation

Table 10 – North elevation thermocouple locations

Channel	ID	Description	Position
31	TC31	North wall upper East	Interface
32	TC32	North wall upper West	Interface
33	TC33	North wall centre	Interface
34	TC34	North wall lower East	Interface
35	TC35	North wall lower West	Interface
36	TC36	North wall upper East	Unexposed
37	TC37	North wall upper West	Unexposed
38	TC38	North wall centre	Unexposed
39	TC39	North wall lower East	Unexposed
40	TC40	North wall lower West	Unexposed

The location of the thermocouples on the unexposed face of the East elevation including those on the unexposed surface and those at the intersection between the CLT and the board is shown in Figure 44 and the relevant section of the channel allocation is reproduced as Table 11.

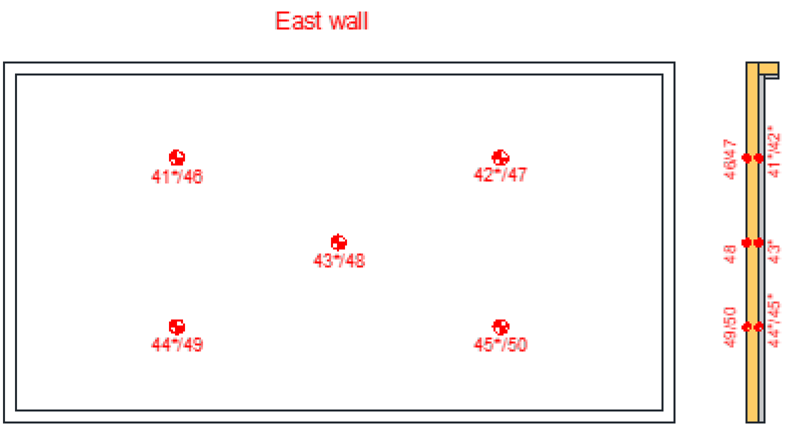


Figure 44 – Thermocouple locations on the East elevation

Table 11 − East elevation thermocouple locations

Channel	ID	Description	Position
41	TC41	East wall upper South	Interface
42	TC42	East wall upper North	Interface
43	TC43	East wall centre	Interface
44	TC44	East wall lower South	Interface
45	TC45	East wall lower North	Interface
46	TC46	East wall upper South	Unexposed
47	TC47	East wall upper North	Unexposed
48	TC48	East wall centre	Unexposed
49	TC49	East wall lower South	Unexposed
50	TC50	East wall lower North	Unexposed

The location of the thermocouples on the unexposed face of the South elevation including those on the unexposed surface and those at the intersection between the CLT and the board is shown in Figure 45 and the relevant section of the channel allocation is reproduced as Table 12.

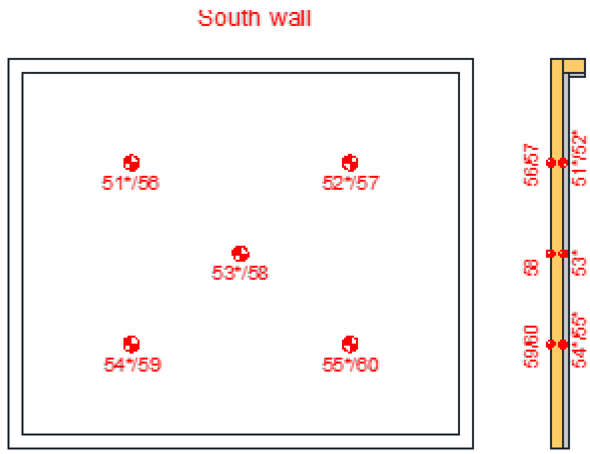


Figure 45 − Thermocouple locations on the South elevation

Table 12 – South elevation thermocouple locations

Channel	ID	Description	Position
51	TC51	South wall upper West	Interface
52	TC52	South wall upper East	Interface
53	TC53	South wall centre	Interface
54	TC54	South wall lower West	Interface
55	TC55	South wall lower East	Interface
56	TC56	South wall upper West	Unexposed
57	TC57	South wall upper East	Unexposed
58	TC58	South wall centre	Unexposed
59	TC59	South wall lower West	Unexposed
60	TC60	South wall lower East	Unexposed

© BRE Global Ltd 2025

8.3 Fire development

Following ignition, the compartment quickly transitioned to flashover following the build-up of hot gases around the ceiling with flames emerging from the opening (see Figure 46).

Figure 46 − External flaming shortly after ignition

The crib fire continued until the fire load was consumed. The time-temperature development based on the atmosphere thermocouples within the compartment is shown in Figure 47.

There was no insulation failure on the unexposed faces of the compartment during the fire exposure measured against the standard fire resistance test performance criteria.

© BRE Global Ltd 2025

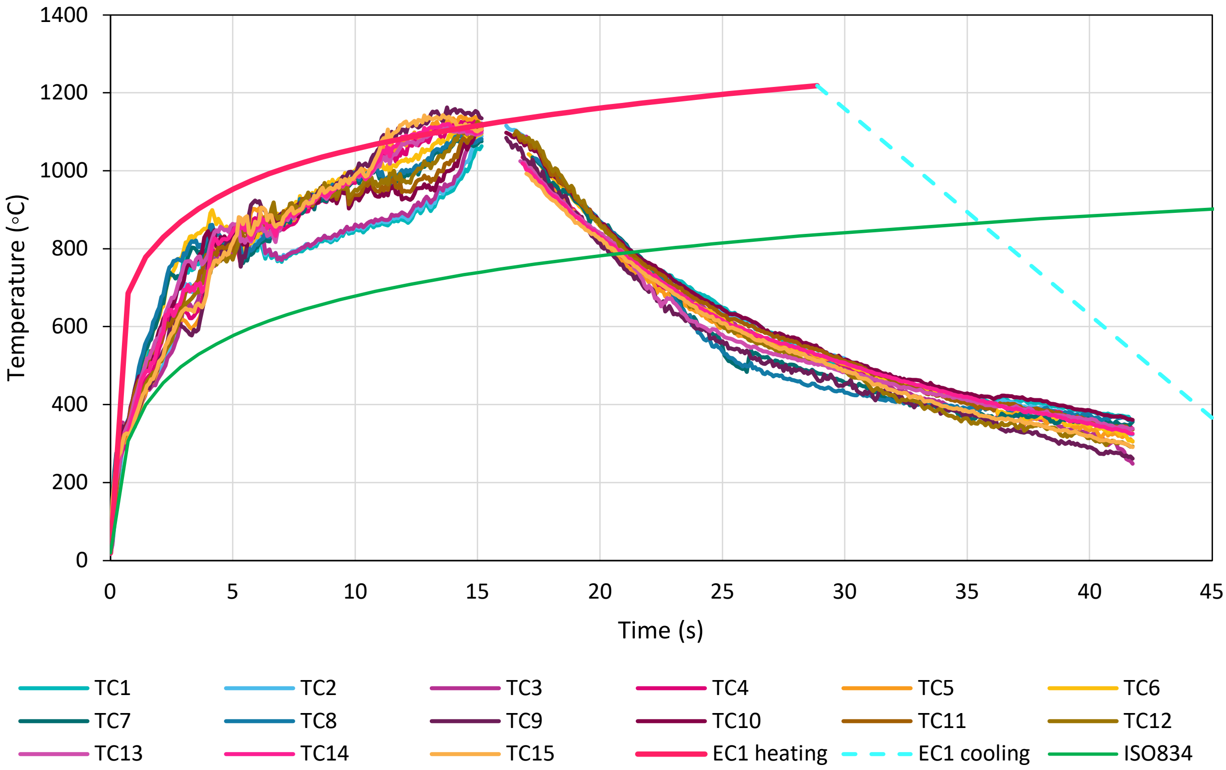


Figure 47 − Compartment time-temperature response related to standard fire exposure and predicted response from EN 1991-1-2 parametric approach

There was a temporary fault with the data acquisition system approximately 15 minutes from ignition. This was rectified and had no impact on the results from the fire experiment. The compartment atmosphere temperature is in excess of the standard curve for the entire heating phase. Although the total area under the measured curve does not equate to the total area under the standard curve for the 60-minute exposure, this issue is discussed in Section 11. The issue of equivalent severity is very much dependent on the nature of the structural element and the configuration and design of any protection system.

The parametric approach provides a good correlation for the maximum temperature within the compartment but overestimates the duration of the heating phase. The graph for atmosphere temperature in comparison with the parametric prediction does not include the pre-flashover phase which is included in the graphs below. This is because the parametric approach is only concerned with post-flashover fire behaviour.

8.4 Structural performance

The compartment survived complete burn out of all combustible material forming part of the moveable fire load while maintaining overall stability. There were no signs of any integrity failure during the course of the fire and no evidence of external flaming away from the ventilation opening.

There was no evidence of any insulation failure during the fire exposure. Figure 48 shows the interface temperatures between the fire boards and the CLT roof slab while Figure 49 shows the unexposed face temperatures on the upper surface of the roof slab. It is likely that the high temperatures measured at channel 22 were related to problems with the data acquisition. Video evidence does not support any insulation or integrity failure in this location.

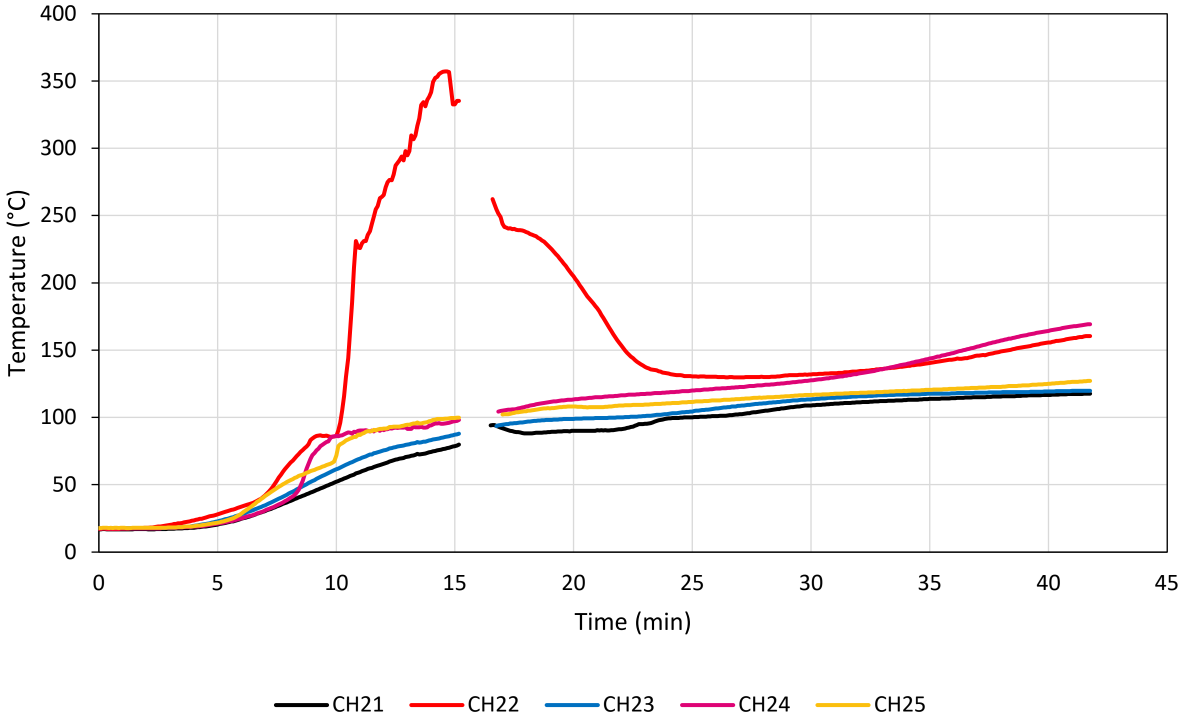


Figure 48 − Temperature of the interface between the boards and the CLT roof slab

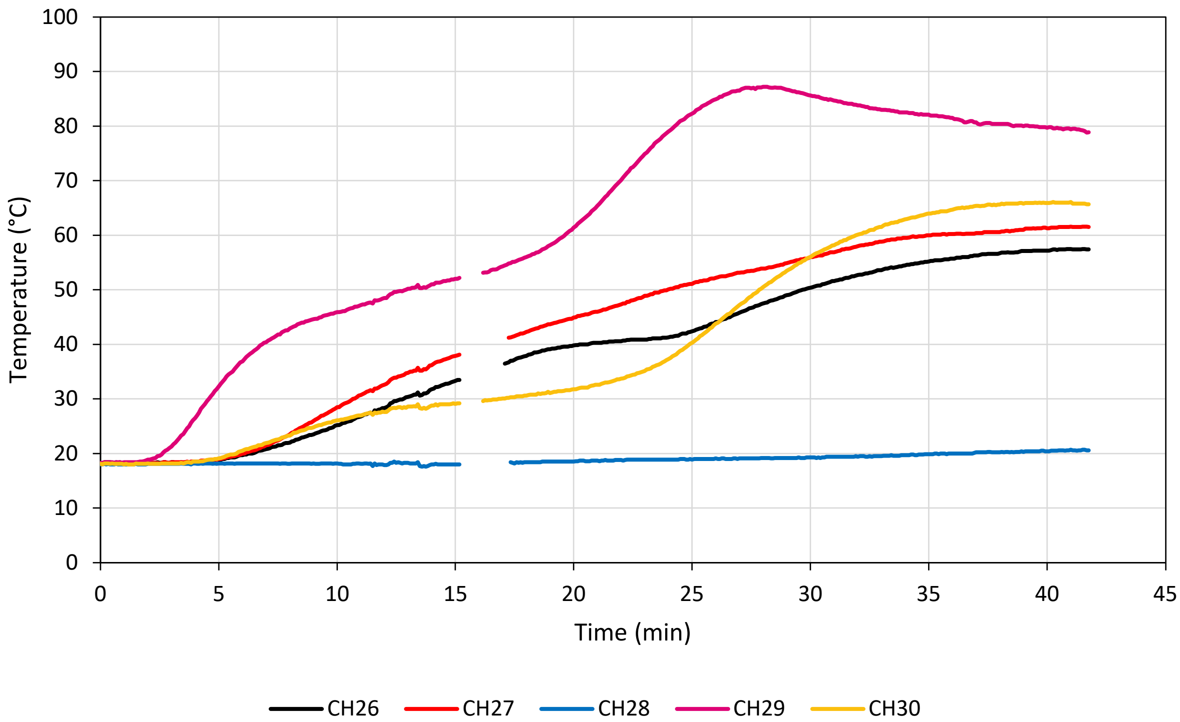


Figure 49 − Temperatures of the unexposed surface of the roof slab

Figures 50 and 51 show the corresponding values for the Southern elevation, while Figures 52 and 53 and 54 show the corresponding values for the East and North elevations. The increase in the temperature at specific locations well into the cooling phase of the fire has been investigated as part of the review of the smouldering combustion which occurred after the moveable fire load had been consumed.

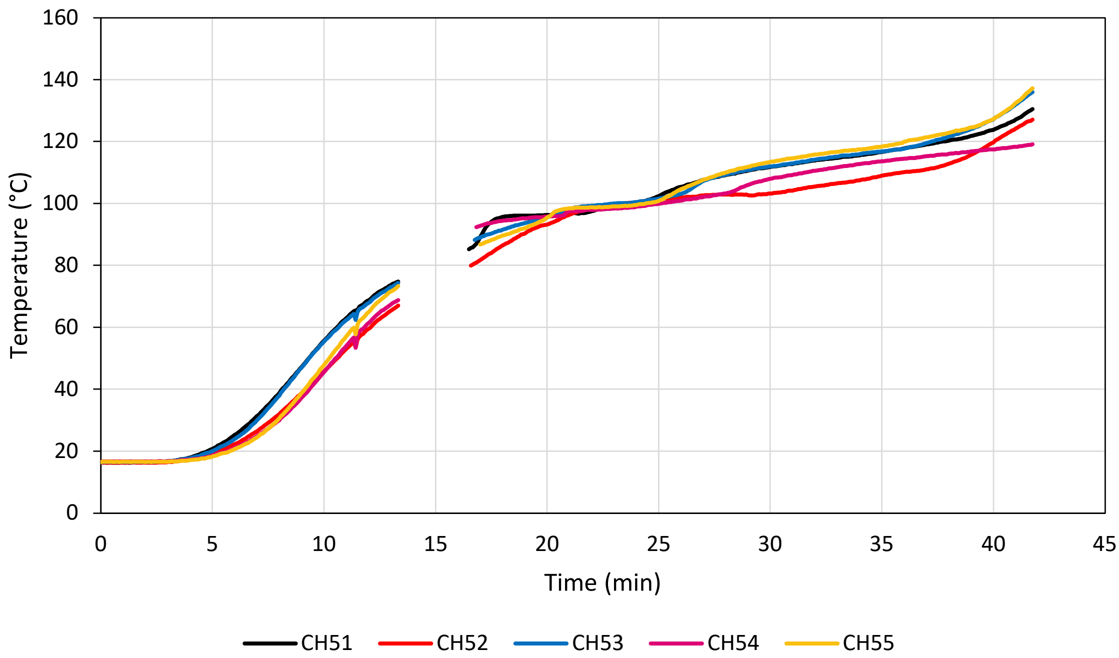


Figure 50 – Temperature of the interface between the boards and the CLT South wall panel

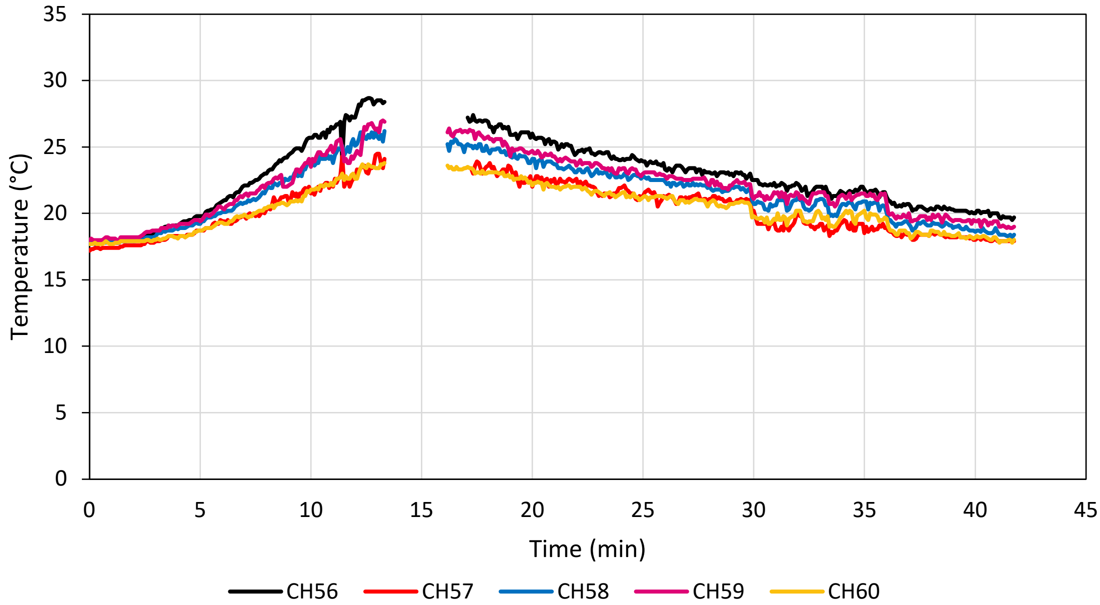


Figure 51 – Temperature of the unexposed surface of South wall panel

© BRE Global Ltd 2025

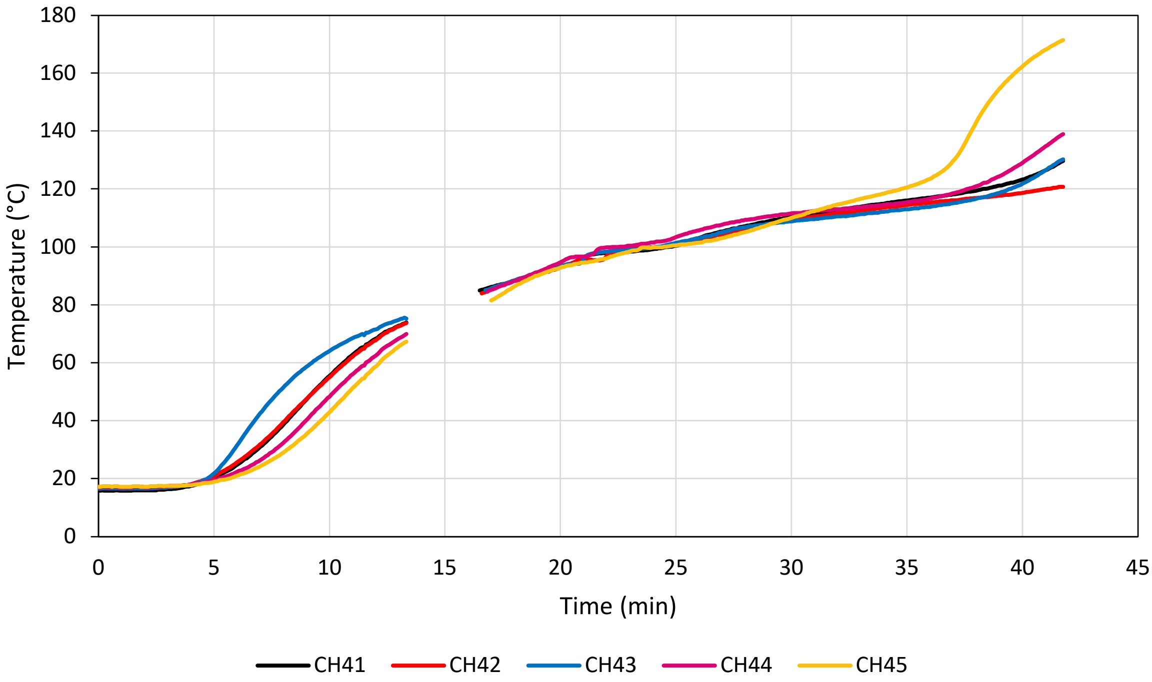


Figure 52 – Temperature of the interface between the boards and the CLT East wall panel

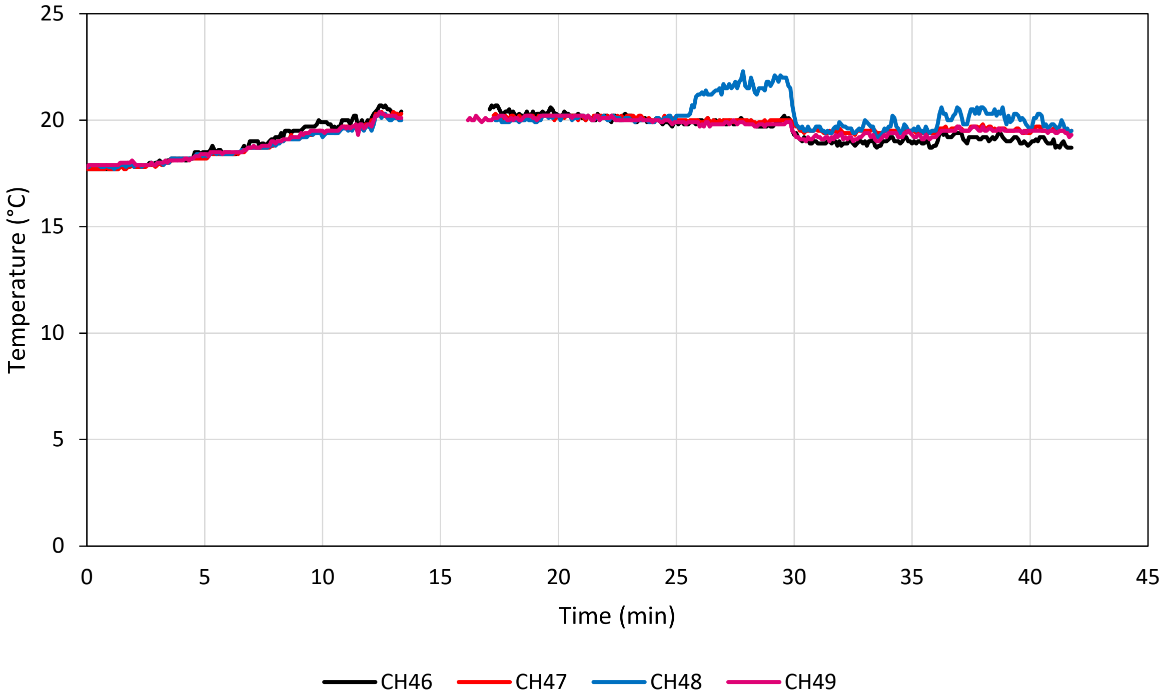


Figure 53 – Temperature of the unexposed surface of the East wall panel

© BRE Global Ltd 2025

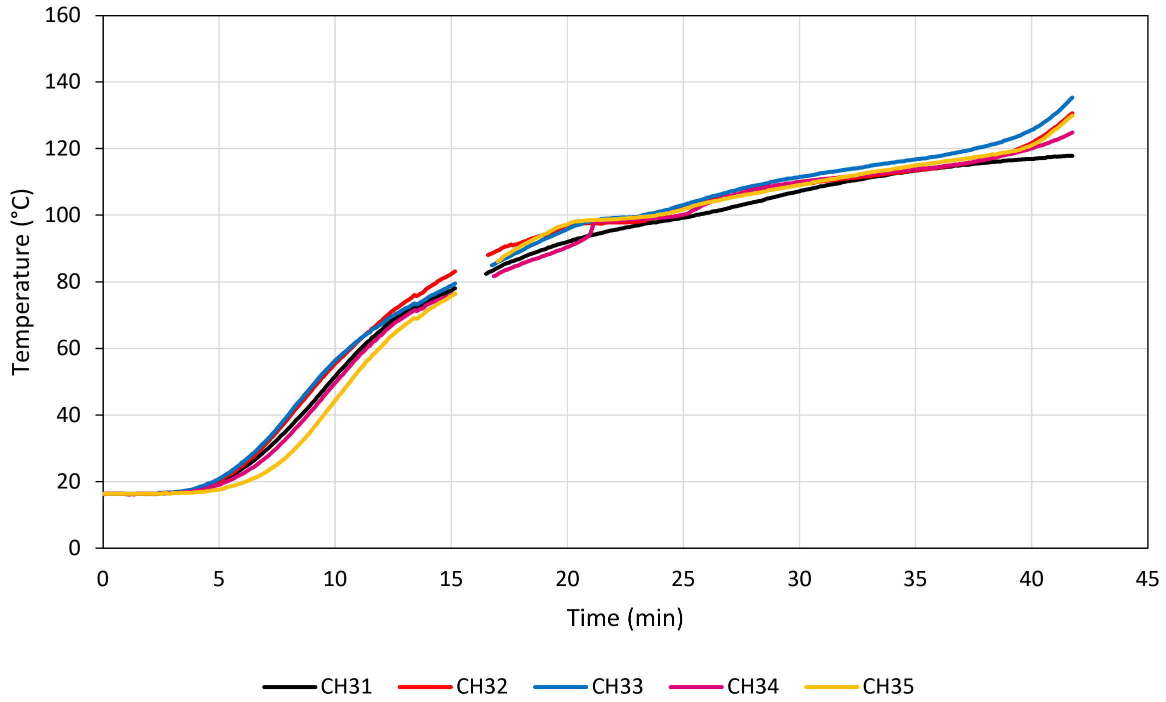


Figure 54 − Temperature of the interface between the boards and the CLT North wall panel

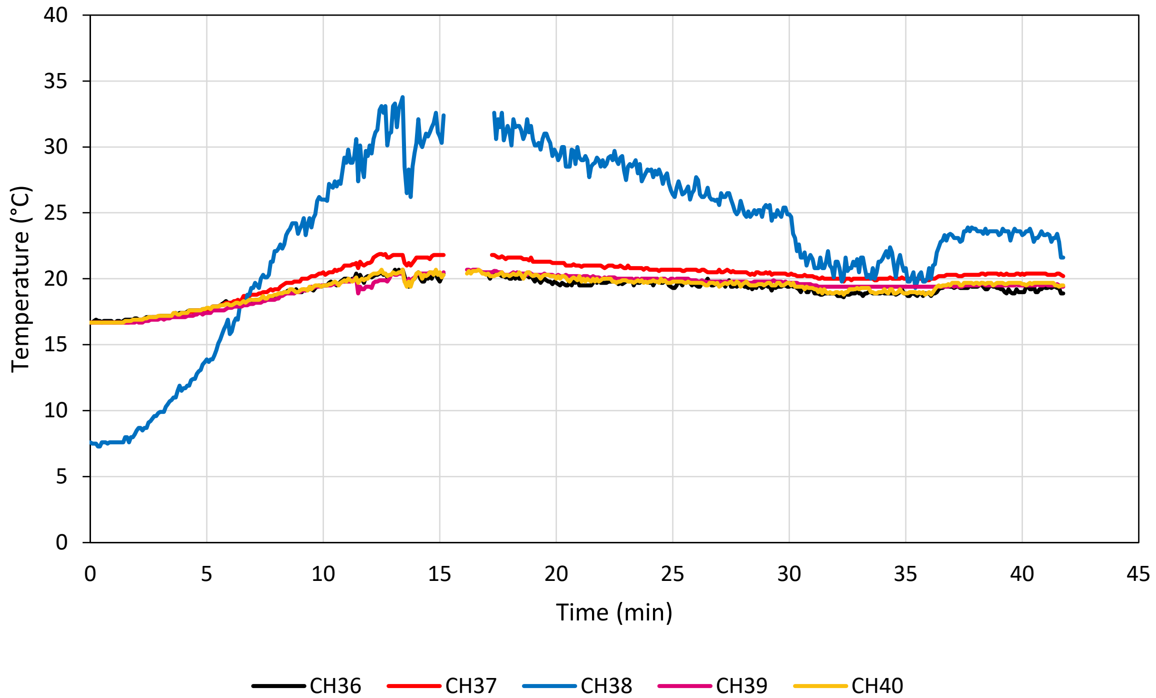


Figure 55 − Temperature of the unexposed surface of the North wall

© BRE Global Ltd 2025

In addition to the temperature measurements, displacement was measured at various locations including the centre of the slab. The maximum deflection during the heating phase was 5.5 mm. The measured value of heat flux 2 m from the centre of the opening is shown in Figure 56.

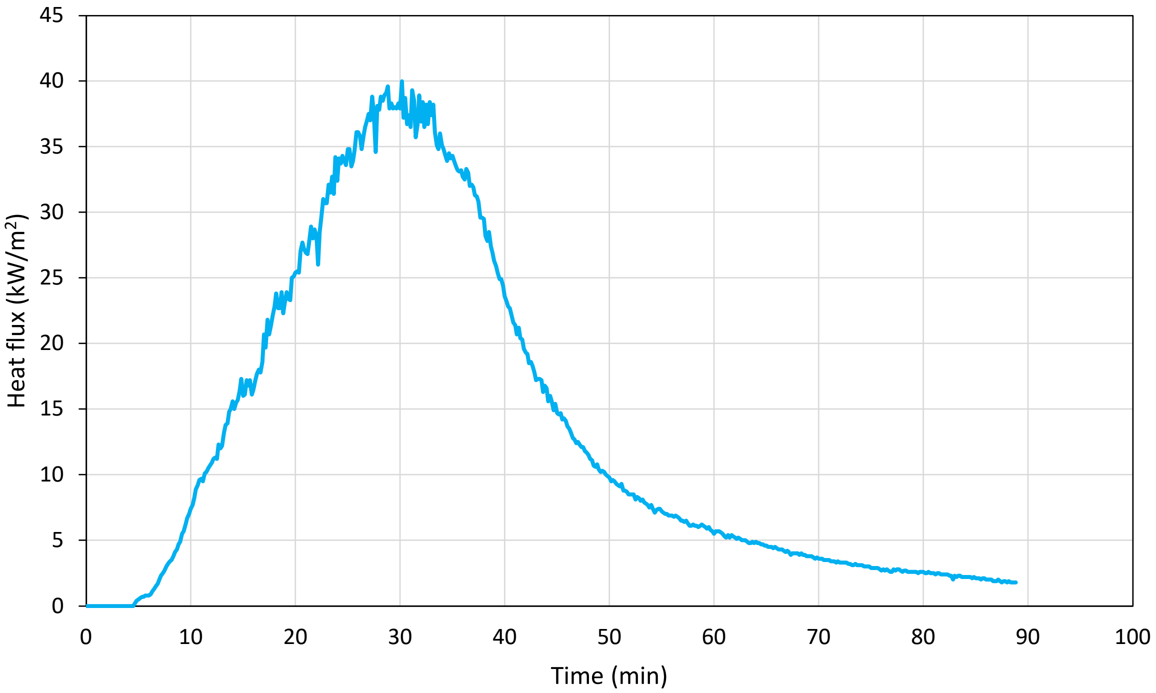


Figure 56 − Heat flux at a height of 1.8 m and a distance of 2 m from the centre of the opening

9 Fire Experiment D – Panellised light steel frame system with concrete floor slab

As described in Table 1, the intention was for the fourth experiment to involve a panellised light steel frame system with a design fire resistance period of 60 minutes. However, the supplier had to withdraw due to commercial pressures. For this reason, the fourth large-scale fire experiment was changed to a panellised light steel frame system incorporating a concrete slab cast on a profiled metal deck. Due to the nature of the system, and the requirement to cure the concrete slab, the panel was supplied in two halves (Figure 57) which were connected together during the installation phase inside the BRE Burn Hall test facility (Figure 58).

The design, supply and construction of the compartment was designed specifically for the fire experiment but is understood to be representative of a real design used for real buildings. The general structural form for the superstructure is a panellised load bearing wall system lined with Type F plasterboard with the walls incorporating mineral wool insulation and the roof formed from a concrete slab cast on a profiled metal deck. In common with the other systems included in this experimental programme, there was a single opening in one of the walls.

The system was constructed directly onto the BRE Burn Hall concrete floor. Plasterboard sheets were laid down internally by BRE Global staff to prevent damage to the laboratory floor.

Figure 57 − One half of unit delivered to the test facility

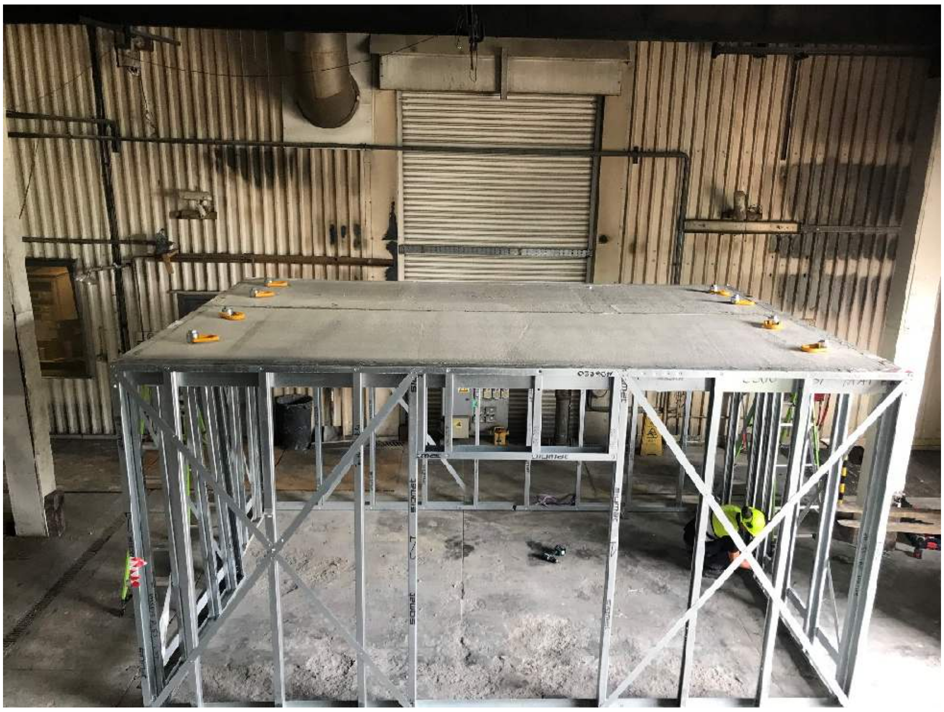


Figure 58 − Frame construction in the test facility

Figure 59 shows the inside of the compartment just prior to ignition and shows the front elevation including the single ventilation opening. The internal dimensions were approximately 5.2 m long by 3.4 m wide by 2.4 m high. The compartment was supplied and delivered to BRE as panels erected on site with linings installed following erection. A detailed specification of the construction of the compartment and additional information related to the linings was provided to BRE Global for review. This information has been forwarded to BSR HSE. The compartment was lined throughout with two layers of 15 mm Type F plasterboard. Additional boards were fixed to the external face of the compartment to prevent ignition from flames emerging from the opening.

No fire stopping or service penetrations were included in this experiment.

The single ventilation opening consists of a single doorway 1.3 m wide and 2 m high. This layout was replicated for all fire experiments. The ventilation has been chosen to represent a severe value in terms of the ratio between openings and floor area and to ensure that the ratio is within the scope of validity of both the time equivalence concept and the parametric approach used to “predict” the compartment time-temperature response. The fires were ventilation controlled.

© BRE Global Ltd 2025

Figure 59 − Front of compartment prior to ignition showing single ventilation opening

9.1 Fire design

Based on information from the supplier, the target market for the panellised system is those buildings with a requirement in relation to fire resistance of up to 90 minutes REI. Therefore, the fire design was predicated on providing a natural fire with an equivalent exposure to 90 minutes under the standard fire curve. In each case, the experiments have been designed to "equate" to the required end use application in terms of fire resistance. This enables determination of one of the critical areas for evaluation namely "*can this system survive burnout without collapse*"?

The concept of time equivalence is a well-established approach incorporated in national and international codes and standards. Use of this technique allows performance in a real fire situation to be related to the results obtained from standard fire resistance testing and to provide a relation between system performance and the minimum periods of fire resistance specified in statutory guidance.

One of the objectives of the project is to see where the boundaries of reliance on standard fire resistance testing lie. This project is not trying to confirm or calibrate the concept of time equivalence but to find out the extent to which reliance can be placed on test results from standard fire tests in a real fire situation which corresponds to a fire of equivalent severity. In this case, the input values are the fire load, the thermal properties of the compartment linings and the ventilation. No attempt is made to define an appropriate fire resistance period for the structure and therefore, the approach does not rely on fitting data from standard fire tests on steel structures.

The formula for the Equivalent time of fire exposure is set out in the fire part of Eurocode 1[3] as:

$$t_{e,d} = (q_{f,d} \times w_f \times k_b) \times k_c$$

Where:

$q_{f,d}$ is the design fire load density per unit floor area (MJ/m²)

k_b is the conversion factor for the compartment thermal properties (min.m²/MJ)

w_f is the ventilation factor

k_c is a correction factor dependent on the structural material

For every structural Eurocode there is a corresponding National Annex for use within the individual member state. Work undertaken in developing the UK National Annex[4] showed that the correction factor k_c for different materials could not be supported and that the use of the concept for unprotected steel structures should be limited to fire resistance periods up to 30 minutes. For reinforced concrete (or protected steel), the correction factor is 1.0, so using the National guidance there is no difference other than the approach is only valid for unprotected steel for periods up to 30 minutes. Therefore, the equivalent time of fire exposure is a function of the fire load density, the thermal properties of the compartment boundaries and the ventilation factor. For present purposes, the ventilation condition and the thermal properties of the compartment boundaries are fixed values, and the choice of fire load density is used to provide the required level of fire severity.

The ventilation factor w_f is derived from a consideration of the height of the compartment and the ratio of the openings to the floor area such that:

$$w_f = (6/H)^{0.3}\,[0.62 + 90\,(0.4 - \alpha_v)^4\,] \geq 0.5\ (in\ the\ absence\ of\ horizontal\ openings)$$

Where:

H is the height of the compartment (m)

$$\alpha_v = A_v/A_f$$

A_v is the area of the ventilation opening (m²)

A_f is the floor area (m²). In this case, the value of w_f = 1.196.

The conversion factor (k_b) for the thermal properties of the compartment linings is related to the b factor which in turn is a function of the specific heat, density and thermal conductivity values for the materials forming the lining of the compartment such that $b = (\rho.c.\lambda)^{1/2}$. In this case, the relevant values are given using generic properties for plasterboard as these will govern behaviour during the growth and steady state phases of fire development. The properties used in the analysis for gypsum-based plasterboard are given in Table 2 (see section 2.1). These were used in the absence of any specific elevated temperature thermal properties for the board used in the experiment. In terms of fire development, unless the lining materials are thermally thin or will not survive for any significant period, it is the thermal properties of the compartment linings that will dictate fire growth and development rather than the underlying substrate. In general, the systems that will be tested rely on maintaining the integrity of the plasterboard lining for a significant duration of the fire exposure. It is therefore the innermost layer that will have the most significant impact on fire development in the growth and steady state phases of the fire. This may change in the cooling phase, particularly where combustible materials are present although no combustible materials other than the moveable fire load were present in this case.

The National Annex[4] sets out the appropriate values for k_b which differ from those in the informative annex. The default value for use in the UK is k_b = 0.09 and this is the appropriate value for this case.

Therefore, to achieve an equivalent time of fire exposure the required fire load density is given by:

$$q_{f,d} = 90/(1.196 * 0.09) = 836\ MJ/m^2$$

In this case, the value adopted was 840 MJ/m², giving an equivalent time of fire exposure of 90.43 minutes.

The concept of time equivalence is used to define the appropriate level of fire load density. The parametric approach set out in EN 1991-1-2 *Eurocode 1: Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire*[3] is used to predict the time-temperature relationship for the compartment.

The time-temperature curves in the heating phase are given by:

$$\theta_g = 1325\left(1 - 0.324\, e^{-0.2t^*} - 0.204\, e^{-1.7t^*} - 0.472\, e^{-19t^*}\right)$$

Where:

θ_g = temperature in the fire compartment	(°C)
$t^* = t.\Gamma$	(h)
t = time	(h)
$\Gamma = [O/b]^2 / (0.04/1160)^2$	(-)
$b = \sqrt{\rho c \lambda}$ and should lie between 100 and 2200	($J/m^2s^{½}K$)
O = opening factor ($A_v \sqrt{h} / A_t$)	($m^{½}$)
A_v = area of ventilation openings	(m^2)
H = height of ventilation openings	(m)
A_t = total area of enclosure (including openings)	(m^2)
ρ = density of boundary enclosure	(kg/m^3)
c = specific heat of boundary enclosure	(J/kgK)
λ = thermal conductivity of boundary	(W/mK)

The parametric approach is an example of a physically based fire model. Although various models are available, the parametric approach is used here due to its inclusion in the fire part of Eurocode 1 and based on the amount of validation available.

The model assumes that the temperature rise is independent of fire load. In order to account for depletion of the fuel the duration of the fire must be considered. This is a complex process and depends on the rate of burning of the fuel which itself is dependent on the ventilation available and the physical characteristics and distribution of the fuel.

The parametric fire curves comprise a heating phase represented by an exponential curve up to a maximum temperature θ_{max} occurring at a corresponding time of t_{max}, followed by a linearly decreasing cooling phase.

The maximum temperature in the heating phase occurs at a time given by:

$$t_{max} = \max\left[(0.2 \times 10^{-3} \times q_{t,d}/O_{lim}); t_{lim}\right]$$

Where:

$$q_{t,d} = q_{f,d} \times A_f/A_t$$

The limiting time period for medium fire growth (residential and offices) is 20 minutes. For most practical combinations of fire load, compartment geometry and opening factor, t_{max} will be in excess of these limiting values. The temperature-time curves for the cooling phase are then given by:

$$\theta_g = \theta_{max} - 625(t^* - t^*_{max})\ for\ t^*_{max} \leq 0.5(h)$$

$$\theta_g = \theta_{max} - 250(3 - t^*_{max})\ (t^* - t^*_{max})\ for\ 0.5 < t^*_{max} < 2(h)$$

$$\theta_g = \theta_{max} - 250(t^* - t^*_{max})\ for\ t^*_{max} \geq 2(h)$$

Using the approach set out above, the predicted behaviour within the compartment is as shown in Figure 60 which also provides a comparison with the standard fire curve for 90 minutes.

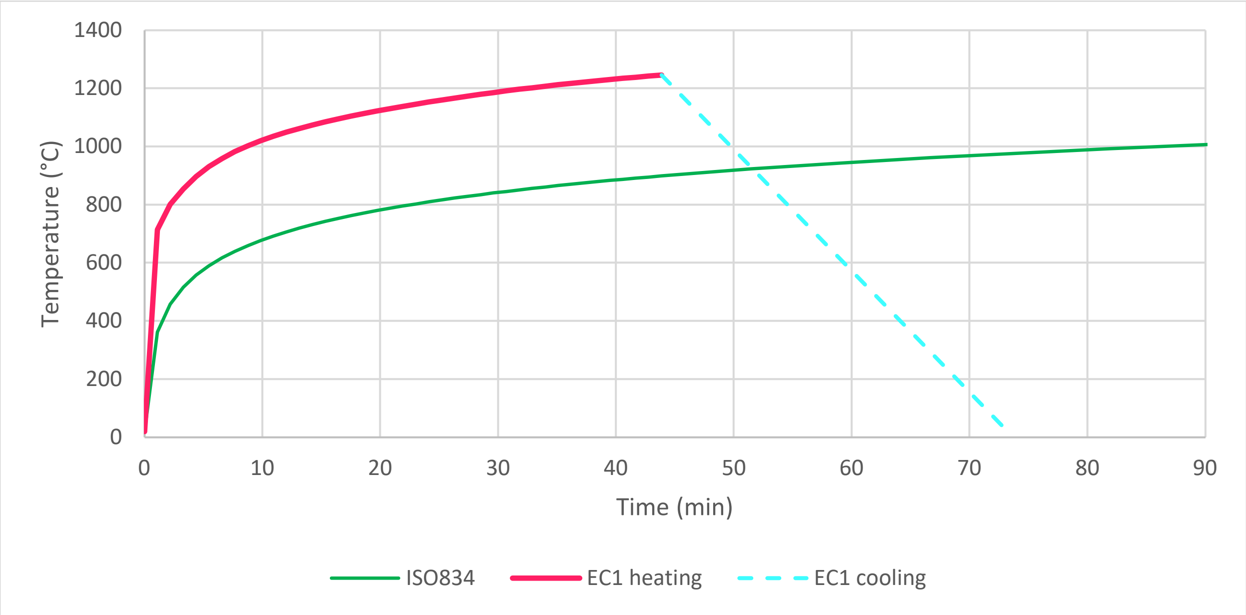


Figure 60 − Predicted compartment time-temperature response compared to standard fire exposure

9.2 Instrumentation

In order to assess performance in relation to the selected performance criteria of loadbearing capacity, integrity and insulation, it is necessary to utilise a combination of visual observations and direct measurement. In general, overall stability and integrity can be assessed through direct observation, while insulation performance is assessed by measuring the temperature rise on the unexposed surface of the compartment boundaries.

Figure 61 shows the basic layout and orientation of the fire compartment.

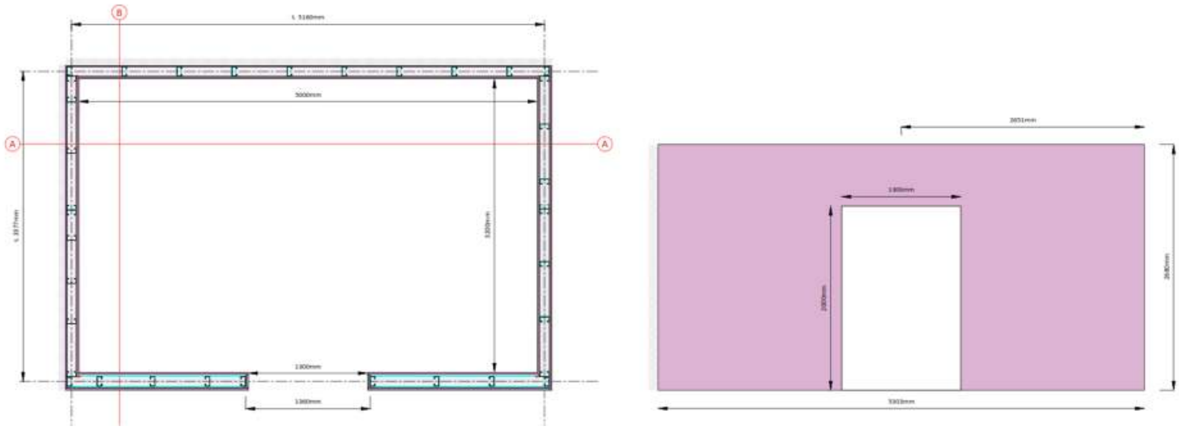


Figure 61 − Plan and front elevation of fire compartment

To measure the gas temperatures within the compartment, 15 thermocouples were positioned above the centre of each of the five cribs with three over each crib at 300 mm, 600 mm and 900 mm from the ceiling. The crib locations and the atmosphere thermocouple locations are shown in Figures 62, 63 and 64.

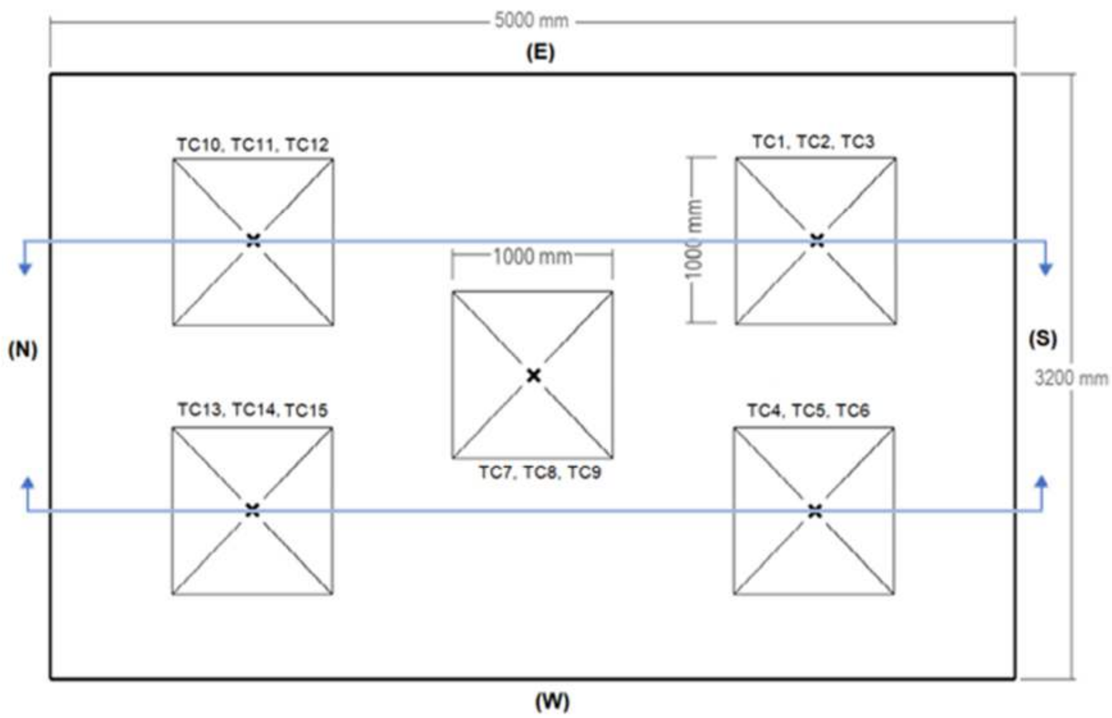


Figure 62 − Plan view of crib locations showing position of atmosphere thermocouples

© BRE Global Ltd 2025

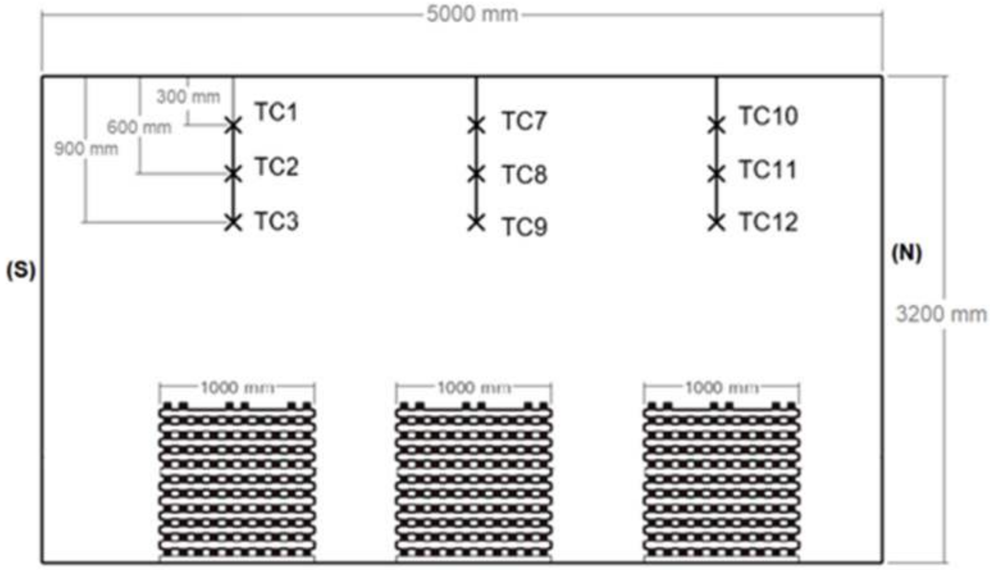


Figure 63 − Location of atmosphere thermocouples (East section)

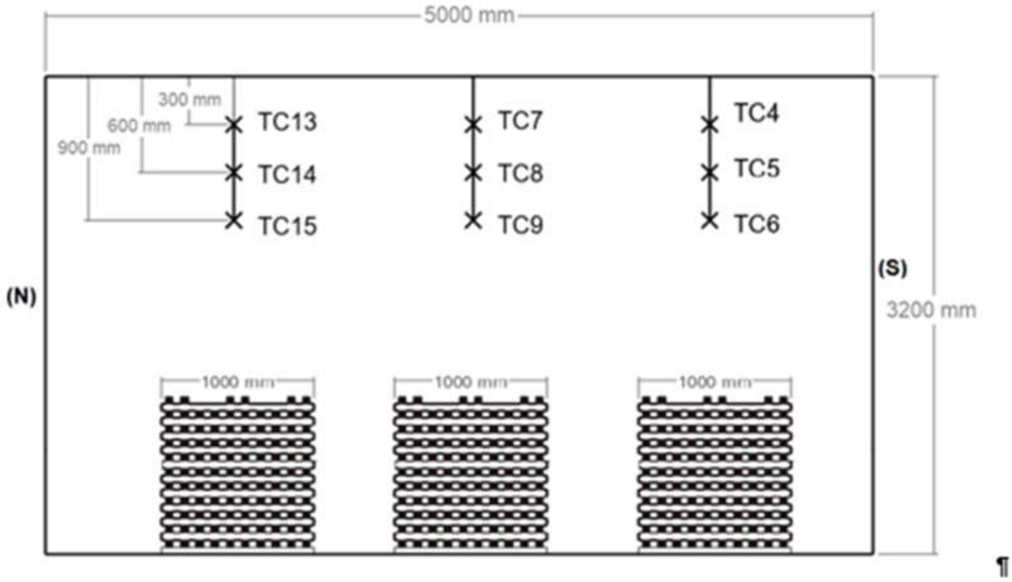


Figure 64 − Location of atmosphere thermocouples (West section)

This report focuses on the instrumentation installed by BRE Global to investigate the overall objectives of the project and to provide a direct comparison with other systems.

In common with the other fire experiments, thermocouples were fixed to the unexposed surface of the roof (Figure 65) and the unexposed surface of all walls other than the West wall incorporating the opening (Figures 66, 67 and 68).

© BRE Global Ltd 2025

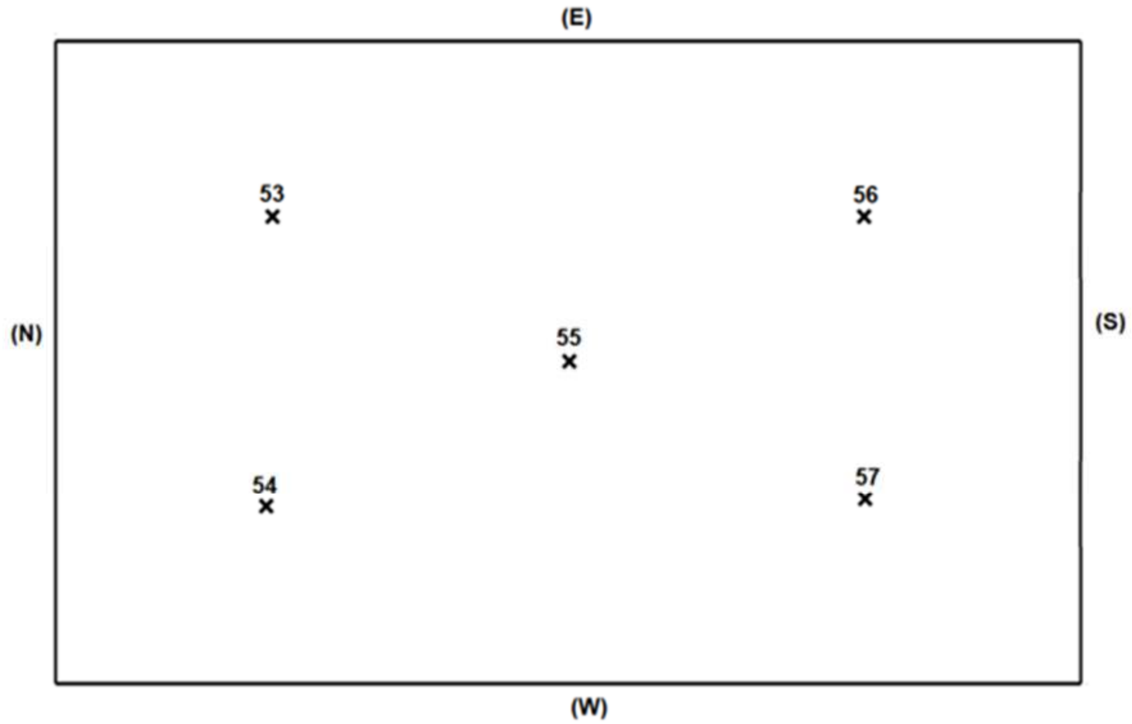


Figure 65 − Thermocouple locations on the roof

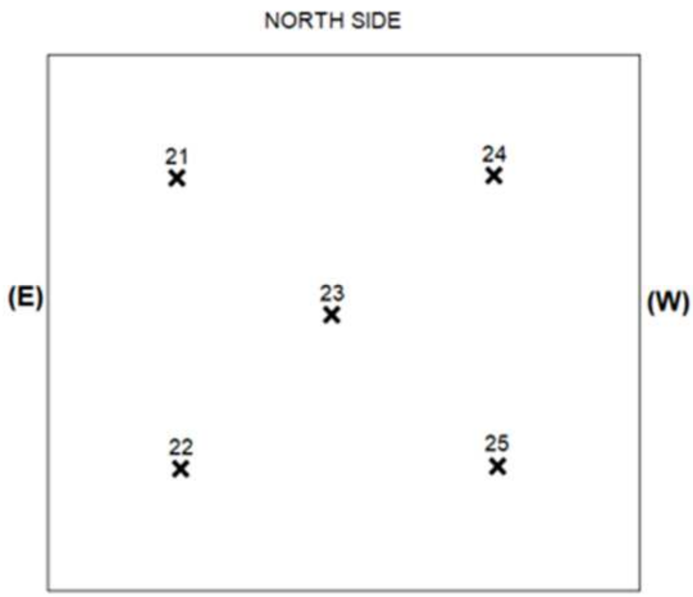


Figure 66 − Thermocouples on unexposed face of North wall

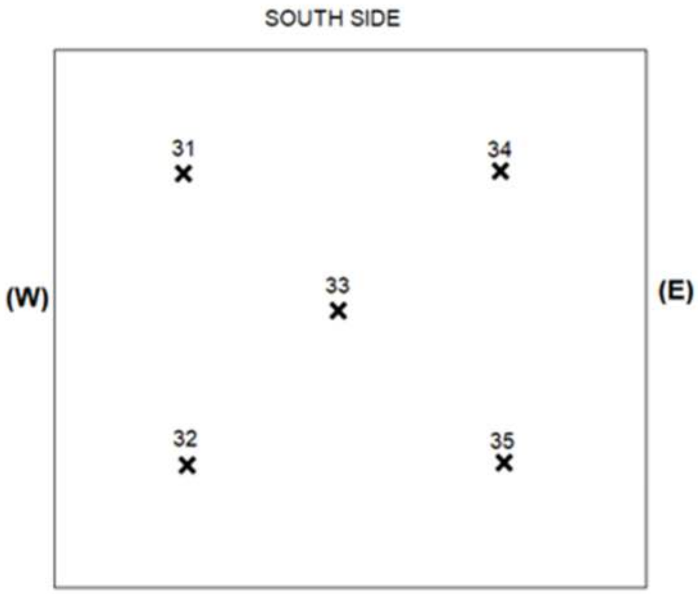


Figure 67 − Thermocouples on unexposed face of South wall

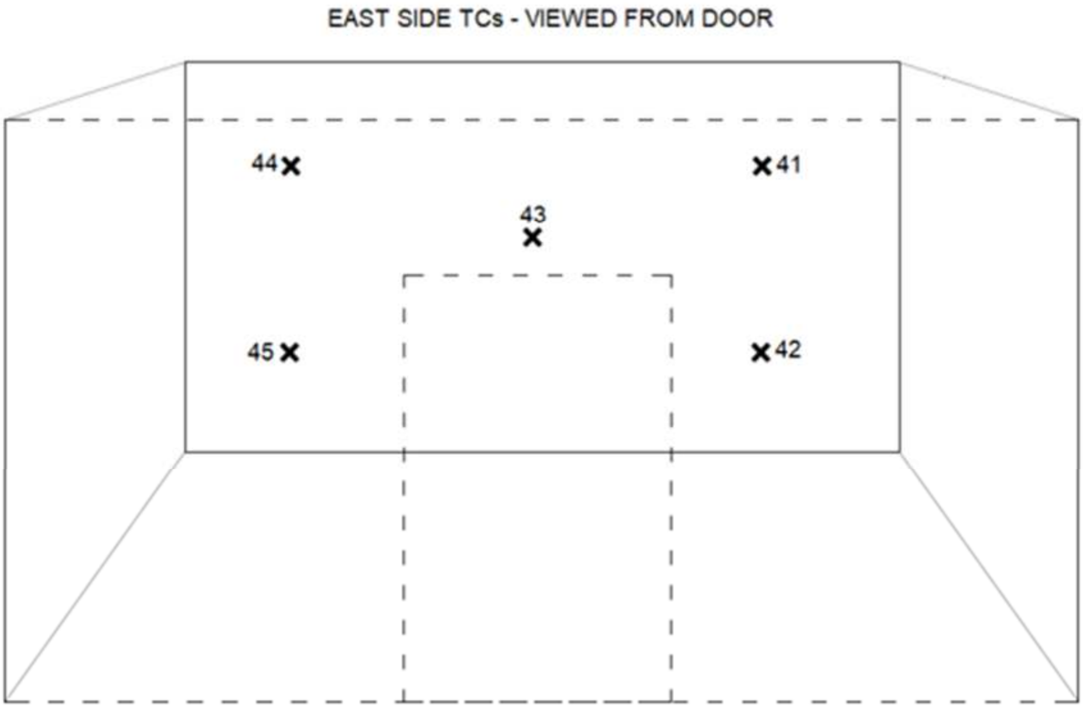


Figure 68 − Thermocouples on unexposed face of East wall viewed from door

Additional thermocouples were installed at specific locations specified by the supplier, but these results are not included within this report.

9.3 Fire development

Following ignition, the compartment quickly transitioned to flashover following the build-up of hot gases around the ceiling with flames emerging from the opening (see Figure 69).

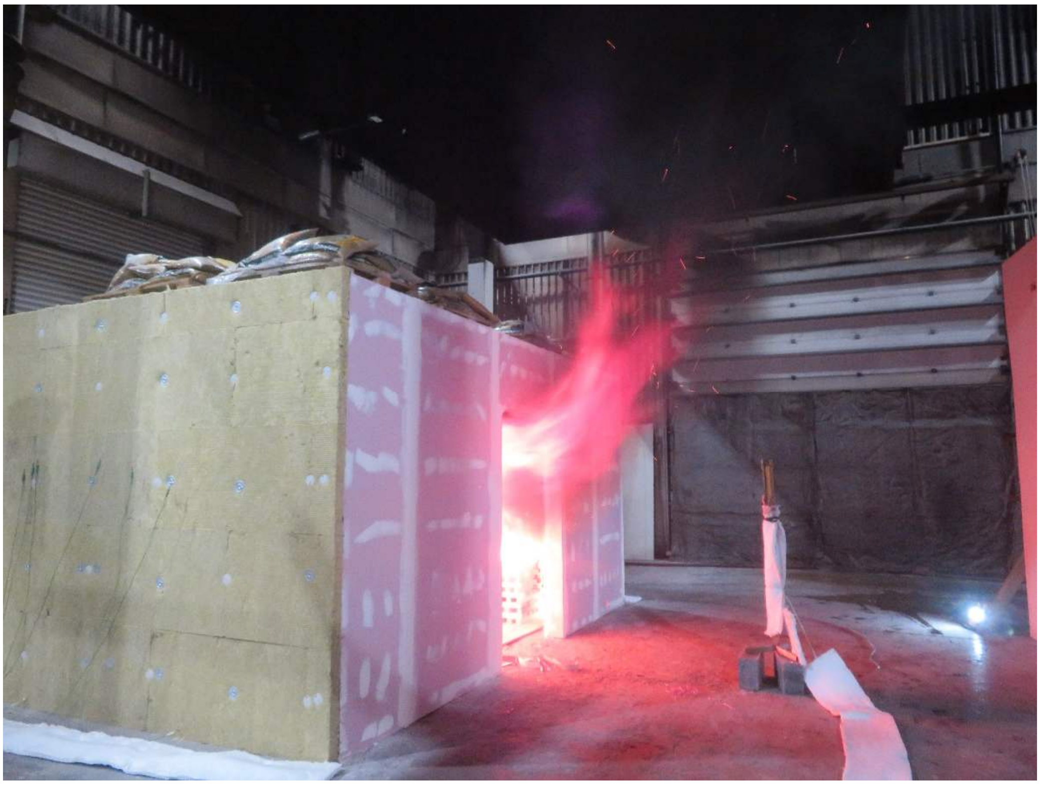


Figure 69 − External flaming shortly after ignition

The crib fire continued until the fire load was consumed. The time-temperature development based on the atmosphere thermocouples within the compartment is shown in Figure 70.

There was no insulation failure on the unexposed faces of the compartment during the fire exposure measured against the standard fire resistance test performance criteria.

© BRE Global Ltd 2025

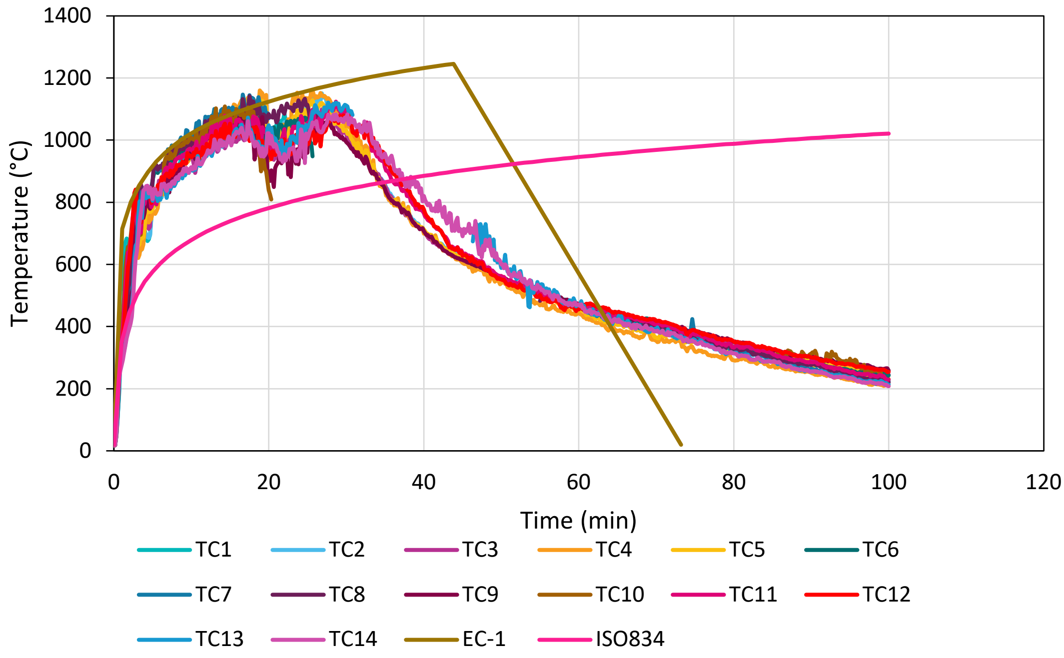


Figure 70 − Atmosphere temperature within the compartment

The compartment atmosphere temperature is in excess of the standard curve for the entire heating phase. Although the total area under the measured curve does not equate to the total area under the standard curve for the 90-minute exposure, this issue is discussed in Section 11. The issue of equivalent severity is very much dependent on the nature of the structural element and the configuration and design of any protection system.

The parametric approach provides a good correlation for the maximum temperature within the compartment but overestimates the duration of the heating phase.

9.4 Structural performance

The compartment survived complete burn out of all combustible material while maintaining overall stability. There were no signs of any integrity failure during the course of the fire and no evidence of external flaming away from the ventilation opening.

There was no evidence of any insulation failure during the fire exposure. Figure 71 shows the unexposed face temperatures on the roof slab. Video evidence does not support any insulation or integrity failure in this location.

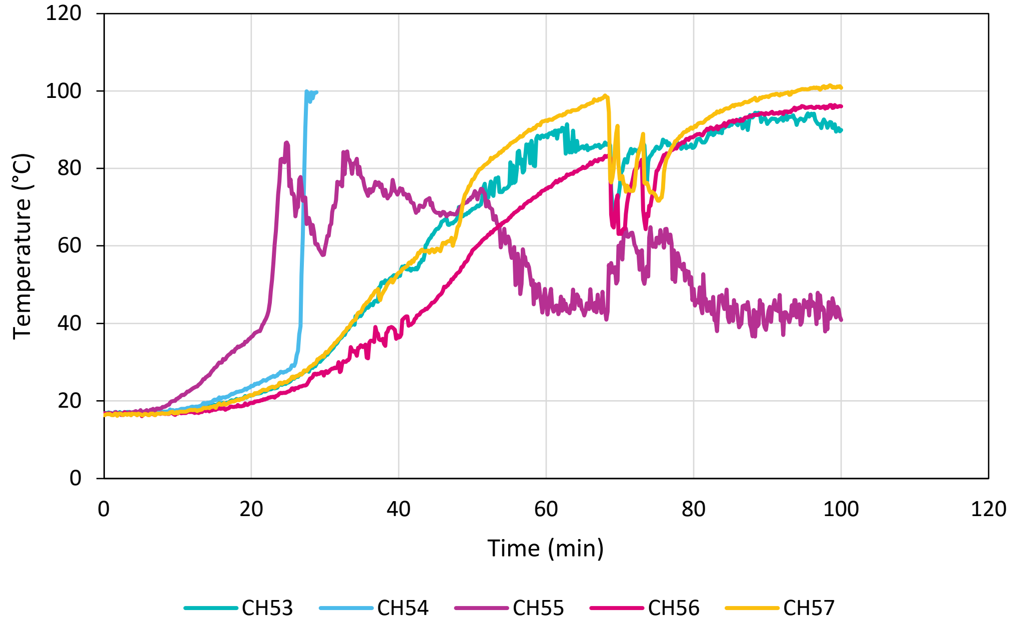


Figure 71 – Temperature of the unexposed surface of the roof

Figure 72 shows the temperature values for the unexposed face of the Southern elevation, while Figures 73 and 74 show the corresponding values for the East and North elevations.

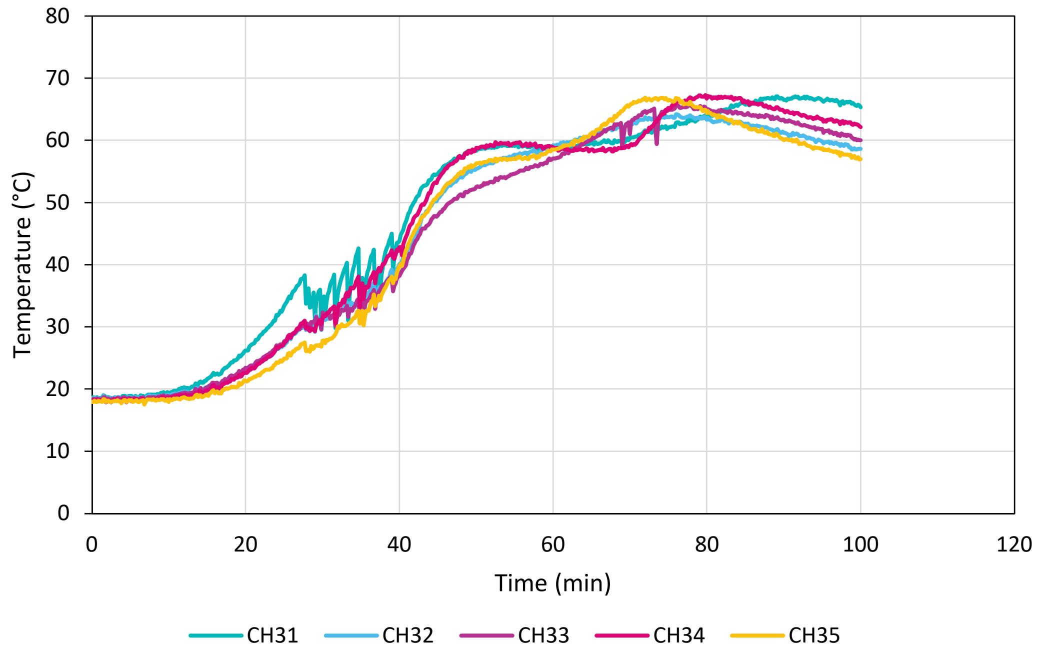


Figure 72 – Temperature of the unexposed surface of the South wall

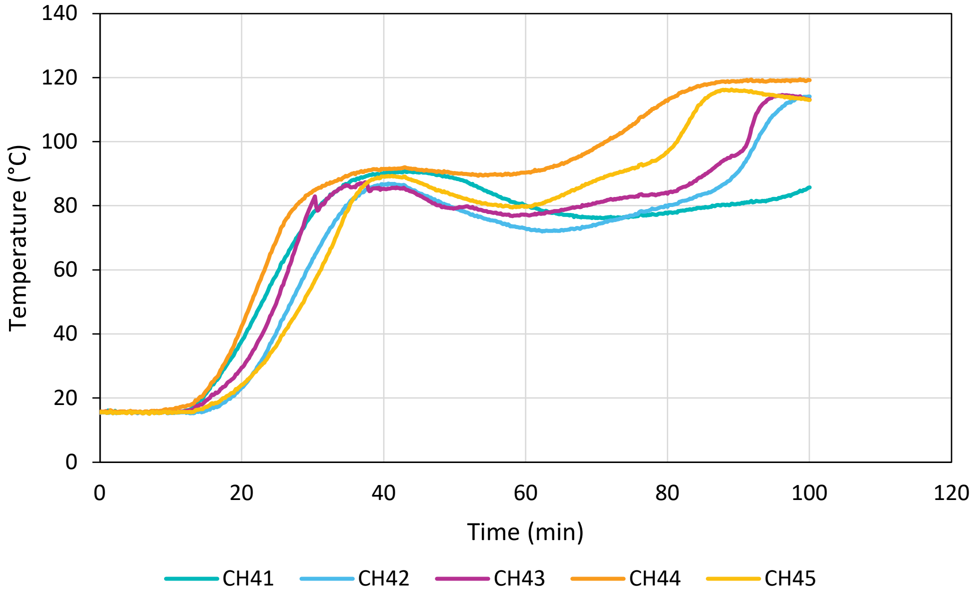


Figure 73 − Temperature of the unexposed surface of the East wall

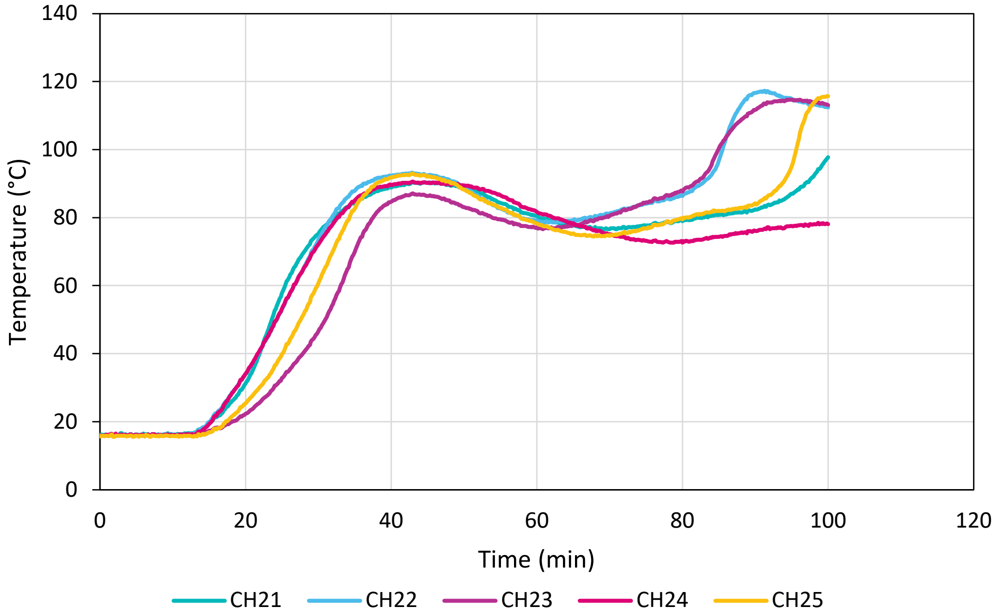


Figure 74 − Temperature of the unexposed surface of the North wall

In addition to the temperature measurements, displacement was measured at the centre of the slab. The maximum deflection during the heating phase was 50 mm with partial recovery as shown in Figure 75. Although the deflection was well within the allowable limits required by fire resistance test standards, the actual value is likely to have been influenced by the method of construction and the fact that the slab was discontinuous at the centre. The measured value of heat flux 2 m from the centre of the opening is shown in Figure 76.

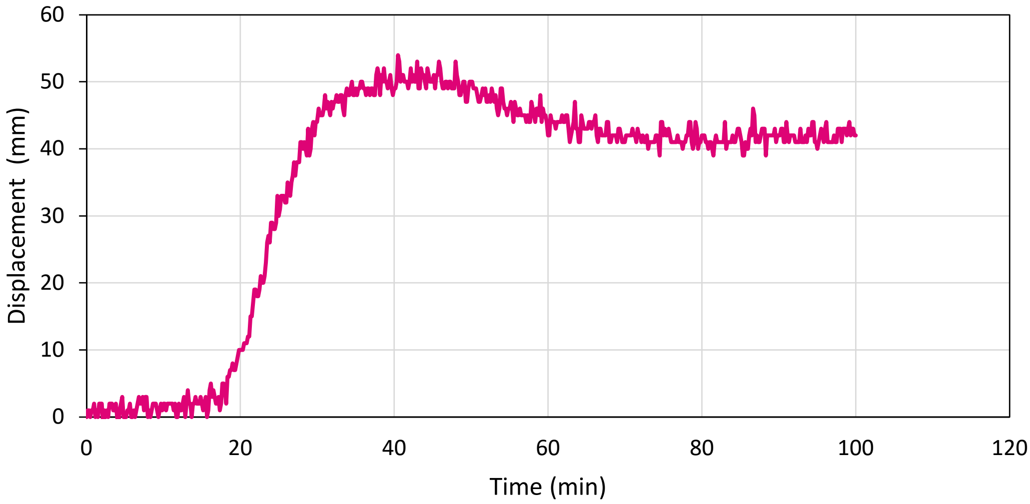


Figure 75 – Mid-span deflection of the floor slab

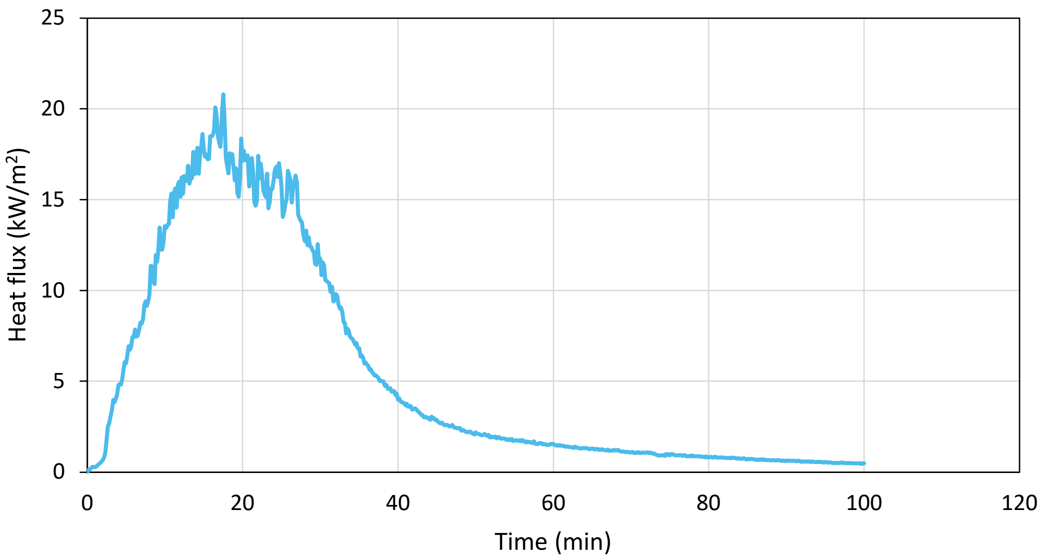


Figure 76 – Heat flux at a height of 1.8 m and a distance of 2 m from the centre of the opening

10 Fire Experiment E – Timber frame

As described in Table 1, the fifth large-scale fire experiment consisted of a timber frame compartment constructed from wall and roof panels. The design, supply and construction of the compartment was organised by an industry group coordinated through the Structural Timber Association (STA). The timber frame structure was designed specifically for the fire experiment but is understood to be representative of a potential real design that may be used for real buildings. The general structural form for the superstructure is a panellised load bearing wall system with timber studs used to form the walls and Engineered Floor Joists (EFJ) used to carry the floor load and transfer the load to the walls. In common with the other systems included in this experimental programme, there was a single opening in one of the walls.

The walls were fixed to the BRE Burn Hall ground slab via sole plates.

Figure 77 shows the compartment during construction prior to installation of the plasterboard linings. Figure 78 show the inside of the compartment with the fire load in place while Figure 79 shows the plasterboard around the opening and the floor load in place. The floor load represented a design load of 1.2 kN/m². The internal dimensions were approximately 5 m long by 3 m wide by 2.4 m high (to underside of floor joists). The compartment was supplied and delivered to BRE as individual panels erected on site with linings installed following erection. A detailed specification of the construction of the compartment and additional information related to the linings was provided to BRE Global for review. This information was forwarded to BSR HSE. The compartment was lined throughout with two layers of 15 mm Type F plasterboard fixed directly to the floor joists and loadbearing studs. An additional layer of 12.5 mm Type F plasterboard was fixed to the ceiling (via resilient bars) and to the walls (via timber battens) to form a service void. This specification differed from that provided initially and forwarded to BSR HSE. Additional boards were fixed to the external face of the compartment around the ventilation opening to prevent ignition from flames emerging from the opening.

No fire stopping or service penetrations were included in this experiment.

The single ventilation opening consists of a single doorway 1.372 m wide and 2.085 m high which is similar to all the previous large-scale fire experiments undertaken as part of this project. The ventilation has been chosen to represent a severe value in terms of the ratio between openings and floor area and to ensure that the ratio is within the scope of validity of both the time equivalence concept and the parametric approach used to “predict” the compartment time-temperature response. The fires are ventilation controlled.

Following completion of the fire experiment, temperatures within the compartment continued to be monitored for more than 24 hours. There was no evidence of smouldering combustion and no reignition.

© BRE Global Ltd 2025

Figure 77 − Timber frame compartment during construction
Note that the additional structure above the fire compartment was provided to provide safe access for installers and the BRE team

Figure 78 − Internal view of fire compartment with fire load in place

Figure 79 − View from above showing protection to opening and floor load

10.1 Fire design

Based on information from the supply team, the target market for timber frame systems is those buildings with a requirement in relation to fire resistance of up to 60 minutes REI. Therefore, the fire design was predicated on providing a natural fire with an equivalent exposure to 60 minutes under the standard fire curve. In each case, the experiments have been designed to “equate” to the required end use application in terms of fire resistance. This enables determination of one of the critical areas for evaluation namely “*can this system survive burnout without collapse*”?

The concept of time equivalence is a well-established approach incorporated in national and international codes and standards. Use of this technique allows performance in a real fire situation to be related to the results obtained from standard fire resistance testing and to provide a relation between system performance and the minimum periods of fire resistance specified in statutory guidance.

One of the objectives of the project is to see where the boundaries of reliance on standard fire resistance testing lie. This project is not trying to confirm or calibrate the concept of time equivalence but to find out the extent to which reliance can be placed on test results from standard fire tests in a real fire situation which corresponds to a fire of equivalent severity. In this case, the input values are the fire load, the thermal properties of the compartment linings and the ventilation. No attempt is made to define an appropriate fire resistance period for the structure and therefore, the approach does not rely on fitting data from standard fire tests on steel structures.

The formula for the Equivalent time of fire exposure is set out in the fire part of Eurocode 1[3] as:

$$t_{e,d} = (q_{f,d} \times w_f \times k_b) \times k_c$$

Where:

$q_{f,d}$ is the design fire load density per unit floor area (MJ/m²)

k_b is the conversion factor for the compartment thermal properties (min.m²/MJ)

w_f is the ventilation factor

k_c is a correction factor dependent on the structural material

For every structural Eurocode there is a corresponding National Annex for use within the individual member state. Work undertaken in developing the UK National Annex[4] showed that the correction factor k_c for different materials could not be supported and that the use of the concept for unprotected steel structures should be limited to fire resistance periods up to 30 minutes. For reinforced concrete (or protected steel) the correction factor is 1.0 so using the National guidance there is no difference other than the approach is only valid for unprotected steel for periods up to 30 minutes. Therefore, the equivalent time of fire exposure is a function of the fire load density, the thermal properties of the compartment boundaries and the ventilation factor. For present purposes, the ventilation condition and the thermal properties of the compartment boundaries are fixed values, and the choice of fire load density is used to provide the required level of fire severity.

The ventilation factor w_f is derived from a consideration of the height of the compartment and the ratio of the openings to the floor area such that:

$$w_f = (6/H)^{0.3}\,[0.62 + 90\,(0.4 - \alpha_v)^4\,] \geq 0.5\ (in\ the\ absence\ of\ horizontal\ openings)$$

Where:

H is the height of the compartment (m)

α_v= A_v/A_f

A_v is the area of the ventilation opening (m^2)

A_f is the floor area (m^2). In this case, the value of w_f = 1.033.

The conversion factor (k_b) for the thermal properties of the compartment linings is related to the b factor which in turn is a function of the specific heat, density and thermal conductivity values for the materials forming the lining of the compartment such that b = $(\rho.c.\lambda)^{½}$. In this case, the relevant values are given using generic properties for plasterboard as these will govern behaviour during the growth and steady state phases of fire development. The properties used in the analysis for gypsum-based plasterboard are given in Table 2 (see section 2.1). These were used in the absence of any specific elevated temperature thermal properties for the board used in the experiment. In terms of fire development, unless the lining materials are thermally thin or will not survive for any significant period, it is the thermal properties of the compartment linings that will dictate fire growth and development rather than the underlying substrate. In general, mass timber and modern forms of construction including modular systems rely on maintaining the integrity of the plasterboard lining for a significant duration of the fire exposure. It is therefore the innermost layer that will have the most significant impact on fire development in the growth and steady state phases of the fire. This may change in the cooling phase particularly where combustible materials are present.

© BRE Global Ltd 2025

The National Annex[4] sets out the appropriate values for k_b which differ from those in the informative annex. The default value for use in the UK is k_b = 0.09 and this is the appropriate value for this case.

Therefore, to achieve an equivalent time of fire exposure the required fire load density is given by:

$$q_{f,d} = 60/(1.033 * 0.09) = 645 \text{ MJ/m}^2$$

In this case, the value adopted was 650 MJ/m², giving an equivalent time of fire exposure of 60.43 minutes.

The concept of time equivalence is used to define the appropriate level of fire load density. The parametric approach set out in EN 1991-1-2 *Eurocode 1: Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire*[3] is used to predict the time-temperature relationship for the compartment.

The time-temperature curves in the heating phase are given by:

$$\theta_g = 1325\left(1 - 0.324\, e^{-0.2t^*} - 0.204\, e^{-1.7t^*} - 0.472\, e^{-19t^*}\right)$$

Where:

θ_g = temperature in the fire compartment	(°C)
$t^* = t.\Gamma$	(h)
t = time	(h)
$\Gamma = [O/b]^2/(0.04/1160)^2$	(-)
$b = \sqrt{\rho c \lambda}$ and should lie between 100 and 2200	($J/m^2s^{½}K$)
O = opening factor ($A_v \sqrt{h}/A_t$)	($m^{½}$)
A_v = area of ventilation openings	(m^2)
H = height of ventilation openings	(m)
A_t = total area of enclosure (including openings)	(m^2)
ρ = density of boundary enclosure	(kg/m^3)
c = specific heat of boundary enclosure	(J/kgK)
λ = thermal conductivity of boundary	(W/mK)

The parametric approach is an example of a physically based fire model. Although various models are available, the parametric approach is used here due to its inclusion in the fire part of Eurocode 1 and based on the amount of validation available.

The model assumes that the temperature rise is independent of fire load. In order to account for depletion of the fuel, the duration of the fire must be considered. This is a complex process and depends on the rate of burning of the fuel which itself is dependent on the ventilation available and the physical characteristics and distribution of the fuel.

The parametric fire curves comprise a heating phase represented by an exponential curve up to a maximum temperature θ_{max} occurring at a corresponding time of t_{max}, followed by a linearly decreasing cooling phase.

The maximum temperature in the heating phase occurs at a time given by:

$$t_{max} = \max\left[(0.2 \times 10^{-3} \times q_{t,d}/O_{lim}); t_{lim}\right]$$

Where:

$$q_{t,d} = q_{f,d} \times A_f/A_t$$

The limiting time period for medium fire growth (residential and offices) is 20 minutes. For most practical combinations of fire load, compartment geometry and opening factor t_{max} will be in excess of these limiting values. The temperature-time curves for the cooling phase are then given by:

$$\theta_g = \theta_{max} - 625(t^* - t^*_{max})\ for\ t^*_{max} \leq 0.5(h)$$

$$\theta_g = \theta_{max} - 250(3 - t^*_{max})\ (t^* - t^*_{max})\ for\ 0.5 < t^*_{max} < 2(h)$$

$$\theta_g = \theta_{max} - 250(t^* - t^*_{max})\ for\ t^*_{max} \geq 2(h)$$

Using the approach set out above, the predicted behaviour within the compartment is as shown in Figure 80 which also provides a comparison with the standard fire curve for 60 minutes.

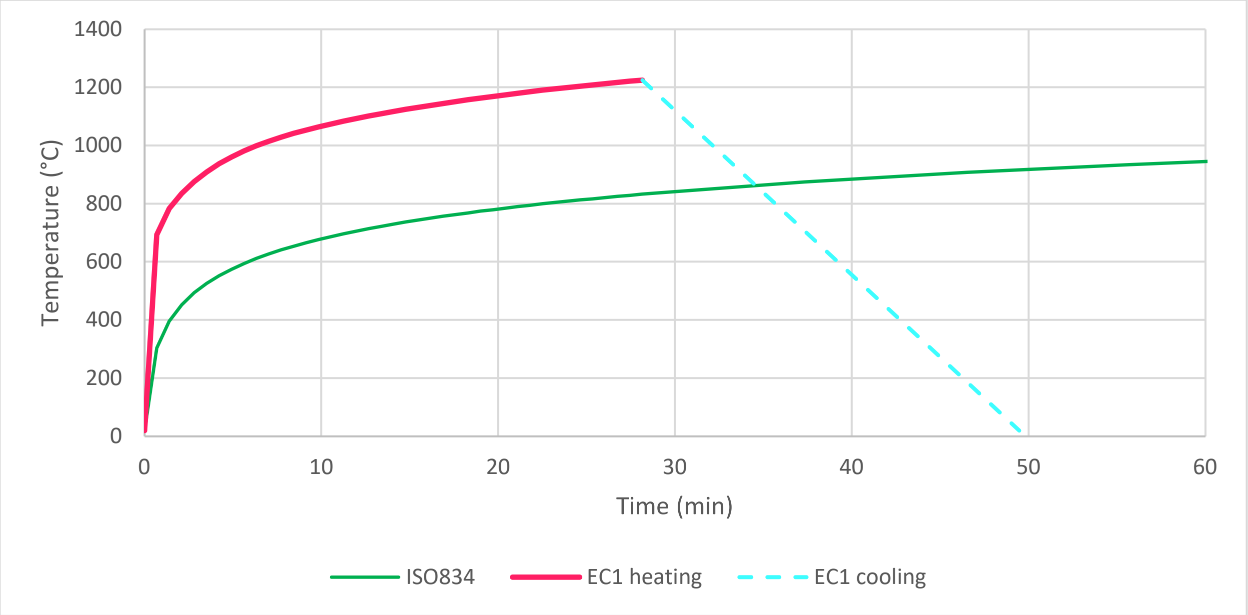


Figure 80 − Eurocode parametric fire curve and ISO 834 time-temperature curve

© BRE Global Ltd 2025

10.2 Instrumentation

In order to assess performance in relation to the selected performance criteria of loadbearing capacity, integrity and insulation, it is necessary to utilise a combination of visual observations and direct measurement. In general, overall stability and integrity can be assessed through direct observation, while insulation performance is assessed by measuring the temperature rise on the unexposed surface of the compartment boundaries.

Figure 81 shows the basic layout and orientation of the fire compartment. The thermocouple channels illustrated relate to the atmosphere temperatures and are located centrally and above each of the four cribs.

The original specification for the compartment included an internal wall to investigate issues around two-sided exposure of internal walls as identified in a recent CROSS report[5]. Although initially built, this internal wall was removed at the request of the frame supplier. Due to the nature of the construction, additional thermocouples were installed at the interface between the plasterboard layers forming the principal fire protection to the structural frame and in the service void formed between the inner layer of plasterboard.

This report focuses on the instrumentation installed by BRE Global to investigate the overall objectives of the project.

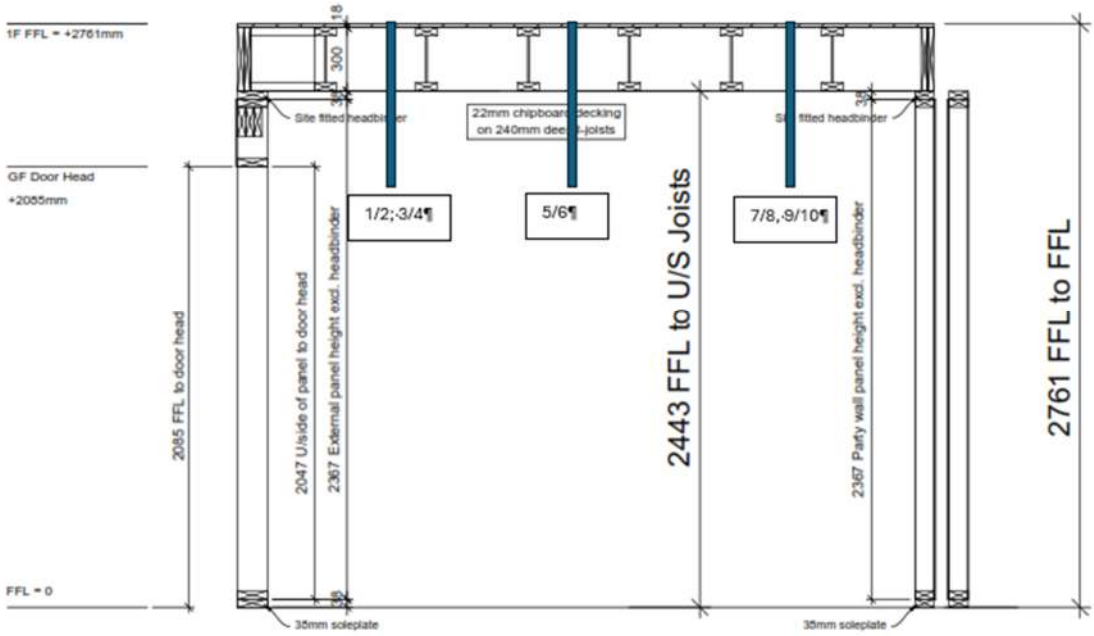


Figure 81 − Section through fire compartment showing location of atmosphere thermocouples

The channel allocation for the atmosphere thermocouples is shown in Table 13 which describes the location within the fire compartment and should be read in conjunction with Figure 81. The directions relate to the orientation of the compartment within the BRE Burn Hall test facility.

© BRE Global Ltd 2025

Table 13 – Atmosphere thermocouple channel allocation

Channel	ID	Description	Position	Direction
1	TC-1	Atmospheric	Atmosphere t/c above Crib 1 100 mm from ceiling	NE
2	TC-2	Atmospheric	Atmosphere t/c above Crib 1 300 mm from ceiling	NE
3	TC-3	Atmospheric	Atmosphere t/c above Crib 2 100 mm from ceiling	SE
4	TC-4	Atmospheric	Atmosphere t/c above Crib 2 300 mm from ceiling	SE
5	TC-5	Atmospheric	Atmosphere t/c centre of compartment 100 mm from ceiling	centre
6	TC-6	Atmospheric	Atmosphere t/c centre of compartment 300 mm from ceiling	centre
7	TC-7	Atmospheric	Atmosphere t/c above Crib 3 100 mm from ceiling	SW
8	TC-8	Atmospheric	Atmosphere t/c above Crib 3 300 mm from ceiling	SW
9	TC-9	Atmospheric	Atmosphere t/c above Crib 4 100 mm from ceiling	NW
10	TC-10	Atmospheric	Atmosphere t/c above Crib 4 300 mm from ceiling	NW

The location of the thermocouples on the top of the roof slab including those on the unexposed surface and those at the intersection between the EFJ and the plasterboard, at the intersection between the plasterboard and in the service void is shown in Figure 82 and the relevant section of the channel allocation is reproduced as Table 14.

© BRE Global Ltd 2025

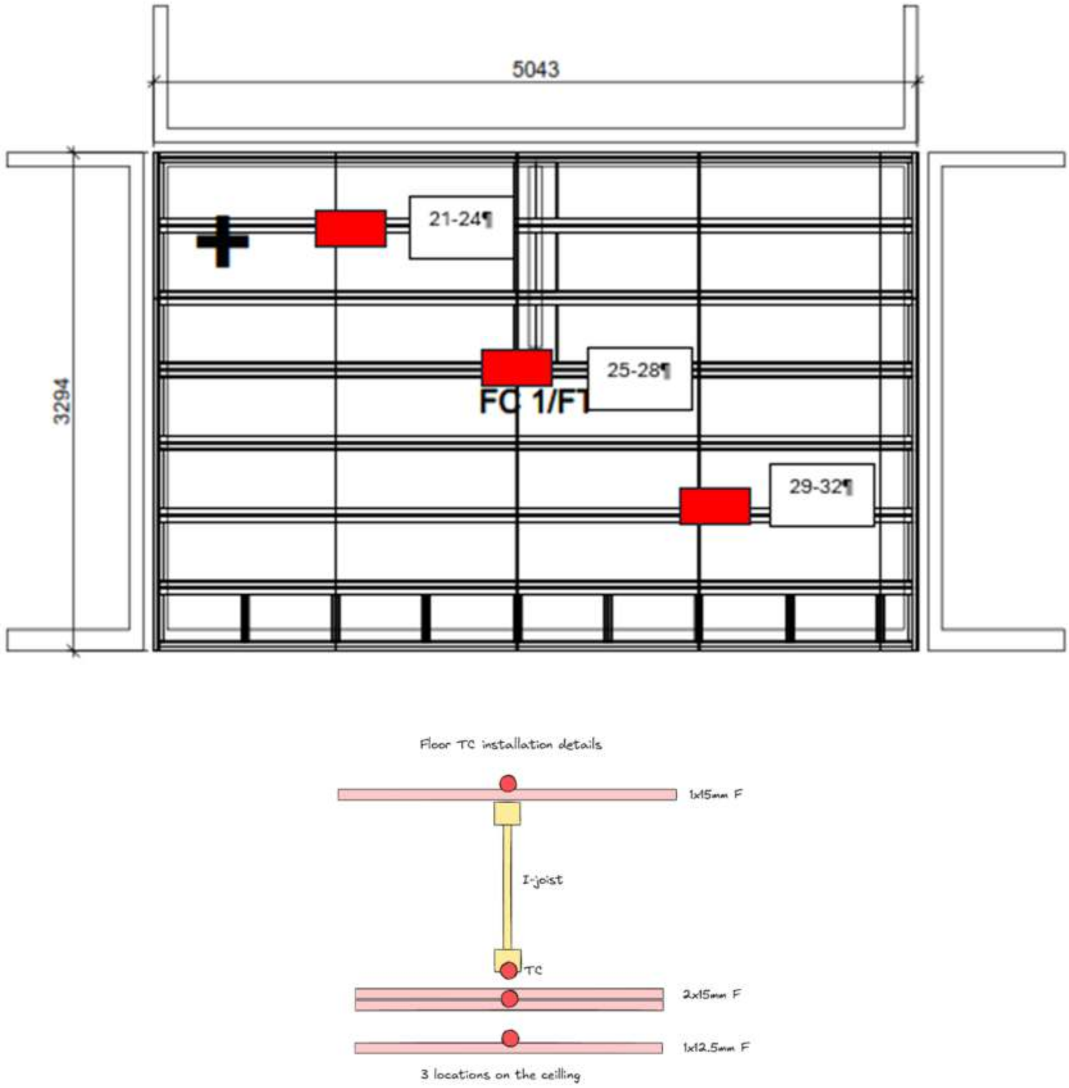


Figure 82 − Thermocouple locations through the depth of the floor

Table 14 − Floor thermocouple channel allocation

Channel	ID	Description	Position	Direction
21	TC-21	Floor	Service void	NE
22	TC-22	Floor	Interface of Type F boards	NE
23	TC-23	Floor	Bottom flange EFJ	NE
24	TC-24	Floor	Unexposed face of OSB	NE
25	TC-25	Floor	Service void	centre
26	TC-26	Floor	Interface of Type F boards	centre
27	TC-27	Floor	Bottom flange EFJ	centre
28	TC-28	Floor	Unexposed face of OSB	centre
29	TC-29	Floor	Service void	SW
30	TC-30	Floor	Interface of Type F boards	SW
31	TC-31	Floor	Bottom flange EFJ	SW
32	TC-32	Floor	Unexposed face of OSB	SW

The location of the thermocouples on the North East and South elevations including those on the unexposed surface and those at the intersection between the Type F boards forming the principal fire protection to the walls and in the service void cavity is shown in Figure 83 and the relevant section of the channel allocation is reproduced as Table 15.

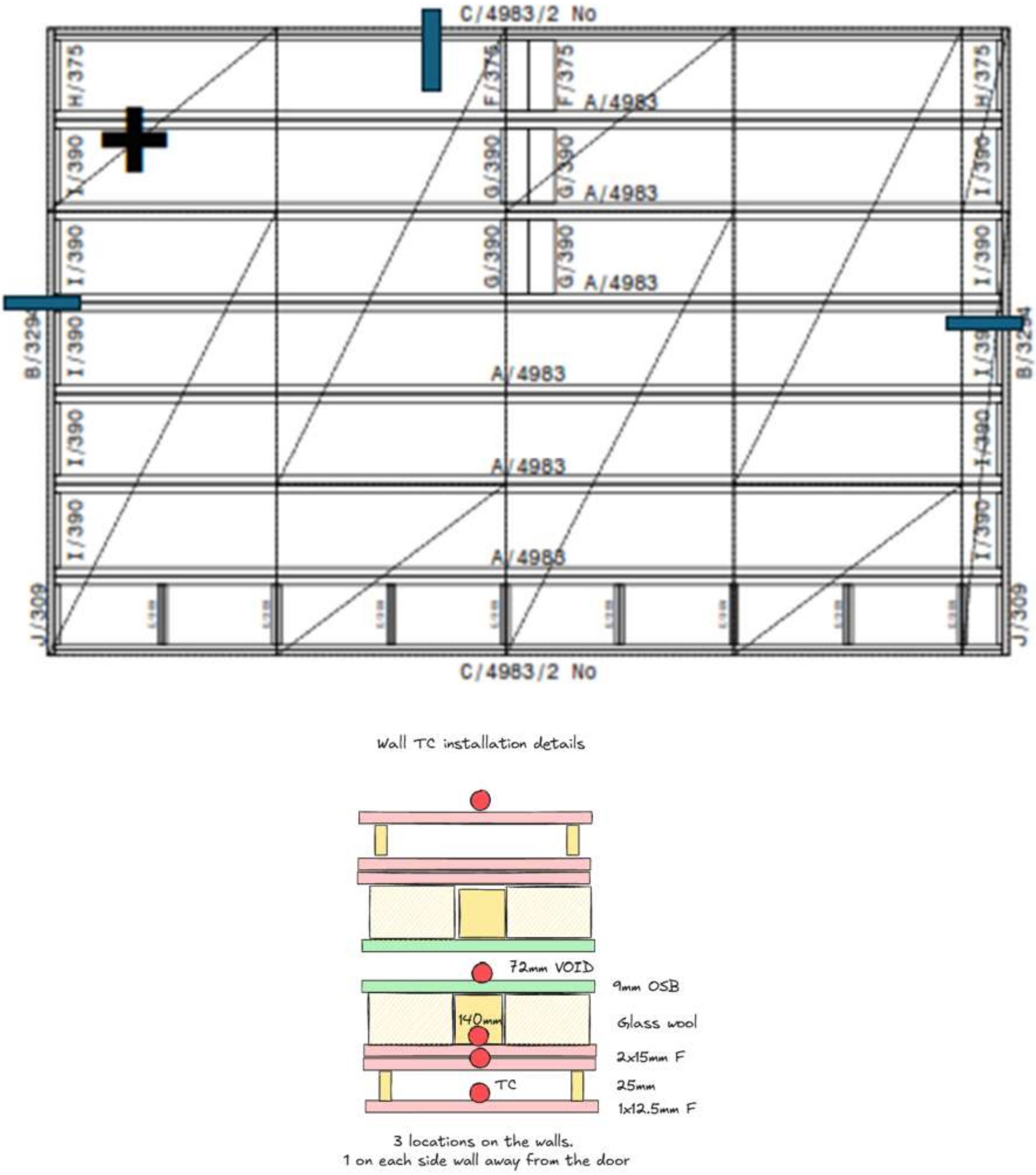


Figure 83 − Thermocouple locations through the depth of the walls

© BRE Global Ltd 2025

Table 15 – Wall thermocouple channel allocation

Channel	ID	Description	Position	Direction
33	TC-33	Wall	Service void	N
34	TC-34	Wall	Interface of Type F boards	N
35	TC-35	Wall	Front of stud	N
36	TC-36	Wall	Unexposed face of OSB	N
37	TC-37	Wall	Unexposed face	N
38	TC-38	Wall	Service void	E
39	TC-39	Wall	Interface of Type F boards	E
40	TC-40	Wall	Front of stud	E
41	TC-41	Wall	Unexposed face of OSB	E
42	TC-42	Wall	Unexposed face	E
43	TC-43	Wall	Service void	S
44	TC-32	Wall	Interface of Type F boards	S
45	TC-45	Wall	Front of stud	S
46	TC-46	Wall	Unexposed face of OSB	S
47	TC-47	Wall	Unexposed face	S

In addition, a displacement transducer was used to monitor the central deflection of the floor plate, while a heat flux meter measured the incident heat flux 2 m away from the ventilation opening.

© BRE Global Ltd 2025

10.3 Fire development

Following ignition, the compartment quickly transitioned to flashover following the build-up of hot gases around the ceiling with flames emerging from the opening (see Figure 84).

Figure 84 − Flames emerging following flashover

The crib fire continued until the fire load was consumed. The time-temperature development based on the atmosphere thermocouples within the compartment is shown in Figure 85.

There was no insulation failure on the unexposed faces of the compartment during the fire exposure measured against the standard fire resistance test performance criteria.

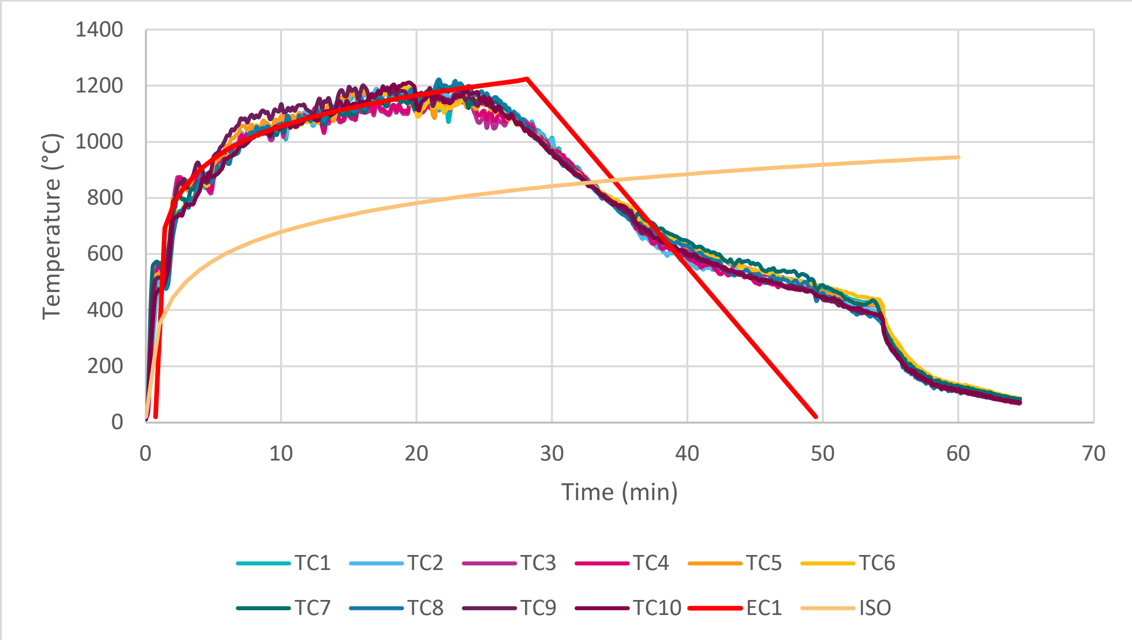


Figure 85 − Compartment time-temperature response related to standard fire exposure and predicted response from EN 1991-1-2 parametric approach

The compartment atmosphere temperature is in excess of the standard curve for the entire heating phase. Although the total area under the measured curve does not equate to the total area under the standard curve for the 60-minute exposure, this issue is discussed in Section 11. The issue of equivalent severity is very much dependent on the nature of the lining materials in the compartment the structural element and configuration and design of any protection system.

The parametric approach provides a good correlation for the maximum temperature within the compartment and a reasonable correlation with the duration of the heating phase.

10.4 Structural performance

The compartment survived complete burn out of all combustible material forming part of the moveable fire load while maintaining overall stability. There were no signs of any integrity failure during the course of the fire and no evidence of external flaming away from the ventilation opening.

There was no evidence of any insulation failure during the fire exposure. Figures 86 and 87 show the temperature of the Engineered Floor Joists and structural loadbearing studs, respectively. Figures 88 and 89 show the unexposed face temperatures of the floor and wall, respectively. The temperatures of the main loadbearing members were below that where pyrolysis could be expected and therefore, there was no charring. During removal of the plasterboard linings the structural members were inspected (see Figure 96) and there was no sign of any charring. The only area where any charring/smouldering had taken place was in a location where the Project team had drilled through to install instrumentation (Figure 97).

Cavity barriers were included in the final timber frame experiment within party wall and external wall details. As there was no breach in compartmentation, the cavity barriers were not impacted by the fire.

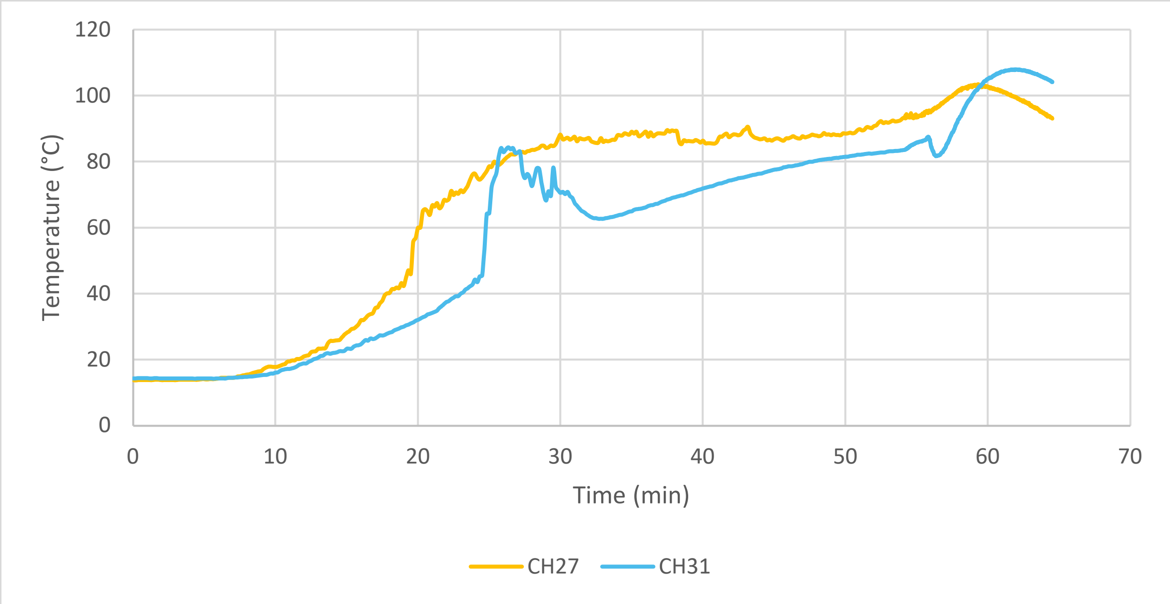


Figure 86 − Temperature of Engineered Floor Joists

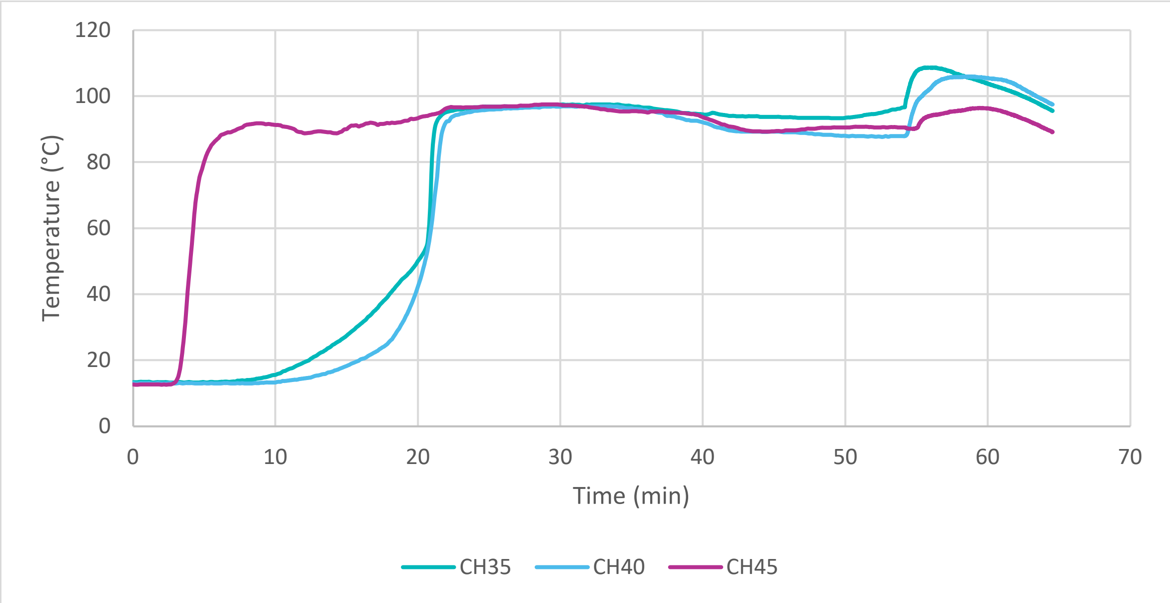


Figure 87 − Temperature of wall studs

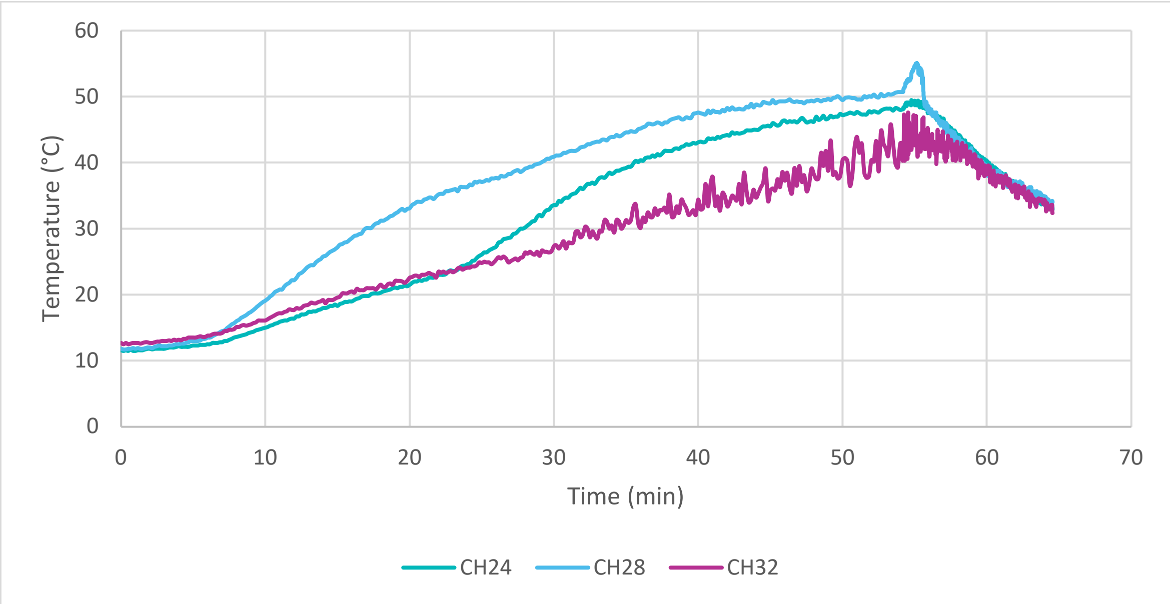


Figure 88 − Unexposed floor temperatures

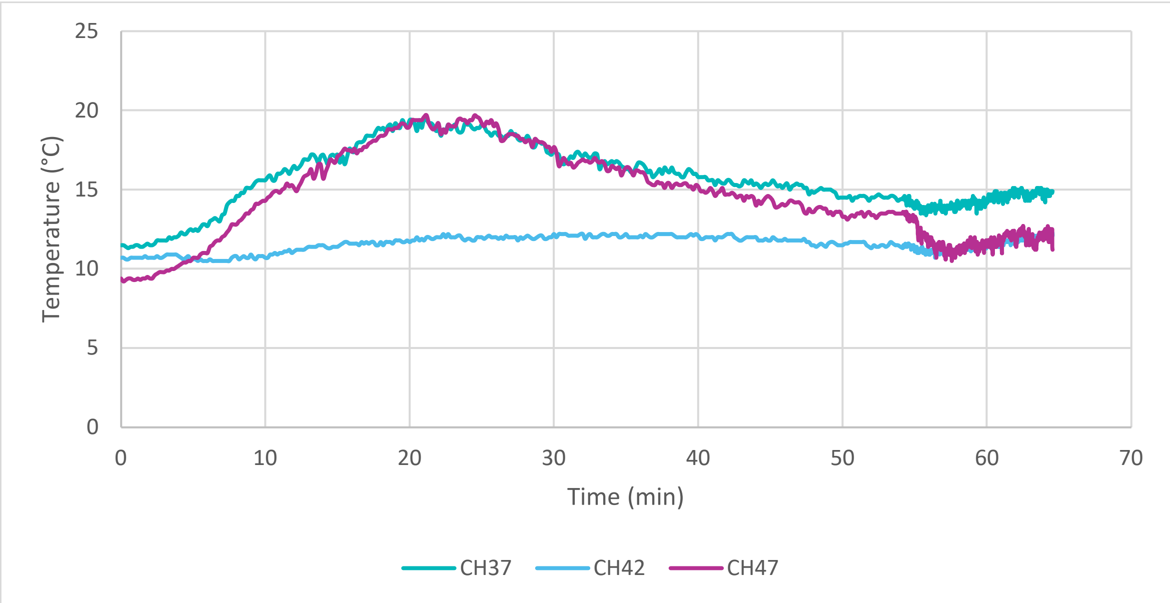


Figure 89 − Unexposed wall temperatures

The temperature within the service void formed behind the inner layer of plasterboard is shown in Figure 90 (for the ceiling) and Figure 91 (for the walls). The figures illustrate the different behaviour between fall-off times for ceiling and wall boards.

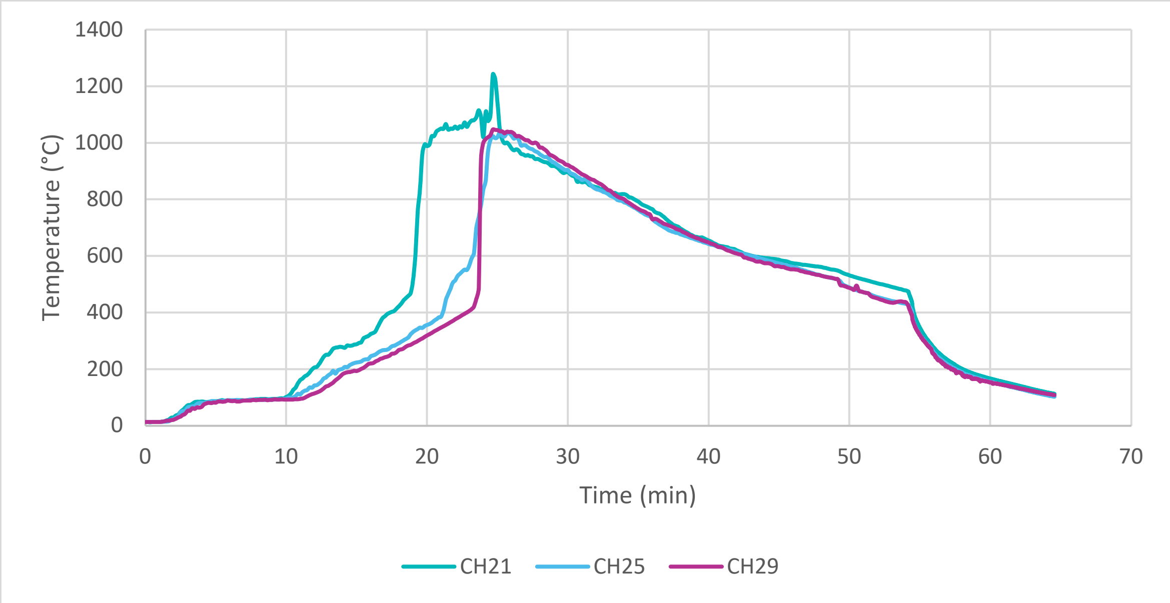


Figure 90 − Temperatures in ceiling service void

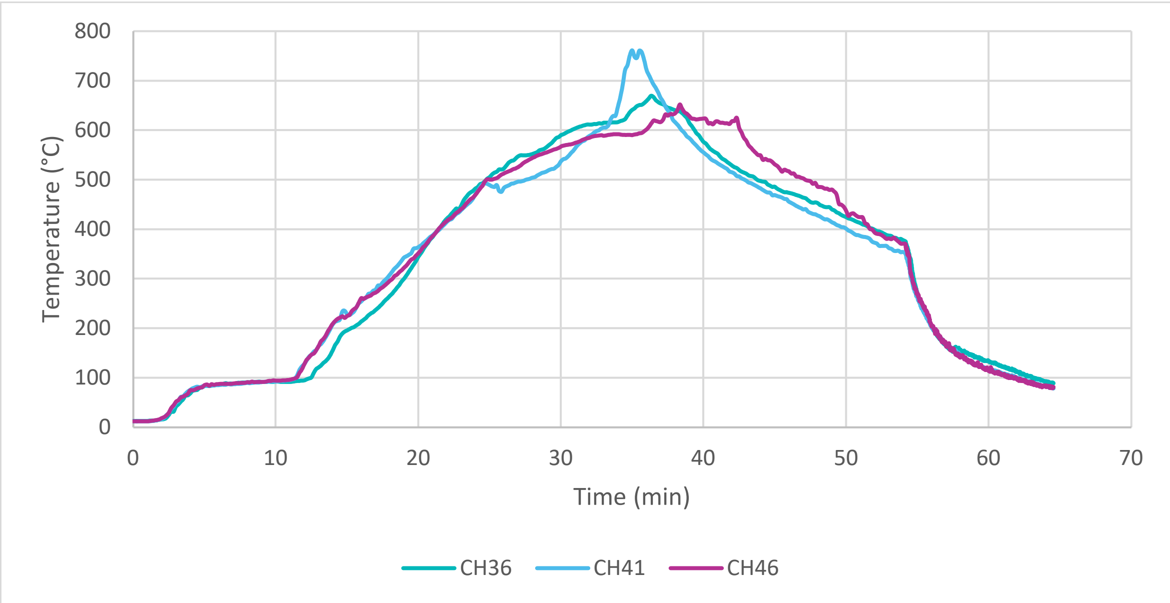


Figure 91 − Temperatures in wall service void

Figure 92 shows the interface temperature between the two Type F boards that form the principal fire protection to the structural frame while Figure 93 shows the temperature within the cavity of the walls.

© BRE Global Ltd 2025

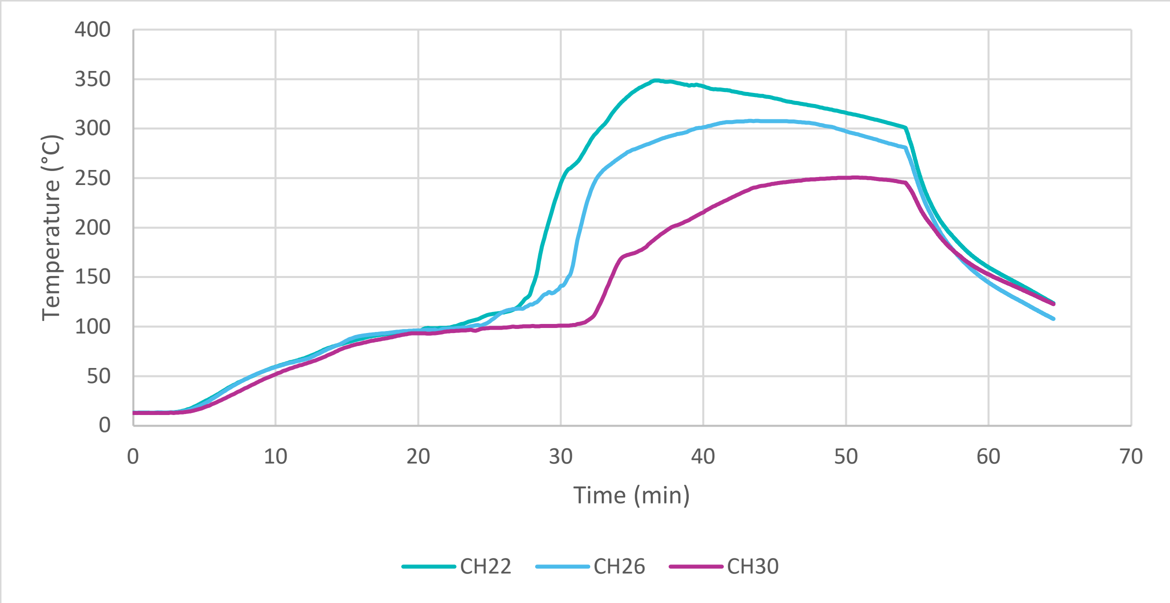


Figure 92 − Interface temperature between Type F wall boards

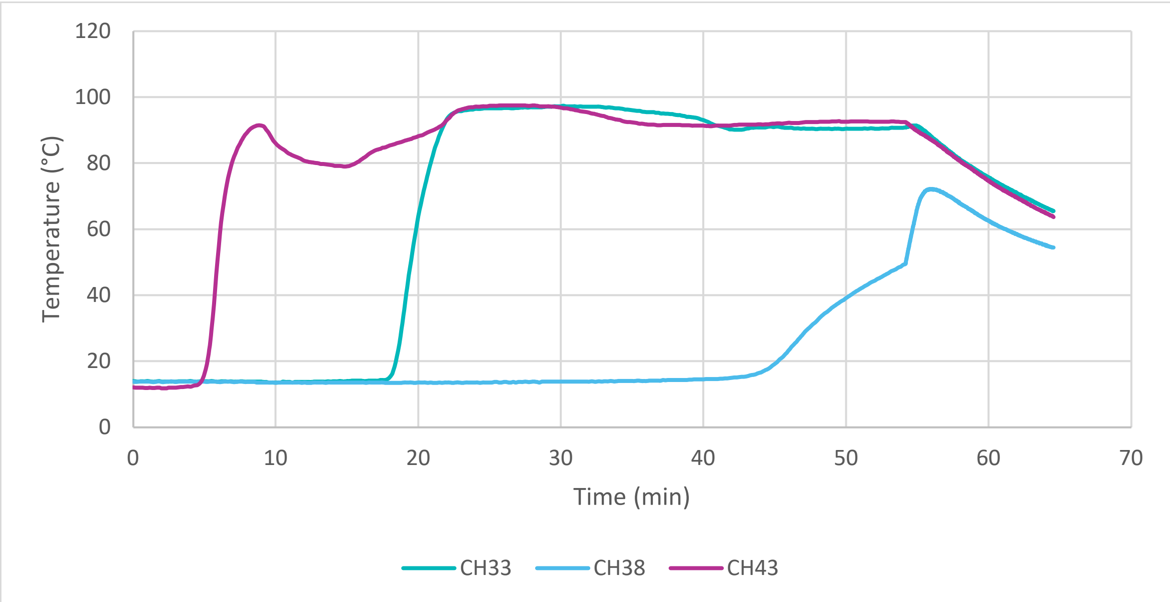


Figure 93 − Cavity temperatures in the external walls

In addition to the temperature measurements, the central deflection of the floor plate was measured as shown in Figure 94 and the incident heat flux at a distance of 2 m opposite the opening is shown in Figure 95. The maximum recorded displacement was 4 mm, preceded by an initial extension of approximately 6 mm. The maximum recorded heat flux was approximately 45 kW/m².

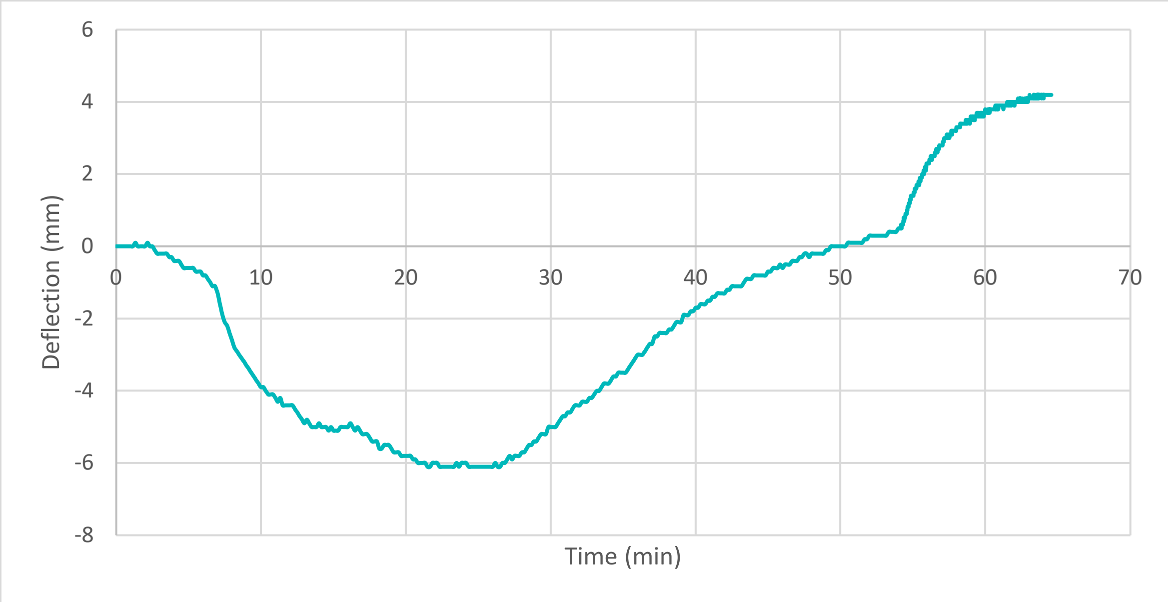


Figure 94 − Displacement of centre of floor plate (In this case a negative value relates to an upward movement while a positive value relates to a downward movement)

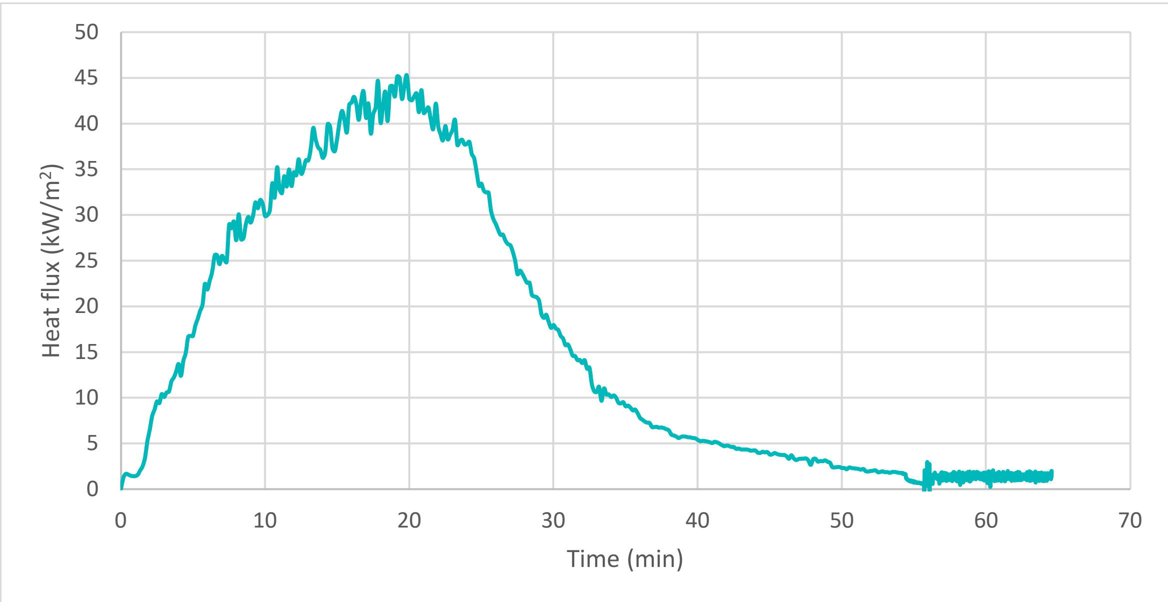


Figure 95 − Heat flux 2 m from opening

© BRE Global Ltd 2025

Figure 96 − Engineered Floor Joists following removal of plasterboard linings

Figure 97 − Localised charring/smouldering at location of thermocouple installation

11 Inform the development of a test methodology (MMC and timber) (Task C4)

The fire experiments described in this report have been used to develop a test methodology that can be used where reliance on standard fire resistance test data is either inappropriate or insufficient. However, it is not intended to replace standard fire testing but can be used where additional assurance is required.

The sections below set out draft text that may be used as the basis for the development of a test method aimed principally at MMC and timber construction, but applicable for any form of construction where reliance on standard fire test data is either inappropriate or insufficient.

11.1 Scope

This methodology provides a specification for fire testing and classification for innovative forms of construction used in the UK.

11.2 Performance in fire

11.2.1 General requirements

The requirements below specifically relate to the method of test described in this document. The basis for performance criteria are to:

- Minimise the effect of fire on the building itself;
- Limit the effects of interruption to the use of a building should a fire occur;
- Allow the building to be reoccupied as soon as possible following a fire incident.

11.2.1.1 Structural collapse

The building system shall have adequate fire resistance to prevent collapse or partial collapse and exhibit restricted deflections.

11.2.1.2 Compartmentation

The building system shall be designed and constructed in such a manner that, if a fire starts, the extent of fire and smoke damage will be minimised. Fire shall not enter into an adjoining property and shall, as far as possible, be prevented from entering concealed cavities or roof voids. If fire does enter any cavities or voids, its spread shall be minimised by appropriate design and/or fire protection measures. Consideration shall be given in the design of the building to measures intended to limit the spread of smoke into adjoining properties.

Note: although smoke densities are not measured as part of this test and do not form part of the acceptance criteria, fire spread routes will provide a good indicator of potential routes for the spread of smoke.

11.2.1.3 Active fire protection (suppression) systems

The building system shall comply with the acceptance criteria in clause 11.3.2 without any active protection (suppression) during the test. The definition of design fire load density ($q_{f,d}$) in accordance with BS EN 1991-1-2 and the UK National Annex and Non-Contradictory Complementary Information contained in PD 6688-1-2[6] incorporates a reduction factor to be used where an approved life safety sprinkler system is present.

Note: enhanced fire protection to approved building systems may be achieved by the installation of approved active fire protection systems and should therefore be considered in order to further reduce the risk.

11.3 Test method and requirements

11.3.1 Full-scale natural fire test

Due to the inherent risks involved with large-scale fire tests, great care shall be taken at all stages of the procedure, including but not exclusive to, build and preparation, loading and unloading, test, monitoring and inspection, and dismantling. A full risk assessment and method statement shall be prepared and agreed by all parties for each system test undertaken.

11.3.1.1 General

In order to demonstrate the performance in fire of innovative construction systems, including the interaction between floors and walls, fire stopping around openings and the correct functioning of cavity barriers, the full-scale test described in this document is required. The precise specification of the test sample will be agreed between the test house and the client to obtain the broadest application from the results, but taking into account the generic configuration described in 11.3.1.2. This is normally interpreted to select the specification that is anticipated to achieve the lowest level of performance.

11.3.1.2 Test building

The test building shall comprise a single module or compartment incorporating both a ceiling/floor junction and a party wall junction (see Figure 98). It shall be constructed with its intended internal and external finishes but excluding any contents including floor coverings or furnishings. The module or compartment shall have dimensions as close as possible to 6 m long by 4 m wide or the nearest specific size available in the manufacturer’s range. The overall dimensions of the test compartment will be representative of the intended end use application and will simulate the accommodation areas of one floor of a single building system unit. The test compartment will be constructed with a party wall junction adjacent to the fire test compartment and a compartment floor junction above the compartment.

The wall and floor adjacent to and above the fire compartment will be lined in accordance with the manufacturer’s requirements. The compartment floor element above will be loaded uniformly over the floor area to provide a value of imposed load as defined in 11.3.1.6. Each building system unit (fire compartment, adjacent compartment wall and compartment floor above) shall be supplied with cables and service connections and penetrations appropriate to the intended end use.

© BRE Global Ltd 2025

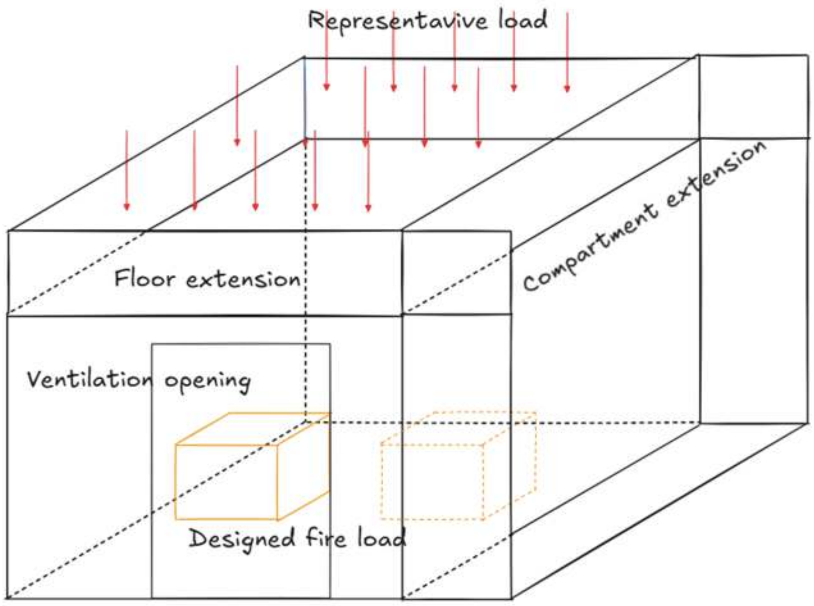


Figure 98 − General arrangement and fire load of test compartment/module

Ventilation shall be provided by a single opening usually on the front elevation of the test building. The size and location will reflect normal building practice and will be typical for the intended end use application but would be expected to provide a ventilation area of approximately 10-20% of the floor area.

11.3.1.3 Fire load/ignition source

The fire load for the test shall comprise a number of softwood timber cribs distributed uniformly over the floor of the fire compartment. Each crib shall consist of rough sawn lengths of kiln dried pine or similar. Each stick shall be nominally 50 mm x 50 mm in section and 1000 mm long*. The timber sticks shall be laid with alternate layers arranged perpendicular in a criss-cross fashion. The timber sticks shall be spaced 50 mm apart in each layer. The moisture content of the timber shall be measured prior to testing and shall be in the range 7-13%. Cribs shall be equally spaced over the entire floor area and be a minimum of 300 mm apart from each other. Consideration shall be given to suitable and safe access for ignition and egress.

* *Note: the length of the sticks may be reduced to a minimum of 500 mm should the size of the test building/compartment be such that longer sticks cause problems with access and egress. However, the nominal fire loads described below shall be maintained.*

Each crib shall be ignited by applying a flame to strips of paraffin-soaked porous fibre insulation board connecting each crib to the adjacent cribs and positioned between the bottom two layers.

The crib specification shall be calculated to represent a nominal fire load based on the floor area and the intended end use of the building system. The choice of the fire load density will be based on the concept of time equivalence (see Annex 1) to provide a natural fire exposure with an equivalent fire severity to the design fire resistance for the specific application. The approach provides the most effective means of maintaining a link between natural fire exposure and the standard fire curve.

11.3.1.4 Temperature measurements

Internal atmosphere temperatures shall be measured 100 mm and 300 mm below the ceiling of the fire compartment using 1.5 mm diameter stainless steel sheathed thermocouples with at least one location per 2 m² of ceiling area. Temperatures of the outer surfaces of the fire compartment (internal surface of the adjoining compartment and floor surface of the compartment above) shall be measured using Type K thermocouples. They shall be positioned on the surface of the wall and floor above with at least five on each element to measure mean temperatures. Additional temperature measurements shall be required on both sides of any cavity barriers present to assess performance. Additional instrumentation may be installed at the request of the client to provide information on the response of floor (joists), wall (studs) and connecting elements.

11.3.1.5 Video record

A photographic and video recording of the fire test shall be provided by the test laboratory. This shall include video coverage of the internal aspects of the adjoining walls and floor with one or more cameras positioned to monitor the compartment wall/floor as appropriate.

11.3.1.6 Floor loading

The floor of the compartment above shall be loaded to provide a uniformly distributed load equal to:

Table 16 − Compartment floor loadings

Purpose group	Load (kN/m²)
Residential	0.75
Offices	1
Hotel	0.75
Shop	2
School	1

11.3.1.7 Full-scale natural fire test procedure

The test shall be conducted under cover to avoid variations due to weather. Ambient temperatures shall be between 5°C and 25°C.

11.3.1.7.1 Start of test

The test shall be started by lighting the timber cribs simultaneously or in succession, provided that all of the cribs are ignited within 60 seconds.

11.3.1.7.2 Gas temperatures

Gas temperatures shall be recorded continuously or at intervals not exceeding 30 seconds. Surface or component temperatures shall be recorded at intervals not exceeding 1 minute.

© BRE Global Ltd 2025

11.3.1.7.3 Integrity

Integrity shall be monitored throughout the test by visual inspection to record any signs of sustained flaming outside the compartment of origin (remote from the opening).

Note: Sustained flaming shall be defined as visible flaming for 10 seconds or greater.

11.3.1.7.4 End of test

The fire shall be allowed to burn out and the test continued until conditions have stabilized. Any residual burning embers can be extinguished at this point.

Note: The laboratory shall reserve the right to end the test at any time if there is considered to be any risk to the health and safety of the persons or property involved in the test.

11.3.2 Acceptance criteria

Fire breaking through openings shall not be taken as failure under the criteria given below:

11.3.2.1 Integrity criteria

The integrity of the building system shall be demonstrated if the fire is restricted to the compartment of origin for the duration of the test.

11.3.2.1.1 Adjacent building system units

Any breakthrough into the adjoining building system units will constitute a failure and will be recorded with respect to time and location.

11.3.2.1.2 Cavities

Any breakthrough into any cavity will be assessed in terms of restricted extent of damage. Spread beyond the cavities immediately adjacent to the compartment of origin (wall or floor) will constitute a failure.

11.3.2.2 Insulation criteria

The insulation criteria will be met if the temperature on the unexposed surface of adjoining building system units i.e. the party wall or the floor of the compartment above, remains below an average value of 200°C and a peak value of 240°C for the entire duration of the fire exposure including the cooling phase.

11.3.2.3 Stability criteria

The loadbearing capacity of the building system shall be met if the floor above continues to support the applied load for the duration of the test.

11.3.2.4 Equivalent time of fire exposure

In order to assess performance, the severity of the natural fire shall be evaluated with respect to an equivalent period in a standard fire test. The equivalent period of fire resistance shall be determined by calculation in accordance with Annex 1.

11.3.3 Test report

The test report shall provide the following information:

- A full description of the building tested including drawings. These shall include full cross-sectional details of the building envelope and material specifications.
- Loading calculations as appropriate.
- Graphs and tables of all measured values.
- Observations and photographs taken before, during and after the test.
- Results in terms of Clause 11.3.2 of this document.
- A statement provided either as an annex to the report or a separate document regarding the field of application of the test results.

11.3.4 Field of application of test results

11.3.4.1 General

The results of the test shall apply only to the specification tested or by application of extended application rules.

11.3.5 Classification

The grading below takes into account the variations between structural load and fire load. To reduce the number of classes, some increase in fire load for specific purpose groups has been introduced.

Table 17 – Grades of performance for innovative methods of building construction

Grading system for innovative methods of building construction			
Grade designation	**Purpose groups covered**	**Load (kN/m²)**	**Nominal fire load (MJ/m²)**
MMC1	Retail	2	Based on specified requirement
MMC2	Residential	0.75	Based on specified requirement
MMC3	Offices, Hotels, Hostels, Schools	1	Based on specified requirement

© BRE Global Ltd 2025

Annex 1 Time equivalent by calculation

According to BS EN 1991-1-2, Eurocode 1: Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire, the equivalent time of fire exposure is given by:

$$t_{e,d} = \left(q_{f,d} \times w_f \times k_b\right)$$

Where:

$q_{f,d}$ is the design fire load density per unit floor area (MJ/m²)

k_b is the conversion factor for the compartment thermal properties (min.m²/MJ)

w_f is the ventilation factor

$$w_f = (6/H)^{0.3}\,[0.62 + 90\,(0.4 - \alpha_v)^4] \geq 0.5\ (in\ the\ absence\ of\ horizontal\ openings)$$

Where:

H is the height of the compartment (m)

$\alpha_v = A_v/A_f$

A_v is the area of the ventilation opening (m^2)

A_f is the floor area (m^2).

© BRE Global Ltd 2025

12 Conclusions

This report has set out the rationale for the experimental programme and provided information on the test methodology and the background to the fire design procedure for the experimental programme.

The results from the initial (control) fire experiment incorporating pre-cast concrete planks with a design fire resistance of 60 minutes are presented. Based on the initial fire experiment, the following conclusions can be drawn:

- The compartment survived complete burn out of all combustible material while maintaining overall stability. There were no signs of any integrity failure during the course of the fire and no evidence of external flaming away from the ventilation opening.
- There was no evidence of any insulation failure during the fire exposure, based on the criterion adopted in standard fire testing.
- The plasterboard linings to the ceiling failed in the early stages of the post-flashover fire development. This led to spalling of the surface of the precast concrete planks. Based on observations during the fire experiment, the spalling was non-explosive and had no significant impact on the fire resistance of the floor slabs.

The results from the second fire experiment with a design fire resistance of 120 minutes are presented. Based on the second fire experiment, the following conclusions can be drawn:

- The compartment survived complete burn out of all combustible material while maintaining overall stability. There were no signs of any integrity failure during the course of the fire and no evidence of external flaming away from the ventilation opening.
- There was no evidence of any insulation failure during the fire exposure, based on the criterion adopted in standard fire testing.

The results from the third fire experiment with a design fire resistance of 60 minutes are presented. Based on the third fire experiment, the following conclusions can be drawn:

- The compartment survived complete burn out of the fire load while maintaining overall stability. There were no signs of any integrity failure during the course of the fire and no evidence of external flaming away from the ventilation opening.
- There was no evidence of any insulation failure during the fire exposure, based on the criterion adopted in standard fire testing.

Some hours after completion of this fire experiment, localised areas of smouldering combustion were present, eventually leading to reignition of the CLT in localised areas. Despite persistent attempts to deal with this through dousing the affected areas with water, the smouldering continued over a period of several days with damage extending to three of the wall panels and spreading through to the roof panel. A summary of these events is included in Appendix D2 in the form of a timeline.

Data was collected overnight and has been reviewed as part of the current project.

The issues around the smouldering combustion and the reignition of the CLT compartment have been reviewed and discussed and findings presented in Appendix D2.

© BRE Global Ltd 2025

The results from the fourth fire experiment with a design fire resistance of 90 minutes are presented. Based on the fourth fire experiment, the following conclusions can be drawn:

- The compartment survived complete burn out of the fire load while maintaining overall stability. There were no signs of any integrity failure during the course of the fire and no evidence of external flaming away from the ventilation opening.
- There was no evidence of any insulation failure during the fire exposure, based on the criterion adopted in standard fire testing.

The results from the fifth fire experiment with a design fire resistance of 60 minutes are presented. Based on the fifth fire experiment, the following conclusions can be drawn:

- The compartment survived complete burn out of the fire load while maintaining overall stability. There were no signs of any integrity failure during the course of the fire and no evidence of external flaming away from the ventilation opening.
- There was no evidence of any insulation failure during the fire exposure, based on the criterion adopted in standard fire testing.

Based on the results from the experimental work undertaken for Tasks C2 and C3 draft text is provided in section 11 of this report for consideration by BSR HSE which may form the basis of a test methodology (Task C4).

© BRE Global Ltd 2025

13 Acknowledgements

BRE Global would like to acknowledge the contributions of the following:

- The Concrete Centre for arranging the provision of materials for the construction of the control fire compartment for the first experiment.
- Supplier 1 for supply, delivery and removal of the module for the second experiment.
- The industry group for the design, supply and construction of the CLT compartment for the third experiment, coordinated through the Structural Timber Association (STA).
- Supplier 2 for supply, delivery and removal of the panellised steel system for the fourth experiment.
- The industry group for the design, supply and construction of the timber frame compartment for the fifth experiment, coordinated through the Structural Timber Association (STA).

© BRE Global Ltd 2025

14 References

1. Loss Prevention Standard LPS 1501 Issue 1.1 Fire test and performance requirements for innovative methods of building construction, BRE Global Limited 2014.

2. BRE Product Standard BPS 7014 Standard for Modular Systems for Dwellings Issue 1.0 Annex B Fire test and performance requirements for whole modules, BRE Global Limited 2021 (withdrawn).

3. British Standards Institution, BS EN 1991-1-2, Eurocode 1: Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire, BSI, London, 2002.

4. British Standards Institution, UK National Annex to Eurocode 1: Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire, BSI, London, 2007.

5. Collaborative Reporting for Safer Structures UK (CROSS-UK), CROSS Safety Report: Fire protection to light gauge steel frame walls, 21 June 2022. Available from: Fire protection to light gauge steel frame walls | CROSS (cross-safety.org). Last accessed 30th March 2023.

6. British Standards Institution, PD 6688-1-2:2007, Background paper to the UK National Annex to BS EN 1991-1-2, BSI, London, 2007.

© BRE Global Ltd 2025

Report Ends

www.bre.co.uk

Health and Safety Executive
Final Report

Structural Fire Resistance and Fire Separating Elements – Appendix D2: Smouldering Combustion – Issues and Implications

Prepared for:	**The Building Safety Regulator**
Prepared by:	**Tom Lennon and Octavian Lalu**
Approved by:	**Tony Baker (original report approval 20th January 2025 and final amendments March 2025) on behalf of BRE Global**
Date:	**20th January 2025**
HSE Contract:	**1.11.4.4436 (previously MHCLG Contract: CPD/004/120/206)**
Report Number:	**P118139-1015 (M11D9V3) Appendix D2**

BRE Global Ltd
Watford, Herts
WD25 9XX

Customer Services 0333 321 8811

From outside the UK:
T + 44 (0) 1923 664000
E enquiries@bregroup.com
www.bregroup.com

This report is made on behalf of BRE Global and may only be distributed in its entirety, without amendment, and with attribution to BRE Global Ltd to the extent permitted by the terms and conditions of the contract.

BRE Global's liability in respect of this report and reliance thereupon shall be as per the terms and conditions of contract with the client and BRE Global shall have no liability to third parties to the extent permitted in law.

Table of Contents

© BRE Global Ltd 2025

1 Introduction

This Appendix relates to issues arising from work carried out under Task C2 (and related to Task C4). As part of the overall programme for this project, BRE Global carried out a large-scale fire experiment within a compartment constructed from Cross Laminated Timber (CLT) on the afternoon of Thursday 19th October 2023. The results of this fire experiment are detailed in Appendix D1. The analysis related only to the heating and cooling phases of the fire up to the time when the moveable fire load (timber cribs) had been consumed. This report covers the events following combustion of the moveable fire load and puts the events into context through the inclusion of additional information related to smouldering combustion.

This report takes into account comments from BSR HSE and the Technical Steering Group.

© BRE Global Ltd 2025

2 Summary of events related to the CLT fire experiment undertaken at the BRE Burn Hall on 19th October 2023

2.1 Background

BRE Global carried out a large-scale fire experiment within a compartment constructed from Cross Laminated Timber (CLT) on the afternoon of Thursday 19th October 2023 as part of the government-funded research project, Structural Fire Resistance and Fire Separating Elements.

The detailed results from the main experiment are included in Appendix D1 and therefore, are not repeated here.

The experimental specimen was a single-storey compartment formed from CLT roof and CLT wall elements. The CLT walls were supported on a CLT floor in a platform construction with the CLT floor supported on timber bearers. The structure had fire-protective finishes consisting of two layers of 18 mm gypsum fibreboard applied to all surfaces and was intended to represent a typical residential compartment.

The specimen was fixed down to the concrete floor of the BRE Burn Hall using steel angles as shown in Figure 1.

Figure 1 – CLT compartment during construction

The fire load consisted of 690 MJ/m² formed from four cribs each containing 111 crib sticks formed from 50 mm x 50 mm softwood 1 m long to provide a fire with an equivalent severity to 60 minutes exposure to the standard fire curve in accordance with Annex F of BS EN 1991-1-2: 2005. The roof was loaded with 70 sandbags providing a uniformly distributed load of 1.14 kN/m².

Figure 2 shows the gypsum fibreboards and the fire load in place prior to ignition, while Figure 3 shows the additional external protection installed to prevent combustion of the unexposed face of the compartment around the single opening.

Figure 2 – Interior view of the compartment showing internal lining boards and fire load

Figure 3 – External view of the compartment showing additional protection around the opening

A timeline of significant events related to the issues that occurred following the combustion of the moveable fire load is provided in Table 1.

Table 1 – Timeline of significant events

Approximate time from ignition (hours:min) Time and date in brackets	Description	Photo
00:00 (14.00) (Thursday 19/10)	Ignition	
00:04 (14.04)	Flashover	

00:27 (14.27)	Peak temperature	
00:50 (14.50)	Cooling phase	

02:00 (16.00)	Burn out of moveable fire load	
02:00 (16.00)	White smoke seen externally at interface between walls and floor	
05:00 (19.00)	BRE staff leave facility, extract running and small amounts of smoke coming from sample. Live stream set up (not recording) and sample monitored.	No photos.

07:00 (21.00)	PM returns to Burn Hall, switches off extract and closes hall. Lights left on and live stream running.	
10:00 (00.00)	PM home	No change from above
12:00 (02.00) (Friday 20/10)	PM views video stream flames visible to left hand side of the door	No photo
12:30 (02.30)	PM arrives at Burn Hall, switches on extract and charges fire hose. Visible flaming from 3 of the 4 sides but easily extinguished.	No photo

 © BRE Global Ltd 2025

12:30 – 18:30 (02.30-8.30)	Smouldering continues, occasionally igniting. Water applied throughout the night.	
Between approx. 27 and approx. 89 hours from ignition (Saturday 21/10 and Sunday 22/10)	Time lapse photos taken over the weekend (one example included here showing ignition of roof)	

Approx. 89 hours from ignition (07.10 Monday 23/10)	Smouldering has spread to the roof of the compartment. Additional water was applied for a couple of hours and sandbags were removed from the front of the compartment.	

2.2 Review of measurements taken overnight

The starting point for assessment of the issues following complete combustion of the moveable fire load should be the time-temperature response of the compartment and the temperature through the depth of the structure, both during and immediately following the fire experiment. Figure 4 shows the time-temperature response within the compartment from ignition through to 45 minutes from ignition.

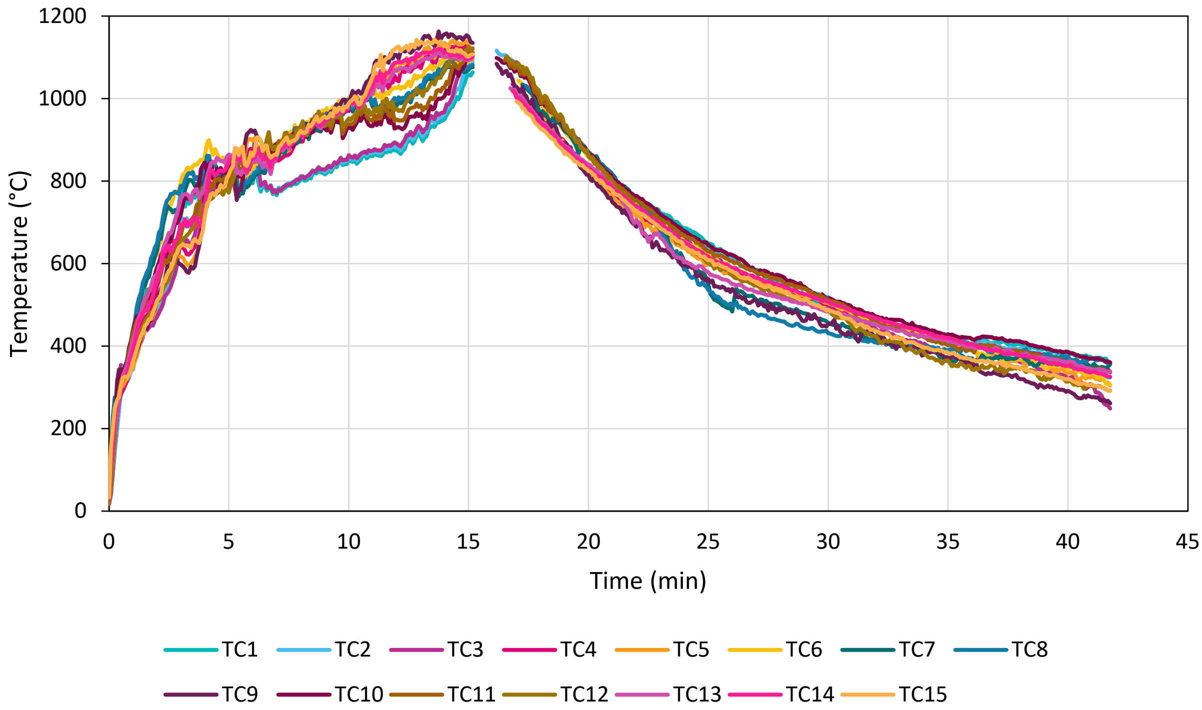


Figure 4 – Compartment atmosphere (gas) temperatures within the compartment during the heating and cooling phases of the fire

The graph shows that:

- The peak measured temperature of approximately 1130°C occurred approximately 15 minutes from ignition.
- Once peak temperatures had been achieved the fire within the compartment rapidly transitioned to the cooling phase and by approximately 40 minutes from ignition temperatures had decreased significantly.

Also of interest is the temperature at the interface of the fire protection board and the CLT and on the unexposed face of the CLT to see if any of these readings at this stage are indicative of potential issues related to smouldering combustion. Figure 5 shows the unexposed face temperatures of the roof structure while Figure 6 shows the temperature at a similar location of the interface between the fibreboard and the CLT. The former appears to have stabilised and shows some signs of reducing towards the end of the initial measurement period. However, leaving aside the unusual shape of the plot for thermocouple 22 (see Figure 6), the interface temperatures appear to be increasing at the end of the period although at quite a slow rate and at temperatures at which charring is unlikely to occur.

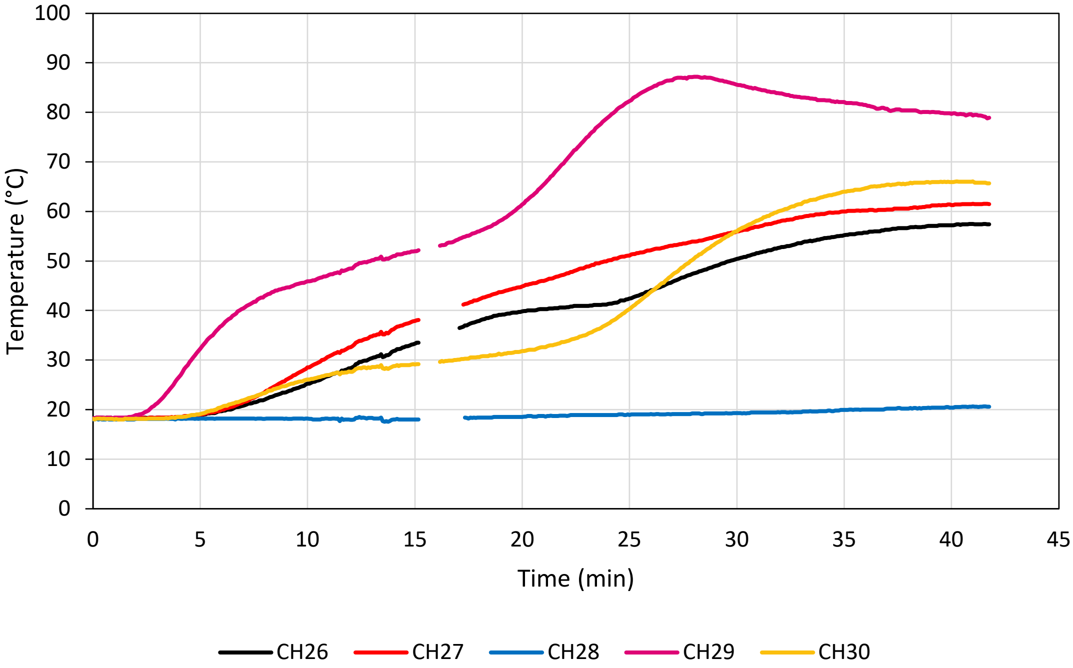


Figure 5 – Unexposed face temperatures of the roof during the initial fire experiment

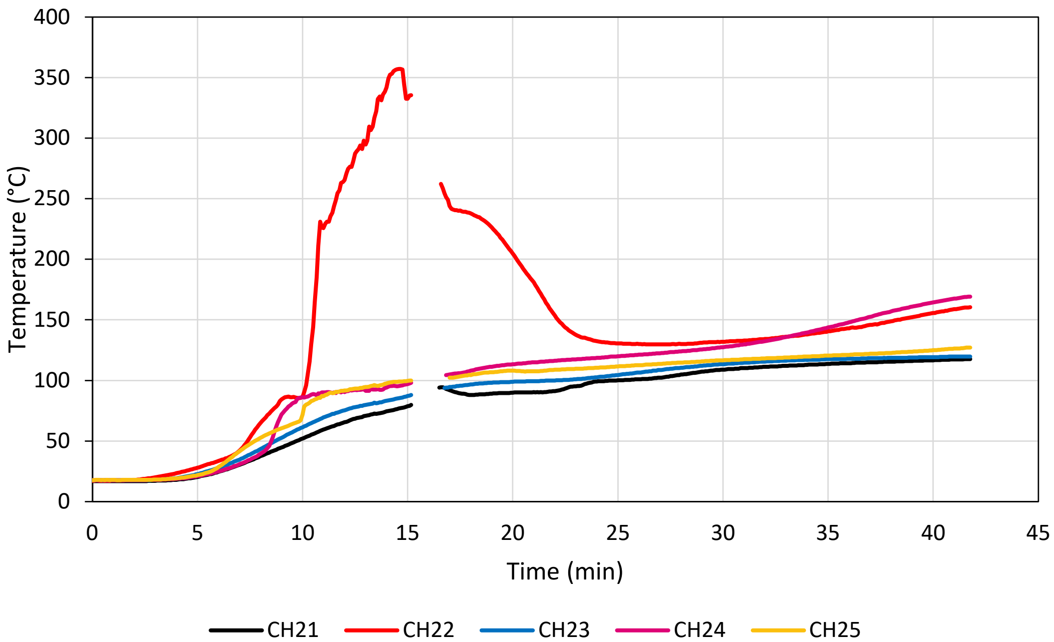


Figure 6 – Temperatures at the interface of the board and CLT in the roof panel during the initial fire experiment

In addition to the above, two readings were taken on the roof with measurements made by drilling into the CLT itself between the lamellas. The results are shown in Figure 7, and it is clear that the temperatures inside the CLT panel are increasing at a time when the atmosphere temperatures are reducing.

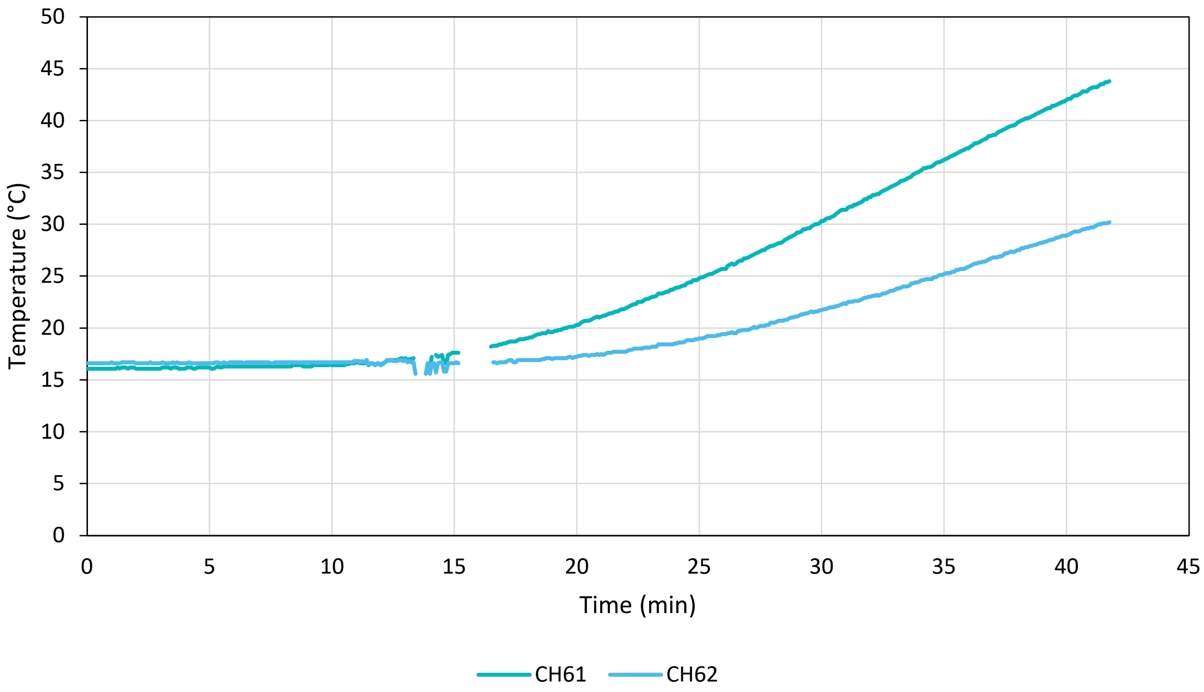


Figure 7 – Temperatures within the CLT layers on the roof panel

Following the fire experiment, the data was saved and the loggers reset to record temperatures throughout the night at an increased scan interval (10 minutes per scan rather than 5 seconds).

The atmosphere temperatures within the compartment over a period of just over 4 hours are shown in Figure 8. All internal temperatures have reduced below 100°C.

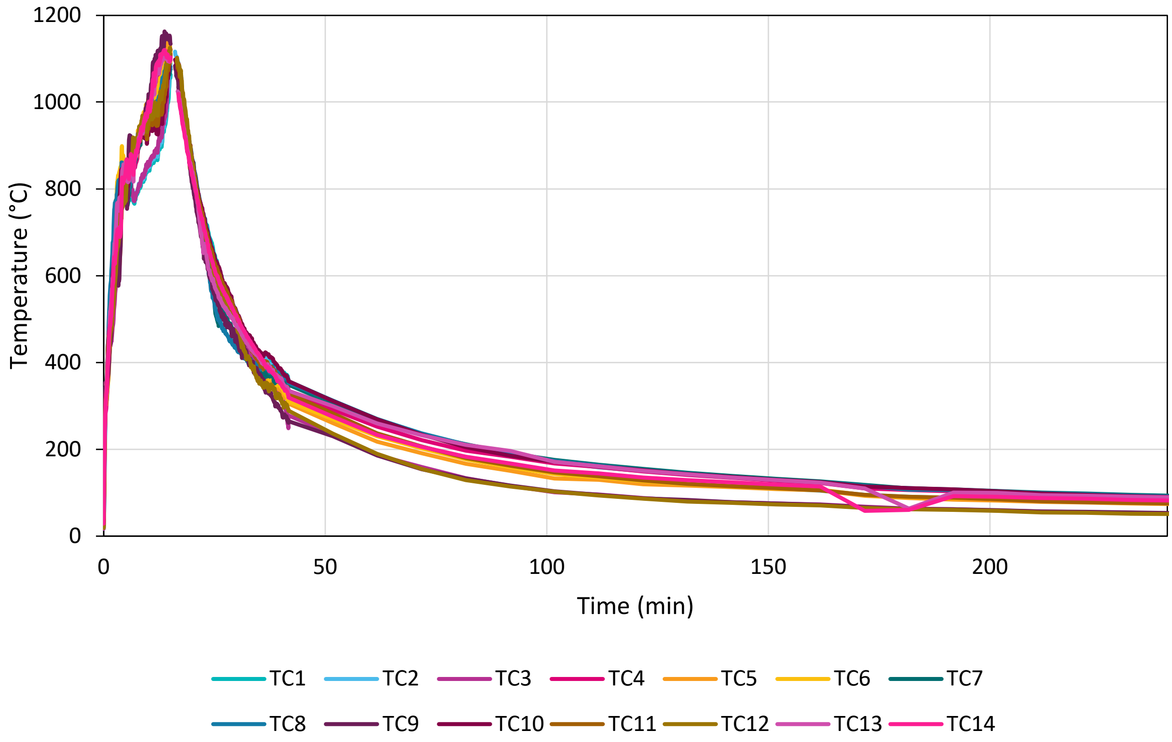


Figure 8 – Atmosphere temperatures during and following the fire experiment

The corresponding readings for the roof structure (unexposed face and interface between board and CLT) are shown in Figures 9 and 10, respectively, for a period of approximately 11.5 hours from ignition. Although the trend identified in Figures 6 and 7 can be seen, it is clear that all temperatures in this area have stabilised or are reducing from about 100 minutes from ignition.

© BRE Global Ltd 2025

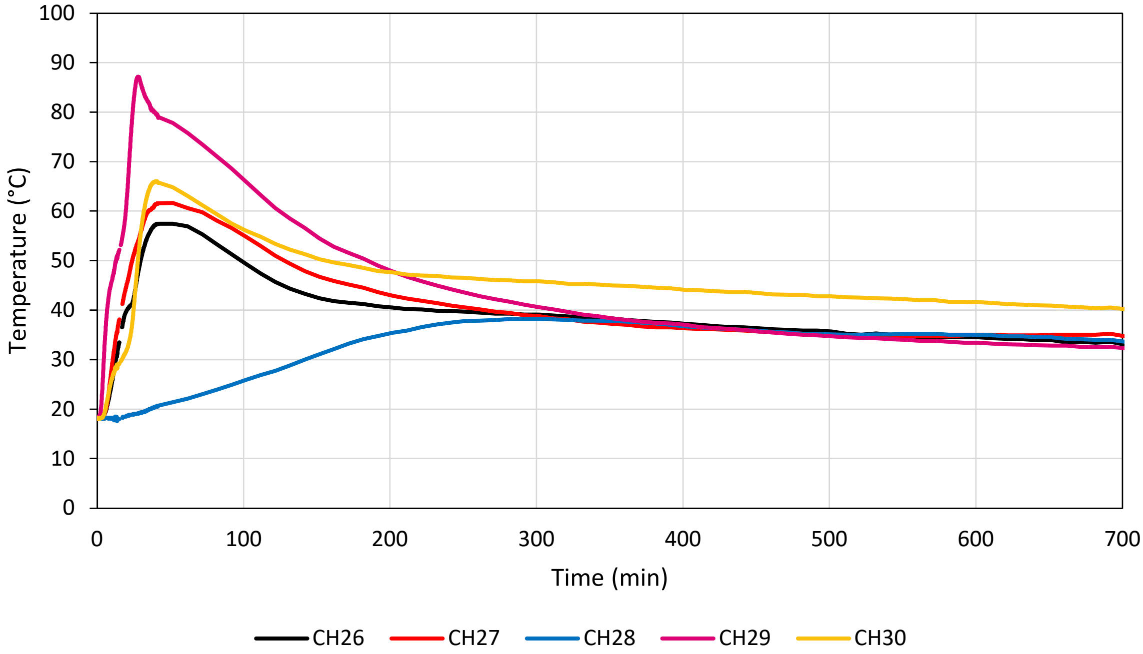


Figure 9 – Temperatures of unexposed face of roof panel overnight

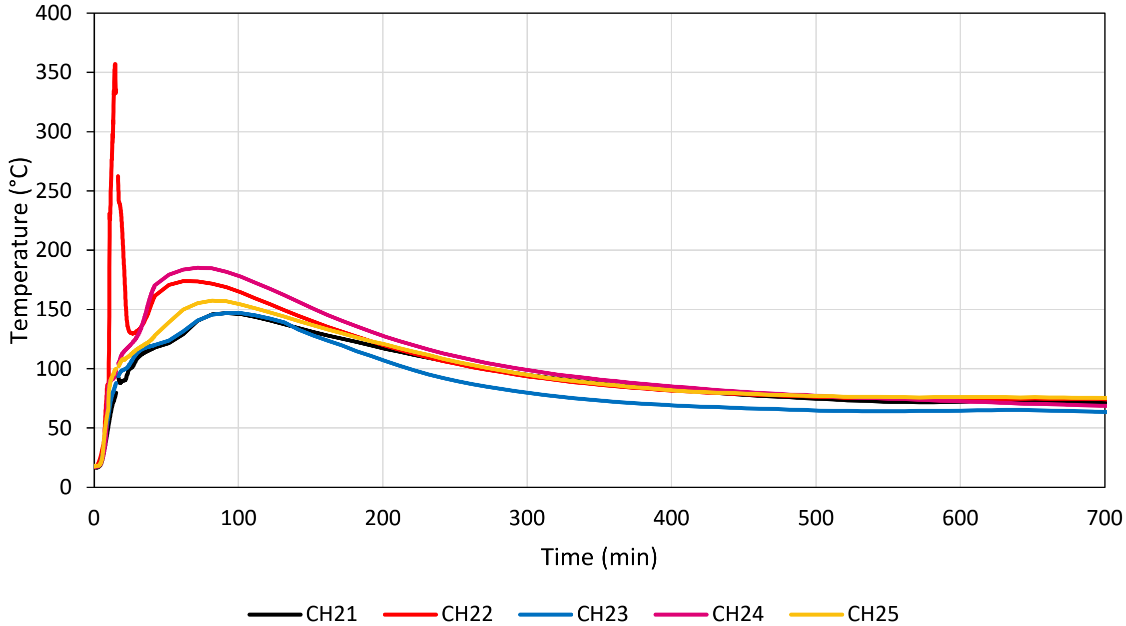


Figure 10 – Temperatures of interface between board and CLT roof panel overnight

The situation is similar for the North and South walls as shown in Figures 11 to 14. However, Figures 15 and 16 show a distinct temperature rise within the East (rear) wall, approximately 5 hours from ignition for the interface and approximately 8 hours from ignition. It is reasonable to assume that the localised increase in temperature on the unexposed face corresponds to burn through of the panel.

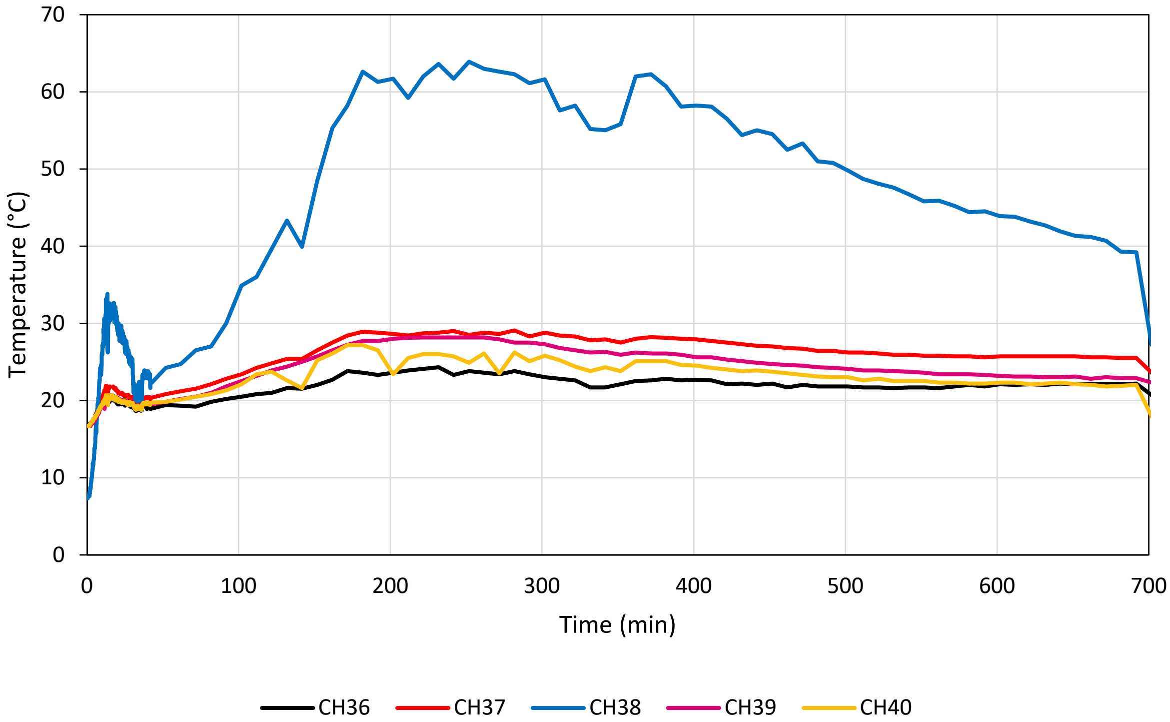


Figure 11 – External temperatures of the North wall over a period of approximately 11.5 hours

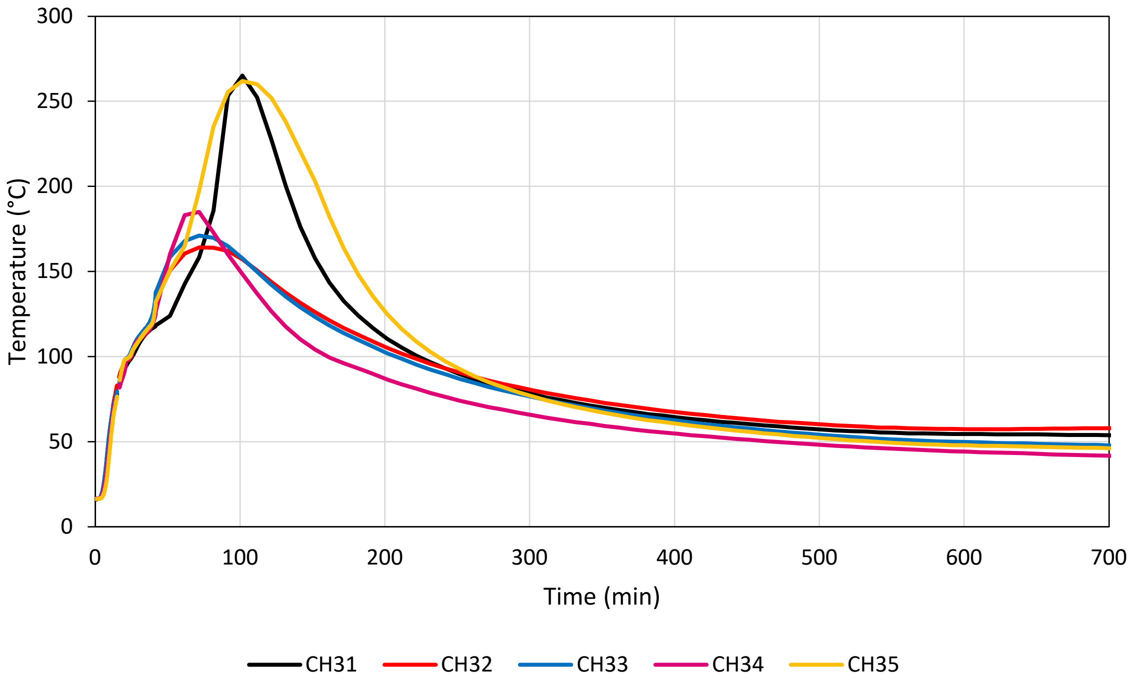


Figure 12 – Board/CLT interface temperatures for North wall over a period of approximately 11.5 hours

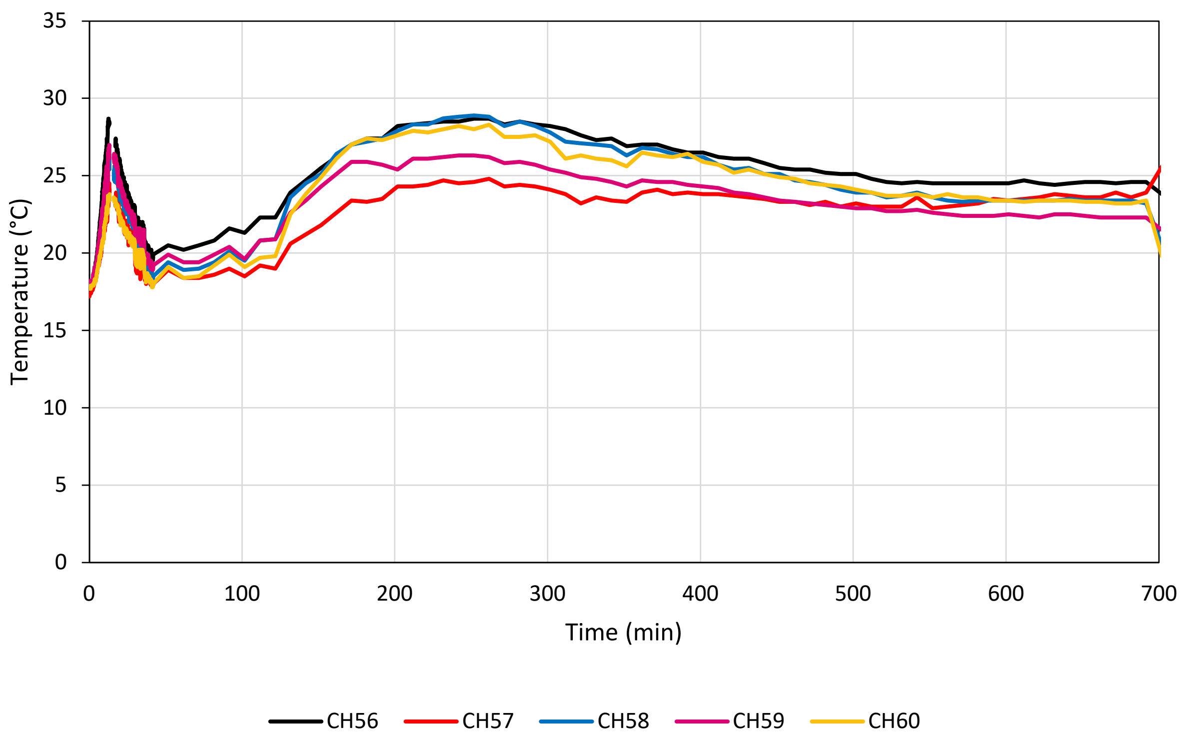


Figure 13 – External temperatures of the South wall over a period of approximately 11.5 hours

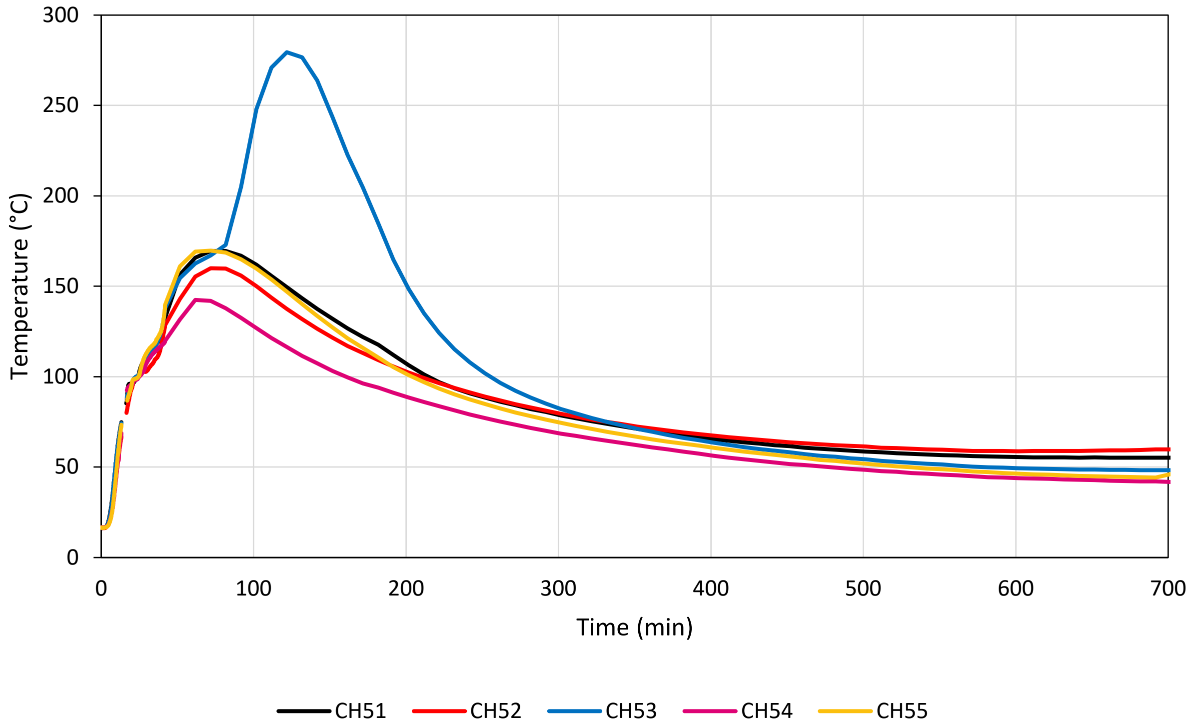


Figure 14 – Fibreboard/CLT interface temperatures for South wall over a period of approximately 11.5 hours

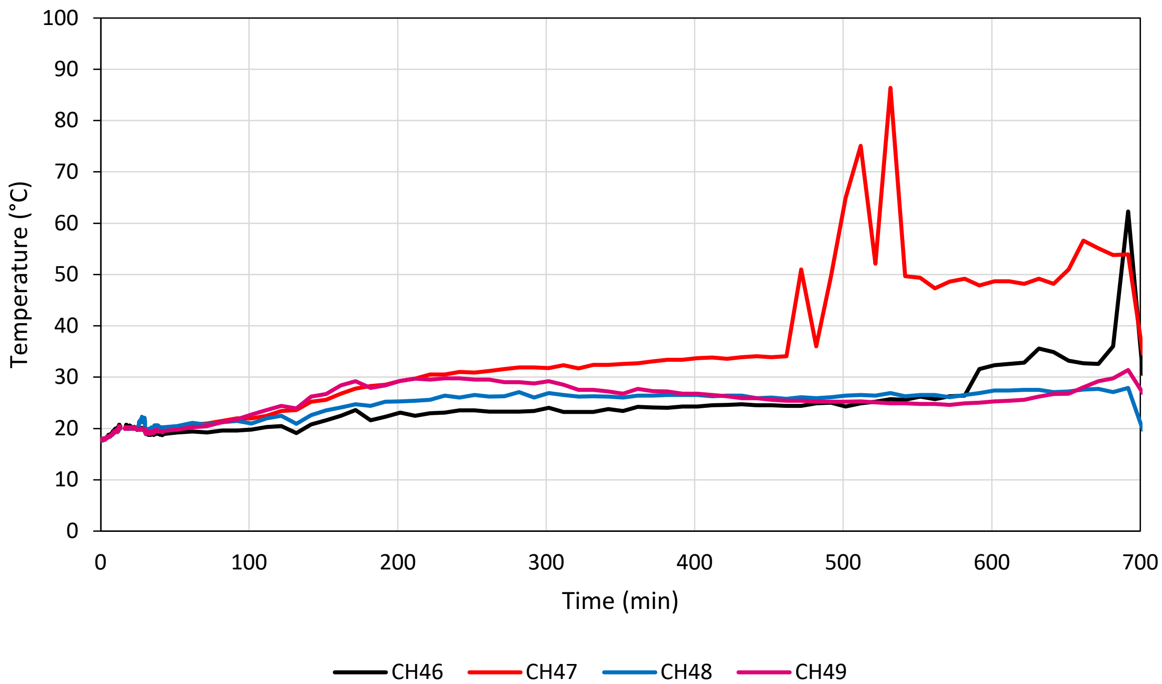


Figure 15 – External temperatures of the East wall over a period of approximately 11.5 hours

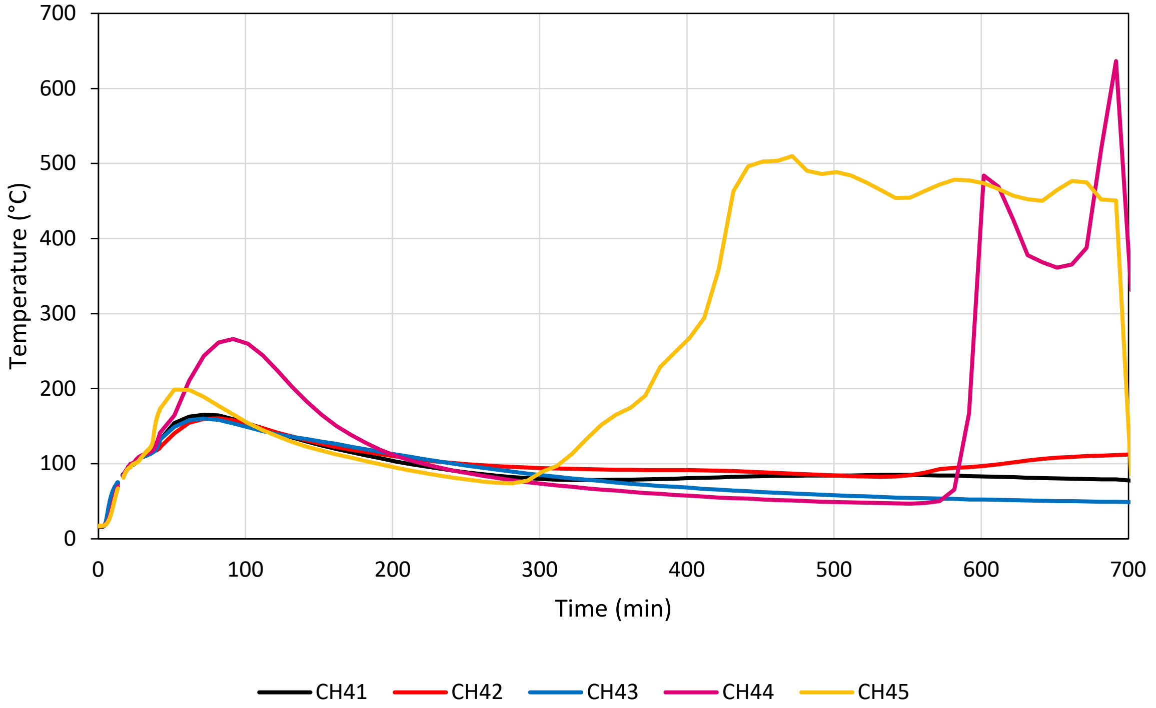


Figure 16 – Board/CLT interface temperatures for East wall over a period of approximately 11.5 hours

The temperature rise noted earlier in Figure 7 was not continued within the specific location within the CLT roof panel as the temperatures had peaked and were falling by the time the measurements were discontinued as shown in Figure 17.

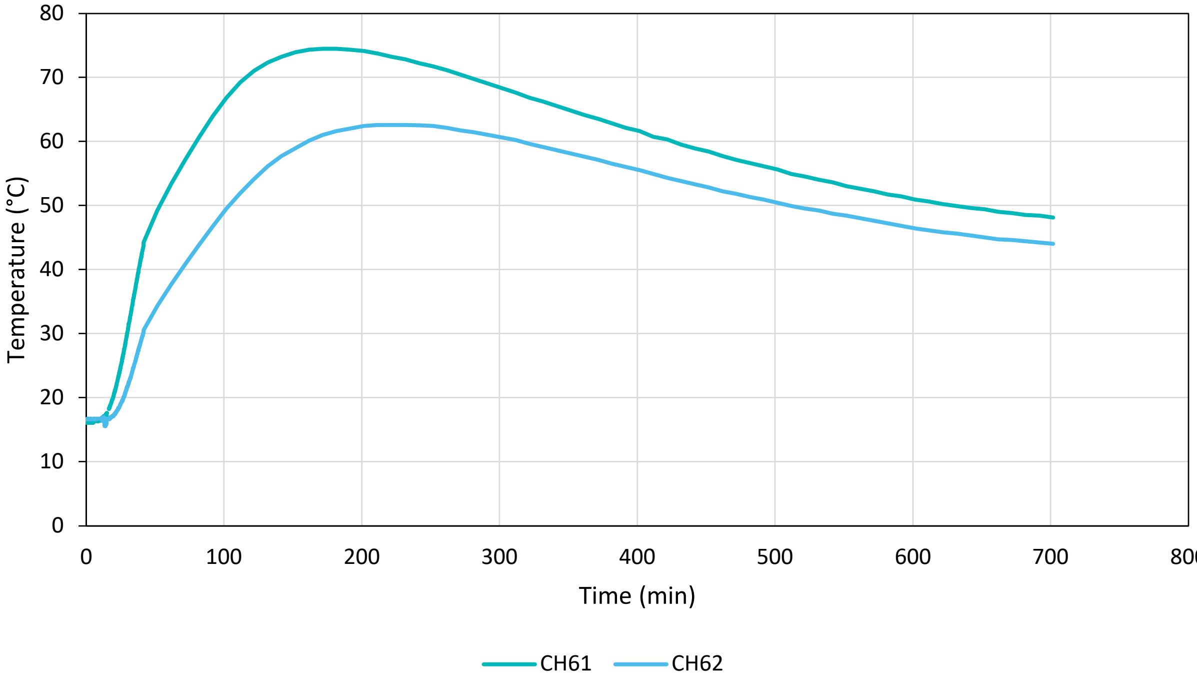


Figure 17 – CLT internal roof panel temperatures over a period of approximately 11.5 hours

Time-lapse photography was continued overnight and shows localised areas of the compartment subject to ignition at various points throughout the night. This localised ignition did not lead to extensive internal or external flaming but does emphasise the localised nature of the smouldering combustion which means it is difficult to interrogate the results from the thermocouples to derive a comprehensive picture of what occurred. Whether the localised smouldering or eventual ignition of the timber coincided with the location of specific thermocouples is largely a matter of chance.

What is clear from observations made on returning to the site on Monday morning is that the smouldering combustion had continued undetected from Friday to Monday morning. The photos below illustrate the extent of the damage at various points including on leaving the Burn Hall at approximately 21.30 on 19th October (Figure 18), towards early morning on 20th October (Figure 19 (external) and Figure 20 (internal) and the following Monday 23rd October.

Figure 18 – Compartment at 21:30 on 19th October

Figure 19 – East (rear) wall early hours of 20th October

Figure 20 – Interior view of compartment early hours 20th October

Figure 21 – Damage to compartment over the weekend

Water was applied to the compartment throughout Thursday night and into Friday before closing up on Friday. Upon arrival on Monday morning, it was clear that further damage had occurred, and parts of the roof structure had been consumed. This was some 89 hours from ignition and again illustrates the timescale required for significant damage to manifest itself. When trying to remove the sandbags and bring down the panels it was clear that the compartment had retained a great deal of strength, and that the fibreboard was still partially intact. The remaining fibreboard was removed with a cordless drill and crowbars. This was a time-consuming and arduous task. The condition of the timber panels away from the smouldering combustion can be seen in Figure 22, while Figures 23 to 25 show the compartment following the removal of the fibreboard.

Figure 22 – Charring of CLT roof panel with intact timber beyond the char layer

Figure 23 – Interior of compartment following removal of gypsum fibreboard

Figure 24 – North wall following removal of the gypsum fibreboard

Figure 25 – West (front) wall following removal of the gypsum fibreboard

3 TF2000 Post-test cavity fire incident

The issue of smouldering combustion was highlighted following the large-scale compartment fire test undertaken at Cardington as part of the TF2000 project[1] in 1999. The original fire was extinguished by the Fire and Rescue Service once specific termination criteria had been achieved. However, some hours after the termination of the fire test, an appreciable amount of steam could be seen emanating from the structure of the building. On further inspection, it was clear that it was not only steam but smoke issuing from the perimeter of the living room window of the fire compartment immediately above the test compartment on the third floor.

Further investigation showed that smoke was emanating from the construction joints in the external brickwork façade suggesting a seat of fire in the external cavity between the brickwork and the timber frame. According to the Fire Service report the emergency call from Cardington, made by the Officer in Charge of the test, was received at 23:48 and the Fire Service arrived at Cardington at 23:55. Once at the scene, the FRS attempted to fight the fire initially from inside the building and were unsuccessful. Shortly after midnight cracks were seen in the external face of the brickwork (Figures 26 and 27) and firefighters withdrew from the building and continued to fight the fire externally from a hydraulic platform.

Figure 26 – Cracking in gable end wall at SW corner of the building

Figure 27 – Cracking in gable wall extending to lower left corner of third floor kitchen window

The fire was eventually brough under control by removing window frames on upper levels and removing the fire protection at the eaves and spraying water directly down the cavity. Where such access to the cavity was restricted holes were made in the brickwork to enable the hoses to be directed towards the seat of the fire (Figure 28).

Figure 28 – Hole made in gable wall by the Fire and Rescue Service

It took some hours to fully extinguish the cavity fire. According to the FRS report, the fire was not brought under control until 05:19 on 16th September (1999). By this time, severe damage to the South wall of the floor above the fire flat had been sustained. The fire consumed the outer layer of OSB and ignited the structural elements in the South wall of the living area. This caused extensive damage to the studs and consumed the ring beam in this area (Figure 29).

Figure 29 – Damage inside the living room of SW flat on the third floor

Data logging for the main fire test commenced at 20:07 and for the figures below this represents time zero. Data logging continued for two hours when the test configuration was shut down. Readings were then taken at an increased scan interval (every 10 minutes) for a further period of approximately 3 hours at which time, due to the amount of water used during firefighting operations, the data acquisition system had to be turned off.

Thermocouples were used to measure the temperature rise in the cavity between the brick cladding and the timber frame. Figure 30 shows the temperature recorded in the external wall cavity between brickwork and timber frame in the south gable wall close to the extreme South West corner of the living room at third floor level.

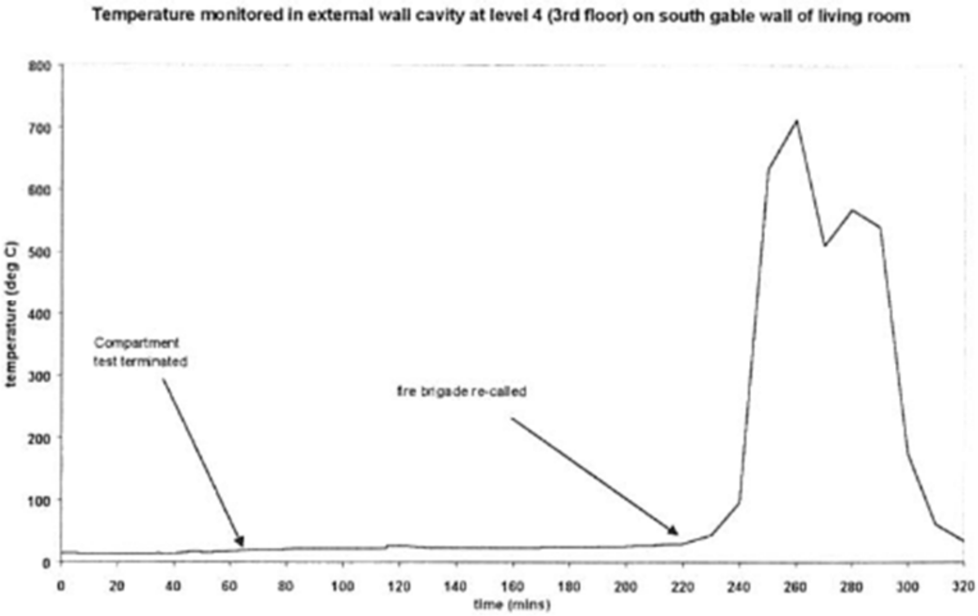


Figure 30 – Temperature monitored in the external wall cavity on the third floor

The data recorded from other cavity thermocouples on the fire floor was inconclusive. Shortly after noticing the hot smoke emanating from the cavity around the living room window opening at the second-floor level, flames could be seen emanating from the cavity around the opening at third floor level.

A post-test inspection provided indisputable evidence that the fire broke through from the cavity to the living area in the flat above the third floor. Figure 31 shows the atmosphere temperature in the living area of the flat above the fire flat. This is inconclusive but shows an increase in the ambient temperature at approximately the same time as the emergency call to the Fire Service was made.

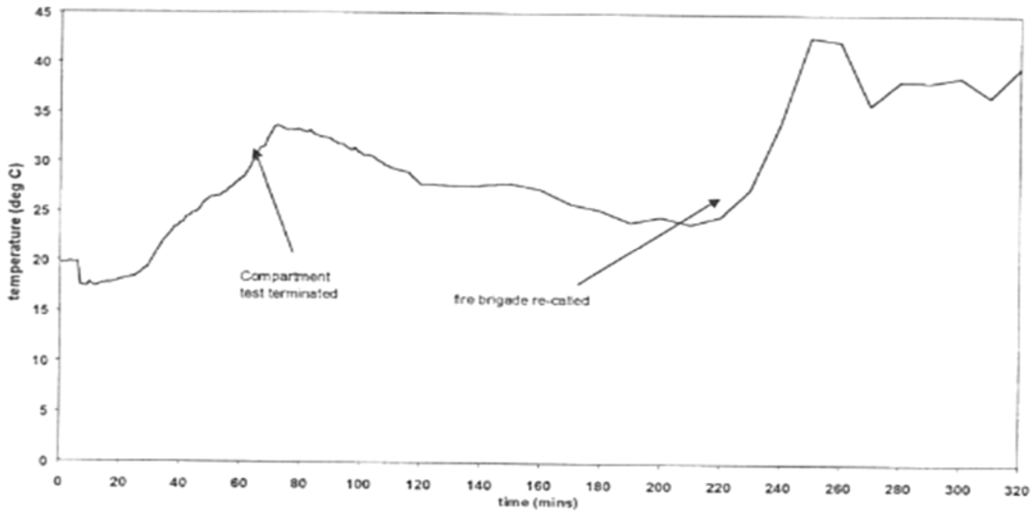


Figure 31 – Atmosphere temperature monitored in the living room of the third floor above the fire flat

Video records indicate the fire began to be effectively fought at approximately 00:30, i.e. coinciding with the peak temperature in Figure 30 at which time the firefighters had gained reasonable access to the seat of the fire.

Based on the results, observations and video evidence, the initial hypothesis was that the fire spread within the cavity was as follows:

1. The initial fire spread into cavity via the window opening in the living room of the fire flat.
2. Horizontal cavity barriers for vertical flame spread between the fire floor and the floor above were ineffective, possibly due to one or a combination of the following:
    a. Discontinuity in the line of the cavity barriers due to them moving under the weight of the bricklayer's mortar deposited on top of them during construction.
    b. Combustion of the timber window frame in the compartment fire test could potentially have allowed flames into the cavity potentially exposing the cavity barrier to an exposure equivalent to or in excess of its required functional performance.
3. The horizontal cavity barriers to mitigate vertical fire spread between the third and fourth floors were ineffective due to the severity of the cavity fire in this area although they may have delayed the spread of fire within the building.
4. The horizontal cavity barriers between the fourth and fifth floors remained intact and effective. They contributed to preventing fire spread to the top floor and roof area.
5. The vertical fire barriers designed to mitigate horizontal (lateral) fire spread remained intact and restricted the fire to the South West corner of the building.

A detailed inspection of the damaged areas of the building was carried out by Tom Lennon (BRE) and Mostyn Bullock (then Chiltern Fire) on 10th December 1999.

Particular attention was paid to attempting to find evidence to validate the above hypothesis that the fire in the cavity originated from the aperture created by damage to the timber frame window of the living room within the fire compartment. However, all the evidence with respect to the charring of timber and the melting of the vapour membrane led to the inescapable conclusion that the original hypothesis was incorrect.

Attention then switched to the timber window of the fire flat which was also discounted as the route of entry of the fire into the cavity. The investigation then focused more closely on the enclosing wall and floor construction.

On removing the remains of some wall plasterboard and insulation material, it was noted that the structural post in the far SW corner of the living room of the fire flat exhibited a greater degree of charring than the adjacent wall studs. This was despite the corner post being formed from several studs fixed back to back to provide a larger section size. On investigation of the charred middle section of the post, it was discovered that it had literally burned right through up to and including the OSB layer facing the cavity. This was the only location of penetration into the cavity found on the fire floor remote from the window locations.

It was evident that a seat of smouldering combustion had remained within the structural post after the initial FRS operation to terminate the compartment fire test. The fact that this penetration into the cavity was just below the ring beam explains why the cavity on the fire floor was relatively unaffected in comparison to the third-floor cavity and also helps to reinforce the opinion that the continuity of the horizontal cavity barrier in the South gable wall between second and third floor had been compromised before the secondary fire event.

As a result of the post-test fire spread within the cavity, a Partners In Innovation research project was undertaken with the title Understanding Fire Risks in Combustible Cavities'. The results from this project have been discussed in greater detail in Task C5 looking at cavity barriers, see Appendix E. However, a number of the conclusions from the investigation have relevance for both cavity barriers and smouldering combustion.

Despite the fact that the main seat of combustion in this instance was due to a hidden seat of smouldering combustion in the corner of the compartment the work also demonstrated the importance of ensuring that the cavity is sealed around window openings.

The efforts of the Fire Service were essential in extinguishing the source of the fire and ensuring the fire spread and subsequent structural damage were limited. Following the test, discussions were held between the experimental staff and the leading firefighters who attended the test and the subsequent call-out. A number of issues relevant to firefighting operations were addressed and included:

1. On arrival, the Fire Service was faced with smoke emanating from the construction joints in the brickwork. The initial strategy was simply to hose down the window frames and external wall from the outside. This had little or no effect on the fire.
2. Following discussion with experimental staff, the plan of action was changed in order to get water into the cavity area. Fire Service personnel entered the building to remove the window frames on the floors above in order to get the hoses into the affected area. This proved difficult, time-consuming and ineffectual.
3. During firefighting operations, cracks appeared in the South gable wall giving the Officer in Charge (OIC) cause for concern over the structural stability of that part of the building. At this point, the OIC ordered firefighting personnel to evacuate the building and firefighting continued externally using a hydraulic platform.
4. As a result of discussions with the test engineers, firefighting attention focused on the roof area. The fire-resistant blanket used to prevent fire spread under the eaves during the test was removed to allow access to the cavity from the top of the building. This approach proved successful in suppressing the fire.
5. The use of an Infra-Red Thermometer or Thermal Imaging Camera allowed officers to identify the seat of the fire in the cavity and to optimise efforts towards the critical locations. This was particularly useful once the extent of the fire had been reduced and helped to prevent re-ignition.
6. The only effective way to access the cavity through the gable masonry wall was to use a hammer and chisel. This is a laborious operation and could lead to a potential localised collapse in areas where the brickwork had already cracked.

Based on the experience gained on the night and subsequent discussions with Fire Service Officers, it was evident that there was a role in educating firefighters to prepare the most appropriate strategy in dealing with fires of this nature in this form of construction. On arrival, it is not immediately apparent to the Fire Service that it is the timber members and not the brickwork which forms the structural frame for such buildings. A better understanding of this form of construction could assist in more quickly being able to identify and deal with concealed fire spread.

The words above were written in 1999 but there remains a need for ongoing dialogue between the Fire and Rescue Service, the timber frame industry (both timber frame and mass timber), independent fire researchers and government officials to ensure that issues around how to deal with smouldering combustion and concealed fire spread are understood.

4 Review and analysis of large-scale fire tests involving CLT

Cross Laminated Timber (CLT) has gained popularity as a sustainable construction material due to its environmental benefits, structural properties, and aesthetic appeal. However, the fire performance of CLT can be a concern, particularly with regard to smouldering combustion. Smouldering is a slow, low-temperature, flameless form of combustion that can persist and reignite even after flames have been extinguished. Understanding smouldering combustion in CLT is crucial for improving fire safety in buildings constructed with this material.

Smouldering combustion in CLT occurs in the solid phase at temperatures ranging from 200°C to 500°C, characterized by a slow oxidative process. Unlike flaming combustion, which is self-propagating due to gas-phase reactions, smouldering can continue beneath the surface, making it challenging to detect and extinguish. Smouldering can propagate through the timber layers, even in the absence of visible flames, making it a critical concern for the fire safety of CLT structures[2].

The type of wood, density, and adhesive used in CLT significantly impact the smouldering behaviour. Higher-density woods smoulder more slowly but sustain combustion longer due to their higher energy content. The adhesives used can influence the thermal degradation pathways, affecting the initiation and propagation of smouldering. For example, phenol-formaldehyde resins may enhance smouldering resistance compared to polyurethane adhesives due to their higher thermal stability[3].

The moisture content is an important factor in the smouldering combustion of CLT. High moisture levels inhibit smouldering by absorbing heat and increasing the energy required for ignition. On the other hand, low moisture content facilitates smouldering due to easier thermal degradation. Moisture acts as a thermal buffer, delaying the onset of combustion and affecting the heat release rate during smouldering[4].

Environmental factors such as oxygen availability can influence smouldering in CLT. Reduced oxygen levels can suppress flaming combustion but may not prevent smouldering[5]. Experimental studies have demonstrated that when smouldering in CLT is initiated it can propagate through the timber layers, sustained by the slow oxidation of the wood. The rate of propagation depends on material properties, moisture content, and environmental conditions. Smouldering can persist for extended periods, leading to significant charring and structural damage[4].

The cooling or decay phase is not typically addressed explicitly within prescriptive building codes and standards. During this phase, the temperatures within structural elements can continue to rise even after the fire has been extinguished. For concrete structures, the core rarely exceeds 300 to 500°C, which is below the threshold for significant structural damage[6]. However, timber is much more susceptible to damage at lower temperatures, losing a substantial portion of its compressive strength and stiffness at just 100°C, and all strength and stiffness at 300°C[7].

Experimental tests[8] have shown that, even after a fire self-extinguishes, the internal temperatures of timber can continue to rise. Specifically, the 200°C isotherm can continue to increase for an additional 10 minutes, and the 100°C isotherm can penetrate deeper into the material for 30 minutes after the fire has gone out. This thermal lag can cause temperatures in the uncharred timber to increase during the decay phase and can generate smouldering combustion. Cracks in the char layer or gaps in connections can accelerate this heat transfer, exacerbating the problem[6].

Eurocode 5[9], which utilizes the standard time-temperature curve, does not account for the delayed heating in timber and the associated loss of strength. Heat transfer calculations based on Eurocode 5 applied to a glued laminated timber column showed that, while it retained 45% of its original crushing capacity immediately after a 90-minute fire resistance test, this capacity dropped to less than 13% within 2 to 3 hours post-fire[7].

A method used to prevent timber from reaching pyrolysing temperatures (above 200°C) is to encapsulate it with protective layers such as gypsum plasterboard. The ability of a protective layer to maintain protection from the increased temperature on the unexposed side is part of current standards for gypsum plasterboard and other protective claddings. The performance of protective claddings is classified as K1 (10, 30, 60) and K2 (10, 30, 60), based on their ability to prevent temperature rise behind the layer to certain thresholds (270°C or 290°C), in accordance with EN 13501-2[10]. These criteria are approximations to account for the failure (or fall-off) of thermally degraded material layers and are not specifically adapted for combustible structures like timber, where pyrolysis typically starts at around 200°C [6,11,12]. This method does not account for measurements of the smouldering combustion several hours following the standard fire resistance tests.

A significant experimental fire test programme has been conducted on mass timber to understand its behaviour under standard and natural fire conditions[13,14]. A selection of large-scale tests with a particular focus on smouldering combustion is presented below.

The study by Mindeguia et al. was part of *The Epernon Fire Tests Programme*, a multi-partner collaborative project aimed at analysing the behaviour of combustible and non-combustible loaded CLT slabs under standard and natural fire exposures[15].

Two standard fire tests were conducted in accordance with BS EN 1363-1[16], and three natural fire tests were conducted using a compartment with internal dimensions of 6.0 m x 4.0 m x 2.52 m (L x W x H) under three different ventilation conditions: opening factors of 0.14 $m^{1/2}$ (Scenario 1), 0.05 $m^{1/2}$ (Scenario 2), and 0.03 $m^{1/2}$ (Scenario 3) as shown in Figure 32. The fuel load consisted of wood cribs with a fuel load density of 891 MJ/m². In all tests, the slabs were mechanically loaded using five steel beams with a total weight of 29.50 kN, corresponding to 0.10 kN/m² partitions, 1.50 kN/m² floor covering, and 0.50 kN/m² variable actions, following Eurocode guidance.

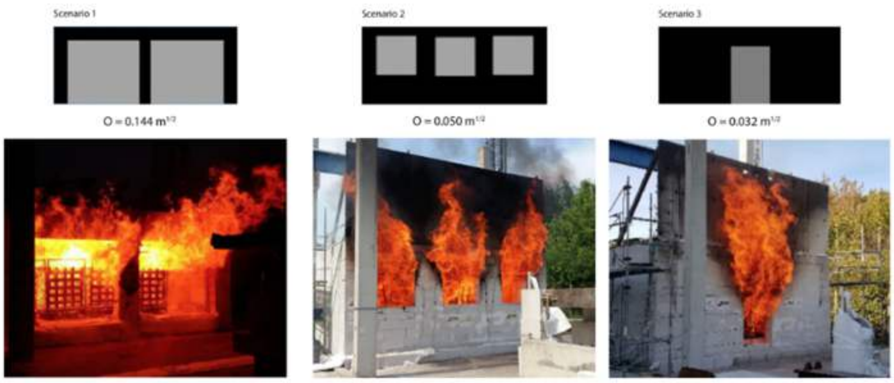


Figure 32 – Fire scenarios used in the Epernon natural fire tests[15]

The natural fire tests exhibited a higher heating rate compared to the standard fire tests, although maximum temperatures were similar, reaching approximately 1200°C, as shown in Figure 33. Localised delamination was observed in both the standard furnace and compartment tests. The charring rates in the standard fire tests were 0.79 and 0.81 mm/min, higher than the 0.65 mm/min rate provided by EN 1995-1-2[9] for solid wood.

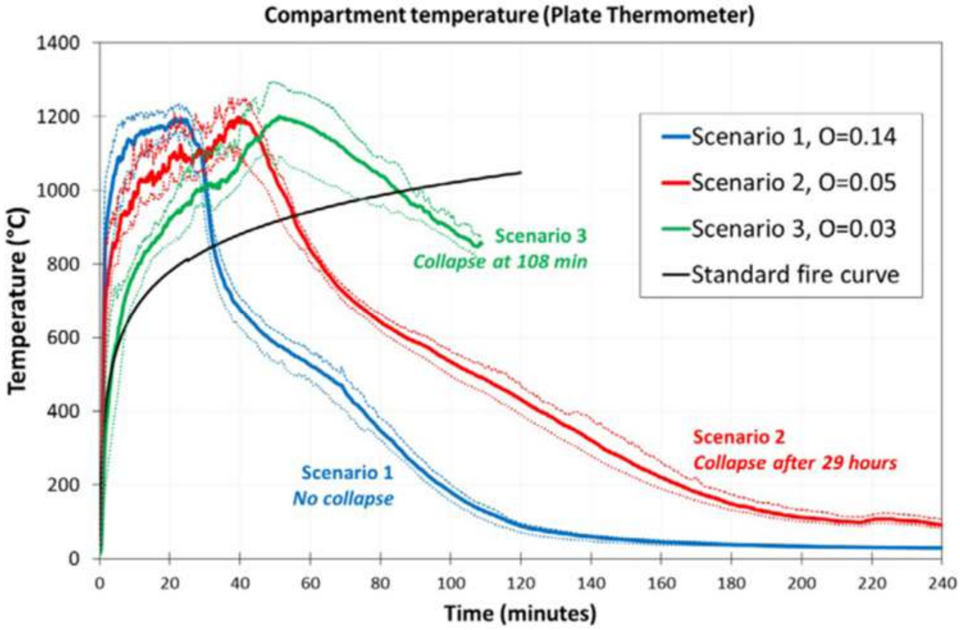


Figure 33 – Time-temperature curves inside the compartment for the three scenarios

The collapse of the slabs under standard fire exposure occurred during the decay phase after the burners were turned off, with mechanical loading less than 10% of the original load. This occurred at 203 and 179 minutes for the two standard fire tests. The acceptability criteria of 475.1 mm deflection, calculated using EN 13501-2[10], were exceeded after 131 and 141 minutes. In the natural fire tests, the CLT slab in Scenario 2 collapsed 29 hours after the test started due to smouldering, while failure in Scenario 3 occurred at 108 minutes. The slab in Scenario 1 survived burn out, maintaining stability indefinitely without intervention. The authors concluded that in Scenario 2 the collapse may have been caused by smouldering combustion. However, the issue around smouldering combustion was not addressed in the research presented.

Hevia conducted a series of three-compartment fire tests at the Carleton University Fire Research Laboratory in Canada[17]. The compartment, constructed using CLT panels, measured 4.5 m x 3.5 m x 2.5 m (L x W x H) with a 1.07 m x 2.0 m (W x H) door opening in the short wall. The tests involved three different wall configurations based on the area of CLT exposed: Test 1: Room with adjacent exposed walls (52.8% unprotected wall area), Test 2: Room with facing exposed long walls (59.4% unprotected wall area) and Test 3: Room with one exposed long wall (29.7% unprotected wall area). The unexposed wall parts and the ceiling were protected with two layers of 12.7 mm-thick Type X gypsum plasterboard.

The study concluded that fire-rated sealant is necessary to seal wall-to-floor joints and lap joints between CLT panels. Flaming from underneath the last layer of gypsum protection was observed, indicating that without sealant, hot gases could escape through gaps between CLT panels, leading to external flaming. Premature delamination occurred in Test 1 (Figure 34) and Test 2, adding fuel to the fire and causing a second flashover, which did not occur in Test 3 due to the different CLT panel construction (wider plies with more adhesive, contributing to full charring without delamination).

Premature delamination of the CLT

Reignition in the corner of the room leading to the second flashover

Flames escaping through the joints of the last protective layer

Figure 34 – Observation during Test 1 showing delamination and reignition[17]

Average charring rates for Tests 1, 2, and 3 were 0.69 mm/min, 0.77 mm/min, and 0.71 mm/min, respectively, higher than the 0.65 mm/min typically cited for standard fire tests. Test 2 had the highest charring rate due to significant radiation exchange between the two exposed walls. In all tests, the charring rate decreased linearly as the char layer developed. Self-extinction occurred in Test 3, unlike in Tests 1 and 2, which had to be manually extinguished. However, water was applied in Test 3 at the end of the test, after 80 minutes. Smouldering over time was not considered in this study.

Emberley et al. conducted a large-scale compartment fire test alongside small-scale tests using a cone calorimeter to determine self-extinction criteria for CLT. The compartment measured 3.5 m x 3.5 m x 2 m (L x W x H) with a 0.85 m x 2.1 m (W x H) door opening[18].

The small-scale tests revealed that the critical heat flux for the self-extinction of Radiata Pine CLT is 45 kW/m². The time to steady-state burning was reported as 10 minutes, and the minimum delamination time was reported as 30 minutes.

The compartment had an exposed ceiling and an exposed wall, with the remaining walls unexposed. The unexposed CLT panels were protected with two 13 mm-thick layers of type F plasterboard secured at 200 mm spacing. The front wall was extended 2.7 m vertically to simulate an additional floor level, constructed using a light timber frame and entirely covered with two 13 mm-thick layers of type F plasterboard (Figure 35).

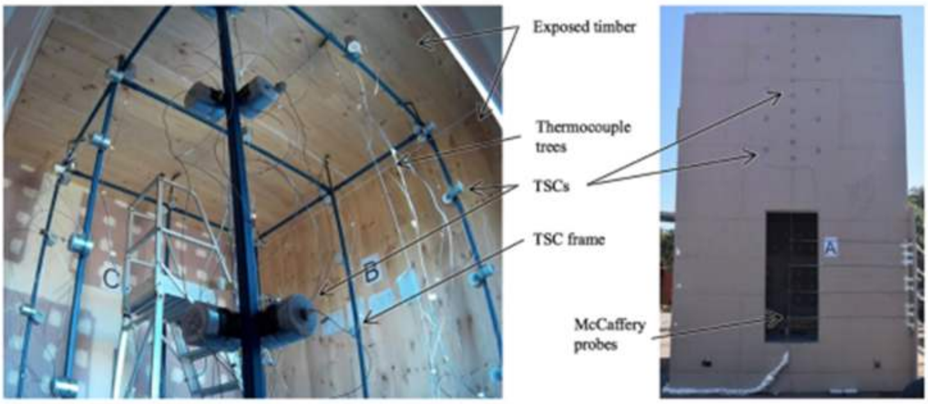


Figure 35 – Internal and external view of the compartment[15]

No delamination occurred during the test, indicating that if delamination is prevented, self-extinction can occur in a compartment with partially exposed walls and a fully exposed ceiling. Self-extinction of the exposed CLT wall and ceiling occurred when the maximum incident heat flux dropped below 45 kW/m², beginning at the base of the exposed wall and progressing to the ceiling. The termination of the test was after 5 hours and 32 minutes. However, it is not specified if any water was applied at the end of the test or if the sample was left to observe smouldering combustion over time.

Su et al. conducted compartment fire tests as part of the Fire Safety Challenge of Tall Wood Buildings – Phase 2 project by the Fire Protection Research Foundation. This study consisted of six tests without sprinklers or firefighting intervention, aimed at quantifying the contribution of CLT to compartment fires[19].

The test compartments measured 9.1 m x 4.6 m x 2.7 m (L x W x H) and the door openings varied in size: four tests had openings of 1.8 m x 2.0 m (W x H), and two tests had openings of 3.6 m x 2.0 m (W x H). Surfaces were protected either fully or partially with multiple layers of 15.9 mm-thick Type X gypsum plasterboard. The fire load consisted of residential furnishings, with a movable fire load density of 550 MJ/m². A schematic of the fire compartment setup is shown in Figure 36.

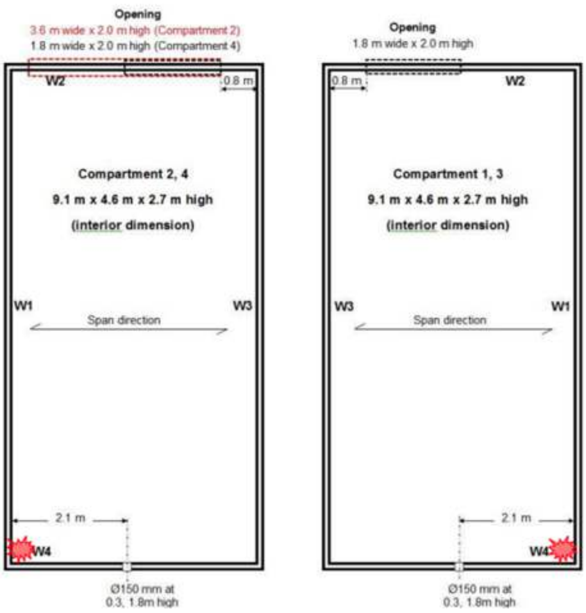


Figure 36 – General view of the test compartments[19]

The matrix of the CLT compartments is illustrated in Figure 37, with Tests 1-1 and 1-2 serving as baselines to assess the contribution of the movable fire load.

Rough Opening in Wall W2	Compartment Surface					Test	CLT Compart-ment	Date
	W1 9.1 m x 2.7 m	**W2** 4.6 m x 2.7 m	**W3** 9.1 m x 2.7 m	**W4** 4.6 m x 2.7 m	**Ceiling** 9.1 m x 4.6 m			
1.8 m wide x 2.0 m high	3GB	3GB	3GB	3GB	3GB	1-1	1	Feb. 16
	3GB	3GB	3GB	3GB	**exposed**	1-4*	1*	Mar. 21
	exposed	3GB	3GB	3GB	**3GB**	1-5	4	Apr. 13
	exposed	3GB	3GB	3GB	**exposed**	1-6	3	Apr. 18
3.6 m wide x 2.0 m high	2GB	2GB	2GB	2GB	2GB	1-2	2	Feb. 23
	exposed	2GB	2GB	2GB	3GB	1-3*	2*	Mar. 16

GB: 15.9 mm (5/8 in.) thick Type X gypsum board; 2GB: 2 layers of GB; 3GB: 3 layers of GB
** Reused CLT structure.*

Figure 37 – Text matrix for the CLT compartments

The size of the openings significantly impacted fire development. Smaller openings led to longer fire durations due to limited ventilation, causing greater involvement of the CLT elements. Larger openings resulted in higher peak HRR but for a shorter duration.

Tests 1-1 and 1-2, with fully protected CLT compartments, established baselines by measuring the contribution of the movable fire load. The use of gypsum board as a protective barrier effectively delayed or prevented the ignition of CLT elements. In Test 1-1, the three-layer gypsum board system completely protected the CLT (Figure 38). Test 1-2, with a two-layer gypsum board system, also successfully protected the CLT, limiting its involvement in surface charring without contributing to the fire (Figure 39).

© BRE Global Ltd 2025

Test 1-1 – gypsum boards remained: 2 layers on the ceiling and 3 layers on the walls

After the removal of the protective layers

Figure 38 – Compartment view at the end of Test 1-1 and removal of the remaining layers

Test 1-2 – gypsum boards remained: 1 layer on the ceiling and 2 layers on the walls

After the removal of the protective layers

Figure 39 – Compartment view at the end of Test 1-2 and removal of the remaining layers

Ventilation plays a significant role in fire development. In Test 1-2, a larger opening accelerated combustion increased exterior exposure, and shortened the intense burning duration, while a smaller opening in Test 1-1 delayed decay, extending the fully developed phase.

Partially exposed CLT structures in Tests 1-3 (Figure 40), 1-4 (Figure 41), 1-5 (Figure 42), and 1-6 (Figure 43) contributed to the fires to varying degrees based on exposed surface area and ventilation conditions. Test 1-3, with a larger opening, showed higher initial HRR and exterior heat fluxes, followed by decay and minor increases due to CLT delamination. Test 1-5, with a smaller opening, trapped more heat inside, leading to a second flashover and full involvement of all panels after delamination.

In tests with exposed CLT surfaces, flashover occurred earlier than in the baselines, adding more fuel to the fire from the CLT panels and either experienced a second flashover or continuous intense burning without decay, except for Test 1-3, which exhibited decay.

Both Test 1-1 and 1-2 did not show any signs of smouldering combustion after the fire test.

 © BRE Global Ltd 2025

Test 1-3 – gypsum boards remained: 2 layers on the ceiling and 2 layers on the walls (W3 and W4)

After the removal of the protective layers

Figure 40 – Compartment view at the end of Test 1-3 and removal of the remaining layers

Test 1-4 – second flashover at 151 min followed by termination

After the removal of the protective layers

Figure 41 – Compartment view at the end of Test 1-4 and removal of the remaining layers

Test 1-5 – second flashover at 155 min followed by termination

After the removal of the protective layers

Figure 42 – Compartment view at the end of Test 1-5 and removal of the remaining layers

Test 1-6 – integrity failure at 160 minutes followed by termination

After the removal of the protective layers

Figure 43 – Compartment view at the end of Test 1-5 and removal of the remaining layers

Mitchell et al. investigated the phenomena of smouldering combustion in mass timber structures and its implications for fire safety[20]. This study is observing smouldering combustion in large-scale timber compartments, specifically focusing on cross-laminated timber (CLT) ceilings and glulam columns. The CodeRed experimental series comprised a 352 m^2 compartment with a CLT ceiling and two glulam columns, as shown in Figure 44. In the three experiments reviewed, the ventilation and level of encapsulation were varied to investigate their impact on fire dynamics and charring during and after the end of the fire.

Figure 44 – CodeRed compartment[20]

The research identified 19 smouldering hotspots in three separate experiments within large timber compartments. These hotspots were typically located along the edges of timber slabs, connections between slabs, and interfaces between timber and other materials like concrete. The hotspots were observed to develop over hours and even days after the visible flames had been extinguished. In some cases, these smouldering areas grew large enough to create holes in the CLT ceiling or cause structural elements like glulam columns to collapse.

The study utilised infrared (IR) imaging and thermocouples to detect and monitor smouldering (Figure 45). This was crucial as smouldering is not always visible to the naked eye, especially when it occurs within concealed or internal parts of the timber structure. The research showed that traditional post-fire inspections might miss these hotspots, as they are often hidden and not detectable without specialised equipment.

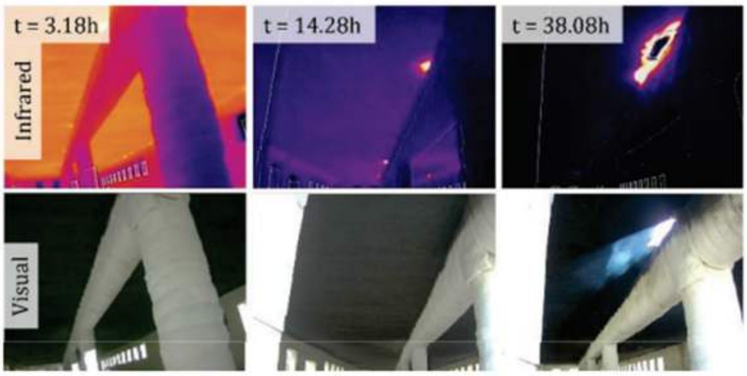
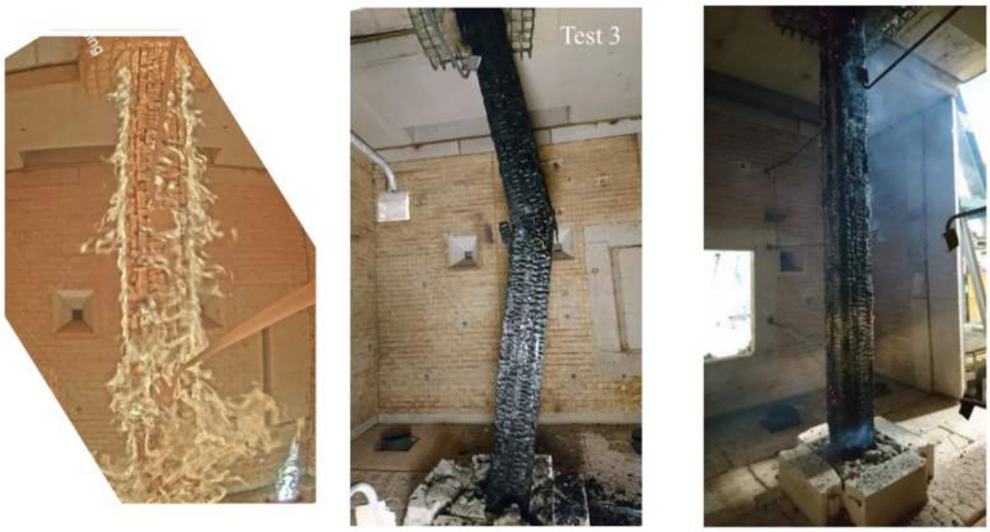


Figure 45 – Hotspots visible in infrared[20]

Encapsulation, commonly used in mass timber buildings to protect against fire by covering timber surfaces, was found to be only partially effective. While encapsulation might protect against the initial fire, smouldering can still occur beneath these layers or spread from exposed areas to encapsulated ones. In one experiment, smouldering spread under the encapsulation and caused significant damage, eventually leading to a large section of the encapsulated ceiling collapsing.

The study highlights that smouldering presents a significant structural hazard in mass timber buildings. Smouldering can severely weaken structural elements, posing a risk of collapse long after the fire is believed to be extinguished. Additionally, smouldering can transition back to flaming combustion if conditions like increased oxygen supply occur, potentially igniting new fires and creating further damage.

Gernay et al. focused on understanding the stability of fire-exposed structures, particularly timber and concrete columns, during and after the burn out phase[21]. Conventional fire resistance tests primarily assess structural performance under continuous heating until failure, without considering the cooling phase that follows burn out. This research addresses the gap by exploring the stability of structural elements throughout the entire fire event, including the cooling phase, using a new experimental method that evaluates the Duration of Heating Phase (DHP). Full-scale furnace tests were conducted on both reinforced concrete and glued laminated timber columns (Figure 46). Each set of experiments involved several identical specimens subjected to different durations of heating based on the ISO 834 fire curve, followed by controlled cooling. The key variable was the heating duration, which was systematically varied to determine the point at which the columns could no longer maintain structural stability.



Test 2 (failed during heating) Test 3 (failed during cooling) Test 4 (survived the fire)

Figure 46 – Timber columns fire tests[21]

The eight tested timber members showed that the columns, which had a fire resistance of 55 to 58 minutes under continuous heating, could fail during the cooling phase after much shorter heating durations (10 to 15 minutes) due to smouldering combustion. The experiments demonstrated that structural failures could occur during the cooling phase, well after the heating phase has ended. This finding highlights the importance of considering the entire fire event, including the cooling phase, when assessing the fire resistance of structural elements.

The large-scale fire test undertaken at BRE fire testing facilities comprised a CLT compartment fully encapsulated. The encapsulation is made of two layers of 18 mm thick type F protection boards installed on the walls and ceiling. The compartment had a floor area of 14.5 m^2 with a single opening (door) as shown in Figure 47. The opening factor is 0.058 $m^{1/2}$ and the movable fire load used is 690 MJ/m^2 which will provide an equivalent fire exposure of 60 minutes to the standard fire curve.

Figure 47 – General view of the encapsulated CLT compartment

The heating phase duration was approximately 15 minutes with peak temperatures inside the compartment of 1100°C. After 60 minutes, the gas temperature inside the compartment was below 250°C. Figure 48 shows the compartment immediately following the flashover and at the end of the fire when the moveable fire load had been fully consumed. At this stage, it can be considered that the sample survived the burn out of the fire load inside the compartment. The measurements are continued to observe smouldering combustion.

Flashover phase (3 minutes) Burn out of the movable fire load (60 minutes)

Figure 48 – Flashover and burn out of the combustible materials

After 12 hours after the beginning of the experiment, smouldering combustion was observed to generate an integrity failure through the back side of the compartment wall (Figure 49). At this stage, water was applied inside the compartment and the data capturing was stopped.

Figure 49 – Smouldering combustion through the back wall

Figure 50 shows the time-temperature curve recorded inside the compartment and the temperatures at the interface layer between the protection and the CLT, on the East wall. It can be seen that smouldering combustion is captured by two instruments after eight hours from the beginning of the experiment.

The temperatures recorded with values of 500°C to 600°C at these locations show that smouldering combustion has transitioned to flaming combustion and justifies the presence of oxygen. This means that at these locations the smouldering combustion process may have burned through the wall.

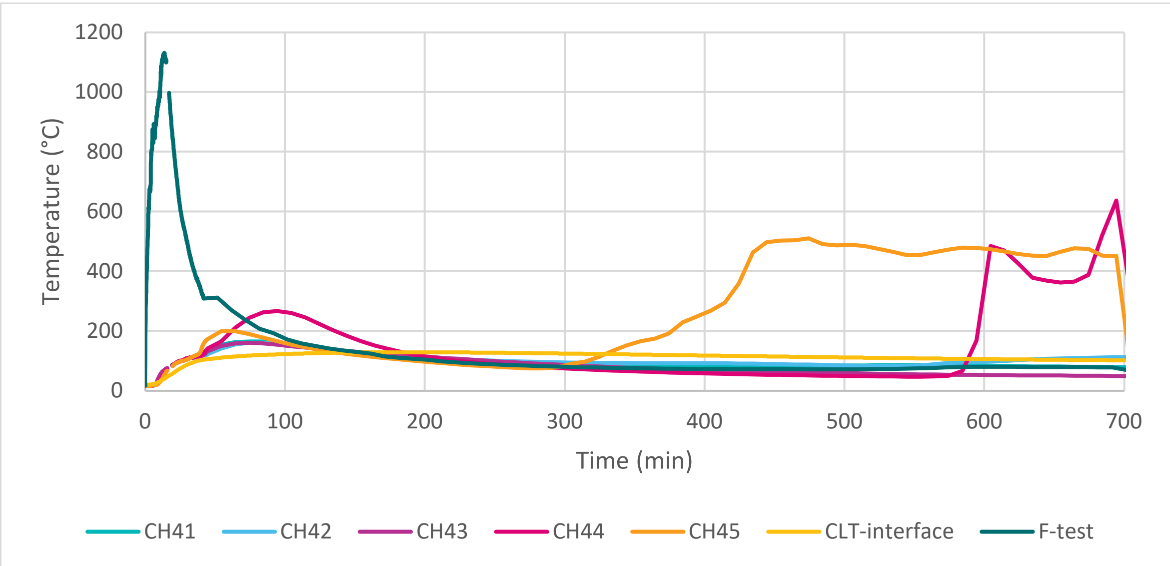


Figure 50 – Time-temperature inside the compartment and interface layer on the East wall

Figures 51 and 52 show the compartment after 90 hours from ignition and water application after 8 hours. Charring of the CLT surface in random areas can be observed. In other areas, the surface of the CLT is intact. Significant charring can be seen where the instruments have been installed through the CLT and the protection. The smouldering combustion process consumed a significant part of the ceiling/floor slab and some parts of the walls.

Figure 51 – View of the compartment after 90 hours

In this particular experiment, it seems that the smouldering combustion is more prominent on the ceiling/floor slab than on the walls even if the same level of protection was used. No conclusions have been drawn as to what may have been generating the prolonged smouldering combustion.

Figure 52 – Consumption of parts of the floors and walls

 © BRE Global Ltd 2025

5 Initial heat transfer analysis

The purpose of the numerical analysis is to explore the heat transfer through the protection layer to the CLT interface. The analysis comprises numerical validation and calibration based on the large-scale fire experiment and explores other possible variations to understand the heat transfer in the heating and cooling phase of the fire.

5.1 Material properties

The apparent temperature-dependent material properties used for timber are adapted from EN 1995-1-2[9] and for the gypsum fibreboard type F protective layer from the literature[22]. Figure 53 shows the temperature-dependent thermal properties adopted for the gypsum fibreboards.

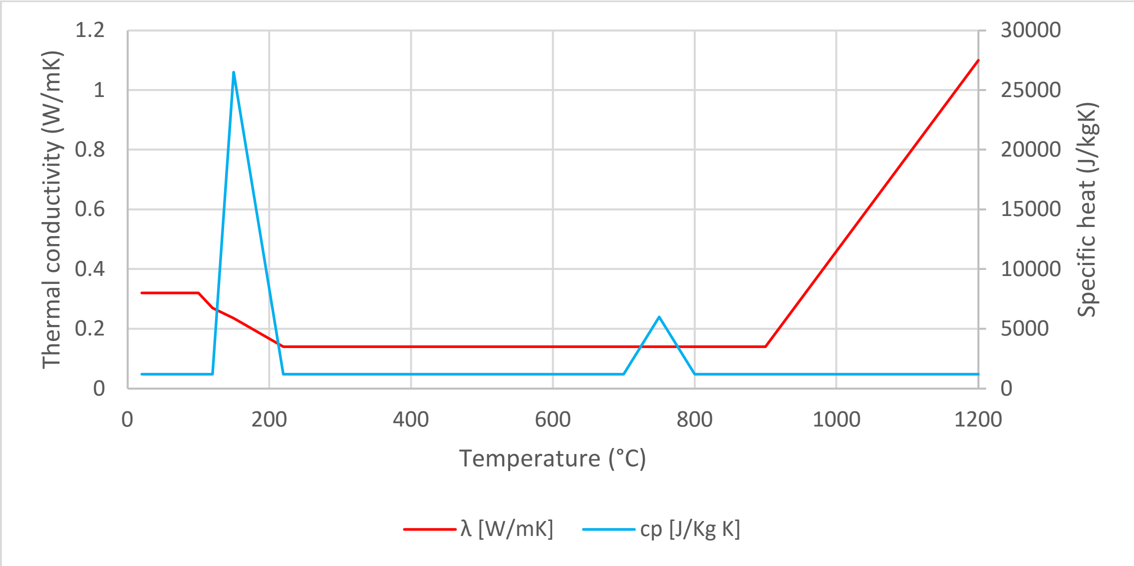


Figure 53 – Temperature-dependent thermal properties for the gypsum-based fibreboard

5.2 Numerical validation

For the numerical validation, BRE Global did not have access to any standard fire resistance test evidence. The validation is based on the system 1HTM34 from Building in Timber (2021)[23] shown in Figure 54. The guidance document provided the tested configuration made of two layers of 12.5 mm protection layer applicable for CLT wall systems greater than 80 mm thickness. The fire resistance achieved in a standard fire test is REI 90 minutes. The maximum temperature at the interface layer is 115°C at 30 minutes of fire exposure. This information is not sufficient to perform a validation of the numerical model. However, an attempt is made to compare the predicted temperature and the maximum reported temperature at the interface layer for exposure to the standard fire curve of 30 minutes.

Figure 54 – Wall configuration in a standard fire resistance testing regime

The general boundary conditions used to validate the numerical model are based on the limited information provided and shown in Figure 55.

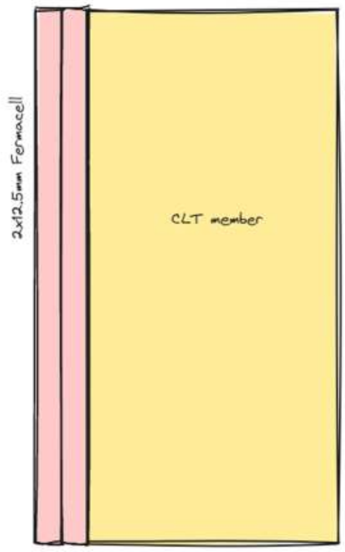


Figure 55 – General view of the validation model

The maximum temperature at the interface layer is 115°C at 30 minutes of exposure to the standard fire curve. The temperatures at 60 minutes or 90 minutes are not reported.

Figure 56 shows the temperature distribution through the CLT wall system at 30 minutes of exposure to the standard fire curve. The calculated temperature at the interface layer is 102°C in comparison with the maximum temperature reported of 115°C.

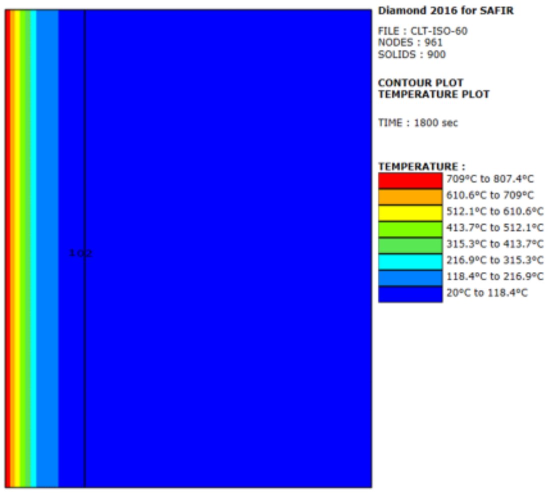


Figure 56 – Heat transfer through the protected CLT wall system

Figure 57 shows a comparison between the calculated time-temperature history and the single maximum temperature point reported at 30 minutes of fire exposure. The graph shows a slight underprediction and this is because the comparison is made with the maximum temperature and not an average value.

There are a significant number of unknowns such as the behaviour of the protective layers, fall-off time, partial detachment and measured temperature profiles which makes the validation difficult to perform.

However, for the following theoretical exercise, the data resulting from the numerical validation can be sufficient.

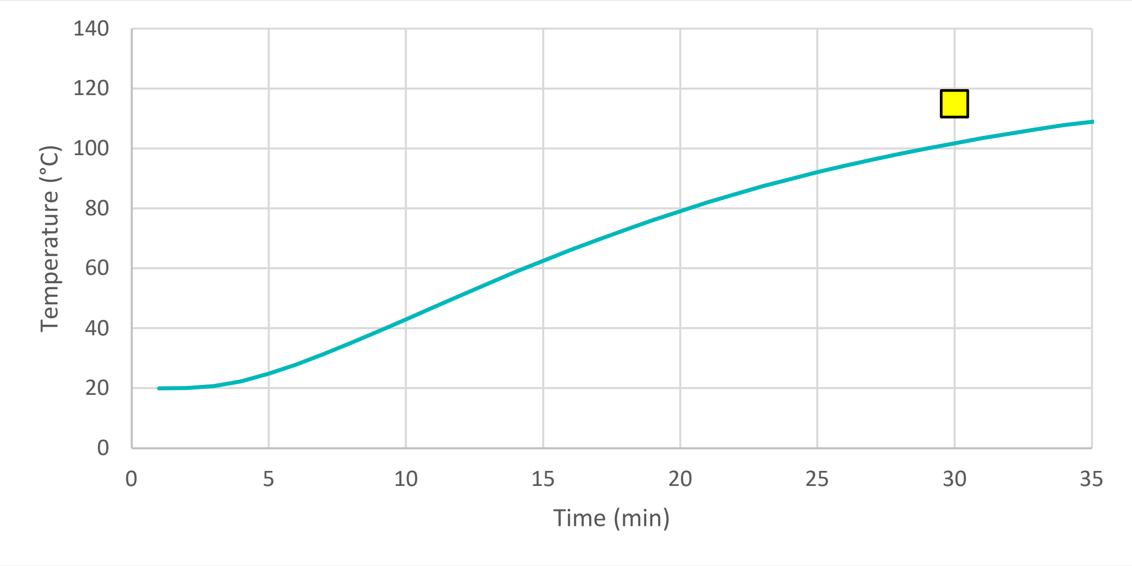


Figure 57 – Comparison between the predicted and reported temperature

5.3 Numerical analysis

The purpose of the numerical analysis is to explore the behaviour of the protective layer during the large-scale test and understand the potential mechanisms that generated the onset of smouldering combustion during the cooling phase of the fire.

The large-scale experiment was performed on a CLT compartment lined with two layers of 18 mm gypsum fibreboards. A simplified construction detail is shown in Figure 58.

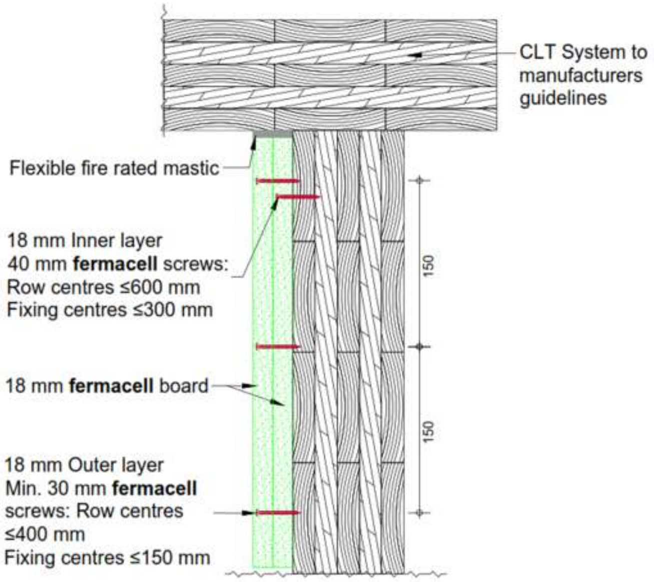


Figure 58 – General construction details of the CLT compartment (Note indicative only Experimental compartment consisted of 3 plys)

Figure 59 shows the ignition in the CLT-protected compartment. The movable fire load inside the compartment was designed to generate a 60-minute equivalent fire exposure to the standard fire curve.

Figure 59 – Ignition of the fire load in the CLT-protected compartment

Figure 60 shows a comparison between the predicted and the measured gas temperature during the fire experiment. It can be observed that the peak temperature is approximately 1140°C after 14 minutes. After 20 minutes of fire exposure, the fire transitions into the cooling phase.

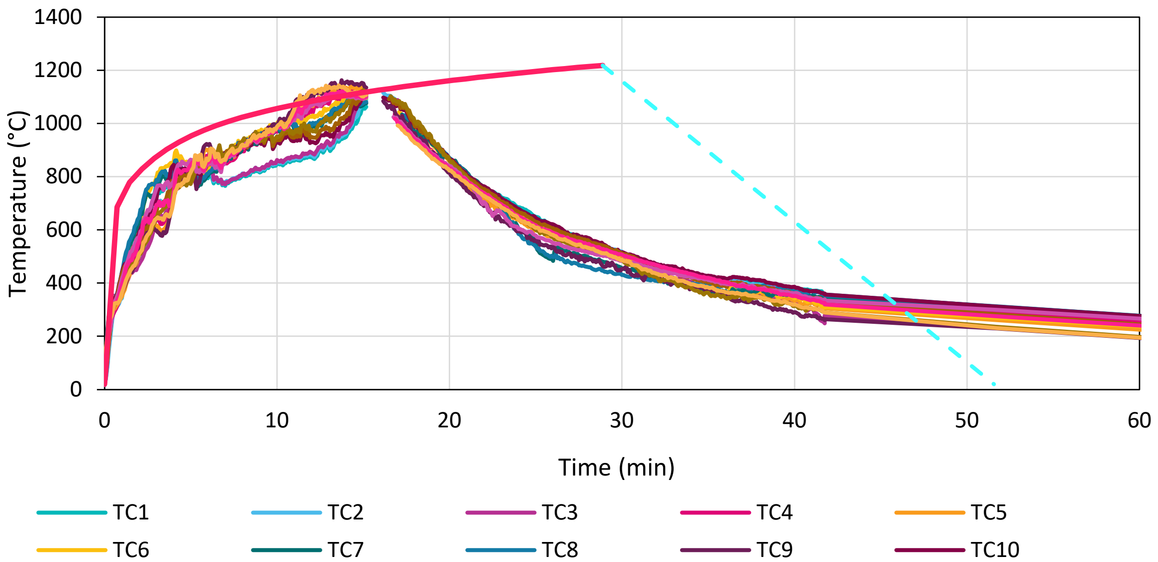


Figure 60 – Calculated and measured gas temperature

5.3.1 First numerical model

The first numerical model considers the generally protected CLT wall construction detail. The time-temperature adopted as an input is the EC parametric prediction, including a cooling phase of up to 240 minutes. The input fire curve is shown in Figure 61.

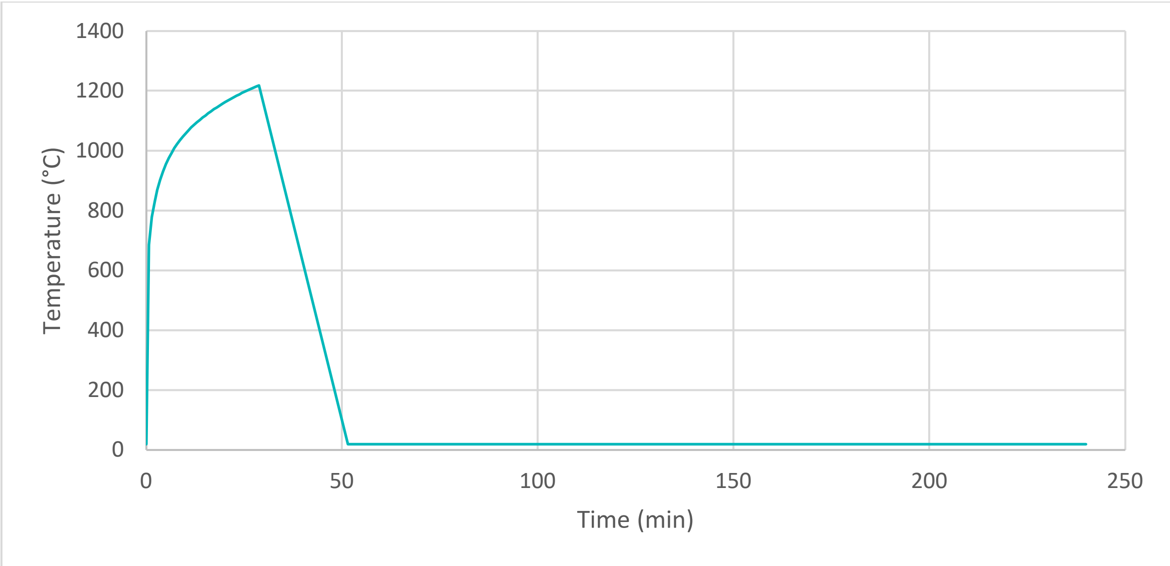
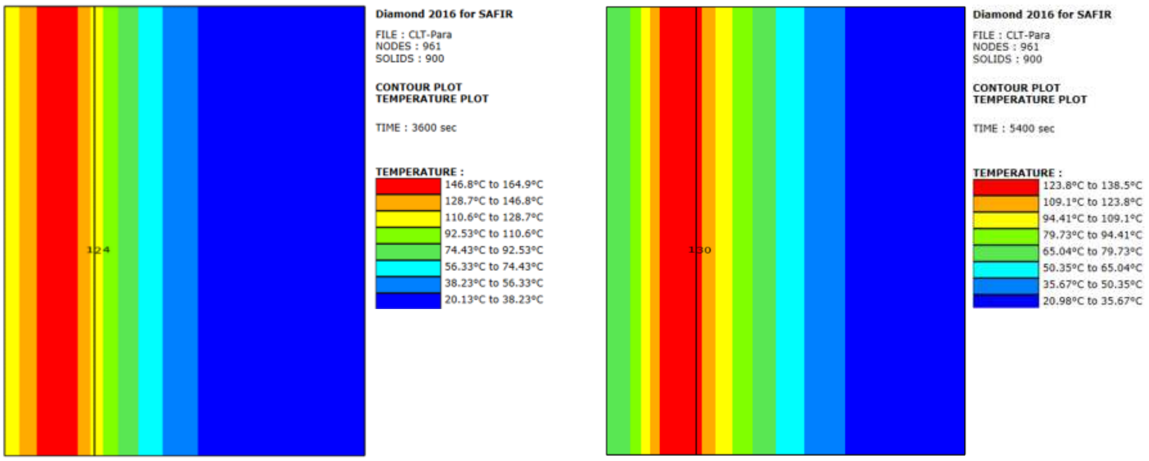


Figure 61 – Fire curve based on the EC parametric prediction

Figure 62 shows the temperature distribution through the section for 60 and 90 minutes of exposure to the parametric fire curve. The maximum calculated temperature at the interface layer is approximately 130°C.



60 minutes 90 minutes

Figure 62 – Heat distribution through the section for 60 and 90 minutes

Figure 63 shows the predicted temperature distribution at the interface between the protective layer and the CLT wall. It can be observed that in the predicted gas phase the temperatures inside the compartment reach the peak after approximately 28 minutes and at the interface layer the peak temperature is reached after 84 minutes.

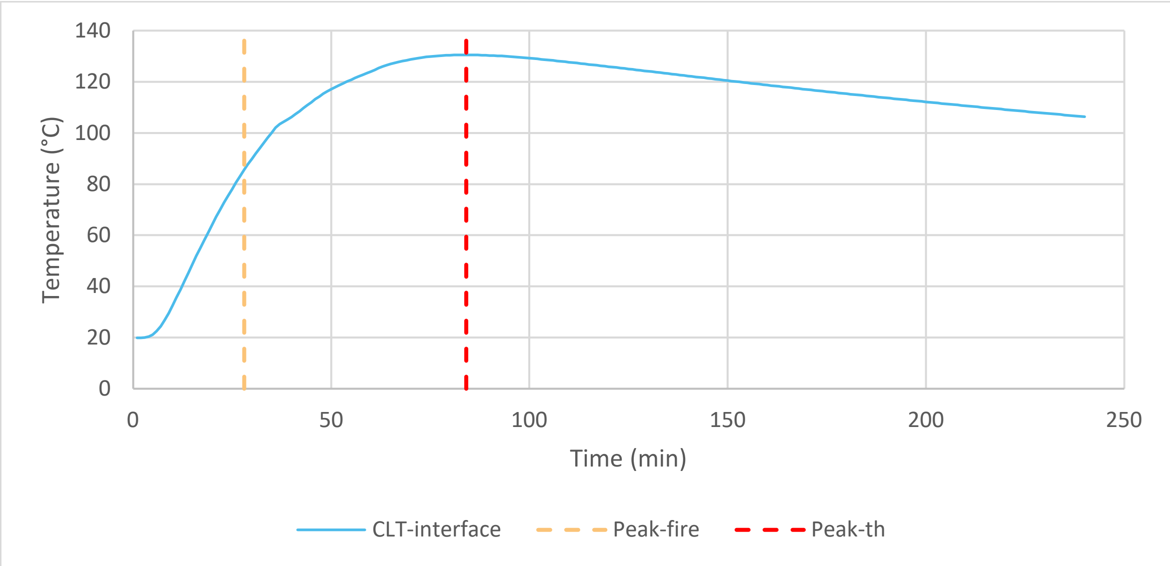


Figure 63 – Temperature distribution at the interface layer

5.3.2 Second numerical model

The second numerical model is based on the time-temperature curve obtained during the fire experiment shown in Figure 64. The analysis was carried out for up to 700 minutes. After this point, there is no measured data available. The peak temperature is approximately 1131°C after 14 minutes of fire exposure. It can be observed that in the experiment the time to peak temperature is 14 minutes shorter than the numerical predictions. However, the peak temperature measured is similar to the predictions.

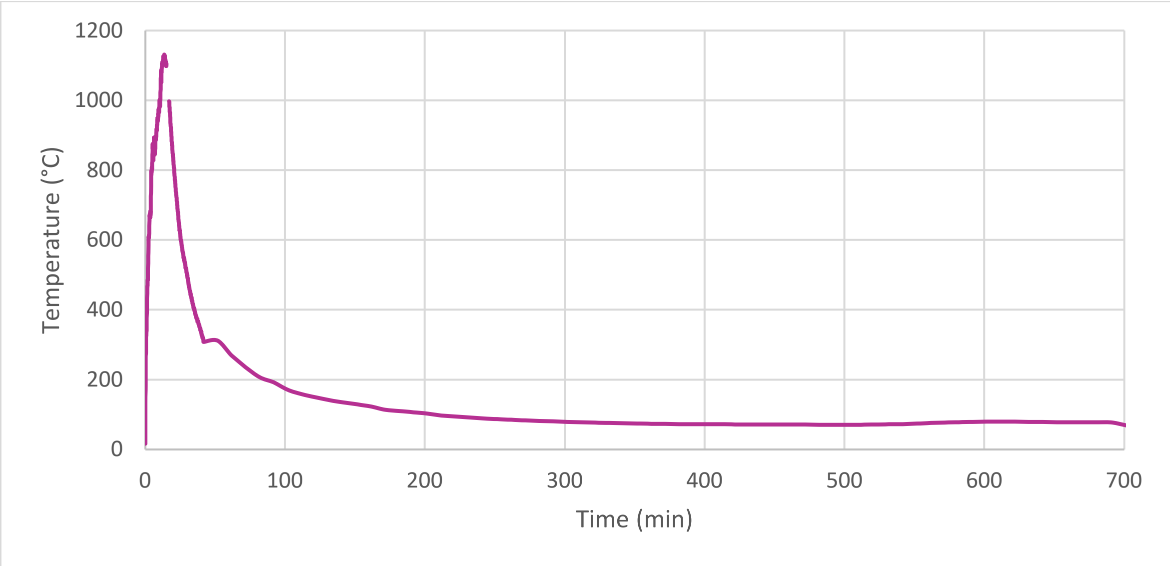


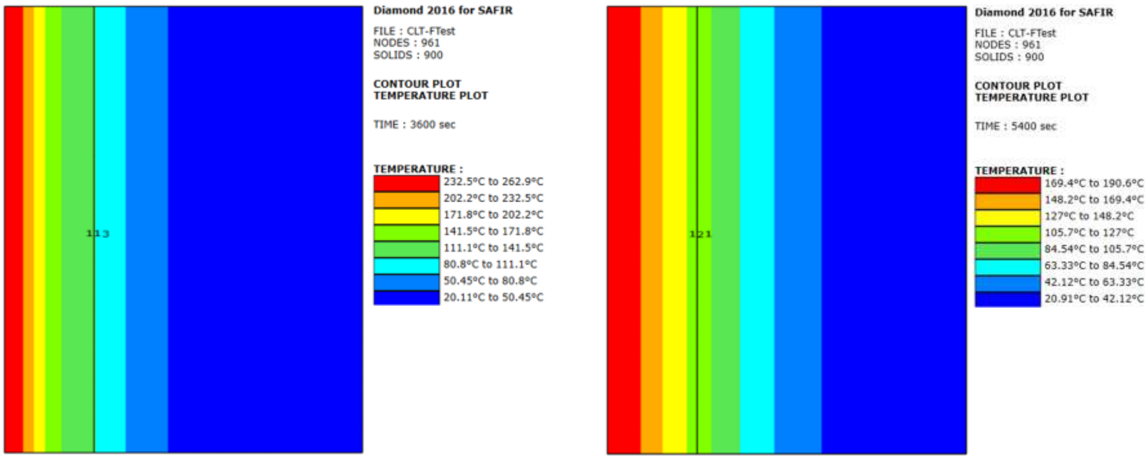
Figure 64 – Time-temperature curve used in the analysis

Figure 65 shows the flashover and the transition to a fully developed fire. The fire exposure showed a high-temperature development over a short duration before the transition into the cooling phase.

Transition to flashover Peak fire development

Figure 65 – Flashover and fully developed fire

Figure 66 shows the heat distribution through the protected CLT section at 60 and 90 minutes of exposure to the natural fire curve. The temperature inside the compartment was below 320°C after 40 minutes.



60 minutes 90 minutes

Figure 66 – Heat distribution through the protected CLT element

Figure 67, Figure 68 and Figure 69 show the measured temperature distribution at the interface layer during the fire test, including the cooling phase, in relation to the calculated temperature. It can be observed that the average temperature at the interface layer between the protection and the CLT peaks at approximately 75 minutes with a value of approximately 160°C. The values recorded up to 250°C are due to localised hot spots or the presence of joints in the protection layer. However, the maximum hot spot temperatures captured are below the value of 300°C associated with the onset of charring.

The numerical model is able to predict the temperature distribution during the heating phase. The peak temperatures at the interface layer are not captured accurately due to complex phenomena such as crack formation, moisture and steam migration and opening of the joints in the protective layer. The cooling phase is also overpredicted because the temperature-dependent thermal properties are considered irreversible.

The numerical model can be further calibrated to provide more accurate predictions. However, for the purpose of this exploratory analysis, the numerical predictions may be sufficient to observe the heat transfer mechanisms.

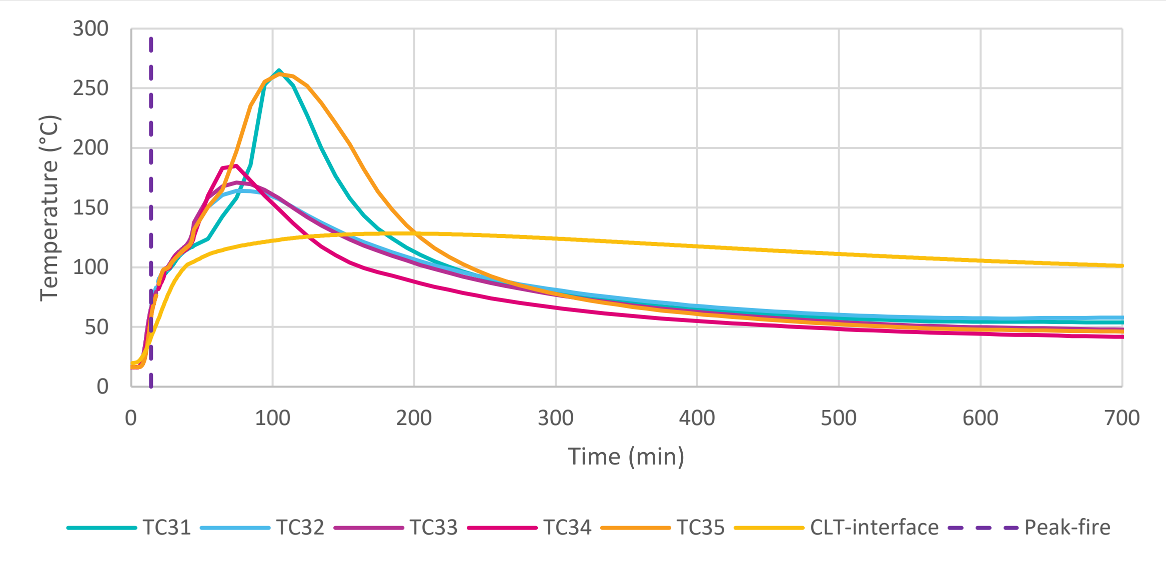


Figure 67 – Temperature distribution on the interface layer N-wall

In Figure 68 it can be observed that after approximately 5 hours from the beginning of the experiment, thermocouple channel 45 (TC45) measures a slow increase in the temperatures recorded. After approximately 1.5 hours since the increase in temperature is recorded, the measured values are above 300°C. The temperature at this location reaches a value of 500°C which can be associated with the presence of oxygen and flaming combustion. On the same wall, smouldering combustion followed by the presence of flames is recorded by thermocouple channel 44 (TC44) after 10 hours from the beginning of the experiment. After 11 hours, water was applied to the sample and the data recording was stopped.

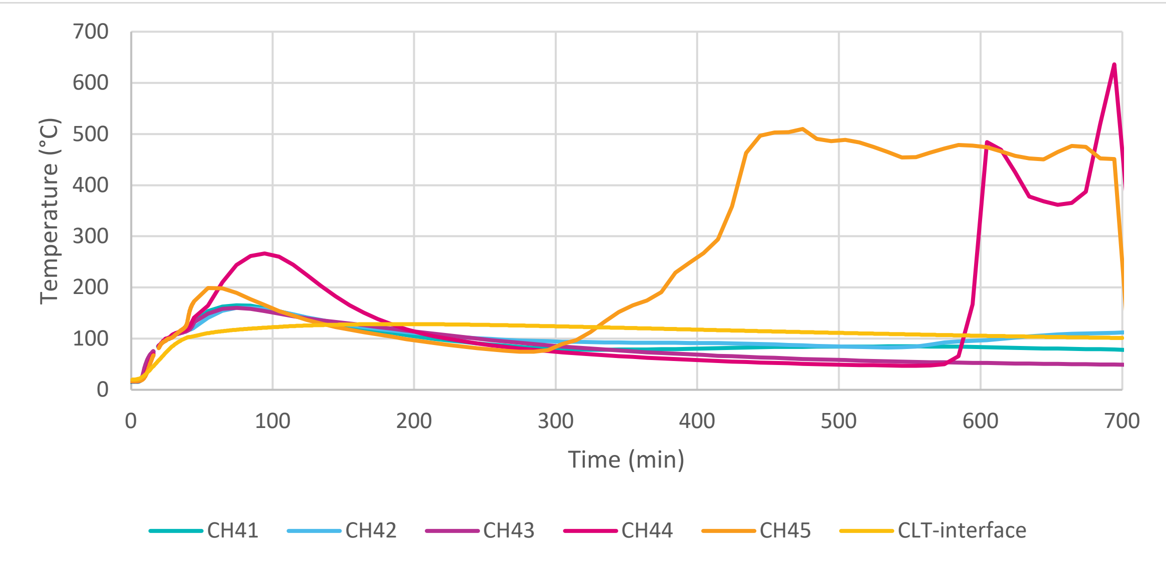


Figure 68 – Temperature distribution on the interface layer E-wall

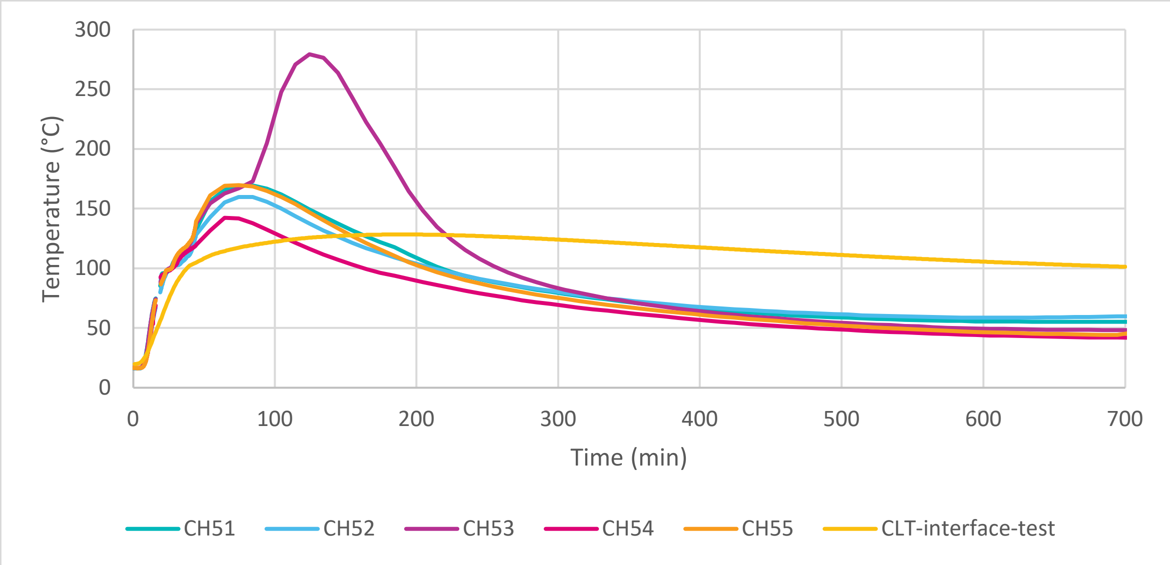


Figure 69 – Temperature distribution on the interface layer S-wall

Figure 70 shows a view inside the compartment after the burn out of the movable fire load. The two gypsum fibreboard protective layers are in place for the walls and the ceiling. Localised detachments and cracks are visible on the walls and the ceiling.

Figure 70 – View inside the compartment after burn out of the movable fire load

5.3.3 Third numerical model

The third numerical model considers the heat transfer through a corner configuration representative of the junction between a floor and a wall (Figure 71). In current practice, the junction between the protective layers on the wall and the floor is sealed with fire-rated mastic to fill any imperfections and allow for movement. The numerical analysis looks at the heat transfer mechanism considering an ideal contact between the protective layers.

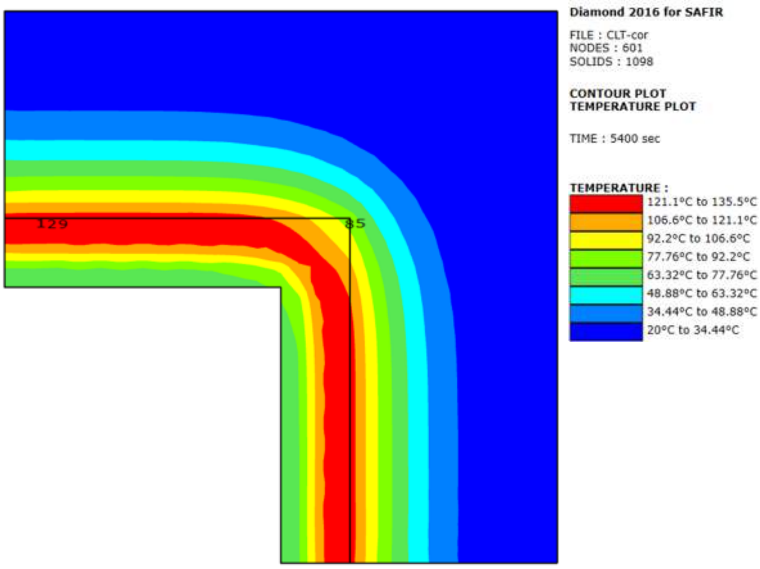


Figure 71 – Heat transfer through a corner configuration

Figure 72 shows the time-temperature history between the CLT and the protective layers at the corner junction, compared with the calculated temperature away from the corner. It can be observed the temperature distribution away from the corner is higher than the temperature in the corner due to the bidirectional heat transfer.

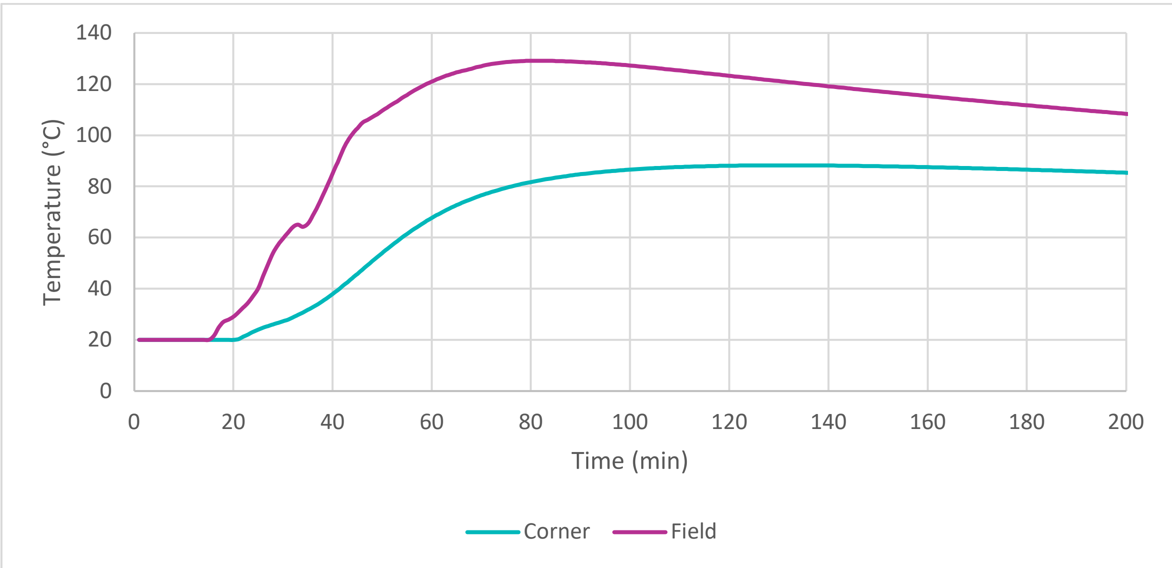


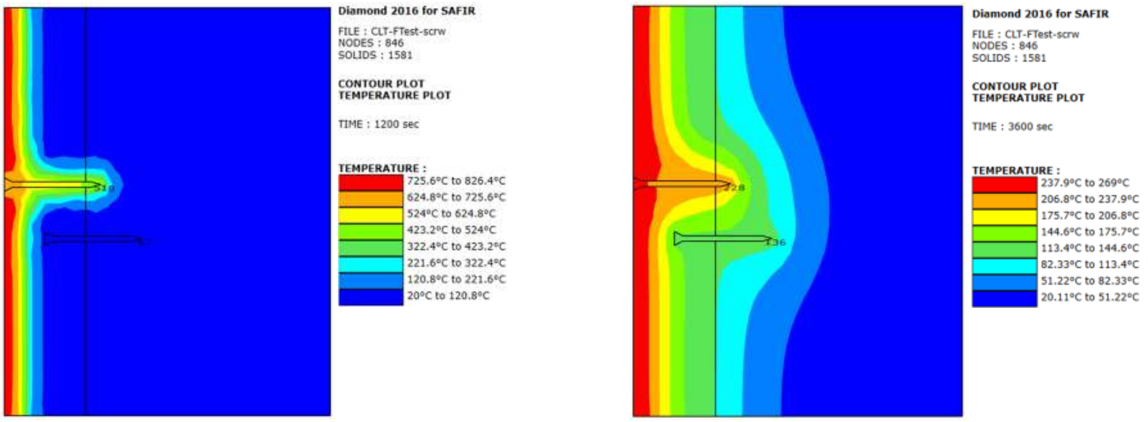
Figure 72 – Time-temperature history of the junction between the CLT and the protective layers at the corner junction

bre

5.3.4 Fourth numerical model

The fourth numerical model considers the heat transfer through the fixings to the CLT member. The protective layers have been installed to the CLT support using 40 mm long screws as shown in Figure 58.

Figure 73 shows the heat transfer through the screws at 20 minutes and 60 minutes of the natural fire exposure. The maximum calculated temperature of the screws fixing the second layer to the CLT is approximately 520°C after 20 minutes. After 20 minutes, the temperature of the screws is decreasing following the cooling phase of the fire. Figure 74 shows the calculated time-temperature history of the junction between the screws and the CLT.



20 minutes 60 minutes

Figure 73 – Heat transfer through the screws at 20 and 60 minutes

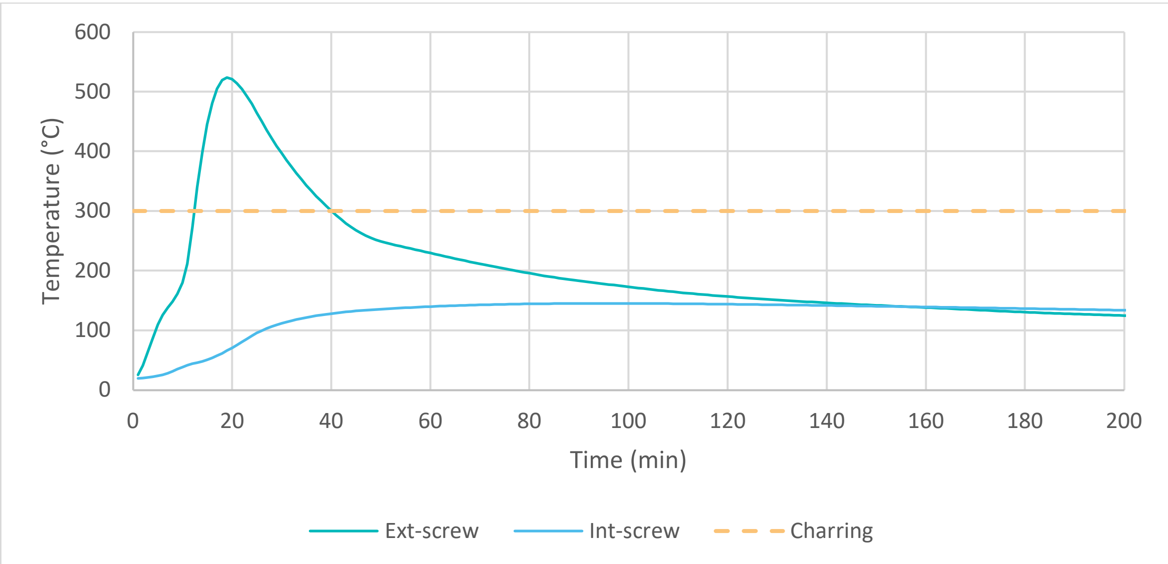


Figure 74 – Calculated time-temperature history of the screws

The temperature of the external screw is sufficient to char the timber locally. However, it is not enough to generate smouldering combustion due to lack of oxygen and localised behaviour.

6 Input from Focus Group relating to Fire and Rescue Services and smouldering combustion

A specific Focus Group was set up to provide additional input to the project on the Fire and Rescue Service experience of post-fire smouldering combustion in timber structures.

The Focus Group was formed following discussions on 20th March 2024 between BRE Global and the Structural Timber Association (STA) representatives involved in the supply of the Cross Laminated Timber (CLT) compartment which formed part of the experimental programme. This meeting was held to discuss issues arising from the CLT compartment fire undertaken and discussed initially between BSR, BRE Global and the CLT supply chain on 19th January 2024. At the 20th March 2024 meeting, the issue of smouldering combustion was discussed in relation to operational firefighting issues and it was felt that input was required from those with experience of fighting fires to ensure all relevant information was considered.

The Focus Group comprised members from: BSR, BRE Global, the National Fire Chiefs Council (NFCC) and the Structural Timber Association. At the first virtual Focus Group meeting held on 3rd July 2024, BRE Global presented a summary of the CLT experiment post-fire findings and the Focus Group members were asked to contribute to an open discussion.

The points made, viewed from the Fire and Rescue Service (FRS) perspective, included the following.

<u>Experience of smouldering combustion or re-ignition where the FRS has been called back</u>

- Instances where the FRS believe they have extinguished the fire but are later recalled are not common but do occur in a number of different types of construction. It was believed that all FRS regions would have some experience of this.
- It is understood that this data is not collected nationally.
- Recall to an incident is taken very seriously within the FRS and may have implications related to potential liabilities. There is sometimes confusion as to whether it is reignition or a secondary fire.
- BRE Global has experience (through the Investigation of Real Fires project) of attending incidents where a small ignition source has ultimately led to disproportionate damage including complete demolition.

<u>Operational guidance, firefighting tactics and training of fire crews for fires in structural timber buildings</u>

- The NFCC has a learning team and there is NFCC Fire Protection and Operational Guidance.
- The 45 UK Fire and Rescue Services do not do everything the same and not every Fire and Rescue Service has adopted the National Operational Guidance.
- Operational crews are told that structural timber buildings exist, and their fire behaviour can be different depending on the compartment set up and how the fire spreads through the building. However, it is not certain that the journey is completed by providing fire crews with proper practical advice.
- Reference was made to the NFCC National Operational Guidance which covers a long list of construction elements/types with associated hazards, control measures and associated

actions (for blockwork, cast iron, cellular steel, cold rolled steel, concrete, cross laminated timber, engineered timber, historic timber, hot rolled steel, stone, structural glass, structural insulated panels, structural timber composites, etc.)

- There is a short section on cross laminated timber [in the NFCC guidance] which *was quoted as: there are inherent hazards in relation to the constitution of timber and adhesives which may degrade at temperatures significantly lower than that required to ignite the timber. Like timber, the form of construction is combustible and may, when exposed, lead to an increase in fire severity (both in terms of peak temperature and overall duration) compared to non-combustible. And as with other combustible structural components and products, it is not always a simple matter to ensure that all seats of combustion have been effectively extinguished following a fire. There is a need to be aware of the potential for ignition and hidden seats of smouldering combustion.* The challenge is for a firefighter/fire crew to ascertain that information.
- Techniques and equipment to enable the Fire and Rescue Services to fight and identify fires change and evolve over time. Some things taught in the early 1990s have returned. There are many different tactics available.
- The Incident Commander needs to be assured that the fire is out/under control before leaving the scene. This is easier in traditional construction than with more complex methods of construction and the challenge with finding hidden seats of smouldering combustion is that they are hidden. Therefore, how much does the FRS dismantle the building?
- Questions were raised as to when it is reasonable to leave the scene.
- It is important to communicate the difference between structural lightweight and mass timber throughout the Fire and Rescue Service and ensure this is part of FRS staff training.
- It is not guaranteed that the FRS will know the type of construction material of the building when they arrive at the fire scene.
- BRE Global shared experience from the ‘Understanding fire risks in combustible cavities’ project (which followed on from theTF2000 project). Part of that project involved FRS training. Various Incident Commanders with fire crews (from Hertfordshire and Bedfordshire) came to BRE Cardington. BRE set up a simulated fire event using a heater ‘fire’ in a cavity. Each group was told there was a fire in the cavity and was asked to deal with this and were given specific tools. The most effective solution was to use a thermal imaging camera to identify the source of any smouldering combustion. This might also be the solution now if the FRS know where to look and where to use it.
- Nowadays, every Fire and Rescue Service will have access to thermal imaging cameras and, for some, they are on every breathing apparatus set for every crew and there are additional ones for Incident Commanders. How FRS assess buildings is different. In some places it is common practice to do a thermal scan before entering the building and then scan continually. There are limitations with thermal imaging cameras. There is a need to be able to see the walls; it is easier on some surfaces than others. Certain thermal imaging cameras can be put in (to a cavity) as well.
- NFCC has recently amended its fires and firefighting guidance.
- LFB has thermal imaging cameras on all their front line appliances. At the Worcester Park fire incident, LFB used their thermal imaging air drone and could see heat starting to rise on the roof of one of the neighbouring buildings, which allowed early intervention.

© BRE Global Ltd 2025

- At the complicated Deptford fire, having an in-house operational fire engineer (with understanding of the building construction, compartment lines, where voids were likely to be located, where detailing likely could work favourably) on the site to support the Incident Commander, was very beneficial in helping operational crews target what they were doing to try to minimise damage.

- Connectivity between the understanding of building construction and how that translates to FRS operations has been missing.

- Operational crews deal with a multitude of new construction typologies, different products and materials. It is a very complex arena to train people in. Having expertise from a range of stakeholders feeding into that would be very beneficial.

- As risks increase, including awareness of contamination, it is likely that firefighting tactics will continue to develop, particularly around the area of the Incident Commander having to justify sending firefighters into a building to be exposed to contamination, if there are no people to save. In the future, there will increasingly be less intervention (offensive action) and increasingly defensive firefighting action from outside the building.

Miscellaneous points

- The opportunity for a discussion on this topic was welcomed, the data collected as part of this project may help inform decisions going forward and discussions about potential further research and experimental testing on this subject.

- There was discussion about potential modifications to e.g. plasterboard type or fixings, in relation to CLT construction. A concern is that reliance on detailed workmanship, during build, and how and where materials are fitted and fixed may not be realised on site. Previously, there have been complications where poor build competence on site has resulted in a final construction not being what had been designed and agreed. This can have an effect on the fire performance of the completed building.

- Workmanship issues can occur across all construction types but the consequences for structural timber are different.

- Concern was expressed about the amount of time these incidents place on the demands of Fire and Rescue Service resources. There have been several fires (e.g. lightweight timber frame, Cheshire and Worcester Park fire incidents) which have tied up FRS resources for many days and resulted in significant overall damage to those buildings.

- There was an offer to share with the Focus Group results and activities from the Academic Collaboration, Evaluation and Research (ACER) Group[1].

[1] ACER is an independent forum, convened by NFCC, to help coordinate and maximise the benefits of academic research with relevance for Fire and Rescue Services (FRS), to contribute to improved public and firefighter safety. ACER has been established to create better national links between the Fire and Rescue Services through the conduit of NFCC and academia. In addition to this, it will provide an ethical approach to research partnerships and potential research funding. It aims to improve the gathering, reviewing and analysis of research findings and set them into context for NFCC and/or FRS.

© BRE Global Ltd 2025

- There is a joint research project HoBraTec (Optimization of Firefighting Methods and Techniques for Buildings in Modern Timber Construction) carried out by The Hamburg Fire Department, Magdeburg-Stendal University of Applied Sciences and the Heyrothsberge Institute for Fire and Disaster Protection, funded by the Federal Ministry of Education and Research[24]. This project aims to gain insights into efficient firefighting in timber construction and to prepare the fire brigade to deal with fires in the building types of tomorrow.

 © BRE Global Ltd 2025

7 Conclusions

The compartment fire experiment carried out as part of the Structural Fire Resistance and Fire Separating Elements project has highlighted a number of issues specifically related to the project objectives. The issues around hidden seats of ignition following combustion of the moveable fire load within the compartment have highlighted a number of issues outside the original scope of the project but of great interest to key stakeholders.

In the opinion of the test engineers involved with the current project, the CLT experiment has demonstrated the ability of a mass timber compartment to withstand burn out of all moveable combustible material whilst maintaining overall stability and compartmentation. This conclusion is based on a specification of the internal linings assuming encapsulation of the CLT as defined in the STA Structural timber buildings fire safety in use guidance Volume 6 covering mass timber structures[25]. The guidance states that:

"Where a lining is specified for the purposes of encapsulation, it should be shown that the interface temperature between the combustible substrate and lining (and away from fixings) remains below 200°C[26] (indicating the decomposition of hemicellulose) for the duration of the relevant fire resistance period. For mechanically fixed lining solutions, this is likely demonstrated through lining systems achieving a K_2 class but should be subject to review of the specific product test data and associated thermocouple readings."

The fire protection ability, K, is defined in BS EN 13501-2[10] as the ability of a wall or ceiling covering to provide for the material behind the covering protection against ignition, charring and other damage for a specified period of time.

During the tests, (in accordance with BS EN 14135[27]) within the classification period (10 minutes, 30 minutes or 60 minutes), there is no collapse of the coverings or parts of it and also the following requirements are fulfilled.

For K_2, it shall be shown for the classification period that for a covering without a cavity or cavities behind it:

- During the test, the mean temperature measured on the lower side of the substrate shall not exceed the initial temperature by more than 250°C and the maximum temperature measured at any point on this side shall not exceed the initial temperature by more than 270°C; and
- After the test, there shall be no burnt material or charred material at any point of the substrate.

From the above, it can be seen that the requirements of compliance with the STA guidance adopted for the CLT experiment are significantly more onerous than those used to demonstrate compliance for the purposes of classification.

The method for ensuring fire protection ability is intended to ensure compliance for "a specified period of time". The general assumption based on the test results is that the specified period of time corresponds to the design fire resistance period. In a real fire situation, this could be assumed to correspond to the burn out of all the moveable fire load within a specific compartment. If this is accepted, then the compartment design achieved the required level of performance and in regulatory terms would have provided stability and compartmentation for "a reasonable period".

 © BRE Global Ltd 2025

None of the above negates the seriousness of the smouldering combustion that occurred following the completion of the fire experiment, but it is important that what happened is seen in the context of regulatory requirements, overall building fire performance and disproportionate damage and understood by key stakeholders.

Smouldering combustion involving elements of structure is nothing new. BRE Global is aware, through the “Investigation of Real Fires” project, of a number of incidents where either a small ignition source has led to a large fire resulting in damage disproportionate to the source or an initial fire incident has been attended by the Fire and Rescue Service and reignition has occurred often many hours after the initial event, resulting in significant damage. Such incidents were often associated with light timber frame construction and, in particular, with fires within cavities leading to the unseen spread of fire and smoke within the building. Within cavities, there is often a limited oxygen supply which may be sufficient to maintain smouldering combustion but would not necessarily be sufficient for flaming combustion. In such cases, as with the post-heating phase behaviour described above, flaming combustion will only manifest when there is sufficient oxygen available, in this case when the smouldering has progressed through the depth of the panel resulting in a breach and opening the charred surface to the atmosphere as shown in Figure 75.

Figure 75 – Localised burn-through of CLT panel leading to visible flaming on the outer surface

It is important to note that where the localised burn-through occurred external flaming was limited to the area around the opening and did not spread over the whole surface. The most likely explanation for this is that there is insufficient energy from the localised flames to ignite the solid timber adjacent to the insulating char layer. Although the CLT compartment maintained overall stability for several days, it is unclear what the outcome would have been had there been no intervention between the Thursday night (of the fire experiment) and the following Monday morning.

CLT is prone to smouldering, a slow, flameless oxidation process that can continue long after a fire is seemingly extinguished. This poses a significant risk to the structural integrity of CLT buildings, as smouldering can persist beneath the surface, leading to eventual structural failure even without visible flames.

The type of wood, its density, and the adhesives used in CLT panels significantly affect smouldering behaviour. Denser woods and certain adhesives (e.g. phenol-formaldehyde resins) may resist smouldering better, while low-density woods and less thermally stable adhesives may exacerbate it. The moisture acts as a thermal buffer, with high moisture content inhibiting smouldering by absorbing heat, while low moisture content facilitates it due to easier thermal degradation. Oxygen availability is important, as reduced oxygen levels may suppress flaming but not necessarily prevent smouldering. Smouldering can propagate through timber layers under varying environmental conditions, leading to extensive charring and structural damage.

Smouldering is difficult to detect, often occurring beneath the surface where traditional post-fire inspections may miss it. Advanced techniques such as infrared imaging are necessary to identify smouldering hotspots. Smouldering can lead to reignition if conditions change, such as increased oxygen supply. This risk complicates post-fire safety assessments and can cause fires to reignite after the main event is believed to be over.

Various large-scale fire tests have shown that smouldering can lead to delayed structural failures, often occurring hours or even days after the main fire has been extinguished. This was observed in tests where smouldering combustion caused integrity failures and structural collapses long after the fire appeared to be extinguished.

While encapsulation (e.g. using gypsum plasterboard) can delay ignition, it does not prevent smouldering combustion. Smouldering can occur beneath protective layers or spread from exposed areas, compromising the structural integrity over time.

Timber structures are especially vulnerable during the cooling phase after a fire. Unlike materials like concrete, which maintain structural integrity at temperatures below 500°C, timber can lose significant strength at much lower temperatures, leading to potential collapse during this phase. Current building codes, such as Eurocode 5, do not fully account for the delayed heating and smouldering risks associated with CLT. There is a need for revised standards that consider the unique fire behaviour of mass timber, particularly regarding smouldering.

There is a need for further research into the phenomenon of smouldering combustion and the factors which may influence this process. Fire resistance tests for CLT should incorporate longer observation periods and consider the cooling phase to better understand the material's behaviour under real fire conditions.

 © BRE Global Ltd 2025

8 Acknowledgements

BRE Global would like to acknowledge the contribution of the industry group for the design, supply and construction of the CLT compartment for the third experiment, coordinated through the Structural Timber Association (STA).

The authors would like to thank the participants of the Smouldering Combustion Focus Group for providing additional input to the project on the Fire and Rescue Service experience of post-fire smouldering combustion in timber structures at the virtual Focus Group meeting held on 3rd July 2024.

9 References

1. Grantham R, Enjily V, Milner M, Bullock M and Pitts G, Multi-storey timber frame buildings a design guide, BR 454, BRE Press, 2003.
2. Rein G, Smouldering combustion phenomena in science and technology, International Review of Chemical Engineering, 1(1), pp. 3-18, 2009.
3. Page I C et al, Material properties affecting smouldering in cross-laminated timber, Fire Safety Journal, 113, 2018.
4. Hadden R M et al, Impact of moisture on smouldering of wood materials, Fire Technology, 54(4), pp. 1061-1081, 2018.
5. McNamee B M et al, Environmental impacts on smouldering combustion of timber structures." Fire and Materials, 41(2), pp. 155-167, 2017.
6. Brandforsk - Swedish Fire Research Foundation, Fire Safety in Timber Buildings, 2021.
7. Wiesner F et al, Structural capacity in fire of laminated timber elements in compartments with exposed timber surfaces, Engineering Structures, Volume 179, pp. 284-295, 2019.
8. Brandon D, Fire safety challenges of tall wood buildings – Phase 2: Task 4 - Engineering Methods. Report FRPF-2018-04. Quincy, MA: Fire Protection Research Foundation, 2018.
9. British Standards Institution, BS EN 1995-1-2, Design of timber structures - Part 1-2: General - Structural fire design, BSI, 2004.
10. British Standards Institution, BS EN 13501-2, Fire classification of construction products and building elements. Classification using data from fire resistance tests, excluding ventilation services, BSI, 2023.
11. Klippel M and Just A, Guidance on Fire design of CLT including best practice. COST FP1404 Fire Safe Use of Bio-Based Building Products, 2018.
12. Babrauskas V, Ignition of Timber: A Review of the State of the Art. Interflam 2001, pp. 71-88, Interscience Communications Ltd., London, 2001.
13. Liu J and Fischer E C, Review of large-scale CLT compartment fire tests, Construction and Building Materials, Volume 318, 7th February 2022, https://doi.org/10.1016/j.conbuildmat.2021.126099.
14. Ronquillo G, Hopkin D and Spearpoint M, Review of large-scale fire tests on cross-laminated timber, Journal of Fire Sciences 39(5), 2021, DOI: 10.1177/07349041211034460.
15. Mindeguia J-C, et al, Thermo-mechanical behaviour of cross-laminated timber slabs under standard and natural fires, presented at the 15th International Conference and Exhibition on Fire Science and Engineering, London, 2019.
16. British Standards Institution, BS EN 1363-1, Fire resistance tests. General requirements, BSI, 2012.

17. Medina Hevia A R, Fire resistance of partially protected cross-laminated timber rooms, Master's Thesis, Carleton University, Ottawa, 2014.

18. Emberley R et al, Description of small and large-scale cross-laminated timber fire tests, Fire Safety Journal, Volume 91, pp. 327–335, July 2017, DOI: 10.1016/j.firesaf.2017.03.024.

19. Su J, et al, Fire safety challenges of tall wood buildings – Phase 2: Task 2 & 3 – Cross laminated timber compartment fire tests', Fire Protection Research Foundation, Quincy, FPRF-2018-01, 2018.

20. Mitchell H et al, Observations of smouldering fire in a large timber compartment, World Conference on Timber Engineering, Oslo, 2023, DOI: 10.52202/069179-0224.

21. Gernay T et al, Experimental assessment of the burnout resistance of timber and concrete columns, SiF 2022, 12th International Conference on Structures in Fire, The Hong Kong Polytechnic University, 30th November to 2nd December 2022.

22. Le Dréau J, Jensen R and Kolding K, Thermal Behaviour of a Gypsum Fibre Board Associated with Rigid Polyurethane Foam Under Standard Fire Conditions, Energy Procedia 78, pp. 2736-2741, November 2015, DOI: 10.1016/j.egypro.2015.11.615.

23. Fermacell CLT/X-LAM – Building in Timber, February 2021.

24. Feuerwehr Hamberg, Joint research project Hobratec of professional and volunteer fire brigades, 28th November 2022. Available from: https://www.feuerwehr-hamburg.de/2022/11/gemeinsames-forschungsprojekt-hobratec-von-berufs-und-freiwilliger-feuerwehr/. Accessed 20th August 2024.

25. Structural Timber Association (STA), Structural timber buildings fire safety in use guidance Volume 6 – Mass timber structures; Building Regulation compliance B3 (1), STA fire safety research and guidance project Version 2.0, April 2023.

26. Di Blasi C, Modeling chemical and physical processes of wood and biomass pyrolysis, Progress in Energy and Combustion Science, Volume 34, Issue 1, pp. 47-90, February 2008.

27. British Standards Institution, BS EN 14135: 2004, Coverings – Determination of fire protection ability, BSI, London, 2004.

© BRE Global Ltd 2025

Report Ends

bre

www.bre.co.uk

Health and Safety Executive
Final Report

Structural Fire Resistance and Fire Separating Elements – Appendix E: Cavity Barriers

Prepared for:	**The Building Safety Regulator**
Prepared by:	**Tom Lennon**
Approved by:	**Tony Baker (original report approval 20th January 2025 and final amendments March 2025) on behalf of BRE Global**
Date:	**20th January 2025**
HSE Contract:	**1.11.4.4436 (previously MHCLG Contract: CPD/004/120/206)**
Report Number:	**P118139-1015 (M11D9V3) Appendix E**

BRE Global Ltd
Watford, Herts
WD25 9XX

Customer Services 0333 321 8811

From outside the UK:
T + 44 (0) 1923 664000
E enquiries@bregroup.com
www.bregroup.com

This report is made on behalf of BRE Global and may only be distributed in its entirety, without amendment, and with attribution to BRE Global Ltd to the extent permitted by the terms and conditions of the contract.

BRE Global's liability in respect of this report and reliance thereupon shall be as per the terms and conditions of contract with the client and BRE Global shall have no liability to third parties to the extent permitted in law.

Table of Contents

 © BRE Global Ltd 2025

1 Introduction

This Appendix covers the findings of Task C5 Cavity barriers and takes into account comments from BSR HSE and the Technical Steering Group.

© BRE Global Ltd 2025

2 Methodology

The methodology for Task C5 is as follows.

The current means of test and assessment for open and closed state fire cavity barriers does not necessarily reflect the end use application. Evidence from standard fire testing was investigated. Alternative approaches to standard fire testing were also reviewed, such as the Association for Specialist Fire Protection (ASFP) Technical Guidance Document TGD 19[1] *Fire resistance test for 'open-state' cavity barriers used in the external envelope or fabric of buildings* which will form the basis of a new harmonised test standard and research undertaken in this area was looked at to try and identify the areas where additional information was required.

It was the intention that the experimental work covered under Tasks C2, C3 and C4 above would also provide an opportunity to assess the performance of cavity barriers when used in conjunction with modern forms of construction. One of the systems incorporated cavity barriers. For the other systems, there were no external wall details or realistic details between modules included.

For modular systems, cavity barriers are often used between modules and fixed to substrates that may differ significantly from those used to determine their performance as linear gap seals in a standard fire test configuration. This leads to some confusion as to the difference between a cavity barrier and a linear gap seal. The impact of movements between modules on the performance of cavity barriers including differential thermal expansion can be evaluated as part of the assessment of performance of realistic structural configurations. This approach will also enable an assessment of service penetrations under realistic conditions of installation and assessed against a realistic thermal exposure.

The justification and background for the recommendations in Approved Document B relating to cavity barriers and cavity closures for masonry walls constructed in accordance with Diagram 5.3 of AD B Volume 1 and Diagram 9.2 of AD B Volume 2, were considered, in particular, the relaxation in the provisions for cavity barriers alongside the stated performance that "do not necessarily achieve the performance specified in paragraph 5.20 (AD B Volume 1)", i.e. do not necessarily achieve 30 minutes integrity and 15 minutes insulation in a fire resistance test. The recommendations were assessed in relation to uninsulated cavities and insulated cavities including partial fill and, where possible, evidence was drawn from real fire incidents.

The programme of work for Task C5 is summarised, as follows:

- To undertake a review of current standardised test and assessment methods for cavity barriers.
- To identify gaps within the current means of testing and assessing cavity barriers.
- To review existing and new research to investigate the relationship between performance when assessed under standard fire resistance conditions and the behaviour under realistic conditions of fire exposure and site installation. Some of the existing research is no longer available in the public domain.

3 Review of standardised test and assessment methods for cavity barriers

The guidance for the performance requirements of cavity barriers in the current version of AD B refers to 30 minutes integrity and 15 minutes insulation when tested to the relevant European standard and classified in accordance with BS EN 13501-2[2]. Although the specific classification standard is referenced, there is no further guidance as to what the appropriate test standard should be.

Traditionally, the performance of cavity barriers was assessed using national[3] or European[4] standards designed for linear gap seals. The performance requirements for these two standards initially took no account of the short-term issues with insulation and integrity associated with open state cavity barriers designed to maintain ventilation within the cavity under normal conditions and to seal the cavity in the event of a fire. In many cases, the tests were conducted with the barrier forming a seal between non-combustible, non-flexible, masonry substrates and the barriers then used outside the scope of application of the tests.

Although there has never been a British Standard particularly focused on the test and assessment procedures for cavity barriers, it is hoped that the move towards a regulatory system focused principally on harmonised European test standards may help to ensure that cavity barriers are tested under circumstances representative of their end use application. BS EN 1366-4[4] explicitly states that “All materials used in the construction, fabrication and installation process of the test specimen shall be representative of the design, materials and workmanship of those to be used in practice.” The standard goes on to say that the supporting construction (into which the cavity barrier is installed) should be “representative of that used in practice”. It is therefore incumbent on those responsible for specifying, selecting and approving cavity barriers for specific applications to ensure that the product selected is backed up by test data that reflects the end use condition. For example, a cavity barrier used in the external wall of a timber frame building to seal the cavity between the Oriented Strand Board (OSB) sheathing board and a masonry rainscreen cladding should have been tested with one leaf formed from an OSB of similar specification and not between two leaves of non-combustible material. Further guidance is available on this form of construction through the Structural Timber Association[5].

There has always been confusion between products provided to meet the requirement (E30, I15 in compliance with regulatory guidance) for cavity barriers and those providing fire stopping to close off gaps in structural elements where the material or product forming the firestopping function requires the same fire resistance as the structural element. The distinction is covered in Diagram 8.1 of AD B (Volume 1 2019 edition incorporating 2020 and 2022 amendments – for use in England). This initial confusion has been exacerbated recently through the definition of external walls used to clarify amendments to the Approved Documents published in April 2019. Prior to this date, there was, for many in the construction industry, a clear distinction between the external wall that formed part of the structure and therefore was subject to the guidance in terms of fire resistance for elements of structure and the non-loadbearing façade which effectively was located on top of the structure and needed to comply with guidance in relation to reaction to fire. Where cavities existed and crossed compartment lines, then cavity barriers would be required whether internally or externally.

The development of large-scale cladding tests such as BS 8414[6,7] meant that some systems were reliant on the inclusion of fire barriers to comply with the (then) regulatory guidance related to external walls for applications for high rise residential use. The location and spacing of such barriers did not necessarily coincide with the internal compartmentation lines. For External Thermal Insulation Composite Systems (ETICS), fire barriers at specified distances and of specified thicknesses were an integral part of the system. They are not cavity barriers and there is no specific requirement for the barrier itself. However, fire barriers are often confused with cavity barriers. The requirement to maintain ventilation within the cavities of external wall systems has seen the development of open state cavity barriers. These products take many different forms but are often formed from non-combustible rock fibre mineral wool with a reactive intumescent layer fixed to the external face and facing the inner face of the external panel or rainscreen. A test method was developed by the ASFP (Association for Specialist Fire Protection)[1] to deal specifically with open state cavity barriers. The test method is similar in many regards to the ad-hoc tests undertaken under BS 476 Part 20 or BS EN 1366-4. The main difference is that the time taken for the intumescent to activate and seal the cavity is measured and this must be achieved within 5 minutes. In terms of performance, criteria integrity and insulation are assessed in the normal way, but the criteria are not considered for the first 5 minutes of the test. This approach has been incorporated into a draft European standard for cavity barriers prEN 1364-6[8], although in this case a removable shield is used underneath the cavity barrier which is removed 5 minutes into the test.

The current status of prEN 1364-6 is unclear but the issue around the use of open state cavity barriers in standard fire resistance tests brings into focus the differences between passing a test and the function of the product in practice.

In terms of Building Regulations requirements, the relevant clause of B3 Internal fire spread (structure) is:

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

This is the purpose of cavity barriers. There is an important distinction to be made between ‘inhibited’ and ‘stopped’. When following the guidance, the way to demonstrate compliance with the Regulations is to demonstrate that the product is capable of providing 30 minutes integrity (E30) and 15 minutes insulation (I15). Prior to the publication of the ASFP TGD 19 and the development of prEN 1364-6 open state cavity barriers could not meet the requirements of the standard fire test as they would fail the integrity criterion in the interval between the start of the test and the time taken for the intumescent to activate and effectively seal the cavity. In this case, failing the test does not necessarily mean failing to meet the functional requirement of the Building Regulations.

The standard time-temperature curve has been developed over many years and its history and derivation has been discussed in great depth elsewhere[9]. Although it has no cooling phase, it is a crude representation of the post-flashover environment (during the heating and steady burning phases) within a compartment. This does not necessarily mean it is a reasonable representation of a fire scenario within a cavity. It is used because this is the way fire resistance tests are done, and it is easier to assess performance using existing equipment and existing metrics than it is to develop an approach more representative of reality. The approach set out in ASFP TGD 19 and prEN 1364-6 enables the use of products that may, in many cases, provide a better means of achieving compliance with the mandatory requirements of the Building Regulations than more established products or systems.

In order to consider issues related to cavity barrier installation and performance in practical applications, existing research and existing fire incidents will be investigated that are more representative of the end use condition, than a reliance on the results from standard fire tests.

© BRE Global Ltd 2025

4 TF2000 post-test cavity fire incident

A report of the TF2000 post-test cavity fire incident is included in Appendix D2. In that case, the reason for its inclusion was in relation to the smouldering combustion that occurred following termination of the original fire test. In this report, the event is revisited to investigate the issues around the cavity fire with a particular emphasis on the role and importance of cavity barriers. Some of the text from the previous deliverable is repeated to provide context for the additional work undertaken in relation to cavity barriers and cavity fires.

The original fire test was undertaken within a flat forming a fire compartment on level 3 of the full-scale six-storey timber frame building as part of the Timber Frame 2000 (TF2000) project (Figure 1).

Figure 1 – Compartment fire test on TF2000 building at Cardington

The original fire was extinguished by the Fire and Rescue Service (FRS), once specific termination criteria had been achieved. However, some hours after termination of the fire test, an appreciable amount of steam could be seen emanating from the structure of the building. On further inspection, it was clear that it was not only steam but smoke issuing from the perimeter of the living room window of the fire compartment immediately above the test compartment on the third floor (Level 4).

Further investigation showed that smoke was emanating from the construction joints in the external brickwork façade, suggesting a seat of fire within the external cavity between the brickwork and the timber frame. According to the Fire and Rescue Service report, the emergency call from Cardington, made by the Officer in Charge of the test, was received at 23.48 and the Fire and Rescue Service arrived at Cardington at 23.55. Once at the scene, the FRS attempted to fight the fire initially from inside the building and were unsuccessful. Shortly after midnight cracks were seen in the external face of the brickwork (Figure 2) and firefighters withdrew from the building and continued to fight the fire externally from a hydraulic platform.

© BRE Global Ltd 2025

Figure 2 – Cracking in gable end wall at SW corner of the building

The fire was eventually brought under control by removing window frames on upper levels and removing the fire protection at the eaves and spraying water directly down the cavity. Where such access to the cavity was restricted, holes were made in the brickwork to enable the hoses to be directed towards the seat of the fire (Figure 3).

Figure 3 – Hole made in gable wall by the Fire and Rescue Service

It took some hours to fully extinguish the cavity fire. According to the FRS report, the fire was not brought under control until 5.19 am on 16th September 1999. By this time, severe damage to the South wall of the floor above the fire flat had been sustained. The fire consumed the outer layer of Oriented Strand Board (OSB) and ignited the structural elements in the South wall of the living area. This caused extensive damage to the studs and the ring beam in this area (Figure 4).

Figure 4 – Damage inside the living room of SW flat on the third floor

As part of the data acquisition for the compartment fire test, additional thermocouples were installed in the area immediately outside the flat, including in the cavity between the masonry rainscreen wall and the timber frame. Data logging for the main fire test commenced at 20.07, and for Figures 5 and 6, this represents time = 0. Data logging continued for two hours when the initial test configuration was shut down. Readings were then taken at an increased scan interval (every 10 minutes) for a further period of approximately 3 hours at which time, due to the amount of water used during firefighting operations, the data acquisition system had to be turned off.

Figure 5 shows the temperature recorded in the external wall cavity between the brickwork and the timber frame in the South gable wall close to the extreme South-West corner of the living room at third floor level i.e. in the vicinity shown in Figure 4 above.

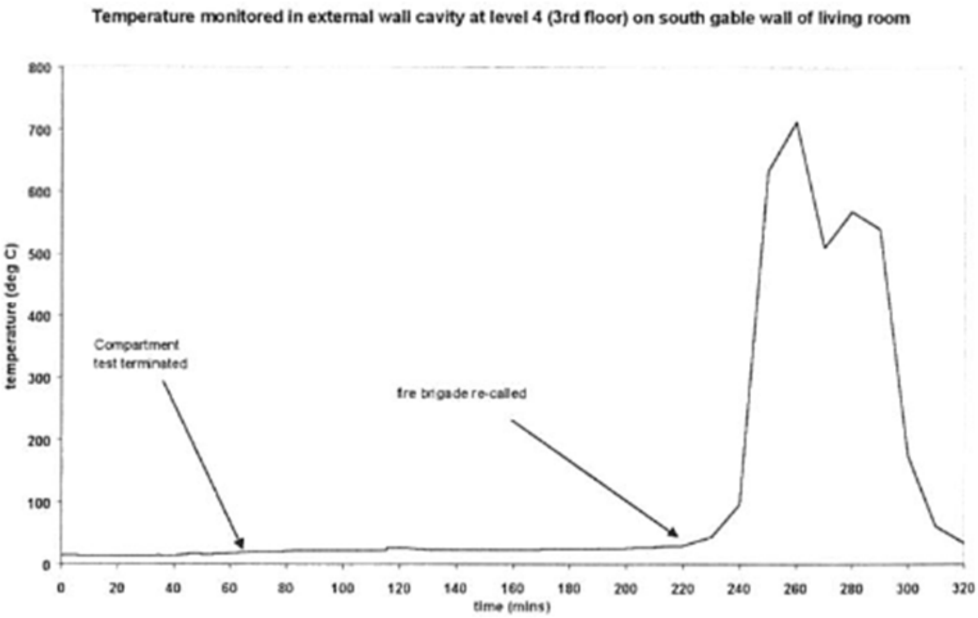


Figure 5 – Temperature monitored in the external wall cavity on the third floor

The data recorded from other cavity thermocouples on the fire floor was inconclusive. Shortly after, noticing the hot smoke emanating from the cavity around the living room window at second floor level, flames could be seen emanating from the cavity around the opening at third floor level suggesting any cavity barrier in this location was ineffective.

A post-test inspection provided indisputable evidence that the fire broke through from the cavity to the living area of the flat above the test compartment. Figure 6 shows the atmosphere temperature in the living area of the flat above the fire flat. This is inconclusive but shows an increase in the ambient temperature at approximately the same time as the emergency call to the Fire and Rescue Service was made. At this point, though the fire may have been in the cavity, the plasterboard linings to the flat would still be intact.

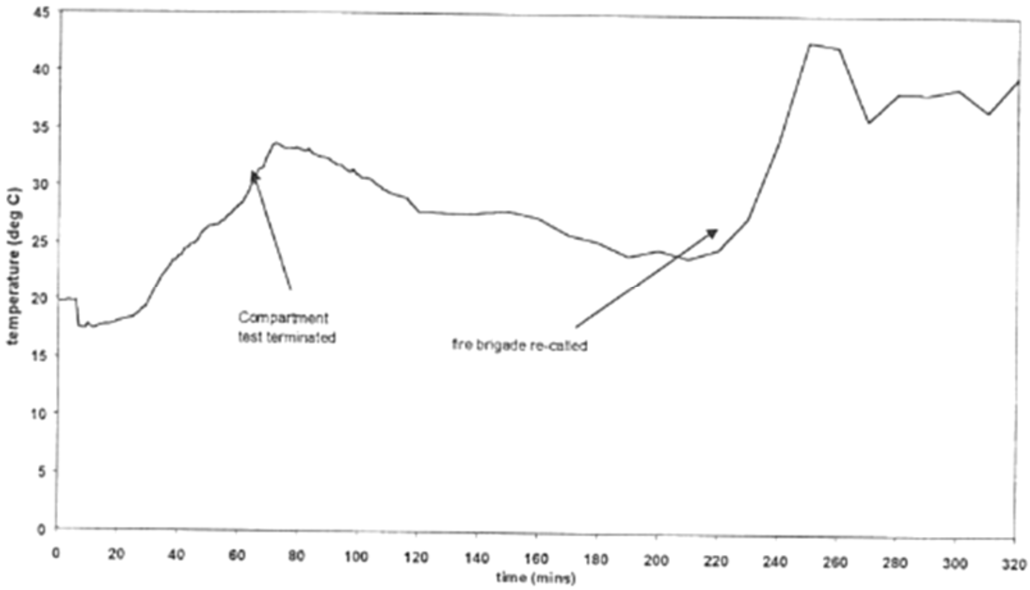


Figure 6 – Atmosphere temperature monitored in the living room of the third floor above the fire flat

Video records indicate the fire began to be effectively fought at approximately 00.30, i.e. coinciding with the peak temperature in Figure 5, at which time the firefighters had gained reasonable access to the seat of the fire within the cavity.

Based on the results, observations and video evidence, the initial hypothesis was that the fire spread within the cavity was as follows:

1. The initial fire spread into cavity via the window opening in the living room of the fire flat.
2. Horizontal cavity barriers for vertical flame spread between the fire floor and the floor above were ineffective, possibly due to one or a combination of the following:
    a. Discontinuity in the line of the cavity barriers due to them moving under the weight of the bricklayer's mortar deposited on top of them during construction.
    b. Combustion of the timber window frame in the compartment fire test could potentially have allowed flames into the cavity potentially exposing the cavity barrier to an exposure equivalent to or in excess of its required functional performance.
3. The horizontal cavity barriers to mitigate vertical fire spread between the third and fourth floors were ineffective due to the severity of the cavity fire in this area although they may have delayed the spread of fire within the building.
4. The horizontal cavity barriers between the fourth and fifth floors remained intact and effective. They contributed to preventing fire spread to the top floor and roof area.
5. The vertical fire barriers designed to mitigate horizontal (lateral) fire spread remained intact and restricted the fire to the Southwest corner of the building.

A detailed inspection of the damaged areas of the building was carried out by Tom Lennon (BRE) and Mostyn Bullock (then Chiltern Fire) on 10th December 1999.

Particular attention was paid to attempting to find evidence to validate the above hypothesis that the fire in the cavity originated from the aperture created by damage to the timber frame window of the living room within the fire compartment. However, all the evidence with respect to the charring of timber and the melting of the vapour membrane led to the inescapable conclusion that the original hypothesis was incorrect.

Attention then switched to the timber window of the fire flat which was also discounted as the route of entry of the fire into the cavity. The investigation then focused more closely on the enclosing wall and floor construction.

On removing the remains of some wall plasterboard and insulation material it was noted that the structural post in the far SW corner of the living room of the fire flat exhibited a greater degree of charring than the adjacent wall studs. This was despite the corner post being formed from several studs fixed back-to-back to provide a larger section size. On investigation of the charred middle section of the post, it was discovered that it had literally burned right through up to and including the OSB layer facing the cavity. This was the only location of penetration into the cavity found on the fire floor remote from the window locations. The situation is illustrated schematically in Figure 7.

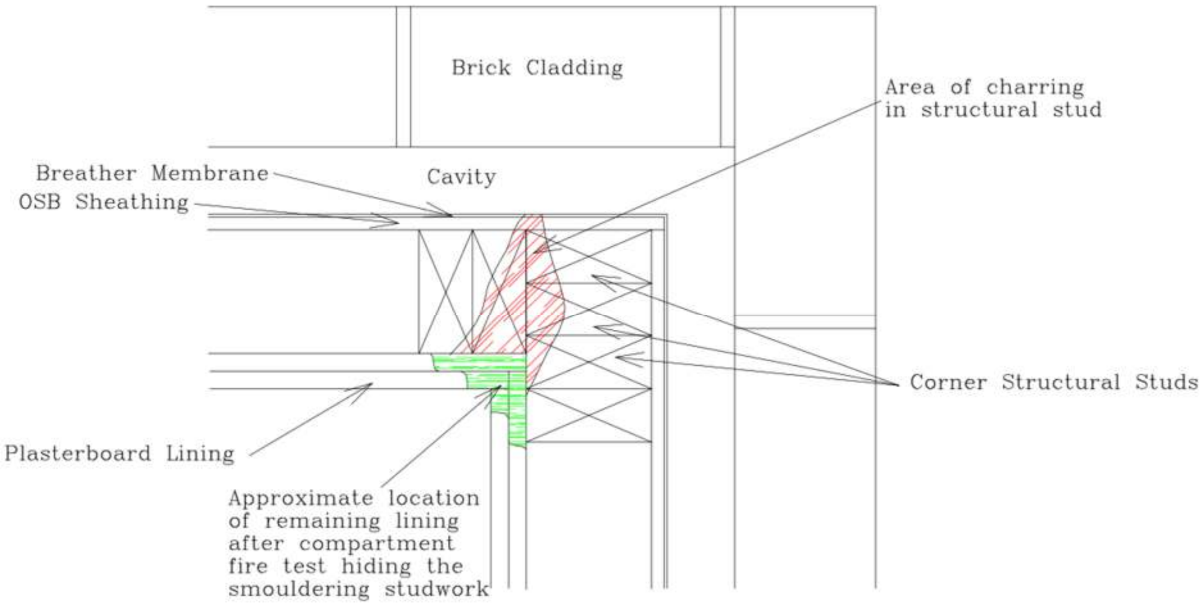


Figure 7 – Plan cross-section of structural studwork and smouldering location

It was evident that a seat of smouldering combustion had remained within the structural post after the initial FRS operation to terminate the compartment fire test. The fact that this penetration into the cavity was just below the ring beam explains why the cavity on the fire floor was relatively unaffected in comparison to the third-floor cavity and also helps to reinforce the opinion that the continuity of the horizontal cavity barrier in the South gable wall between second and third floor had been compromised before the secondary fire event.

The efforts of the Fire and Rescue Service were essential in extinguishing the source of the fire and ensuring the fire spread and subsequent structural damage were limited. Following the test, discussions were held between the experimental staff and the leading firefighters who attended the test and the subsequent call-out. A number of issues relevant to firefighting operations were addressed and included:

1. On arrival, the Fire and Rescue Service was faced with smoke emanating from the construction joints in the brickwork. The initial strategy was simply to hose down the window frames and external wall from the outside. This had little or no effect on the fire.
2. Following discussion with experimental staff the plan of action was changed in order to get water into the cavity area. Fire and Rescue Service personnel entered the building to remove the window frames on the floors above in order to get the hoses into the affected area. This proved difficult, time-consuming and ineffectual.
3. During firefighting operations, cracks appeared in the South gable wall giving the Officer in Charge (OIC) cause for concern over the structural stability of that part of the building. At this point, the OIC ordered firefighting personnel to evacuate the building and firefighting continued externally using a hydraulic platform.
4. As a result of discussions with the test engineers, firefighting attention focused on the roof area. The fire-resistant blanket used to prevent fire spread under the eaves during the test was removed to allow access to the cavity from the top of the building. This approach proved successful in suppressing the fire.
5. The use of an Infra-Red Thermometer or Thermal Imaging Camera allowed officers to identify the seat of the fire in the cavity and to optimise efforts towards the critical locations. This was particularly useful once the extent of the fire had been reduced and helped to prevent re-ignition.
6. The only effective way to access the cavity through the gable masonry wall was to use a hammer and chisel. This is a laborious operation and could lead to a potential localised collapse in areas where the brickwork had already cracked.

Based on the experience gained on the night, and subsequent discussions with Fire Service Officers, it was evident that there was a role in educating firefighters to prepare the most appropriate strategy in dealing with fires of this nature in this form of construction. On arrival, it is not immediately apparent to the Fire and Rescue Service that it is the timber members and not the brickwork which forms the structural frame for such buildings. A better understanding of this form of construction could assist in more quickly being able to identify and deal with concealed fire spread.

There were specific circumstances concerning the location of the cavity fire that are likely to have increased the risk of a cavity fire occurring at this location. The corner of the building at ground floor below the fire flat had been removed to undertake research work related to robustness and the potential for disproportionate collapse. For this reason, the cavity was open at ground level at this location so development of the smouldering combustion would have been assisted by a ready supply of air from below. Although this is true, the incident highlighted the dangers of fire spread within cavities incorporating combustible materials and the importance of the correct specification and installation of cavity barriers.

The incident highlighted a number of issues of direct relevance to the current project. As a consequence of this incident, many of these issues were investigated in greater detail in a subsequent Partners In Innovation (PII) research project led by Chiltern Fire with the participation of BRE. The project was called *Understanding Fire Risks in Combustible Cavities*[10]. Although a series of workshops and seminars were held, and the outputs were made available to both the Government sponsor and the key stakeholders involved in the project Steering Group, the work was never properly disseminated. For this reason, it is revisited in some detail here as the information from this project will be publicly available.

4.1 Understanding fire risks in combustible cavities

The work described below was produced under a Partners In Innovation (PII) contract (CI 39/3/639, cc2252 – understanding fire risks in combustible cavities). PII was a collaborative research programme co-funded by the Department of Trade and Industry and the industrial partners/researchers associated with the project and the Office of the Deputy Prime Minister (ODPM) overseeing and managing the project.

The information provided here was produced by Chiltern International Fire as part of a contract placed by the DTI and managed by the ODPM.

The report produced as a final output for the project covered issues ranging from regulatory requirements in the various parts of the UK to statistics on cavity fire incidents and surveys of practice on live construction sites. However, the principal motivation for carrying out the work and for funding the project was the post-test cavity fire incident on the TF2000 building described above.

As a response to this, work was undertaken in the PII project to investigate different forms of wall construction conducting further tests on the TF2000 building itself, small-scale tests looking at the ignitibility of different products found within timber frame cavities, larger-scale tests of cavity barriers and training and education exercises with the Fire and Rescue Service.

The information presented here will focus on the activities specifically related to the post-test cavity fire incident and will exclude the summary of the statutory instruments for the various parts of the UK and the section covering fire statistics (for cavity fires) as both of these are out of date.

4.1.1 Site surveys

A series of site surveys was undertaken to establish current building practices in relation to cavity barrier installation and to highlight any issues of note.

4.1.1.1 Site 1

The first site visited comprised a single building. The phased method of construction allowed for the examination of cavity barriers.

The horizontal and vertical cavity barriers were not properly butted together. The individual employed to install the cavity barriers was unaware of their required location. Vertical barriers were installed next to a doorway and were not in line with any internal fire compartmentation or separation lines.

4.1.1.2 Site 2

This site comprised a number of two- and three-storey dwellings designated for social housing. The only cavity barriers fitted to the timber frame dwelling houses were along the vertical compartmentation line between each dwelling.

As the installation of the cavity barriers was very simple, not many discontinuities were noted. Evidence was discovered of cavity barriers being inadequately butted together thus failing to ensure closure of the gap between the mineral fibre infill of the individual barriers. Areas of brickwork were also seen where the width of the cavity was such that it was appreciably greater than the width of the cavity barrier thus resulting in incomplete sealing of the cavity at the barrier location.

© BRE Global Ltd 2025

4.1.1.3 Site 3

A fire had occurred due to arson during the construction of the building. The fire originated on the ground floor and spread up the stairwell and into the cavity and loft space due to the incomplete nature of the structure and not due to discontinuities or poor workmanship in relation to installed fire protection.

Evidence of external brickwork being laid within approximately 15 mm of the loadbearing timber frame wall was discovered. Assessing whether any cavity barriers were present in this section of the wall was difficult, but it could reasonably be assumed that none were present as they would have prevented the bricks from being laid this close to the timber frame.

In other locations it was discovered that there were residual gaps between the face of installed cavity barriers and the internal face of masonry cladding as noted for Site 2.

4.1.1.4 Site 4

Following a fire incident, a survey of the building was conducted to establish why the fire spread vertically within the confines of the cavity.

In several areas around the building, the cavity was opened up and the condition of the cavity barriers was examined. Cavity barriers were installed in all the correct locations but not necessarily installed correctly.

One possible cause for the vertical fire spread was found. In several locations, there was a large amount of mortar deposited on the top of the cavity barriers. Where these mortar deposits had landed close to the joint between two cavity barriers, the weight of the material had dislodged one or both of the barriers and created a gap. In some places, a gap of approximately 50 mm between two cavity barriers could be seen with mortar deposits more than 25 mm thick in places.

During construction of the external brickwork, it is normal practice for the bricklayer to clean the back face of the masonry with a trowel. It is likely that the trowel would then be cleaned by “flicking” the remnants of the mortar down the cavity where it could collect on the cavity barrier. This action would impact on horizontal barriers but not vertical barriers. During the fire incident, there was vertical fire spread but no horizontal fire spread, which ties in with observations from the post-fire TF2000 cavity fire incident.

4.1.2 Cavity fire research on the TF2000 test building

The TF2000 test building had been constructed using two different types of wall construction. The majority of the building was constructed utilising the standard wall construction shown in Figure 8. This form of construction has the internal cavity face formed from an OSB sheathing board lined with a breather membrane. However, the North facing gable wall was constructed using a “reverse wall” construction of the type shown in Figure 8. This form of construction has the internal face of the cavity lined with plasterboard.

© BRE Global Ltd 2025

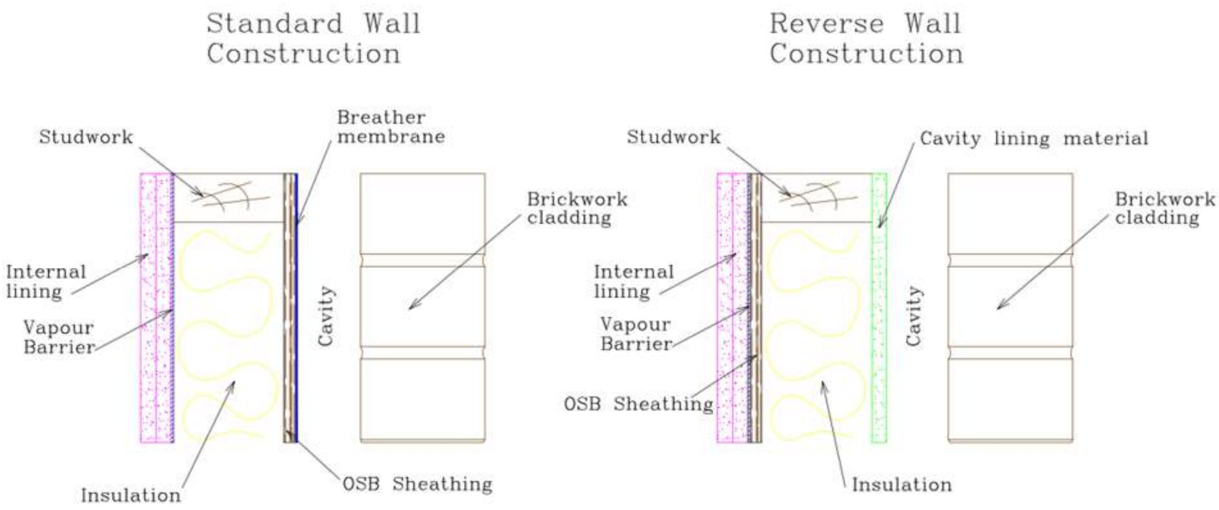


Figure 8 – Sections showing standard and reverse wall construction

The term “Reverse Wall” refers to a form of timber frame construction where the sheathing/racking board is located on the inside of the timber studwork, as opposed to traditional timber frame construction where the sheathing/racking board is located on the outside of the timber studwork.

Many materials can be used to provide the properties required by a cavity lining material. Moisture Resistant (MR) plasterboard was used in the “reverse wall” construction on the TF2000 building at Cardington.

The project team attempted to recreate a cavity fire event on both types of wall. One test was conducted at the base of the East facing wall of the TF2000 building and a similar test conducted on the reverse wall on the north facing gable wall of the building.

This work had to be carefully controlled as there was a risk that any fire initiated could spread in a similar manner to the original post-test cavity fire.

4.1.2.1 Standard wall construction

The test set up is illustrated in Figure 9 for the standard wall construction on the East face of the building. An area of brickwork was cut away to create a hearth for the ignition source and to allow the project team to view the fire spread inside the cavity. The apertures cut away were sealed with a pane of 6 mm thick Georgian wired safety glass with an opening left at the bottom close to the ignition source. The small area was sealed once the fire was ignited with ventilation to the cavity provided by holes drilled into the brickwork (see Figure 9). The holes represented the ventilation present for a full exterior flat wall and included an allowance for leakage factors through loose brickwork, door and window apertures as well as an allowance for open perpends associated with the requirements for a ventilated cavity.

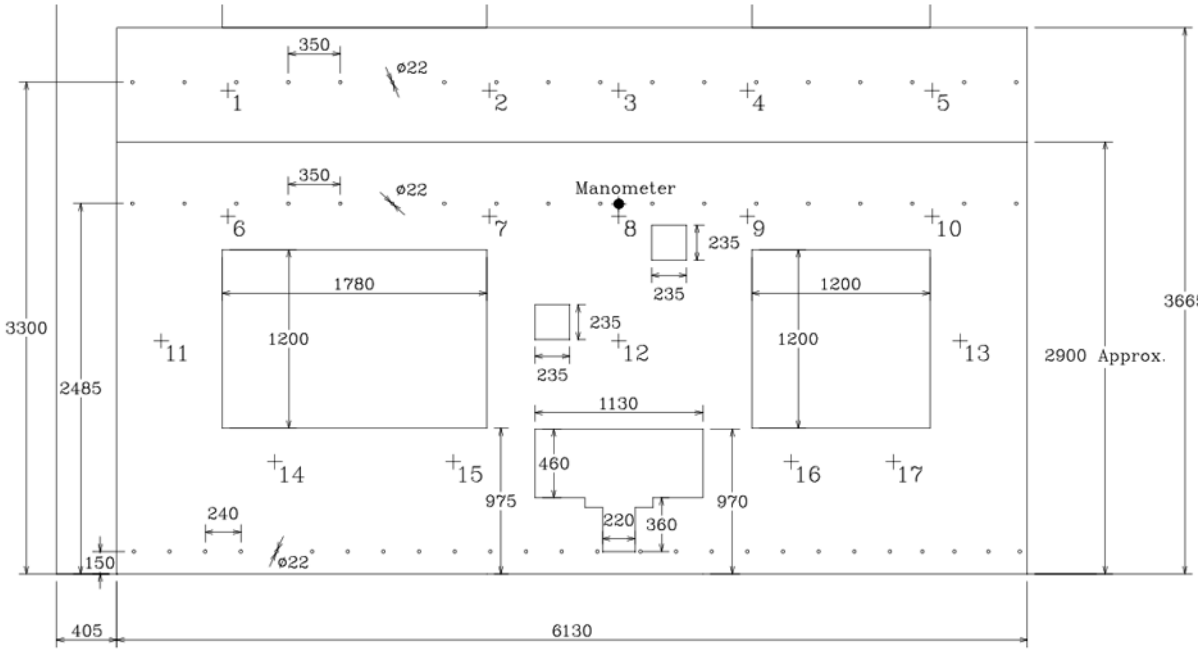


Figure 9 – Standard wall construction setup

The window frames were removed, and the cavity sealed with a fire rated plasterboard sealed with silicone.

To prevent unintended fire spread within the cavity, an additional line of cavity barriers was installed by cutting away the internal linings and sheathing board and sealing the area illustrated above with mineral fibre filled cavity barriers ensuring there were no gaps present between the masonry and the barriers. The details for the first experiment and observations from the test are summarised in Table 1.

Table 1 – Cavity fire test on TF2000 Building - standard wall construction

Location	Standard wall construction East elevation
Fuel source	Four No. 5 cribs (as defined in BS 5852: Part 2: 1982[11]), six strips of softboard (100 mm x 20 mm x 15 mm), approximately 100 ml of paraffin
General observations	Initial fire growth following ignition. The localised high temperatures caused the breather membrane to shrink and melt away. Once the fire had died down the material was left to smoulder. Every 30 minutes, the board was removed from in front of the ignition area to allow a visual inspection of the smouldering. It was noted that the largest char formation was between two of the timber studs. Approximately 3.5 hours from ignition, the smouldering combustion transitioned to ignition and the fire began to grow again. The fire did not grow with the same intensity as the initial ignition source but a peak temperature of 280°C was recorded in the cavity. The reignition coincided with the point where charring had completely consumed the rear face of one of the timber studs which allowed the smouldering to break into the cavity between the sheathing and the plasterboard where the insulation material was located. The reignition is illustrated in Figure 10. Once reignited, all materials in the local area were contributing to the fire. Figure 11 shows the maximum recorded temperature in the cavity.

Figure 10 – Reignition of fire

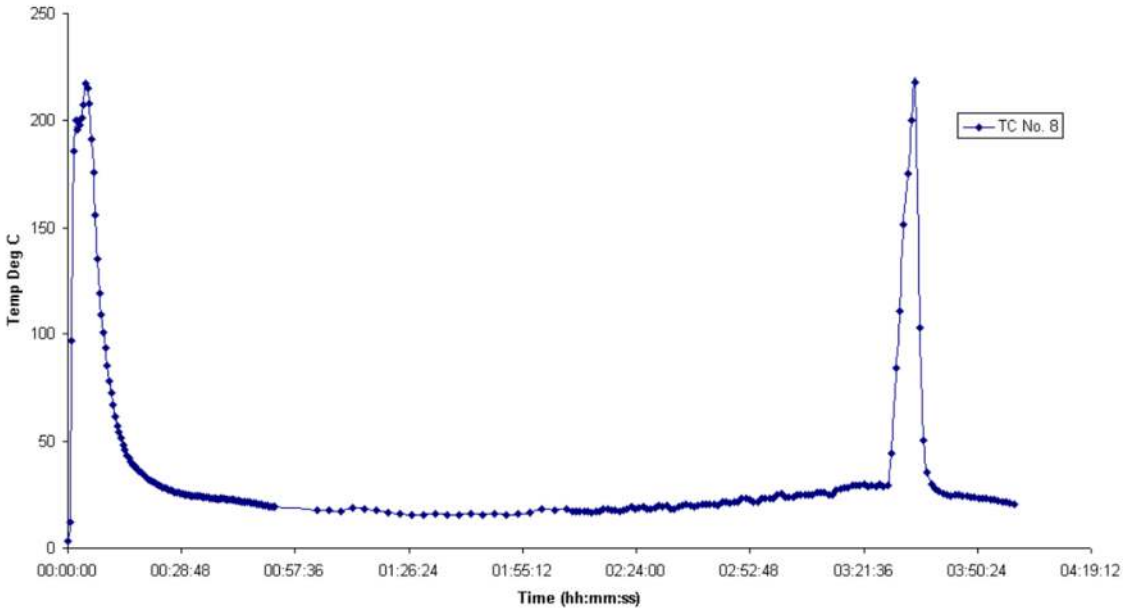


Figure 11 – Maximum temperature recorded in the cavity (see Figure 9 for location of thermocouple)

The fire was extinguished shortly after reignition to prevent further damage to the building. The test demonstrated the effect a hidden seat of combustion within the cavity can have on fire development. Where this occurs and there are gaps or discontinuities in the installation of the cavity barriers, there is the potential for fire to bypass compartment lines and spread throughout the building.

4.1.2.2 “Reverse” wall construction

The test set up was located on the North face of the TF2000 building which incorporated the “reverse” wall construction.

The test set up was similar to that described above, with sections of brickwork removed, the window aperture sealed, and the additional line of cavity barriers installed to prevent unintended fire spread.

The principal difference between the two tests is that in this case the cavity was lined with (moisture resistant) plasterboard and not OSB sheathing covered with a breather membrane, and the ventilation conditions were different. For the reverse wall construction, no cavity barriers were installed, and therefore, the ventilation factor for the test area encompassed the available ventilation, not just for a single fire compartment, but for the whole of the gable wall. Therefore, the area for ventilation was increased as shown in Figure 12.

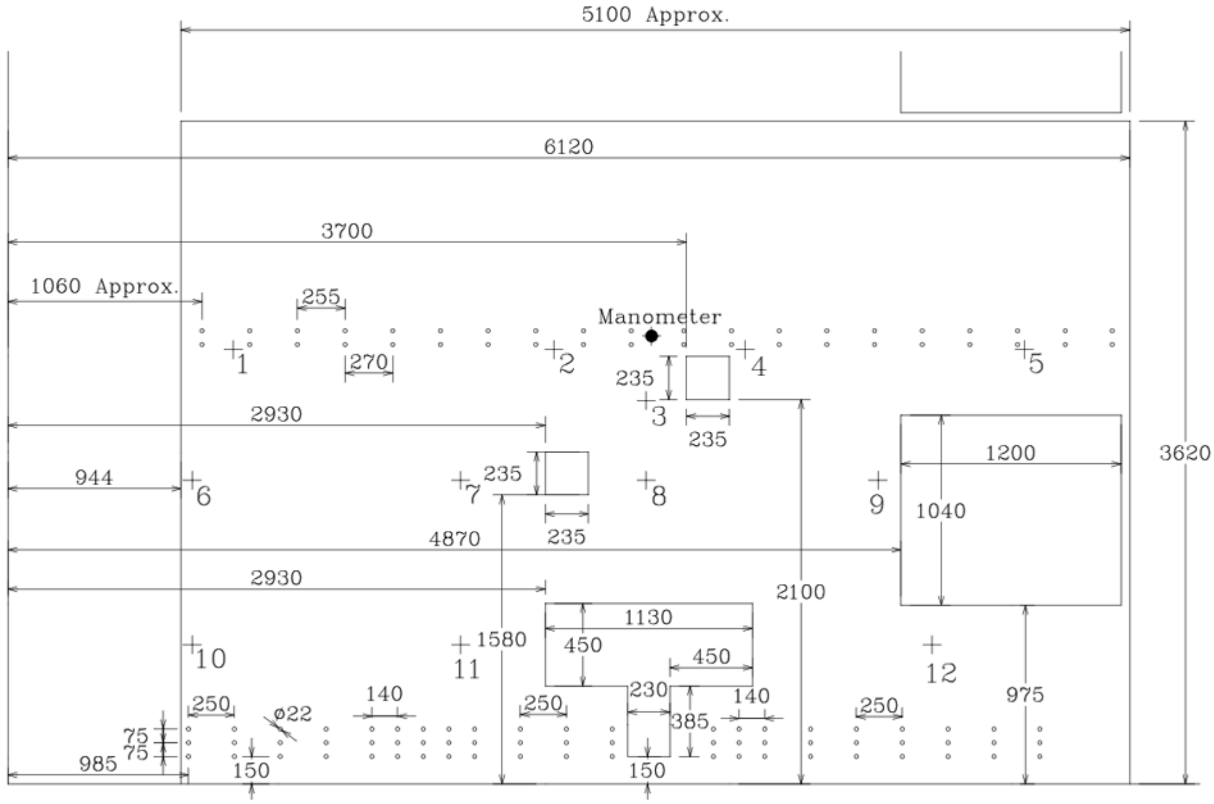


Figure 12 – Test set up for "reverse" wall construction

The details for the second experiment and observations from the test are summarised in Table 2.

Table 2 – Cavity fire test on TF2000 Building "Reverse" wall construction

	"Reverse Wall" construction North elevation
Fuel source	Four No. 5 cribs (as defined in BS 5852: Part 2: 1982[11]), six strips of softboard (100 mm x 20 mm x 15 mm), approximately 100 ml of paraffin
	After ignition, the fire developed in a manner similar to that of the test on the standard wall construction. There was evidence of the influence of the increased ventilation in the cavity causing the flames to lean to one side. Temperatures in excess of 100°C were measured in the cavity void as shown in Figure 13. The fuel source was completely consumed but the only damage sustained by the building was charring and burning of the paper facing the plasterboard. There was some localised degradation of the plasterboard core adjacent to the fuel source, but this did not extend through the full depth of the board (Figure 14).

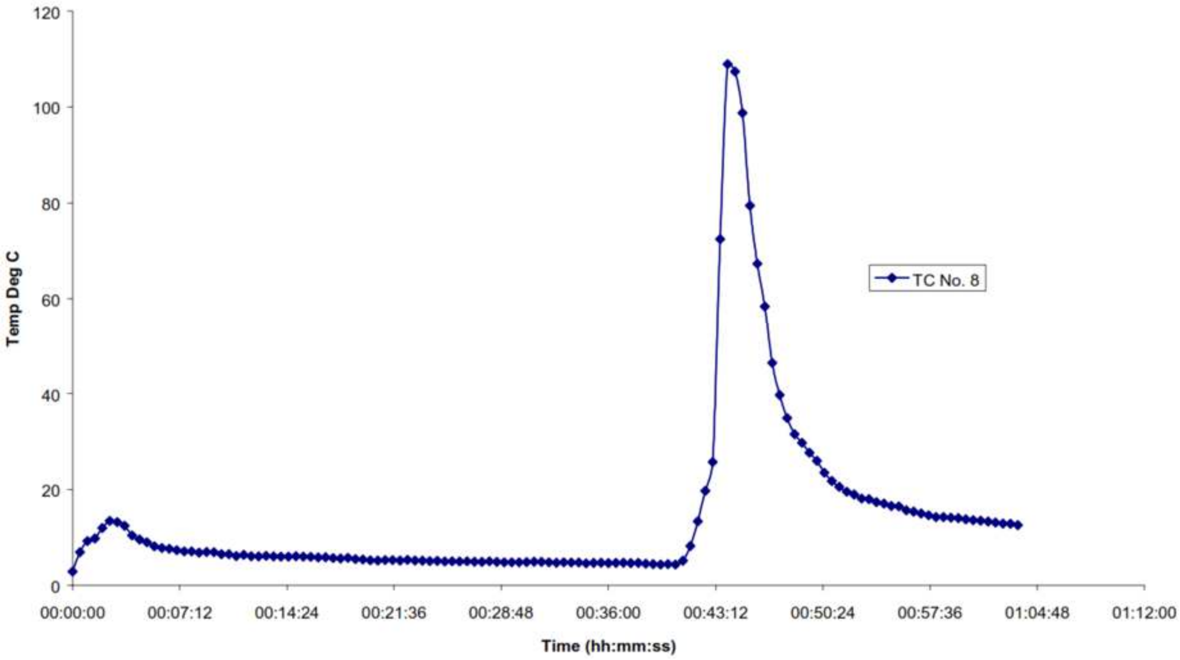


Figure 13 – Maximum temperature recorded in the cavity (see Figure 12 for location of thermocouple)

Figure 14 – Localised damage to "reverse" wall construction

The test demonstrated the effectiveness of this form of construction in limiting fire spread from a fire within the cavity.

4.1.3 Ignitability tests of cavity materials

Upon ignition of a cavity fire, some of the first products that could potentially contribute to fire spread would be those lining the cavity. A series of small-scale reaction to fire tests was conducted to establish the possible contribution that some commonly used cavity lining materials may have on fire spread within a cavity. The following is a list of the materials tested:

- Breather paper
- Wood fibre sheathing board
- OSB
- Bitumen impregnated sheathing board (high and low density)
- Plasterboard
- Cement bonded particle board
- Breathable foil membrane

The purpose of the material testing was not to classify their reaction to fire properties against any specific standard but to benchmark relative material performance. The objectives were twofold. Firstly, to establish the relative level of risk for the materials forming the lining of cavities and secondly, to establish the most appropriate products to be taken forward for the next stage of testing (see section 4.1.4).

The samples were tested to assess their ignitability when subject to direct flame impingement. The tests were conducted to the principles of EN ISO 11925-2[12].

The tests conducted differed from the standard in two ways:

- The specimens were subject to the direct flame impingement for 10 minutes, while the standard requires only 30 seconds. The prolonged exposure was to simulate common sources of ignition such as hot works where cavity lining materials could be exposed to heat for a considerable time.
- The results were not used for classification purposes as this would have required testing to a number of different reaction to fire tests.

The results are summarised in Table 3.

bre

Table 3 – Results of ignitability tests

Material	Observations (min:sec)	Photo
12.5 mm thick bitumen-impregnated softboard (high density)	0:40 Small pilot ignition of the sample 2:00 Charring of the material surface close to the flame source 10:00 No continued flaming of the specimen The sample was still smouldering on removal from the test rig	
18 mm thick bitumen-impregnated softboard (low density)	0:31 Surface of material ignited 1:00 Flame front is spreading across the face of the specimen 1:40 Flaming has reached the top of the specimen 9:20 Glowing embers can be seen around the area of direct flame impingement Specimen still smouldering on removal from the test rig Specimen continued to smoulder for a period in excess of 40 minutes after termination of the test Specimen reignited approximately 60 minutes after termination of the test	 

Material	Observations (min:sec)	Photo
9 mm thick racking resistant fibreboard	The “shiny” side of the board was exposed to flame 1:05 Small pilot ignition of sample close to flame source 1:43 Further surface ignition 3:06 Cracking of the specimen surface 5:09 Surface flaming stopped 10:00 Small embers glowing around flame impingement area	
18 mm thick Cement bonded particleboard	4:49 Small area of surface cracking around flame source 10:00 No further damage sustained No smouldering following termination of the test	

Material	Observations (min:sec)	Photo
11 mm thick OSB	0:39 Small pilot ignition of sample 5:00 Charring of material close to flame source 10:00 No continue flaming of the specimen No further smouldering after test	
12.5 mm thick plasterboard	1:28 Paper of plasterboard beginning to char 4:55 Paper burning away 10:00 No continued flaming. Localised damage to core of the plasterboard	

Material	Observations (min:sec)	Photo
5 mm thick FR breather foil	The aluminium foil side of the membrane was exposed to flame 0:09 Softening of the surface, smoke issuing from rear face of specimen 5:00 Area around flame source softening, becoming molten and beginning to flow 10:00 No continued flaming of the specimen	
0.3 mm thick breather membrane	0:01 Specimen ignited 0:12 Large hole burnt through specimen 0:28 50% of the specimen has burnt away 1:00 Test terminated due to destruction of the specimen	

The results indicated that the 18 mm thick low-density bitumen impregnated softboard provided the greatest risk of fire spread within a cavity. It was therefore decided to use this material as the sheathing board for the next stage of cavity fire tests described below.

4.1.4 Cavity barrier fire tests

A number of issues such as the incorrect installation of cavity barriers and the presence of discontinuities due to mortar droppings on the barriers suggested there were issues with the current methods used to assess the performance of cavity barriers. Fundamental research was required to establish realistic performance criteria and a realistic thermal exposure for cavity barriers, particularly where the products within the cavity include combustible material.

To simulate a combustible cavity construction, the project team designed a test to evaluate the performance of different cavity barriers. The test utilised one face of one of the cladding test rigs located at BRE Cardington to simulate the external masonry wall. Timber frame panels were built against the wall with the cavity space maintained. Wall panels of approximately 2.4 m width were built facing the masonry wall and extending to a height of approximately 5 m to simulate two floors of a real building. The cavity barriers were installed at the required location (between floors) and the panels were extensively instrumented either side of the barrier to monitor temperatures during the test.

A single timber crib was placed alongside the inner face of the wall to provide a repeatable fire source for the tests. The intention was to maintain combustion for a reasonable period. Each of the tests conducted lasted for 60 minutes. The crib was formed from approximately 18 kg of timber in 50 mm x 50 mm section kiln dried softwood with a minimum moisture content of 14%. A small amount of accelerant was used to ignite the crib.

The panels were constructed to simulate a timber frame wall with the exposed face consisting of bitumen impregnated softboard chosen as the worst-case scenario in terms of reaction to fire characteristics. A double joist ring beam was installed between the two panels to simulate the floor zone of a building. The panels were infilled with insulation.

The panels were mounted on a series of bricks that were arranged to allow correct and even ventilation across the crib. At the top of the lowest panel, a small hole was cut through the panel to allow ventilation for the fire. Ventilation was also provided at the head of the test specimen. The amount of ventilation provided was equivalent in terms of percentage of the wall elevation to a standard wall construction as considered in section 4.1.2.

The test set up is illustrated in Figure 15.

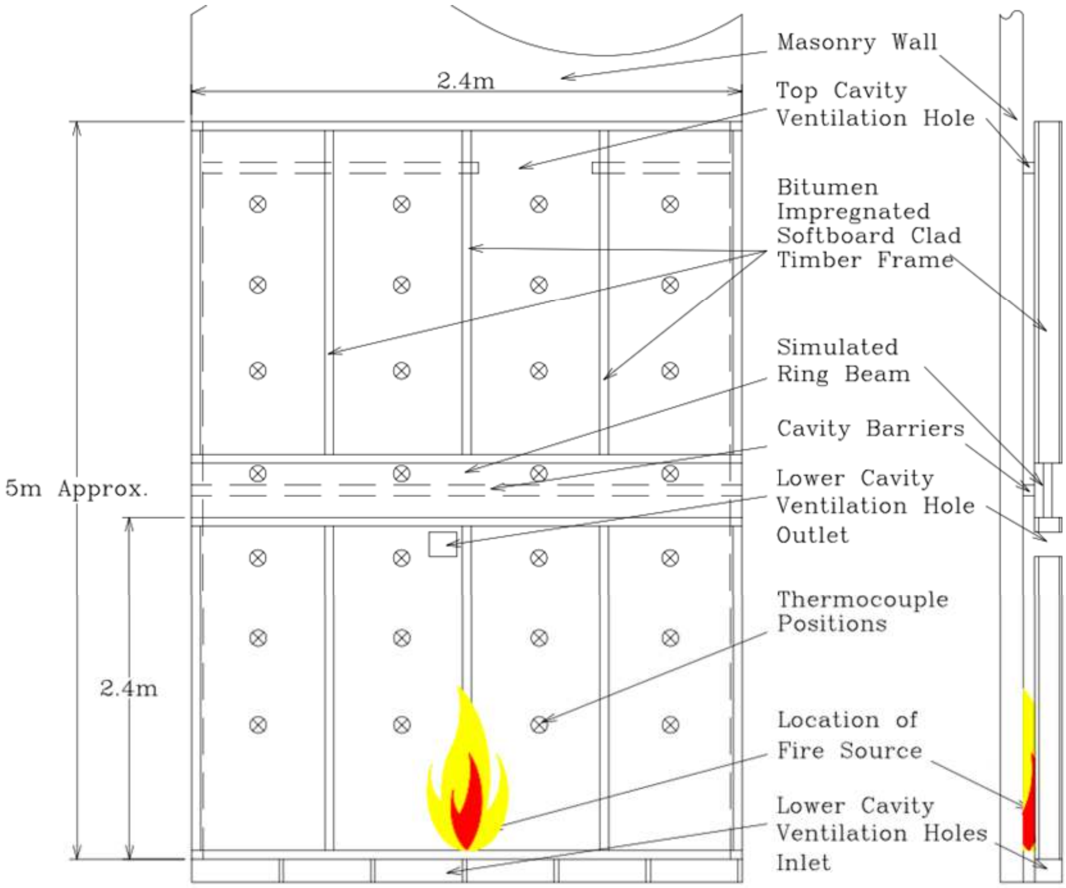


Figure 15 – Cavity fire test set up

Figure 16 shows the size of the crib used located inside the hearth of the cladding wall.

Figure 16 – Crib located within the hearth of the cladding rig

Four fire tests were undertaken on different types of barrier as described in Table 4.

Table 4 – Cavity barrier full-scale test specimens

Test Number	Description
1	PVC wrapped mineral fibre core cavity barriers
2	Solid timber battens
3	PVC wrapped mineral fibre core cavity barriers, including discontinuities to simulate poor workmanship
4	Proprietary intumescent honeycomb cavity barrier

In each case, the wall panel and the design fire scenario were the same. The tests provided an indication of the relative performance of each method and an assessment in terms of fire development within the cavity, as opposed to within the room of origin.

Thermocouples were used to provide detailed information on the performance of the cavity barriers. As there was no risk of extensive damage to the structure or risk of personal injury to any of the personnel involved, the failure criteria for termination of the test was either:

- A temperature recorded above the cavity barrier of 400°C or
- 60 minutes from the start of the test.

 © BRE Global Ltd 2025

4.1.5 Test observations and results

All of the fire tests lasted for 60 minutes. The average temperature within the cavity below the horizontal cavity barriers was approximately 600°C. The temperature was maintained for the duration of the test and was relatively even across the length of the specimen. Figure 17 shows the set up during one of the fire tests.

Figure 17 – Typical test set up with smoke issuing from the ventilation hole at the top of the panel

Table 5 summarises the test results, while the measured values are shown in Figure 18.

Table 5 – Cavity barrier fire test results

Test No.	Description	Comments
1	PVC wrapped mineral fibre cavity barriers	Prevented fire spread > 60 minutes
2	Solid timber battens	Prevented fire spread > 60 minutes
3	As 1 but including discontinuity	Temperatures > 250°C 2 minutes from ignition. Fire spread to top panel through the cavity.
4	Proprietary intumescent honeycomb cavity barrier	Prevented fire spread > 60 minutes

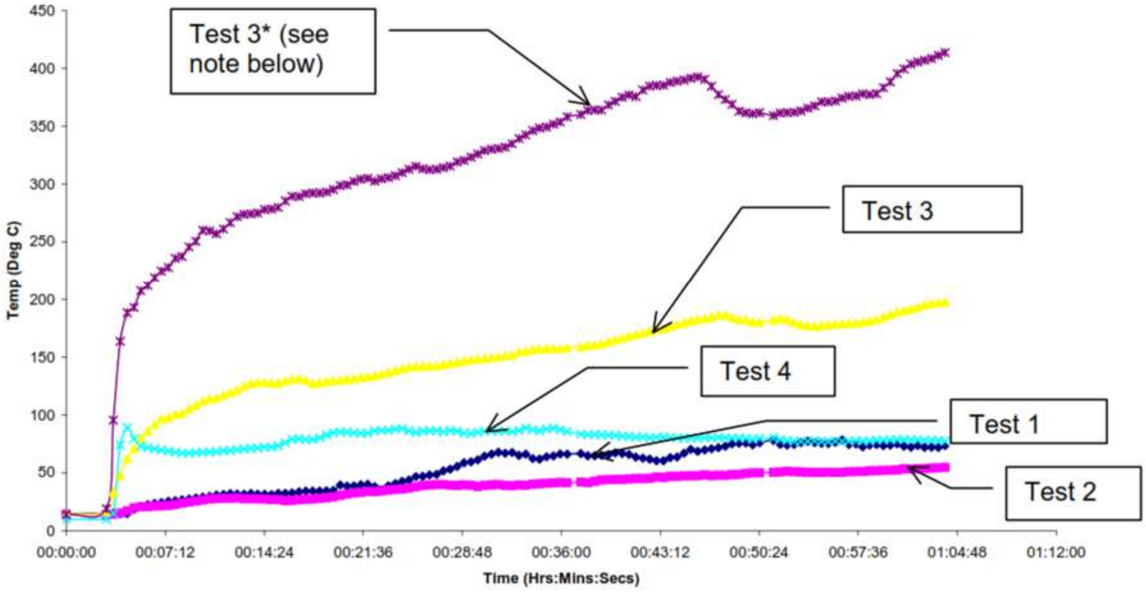


Figure 18 – Sample temperatures above cavity barriers

** Note to Figure 18. Thermocouple data for Tests 1, 2 and 4 were recorded 50 mm above the line of cavity barriers. None of these reached a temperature greater than 100°C. Thermocouple data for Test 3 was recorded 250 mm above the line of cavity barriers and also indicates the higher peak temperature in this cavity due to discontinuities in the barrier.*

For Test 3, on a PVC wrapped mineral fibre cavity barrier, two discontinuities were incorporated along the length of the barrier:

- A 25 mm to 50 mm wide gap between the two barriers (see Figure 19).
- A 100 mm long section where the barrier had been pinned back to the timber section, resulting in a residual gap between the face of the barrier and the masonry wall.

Figure 19 – Discontinuity at the junction between two cavity barriers

Test 4 incorporated a proprietary intumescent product as a cavity barrier consisting of a 40 mm deep cardboard impregnated hexagonal honeycomb structure. The barrier was located centrally along the floor zone tight against the timber. A gap of approximately 10 mm was left between the front face of the barrier and the masonry wall. Figure 20 shows the barrier in place prior to the fire test.

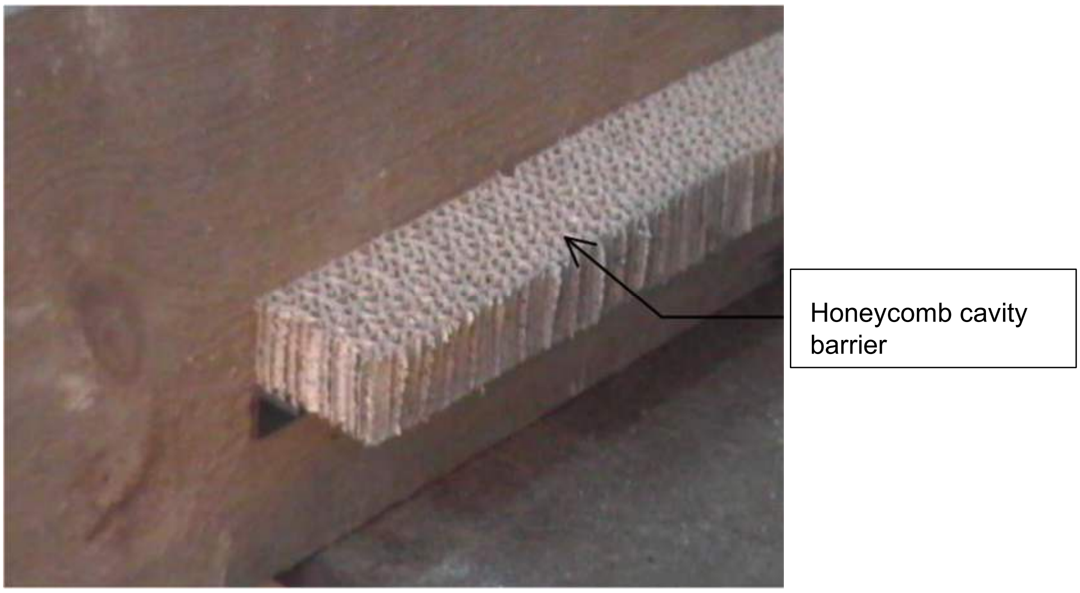


Figure 20 – Honeycomb cavity barrier

The results indicate a number of potential conclusions:

- Commonly used cavity barriers can provide the required level of performance (to inhibit the unseen spread of fire and smoke) when correctly installed with no gaps or discontinuities present when subject to a realistic fire exposure.

- The presence of gaps and discontinuities between barriers or between the barrier and the external façade can have a significant impact on performance when subject to a realistic fire exposure.
- Intumescent products can provide the required level of performance (to inhibit the unseen spread of fire and smoke) when subject to a realistic fire exposure and can provide a means of sealing gaps and discontinuities. The initial temperature rise in the early stages prior to activation of the intumescent does not have an adverse impact on performance although may lead to a "failure" when assessed against a standard fire exposure.

4.1.6 Fire and Rescue Service operations

The cavity fire incident on the TF2000 building described in detail above presented the FRS with a number of problems in locating the seat of the fire and fighting the fire. It was a protracted incident as illustrated in Figure 21 which shows the timeline of events from the end of the compartment fire test to completion of firefighting activities.

Time (real)	Duration (hr. m.)	Event
21:17	0:00	Successful completion of compartment fire test
22:38	1:21	Temperature rise in cavity
23:48	2:31	Fire Service called on discovery of fire in the cavity
23:55	2:38	Fire Service arrive and start to fight fire
00:22	3:05	Inclined cracks visible in brickwork of gable end wall
00:30	3:12	Fire Service evacuate the building because officer in charge believes building to be unsafe
00:34	3:16	Eaves protection of the building removed to enable access to cavity
00:43	3:23	Additional window frames removed to gain access to the cavity
05:19	8:02	Fire Service recorded the fire as being extinguished

Figure 21 – Timeline of events related to firefighting activities

The incident demonstrated there was a problem in identifying the origin of a fire within a cavity in this form of construction, where the only evidence visible on arrival during the smouldering phase is the presence of smoke emanating from gaps or openings in the structure. If the seat of fire is some distance from an opening, then it can be difficult to identify the source.

Following discussions with the FRS, training exercises were undertaken on the TF2000 building. The intention was to identify strategies adopted to fight fires in cavities and to establish the benefits of specialist tools and equipment such as handheld thermal imaging cameras to locate hot spots within the building.

The Project Team simulated a smouldering fire that had been burning slowly for approximately two hours. The heat source was concealed within the external cavity wall of the TF2000 building approximately 2 m from the Southeast corner of the building along the gable wall on Level 3. The plasterboard was removed internally and the OSB sheathing cut away. Two Positive Temperature Coefficient (PTC) heaters were installed within the cavity, capable of generating a localised temperature of 110°C. The heaters were attached to the rear face of the masonry cladding. In addition to the heaters, a 50 mm diameter section of copper pipe was installed. The copper pipe was fitted with three electric band heaters connected to a flexible plastic hose and fed back down through the cavity to the flat below where the power supply leads for the heating elements were as seen in Figures 22 and 23.

Figure 22 – Internal view of gable end wall with linings removed

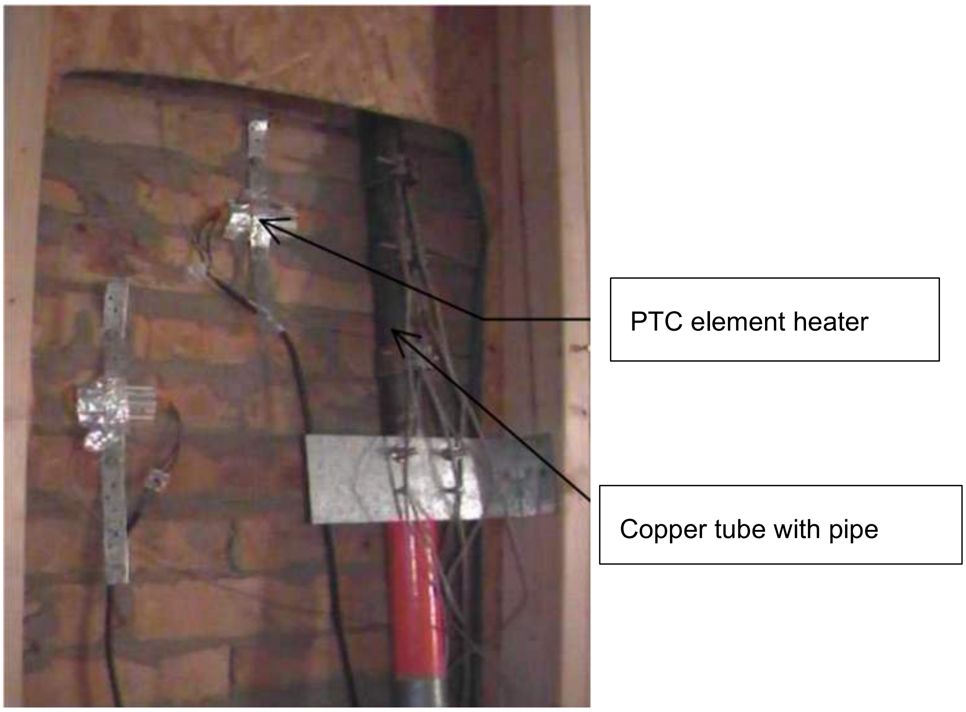


Figure 23 – Close up of heaters and copper tubing

The plastic pipe was to allow smoke produced by an artificial smoke generator located in the flat below to be piped to the heated location. The heaters on the copper tube were to provide buoyancy to the smoke. The temperature of the smoke exiting the tube was approximately 65°C. The plasterboard linings were reinstated once the heaters had been installed.

Three exercises were conducted with different fire crews. Prior to commencing the exercise, each crew was briefed on the purpose of the project, but no information was provided on the location of the simulated fire source.

The fire crews were instructed that they should follow all standard operating procedures and the exercise was to be treated as a real fire incident. One of the project engineers acted as the building manager and assisted the crews who were informed that all occupants had been safely evacuated and were accounted for and no work had been undertaken on the building recently.

Access was available from either inside or outside the building. A period of 60 minutes was allowed to locate the “fire” source. This time was assumed to be sufficient for the smouldering “fire” to transition to a fully developed fire.

The variable parameter was the tools available to the crews. The variation is summarised below:

- Dunstable Red Watch – Marconi Applied Technologies “Argus 2” solid state thermal imaging camera.
- St Albans Green Watch – 3M “Scotch-Trak” Infrared Thermometer.
- Kempston Red Watch – Only hand tools available on the appliance. Hydraulic platform available.

The clock was started once the crews approached the TF2000 building and timing continued until the seat of the “fire” was identified.

Before starting the exercise, the wall heaters, pipe heaters and the smoke generation unit were switched on until smoke could be seen emanating from the construction joints and the window openings in the external wall. Additional smoke cartridges were released in the stairwell and on alternate lobbies throughout the building.

Each of the crews began their search inside the building and were equipped with Breathing Apparatus (BA). All crews were followed by a project engineer and their activities noted as shown below.

Table 6 – Summary of results from FRS training exercise

Crew No.	Tools available	Results and Observations
1	Thermal Imaging Cameras	Fire source was located within 27 minutes. The initial search was conducted internally but the seat of the fire was eventually located from the exterior 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 exterior of the building
3	Traditional Hand Tools, only to gain access to the external cavity	Fire was not located within 40 minutes after initial internal search of the building. After 40 minutes the crew was presented with a Thermal Imaging Camera. The fire source was located within 2 minutes on an external search of the building.

The following observations were made by the project engineers, together with information provided by the crews during a debrief session. It should be borne in mind that the information presented below is more than 20 years old and it is highly likely that operational firefighting procedures and access to equipment have developed during this period. Based on information from a Fire and Rescue Service representative of the Technical Steering Group, Thermal Imaging Cameras are now standard equipment on most appliances and would be used internally and externally.

- Some frontline appliances carry thermal imaging cameras (TIC), but they are normally only used for internal searches of the building. The seat of the fire was located by the operator scanning the outside of the building.
- Infrared thermometers (IRT) are not commonly carried on fire appliances. The operatives had greater difficulty in locating the fire as the IRTs only provide a point temperature of the surface being scanned whereas the TIC provides a wider view of the surface. It was suggested that there may be issues reading the temperature while scanning the surface and these difficulties would be exacerbated in poor light or smoky conditions.
- During the search, the crew that had only hand tools available began searching the internal walls by running their bare hands over the wall feeling for an increase in temperature. It is understood that Fire and Rescue Service safe systems of work would prevent crews searching by this method as they are expected to keep their gloves on at all times on the fire-ground.
- Searching by hand did not yield any positive results. The crew then began to access the cavity closest to where the greatest amount of smoke was coming from. This was actually on a different wall to the fire source but still within the compartment lines for the "fire flat".

- The firefighters used a small axe (hatchet), large axe and a large sledgehammer to access the cavity. None of these tools made much of an impression in breaking through the plasterboard and OSB layers.
- The most effective method to access the cavity is to cut/saw through the materials. The plasterboard can be easily cut using a keyhole plasterboard saw. An alternative would be required for the OSB with a powered reciprocating saw producing good results.
- The energy expended by the crews using just the hand tools was such that the firefighters used up the air from their BA equipment and had to withdraw and replace their cylinders.
- The third crew only located the fire after being given a TIC. The senior firefighter had attended similar fire incidents and knew from experience that the quickest way to locate a fire of this nature was by scanning the external wall first. The fire location was found within 2 minutes of receiving the TIC.

4.1.7 Conclusions from *Understanding fire risks in combustible cavities* project

- When properly installed, current commonly specified cavity barrier types can comply with the functional requirements of the Building Regulations through inhibiting the unseen spread of fire and smoke within a cavity when assessed against a realistic thermal exposure. Poor quality installation and the presence of gaps and discontinuities adversely impact on performance and compliance with the requirement.
- Fires within cavities are difficult to locate and difficult to extinguish. This is particularly true for external wall cavities.
- The use of non-combustible products and materials within the cavity can remove or reduce the risk from cavity fires.
- Information/training on the correct method of searching a building for a fire source located within a cavity needs to be disseminated. If following discussions with FRS representatives on the Steering Group for the current project, this is still the case, then further action may be required.
- The Understanding Combustible Cavities project highlighted a number of “toolkit” measures that may be employed by design/project teams to ensure the risk of cavity fire incidents leading to disproportionate damage is reduced. They were as follows:
    - The option of designing the cavity to limit the use of combustible materials.
    - Use of tested and approved proprietary cavity barriers fitted in accordance with manufacturer's instructions and used within the limits of the stated field of application for the product.
    - Clarification of responsibility within the construction Project Team in relation to the inspection of the installation of cavity barriers.
    - Instruction of contractors by approved training bodies and appropriate supervision at key stages to ensure that cavity barriers are being installed correctly and the installation is not compromised by follow-on trades.

© BRE Global Ltd 2025

4.1.8 Recommendations from *Understanding fire risks in combustible cavities* project

A number of specific recommendations were provided based on the lessons learnt from the Partners In Innovation project. These are included below, not just as a simple rewrite, but with a critical review based on the current state of knowledge:

- The construction industry needs to raise the awareness of the importance of satisfactory standards of workmanship. Specifically, with regard to the provision of cavity barriers in buildings, clarity of responsibility needs to be ensured at Project Team level so that correct installation is guaranteed and that follow-on trades are aware of the important role played by cavity barriers.

- It was recommended that guidance is produced for contractors, advising them of why controls and procedures are important and technical guidelines produced to help them to exercise their responsibility in this area. The recommendations were less clear about who should be providing this guidance. Although industry specific guidance has been produced and this is covered later in this report.

- Industry should consider developing recognised professional training schemes to deliver appropriate levels of confidence in those involved in fire precautions. Again, the recommendations were less clear about what "Industry" means and tended to confuse the installation of cavity barriers with fire stopping generally.

- The construction industry should review current detailing practices with a view to considering more robust details that may help prevent the disruption of cavity barriers during the construction process. Again, a lack of clarity over what constitutes "the construction industry", but again, reference may be made to more recent industry guidance.

- Guidance was needed from trade associations for those carrying out repairs to buildings to advise that many cavities in modern buildings include combustible materials and that any tools or equipment generating heat, flame or sparks should be used with care.

- There was a recommendation that further work should be carried out on open state cavity barriers of the type covered in the research. There was a recognition that any further work should consider the relevance of the recommendation for 15 minutes insulation performance to be reviewed. Again, this has partly been achieved through the ASFP Technical Guidance Document[1] and the proposed EN 1364-6[8].

- It was recommended that further work be carried out to consider whether a dedicated standard test for cavity barriers would be appropriate rather than a continued reliance on adherence to standard fire resistance tests that bear little relation to the thermal exposure within a real cavity.

- Fire and Rescue Service training was highlighted as a potential issue. There is a need to ensure firefighters are aware of developments within the construction industry which may have an impact on their operational response. This will be discussed within the current project.

- It was recommended that consideration be given to amending the current FDR1 Reports (now replaced by the IRS system) to include details of the specific form of construction. It is unclear if this has been adequately addressed in the interim and again will be discussed with FRS representatives on the Steering Group.

- The research highlighted the issue of differences between the requirements around window and door openings and those related to lines of compartmentation. There may be a requirement to review the guidance in 5.21 of AD B (Volume 1) in relation to materials that do not provide 30 minutes integrity or 15 minutes insulation.

© BRE Global Ltd 2025

5 Fire in cavities in residential buildings

In April 2013, a document was published by the NHBC Foundation as a result of a research project funded jointly by the NHBC Foundation and the BRE Trust[13]. This research was undertaken to investigate the nature of fire spread within combustible cavities and was a direct result of issues discussed above in relation to the TF2000 cavity fire incident. In addition to new research going further than the initial cavity fire tests covered in the Understanding Fire Risks in Combustible Cavities project, it also considered a review of relevant information from real fires provided by the London Fire Brigade and BRE fire investigations. In part, the motivation for the project was to publicise the lessons learnt during the TF2000 tests and it is this same motivation that drives the inclusion of this information in the current Structural Fire Resistance and Fire Separating Elements project.

It is to be hoped that the NHBC Foundation publication went some way to providing guidance for building control authorities and other building professionals on best practice relating to the installation of cavity barriers and inspection techniques both during and post construction.

The first part of the publication covered similar ground to that discussed above in relation to the TF2000 cavity fire incident, the subsequent collaborative research project into fire risks in combustible cavities and a review of the (then) current guidance in Approved Document B. However, it also included a short section which went back before the TF2000 project. There seems to be a recurring theme that the issues raised are consistent, but it is unclear if the message is getting through to those responsible for the design, testing, specification and installation of cavity barriers.

5.1 Fire performance in timber-framed housing

Wall cavities and the behaviour of the materials in fire within timber-framed dwellings have been a topic for discussion among regulatory authorities and government scientists for many years before the TF2000 project. In 1983, BRE published *Timber-Framed Housing – A Technical Appraisal*[14]. The report made five recommendations specifically related to fire performance, three in relation to fire protection and two in relation to durability as outlined below:

- 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.
- Assess the effect of introducing new materials, such as readily combustible sheathing boards, on fire performance.
- Emphasise in the site inspection the importance of proper installation of cavity barriers and fire stops.
- Carry out research to resolve the potential conflict between the need for cavity barriers (for performance in fire) and the need for ventilation of the cavity (to reduce the risk of interstitial condensation).
- Introduce performance criteria for sheathing materials and breather papers, including development of appropriate test methods.

Following publication of *Timber-Framed Housing – A Technical Appraisal*[14], the UK government through the Department of Environment commissioned the Fire Research Station to provide a discussion paper. The subsequent unpublished output, *Timber Framed Buildings: The Role of the Wall Cavity and its Materials in Fire*[15], set out the role of the wall cavity and construction materials that form the cavity in a fire. The discussion paper acted as a guide to the implementation of the recommendations, provided background information to aid policy decisions within DoE and suggested areas having implications for Building Regulations. It concluded that there was no evidence to suggest that timber-framed dwellings are any more or less likely to produce fatalities in fire than dwellings of any other construction. However, it was acknowledged that there had been damage to the fabric of buildings as a result of fire spread through wall cavities.

5.2 Cavity barriers – Review of guidance in Approved Document B

As part of an overall review of the guidance provided in Approved Document B, an experimental programme was undertaken on cavity barriers in 2005[16]. 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 perform 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 this experimental programme were:

- Confirmation that cavity barriers, when appropriately designed and installed, offer a means by which unseen smoke and fire spread may 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.

5.3 Real fire incidents

5.3.1 London Fire Brigade statistics

As part of the research project, London Fire Brigade (LFB) were asked to interrogate its real fires database to identify incidents involving fire spread through cavities in an attempt to evaluate the scale of the problem, the nature of potential ignition sources and the extent of damage related to cavity fire incidents. A total sample of 30,086 building fires attended in London between 2009 and 2011 were considered. Of this sample, 92 cases were identified where the fire had spread through gaps or voids in the construction, resulting in fire spread beyond the floor of origin to other floors or the whole building. The data is summarised in Table 7.

Table 7 – Fire spread through gaps or voids in construction 2009 to 2011 (Source: London Fire Brigade)

Ignition source	Extent of fire spread					
	Whole building	> 2 floors	Roof space and other floors	Roof space only	External roof only	Whole roof
Barbecue		2			1	
Blow lamp/paint stripper	1		3			
Candle or tea light	2		1			
Chimney		1				
Cooker including oven	1	2				
Deep fat fryer	1	1				
Extractor fan		1	1			
Fireworks						1
Fridge/freezer	1		1			
Fluorescent lights	1					1
Heating/fire	1	2		1		
Kiln/oven/furnace		2				
Lighted paper, card or other naked flame	19	2		1	1	
Liquids, petrol/oil-related	1					
Matches	2	1				
Not known	5					
Other		1		1	1	
Other appliance or equipment	1	4				1
Other domestic appliance	1			1		
Other lights	1		1			
PC/computer terminal		1				
Ring/hot plate	1	3				
Smoking materials (not cigarettes)	1	3				
Spread from secondary fire	1					
Wiring, cable, plugs	2	4	2			
Total	**43**	**30**	**9**	**4**	**3**	**3**

The number of cases reflected the fact that fire spread in cavities is a relatively rare event. This is a conclusion supported by earlier studies[13]. These cases were where the fire had spread beyond the floor of origin. The number of cases involving fire spread through voids regardless of the extent of fire spread was 296. Therefore, of the cases involving fire spread in voids, 31% spread beyond the floor of origin and in 14.5% of cases the extent of fire spread was such that the whole building was involved.

Further analysis of the data was undertaken to evaluate the extent of fire spread where the whole building was involved. There were a number of cases where the buildings involved were constructed of three floors or more. Of these, there was one case involving the category flats/maisonettes from four to nine storeys where a fire occurring on the second floor had spread throughout the building.

5.3.2 Investigation into fires of special interest

At the time of the publication of the NHBC Foundation/BRE Trust document, BRE Global was contracted by the Department of Communities and Local Government (DCLG) to attend fires of special interest to investigate issues that may impact on Building Regulations. Information is provided below in terms of case studies from investigation of such incidents.

5.3.2.1 Case study 1: Five-storey modular timber-framed residential building

Fire started in an electrical consumer unit within one of the flats on the first floor 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 led to further fire spread into the floor void supporting the first floor leading to extensive damage to the supporting engineered timber beams and traditional timber studs. The fire also spread upwards to the walls on the second, third and fourth floors.

The fire spread through cavities in external walls resulting in fire damage within 12 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.

5.3.2.2 Case study 2: Three-storey timber-framed block of flats

The fire was thought to be the result of hot working being carried out on the overflow pipes which penetrated the external wall. The fire spread initially through the cavities up and along the front face of the building. 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*[10] project. 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. Observations and ad-hoc fire tests 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 the fire spread within the roof space.

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

5.3.2.3 Case study 3: Four-storey timber-framed block of flats

The fire occurred within one of the flats on the ground floor and was attended by the Fire and Rescue Service. They extinguished the fire, and before leaving the scene, checked the area with a Thermal Imaging Camera to ensure there were no hidden hot spots. The FRS were 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 the collapse of the building.

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 tests (BS EN 11925-2[12]) conducted as part of the collaborative *Understanding fire risks in combustible cavities* research project (see Table 3).

5.3.2.4 Case study 4: Four- and three-storey timber-framed block of flats

The fire is thought to have started through a carelessly discarded cigarette thrown into a pile of wood/bark chippings laid in the flower beds in contact with the external wall. 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 firefighting approach because of the extent of the fire spread and based on experience from other fires. The fire caused the collapse of a large area of the development.

The fire investigation reports, taken with the statistical evidence provided by the London Fire Brigade, identified a number of issues raised in previous research reports[10,14].

- Cavities between external facades and internal combustible frames provide a route for vertical and horizontal fire spread.
- The presence and condition of cavity barriers within external walls is difficult to determine.
- Common methods of mitigating the spread of fire and smoke within buildings are reliant on proper installation and inspection.
- The materials within external wall cavities (sheathing boards, breather membranes, cavity barriers and service ducts) can have a major impact on fire development.
- Extensive damage can result from a small ignition source if the fire breaks into the external wall cavity and there are inadequate barriers at compartment boundaries and between the external wall and the roof space.

Fires within external walls may be initiated as a result of either a seat of smouldering combustion following a fire inside the building or as a result of careless activities (e.g. smoking and hot working) in the proximity of the external wall.

5.4 Experimental programme

This project involved a programme of 21 large-scale fire tests, based on the earlier work undertaken at BRE Cardington (see section 4.1.4). The experiments were undertaken within the BRE Burn Hall test facility, using one of the cladding walls normally used to conduct BS 8414-1 tests[6].

In order to simulate an external masonry wall, it was necessary to brick up the hearth of the BS 8414 cladding rig as shown in Figures 24 and 25. An opening was cut into the back of the hearth to allow entry to ignite the fire load and to provide a (limited) source of ventilation.

In order to assess the performance of the cavity barriers, it was essential that the combination of fire load and ventilation conditions were sufficient to ignite the surface of the combustible lining to the timber frames. The hole at the bottom of the wall was 350 mm x 280 mm giving a free open area of 98,000 mm².

The openings at the top of the lower timber frame panel and at the bottom and top of the upper timber frame panel were sized to give the openings specified in Table 8. The holes were made by taking cores out of the concrete blocks.

Table 8 summarises the main parameters of the experimental programme. In each case, the test configuration consisted of two 2.4 m x 2.4 m timber panels fixed to the masonry wall and separated by a timber beam as shown in Figure 15.

Figure 24 – Cladding wall showing hearth

Figure 25 – Cladding wall with hearth bricked in

The first fire test consisted of a control specimen without any form of cavity barrier. The external face (the internal face of a real building) is shown in Figure 26 prior to ignition. Figure 27 shows the ignition source adopted at the entrance to the hearth and Figure 28 shows a clear breach of compartmentation with flames emerging from the upper panel.

Figure 26 – "Interior" view showing plasterboard to timber frames and central beam

Figure 27 – Ignition source within hearth of cladding rig

Figure 28 – Fire spread to upper level

Table 8 – Fire experiments to assess the performance of commonly used cavity barriers

	Sheathing	Cavity barrier			Vent area (mm^2)	
		Generic type	Cavity width (mm)	Discontinuity	Bottom	Top
1	OSB	None (calibration)	50	N/A	8125	8125
2	OSB	Stone wool barrier 65 mm x 65 mm	50	N	8125	8125
3	OSB	Glass wool barrier 100 mm by 100 mm	50	N	8125	8125
4	OSB	Timber batten 50 mm by 50 mm	50	N	8125	8125
5	OSB	Intumescent 25 mm by 75 mm (Type 1)*	50	N	8125	8125
6	OSB	Intumescent 25 mm by 75 mm (Type 2)*	50	N	8125	8125
7	OSB	Stone wool barrier 65 mm x 65 mm	50	N	4550	4550
8	OSB	Timber batten 50 mm by 50 mm	50	N	4550	4550
9	OSB	Intumescent 25 mm by 75 mm* (Type 1)	50	N	4550	4550
10	MgO	Stone wool barrier 65 mm x 65 mm	50	13 mm gap in centre	8125	8125
11	MgO	Glass wool barrier 100 mm by 100 mm	50	13 mm gap in centre	8125	8125
12	MgO	Timber batten 50 mm by 50 mm	50	13 mm gap in centre	8125	8125
13	OSB	Intumescent 25 mm by 75 mm* (Type 2)	50	13 mm gap in centre	8125	8125
14	OSB	Stone wool barrier 65 mm by 65 mm (PIR insulation)	50	13 mm gap in centre	8125	8125
15	OSB	Glass wool barrier 100 mm by 100 mm	50	13 mm gap in centre	8125	8125
16	OSB	Stone wool barrier 65 mm by 65 mm	55	13 mm gap in centre	8125	8125
17	OSB	Timber batten 50 mm by 50 mm	55	13 mm gap in centre	8125	8125
18	OSB	Intumescent 25 mm by 75 mm* (Type 2)	55	13 mm gap in centre	8125	8125
19	OSB	Stone wool barrier 65 mm by 65 mm	55	13 mm gap in centre	8125	8125
20	OSB	Timber batten 50 mm by 50 mm	55	13 mm gap in centre	8125	8125
21	OSB	Intumescent 25 mm by 75 mm* (Type 2)	55	13 mm gap in centre	8125	8125

*Vent only at bottom of lower panel and top of upper panel otherwise vents at top and bottom of each panel.

Notes

1 Minimum vent size (4550 mm^2) based on 10 m run between vertical barriers and one open perpend joint/1.5 m run

2 Maximum vent size (8125 mm^2) based on 15 m run between vertical barriers and one open perpend joint/1.2 m run

Temperatures were measured at specific locations within the cavity and through the depth of the panel as shown in Table 9.

Table 9 – Instrumentation locations

Thermocouple No.	Location
1	Centre of cavity 1.2 m from ground level
2	Centre of cavity 1.8 m from ground level
3	Centre of cavity below cavity barrier
4	Centre of cavity above cavity barrier
5	Centre of cavity 0.6 m above ring beam
6	Centre of cavity 1.8 m above ring beam
7	Quarter point in cavity LHS below cavity barrier
8	Quarter point in cavity RHS below cavity barrier
9	Quarter point in cavity LHS above cavity barrier
10	Quarter point in cavity RHS above cavity barrier
11	Quarter point in cavity LHS 0.6 m above ring beam
12	Quarter point in cavity RHS 0.6 m above ring beam
13	Mid-point of timber frame 1.8 m from ground level
14	Mid-point of timber frame above ring beam

LHS – left hand side RHS – right hand side

In terms of comparing experiments, the main focus was on the two sets of three thermocouples immediately below and immediately above the cavity barrier (thermocouples 3,7,8 and 4,9,10). The maximum temperature above the cavity barrier for the first 30 minutes of the tests and for the period from 30 minutes to 60 minutes are shown in Figure 29 for all tests.

© BRE Global Ltd 2025

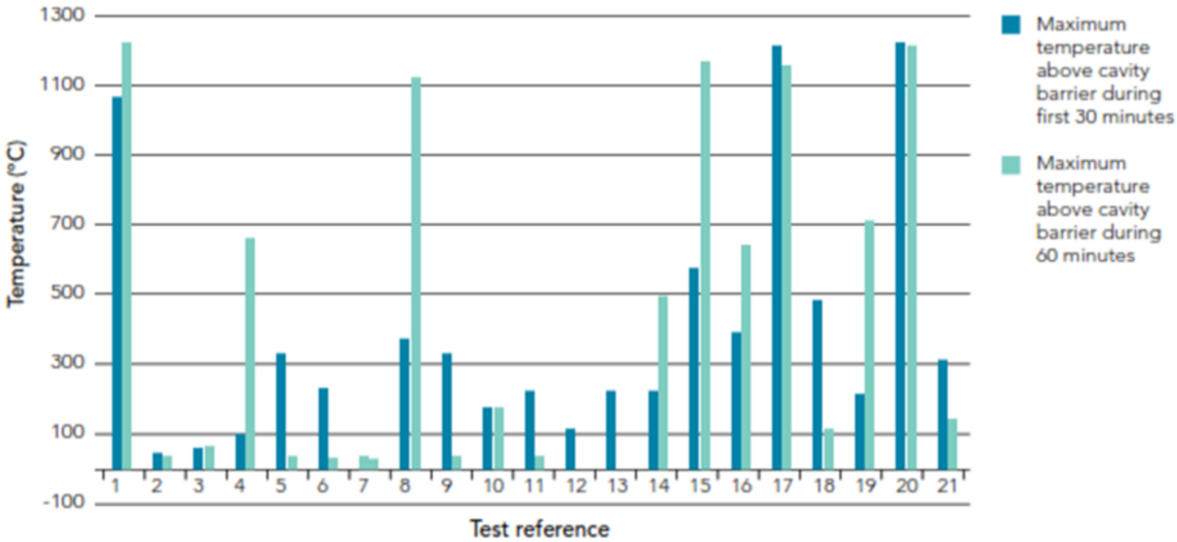


Figure 29 – Maximum recorded temperatures above the cavity barriers for all experiments

A thermal imaging camera was used for a number of the experiments. This provided a means of rapidly identifying hot spots within the construction and assessing the extent of fire spread beyond the localised area of the ignition source.

The principal results are summarised in Figure 29 in relation to peak temperatures recorded above the cavity barrier for the first 30 minute period and the subsequent period from 30 to 60 minutes. Temperatures in excess of 300°C for a period greater than one minute indicate that the cavity barrier was breached. (Note that Figure 29 shows all data, including peaks of less than 1 minute duration).

Based on the performance criteria above, Table 10 summarises the results.

Table 10 – Summary of performance against specific performance criteria (temperature above the barrier > 300°C for > 1 minute)

Test/Description	Temperature in excess of 300°C for > 1 minute for first 30 minutes	Temperature in excess of 300°C for > 1 minute for 30-60 minutes
1 Control (no cavity barrier)	Y	Y
2 Stone wool barrier, OSB sheathing, no discontinuity, 50 mm cavity, full vent area	N	N
3 Glass wool barrier, OSB sheathing, no discontinuity, 50 mm cavity, full vent area	N	N
4 Timber batten, OSB sheathing, no discontinuity, 50 mm cavity, full vent area	N	Y
5 Intumescent barrier, no discontinuity, 50 mm cavity, full vent area	N	N
6 Intumescent barrier, no discontinuity, 50 mm cavity, full vent area	N	N

Test/Description	Temperature in excess of 300°C for > 1 minute for first 30 minutes	Temperature in excess of 300°C for > 1 minute for 30-60 minutes
7 Stone wool barrier, OSB sheathing, no discontinuity, 50 mm cavity, reduced vent area	N	N
8 Timber batten, OSB sheathing, no discontinuity, 50 mm cavity, reduced vent area	Y	Y
9 Intumescent barrier, no discontinuity, 50 mm cavity, reduced vent area	N	N
10 Stone wool barrier, MgO sheathing, 13 mm gap in centre, 50 mm cavity, full vent area	N	N
11 Glass wool barrier, MgO sheathing, 13 mm gap in centre, 50 mm cavity, full vent area	N	N
12 Timber batten, MgO sheathing, 13 mm gap in centre, 50 mm cavity, full vent area	N	N
13 Intumescent barrier, OSB sheathing, 13 mm gap in centre, 50 mm cavity, full vent area	N	N
14 Stone wool barrier, OSB sheathing, 13 mm gap in centre, 50 mm cavity, full vent area	N	Y
15 Glass wool barrier, OSB sheathing, 13 mm gap in centre, 50 mm cavity, full vent area	Y	Y
16 Stone wool barrier, OSB sheathing, 13 mm gap in centre, 55 mm cavity, full vent area	Y	Y
17 Timber batten, OSB sheathing, 13 mm gap in centre, 55 mm cavity, full vent area	Y	Y
18 Intumescent barrier, OSB sheathing, 13 mm gap in centre, 55 mm cavity, full vent area	N	N
19 Stone wool barrier, OSB sheathing, 13 mm gap in centre, 55 mm cavity, full vent area	N	Y
20 Timber batten, OSB sheathing, 13 mm gap in centre, 55 mm cavity, full vent area	Y	Y
21 Intumescent, OSB sheathing, 13 mm gap in centre, 55 mm cavity, full vent area	N	N

Performance in the experimental programme ranged from rapid fire spread with flames emerging from the upper panel approximately six minutes from ignition followed shortly after by collapse of the system, to complete burn out of the localised fuel source with no fire spread or damage to the upper panel.

The experiments undertaken as part of the NHBC Foundation and BRE Trust research project have demonstrated the critical role that installation plays in relation to the performance of cavity barriers in the event of a fire. It is essential to ensure that the cavity barrier is correctly specified to accommodate the notional cavity width and any deviations from this value arising from tolerances on site.

The experiments undertaken confirmed that when specified and installed correctly all commonly used horizontal cavity barriers are capable of meeting the relevant functional objectives of the Building Regulations when subject to a realistic fire scenario corresponding to the conditions set out in the NHBC Foundation and BRE Trust research report. The most significant issue is to ensure that cavity barriers are installed correctly in accordance with manufacturer's instructions and are not damaged, removed or interfered with during the period between installation and completion of the external façade.

Those involved in site supervision and the building control and approvals process should be made aware of the crucial role that cavity barriers play in restricting fire growth and spread in the aftermath of an incident. They should also be aware of the significant impact that relatively small gaps and discontinuities within the line of compartmentation provided by cavity barriers can have on the spread of a fire and the potential for disproportionate damage.

The experiments have demonstrated that certain products are more likely to continue to provide their regulatory function even where gaps and discontinuities are present. The work has also identified potential issues within the current means of assessment in relation to intumescent (open state) cavity barriers where a limited temperature rise over a short period of time is deemed to be a failure even if the intumescent coating subsequently activates and seals the cavity before there has been any fire spread to the upper level.

The project has provided data on the performance of horizontal cavity barriers designed to inhibit the spread of fire and smoke within external walls of timber frame construction. However, the results are generally applicable to any form of construction where differential movement may lead to gaps and discontinuities within the cavity. The research has demonstrated the effectiveness of designing the cavity to exclude combustible lining materials to reduce or eliminate the spread of fire within the cavity. It has confirmed the importance of using tested and approved proprietary cavity barriers fitted in accordance with manufacturer's instructions and used within the limits of the stated field of application for the product.

Clarity is required within the construction project team on who is the responsible person in relation to the installation and inspection of critical fire protection measures such as cavity barriers. The use of approved contractors and appropriate supervision at key stages during the construction will help to ensure that cavity barriers are installed correctly, and the installation is not compromised by follow-on trades.

There are a number of conclusions that can be drawn based on the work undertaken:

- The control experiment has highlighted the need for cavity barriers within external wall constructions where combustible material is included either as a lining or as insulation when subject to a realistic fire scenario.
- All generally available proprietary systems are capable of inhibiting the spread of fire and smoke when installed in accordance with the manufacturer's instructions and when no gaps and discontinuities are present.
- The relationship between the ignition source and the ventilation conditions within the cavity is complex and may have a marked impact on fire development.
- 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

© BRE Global Ltd 2025

variations in cavity widths any inconsistencies will lead to the creation of gaps around the timber batten impacting on compartmentation.

6 Industry Guidance

6.1 Structural Timber Association

The Structural Timber Association (STA) has produced guidance[17] for members that attempts to cover a number of the issues raised above in relation to providing a clear understanding of who is responsible for design, supply and installation of cavity barriers. The guidance provides industry agreed locations and detailing for cavity barriers where the Fire Strategy is based on the use of statutory guidance for fire safety.

In addition to the guide, the STA provide cavity barrier installer training for their members, together with an online test.

Section 2.6 of the STA guidance presents a number of key points in relation to cavity barriers:

- The Building Designer follows the project Fire Safety Strategy for the project cavity barrier requirements.
- The cavity barrier functional objective is to inhibit the spread of fire (flames and smoke), not to necessarily stop it, delaying spread from beyond the point of origin.
- The location of cavity barriers is dependent on the use of the building, its size and location within the building.
- When fire occurs in a building, a ventilated cavity can act as a chimney to allow the passage of smoke and flames. The cavity barrier (when correctly specified and installed) can restrict air flow which will delay or prevent the passage of smoke and flames.
- Gaps within the line of cavity barriers may allow flames and smoke to penetrate.
- Cavity barriers should be fitted in accordance with manufacturer instructions with no gaps or discontinuities.
- The location and product design are the responsibility of the Principal Designer, not the structural timber building supplier, unless agreed in the contract.
- The design and installation of the cavity barrier shall follow the care points listed in Part 5 of the guidance.
- Installation of the cavity barrier shall be to the design and specification provided by the Principal Designer.

The STA has a quality installation programme for its members. The STA Assure process for cavity barrier installation covers the installer training and sign off that the barrier has been installed correctly, presenting the customer with a technical trail of installation plus the provision, where appropriate, of follow on trade information to reduce errors or mistakes by others during the build process.

The time at which a cavity barrier is installed is important. If a cavity barrier is installed onto a frame before the cavity is formed, then the responsibility for compliance and tolerance rests with the follow on trades that complete the assembly.

The STA guide provides the following information in relation to the Roles, Responsibilities and Accountability (RRA) for design and supply. The RRA for installation is summarised in Table 12.

 © BRE Global Ltd 2025

Table 11 – RRA for design and supply

Subject	Location	Function	Role	Responsibility	Accountability
Cavity Barrier	External envelope = through the wall assembly (façade cavity to structural frame and internal service void, roof eaves to external wall, floor to external wall interface and termination of external wall cavities)	To close off cavities so to inhibit hot smoke and fire spread within relevant cavity compartments	To present justification and drawing on the location and specification	Building Designer	Compliant to the Statutory Guidance OR BS 9991/ BS 9999 OR Fire engineering bespoke design agreed by Building Control
	Boundary between attached properties (soffit eaves junction, party wall to external wall cavity junctions, horizontal junction between party floors)				
	Internal wall cavity termination at openings				
	Internal boundary between attached properties (party wall floor and roof junctions)				

© BRE Global Ltd 2025

bre

Table 12 – RRA for installation

Subject	Location	Function	Role	Responsibility	Accountability
Cavity Barrier	External envelope = through the wall assembly (façade cavity to structural frame and internal service void, roof eaves to external wall, floor to external wall interface and termination of external wall cavities)	To close off cavities so to inhibit hot smoke and fire spread within relevant cavity compartments	To fit specified cavity barrier to drawing locations and to appropriate installation instructions and tolerances. To stop work and highlight discrepancies in design compared to as built.	Contract agreement on installer. Contract Type CBFS-B – structural timber framer OR Contract Type CBFS-A façade or specialist installer.	Contract Type CBFS-B structural timber framer Company site safe audit and sign off for the as installed products against the structural frame only. STA install care point sign off OR Contract Type CBFS-A façade or specialist installer. Façade install care point sign off. Principal Contractor sign off that function of the cavity barrier is complete to design and specifications.
	Boundary between attached properties (soffit eaves junction, party wall to external wall cavity junctions, horizontal junction between party floors)				
	Internal wall cavity termination at openings				
	Internal boundary between attached properties (party wall floor and roof junctions)				

The document goes on to provide detailed guidance on locations requiring cavity barriers and provides best practice details for multiple applications such as the compartment wall detail shown in Figure 30 below.

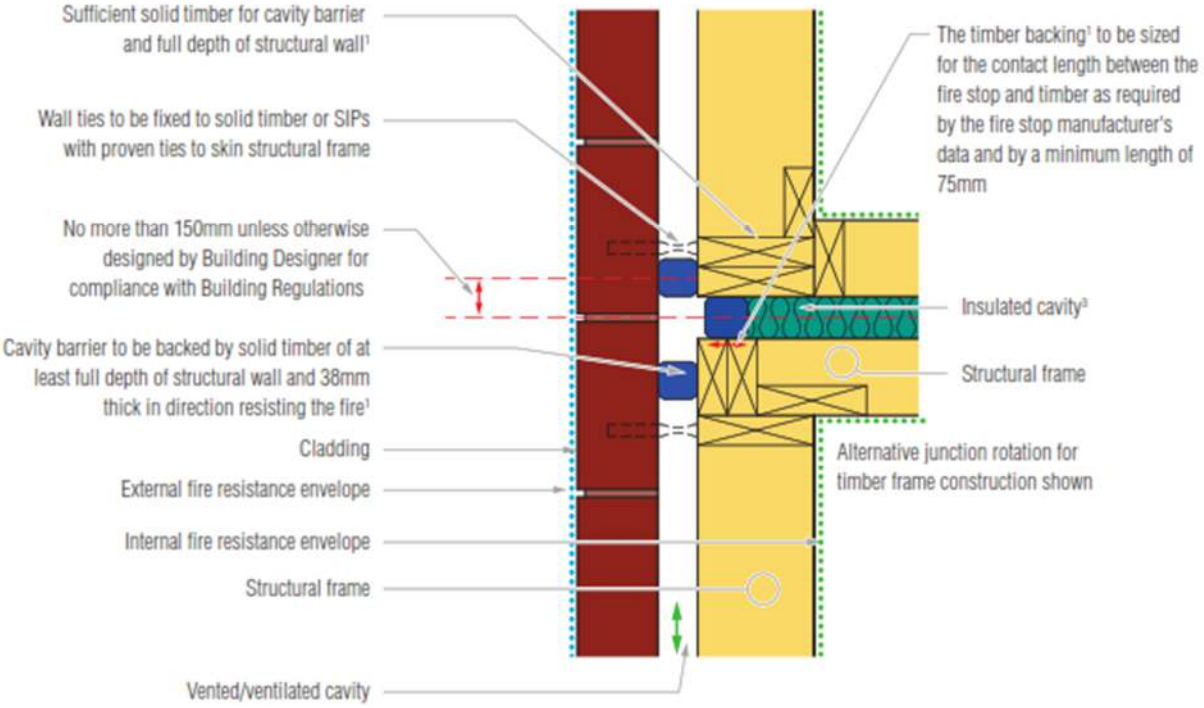


Figure 30 – Compartment wall cavity barrier detail

Further information is provided covering contractual responsibilities, care points and a check list for designers and similar guidance for installers and checkers, structural timber frame erectors and for cladding installers.

Appendix 7 of the STA document provides information on cavity barrier research undertaken by Milner Associates. The work included two sets of EN 1366-4[4] tests on timber cavity barriers and stone wool barriers in both the horizontal and vertical orientation as well as BS 8414 tests for external cladding systems. BS 8414 tests are full system tests, depending on the overall specification and performance of the tested system, the cavity, and hence the cavity barriers, may not have been exposed in such tests.

The results are summarised in Table 13, with the test configurations shown schematically in Figures 31 and 32 for the solid timber barriers.

Table 13 – Summary results for timber battens C16

Application	Cavity barrier type	Test	Tested against	Outcomes
Vertical orientation	50 mm x 38 mm C16 timber batten butt jointed	BS EN 1366-4	Masonry one side	EI 66/66
Horizontal orientation	50 mm x 38 mm C16 timber batten butt jointed	BS EN 1366-4	Masonry one side	EI 66/66

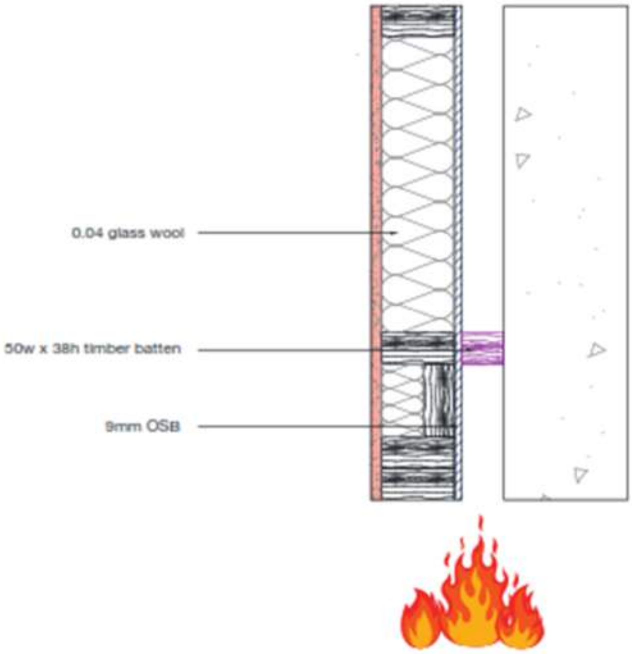


Figure 31 – Vertical fire test for timber batten window reveal or party wall condition

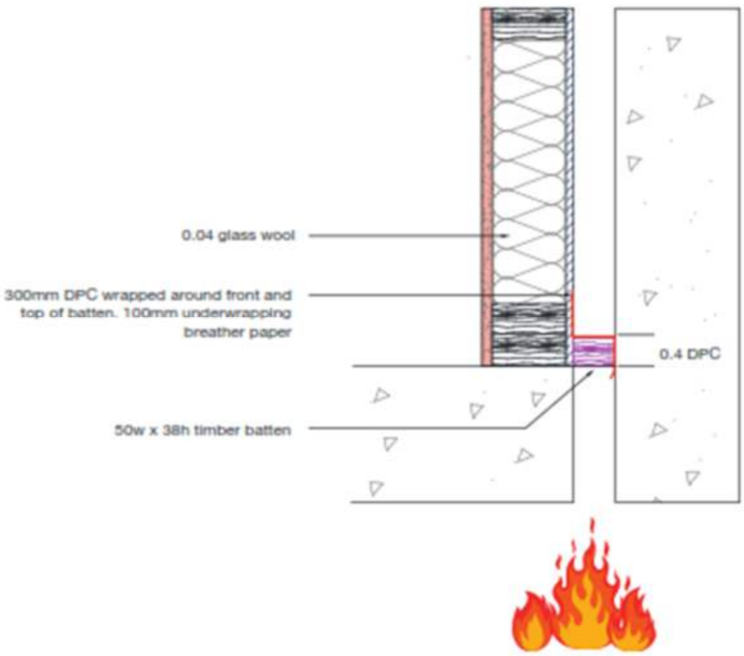


Figure 32 – Horizontal fire test for timber batten simulating floor zone condition or window lintel

The results are summarised in Table 14, with the test configurations shown schematically in Figures 33 and 34 for the stone wool filled polyethylene sock barriers.

Table 14 – Summary results for stone mineral wool cavity barriers

Application	Cavity barrier type	Test	Tested against	Outcomes
Horizontal	63 mm x 65 mm stone wool 43 kg/m³	BS EN 1366-4	Masonry one side full timber frame assembly. OSB sheathing and glass wool insulation behind sheathing	EI 66/64
			Masonry one side full timber frame assembly OSB sheathing and PIR insulation behind sheathing	EI 66/55
Vertical	63 mm x 65 mm stone wool 43 kg/m³	BS EN 1366-4	Masonry one side full timber frame assembly OSB sheathing and PIR insulation behind sheathing	EI 66/66
			Solid timber backing Full insulation in party wall	EI 66/28

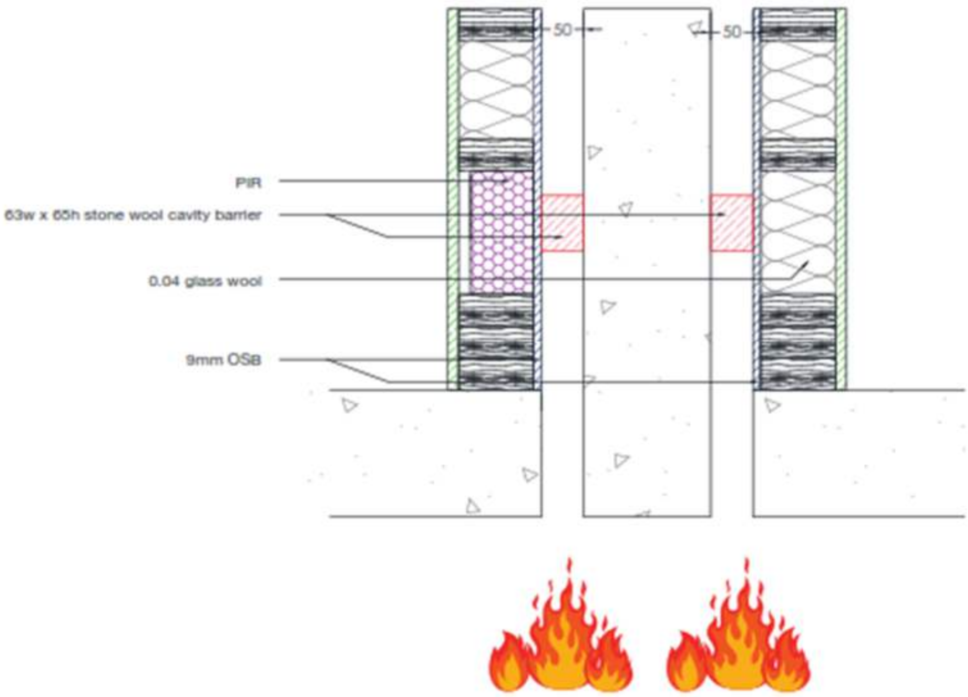


Figure 33 – Horizontal fire test for stone wool cavity barriers without solid timber backing behind the OSB sheathing

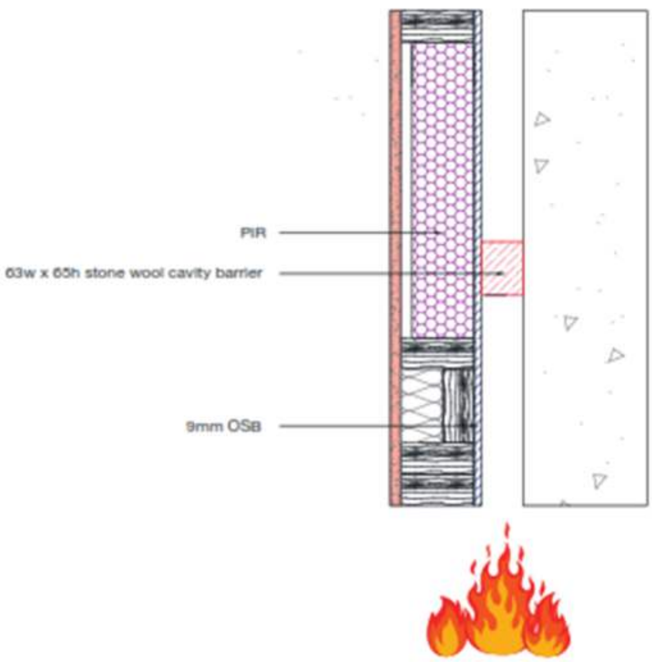


Figure 34 – Vertical fire test for stone wool cavity barriers without solid timber backing behind the OSB sheathing

6.2 Cavity barriers in light steel framed buildings

The Steel Construction Institute (SCI) have produced Technical Information Sheet P438[18] providing guidance on cavity barriers in light steel framed buildings.

The objective of the document is to:

- Provide guidance on the performance of cavity barriers in light steel framed buildings.
- Disseminate test evidence of the satisfactory performance of cavity barriers used with light steel framing.
- Highlight that equivalent performance of cavity barriers can be obtained for cavity barriers between masonry cladding and an inner leaf of masonry or an inner leaf of light steel framing.

As with the STA guidance, the document provides information on the required location of cavity barriers. The document provides good practice details, such as that shown in Figure 35.

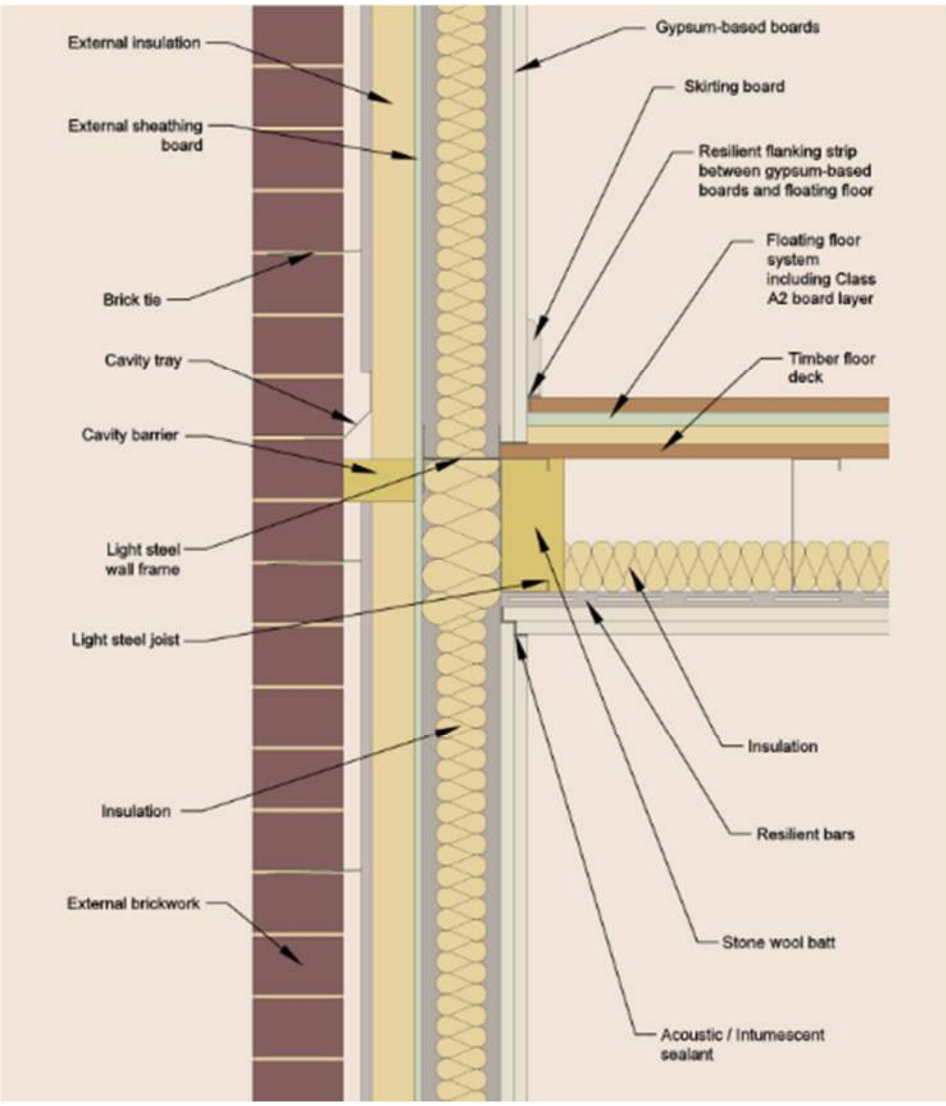


Figure 35 – Cavity barrier at junction of an external light steel wall with brickwork cladding and a light steel joisted floor

The document also presents the results from a series of fire tests incorporating barriers between two leaves of masonry and between a masonry external leaf and light steel frame inner leaf to allow for direct comparison. The tests were carried out in accordance with EN 1366-4 and the results are summarised in Table 15.

Table 15 – Summary of light steel frame cavity barrier test programme

Test No.	Outer leaf/inner leaf	Cavity insulation	Sheathing board	Cavity barrier type	EI performance expected (min)	EI performance achieved (min)
1	Masonry/masonry	75 mm stone wool slab	None	Siderise EW-FS-120	120	132/132
2	Masonry/masonry	None	None	FSi Paraflam 100mm	120	132/132
3	Masonry/LSF	75 mm rigid PIR	12 mm CaSi	Siderise EW-FS-60	60	66/66
4	Masonry/LSF	75 mm rigid PIR	12 mm cpb	Siderise EW-FS-60	60	66/66
5	Masonry/LSF	75 mm rigid PIR	2 x 12.5 mm Gypsum board	FSi Paraflam 120mm	90	122/115
6	Masonry/LSF	75 mm rigid PIR	2 x 12.5 mm Gypsum board	Siderise EW-FS-60	60	104/89
7	Masonry/LSF	75 mm rigid PIR	12 mm cpb	Siderise EW-FS-60	60	66/63
8	Masonry/LSF	75 mm stone wool slab	12 mm CaSi	Siderise EW-FS-120	120	132/132
9	Masonry/LSF	75 mm stone wool slab	2 x 12.5 mm Gypsum board	Siderise EW-FS-120	120	132/132
10	Masonry/LSF	75 mm stone wool slab	12 mm CaSi	Siderise EW-FS-120	120	132/132
11	Masonry/LSF	75 mm stone wool slab	2 x 12.5 mm Gypsum board	FSi Paraflam 120 mm	120	132/132

The principal conclusion from the experimental programme is that the performance of cavity barriers between masonry cladding an inner leaf of light steel framing is similar to that where both leaves are formed of masonry.

6.3 Alternative approaches

An alternative test method for open state cavity barriers has been developed by the Fire Protection Association (FPA) and was highlighted by a member of the Technical Steering Group. This information came to light after the work on this report was complete. It is included as a reference[19] but has not been reviewed by the Project Team. The test focuses on the activation of the cavity barrier rather than fire resistance.

The key points this method tries to address, which are not addressed by the TGD 19 furnace method, are:

- How long do flames pass the cavity barrier before it seats in the location of the flame?
- Is that duration sufficient to propagate fire on the other side of the cavity barrier for the given material collection?
- What is the horizontal seating rate of the cavity barrier?
- What is the critical temperature at which the cavity barrier seats?
- What is the system's ability to prevent the passage of (a) flame, (b) heat, (c) smoke, (d) toxic products?
- How has the presence of the cavity barrier reduced the potential fire size?

A member of the Project Team also highlighted approaches adopted by a certification body in the USA[20] and research undertaken in Slovenia[21]. This information also came to light after the work on this report was complete and is included as references but have not been reviewed by the Project Team.

7 Conclusions

The work presented in this report encompasses observations and research undertaken over a number of years, not all of which is in the public domain.

The methodology for Task C5 work programme is as follows:

- To undertake a review of current standardised test and assessment methods for cavity barriers.
- To identify gaps within the current means of testing and assessing cavity barriers.
- To review existing and new research to investigate the relationship between performance when assessed under standard fire resistance conditions and the behaviour under realistic conditions of fire exposure and site installation.

From the review of current standardised test and assessment methods for cavity barriers, there is currently no harmonised test standard for cavity barriers nor has there ever been such a standard even under the previous (BS 476) National series of test standards.

Traditionally, cavity barriers have been assessed using ad-hoc tests, designed principally for linear joint seals. Traditional means of test and assessment using the standard fire curve and the relevant performance criteria associated with standard fire testing (EI) negated the validation and application of open state cavity barriers.

The development of the ASFP Technical Guidance Document 19 provided a methodology to enable open state cavity barriers to demonstrate compliance with the functional requirement of the Building Regulations. This general approach has been adopted in prEN 1364-6 which, when published for the first time will provide a harmonised European standard specifically for cavity barriers and with performance criteria suitable for both closed and open state cavity barriers. This, in BRE Global's opinion, is a welcome development. The implications for the widespread use of open state cavity barriers on operational firefighting need to be clearly understood. There is the potential for greater (cold) smoke spread within a cavity during the early stages of a localised fire where the intumescent remote from the incident has not yet activated.

The current means of test and assessment are all predicated on the use of the standard time-temperature curve generally used for fire resistance testing. This may well be a conservative procedure but is not representative of real fires within cavity spaces which are often characterised by slow fire growth over an extended period dictated by the availability of oxygen for combustion.

Existing and new research have shown that systems on the market are capable of achieving the functional requirement of the Building Regulations when properly specified and installed and where there are no significant gaps or discontinuities both in relation to standard fire testing and more realistic fire scenarios.

Industry guidance has covered many of the issues raised in previous research in relation to workmanship issues and the roles and responsibilities of members of the design and construction teams. The STA guidance provides a framework to reduce the risk of a small ignition source resulting in disproportionate damage of the kind described in the TF2000 reports and subsequent research. There should be no excuse for ignorance in terms of the importance of cavity barriers and ensuring they are installed in a manner that will not adversely affect their functionality.

In terms of modern forms of construction, one of the major concerns is that barriers are often tested between rigid substrates and the results extrapolated for use in systems with greater flexibility. The SCI research concluded that commonly used barriers can perform adequately (under standard fire test conditions) in either application.

The inappropriate use of fire resistance test data applies to all forms of construction but may be particularly significant for certain forms of modular construction where multiple horizontal and vertical cavities are formed between modules.

 © BRE Global Ltd 2025

8 Recommendations for further work

Recommendations for further work are:

- Review of guidance in 9.14 of AD B Volume 2 (2019 Edition incorporating 2020 and 2022 amendments – for use in England) in relation to the deemed to satisfy provisions for cavity barriers in a stud wall or partition or provided around openings.
- Dissemination to the construction industry of the principal findings of this report in relation to the installation and specification of cavity barriers.
- Liaison with the Fire and Rescue Service to ensure the implications of any changes to the guidance are understood in relation to operational firefighting.
- Research into the impact of the initial fire source on the activation time of open state cavity barriers.
- Consideration should be given to mandatory checks of life-safety critical aspects of building construction such as the correct installation of cavity barriers particularly in high risk buildings.

© BRE Global Ltd 2025

9 References

1. Association for Specialist Fire Protection (ASFP), Fire Resistance Test for 'Open-State' Cavity Barriers used in the external envelope or fabric of buildings, ASFO Technical Guidance Document – TGD 19, ASFP, July 2014.
2. British Standards Institution, BS EN 13501-2: 2023 Fire classification of construction products and building elements Part 2: Classification using data from fire resistance and/or smoke control tests, excluding ventilation services, BSI, London, 2023.
3. British Standards Institution, BS 476-20: 1987 Fire tests on building materials and structures – Part 20 Method for determination of the fire resistance of elements of construction (general principles), BSI, London, 1998.
4. British Standards Institution, BS EN 1366-4: 2021 Fire resistance tests for service installations Part 4: Linear joint seals, BSI, London, 2021.
5. Structural Timber Association, Structural timber buildings fire safety in use Volume 2 – Cavity barriers and fire stopping for timber frame structures, Version 3.0, April 2024.
6. British Standards Institution, BS 8414-1: 2020 Fire performance of external cladding systems Part 1: Test method for non-loadbearing external cladding systems fixed to, and supported by, a masonry substrate, BSI, London, 2020.
7. British Standards Institution, BS 8414-2: 2020 Fire performance of external cladding systems Part 2: Test method for non-loadbearing external cladding systems fixed to, and supported by, a structural steel frame, BSI, London, 2020.
8. CEN, Draft prEN 1364-6 Fire resistance tests for non-loadbearing elements – Part 6: Cavity barriers, CEN, 2022.
9. Law A and Bisby L, The rise and rise of fire resistance, Fire Safety Journal, 116, 103188, 2020.
10. Understanding fire risks in combustible cavities. Report reference: Chilt/EO1006TR, PII Reference No. O-CIF004, 2000.
11. British Standards Institution, BS 5852: Part 2: 1982, Fire tests for furniture Part 2. Methods of test for the ignitability of upholstered composites for seating by flaming sources, BSI, London, 1982.
12. British Standards Institution, BS EN ISO 11925-2: 2002 Reaction to fire tests – Ignitability of building products subjected to direct impingement of flame – Part 2: Single-flame source test, BSI, London, 2002.
13. Lennon T, Fires in cavities in residential buildings, The performance of cavity barriers in external walls with combustible materials, NHBC Foundation report NF51, April 2013.
14. Freeman I L, Butlin R N and Hunt J H, Timber-framed housing – a technical appraisal, IHS BRE Press, 1983.
15. Williams A W, Timber framed buildings: The role of the wall cavity and its materials in fire, Fire Research Station, June 1984 (unpublished), Private Communication.
16. BRE, Cavity barriers: Final factual report of the experimental programme, report for ODPM, 2005. Available from: Microsoft Word - BD2411 _FINAL FACT REPORT _ 218236 2.doc (bregroup.com). Last accessed 10th October 2024.

17. Structural Timber Association (STA), Structural timber buildings fire safety in use Volume 2 – Cavity barriers and fire stopping for timber frame structures, STA fire safety research project, Version 3.0, April 2024.

18. Way A G J, Light Steel Framing and Modular Construction, Technical Information Sheet P438, Cavity barriers in light steel framed buildings, The Steel Construction Institute, Silwood Park, Ascot, 2022.

19. Glockling J D, A realistic test for cavity barrier performance, Fire Protection Association Website News article, published 18th August 2022. Available from: A realistic test for cavity barrier performance | Fire Protection Association. Last accessed 12th March 2025.

20. FM Approvals, FM Approval Standard 4411. See https://www.abaaconference.com/wp-content/uploads/2018/05/Mark-Tyrol-FM4411---Approval-Standard-For-Cavity-Walls-And-Rainscreens.pdf).

21. Singh A, Hinojosa F, Mannan M B and Lima M P, Open cavity barriers investigation, Window and Façade Magazine, Volume 6, Issue 5, pp 8-14, January to February 2024. Available from: https://wfmmedia.com/magazine/window-facade-magazine-global-jan-feb-2024/. Last accessed 12th March 2025.

 © BRE Global Ltd 2025

Report Ends

bre

www.bre.co.uk

Health and Safety Executive
Final Report

Structural Fire Resistance and Fire Separating Elements – Appendix F: Car Parks

Prepared for: The Building Safety Regulator

Prepared by: Grunde Jomaas and Tom Lennon

Approved by: Tony Baker on behalf of BRE Global

Date: 28th March 2024

HSE Contract: 1.11.4.4436 (previously MHCLG Contract: CPD/004/120/206)

Report Number: P118139-1015 (M11D9V3) Appendix F

BRE Global Ltd
Watford, Herts
WD25 9XX

Customer Services 0333 321 8811

From outside the UK:
T + 44 (0) 1923 664000
E enquiries@bregroup.com
www.bregroup.com

This report is made on behalf of BRE Global and may only be distributed in its entirety, without amendment, and with attribution to BRE Global Ltd to the extent permitted by the terms and conditions of the contract.

BRE Global's liability in respect of this report and reliance thereupon shall be as per the terms and conditions of contract with the client and BRE Global shall have no liability to third parties to the extent permitted in law.

Table of Contents

 © BRE Global Ltd 2025

1 Introduction

This Appendix contains the findings of Task C6 and takes into account comments from DLUHC and the Technical Steering Group.

Note that this Appendix was written and commented on before the occurrence of the London Luton Airport Car Park Fire in Terminal Car Park 2 on 10th October 2023. Whilst the authors of this Appendix have not been involved in the investigation of this fire and therefore have no knowledge of the cause or the outcome, the visible evidence from information in the public domain confirms the main conclusions of the current report, as several hundred cars became involved, the structure suffered a collapse, and the car park will be fully demolished. (See reference 1).

Note also that since the work on Task C6 was completed, Bedfordshire Fire and Rescue Service has published a Significant Incident report detailing the London Luton Airport's Terminal Car Park fire. (See reference 2).

2 Background

2.1 Context

In order to define research priorities for Task C6, a virtual meeting of a Focus Group on car parks was held on 29th July 2022. Attendees included representatives from DLUHC, the Project Team and invited participants from the Office for Zero Emission Vehicles (OZEV), the British Parking Association (BPA), the National Fire Chiefs Council (NFCC) and consultants from OFR and Arup with expertise in relation to fires in car parks.

This Focus Group was asked to consider a number of questions related to car parks and to determine priorities in relation to research having a direct impact on the subject of the current project (i.e. Structural Fire Resistance and Fire Separating Elements).

The principal issue identified at the meeting relevant to the current project is the justification for the specification in AD B for a recommended minimum period of fire resistance of 15 minutes for open sided car parks up to 30 m high. This has been considered in the light of recent fire incidents and recent research into the changing nature of vehicles and car park design.

2.2 Fire resistance of car parks

In terms of design, car parks can be a stand-alone construction or adjacent to another structure, for example, underground parking in a residential building. Car parks can be public or private, single-level or multi-level construction, located underground or above ground. Specific features of car parks compared to other facilities are that they have relatively low ceilings and a large area in both horizontal directions without subdivision to compartments. In terms of ventilation, car parks can be open or closed. Open car parks are the ones with permanent distributed openings of a certain minimum area and with walls open to the outside[3,4]. Although there are various definitions of what constitutes an open sided car park, the most relevant definition is that found in the current version of AD B. Section 11 of AD B (Volume 2) covers Special provisions for car parks and defines an open sided car park as one with no basement levels and where each storey is naturally ventilated by permanent openings at each car parking level. The aggregate vent area is a minimum of 1/20 of that levels' floor area, at least half of which is provided equally by two opposite walls. There are no limitations in terms of overall geometry or size of the floor plate and Table 8.1 of the section dealing with compartmentation does not impose any limitations on the size of compartments.

The guidance on the minimum periods of fire resistance for such structures is provided in Table B4 in Appendix B dealing with the Performance of materials, products and structures. Here, the recommended minimum period of fire resistance is 15 minutes for open sided car parks with a height of up to 30 m. Above this height, the recommended fire resistance value is 60 minutes.

Historically, car parks have been associated with a relatively low fire risk due to limited fire load and low fire spread probability and there is a specific reference in AD B Section 11 that states that the probability of fire spreading from one storey to another in a well-ventilated car park is low[5,6]. The frequency of fires in car parks is also lower compared to other premises. For instance, in 2006 in the UK, the total number of registered fire incidents was 426 200, with less than 0.1% of that number occurring in car parks[7]. For comparison, in the same year in England, 13% of fires took place in dwellings and 14% in road vehicles[8]. The current fire safety requirements and guidance on car parks are based on those traditional beliefs and are based on fire tests of cars that were available at the time when codes were in development[3,9].

The fire risk (i.e. the product of the fire probability and the fire consequence) in car parks is typically low. This can be related to the assumed low probability of ignition and fire spread, but also due to the low consequences in terms of life safety (injuries and fatalities) (see Table 1).

Table 1 − Total number of non-fatal and fatal casualties in fires in car park buildings, England 2010-2020 (from Alimzhanova et al.[3,10]). Note that the Home Office[11] did not specify "other", but it is assumed that this category holds all other parking types except MSCP and underground, such as single-level surface car parks.

	Multi-Storey Car Park (MSCP)	Underground	Other	Total
Hospital treatment - severe	0	0	1	1
Hospital treatment - slight	3	4	2	9
First aid treatment	3	0	0	3
Precautionary checks	4	3	0	7
Total non-fatal casualties	10	7	3	20
Fire-related fatalities	1	0	0	1

The assumed low fire risk has resulted in approaches with lower fire protection costs, such as car parks with unprotected steel construction with a fire resistance rating as low as 15 minutes, or even 10 minutes in the case of the Sola Airport car park. Also, sprinkler systems have not been incorporated based on cost arguments, and sometimes on cost-benefit arguments. Such arguments have also been supported by the relative low damage in most car park fires (see Table 2).

The focus in this report is on open car parks and the recommended minimum 15-minute fire resistance rating that is currently within Table B4 of AD B. Thus, it is necessary to look at the history behind this rating, as well as on events and developments that suggest that this fire resistance rating needs to be revisited. Support for such a critical review can be found in recent CROSS-UK reports, with one report from 2020[12] stating that "The Echo Arena Multi Storey Car Park fire in Liverpool demonstrated that a 15-minute fire resistance rating may be totally inadequate for exposed steel framed MSCP structures occupied by modern vehicles." Another report from August 2022[13] writes that stakeholders should "Be aware that a multi storey car park structure designed to a fire resistance rating of 15 minutes may not satisfy the functional requirement of the building regulations."

Table 2 − Average extent of damage (m^2) in car park fires attended by fire and rescue services, England 2010-2020 (from Alimzhanova et al.[3,10]). Note that the Home Office[11] did not specify "other", but it is assumed that this category holds all other parking types except MSCP and underground, such as single-level surface car parks.

	Multi-Storey Car Park		Underground		Other	
Financial year	**Number of fires**	**Average area of fire damage, m^2**	**Number of fires**	**Average area of fire damage, m^2**	**Number of fires**	**Average area of fire damage, m^2**
2010/11	43	12.2	26	23.8	16	1258
2011/12	30	10.9	16	20.8	19	31.6
2012/13	29	59.6	16	9.2	10	19.6
2013/14	34	62.6	18	34.9	19	11.8
2014/15	26	12.1	23	351	20	30.2
2015/16	41	4.2	20	92.8	16	16.8
2016/17	52	56.1	24	46.6	22	10.4
2017/18	59	371	19	13.6	13	20.1
2018/19	51	35.7	23	4.3	17	14.6
2019/20	43	31.3	27	41.4	21	9.6
Average		**66**		**64**		**142**

2.3 Historical tests in support of 15-minute fire resistance rating

Key support for the minimum recommended R15 requirement in regulatory guidance was provided by a report that is entitled “Demonstration of real fire tests in car parks and high buildings”[14], which was published in 2002 and sponsored by ECSC (the European Coal and Steel Community). The recommendations in the report were based on two tests with three cars burning in a car park, a fire propagation test with two cars, plus tests of one car under a hood with calorimeter measurements.

The reported experiments were planned and carried out based on a statistical survey which states[14]: “The number of vehicles involved in the fire development in underground car parks varies between 0 and 7. The number of car fires is 158, involving a total number of 192 cars. Only 2 cases (one was arson) involved 7 cars; 1 case involved 5 cars, and 2 cases involved 4 cars. Therefore, the number of fires in underground car parks involving less than 4 cars represents 97.9% of all cases. The number of vehicles involved in the fire development in open car parks varies between 0 and 3. The number of car fires is 55, involving a total number of 72 cars. The maximum number of cars involved in fires was 3. This number corresponds to only 10% of the fires.” These data were primarily drawn from reports written by the Fire Brigade of Paris in the years 1995 to 1998. The report also classified cars according to Table 3.

Table 3 − Car categories used in the work sponsored by ECSC[14]

Type	Category 1	Category 2	Category 3	Category 4	Category 5
Peugeot	106	306	406	605	806
Renault	Twingo-Clio	Mégane	Laguna	Safrane	Espace
Citroën	Saxo	ZX	Xantio	XM	Evasion
Ford	Fiesta	Escort	Mondeo	Scorpio	Galaxy
Opel	Corsa	Astra	Vectra	Omega	Frontera
Fiat	Punto	Bravo	Tempra	Croma	Ulysse
Volkswagen	Polo	Golf	Passat	//	Sharan
Theoretical energy	6000 MJ	7500 MJ	9500 MJ	12000 MJ	

Figures 1 and 2 show the heat release rates (HRR) vs time for the calculations that were carried out in the report. These were not based on the actual experiments in a car park, as the HRR was not measured in those tests. The HRR development in Figure 2, which is for three cars, should be contrasted to the actual experiments (see Figure 3). In the tests, Figure 3 shows that all three cars are almost consumed after 17 minutes, while the curves used for the calculations indicate that not even the first car is fully involved in the fire after 17 minutes. With the energy being released in the fire tests in about 20 minutes rather than in an hour in the calculations, the thermal impact on the structure is obviously very different. Such a difference can possibly be explained by the well-known fact that burning in the free air under a calorimetric hood yields lower HRR than burning in an enclosure. In calorimetric tests, the hood extracts the smoke, thus preventing build-up of a smoke layer that can re-radiate heat to the burning item, and pre-heat other objects below it.

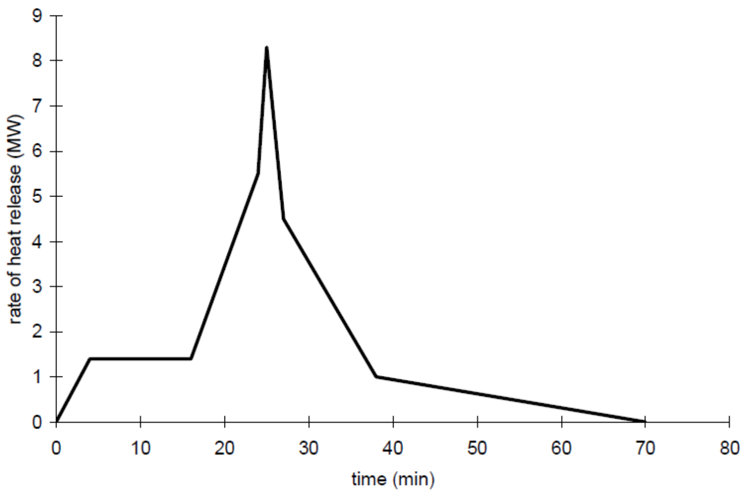


Figure 1 − Heat Release Rate (HRR) used for calculations with a category 3 car burning[14]. No firefighting was included.

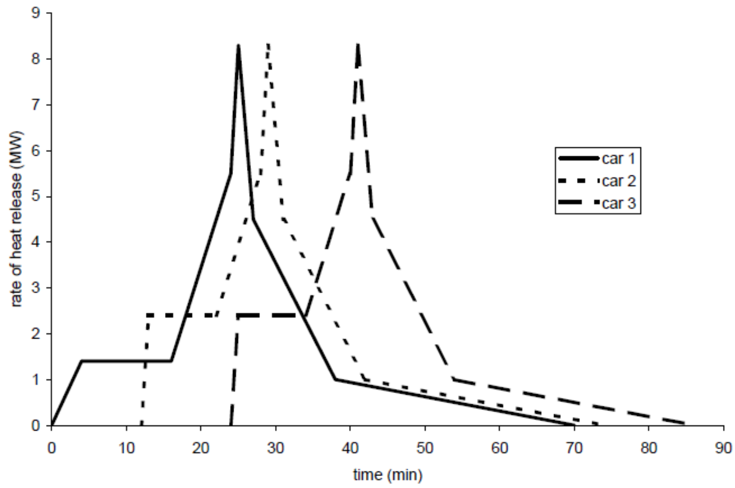


Figure 2 − Heat Release Rate (HRR) used for calculations with three category 3 cars burning[14].
Note that there is no addition of HRR even when the cars are meant to burn simultaneously.

The cars in the tests in the open car parks were quite far apart, and the open car park was extremely open (about 50%, see further explanation below), as shown in Figures 4 and 5 (test 1) and Figures 6 and 7 (test 2). A large amount of the energy from the fire spilled into the open air during the tests, especially in test 2, as seen in Figure 3. Note that the fire did spread to all three cars involved in that test, and the three cars were almost fully consumed after 17 minutes. The pictures also clearly show that the cars in the tests are quite different from the cars you would find in a car park currently, something which will be elaborated on later in the report.

Photo 4.13: 7 minutes after ignition

Photo 4.14: 17 minutes after ignition

Figure 3 − The open car park configuration used in the tests sponsored by ECSC allowed for a substantial amount of energy to be released outside of the structure[14]. This is for the setup in test 2.
Note that all three cars present were close to being fully consumed after as little as 17 minutes.

Figure 4 − The open car park configuration used in the tests sponsored by ECSC[14].
This is for the setup in test 1.
Note that this appears more like a large car port than a car park.

Figure 5 − The open car park configuration used in the tests sponsored by ECSC[14]. This is for the setup in test 1.

Figure 6 − The open car park configuration used in the tests sponsored by ECSC[14]. This is for the setup in test 2.

Figure 7 − The open car park configuration used in the tests sponsored by ECSC[14]. This is for the setup in test 2.

It is worth considering the parameters of the ECSC tests alongside the definition of an open sided car park in the current version of AD B. As mentioned, AD B requires a minimum ventilation area of 5% of each floor area to be present at least half of which is provided equally by two opposite walls.

For the ECSC demonstration tests, the floor area was 480 m^2 and the approximate opening area based on the information in the report[14] was 240 m^2. This represents a ratio between the ventilation area and the floor area of 50%, which is an order of magnitude greater than the minimum value in the guidance. In order to comply with the guidance, the ventilation could be reduced to an area as low as 24 m² as long as at least 50% of this was provided by two opposite walls. In such a case, a higher proportion of the total energy would be retained inside the car park and the temperatures of the structural members would be in excess of those recorded.

It is not only the ratio between the ventilation area and the floor area that impacts on the fire development but also the overall dimensions and the minimum linear distance between the ventilation area and the ignition source. In this case, the minimum distance between any point in the car park and the closest opening was 7.5 m.

It is worth comparing these values with those of a “typical” open sided car park. The Echo Arena car park at King’s Dock in Liverpool in which a severe fire occurred on New Year’s Eve 2017 was also classed as an open sided car park and therefore could have been designed in accordance with the guidance for a fire resistance period of 15 minutes. The Echo Arena car park had a footprint of approximately 70 m by 75 m and the minimum linear distance from the centre of the car park to the ventilation openings was close to 30 m. The floor-to-floor height was approximately 2.85 m. Based on an assumption that the car park was completely open on all four sides and the height of the ventilation opening was 2 m, then the total opening area is approximately 592 m² and the overall floor plate is approximately 5,468 m², giving a ratio between opening area and floor area of approximately 10.8%. In reality, this is an overestimate due to the presence of the stair shafts even before any account is taken of the restrictions provided by advertising hoardings or adjacent buildings. In reality, the ratio between open area and floor area will be closer to the limiting value of 5%. Due to these differences, a building with this configuration cannot be predicted based on the results from demonstration tests such as those described in the ECSC report[14]. The principal structural elements in the Echo Arena had a fire resistance considerably in excess of 15 minutes and therefore, in this instance, overall stability was maintained even though the level of damage led to an eventual demolition of the car park.

3 Current situation

More recently, changes in the design and manufacture of vehicles have taken place, including a greater use of plastics, increased vehicle size, the use of alternative fuel types, and the concept of self-driving cars[15]. A comprehensive analysis of the fire hazards of modern vehicles in parking structures is presented in the work by Boehmer et al.[4,9]. Such changes can potentially pose an increased risk to the fire safety of car parks.

Additionally, a few significant fires that challenge the arguments for low fire risk (with property damage as the consequence) in car parks have occurred in the last few years, such as the Stavanger airport fire with several hundred cars burnt[16] and the Liverpool Kings Dock fire with around 1150 cars destroyed[17].

Structural solutions with 15-minute fire resistance rating have been highlighted as problematic based on fires such as the Sola Airport (Stavanger, Norway) fire in January 2020, which led to partial collapse. The collapse was in the new part with this type of solution (unprotected steel, no sprinklers), whereas the old part consisting of a heavier concrete structure remained standing. A detailed analysis of this fire was undertaken by RISE FR in Norway[16]. As a collapse jeopardizes the life safety of occupants and firefighters, it is always an undesirable event. Thus, even if the collapse occurred after the period for the fire resistance rating had passed, it would be an extreme interpretation of the design to argue that the structure thus behaved as it was intended to. This highlights the need for calculations for the structure as a whole, not only for individual elements. In a UK context (AD A), the requirement is for the building to be constructed so that, in the event of an accident, the building will not suffer collapse to an extent disproportionate to the cause. In a fire situation, this means that a small ignition source should not cause significant damage. If it is known that the fuel load will be high, then there is a need to ensure the building is sufficiently robust. In this case, that means ensuring the fire resistance is proportionate to the conceivable fire scenario. As things stand, this is out of balance.

Although not part of the UK structural fire design process, this type of solution is often argued to be sound, based on early arrival of the Fire and Rescue Service, but this is a problematic assumption, as the arrival time can vary, and so can the time to initiate active firefighting (water or foam). The Sola Airport fire is an example of how wrong the design assumption of early arrival of the Fire and Rescue Service can be, as the airport even had its own, local 'fire brigade unit'. This unit, however, could not be used for the car park fire while the airport was in operation. To the BRE Global Project Team authors' knowledge, no account is taken in relation to Fire and Rescue Service intervention in terms of structural fire design particularly where the building has been designed for burn out. Whether this is required depends on the size, location and importance of the building, but Fire and Rescue Service intervention should not be used as an input to structural fire design. This is the reason why the approach set out in Annex E of the Eurocode is not used in the UK.

Another argument used, as in the aforementioned report sponsored by ECSC[14], is that the fire will be relatively small, and the design fire used for the calculations assumes that the initial fire will spread to no more than a couple of vehicles. This was based on their study, in which the number of fires in underground car parks involving less than 4 cars represents 97.9% of all cases (with 7 cars being the maximum number of cars involved). For open car parks, the maximum number of cars involved in fires was 3 (and this happened in only 10% of the fires). This assumption (of only a few vehicles being involved) has been proven wrong by previous studies and multiple recent fires worldwide (see Table 4)[18]. In addition, reports have established that there is a faster fire development (peak HRR occurring earlier) for newer cars, which in turn results in faster fire spread, and thus also a higher probability of spread to more cars. Figure 8 shows the data reported in a recent report by NFPA[9]. The fire spread is also facilitated by the fact that cars have become larger and parking spaces [the space where the cars are parked] have become smaller, thus decreasing the separation distance between cars in car parks. The observations in the NFPA report apply to the experiments in the ECSC report, as these cars are smaller than current cars and they were parked in a larger parking space than what is the current standard. All in all, these changes indicate that there is a need for establishing a new assumption for the design fire scenario in modern car parks. The new scenario should be used in calculations and models in order to establish the appropriate fire resistance requirements for different types of car parks (open and closed), as well as for different geometries (typography of open car park and percentage of opening).

It has also been argued that the car park will not be full, and that this can be used for design calculations. This is a significant misconception, because probabilistic input cannot be used for the magnitude of the consequence. A full risk analysis would have to be carried out, and the probability of different scenarios could then be based on statistics of how many cars are present at a given time. This aspect seems to be of less importance than making sure that the design fire scenario involves more than 2 to 3 cars. To avoid speculations about what is the 'reasonable worst case' or 'worst case', it is suggested that one scenario should be that the car park is fully occupied with cars, and that the consequences are calculated based on this. Further experiments and detailed calculations can be used to indicate how many cars will be involved, and thus set the precedence for a design fire scenario.

Table 4 − Examples of car park fires with several cars burning simultaneously (from Hertz et al.[18])

Date	Location	Burned cars	Construction type	Notes
2001-09-16	Fasanvænget, Kokkedal, Denmark	30	**Open**	30 cars on fire at the same time 70 people evacuated
2002-10-13	Schiphol airport, Netherlands	51	**Open**	30 cars on fire at the same time
2004-04-06	Jacob Hansensvej Odense, Denmark	10	**Open**	**Collapse of the steel shelter structure**
2010-08-30	Stansted airport, UK	24	**Open air**	High wind reported
2013-10-14	Olympic Park Aquatic Center, Sydney, Australia	80	**Open air**	1500 people evacuated
2016-03-25	Nygaards Plads Brøndby, Denmark	19	**Open**	Fire started in one car. Steel shelter repaired
2017-04-16	Von Lingens Väg Malmö, Sweden	35	Closed	Probably ignited on purpose
2018-01-01	Echo Arena, Liverpool UK	1400	**Open**	Fully developed fire started in one car Concrete building demolished
2019-08-31	Douglas Shopping Centre Cork, Ireland	60	**Open**	Fully developed fire started in one car **Steel building demolished**
2019-10-14	Münster-Osnabrück Airport, Germany	73	Closed	Fire started in one car. Concrete building repaired
2020-01-07	Sola Airport Stavanger, Norway	300	**Open**	Fully developed fire started in one car. **Steel building collapsed in fire**

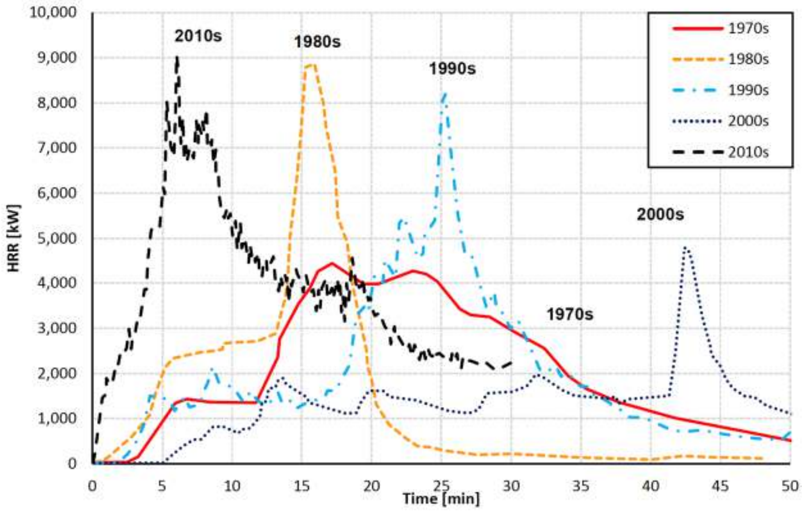


Figure 8 − HRR curves for vehicles from each decade[9]

4 Note on sprinklers

With respect to sprinklers, several studies, predominantly based on low fire occurrence and a very low probability of injuries and fatalities (see Table 5), have shown that they are not cost-effective for car parks. However, as these studies focused on injuries and fatalities, they may have underestimated the property losses in modern car parks. Furthermore, the latter number needs revisiting after the very large fires (Liverpool Echo and Sola Airport), which might be related to the changes associated with modern car parks (e.g. more compact parking, electric vehicles, larger fire load and faster fire development).

Table 5 − Fire occurrence, fatalities and injuries without sprinklers installed (from Alimzhanova et al.[3,10])

Place and type (range of years considered)	Annual fire occurrence rate	Probability of fatality	Probability of person having a severe injury	Probability of person having a slight injury
	λ_{ig}, fires/year/car park	$N\lambda_{f,0}$, fatalities/fire	$N\lambda_{Si,0}$ injuries/fire	$N\lambda_{si,0}$ injuries/fire
UK All (1994/2005)	0.0105	0.0006	0.0029	0.0252
UK Multi-Storey Car Park (1994/2005)	0.0484	0.0009	N/A	0.0183
England All (2010/2020)	0.0036	0.0013	0.0013	0.0114
England Multi-Storey Car Park (2010/2020)	0.0128	0.0025	N/A	0.0074
England Underground (2010/2020)	0.0353	0	N/A	0.0189
England Other (2010/2020)	0.0009	0	0.0058	0.0116
Scotland All (2009/2020)	0.0050	0	N/A	0.0106
Wales All (2009/2020)	0.0046	0	N/A	0.0401

5 International perspectives

In this section, the perspectives from three recent studies on car park fire safety are presented, along with some relevant details that were gathered in a paper published in 2013 (which will be presented first).

The three major international reports that have been published in the last few years are:

1. “Fire safety in car parks, storage of lithium-ion batteries and batteries for solar systems in buildings,” by DBI (The Danish Institute of Fire and Security Technology)[19]
2. “Evaluation of fire in Stavanger airport car park 7 January 2020,” by RISE (Research Institutes of Sweden)[16]
3. “Modern Vehicle Hazards in Parking Structures and Vehicle Carriers,” by NFPA (National Fire Protection Association)[9]

These three reports have a large number of references, and this is pointed out to highlight that the reports are very substantial and thorough, and to emphasise that there are a lot of references used in the support of their logic and conclusions. All reports have had steering groups and been through strong quality assurance processes before being published.

 © BRE Global Ltd 2025

5.1 "Design of open steel and composite car parks under fire"

The definition of what constitutes an open car park can differ from country to country, as shown in Table 6, which is from a paper by Haremza et al.[20]. In terms of required fire resistance, the range is from R0 (no requirement) in Germany, via R15 in UK to as high as R180 in Portugal.

Note that although the UK regulatory system permits performance-based approaches, it is perceived that they are not generally used for the design of car parks, quite possibly due to the high cost of, for example, running numerical models for design purposes. In most cases, the recommended minimum values from the guidance would be adopted and the "fire design" may be as simple as checking that the requirements for open sided car parks are met and that the section factor (A_m/V or H_p/A) conforms to the requirements set out in the notes to Table B4 of AD B.

Haremza et al.[20] continues [*Note that this is all quotation until the end of the page*]:

"According to the ECCS (European Convention for Constructional Steelwork) report[21], steel structures in open car parks do not require fire protection, and therefore have economic advantages. The fire safety of these structures is ensured by the following conditions:

i) the design at room temperature (or "cold design"), according to the current rules, is the basic condition for the stability of the structure in the fire situation; no additional measures for fire [or] a special "hot" design are required;

ii) beams with composite steel concrete section including shear studs should be used; for economic reasons, it is recommended to use light weight sections (IPE, HEAA and UB);

iii) large flange sections (HEA, HEB, UC) should be considered for the columns; and

iv) horizontal forces must be supported by frames or bracings (protected against fire).

Additionally, CTICM (Centre technique industriel de la construction métallique/Technical reference organization in metal and mixed construction[22] indicates:

i) the same cross-sections for all columns in the same floor; these columns must be filled with concrete between the flanges,

ii) use of concrete stairs to increase the horizontal stability and to be used as emergency stairs;

iii) use a minimum steel grade of S355, and minimum concrete class of C30/37;

iv) steel beams connected to the concrete slab by shear studs with a minimum degree of connection of 80%;

v) concrete slabs built in situ or precast concrete; the essential point is the static and structural integration of the slab in the load-bearing system[20]."

 © BRE Global Ltd 2025

bre

Table 6 − Overview table of requirements for open car parks (and what defines 'open') from a number of European countries (from Haremza[20])

Country	Limitations						General requirements for fire ISO 834	Alternative design conditions	
	Minimum percentage of openings (%)		Maximum						
	Openings/ floor	Openings/ walls and facades (*1)	Dist. between opposite façades (m)	Nº of stories	Building height (m)	Floor area per storey (m^2)		No fire protection	Natural fire (*3)
Germany	-	33	70	-	22	-	R0	/	/
Austria	-	33	70	-	22	-	Up to R90	Yes	Yes
Belgium[23]	-	17	60	-	-	-	R0 to R120	/	Yes
Denmark	5	-	24	-	-	-	R0 to R60	Yes	Yes
Spain	-	-	-	-	-	-	R60 to R120 (*2)	-	-
Finland	10	30	-	8	-	9000	R60	No (*4)	Yes
France[24]	5	50	75	-	-	-	Up to R90	Yes	Yes
Netherlands	-	30	54	-	20	-	R0 to R30	/	/
Hungary	-	-	-	-	-	-	R30 to R90 (*2)	No	No
Italy[25,26]	15	60	-	-	-	-	R0 to R90		
Luxemburg[27]	-	50	-	-	-	-	R0 to R30	/	/
Norway	-	33	-	-	16	5400	R10 to R60	Yes	-
Poland	-	-	-	-	25	4000	R60	No	-
Portugal[28,29]	-	-	-	-	-	-	R60 to R180	-	Yes
UK[30]	5	-	-	-	30	-	R15	Yes	Yes
Sweden	-	-	-	-	-	-	R60 to R120 (*2)	Yes	Yes
Switzerland	-	25	70	-	-	-	R0	/	/

*1 Total area of openings/total area of walls and facades surrounding one parking level.
*2 General requirements of National Building Code.
*3 Use of Natural Fire as an alternative to ISO fire to prove the fire resistance.
*4 Bare steel is allowed if this can be proved by tests or scientific studies.

© BRE Global Ltd 2025

5.2 "Fire safety in car parks, storage of lithium-ion batteries and batteries for solar systems in buildings," by DBI (The Danish Institute of Fire and Security Technology)

The DBI report[19], which has 116 references, covers many other aspects that are beyond the scope of the current report (such as solar systems and lithium-ion batteries in a general, non cark park, context). It includes detailed discussions of various fire protection measures and the influence of electric vehicles (EVs) and battery packs.

The main findings are of relevance, as they all challenge the assumptions based on the ECSC report. Note that Danish regulations have different requirements for different car parks based on size, location, geometry, and height. The requirements range from R30 to R120; thus, they are higher than the R15 used in England and Wales (as Scotland (Non-Domestic Technical Handbook) does not adhere to AD B requirements), and the criteria are different, as the Danish regulations do not just use height as a criterion. It is worth highlighting that despite the requirements being stricter in Denmark (R30 and up), an evaluation of the safety was still commissioned there, thus indicating that there was a perceived need to revisit R30 as a design criterion for fire resistance.

The key recommendation in the report is that the probability of fire spread between vehicles needs to be reduced, and this recommendation is independent of the type of cars. In support of this, there have been examples of fires in car parks in Liverpool, Stavanger, and Amsterdam, where the fire spread very quickly between the first vehicles. The fire spread was such that the fire department in connection with these fires did not have an immediate opportunity to limit the spread of the fire upon arrival at the scene of the fire. The most extreme fire spread observed in previous incidents occurred at the fire at Schiphol Airport in Amsterdam. Testimony from the Schiphol fire[31] states that it spread from 1 to 10-15 cars within 8 minutes. Lessons learned from the Schiphol fire were that:

- All cars were parked at a small distance (40 cm) from each other, which can increase the spread of fire from car to car.
- All cars were new and new cars contain more plastic parts than older cars.
- All cars' fuel tanks were completely full, leading to a high fire load.
- The fuel tanks were made of plastic and began to leak fuel, creating pool fires which can also cause the fire to spread by running away and under other cars.

DBI suggests that due to the rapid change in modern cars, the recommendations should be re-evaluated every five years. Note that if the argument is to revisit it periodically and often, it might make more sense to follow a conservative approach now instead of incrementally adding to the provisions.

Furthermore, DBI recommends that individual analyses of the risk associated with fire are carried out for car parks where the fire resistance of the load-bearing structures is based on old criteria, where, for example, a value for the maximum HRR of 5 MW was used and with only a few cars involved in the fire. It is the increased fire load for the car fleet in general that is problematic, which means that fire safety in these car parks must be looked at more closely.

Overall, DBI summarises their findings as follows, where points 3, 4 and 8 being of particular interest for the current study:

1. The risk of fire in electric cars (including charging) is less than in cars with a combustion engine, which is in line with new Norwegian statistics. [*BRE Global Project Team authors' note. Risk is here referring to frequency of occurrence*].

2. The [peak] heat release in case of fire from new electric cars is about the same as the [peak] heat release from new internal combustion engine cars (ICEV) (based on, among other things, full-scale combustion tests).
3. New cars (both EV and ICEV) have approximately a 40% higher heat release contribution than the standard heat release values used for building dimensioning [read: design].
    a. The maximum HRR for a car has been increased from the 5 MW standard value to 6-10 MW according to the literature [e.g. reference 18]. A minimum value of 7 MW should be used going forward.
4. There is a tendency to increase the density of cars in car parks.
    a. Parking lots and access roads are made narrower to make room for more cars in relation to the building cost (leading to inconvenience for the car's passengers and firefighters in the event of a fire).
    b. There are sometimes parking areas for small cars that can be parked closer.
    c. Lift parking systems can be installed in two or more layers to utilise the ceiling height for more parking spaces.
    d. Automatic parking facilities are being built, where cars can be tightly packed in a robot-operated warehouse without staff.
5. In car parks, it cannot be expected that car park users alert the fire service in the event of a fire – people observe the fire but do not call the fire service. Car parks should have automatic fire detection and alarm.
6. Fire ventilation conditions are not necessarily an effective tool against the spread of fire from car to car. There are several examples of relatively rapid fire spread in open car parks with fire ventilation via openings in the facades.
7. A single burning car with high HRR is not considered critical for car parks, but the higher HRR contributes to the spread of fire becoming critical more quickly. Therefore, delaying the spread of fire in car parks is advised, for example through increased requirements for the installation of sprinkler systems.
8. In the case of several major car park fires, a faster fire spread than assumed has been observed, regardless of car type. The increased fire load and fire effect from the cars can therefore be problematic for a number of existing car parks if the fire engineering construction requirements were based on an assumed HRR of 5 MW and a limited number of cars are assumed to be involved in the fire. [*BRE Global Project Team authors' note. Design in the UK is based on standard fire exposure and not on a specific design fire scenario*].

It is essential to highlight that DBI also reports that higher temperatures than those prescribed by the standard fire curve have been observed in connection with fires in car parks in relation to the dimensioning of fire-related load-bearing and separating building parts. This may have the consequence that the load-bearing capacity or fire resistance of a construction may be less than assumed and thus produce unexpected failure of supporting and separating structures.

The literature study undertaken by DBI and their experience from fire tests have shown that automatic sprinkler systems in car parks are a decisive factor in relation to limiting the spread of significant fire and in relation to ensuring the response options of the Fire and Rescue Service. The effect of fire ventilation, often in the form of permanent openings in the facade, is uncertain. [See more on this in the discussion of Figure 10 and in Section 6 of the current report].

For future projects, DBI recommends:

- That the effect and function of fire ventilation in car parks are examined in more detail in connection with a generally greater fire load for newer cars compared to standard cars, e.g. to reduce the risk of fire spreading and in relation to the increased temperature and the influence on the construction.
- To examine what influence the geometric conditions in a car park have in relation to the risk of fire and fire spread. The geometric conditions can be a limiting factor in relation to the risk by fire. Larger distances between the individual parking spaces and possibly division between groups of several vehicles with greater mutual distance (free areas) and the room height of car parks can be limiting factors for fire spread.

DBI comments on the use of structural steel

The design of car parks using structural steel is based on the guidelines in the European standard ISO/TC92/SC4, where unprotected steel elements are allowed in open car park installations. An older European standard for closed car parks also allows the use of unprotected steel members in the event of a single-cell fire, where it is assumed that the heated parts of the structure will be supported by the rest of the structure, which is not affected by high temperatures[32].

However, in recent years, as previously highlighted, the fire load for newer vehicles has increased. It therefore gives a higher risk for fire spread to the adjacent vehicles and it can therefore no longer be assumed that only local heating and local temperature rises impact on the construction. The DBI report states that a car park facility designed according to the aforementioned guidelines will no longer be safe when the fire has spread to several vehicles.

This problem has been addressed in a recent study[18] that also contains suggestions for prerequisites for the structural dimensioning of car parks in steel, while accounting for the risk of fire spread.

According to this study[18], fire spread between vehicles in a car park facility is dependent on several factors such as: ventilation, ceiling height, vehicle type, fuel quantity, distance between cars, ignition point and weather conditions (for open car parks). The type of vehicle, the amount of fuel and the type of fuel are the main contributors to the fire load, and where significant changes have occurred over the past few decades. Because of changes to the make-up of modern vehicles (increased flammability due to the use of plastic, fuel spillage from plastic fuel tanks, use of multiple electrical components) there is a higher risk of fire and of fire spread. According to the study, the design and use of plastic-based materials for vehicles increased the fire load of a modern ICEV to 12 GJ and to 15 GJ for EV in 2021. As an average for a car park facility with 25% electric cars, the authors recommend an average value of fire load at 13 GJ in the future for a vehicle. In addition to the greater fire load posed by newer vehicles, the distance between cars has also changed over the years, and this value can be as low as 40 cm, which increases the risk for fire spread even more.

The proposals for criteria for dimensioning steel car parks [*according to Hertz et al.*[18]], as presented in the report by DBI, include:

1. That the assumption of local heating of individual elements should be disregarded.
2. That yield stress fy(T) is set at 0.2% strength at high temperatures.
3. That fully developed fire processes can be considered a worst-case scenario until more research is done on fire spread between vehicles both experimentally and numerically.
4. That the energy contribution per car is set at 13 GJ/car for a car park facility with 25% electric cars (future). (The current value is 12 GJ) or;

5. That the fire load be set at 660 MJ/m^2 of the floor area or 330 MJ/m^2 of the surrounding area in parking lots with an area of 18 m^2 (closely located).
6. That the fire load be set at 260 MJ/m^2 surrounding area for car parks with larger parking spaces.

Using the above criteria[18], comparative calculations have been made between unprotected and protected steel elements. These calculations show the effect of insulation on both a steel column and a steel beam. According to the calculated results, unprotected columns reach temperatures above 1,000 °C and 'have a reduction of the 0.2% yield strength and E-modulus corresponding to 0.0076. When the strength is reduced to this extent, no steel column can carry its load'[18]. For a steel beam, the calculations showed that an unprotected steel beam cannot even achieve an R30 rating (30-minute load-bearing capacity in a standard fire test) compared to the standard fire curve.

According to the calculations by Hertz et al.[18], insulated elements could achieve an R90 classification (90-minute bearing capacity in a standard fire test). However, it should be noted that classification of the protected elements depends on the type of insulation protection applied and the thickness. The DBI report concludes that the calculation examples show that the use of outdated dimensioning criteria can result in constructions not having desired safety [for occupants and firefighters] in the event of a fire, and at the same time shows the importance of constantly updating the dimensioning criteria adapted to developments within the automotive industry.

5.3 "Evaluation of fire in Stavanger airport car park 7 January 2020," by RISE (Research Institutes of Sweden)

The RISE report[16] on the Stavanger airport (Sola) fire in January 2020 has 66 references. The report has in-depth information and analysis of the fire that occurred at the Stavanger airport, Sola, in the afternoon of 7th January 2020. The fire started in an Opel Zafira, which was parked on the ground floor. As the fire damaged more than 300 cars, resulted in a partial collapse (see Figure 9), and a shutdown of the airport, the financial consequences were significant. The fire did not result in injuries or fatalities. The report did not cover details of the business interruption losses or assessment of environmental impacts of the fire and firefighting.

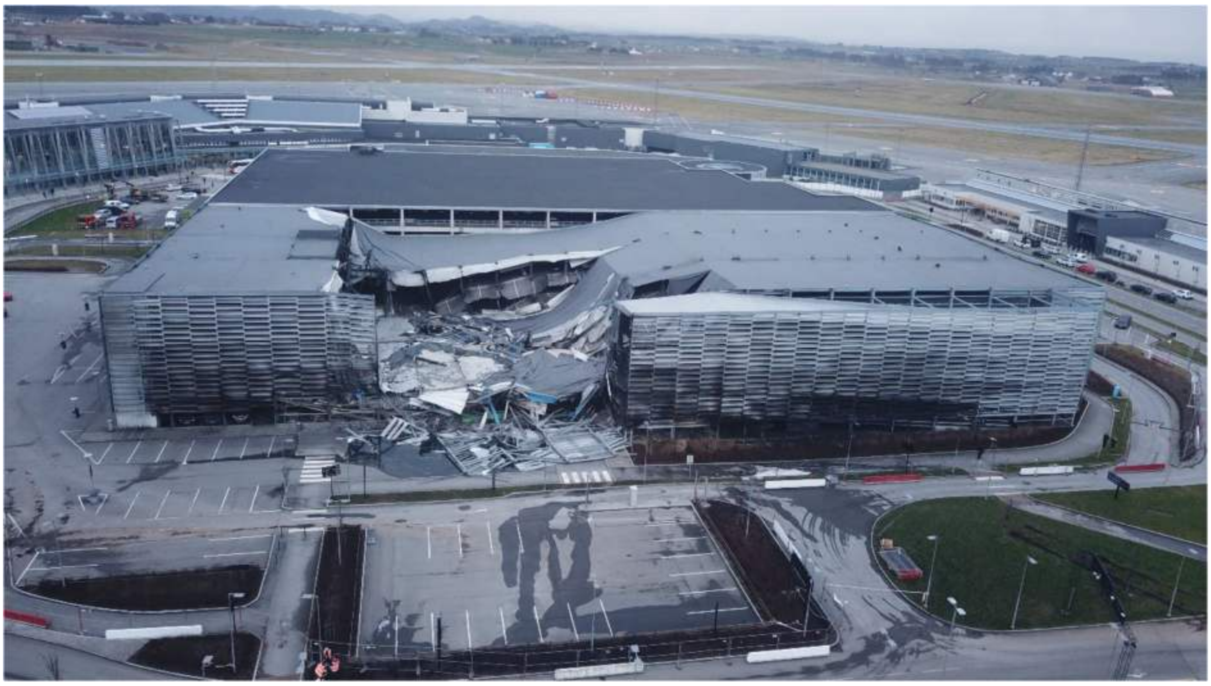


Figure 9 − Aerial photo of the Sola airport car park after the fire, showing the partial collapse[17]

The report states that “the fire became so extensive due to a combination of factors:

- It took a relatively long time from the start of the fire until the fire service was notified.
- There was no automatic fire alarm system in the building.
- There was no automatic extinguishing system in the building.
- There was no fire compartmentation in the car park.
- Fire extinguishers in the car park were not used to try to extinguish the initial fire.
- The fire spread rapidly to several vehicles.
- Strong wind helped accelerate the spread of fire.
- The leakage of fuel from burning vehicles contributed to the fire spreading.
- A response plan with a corresponding layout of the car park was lacking. This could have helped the fire service with the wayfinding, establishing assembly points, and general organization.”

As the car park was designed based on the common assumption that the fire spread would be slow and limited, the analysis by RISE FR shows that, in retrospect, several design features were not robust enough. In the report, the following design mistakes were pointed out by RISE FR:

- The car park was placed in fire class 3 [Norwegian building codes]. The authors stated that it should have been placed in fire class 4 [Norwegian building codes] due to its location close to the airport, which is considered to be infrastructure of national importance. Placement in fire class 4 would have required fire safety engineering (analysis).
- Building C: The fire resistance rating for load-bearing structural parts in a car park in fire class 3 should under TEK10 with guideline have been designed as R 90, not R 10.
- Due to the large area, the car park should have been divided into fire compartments to prevent large material losses. The building was not designed with fire compartmentation.

According to RISE FR, this fire highlighted that “fires in car parks with large openings in wall areas may develop into unacceptable proportions, if the wind conditions are unfavourable.” They also recommend that it should be “examined to which the extent of openness (size, shape and distribution of openings) impact the fire development, and what may be considered as adequate and suitable ventilation.”

Of relevance to the current report, the RISE FR report concludes that the main aspects that made the fire become so damaging were the following. Note that references in the design were made to studies that were from the 1980s:

1. The effect of open walls was misjudged.
    a. “A minimum of 50% open facades in the car park is assumed, and no internal division by walls. This will prevent critical pressure and temperature build-up which may impact on the steel to an extent which may entail collapse before escape and rescue have been achieved. Flue gases with high temperatures will be ventilated and cooled through incorporation of fresh air. Long-term fire exposure of the load-bearing structure of a magnitude that causes the steel to lose its load-bearing capacity is therefore not very likely, even if it were to be directly exposed to fire. Reference is made to the study entitled ‘Open-deck car park fire tests’[33] where the results of full-scale trials document that the steel will not reach critical temperatures. The trials do not take manual extinguishing efforts by the fire service into

consideration, which further reduces the probability of a critical damage to the steel through fire exposure."

2. It was assumed that a fire in one car will not spread to neighbouring cars. [This assumption, along with the ventilation assumption, both turned out to be wrong, and the steel thus reached critical temperatures in several places. As a result, the building suffered a partial collapse.]

    a. "A potential collapse of beams locally across the fire scene will not entail collapse of the building at large. The most likely fire scenario is a car fire on one of the parking decks. Such a fire has a scant likelihood of spreading to other cars[33]. Besides, there will not be other combustible material on the parking decks. This means in all probability that only a small local part of the load-bearing structure in the immediate vicinity of the burning vehicle will be affected."

3. It was assumed that the fire service is able to access floors with a low ceiling, and with considerable thermal stress and fume emission, 10-20 minutes after the start of fire.

A follow-up study by RISE FR Norway entitled "Fire safety in naturally ventilated car parks" was published recently, and it focused on CFD calculations related to open car parks[34]. It includes considerations of wind (speed and direction) and opening percentages, but does not cover other aspects, such as floor plate size. Their main conclusion is strong and is given in bold in the English abstract: "**The results of this study indicate that the fire resistance of the load-bearing structures should not be reduced from R30 - R60 to R15, even if the wall surfaces have more than 1/3 open area fraction.**" With respect to the wind conditions, they add: "Regardless of wind conditions, the structural analysis showed that expanding the open area fraction from 21% (i.e. less than 1/3) to 41% (more than 1/3), has a smaller effect on the collapse time than reducing the fire resistance from R30 to R15. The difference is even more pronounced in a reduction from R60 to R15. By using R60 none of the beams collapsed." The results of this study indicate that the fire resistance for load-bearing structures should not be reduced even if the wall surfaces have more than 1/3 open area fraction.

They add nuances to this with the following text: "In a car park with 41% open area fraction, i.e. more than 1/3 open wall area, the main load-bearing system may under certain conditions be constructed with a fire resistance of minimum R 15 A2-s1,d0 [incombustible material]. For a car park with 21% open area fraction, the fire resistance must be minimum R30 or R60 depending on the number of floors." It is, however, worthwhile to point out that the 50% open wall area that was a design criterion in the Stavanger airport car park did not prevent partial collapse, as mentioned in the other report by RISE FR.

Figure 10 shows the significant difference between opening levels of 21% and 41% for the case of no wind, and also shows how significant the one closed wall (top wall in figure) is, as spread was much more limited in that direction. In Figure 11, the wind was coming from 'West' [left] and had a velocity of 3 m/s. Simulations were also carried out for a wind speed of 11 m/s. The wind directions explored in the study were from the 'West' and the 'South'.

It is clear from Figures 10 and 11 that the smaller opening percentage results in worse conditions, and this is confirmed in Figure 12 (in terms of HRR) and Figure 13 (in terms of number of collapsed beams). These results clearly show that design details matter, and also that less ventilation plays a significant role, as seen both in terms of 21% vs 41% opening and in terms of the closed back wall ('North' (top of Figures 10 and 11).

© BRE Global Ltd 2025

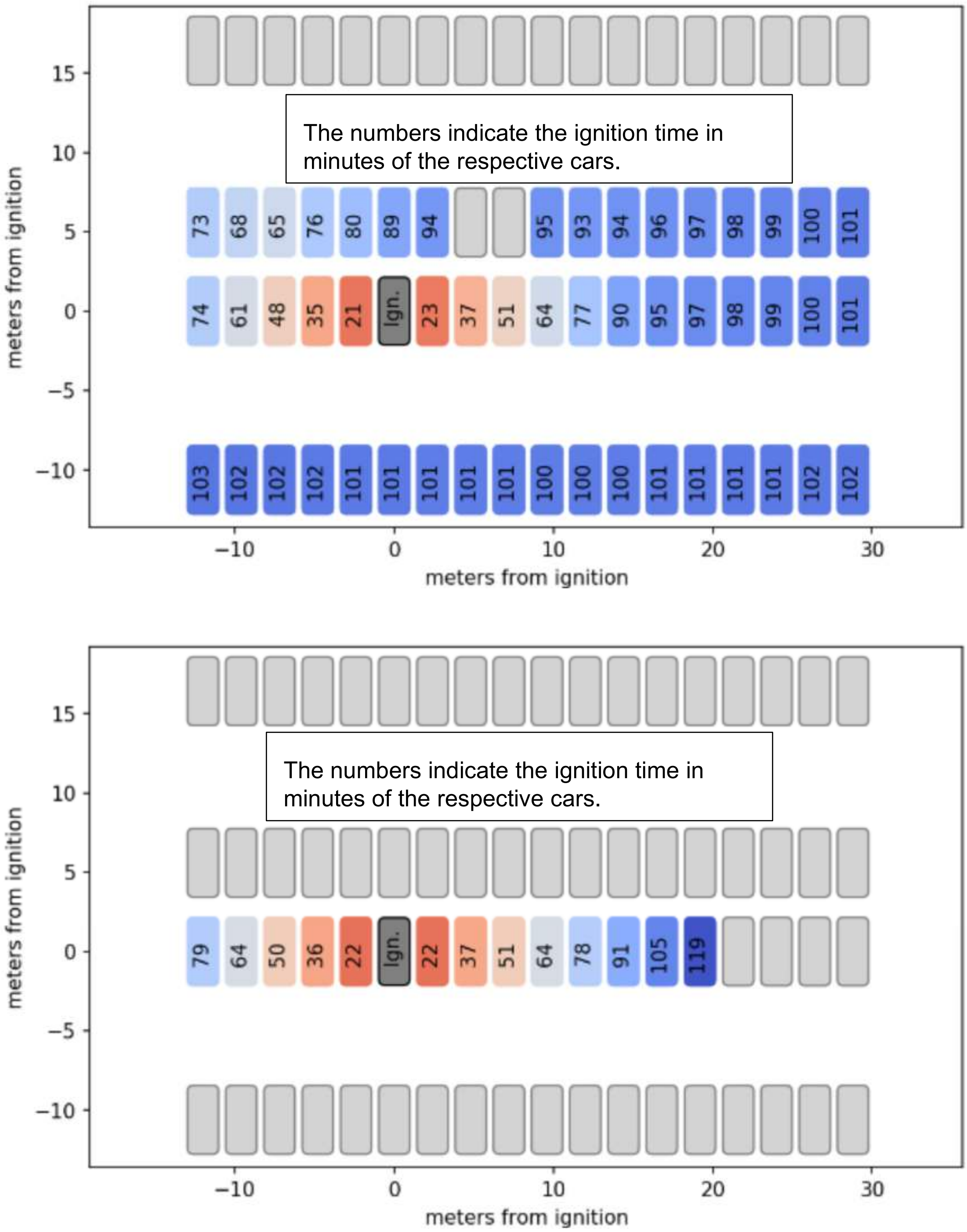
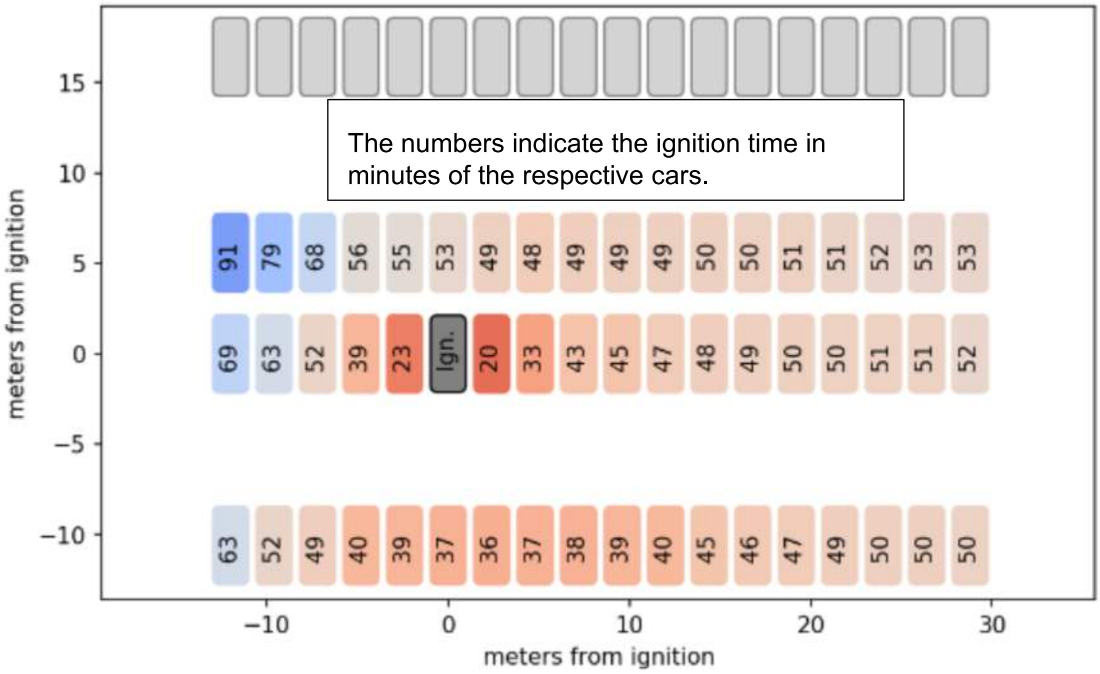


Figure 10 – Illustrations from the RISE FR Report[34] showing the clear difference between simulation results of the ignition time (in minutes, based on ignition in the car labeled 'Ign.') for two scenarios. The upper scenario has an opening level of 21%, whereas the lower scenario has an opening level of 41%. In both cases, the 'North' wall, which corresponds to the top wall in the figures, was closed. These results are for no wind.



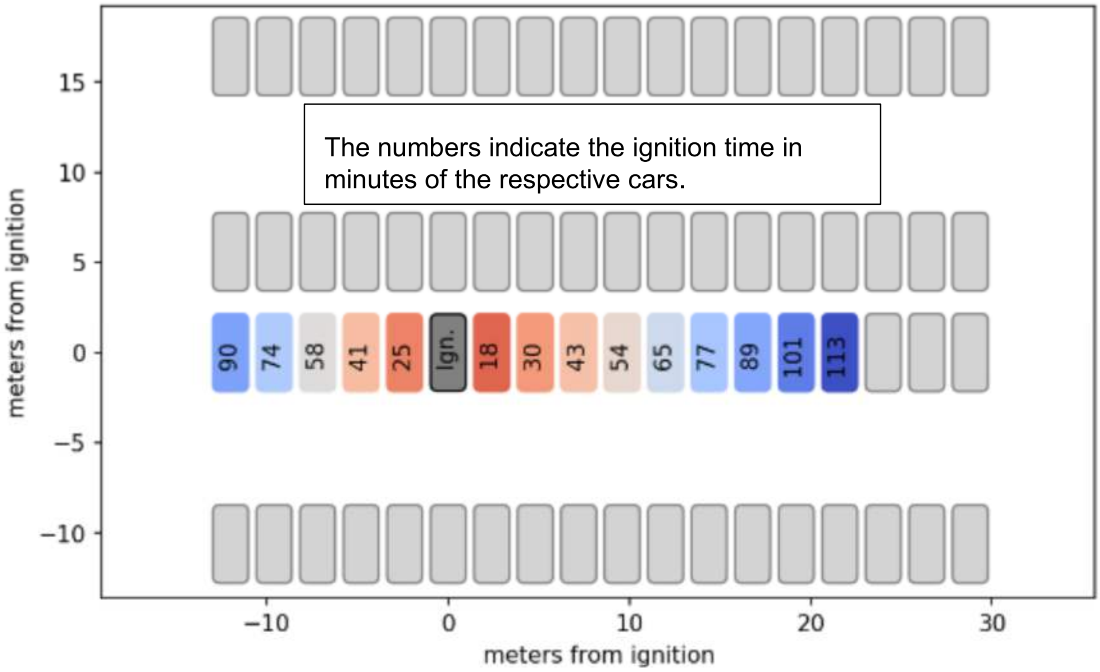


Figure 11 – Illustrations from the RISE FR Report[34] showing the clear difference between simulation results of the ignition time (in minutes, based on ignition in the car labeled 'Ign.') for two scenarios. The upper scenario has an opening level of 21%, whereas the lower scenario has an opening level of 41%. In both cases, the 'North' wall, which corresponds to the top wall in the figures, was closed. The wind had a velocity of 3 m/s and was coming from the 'West' (i.e. from the left as seen here).

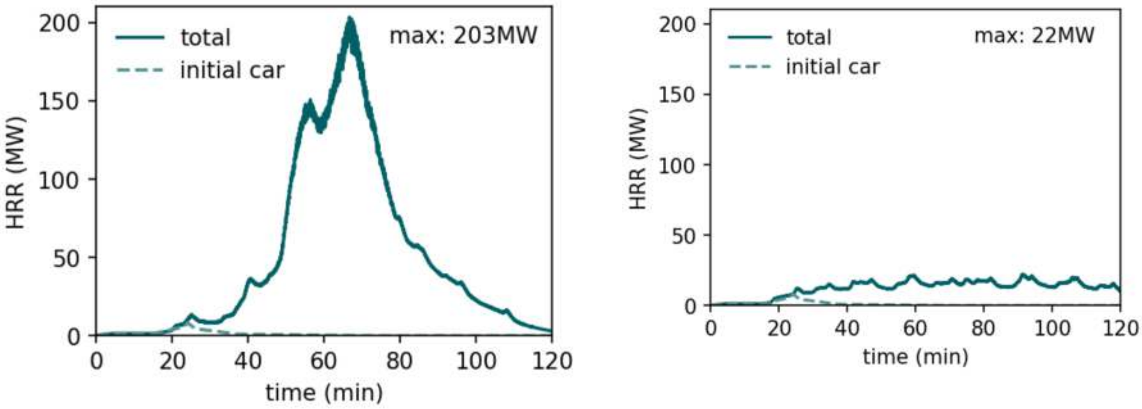


Figure 12 – Illustrations from the RISE FR Report[34] showing the clear difference between the HRR development for 21% opening (left) and 41% opening (right) for a wind speed of 3 m/s.

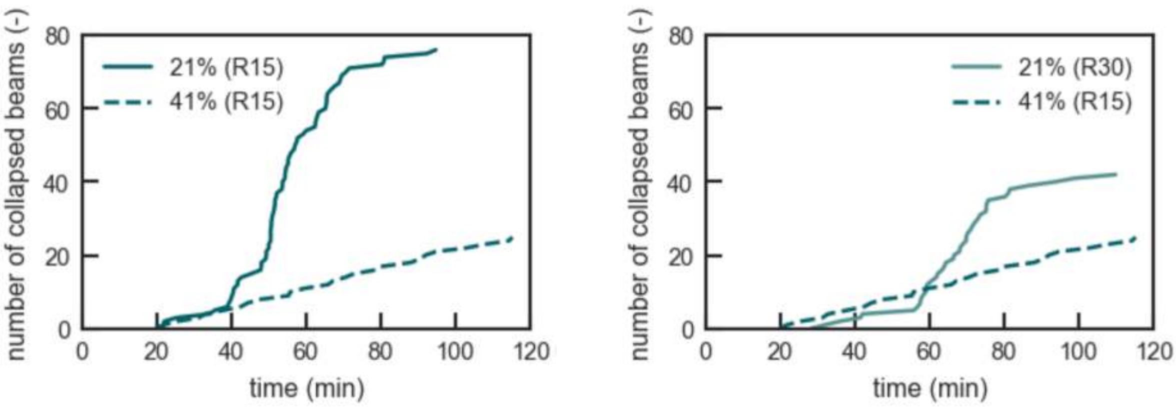


Figure 13 – Results from the RISE FR Report[34] for number of beams collapsed for 21% opening (left) and 41% opening (right) for a wind speed of 3 m/s.

5.4 "Modern Vehicle Hazards in Parking Structures and Vehicle Carriers," published by NFPA (National Fire Protection Association)

The NFPA report from July 2020[9] has 98 references. The following are the key elements, and the bold is used [*by BRE Global Project Team authors*] to emphasise some points of particular relevance to the current report. In the following, the references have been converted to the reference numbers of the current report.

In the USA, and some other jurisdictions, vehicle parking structures are governed by NFPA 88A, *Standard for Parking Structures*[35]. Including the 2019 edition, there have been little changes to the fundamental protection requirements in the NFPA 88A standard since the initial 1973 and 1979 editions.

The NFPA report states that "when considering property loss, **three main findings indicate that modern vehicle fires present an unacceptable hazard in open parking structures** under the current code requirements in NFPA 88A (as well as similar code requirements elsewhere)." These three findings are:

1. **Potential for very rapid spread of fire between vehicles, in as little as 10 minutes from ignition, due to:**

a. **The increased use of plastics in vehicle construction**

b. **The shrinking distance between parked vehicles**

c. The low ceilings in many car parks that enhance heat transfer from hot gases

2. No requirement for automatic fire detection, notification or extinguishment.

3. Large, tightly packed car parks where it takes the fire department a long time to respond and makes extinguishment difficult.

   a. News articles about the Sola airport fire report that it took the fire department approximately 19 minutes from ignition until first units arrived[36,37], and that the first firefighters claimed to have seen as many as 10 vehicles burning on arrival, though this has not been confirmed. As the airport firefighters are not able to respond to non-aircraft fires while the airport is operating, the closest responding firefighters had a travel time of up to 13 minutes (at normal driving speed).

In support of these three main points, the NFPA report expands by adding that:

- **"Vehicles have changed significantly over the years.** Modern vehicles present new hazards, such as due to the incorporation of larger quantities of combustible materials (e.g. fuels, plastics, synthetic materials, etc.) into their designs. As alternative fuel vehicles are popularized, concerns regarding their unique hazards, burn characteristics, and typical burn duration have been raised. Compared to older vehicles, modern vehicles burn differently. Modern car parks have optimized space requirements for vehicle parking and storage and often implement automated retrieval features and car stacking, which presents unique hazards as well. Thus, it raises the question if the safety infrastructure of these parking structures and vehicle carriers (i.e. maritime vessels) have kept pace. This project aimed to quantify the fire hazard of modern vehicles in parking structures and vehicle carriers to provide guidance for the applicable technical committees."

  Table 7 provides some details to support this.

Table 7 – Table 4 from the NFPA report that shows examples of the width and weight increase of some cars

	Width increase	Weight increase
Toyota Corolla	21 cm (8.3 in)	430 kg (948 lb)
Ford F150	8 cm (3.1 in)	150 kg (332 lb)

- **"There has been an increase in the fire hazard from changes in vehicle design and increased use of plastics and other combustible materials in vehicle construction.** The increased plastic content of modern vehicles manifests as faster flame spread within the vehicle, easier ignition and more rapid fire spread to neighboring vehicles. Modern car parks tend to have narrower parking spaces than before, with increasing use of vertical stacker systems, leading to more densely packed fuel loads. The spread of fire between cars in a car park, especially from the initial to the second and third vehicles, is shown to be critical in determining the extent of the fire and the ability of the fire department to successfully control and extinguish it."

- **“There is limited test data available on this spread between multiple vehicles, especially on newer cars.** Some testing of multiple modern vehicles has shown very rapid fire spread between vehicles in a car park configuration, on the order of 10-20 minutes. Based on the findings, test data from older vehicles (>15-20 years at the time of writing) should not be used as basis for development of codes and regulations.”

The NFPA report[9] also points out that “With no detection or notification system, preventing a single car fire from spreading and potentially causing a conflagration throughout the whole parking structure is therefore solely reliant on the rapid response of the local fire department.” Given that Fire and Rescue Service response is not a design criterion in England, it can therefore be concluded that car parks should be designed for fires involving several cars. Table 4, presented earlier, provides further support for the need for a design that assumes several cars burning simultaneously.

The distinction between an enclosed and open car park in NFPA 88A is simply the percentage of wall area open to the outside. The BRE vehicle tests[7] showed that openings placed low or high on the wall can both satisfy the requirement but have very different impact on the development of the fire and hot gas layer. Certain opening placements could result in fire conditions similar to those in a fully enclosed car park, without the stricter protection requirements.

With modern vehicle fires in dense parking structures leading to more rapid fire spread, and thus greater smoke and heat production, the code distinction between open and enclosed car park currently set at 20% open area should be examined. The requirement was changed in the 2019 edition of the code. In the previous edition, the opening requirement was 0.4 m^2 per linear metre of exterior (1.4 ft^2 per linear foot). Depending on the height of each level this could lead to less than 20% of the wall area being open. To evaluate these issues, testing and modelling should be performed of vehicle fires in enclosures with various opening configurations, placements, and open percentages (within the ‘open’ definition). However, comparison between different countries/jurisdictions is difficult, due to differences in what constitutes an ‘open area’.

The International Building Code (IBC)[38] contains similar requirements as NFPA 88A. Open parking structures are defined as those with greater than 20% of the exterior wall area open to the outside. Like NFPA 88A, the IBC require that these openings be uniformly distributed across the wall area. The current (2018) edition of the IBC also follows NFPA 88A and does not require sprinklers in open car parks. In 2018, a change was approved (as modified) for the next 2021 edition of the IBC regarding sprinklers in open car parks[39]. The proposed (and accepted) change will require that automatic sprinkler systems be installed in open car parks with greater than 48,000 ft^2 (4,459 m^2) fire area or 55 ft (16.8 m) in height[40].

The NFPA report concludes that “**Open parking structures emerge as the main area of concern regarding fires in modern vehicles.** The lack of any requirements for active protection systems in fire codes, and trends in both vehicle and car park design suggest that large, devastating fires in these structures could become increasingly common. Though the risk of civilian injuries will continue to remain low, these fires could cause extremely large property losses, business disruption, and adverse environmental impact.”

© BRE Global Ltd 2025

6 Note on wind

The BRE Global Project Team authors were given access to a paper submitted to the 14th IAFSS symposium later in the year[41], so the following is confidential information, and not yet fully peer reviewed at the time of writing this report.

The open car park shown in Figure 14 was modelled for different cases of wind (angle and strength) and four fire sizes (all on the fourth floor), for a total of 192 scenarios.

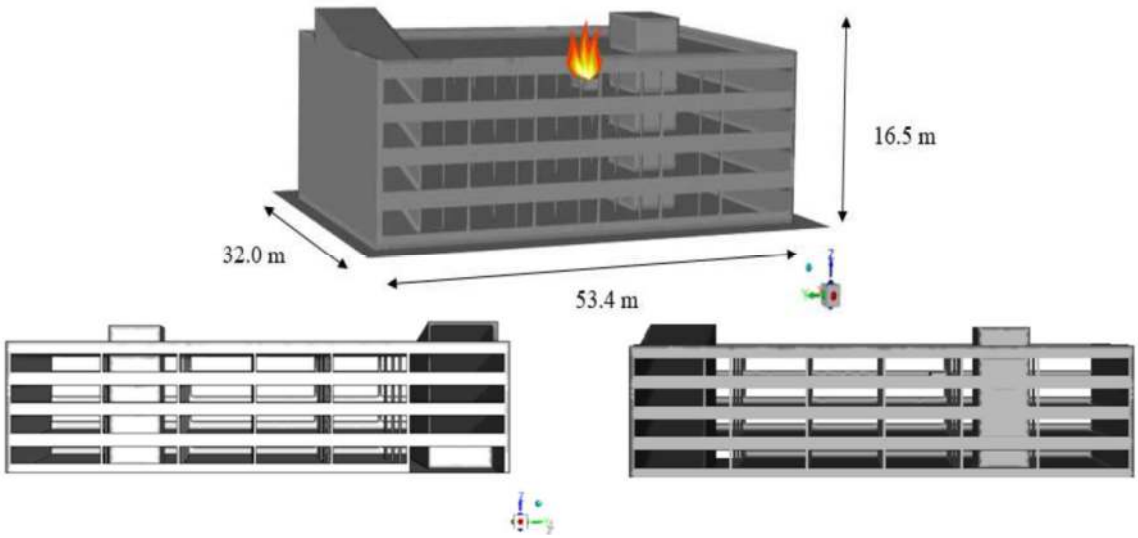


Figure 14 – The car park that was modelled – it had 42% open area (in terms of the total façade area)

For the fires of 1.4 MW; 4.0 MW; 6.0 MW and 8.8 MW, the ventilation of the car park was found to be insufficient 11%, 59%, 64% and 83% of the time, respectively. Based on what has been stated earlier in the current report, the three larger fire sizes are to be expected in modern car parks. As such, it is more likely than not that the 'natural ventilation', even for a relative open configuration as the one studied, is insufficient in venting the smoke and heat. As a result, a high temperature smoke layer will build up, and the structural elements will be exposed to temperatures similar to those in closed car parks. Though a preliminary study, it points out that, similarly to the numerical study by RISE FR, car parks have to be extremely open for the desired ventilation effects to be present. Therefore, this is yet another piece of evidence in support of revising the structural fire resistance requirements in open car parks in AD B and elsewhere.

7 Conclusions

Discussions during the Car Park Focus Group meeting held on 29th July 2022 identified the specification of a minimum recommended period of fire resistance of 15 minutes for open sided car parks as the major issue of concern in relation to this research project. A thorough literature review was therefore undertaken to address this aspect of fire safety in open sided car parks. The focus was not on ICEV (Internal Combustion Engine Vehicles) vs EV (Electric Vehicles), as it has been reported that the HRR (Heat Release Rate) is similar for these two car categories.

In terms of an international perspective, the findings of this report indicate that England has one of the lowest requirements for fire resistance in car parks, combined with the least restrictive constraints on what constitutes an "open sided" car park. Based on the review, the research evidence underpinning the change in fire resistance for open sided car parks is akin to a fire in the open with no restrictions on ventilation and large heat losses to the external environment while a number of recent fire incidents are more like compartment fires or fires within a closed car park.

Reports from leading fire safety institutions including NFPA (USA), RISE FR (Norway) and DBI (Denmark) all provide evidence and support for revisiting outdated design practice related to open sided car parks. There are several reasons in support of this need.

First, the need for review and potential revision has arisen due to a number of recent fire incidents involving multiple vehicles, as this challenges the classic design premise of only a small number of vehicles burning simultaneously.

Second, changes to the design of both vehicles and car parks have exacerbated the situation, as cars have become larger and contain more plastic while parking spaces have become smaller. As a result of these changes, the total heat release from a single vehicle has increased and the time to peak heat release in the event of a fire has decreased, both resulting in an increased probability for involvement of several cars (along with the fact that they are more closely spaced) and thus more intense thermal exposure for the structural elements.

Therefore, in the current situation, the assumption of a localised fire with a limited number of vehicles involved cannot be sustained. The simple approach set out in AD B and based on standard fire resistance has enabled the use of unprotected steel for open sided car parks. The guidance needs to be revisited in the light of recent fire incidents and based on research findings for modern vehicles, as well as due to changes to the design of car parks. Further to that, as the Fire and Rescue Service response is not a design criterion in England, it can be concluded that car parks should be designed for fires involving several cars (i.e. significantly more than 2 to 3).

The international reviews all point in the direction of the need for increased fire safety provisions for open sided car parks. For example, one of the main recommendations from the Danish report (DBI) is that sprinklers are installed. Sprinklers are also a theme in the report from NFPA, which also concludes that "Open parking structures emerge as the main area of concern regarding fires in modern vehicles."

Third, the report from Norway (RISE FR), and the fire at the Stavanger Airport (Sola) itself, clearly demonstrates that R15 was insufficient, as the car park experienced a partial collapse. The supporting numerical report indicated that R60 was a more appropriate fire resistance rating for this type of car park, and that close attention must be given to the percentage of open area.

Finally, a recent study from researchers in Poland found that when wind is considered, the open sided car parks perform worse, as the expected ventilation from the open sides fails, thus leading to more smoke accumulation and higher temperatures in the parking structure.

To move forwards, work needs to be commissioned to look at the sensitivity of fire growth based on a variation in the relationship between the open area and the overall geometry of the car park including the ratio between opening area and floor area and the minimum distance between any area within the car park where a fire might be initiated and the closest opening. The recent report by RISE FR Norway supports this.

In summary, the current requirement in the guidance to the Building Regulations for England for fire resistance (i.e. 15 minutes) in open sided car parks up to 30 m in height should be revisited. Where fire engineering methods are adopted the scenarios and input values used for design fire calculations in car parks should be revisited. This could also be used to further upgrade the numerous recent studies that have focused on the predictive capability of CFD models used in support of design calculations.

To evaluate the outstanding issues, testing and modelling should be performed of fires involving multiple vehicles (significantly more than 2 to 3) in enclosures with various opening configurations, placements, and opening percentages (within the 'open' definition), and possibly also closed car parks. Given the large property losses in recent car park fires, it is recommended that insurance companies and large car park developers and owners are asked to contribute. Car manufacturers should also be asked to provide a variety of modern vehicles for this purpose.

Based on the review conducted of the current guidance related to the fire resistance of open sided car parks and based on published information and real fire incidents, it is our understanding that the following tasks are required:

- A study to relate assumed heat release rates to an equivalent period of fire severity. In this way more recent data on fire growth can be used to provide input data to structural calculations (see next bullet point below) as design in England is generally not based on structural fire engineering design from first principles but on prescribed periods of fire resistance.
- A parametric study to consider the response of typical structural members (generally composite beams and steel columns) to a variation in fire severity related to either specific design fire scenarios or specified periods of exposure to the standard curve. This study should be informed by those involved in the design of car parks to ensure the structural elements are representative of current practice.

8 Acknowledgements

BRE Global would like to acknowledge the contribution of project partner University of Edinburgh, the principal author of this report.

The authors would like to thank the participants of the Car Parks Focus Group meeting for their valuable contributions.

9 References

1. BBC news, Bedfordshire, Luton airport fire car park to be ‘fully demolished’, 3 November 2023. Available from: Luton airport fire car park to be 'fully demolished' - BBC News. Last accessed 20th February 2024.

2. Bedfordshire Fire & Rescue Service, Significant Incident Report: London Luton Airport Terminal Car Park 2, 10/10/2023, Terminal Car Park 2, Easy Way, Luton, Bedfordshire, GB-040100-2023, published 9th October 2024. Available from: Significant Incident Report LLA Car Park 2 fire.pdf. Last accessed 5th March 2025.

3. Alimzhanova M, Spearpoint M and Jomaas G, Fire safety assessment of sprinkler systems for car parks using the J-value methodology, Fire Safety Journal, volume 129, 2022. Available from: https://doi.org/10.1016/j.firesaf.2022.103565. Last accessed 10th August 2023.

4. Boehmer H R, Klassen M S, and Olenick S M, Fire Hazard Analysis of Modern Vehicles in Parking Facilities, Fire Technology, 2021, Doi: 10.1007/s10694-021-01113-1.

5. Butcher E G, Langdon-Thomas G J and Bedford G K, Fire and car-park buildings. Fire Note 10, Joint Fire Research Organization, 1968.

6. Marchant E, Time is opportune to revise fire safety standards for multi-storey car parks, Fire, 1990.

7. BRE, Fire spread in car parks BD 2552, Department for Communities and Local Government, December 2010. Available from: https://webarchive.nationalarchives.gov.uk/ukgwa/20120919132719/http://www.communities.gov.uk/documents/planningandbuilding/pdf/1795610.pdf. Last accessed 24th February 2023.

8. The UK Home Office, Fire statistics data tables. Available from: www.gov.uk/government/statistical-data-sets/fire-statistics-data-tables. Last accessed 19th January 2021.

9. Boehmer H, Klassen M, and Olenick S, Modern Vehicle Hazards in Parking Structures and Vehicle Carriers, NFPA Fire Protection Research Foundation, FPRF-2020-07, July 2020.

10. Alimzhanova M, J-value assessment of sprinkler systems in car parks, IMFSE thesis, University of Edinburgh (supervisors: Michael Spearpoint and Grunde Jomaas), 2021. Available from: Thesis+Malika+Alimzhanova.pdf (squarespace.com). Last accessed 10th August 2023.

11. The UK Home Office, Ad-hoc fire and rescue statistics. Available from: Home Office: ad-hoc fire and rescue statistics - GOV.UK (www.gov.uk). Last accessed 20th February 2024.

12. CROSS UK, Fire risks in multi-storey car parks, Report ID: 940, CROSS Safety Report, Published 14 October 2020. Available from: https://www.cross-safety.org/uk/safety-information/cross-safety-report/fire-risks-multi-storey-car-parks-940. Last accessed 10th August 2023.

13. CROSS UK, Fire protection to car park steel frame, CROSS Safety Report, Report ID: 1007, Published 26 August 2022. Available from: https://www.cross-safety.org/uk/safety-information/cross-safety-report/fire-protection-car-park-steel-frame-1007. Last accessed 10th August 2023.

14. Joyeux D, Kruppa J, Cajot L, Schleich J, van de Leur P and Twilt L, Demonstration of real fire tests in car parks and high buildings, European Commission, 2002.

15. Spearpoint M, Hopkin D and Arnott M, The historical background to fire resistance periods for the design of car parks in the UK, presented at the 3rd International Conference on Structural Safety under Fire & Blast Loading, CONFAB 2019, Brunel University, London, UK, September 2019.

16. Storesund K, Sesseng C, Mikalsen R F, Holmvaag O and Steen-Hansen A, Evaluation of fire in Stavanger airport car park 7 January 2020, RISE Research Institutes of Sweden, RISE-report 2020:91, September 2020. doi: 10.13140/RG.2.2.24520.14080.

17. Merseyside Fire & Rescue Service, Kings Dock car park fire - Protection Report, April 2018. Available from: kings-dock-car-park-fire-protection.pdf (merseyfire.gov.uk). Last accessed 10th August 2023.

18. Hertz K D, Sørensen L S and Giuliani L, Reliable assumptions for structural fire design of steel car parks, Journal of Structural Fire Engineering, volume 13, no. 1, pp. 32-48, 2022. Available from: https://doi.org/10.1108/JSFE-01-2021-0002. Last accessed 10th August 2023.

19. Dansk Brand- og sikringsteknisk Institut (DBI) and Teknologisk Institut (TI), Brandsikkerhed i car parkanlæg, oplag af litium-ion batterier og batterier til solcelleanlæg i bygninger, Version: 02, January 2022. Available from: https://bpst.dk/da/-/media/BPST-DA/Byggeri/Nyheder/Analyse-af-brandsikkerhed-i-car parkanl%C3%A6g---Ved-batterioplag-og-BESS-02_2022_01_14.pdf. Last accessed 10th August 2023.

20. Haremza C, Santiago A and Simões da Silva L, Design of steel and composite open car parks under fire, Advanced Steel Construction, volume 9, no. 4, pp. 350-368, 2013. Available from: http://ascjournal.com/down/vol9no4/vol9no4_6.pdf. Last accessed 10th August 2023.

21. ECCS, Fire safety in open car parks, modern fire engineering, Technical Committee 3, nº75, European Convention for Constructional Steelwork: Brussels, Belgium, pp. 90, 1993.

22. Fraud C, Zhao B, Joyeux D, Kruppa J, Guide Pour la Vérification du Comportement au Feu de Parcs de Stationnement Large Mentventilés en Superstructure Métallique, CTICM, INSI – 03/233d – BZ/PB, pp. 75, 2004.

23. Arrêté royal fixant les mesures en matière de préventioncontrel'incendie et l'explosionauxquelles les parkingsfermésdoiventsatisfaire pour le stationnement des véhicules LPG, MoniteurBelge, BelgischStaatsblad. Ed. 3, pp. 33997, 20 June 2007.

24. Arrêté du 9 mai 2006 portant approbation de dispositions complétant et modifiant le règlement de sécuritécontre les risquesd'incendie et de paniquedans les établissementsrecevant du public (parcs de stationnementcouverts), Ministère de l'intérieur et de l'aménagement du territoire, Journal Officiel de la République Française, 8 July 2006.

25. Ministry of Interior (Italian Government), Decree 9 May 2007. Direttive per l'attuazionedell'approccioingegneristicoallasicurezzaantincendio, GU n. 117, 22 May 2007.

26. Nigro E, Cefarelli G, Ferraro A, Manfredi G and Cosenza E, Fire safety engineering for open and closed car parks: C.A.S.E Project for L'Aquila, Applied Mechanics and Materials, volume 82, pp. 746-751, 2011. ISSN: 1662-7482. doi:10.4028/www.scientific.net/AMM.82.746.

27. ArcelorMittal – Car parks in steel, Commercial Sections, 1996.

28. Portaria nº1532/2008, Diário da República, 1ª série, N.º 250, pp. 9050-9127, 29 December 2008.

29. Decreto-Lei nº220/2008, Diário da República, 1ª série, N.º 220, pp. 7903-7922, 2008.

30. Corus, Steel-framed car parks, Corus Construction & Industrial, 2004.

31. Marton T, Dederichs A, and Giuliani L, Modelling of fire in an open car park, Applications of Structural Fire Engineering, 2015. Available from: https://ojs.cvut.cz/ojs/index.php/asfe/article/view/3365. Last accessed 10th August 2023.

32. Cresson E (Editor), Development of design rules for steel structures subjected to natural fires in closed car parks, p. 160, 1991. Available from: https://gratis-publicaties.bouwenmetstaal.nl/pdf_serve.lasso?p=pdf&n=Development%20of%20design%20rules%20for%20steel%20structures%20subjected%20to%20natural%20fires%20in%20closed%20car%20parks-1.pdf&pub=125-1.pdf Last accessed 14th December 2023.

33. Bennetts I D, Proe D J, Lewins R R, and Thomas I R, Open-deck car park fire tests, BHP Melbourne Research Laboratories, Clayton, Victoria, Australia, August 1985, ISBN 0 8679 012 7.

34. Meraner C and Arsava K S, Fire safety in naturally ventilated car parks, [in Norwegian with Abstract in English], RISE FR Norway, RISE Report 2022:95, 2022. Available from: https://risefr.no/media/rapporter/brannsikkerhet-i-naturlig-ventilerte-parkeringshus.pdf Last accessed 10th August 2023.

35. NFPA 88A, Standard for Parking Structures, 2019 edition, National Fire Protection Association, Quincy, MA, USA, 2019. [*Note: New edition in 2023*].

36. Klingenberg M and Ramsdal R, Bare det nye stålbygget kollapset i Sola-brannen. Tysk firma hadde ansvaret for konstruksjonssikkerhe. tu.no (Norwegian), published 24 January 2020. Available from: https://www.tu.no/artikler/bare-det-nye-stalbygget-kollapset-i-sola-brannen-tysk-firma-hadde-ansvaret-for-konstruksjonssikkerhet/483498?key=pTj9RrwD. Last accessed 26th March 2020.

37. Klingenberg M and Ramsdal R, Sola-brannen: Avinor fikk prosjektert lavere brannmotstand enn anbefalt. tu.no (Norwegian), published 8 January 2020. Available from: https://www.tu.no/artikler/sola-brannen-avinor-fikk-prosjektert-lavere-brannmotstand-enn-anbefalt/482449?key=zDqjzIkuhttps://www.tu.no/artikler/bare-det-nye-stalbygget-kollapset-i-sola-brannen-tysk-firma-hadde-ansvaret-for-konstruksjonssikkerhet/483498?key=pTj9RrwD. Last accessed 26th March 2020.

38. International Code Council, International Building Code, 2018 edition, May 2018.

39. The Fire Code Action Committee, Hearing order suggestion, 6 August 2018.

40. National Fire Sprinkler Association, Vote on 2021 IFC and 2021 IBC — ICC Group A, Posted 8 November 2018. Available from: https://nfsa.org/2018/11/08/2021-ifc-ibc-codes-icc-group-a/. Last accessed 18th June 2020.

41. Wegrzynski W, Jaminska-Gadomska P, Miechowka B and Krajewski G. Evaluating the operational uptime of natural smoke control in an open car park. Paper submission to 14th International Symposium on Fire Safety Science (IAFSS 2023). Undergoing peer review at the time of writing.

 © BRE Global Ltd 2025

10 Further references of relevance

The following references were consulted while working on this report, but they are not used as direct references in the text. They are deemed to be of value for the interested reader.

i. Spearpoint M, Design for life: The changing face of car parks and fire safety compliance, Parking News, Issue 388, pp. 24-25, August 2019. Available from: portfolio.cpl.co.uk/Parking-News/388/24/. Last accessed 10th August 2023.

ii. Shipp M and Spearpoint M, Measurements of the severity of fires involving private motor vehicles, Fire and Materials, volume 19, issue 3, pp. 143-151, 1995, doi: 10.1002/fam.810190307.

iii. Li Y and Spearpoint M, Cost-benefit analysis of sprinklers for property protection in New Zealand parking buildings, Journal of Applied Fire Science, volume 12, June 2004, doi: 10.2190/C8AU-TKTU-17CW-HAJN.

iv. Spearpoint M, Tohir M, Abu A and Xie P, Fire load energy densities for risk-based design of car parking buildings, Case Studies in Fire Safety, volume 3, pp. 44-50, 2015.

v. Schleich J, Cajot L, Pierre M et al, Development of design rules for steel structures subjected to natural fires in closed car parks. European Commission Report EUR 18867, ECSC Publication, Brussels, Belgium, 1999.

vi. Katsuhiro O, Watanabe N, Hagimoto Y, Chigira T, Masano R, Ochiai M H S, Satoh H, Tamura Y, Hayano K, Maeda Y and Suzuki J, Burning behaviour of sedan passenger cars, Fire Safety Journal, volume 44, pp. 301-310, 2009.

vii. US Fire Administration - FEMA, Vehicle arson - A combustible crime, in National Arson Awareness Week Media Kit, 4-10 May 2014.

viii. Sørensen T, Fire design of unprotected steel structures in parking houses, MSc Thesis, University of Southern Denmark, Denmark, 2016.

ix. Van der Heijden M, Loomans M, Lemaire A and Hensen J, Fire safety assessment of semi-open car parks, Proceedings of Building Simulation 2011, 12th Conference of International Building Performance Simulation Association (IBPSA2011), pp. 2843-2850, Sydney, Australia, 2011.

x. Christiansen T, Fire load on car parks (in Danish), MSc Thesis, Department of Civil Engineering, Technical University of Denmark, Lyngby, Denmark, 2007.

xi. Janssens M and MacNaughton M, Development of a database of full-scale calorimeter tests of motor vehicle burns, SwRI Project 01.06939.01.003. Southwest Research Institute Texas, USA, 2008.

xii. Li Y, Assessment of vehicle fires in New Zealand parking buildings, PhD thesis, Department of Civil Engineering, University of Canterbury, New Zealand, 2004.

xiii. Zahirasri M, Multiple vehicle design fire scenarios in car parking buildings, PhD Thesis, University of Canterbury, New Zealand, 2015.

xiv. Fettah B, Fire analyses of car park building structures, MSc Thesis, Polytechnic Institute of Brangança, Portugal, 2016.

xv. Larsson F, Battery aspects on fires in electrified vehicles, in Proceedings of the 3rd International Conference on Fire in Vehicles, pp. 209-220, Berlin, Germany, October 2014.

xvi. Lecocq A, Bertana M, Truchot B and Marlair G, Comparison of the fire consequences of an electric vehicle and an internal combustion engine vehicle, in 2nd International Conference on Fires in Vehicles, Washington, 2012.

xvii. MacNeil D D, Lougheed G, Lam C, Carbonneau G, Kroeker R, Edwards D, Tompkins J and Lalime G, Electric vehicle fire testing, in 8th EVS-GTR Meeting, Washington, 2015.

xviii. NEN2443, Parking and stalls of passenger cars on terrains and car parks (In Dutch: Parkeren en stallen van personenauto's op terreinen en car parks) ICS 91.040.99, Nederlands Normalisatie-instituut, Delft, Netherland, 2000.

xix. Jangi M, Tilley N and Merci B, Numerical simulations of some possible fire scenarios in a closed car park with RANS and LES, in Fire protection and life safety in buildings and transportation systems, Advanced research workshop proceedings. Presented at the IAFSS Advanced Research Workshop 2009, Santander, Spain, 2009.

xx. Noordijk L and Lemaire T, Modelling of fire spread in car parks, Heron Journal, volume 50, no. 4, pp. 209-218, 2005.

xxi. Van der Heijden M G M, Loomans M G L C, Lemaire A D and Hensen J L M, Fire safety assessment of semi-open car parks based on validated CFD simulations, Building Simulation, An International Journal, volume 6, no. 4, pp. 385-394, 2013.

© BRE Global Ltd 2025

Report Ends