Multi-scale characterisation of the fire hazards of timber cladding (Phase 1 and 2)

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Contents

1 INTRODUCTION

1.1 Appointment

OFR Consultants, in collaboration with DCCH Experts LLP, were engaged by the Department for Levelling Up, Housing and Communities (DLUHC) to deliver the "Real Fires" project (CPD/004/122/039) in support of fire safety technical policy, which commenced on 22nd of October 2021, and will run for three years from this date. The contract has since been novated to the Building Safety Regulator (BSR), formed within the Health & Safety Executive (HSE). As part of this project, the contract makes allowance for ad-hoc research to be undertaken to support fire safety technical policy on matters that emerge through dialogue with industry or through observations from real fires. Through this mechanism, OFR have been engaged to undertake research on the fire safety hazards of thermally modified / treated timber cladding. This research is a continuation of a study instigated prior to the award of the "Real Fires" contract to OFR, by the then supplier, the Building Research Establishment (BRE Global). BRE Global now act in a capacity of a sub-contractor to OFR and have been charged with completing the experimental programme commissioned by DLUHC after a fire at Samuel Garside House, Barking, in June 2019. This research has been delivered across two phases: Phase 1 – the original scope of work for which BRE Global were instructed by the then Ministry for Housing, Communities and Local Government (MHCLG), and Phase 2 – an extended scope of work proposed by OFR to address additional matters that have arisen through the course of the delivery of the Real Fires contract.

1.2 The research project

On 9th June 2019, a fire at Samuel Garside House, Barking, spread across balconies and façade composed of timber, affecting eight flats. BRE Global investigated the fire and produced a report on 21st February 2020, which was delivered to the then Ministry for Housing, Communities and Local Government (MHCLG) on 27th February 2020.

The report determined that the timber was thermally modified Scots pine and examined the balcony construction's contribution to unprotected areas. MHCLG sought to better understand the fire characteristics of thermally modified timber, leading to a research project proposal by BRE Global. The project aimed to measure and characterise the fire behaviour of Scots pine timber in four different states: i) aged and thermally modified (from Barking), ii) a virgin state, iii) a thermally modified state, and iv) a thermally modified and fire-retardant treated state. The proposal was accepted in January 2021, experiments commenced in March 2022 and concluded in October 2023. OFR received BRE's draft final report in November 2023 [1]. For the purposes of reporting, this initial series of experiments is denoted as Phase 1.

In May 2024, the BRE commenced further experiments under OFR's instruction to compare (a) the Barking cladding in a flat configuration (i.e., 19 mm Scots Pine) and (b) the implications of reducing the thickness of cladding to align with ADB recommendations, i.e., 9 mm Cedar cladding. This amended report, i.e., Rev 02, includes the results of (a) and (b), with these two additional experiments denoted as Phase 2. The motivations for both phases are discussed in Section 2.

1.3 Purpose of this report

This report has been prepared as the final deliverable of the research project and sets out OFR's analysis, view and recommendations that relate to the experimental campaign delivered by BRE Global in the two phases noted. The report considers the timber cladding from three perspectives:

- The potential hazards associated with timber cladding, how these hazards might vary in function of the cladding form and what role reaction-to-fire classifications have in supporting compliance with Part B of Schedule 1 of the Building Regulations.
- Changes in the hazard associated with timber cladding that might arise due to thermal modification.
- Changes in the hazard arising because of aging of thermally treated wood.
- The role that fire-retardant treatments could have in mitigating timber cladding fire hazards.

1.4 Format of this report

The report is structured as follows:

- Section 2: Triggers for timber cladding research – this section outlines the events that led to the commissioning of this research under the Real Fires contract.
- Section 3: Timber cladding – this section provides the motivations for using and types of timber cladding are discussed.
- Section 4: Research methodology – this section identifies salient research questions and sets out the method adopted to answer them.
- Section 5: Sample sourcing and characteristics – in this section timber samples are described in terms of how they were sourced, conditioned and their resulting characteristics.
- Section 6: Reaction to small flame and cone calorimeter scale experiments – this section discusses results at the scale of the small flame test and cone calorimeter.
- Section 7: Single burning item testing – results from single burning item testing are presented.
- Section 8: Intermediate scale experiments – this section outlines the BRE intermediate scale rig, and the results of tests undertaken on the four timber sample types identified for investigation at this scale.
- Section 9: Intermediate scale experiments - this section outlines the BRE intermediate scale rig, and the results of tests undertaken on the two timber sample types identified for investigation at this scale.
- Section 10: Discussion of Phase 1 results– this section discuses the results across the different scales, in the context of how they serve to characterise the external fire spread hazard of timber cladding.

- Section 11: Discussion of Phase 2 results – this section discusses the additional experiments undertaken at intermediate scale, drawing comparisons with Phase 1.
- Section 12: Conclusions– conclusions are given in direct response to the research questions. Recommendations in respect of fire safety technical policy are provided and areas where further work could be undertaken are noted.
- Section 13: References – Literature cited in the process of the developing the report is given.

2 TRIGGERS FOR TIMBER CLADDING RESEARCH

2.1 Fire at Samuel Garside House, Barking

2.1.1 Overview of the incident & initial investigation response

Fire and emergency services responded to a fire at Samuel Garside House, De Pass Gardens, Barking, IG11 0FQ, on June 9, 2019, at 15:31. This incident occurred at a specifically designed apartment complex constructed around 2013, with varying heights ranging from four to six stories (from the lower ground to the fourth floor, as depicted in Figure 1). The structure featured continuous timber balconies on its west side and five balcony sections on the east side (refer to Figure 1). These balconies were constructed with a steel framework and included timber elements such as decking, joists, soffits, and privacy screens, which incorporated soft plastic netting.

Figure 1. Samuel Garside House (East elevation) – Image from map data © 2019 Google. Last accessed 12 December 2019.

Additionally, according to BRE Global incident reports, the building featured a continuous, full-height façade made of timber slats. These slats, set at 110 mm intervals, were vertically aligned and attached to steel angle irons. The fire, as shown in Figure 2, spread both vertically and horizontally, engulfing an entire section of the building's balconies from the upper ground to the fourth floor. A video titled "Barking Riverside Fire" on Nuno Amorim's YouTube channel [2] captures the lateral spread of the fire at Samuel Garside House. The footage shows the fire moving 13.7 m horizontally across the third and fourth floors in 265 s, equivalent to a rate of approximately 50 mm per second.

The fire also spread to adjacent flats in the complex, resulting in significant damage or complete consumption of the combustible contents of eight flats, as reported by London Fire Brigade [3]. While the fire did not spread to other buildings, there was noticeable heat damage to properties across the street, with the timber façade being approximately 13.5 m away from these dwellings.

Media reports suggested that the timber used might have been thermally modified, but this detail was not confirmed. Additionally, it remained unclear whether the timber had undergone chemical treatment to enhance its fire-retardant properties.

BRE Global, who at that time delivered the "Real Fires" project investigated this fire under its contract with the Ministry of Housing Communities and Local Government (MHCLG), which later became the Department for Levelling Up Housing and Communities (DLUHC) in September 2021.

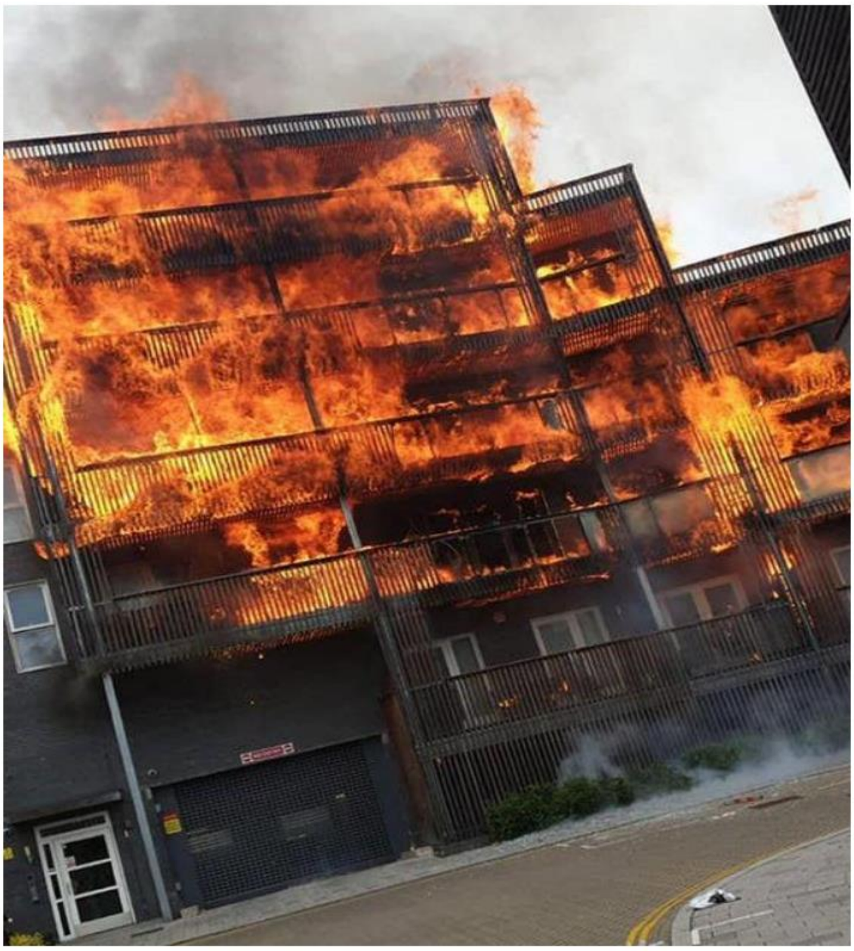


Figure 2. The fire captured by https://twitter.com/mobee_me?lang=en @mobee_m(c). Last accessed on 12 December 2019 [4].

Consequently, BRE Global was commissioned to conduct a detailed study on the timber used in the balcony façade. This research was aimed at identifying the species of the timber, examining its physical properties, and understanding its indicative fire behaviour. Additionally, the study focused on analysing the geometry of the façade and identifying any areas that lacked fire protection. The outcomes of that study were reported in reference "P13072-1003 Issue 14: Fires, timber balconies and boundary separation – a case study" [5].

2.1.2 BRE Global report P13072-1003 – summary of findings

BRE Global provided P13072-1003 to the MHCLG on 27 February 2020. This report identified that:

- Timber samples taken from Samuel Garside House were identified as thermally modified Pinus sylvestris (Scots pine).
- Tests on the timber following BS 476-7:1997 [6] for an indicative reaction to flame classification – revealed the timber was likely to fail to achieve the Class 3 limit. This was the recommendation of ADB at the time of construction; however, this is not the case in the contemporary edition of ADB.
- Chemical analysis of samples taken from Samuel Garside House did not indicate the presence of Didecyldimethylammonium chloride (DDAC), which is a common ingredient of fire-retardant treatments adopted on timber in the UK. This led BRE to conclude that it was unlikely that the timber balcony construction to the building was fire retardant treated.
- Testing to BS EN ISO 11925-2:2010 [7] (modified) – revealed the timber samples met the requirement of Class E (indicative – following the principles of classification given in BS EN 13501-1:2018 [8]. However, it was not possible to determine if the timber was capable of achieving a higher indicative classification i.e., D or C or B, as there was insufficient material to conduct a BS EN 13823:2010+A1:2014 (Single Burning Item) test [9].

BRE Global report concluded by recommending that further experiments be undertaken to characterise timber cladding fire performance, considering four states:

1. Aged thermally treated Scots pine (from Samuel Garside House).
2. New thermally treated Scots pine, with fire retardant coating.
3. New thermally treated Scots pine.
4. Virgin Scots pine (i.e., neither thermally nor fire retardant treated).

2.2 Concerns raised through Collaborative Reporting for Safer Structures (CROSS) submission

Aside from the fire at Samuel Garside House, timber cladding was the subject of a CROSS report published on 20th November 2023, report ID: 1194 [10]. This report was published under the title: "Fire performance of timber cladding". The CROSS report can be distilled to two issues that require consideration by the Building Safety Regulator (BSR). These relate to a footnote to an ADB table that supports the use of 9 mm thick timber and, more generally, on the application of generalised Euroclasses for materials. These are discussed further below.

2.2.1 ADB guidance relating to 9 mm timber

Approved Document B has previously and continues to permit the use of 'timber cladding at least 9 mm thick' in the guidance related to the reaction to fire performance of external walls. The current format of this guidance from Approved Document B [11], [12], states in footnote (3) of Table 12.1 - "*timber cladding at least 9mm thick is also acceptable*". The guidance makes no specific mention of the type or configuration of timber cladding, or indeed what may or may not constitute 'timber'.

The CROSS reporter traced the origins of the 9 mm recommendation back through to the original research by Ashton and Malhotra [13], and its subsequent interpretation by Langdon-Thomas and Law [14] in the process of developing the first English National Building Regulations [15]. The CROSS report identifies that the basis for the 9 mm recommendation was likely an error, arising from confusing the thickness of timber cladding with the thickness of the plasterboard also used in the original research. The timber cladding tested was ca. 22 mm and not 9 mm thick. This brings into question the validity of the recommendation in footnote (3) of Table 12.1 and whether cladding that is 9 mm thick would result in a greater hazard than was originally foreseen.

Further to the above, the CROSS report notes that "*timber cladding*" is poorly defined in ADB, whilst the original research by Ashton and Malhotra adopted a specific configuration. This configuration was flat lapped cedar planks, heated from the outside only. This sat on a timber frame, sheathed on the inside with plasterboard. It is foreseeable that a user of ADB could interpret the definition of timber cladding in various ways. This could affect both the configuration, e.g., slats heated on four sides, and the material, e.g., timber could be considered to include timber-based products or thermally modified timber. Given the lack of precision in the statement "timber cladding", it is expected that a range of external fire spread hazards could result.

2.2.2 Generalised classifications of façade materials

In the closing remarks of CROSS report 1194, the reporter states that in their experience, there are often attempts by designers to generalise reaction-to-fire classifications of materials, e.g., 'timber is Class D'. This can be supported by technical literature, such as the "Technical Guideline for Europe" on "Fire Safety in Timber Buildings" [16], and the content of EU Commission Decision 2006/213/EC [17]. However, it is posited by the reporter that the reaction-to-fire classification is specific to a system and not a material, i.e., how the material is configured can have a substantial influence over the resulting classification. To some extent, ADB facilitates the idea of generalised classifications for timber through footnote (3) to Table 12.1.

2.2.3 CROSS Expert Panel Recommendations

In concluding the report, the CROSS expert panel makes the following recommendations:

- "*The government needs to consider this further and reflect upon the apparent fragility of a guidance system that includes generic recommendations based on research that is more than 60 years old, with little evidence of subsequent re-examination and verification.*"

- *"The government should confirm whether the test mentioned by the reporter was used as a basis for the minimum 9 mm timber cladding panel thickness. Also, it is essential to understand the factors considered for this decision."*

3 TIMBER CLADDING

This section describes the typical applications of timber cladding, the motivations for thermal modification and relevant fire safety regulation and guidance that affects the use of timber cladding on buildings in England.

3.1 Overview

Timber-clad facades are commonly used in North American and Scandinavian countries already, while there is an increasing interest in central Europe and UK in its application beyond low-rise residences in recent times [18]. Compared to typical cladding materials like masonry, timber is distinctly different because it is non-uniform, combustible, and moisture sensitive [19]. These differences necessitate a distinctive approach in the façade design – addressing the moisture-induced leakages while managing the non-uniformity and combustibility of the timber material.

Despite the design challenges, timber offers benefits that make it a material of choice for facades. Firstly, it is practical for being strong but lightweight and easy to work with, among other things. Secondly, its aesthetics provide a sense of connectivity with nature. Lastly, it is environmentally friendly with its renewability, recyclability, ease of disposal, as well as its raw tree material's CO_2 absorption capability [20].

Timber cladding comes in various types, differentiated primarily based on the type of wooden material, profile styles, and board arrangement. The wood can either be softwood, hardwood, or modified wood. The typical profiles can be tongue and groove, rectangular, feather edge, shiplap, or parallelogram. Meanwhile, the board can be arranged horizontally, vertically, or diagonally [20].

3.2 Motivations for use

Timber cladding has emerged as a prominent choice for exterior building surfaces and balconies, blending aesthetics with functionality. This section sets out some stated qualities that give rise to this prominence:

- **Aesthetic Appeal:** Timber cladding is said to be known for its visual appeal and ability to work with diverse architectural styles. The variety of timber species, from pine to cedar and oak, offers a range of textures, colours, and finishes, allowing architects and designers to create unique and visually appealing exteriors.
- **Sustainability and Environmental Benefits:** In the context of growing environmental concerns, timber cladding is said to offer benefits in terms of its carbon-sequestering properties. Sourced from renewable forests and possessing a lower carbon footprint compared to many other building materials, timber cladding is often promoted as a sustainable choice.
- **Versatility and Design Flexibility:** Timber cladding is said to be adaptable to various design requirements. It can be used in multiple forms, from traditional lap siding to modern panel systems, allowing for creative freedom in design. This versatility extends to its application on different building types, including residential,

commercial, and public structures. Also, attachments to buildings, such as balconies.

- **Durability and Maintenance:** While timber is a natural material, modern treatment techniques are said to have enhanced its durability and resistance to weather, pests, and decay. With proper maintenance, timber cladding can withstand the elements for decades, making it a practical choice for building exteriors and balconies.

3.3 Thermal modification

Thermally modified timber is adopted for outdoor applications like cladding, decking, siding, and landscaping, and for interior uses such as flooring, saunas, and cabinetry where stability and resistance to humidity are essential [21].

Thermal modification is a process designed to enhance the durability and stability of timber through the application of heat. This process, also known as heat treatment or thermal modification, fundamentally changes the physical and chemical properties of wood, making it more suitable for various applications, especially in environments where wood is exposed to harsh conditions [22].

3.3.1 Process

The process of thermal modification typically involves the following:

- **Heating:** The wood is heated in a controlled environment, typically in a kiln or a specialized chamber. The temperatures used in this process usually range from 160°C to 230°C.
- **Absence of Oxygen:** This heating is done in a low-oxygen environment to prevent the wood from burning. The reduced oxygen level can be achieved through a having a partial vacuum, injecting an inert gas like nitrogen, or injecting steam.
- **Duration:** The duration of the heat treatment varies depending on the desired properties and the type of wood. It can last from a few hours to a couple of days.

3.3.2 Changes in properties

The changes arising from the thermal modification process are set out below:

- **Chemical Changes:** The high temperatures break down hemicellulose (a type of carbohydrate in wood), reduce the amount of hygroscopic (moisture-absorbing) sugars, and cause chemical modifications in cellulose and lignin. These changes reduce the wood's ability to absorb moisture.
- **Physical Changes:** The wood becomes less prone to swelling and shrinkage because of its lower equilibrium moisture content. This leads to increased dimensional stability, which is crucial for applications like flooring or cladding where changes in moisture can cause warping or deformation.
- **Colour Alteration:** Thermal modification often darkens the wood, giving it a richer, more uniform colour. This colour change is consistent throughout the wood, not just on the surface.

- **Decreased Weight:** The process may result in a slight reduction in the wood's weight due to the loss of volatile compounds and moisture.

3.3.3 Benefits and limitations

The process of heat modifying timber is intended to induce improved durability performance, specifically:

- **Resistance to Decay:** The reduced moisture content and altered chemical composition make the wood less attractive to fungi and insects, leading to enhanced decay resistance.
- **Longevity:** Thermally modified wood tends to have a longer lifespan compared to untreated wood when used in exterior applications.

However, the heat modifying process has some trade-offs, such as:

- **Brittleness:** The process can make the wood more brittle, which may require careful handling during installation.
- **Cost:** Thermal modification is a more expensive process compared to standard treatments, which can increase the cost of the finished product.
- **Strength Reduction**: Some mechanical properties like strength and toughness may be slightly reduced.

3.4 Fire safety legislation, guidance & directives applicable to timber cladding

This section discusses the regulatory framework within which timber cladding can be adopted. It starts with a brief description of the Regulations and subsequently goes on to describe under what conditions Approved Document B supports the use of timber cladding. It concludes with deemed to satisfy directives that may be used to specify timber cladding without recourse to reaction-to-fire testing.

3.4.1 The Building Regulations

The fire safety hazards associated with timber cladding can be considered to fall within the remit of B3 – Internal fire spread (structure) and B4 – external fire spread [23]. In the case of the former, timber cladding can provide a means by which compartmentation is circumvented, leading to a larger fire within the building of origin. This might be through fire spread over or within the cladding system. From an external fire spread perspective, the timber cladding can facilitate fire spread to and over the walls and, owing to the increased area of burning, influence the prospect of fire spread from one building to another.

3.4.2 Approved Document B guidance

The guidance in Approved Document B [11], [12] concerning internal fire spread (structure) does not include any specific provisions to mitigate circumvention of compartmentation due to fire spread over the cladding system but does include provisions for concealed fire spread. Guidance relevant to the combustibility of cladding systems or specified attachments, such as balconies, is provided under the guise of external fire spread. However, much of this guidance has been taken or evolved from previous editions of ADB, where (in the supplier's view) the stated intent of Regulation B4 was in addressing the prospect of fire spread from one building to another, not fire spread on the building of origin. Since the introduction of the in-effect ban on combustible materials [24] in the external wall zone, two situations should be distinguished which would affect the use of timber cladding to external walls or relevant attachments. These are "*relevant buildings*" and other "*common building situations*".

3.4.2.1 Relevant buildings

A relevant building is as defined in Regulation 7(4) of the Building Regulations 2010 as amended, with it stated that:

"(a) A "relevant building" means a building with a storey (not including roof-top plant areas or any storey consisting exclusively of plant rooms) at least 18 metres above ground level and which— (i) contains one or more dwellings; (ii) contains an institution; or (iii) contains a room for residential purposes; and (b) "above ground level" in relation to a storey means above ground level when measured from the lowest ground level adjoining the outside of a building to the top of the floor surface of the storey."

For such cases, Regulation 7(2) states that:

"building work shall be carried out so that materials which become part of an external wall, or specified attachment, of a relevant building are of European Classification A2-s1, d0 or A1 (classified in accordance with the reaction to fire classification)"

Whilst exemptions apply to the statement in Regulation 7(2), timber cladding either on a building or balcony would not be permitted for relevant buildings.

3.4.2.2 Other common building situations covered by ADB

For buildings not falling within the scope of Regulation 7(2), the route to compliance adopting the guidance of ADB advocates either that recommendations are followed relating to (i) external surface, (ii) materials and products and (iii) cavities and cavity barriers, or that large scale testing be undertaken (using data from BS 8414-1/2 [25], [26] and the performance criteria in BR 135 [27]). Separate guidance is provided for balconies.

Considering external surfaces and balconies, Table 1 presents an overview of situations in which timber cladding (in either a fire-retardant treated form or not) could conceivably be used without large-scale testing. This table presents a traffic lighting format whereby: red indicates timber cladding would not meet the noted classification, amber suggests timber cladding could be used, but would likely require a fire-retardant treatment to meet the classification and green notes that timber cladding would be permitted. In some cases, i.e., where a Euroclass Class C-s3, d2 or better external surface is advocated by ADB, timber cladding would be possible through note (3) to ADB Table 12.1, where it is stated that "*Timber cladding at least 9 mm thick is also acceptable*".

In principle, the external surface limitations given in Table 1 could be overcome by adopting the alternative compliance pathway involving assessment against the performance criteria in BR 135, using test data from BS 8414-1/2.

Considering the guidance in ADB regarding materials and products, timber cladding is not an "insulation product, filler material (such as the core materials of metal composite panels, sandwich panels and window spandrel panels but not including gaskets, sealants and similar) etc. used in the construction of an external wall". Therefore, the combustibility characteristics of the cladding would be governed solely by the guidance for external surfaces.

Table 1. Overview of situations in which timber cladding to the external wall or specified attachment would be permissible based on ADB guidance

Building type	Building height	Boundary distance	Extent of external surface	External surfaces	Cladding to balconies / balcony construction
All residential purpose groups not defined as relevant buildings	> 11 m	Any	All	Class A2-s1, d0 or better	Class A1 or A2-s1, d0 where the storey height is ≥ 11 m Permissible subject to an imperforate soffit achieving REI 30 and formed of materials achieving class A2-s1, d0 or better.**
	≤ 11 m	Within 1 m	All	Class B-s3, d2 or better	No provision
	≤ 11 m	1 m or more	All	No provision	
Assembly and recreation	> 18 m	Within 1 m	All	Class B-s3, d2 or better	
		1 m or more	From ground level to 18 m	Class C-s3, d2 or better*	
			From 18 m in height and above	Class B-s3, d2 or better	
	≤ 18 m	Within 1 m	All	Class B-s3, d2 or better	
		1 m or more	Up to 10 m above ground level	Class C-s3, d2 or better*	
			Up to 10 m above a roof or any part of the building to which the public have access	Class C-s3, d2 or better*	
			From 10 m in height and above	No provision	

Building type	Building height	Boundary distance	Extent of external surface	External surfaces	Cladding to balconies / balcony construction
Any other building	> 18 m	Within 1 m	All	Class B-s3, d2 or better	
		1 m or more	From ground level to 18 m	Class C-s3, d2 or better*	
			From 18 m in height and above	Class B-s3, d2 or better	
	≤ 18 m	Within 1 m	All	Class B-s3, d2 or better	
		1 m or more	All	No provisions	
	Timber cladding would not be permissible				
	Timber cladding with a fire-retardant treatment could achieve the recommended classification				
	Timber cladding would be permissible				
* Based on Note (3) to ADB Table 12.1, "Timber cladding at least 9mm thick is also acceptable".					
** Materials achieving class B-s1, d0 or worse extending beyond the boundary of a single compartment should include a band of material rated class A2-s1, d0 or better, a minimum of 300mm in width centred on that boundary line.					

3.4.3 EU Commission Decision 2006/213/EC

EU Commission Decision 2006/213/EC [17] covers "*establishing the classes of reaction-to-fire performance for certain construction products as regards wood flooring and solid wood panelling and cladding*" and notes that:

"*The reaction-to-fire performance of many construction products and/or materials, within the classification provided for in Decision 2000/147/EC, is well established and sufficiently well known to fire regulators in Member States that they do not require testing for this particular performance characteristic.*"

Table 2 in the Annex of EU Commission Decision 2006/213/EC gives generalised reaction-to-fire classifications for solid wood panelling and cladding, with an extract provided in Figure 3. Where falling within the field of application, the annex can be used in the place of product specific testing.

CLASSES OF REACTION TO FIRE PERFORMANCE FOR SOLID WOOD PANELLING AND CLADDING

Material (11)	Product detail (5)	Minimum mean density (6) (kg/m^3)	Minimum thicknesses, total/minimum (7) (mm)	End-use condition (4)	Class (3)
Panelling and cladding (1)	Wood pieces with or without tongue and groove and with or without profiled surface	390	9/6	Without air gap or with closed air gap behind	D - s2, d2
			12/8		D - s2, d0
Panelling and cladding (2)	Wood pieces with or without tongue and groove and with or without profiled surface	390	9/6	With open air gap ≤ 20 mm behind	D - s2, d0
			18/12	Without air gap or with open air gap behind	
Wood ribbon elements (8)	Wood pieces mounted on a support frame (9)	390	18	Surrounded by open air on all sides (10)	D - s2, d0

(1) Mounted mechanically on a wood batten support frame, with the gap closed or filled with a substrate of at least class A2 - s1, d0 with minimum density of 10 kg/m^3 or filled with a substrate of cellulose insulation material of at least class E and with or without a vapour barrier behind. The wood product shall be designed to be mounted without open joints.
(2) Mounted mechanically on a wood batten support frame, with or without an open air gap behind. The wood product shall be designed to be mounted without open joints.
(3) Class as provided for in Table 1 of the Annex to Commission Decision 2000/147/EC.
(4) An open air gap may include possibility for ventilation behind the product, while a closed air gap will exclude such ventilation. The substrate behind the air gap must be of at least class A2 - s1, d0 with a minimum density of 10 kg/m^3. Behind a closed air gap of maximum 20 mm and with vertical wood pieces, the substrate may be of at least class D - s2, d0.
(5) Joints include all types of joints, e.g. butt joints and tongue and groove joints.
(6) Conditioned according to EN 13238.
(7) As illustrated in Figure a below. Profiled area of the exposed side of the panel not more than 20 % of the plane area, or 25 % if measured at both exposed and unexposed side of the panel. For butt joints, the larger thickness applies at the joint interface.
(8) Rectangular wood pieces, with or without rounded corners, mounted horizontally or vertically on a support frame and surrounded by air on all sides, mainly used close to other building elements, both in interior and exterior applications.
(9) Maximum exposed area (all sides of rectangular wood pieces and wood support frame) not more than 110 % of the total plane area, see Figure b.
(10) Other building elements closer than 100 mm from the wood ribbon element (excluding its support frame) must be of at least class A2 - s1, d0, at distances 100 - 300 mm of at least class B - s1, d0 and at distances more than 300 mm of at least class D - s2, d0.
(11) Applies also to stairs.

Figure 3. Extract from EU Commission Decision 2006/213/EC

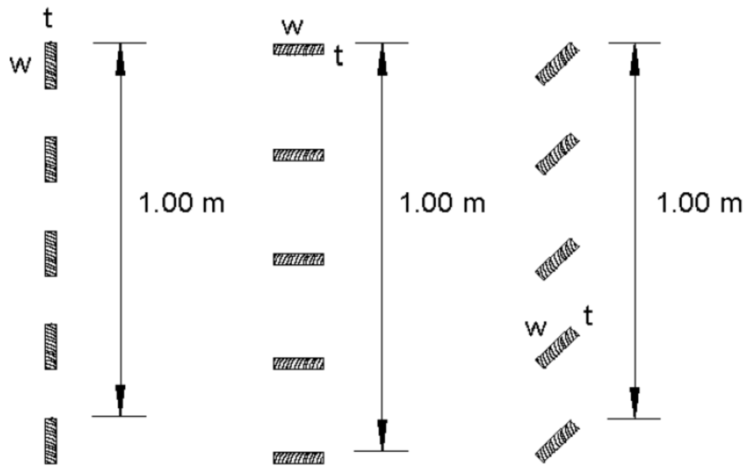
Figure 3 is of note firstly because it suggests flat timber cladding nominally 9 mm thick is considered Euroclass D. Within ADB, 9 mm thick timber can be used as a substitute for surfaces that would otherwise be expected to achieve Euroclass C-s3, d2 or better. This could be viewed as putting ADB in conflict / contradiction with the EU Commission Decision 2006/213/EC.

For slatted timber cladding, EU Commission Decision 2006/213/EC provides a category for "*wood ribbon elements*". These can be considered Euroclass D-s2, d0, subject to notes 9 and 10. The former of these states that:

"*Maximum exposed area (all sides of rectangular wood pieces and wood support frame) not more than 110 % of the total plane area*".

This effectively places a constraint on the spacing of slats in function of the timber slat size, with a supporting figure provided, as shown in Figure 4.

Maximum exposed area of wood ribbon element $2n(t + w) + a \leq 1{,}10$



n = number of wood pieces per meter
t = thickness of each wood piece, in meter
w = width of each wood piece, in meter
a = exposed area of wood support frame (if any), in m^2, per m^2 of wood ribbon element

Figure 4. Limitations on slat sizing and spacing per Figure b of EU Commission Decision 2006/213/EC

As an example, for 25 x 25 mm timber elements, 11 slats would be permitted per metre, spaced 72.5 mm apart. This configuration would be deemed to achieve Class D-s2, d0.

4 Research methodology

4.1 Research questions

The research questions intended to be resolved in this study are set out below and have been shaped by the discussion provided in Section 2:

- Does thermal modification of timber result in a greater external fire spread hazard than virgin timber, and how does this change with ageing / weathering?
- Does the slatted configuration of timber cladding, the like of which was observed at Samuel Garside House, result in a greater external fire spread hazard than more traditional flat / lapped timber cladding?
- To what extent can the external fire spread hazard associated with timber cladding be mitigated through the application of fire-retardant treatments?
- To what extent does small-intermediate scale standard testing correlate with the behaviour at a larger scale with more realistic heat fluxes?
- Is the guidance in ADB able to capture and differentiate any such hazards that might arise from material changes (e.g., thermal modification) or configurational changes (e.g., slats)?
- Can generalised guidance for timber cladding justifiably be included in ADB, such as Note 3 to Table 12.1 of Approved Document B?

4.2 Phase 1: Sample types

To address the research questions, it is identified that four different sample types are required. Namely:

- Virgin timber (PS-Virgin),
- Thermally modified timber that is new (PS-TM-New),
- Thermally modified timber that is aged (PS-TM-Aged), and
- Thermally modified timber that is treated with a fire retardant (PS-TM-FR).

To align with the timber species seen at Samuel Garside House, Pinus sylvestris (PS) was adopted throughout Phase 1.

4.3 Phase 2: Sample types

Phase 2 followed Phase 1 and involved the following samples:

- Virgin cedar cladding 9 mm thick (CD-Virgin-9mm)
- Virgin Scots pine cladding 19 mm thick (PS-Virgin-19mm)

4.4 Scales of investigation

There are limited studies available in the literature that provide insight into the identified research questions. As such, it was determined that experimental investigations provide a means to both characterise differences in fire behaviour at the scale of the material and the system. It was also identified that, in seeking to understand ADB's role in capturing and differentiating timber fire hazards, the adoption of classification tests referenced in ADB has utility. Therefore, a suite of tests across different scales have been undertaken with the goals set out below:

- BS EN 11925 [7] indicative Single-flame source test: the single-flame source test is a prerequisite of progressing to Euroclass classification in the grades of B to D. Except for taller buildings, ADB sets out guidance for external surfaces within this classification range. To benchmark the performance of the timber cladding systems of interest against ADB guidance, it is necessary to determine their likely Euroclass.
- Mass loss cone (BS ISO 5660-1:2015+A1:2019 [28]): The mass loss cone provides a means of directly comparing the burning rate and heat release rate of small timber samples under a constant heat flux. Thus, any differences in burning characteristics arising from thermal treatment, aging, etc., can be isolated from the impact of the configuration. Annex H of the standard provides a method for determining the critical heat flux for piloted ignition of a material. Again, this provides a means of contrasting the impact of treatment, aging, etc., on the ignition characteristics of the materials.
- BS EN 13823:2020 (Single Burning Item, SBI) test [9]: subsequent to completing and passing the single-flame source test, the single burning item test provides the fire growth index (FIGRA), smoke production rate and droplet production characteristics necessary to achieve a Euroclass in grades B to D. Within ADB, situations where external surfaces are recommended to achieve Euroclasses B to D, or no provision, are the most likely situations in which timber cladding would be adopted.
- BRE Intermediate scale test [29]: The test frame was designed by BRE Global's Fire Engineering Team for a separate fire research project (that took place between 2018 and 2020). The design was predicated on the Annex B in BS 8414 parts 1 and 2. Annex B considers an alternative fuel source capable of delivering a heat flux at 1.0 m above the crib within the range 45 to 75 kW/m^2. This heat flux is more representative of that expected from flames emanating from an opening and is substantially higher than that induced in the SBI. The intermediate scale rig is intended to provide similar insight on cladding fire spread performance to that of BS 8414-1/2, but at a reduced scale, with greater emphasis on the external surface versus a full cladding system build-up. The scale permits the measurement of additional parameters, such as heat release rate via oxygen depletion calorimetry, from an assembly of a scale that is representative of the end-use.

5 SAMPLE SOURCING AND CHARACTERISTICS

5.1 Phase 1: Aged thermally modified Pinus sylvestris (PS-TM-Aged)

The principal contractor responsible for the phased redevelopment at Barking Riverside allowed BRE Global to collect a 'batch' (80 lengths at approximately 1.5 m length) of the PS-TM-aged timber slats from Barking, in May 2020. At the time of collection, the principal contractor had already commenced on a programme of balcony and façade replacement at both Samuel Garside House and Ernest Websdale House (another block on the Riverside development at Harlequin Close, with identical balcony and façade design). The contractor could not confirm from which of the two buildings the timber slats had been removed.

It was estimated (by BRE) from Google Earth imagery that the slats had been on the buildings at the Riverside development (i.e., being weathered) for approximately seven years. The slats were stored for a month, under cover at BRE Global's Garston facility, before being moved to a conditioning room (adjacent to the testing laboratories) until they had reached constant mass, as defined by BS EN 13238:2010.

5.2 Phase 1: New thermally modified Pinus sylvestris (PS-TM-New)

The material purchased for these tests was sourced from a timber cladding specialist supplier, based in Birmingham, from Scandinavian forests certified under the Pan European Forestry Certification (PEFC) scheme. The thermal modification process was achieved by application of heat and steam to 212 °C to achieve a durability rating 'D'. BRE Report P113072-1003 [5] explains the thermal modification process. The material was delivered to BRE Global in November 2021, it was stored for a month, under cover at BRE Global's Garston facility, before moving it to a conditioning room (adjacent to the testing laboratories) until it reached constant mass, as defined by BS EN 13238:2010. This PS-TM-New was not exposed to weathering.

5.3 Phase 1: New virgin Pinus sylvestris (PS-Virgin)

In summer 2021, BRE Global approached sawmills in Scotland which owned their own managed forests. One sawmill was prepared to supply Pinus sylvestris to BRE Global to assist with the programme of research. The trees were cut down in October 2021 and the timber regularised in November 2021. BRE collected the timber in early November 2021 and stored it for a month.

5.4 Phase 1: New thermally modified Pinus sylvestris with fire retardant (PS-TM-FR)

The material purchased for these tests was sourced from the same timber cladding specialist supplier under the PEFC scheme to the same durability grade 'D'. Once the material had been imported to England, the supplier arranged for it to be chemically treated using chemical(s) approved by the Wood Protection Association (WPA). The resulting grade was described as external, Leach Resistant (LR) grade.

It should be noted that whilst the Treatment Certificate for the product states that the treatment was of such 'loading' necessary for the thermally modified material to achieve a B classification under BS EN 13501-1:2007, it is not known what end-use arrangement was envisaged (by the supplier) for the BS EN 13823:2010+A1:2014 (Single Burning Item) test.

5.5 Phase 1: Material densities

The average densities of the timber samples were recorded as follows. These reflect the sample densities after thermal treatment and application of fire retardant, as applicable:

- PS-Virgin 485 kg/m^3
- PS-TM-New 425 kg/m^3
- PS-TM-Aged 444 kg/m^3
- PS-TM-FR 503 kg/m^3

5.6 Phase 2

Phase 2 of the project adopted:

- 9 mm thick Cedar tongue and groove cladding: CD-Virgin-9mm
- 19 mm thick Pinus sylvestris tongue and groove cladding: PS-Virgin-19mm

At the time of writing, OFR are awaiting density and moisture contents for the Phase 2 samples.

6 Reaction to small flame and cone calorimeter scale experiments – Phase 1

6.1 BS EN 11925 indicative Single-flame source test

This test format is generally adopted as part of the route to obtaining a Euroclass in accordance with EN 13501-1. The method specifies a test for determining the ignitability of products by direct small-flame impingement using vertically oriented test specimens.

The method is designed to assess ignitability and this is addressed by measuring the spread of a small flame up the vertical surface of a specimen following application of a small (match-sized) flame to either the surface or edge of a specimen. The determination of the production of flaming droplets depends on whether the filter paper placed beneath the specimen ignites.

A full test to BS EN ISO 11925-2:2020 requires eight test specimens per exposure condition to be tested, up to 16 samples in total. Under this programme, one run was conducted comprising one surface exposure and one edge exposure to flame (i.e., two tests). Both tests were conducted at an exposure period of 30 s. A summary of the results is shown in Table 2.

Table 2. Summary of results from BS EN 11925 indicative single-flame source test

	PS-Virgin	PS-TM-New	PS-TM-Aged	PS-TM-FR
Flame spread ≤ 150 mm within 60 s	Yes	Yes	Yes	Yes
Ignition of filter paper	No	No	No	No
Threshold achieved	Class B-E	Class B-E	Class B-E	Class B-E

Figure 5 shows the samples after the small flame test.

Figure 5. Samples following small flame test, from left to right. PS-TM-Aged, PS-Virgin, PS-TM-New and PS-TM-FR

Whilst the test produces no quantitative outcomes, a review of Figure 5 suggests that there were varying extents of flame spread, with PS-TM-Aged showing the most and PS-Virgin the least.

6.2 Mass loss cone (BS ISO 5660-1:2015+A1:2019)

Samples approximately 92 mm × 99 mm were placed in aluminium foil 'boats,' as described in BS ISO 5660-1:2015+A1:2019 and exposed to an incident heat flux of 35 kW/m².

Each sample type, i.e., Pinus sylvestris virgin (PS-Virgin), new thermally modified (PS-TM-New) and aged thermally modified (PS-TM-Aged), was tested three times. Cone calorimeter tests were not completed for the FR treated samples (PS-TM-FR). This is because the FR treatment expanded, coming into contact with the cone spark igniter, with BRE stating insufficient samples were available to conduct further trials.

A summary of mean values for each trio of samples is given in Table 3.

Table 3. Summary of parameters for the three sample typologies tested in accordance with BS ISO 5660-1:2015+A1:2019

Parameter	Unit	PS-Virgin	PS-TM-New	PS-TM-Aged
Specimen thickness	mm	43	43	42
Specimen initial mass	g	191.4	159.7	175.0
Time to ignition	s	43	35.3	35.7
Total heat release	MJ/m²	97.4	106	111.2
Peak heat release rate	kW/m²	141.2	151.3	148.5

Figure 6 plots the relationship between time and three metrics: heat release rate, heat of combustion and mass loss rate. These are plotted in 60 s increments relative to ignition and reflect the transient phase of the burning of wood as the char develops and the mass loss rate tends towards a steady value. This was observed to take ca. 6 min from ignition.

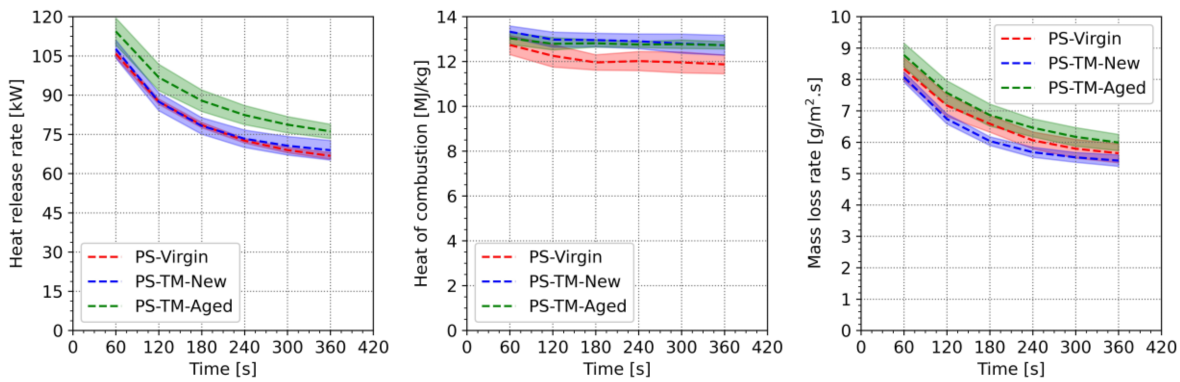


Figure 6. Heat release rate, heat of combustion and mass loss rate at 35 kW/m², for virgin, thermally modified (TM) and thermally modified plus aged Pinus sylvestris

6.3 Critical heat flux for ignition - BS ISO 5660-1:2015+A1:2019 (Annex H)

Eleven samples were prepared in advance of the indicative testing for each non-fire-retardant treated state, i.e., PS-Virgin, PS-TM-New and PS-TM-Aged. A high heat flux was selected (for the first run) which was known (by experience) to ignite the surface of the sample and give rise to sustained flaming. The process was repeated with heat flux reduced (in 5 kW/m^2 increments) to the point where no ignition and no sustained flaming was observed. Thereafter, the heat fluxes were reduced to finer 1 kW/m^2 increments to determine the critical heat flux for ignition and sustained flaming within 15 min of exposure.

Table 4 summarises the time to ignition in function of the incident heat flux. Where multiple tests are undertaken, these are separated by "/" in the table. One of the timber samples, PS-Virgin exhibited a cross-over, whereby the lowest heat flux at which ignition occurred was lower than the highest heat flux at which no ignition occurred. It was therefore necessary to conduct triplicate runs at each heat flux to determine an average time to ignition.

Table 4. Time to ignition for samples under different heat flux exposure in the cone

Heat flux [kW/m^2]	Cone heater temperature [°C]	Time to ignition [s], 'NI' indicates no ignition. '–' indicates not tested at this exposure heat flux		
		PS-Virgin	**PS-TM-New**	**PS-TM-Aged**
20	446	398	188	121
19	437	-	-	-
18	427	NI/648/862	631	-
17	418	432/NI/NI	NI	-
16	409	NI	-	-
15	399	NI	NI	860
14	390	-	-	NI
13	380	-	-	-
12	370	-	-	-
11	360	-	-	-
10	350	-	-	NI

Applying the Annex H procedure of BS ISO 5660-1:2015+A1:2019, the effective critical heat flux for ignition is as given below:

- PS-Virgin – 17.7 kW/m^2
- PS-TM-New – 17.5 kW/m^2
- PS-TM-Aged – 14.5 kW/m^2

7 SINGLE BURNING ITEM TESTING – PHASE 1

7.1 The SBI test

The BS EN 13823:2020, Single Burning Item (SBI) is a method of test for determining the reaction-to-fire behaviour of building products (excluding floorings) when exposed to the thermal attack by a single burning item (a sand-box burner supplied with propane). The specimen is mounted on a trolley that is positioned in a frame beneath an exhaust system. The reaction of the specimen to the burner is monitored instrumentally and visually. Heat and smoke release rates are measured instrumentally, and physical characteristics are assessed by observation.

7.2 Construction

Each sample was fixed into the test rig to closely resemble the end-use arrangement at Samuel Garside House. The 'slats' of the façade were ventilated (to the front, sides and rear). There were 68 mm gaps between the faces of adjacent slats i.e., slats were installed at 110 mm centres (note each slat was nominally 42 mm wide). Angle irons were 60 mm x 60 mm x 8 mm thick, with a localised cavity behind the angle iron 20 mm wide. The slats stood on the trolley tight against the head and base welded U-profiles. Both wings were secured from behind the U-profiles with L-profile clamps in the C-shaped profiles i.e., the SBI test equipment. See Figure 7 and Figure *8*.

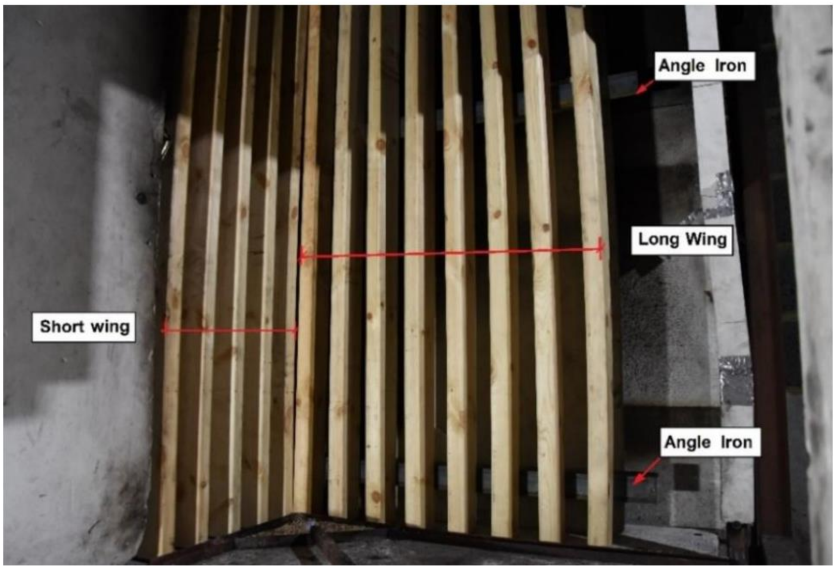


Figure 7. Close up of the wings and the angle irons, prior to the test of PS-Virgin sample

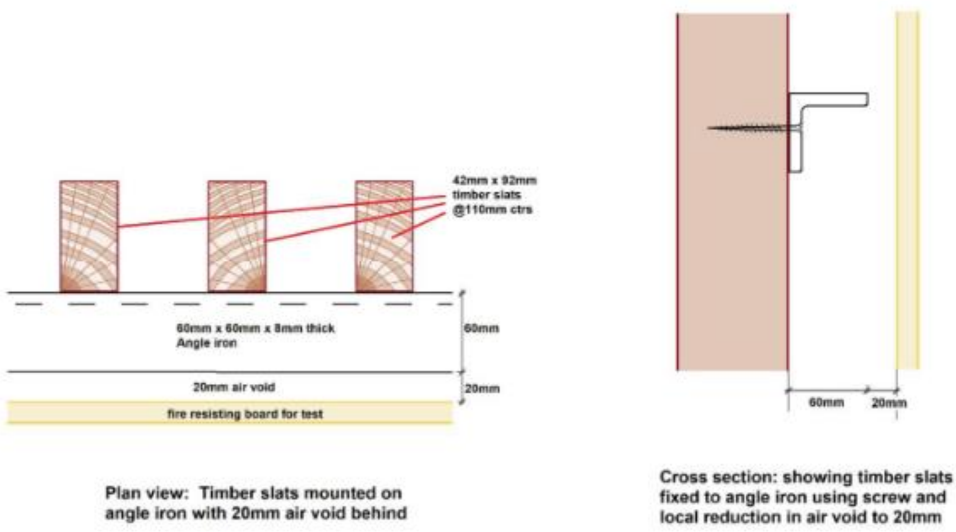


Figure 8. Plan view and cross section drawings showing mounting arrangements onto angle iron leaving nominal 80 mm (20 mm) air void (not to scale)

7.3 Heat release rate

Figure 9 compares the four sample types in terms of heat release rate with time. For comparison against the classification criteria, the FIGRA limits for Class B to D materials are indicated as black hatched lines. Where the HRR plot remains below a given line, it would achieve the applicable classification, i.e., all samples except that treated with a fire retardant exceed the FIGRA for Class D.

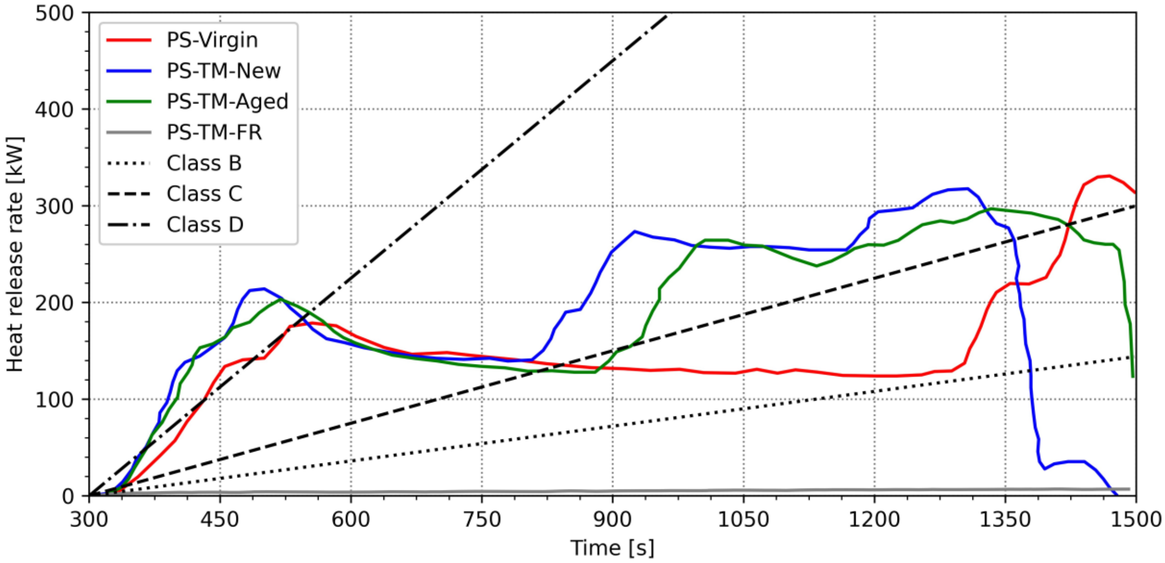


Figure 9. Heat release rate with time for four timber cladding states, alongside FIGRA thresholds for Class B, C and D materials

The PS-TM-FR sample had such a low HRR, it is barely distinguishable from the x-axis.

7.4 Summary of results

Table 5 summarises the SBI testing outcomes for the four samples, noting their final classification. It should be stated that no further differentiation is provided beyond Class E, i.e., anything performing worse than Class D is denoted Class E, meaning substantial differences in fire hazard can exist under the worst classification.

Table 5. Summary of SBI results

Parameter	Unit	PS-Virgin	PS-TM-New	PS-TM-Aged	PS-TM-FR
Fire growth rate - $FIGRA_{(0.2\ MJ)}$	W/s	-	-	-	37.1
Fire growth rate - $FIGRA_{(0.4\ MJ)}$	W/s	855	1283	1187	-
Total heat release – THR_{600s}	MJ	75	88	80	2.3
Smoke growth rate – SMOGRA	m^2/s^2	4.5	19.1	5.1	6.9
Total smoke production – TSP_{600s}	m^2	42.5	47.4	30.8	65.8
Flaming particles within 600s	-	Yes	No	No	No
Flaming > 10 s within 600s	-	Yes	-	-	-
Lateral flame spread reaches sample edge	-	No	No*	No*	No
FIGRA for Class B	W/s	120			
THR_{600s} for Class B	MJ	7.5			
FIGRA for Class C	W/s	250			
THR_{600s} for Class C	MJ	15			
FIGRA for Class D	W/s	750			
THR_{600s} for Class D	MJ	No limit			
Classification achieved	**-**	**E-s1, d2**	**E-s1, d0**	**E-s1, d0**	**B-s2, d0**
* Test terminated prematurely due to high temperatures in exhaust duct.					

8 Intermediate scale experiments – Phase 1

8.1 Experimental protocol

The intermediate-scale experimental protocol is as per that developed by the BRE for the purpose of delivering the then MHCLG contract CCZZ17A36. The background to and detailed description of the protocol is given in ref. [29] and is not repeated in detail here.

The experimental rig was constructed from a hot-rolled steel frame made up of rectangular hollow steel sections. Lateral mild steel angles were fixed to the frame, on to which the timber cladding was fixed (Figure 10).

The cladding was subject to fire exposure via a crib, consisting of 40 sticks of 50 × 50 × 500 mm softwood, placed in contact with the centre of the experimental sample. Through calibration experiments, the crib was shown to induce an incident heat flux of between 45 to 75 kW/m^2 on a non-combustible reference sample, at a point 1 m above the crib (on the centreline).

Figure 10. Image of the experimental setup prior for PS-TM-FR

8.2 Measurements

Thermocouples were provided at various locations within the intermediate-scale sample. The heat release rate (HRR) from the combination of the cladding sample and the crib was monitored through oxygen consumption calorimetry, with the rig located below an extractor hood. The HRR is the focus of this report.

8.3 Sample HRR

The HRR with time for the four sample types is shown in Figure 11. All plots are offset such that 0 min corresponds with the time of ignition of the timber crib. The peak heat release rate of the crib in isolation is ca. 300 (± 20) kW. Any heat release above this threshold can be attributed to the sample.

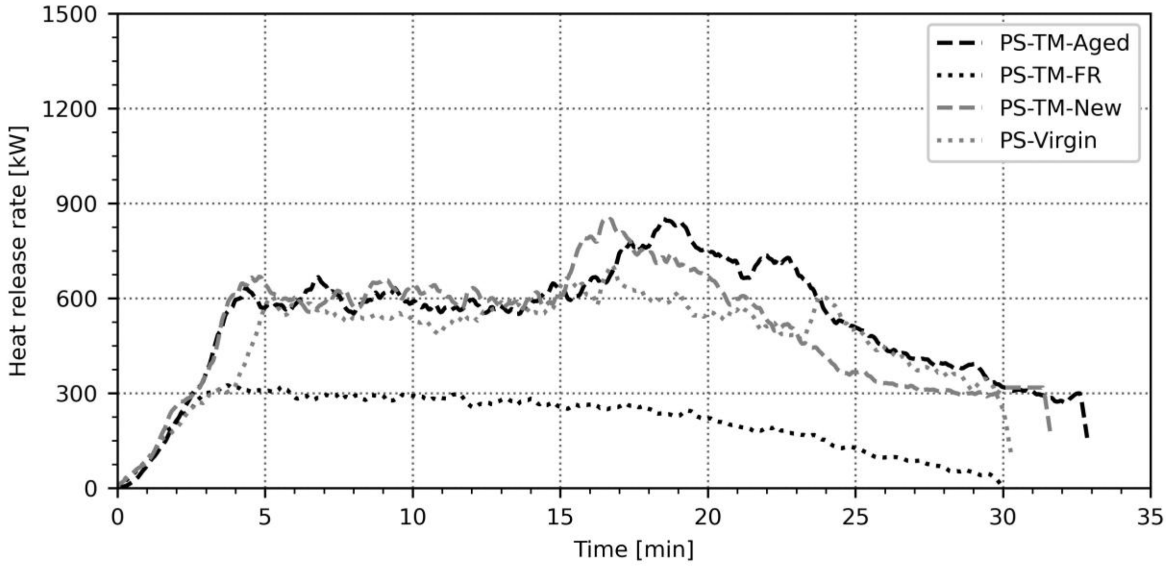


Figure 11. Heat release rate with time for experiments 1 to 4

Qualitatively, it is observed that no significant difference exists between PS-Virgin, PS-TM-New and PS-TM-Aged. PS-TM-FR results in substantially reduced HRR, i.e., by circa a factor of two considering the timeframe of 5 to 15 min from ignition. Nearly all the heat release rate for the PS-TM-FR sample can be attributed to the timber crib.

8.4 Results summary

A summary of the intermediate-scale results is given in Table 6. Sample images are given in Appendix A.

Table 6. Summary of intermediate-scale results

Parameter	PS-Virgin	PS-TM-New	PS-TM-Aged	PS-TM-FR
Peak HRR [kW]	792	975	893	382
Time to peak [s]	999	993	1143	336
Average HRR during first 8 min [kW] (including crib)	362	433	437	249

8.5 Benchmarking

In developing the intermediate-scale experimental protocol, the BRE undertook experiments on both 100% PE core aluminium composite material (ACM) and horizontally oriented cedar wood planked cladding [29]. In both cases, each sample was repeated resulting in four experiments for benchmarking purposes, as set out below:

- PE-ACM experiment 1 (PE_ACM_1): 4.0 mm thick ACM, consisting of 0.5 mm thick aluminium faces and a 3.0 mm thick PE core. Based on bomb calorimeter tests, the gross heat of combustion was determined as ca. 46 MJ/kg,
- PE-ACM experiment 2 (PE_ACM_2): as per PE ACM experiment 1,

- Cedar cladding experiment 1 (Cedar_1): Untreated cedar wood timber slats of tongue and groove type, 19 mm in thickness and of width 140 mm. The density of the cladding was 355 kg/m^3, with a moisture content of between 13 and 15%. Slats were horizontally oriented,
- Cedar cladding experiment 2 (Cedar_2): As per Cedar cladding experiment 1.

HRR with time for experiments 1 to 4 is contrasted against the PE-ACM and Cedar cladding samples noted above in Figure 12.

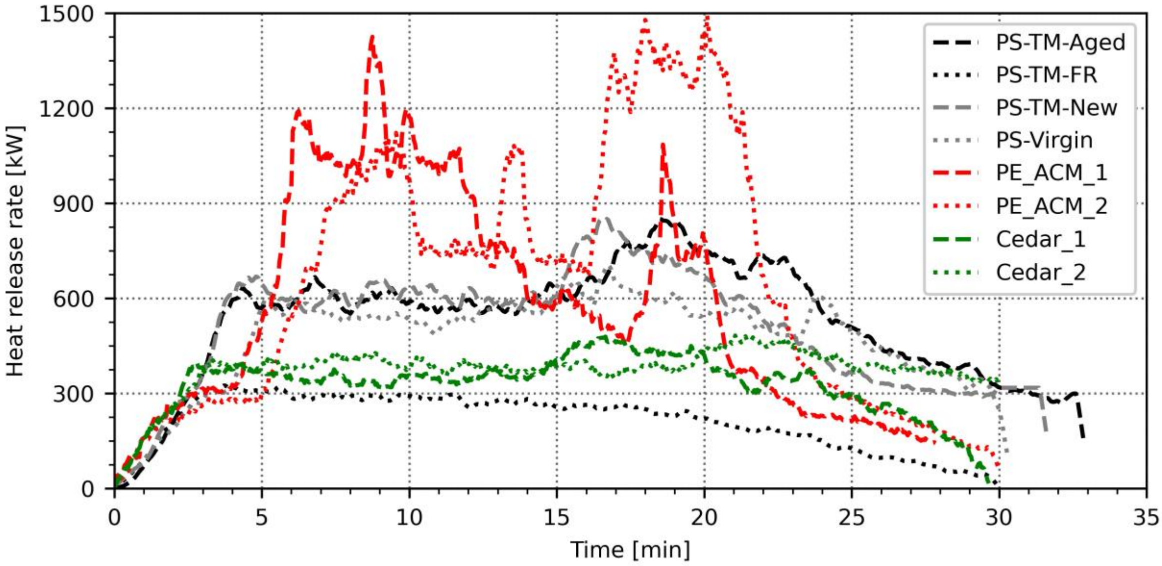


Figure 12. Heat release rate with time for experiments 1 to 4, benchmarked against PE-ACM and Cedar cladding

Comparing PS-Virgin, PS-TM-New, PS-TM-Aged and PS-TM-FR with PE-ACM and Cedar cases indicates that: (i) the initial growth rates of all experiments are comparable, with this similarity attributed to the consistent burning of the initial crib heat source, (ii) that non-fire-retardant treated timber cladding, in a vertical orientation with gaps in-between, results in a HRR of circa twice that of horizontally oriented Cedar cladding without gaps in-between, (iii) non-fire-retardant treated timber cladding, in a vertical orientation with gaps in-between, results in a HRR of circa half that of PE-ACM, and (iv) new fire-retardant treated timber cladding, in a vertical orientation with gaps in-between, results in the lowest HRR of all samples, i.e., below that of the Cedar reference experiments.

9 INTERMEDIATE SCALE EXPERIMENTS – PHASE 2

9.1 Protocol and configuration

The Phase 2 samples were subject to the intermediate scale testing procedure previously presented in Section 8. Two tests were completed for Phase 2, one for each of CD-Virgin-9mm and PS-Virgin-19mm. Images in advance of the tests are shown in Figure 13 and Figure 14, respectively.

Figure 13. Phase 2 CD-Virgin-9mm before test

The installation procedure for the two cladding samples 9 mm and 19 mm was the same. The timber tongue and groove slats were installed in a vertical position and mechanically fixed to an aluminium subframe, and horizontal strips positioned at approximately 400 mm spacing. The installation allowed for a ventilated cavity behind the sample. The cavity was left open on all edges of the sample.

Figure 14. Phase 2 PS-Virgin-19mm before test

9.2 Calibration of oxygen consumption calorimetry (OCC)

Before each fire test, a calibration procedure of the OCC was performed using a pool fire with heptane fuel. The estimated peak HRR was approximately 240±50 kW which aligned with that determined through OCC.

A separate calibration was undertaken using the crib adopted in the intermediate scale protocol. This delivered an average heat release rate of ca. 320 kW in the period 5-15 min from ignition.

9.3 Sample heat release rate

Figure 15 shows the Phase 2 sample heat release rate with time. Both samples follow a similar trend with a significant increase in HRR at the point the cladding is penetrated and begins to burn on the unexposed face. This occurs predictably earlier for the CD-Virgin-9mm sample (ca. 6.5 min from ignition) versus the PS-Virgin-19mm sample (ca. 12 min from ignition). At this point, flaming was visible from the top of the rig, emerging from the cavity (see Figure 16).

PS-Virgin-19mm produced a higher peak heat release rate of ca. 800 kW versus ca. 600 kW for the CD-Virgin-9mm sample.

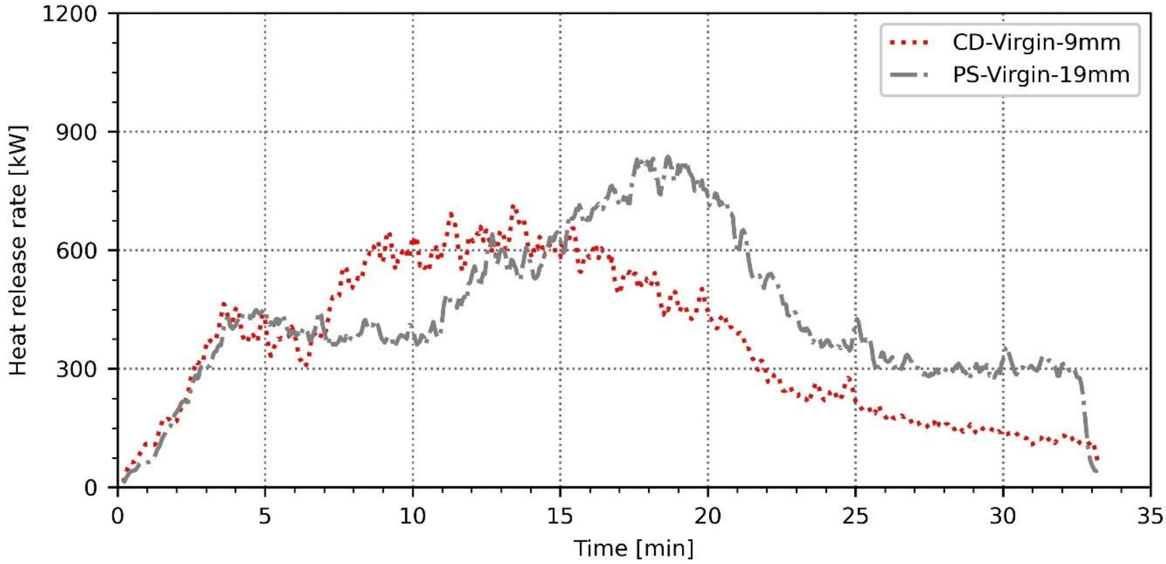


Figure 15. Phase 2 sample heat release rate with time

Figure 16. Fire penetration through samples (left) CD-Virgin-9mm after ca. 6.5 min, (right) PS-Virgin-19mm after ca. 12 min)

9.4 Comparison against Phase 1 – Implications of cladding configuration

The first comparison considers the impact of a flat homogeneous timber surface, i.e., PS-Virgin-19 mm from Phase 2 to that of a comparable unmodified wood species, but with gaps between thicker (42 x 92 mm) slats from Phase 1 (PS-Virgin). The latter is like that observed at Samuel Garside house, albeit in its virgin (un-thermally modified) state. The HRR with time for the two cases is shown in Figure 17.

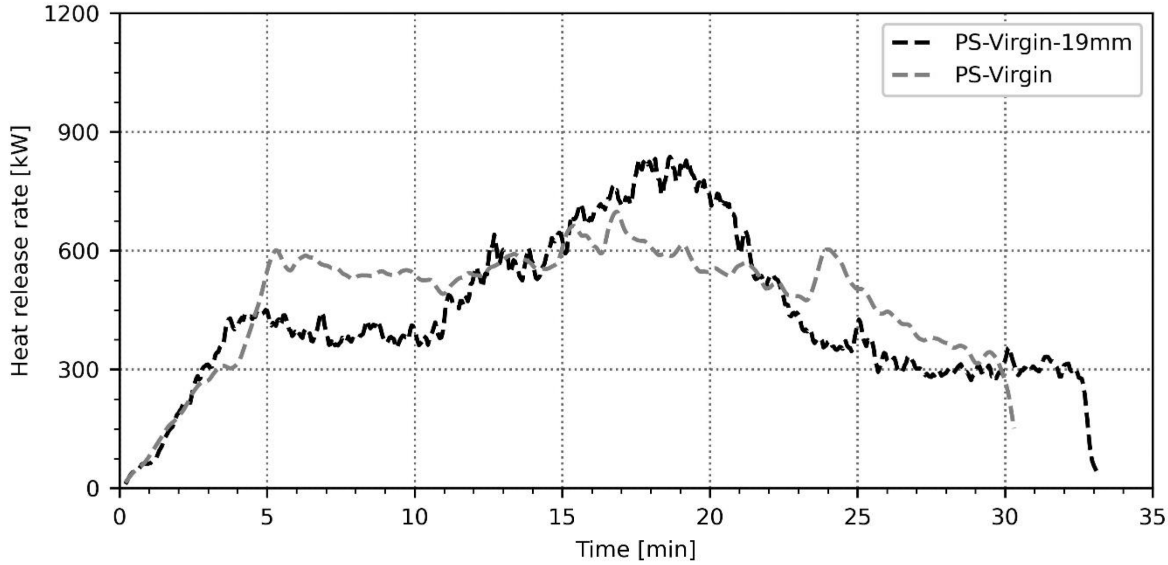


Figure 17. Comparison of HRR with time for PS-Virgin-19mm (no gaps) and PS-Virgin (with gaps)

It is seen that over the first 3-4 min the HRR is governed by the crib heat source as it rises to ca. 300 kW. From this point the timber cladding ignites. Where gaps are formed between timber elements (PS-Virgin) fire spread is initially greater, leading to a steady HRR approaching ca. 600 kW. In contrast, the flat surface (PS-Virgin-19mm) stabilises at ca. 450 kW. After ca. 10 min, the fire can break through the flat timber surface leading to an increase in fire spread extent and, consequently, HRR. When burning on both the exposed and unexposed faces, the HRR for the flat surface increased beyond that of the configuration at Samuel Garside House, reaching ca. 800 kW.

9.5 Comparison against BRE "Fire Performance of Cladding" research

The Technical Policy Division of the Ministry of Housing, Communities and Local Government (MHCLG) commissioned BRE Global to undertake a research project, titled "The fire performance of cladding materials"; contract reference: CCZZ 17A36. This research was concluded and reported in April 2020. Appendix G of that study presents supplementary experimental work, which included intermediate-scale experiments on 19 mm thick Cedar wood cladding (Figure 18). These results, denoted as CD-Virgin-19mm (1) and (2) are used as a basis of comparison against the results of Phase 2, providing some insight into the implications of wood species and the means of fixing the cladding; CD-Virgin-19mm (1) and

(2) were fixed with plank joints formed horizontally, whilst CD-Virgin-9mm and PS-Virgin-19mm adopted vertical joints.

Figure 18. 19 mm thick Cedar timber cladding (CD-Virgin-19mm) installed on the intermediate-scale rig

The HRR results of Phase 2 are compared to CD-Virgin-19mm (1) and (2) in Figure 19. This indicates that:

- In the early phases of the tests, i.e., up to 7 min from ignition, there is very little different in the HRR. This is largely because the test is dominated by the burning of the crib during this time but does suggest that the initial ignition and burning characteristics of the samples are comparable.
- That a change in behaviour is observed for the vertically jointed samples, i.e., CD-Virgin-9mm and PS-Virgin-19mm, which is attributed to burn through of the cladding and involvement on the cavity side. This is apparent where the HRR increases after ca. 7 min and 10 min, respectively.
- The stable burning and thus HRR of CD-Virgin-19mm (1) and (2) suggests no burn through, despite being of the same thickness as PS-Virgin-19mm. This would suggest that the orientation and fixing arrangement of the cladding is a significant factor in the burning behaviour.

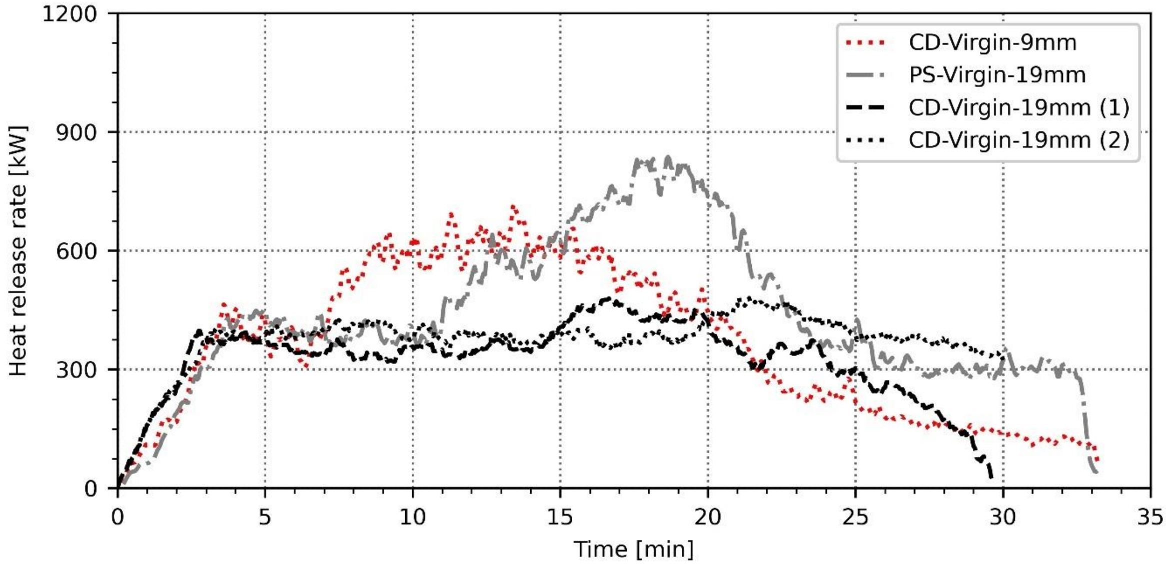


Figure 19. Comparison of HRR with time for Phase 2 samples (vertical joints) against CD-Virgin-19mm (1) and (2) (horizontal joints)

9.6 Comparison of fire growth rates

Figure 20 shows the fire growth rate index (FIGRA) with time for all sample typologies discussed in Sections 9.4 and 9.5. This is shown after 5 min so as to exclude the initial growth phase of the timber crib heat source. The FIGRA is simply the gradient of the tangent of the HRR curve relative to the zero-zero point of the axes.

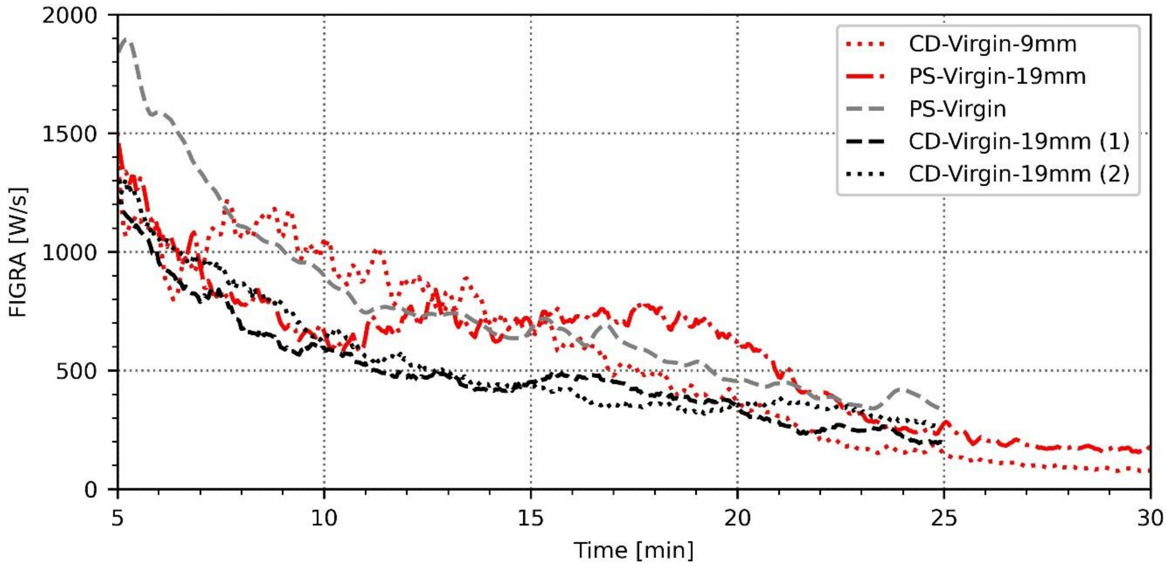


Figure 20. FIGRA beyond 5 min from ignition

In terms of ranking / performance, it is seen that:

- Virgin Scots pine with gaps between (PS-Virgin), i.e., as per the Samuel Garside House configuration, results in the highest FIGRA once ignited.
- All flat timber configurations, regardless of species or thickness, have broadly the same initial FIGRA after ignition.
- The 9 mm flat Cedar cladding (CD-Virgin-9mm) sees an increase in FIGRA beyond thicker samples after ca. 7 min due to burn-through and involvement on the unexposed face.
- A comparable burn-through behaviour is seen for PS-Virgin-19mm after ca. 10 min, with the FIGRA also observed to increase when burning occurred on the cavity side.
- CD-Virgin-19mm (1) and (2) see a gradual reduction in FIGRA with time after the sample's initial ignition.

10 Discussion of Phase 1 results

The discussion of results of the testing presented in Sections 6, 7 and 8 is provided at two scales. Namely that of the material, informed by testing in the cone calorimeter and small flame test, and that of the system, informed by testing in the SBI or BRE intermediate-scale rig.

10.1 Material characteristics

At the material scale, the ignition and burning / heat release rate characteristics are discussed in the sub-sections that follow.

10.1.1 Ignition

Ignition characteristics have been considered based on small flame testing and the Annex H procedure of BS ISO 5660-1:2015+A1:2019.

10.1.1.1 Small flame

Section 6.1 presents the results for the small flame test. The small flame test is a prerequisite of moving to classification via the SBI. It gives no numerical data and uses an extent of flame spread as a proxy for ignition. In this respect, all four timber states would have been permitted to progress to classification in the Euroclass bandings B to E. Of the non-fire-retardant treated samples, qualitatively, it can be said that virgin timber exhibited the lowest extent of flame spread, followed by the new thermally modified sample and then the aged thermally modified sample. However, differences in this extent of flame spread were nominal.

10.1.1.2 Cone calorimeter

Section 6.3 presents the results for the critical heat flux for piloted ignition for the non-fire-retardant treated samples.

The critical heat flux for piloted ignition of PS-Virgin, PS-TM-New and PS-TM-Aged were 17.7, 17.5 and 14.5 kW/m^2, respectively. This is generally greater than that quoted in Drysdale [30] for Red Cedar (13.3 kW/m^2), Radiata Pine (12.9 kW/m^2) and Douglas Fir (13 kW/m^2).

For the new thermally modified cladding material, the critical heat flux for piloted ignition appears to be unaffected by the process, with the virgin material having nominally the same value.

Aging of the sample appears to have reduced the critical heat flux for piloted ignition by ca. 3 kW/m^2. This could be for several reasons related to weathering and heat cycles, such as physical degradation, leading to fissures, or further changes in the timber composition. However, as aged virgin timber samples have not been studied, it is not possible to determine if thermally modified timber is unduly affected by aging relative to virgin timber. To assess this would require aged timber to be studied for reference purposes.

10.1.2 Burning rate / heat release rate

Mass loss rate and heat release rate when subject to an incident heat flux of 35 kW/m^2 has been reported in Section 6.2 for non-fire-retardant treated samples. This indicates comparable trends for both parameters. Like the critical heat flux for piloted ignition, there was no appreciable difference between the new virgin and thermally modified samples. The aged thermally modified timber produced a slightly higher heat release rate per unit area and, correspondingly, had a higher heat of combustion. It also produced the highest total heat release rate over the course of the 30 min test.

10.2 System characteristics

System characteristics have been considered at the scale of the SBI and BRE intermediate rig.

10.2.1 Single burning item testing

All non-fire-retardant treated samples exceeded the FIGRA for Class D and, therefore, were classified as Class E. In both tests involving thermally modified timber (aged and new), the test was terminated prematurely due to high temperatures in the calorimetry ductwork. This is attributed to an increase in heat release rate after ca. 800 s indicating a greater extent of spread. The same increase in heat release rate was observed for the virgin timber case, but developed much later, i.e., after ca. 1,300 s.

When the new thermally modified timber was treated with a fire retardant, the cladding FIGRA was below the threshold for Class B. The resulting total heat release rate was an order of magnitude below that of the non-fire-retardant treated samples.

10.2.2 Intermediate scale testing

At an intermediate-scale, results for all four timber typologies are shown in Section 8. From those results, it is observed that no significant difference exists between experiments 1 (aged thermally modified timber), 3 (new thermally modified timber) and 4 (virgin timber). In both thermally modified cases, there are indications of further spread, apparent through an increase in HRR after ca. 15 min. This increase was not observed for the virgin timber case. Experiment 2 (new thermally modified timber with fire retardant) results in substantially reduced HRR, i.e., by circa a factor of two considering the timeframe of 5 to 15 min from ignition.

In Section 8.4 comparison is made to other samples tested by the BRE as documented in ref [29]. The intention was twofold:

1. To place the timber cladding at Samuel Garside House into context by comparing fire growth characteristics to that of other cladding materials, i.e., flat cedar cladding and PE-ACM, and
2. To isolate the impact of the configuration of the cladding by comparing the Samuel Garside House slatted arrangement to that of a flat timber (Cedar) cladding.

Considering this, the benchmarking exercise demonstrates that:

- The initial spread rates of all materials, excluding that of the fire retardant treated thermally modified timber, are comparable in the first 2-3 min from ignition.
- PE-ACM accelerates rapidly to HRR ca. twice that of the timber cladding types studied herein (PS-Virgin, PS-TM-New and PS-TM-Aged).
- The slatted configuration at Samuel Garside House, whether thermally modified or not, aged or new, results in substantially higher sample HRR compared to that of a flat timber cedar cladding.
- The HRR of the PS-TM-FR sample was comparable to that of the flat cedar cladding, indicating that, in a new state, fire retardant treatments can result in slatted configurations that are of a comparable hazard to that of flat timber (cedar) surfaces.

10.3 Impact of scale

There is some consistency in the results of samples regardless of scale, i.e., high release rates in the cone generally corresponded with high heat release rates in both the SBI and intermediate-scale rig.

11 DISCUSSION OF PHASE 2 RESULTS

A separate discussion relating to the Phase 2 experiments is provided in this section, focussing on the specific motivations for the extension, i.e., the impact of cladding thickness (Section 11.1) and the configuration (Section 11.2) on the fire spread characteristics.

11.1 Impact of cladding thickness

Combing the results of Phase 2 and the previous "The fire performance of cladding materials" project undertaken by the BRE Global, the implications of cladding thickness are apparent both for the same species and across species of wood. The relevant samples are:

- CD-Virgin-9mm (Phase 2);
- PS-Virgin-19mm (Phase 2); and
- CD-Virgin-19mm (1) and (2) (The fire performance of cladding materials study).

Owing to some configurational differences between Phase 2 and the fire performance of cladding materials study, the more straightforward comparison is between CD-Virgin-9mm and PS-Virgin-19mm. This suggests that cladding thickness does have an impact on the fire spread characteristics of timber cladding. However, this is more a matter of the relative delay in time to burn through of the cladding, thus allowing it to burn on two sides simultaneously earlier when the cladding is thinner. For 9 mm cladding, this burn-through was observed after ca. 7 min and increased to ca. 10-11 min when the cladding was 19 mm thick.

It is posited that the configuration and orientation of the cladding were factors that facilitated burn-though, i.e., vertically oriented joints with tongue and groove connections. In particular, the tongue and groove connection points were substantially less thick than the main body of the timber planks. Burn-through of the timber cladding was not observed for the horizontally jointed cedar cases from the fire performance of cladding materials study.

This indicates that thickness in isolation is not a good indicator of fire performance of timber cladding materials and that the configuration is also important.

11.2 Impact of cladding configuration

Combining the results of Phase 1, Phase 2 and the fire performance of cladding materials study by the BRE allows the comparison of three configurations. Namely:

- Timber planks with gaps in-between, per Samuel Garside House, denoted PS-Virgin (Phase 1)
- Vertically jointed tongue and groove timber cladding, PS-Virgin-19mm (Phase 2)
- Horizontally jointed tongue and groove timber cladding, CD-Virgin-19mm (1) and (2) (The fire performance of cladding materials study)

These are shown side by side in Figure 21.

PS-Virgin | PS-Virgin-19mm | CD-Virgin-19mm (1) & (2)

Figure 21. Different configurations of timber cladding across phases 1, 2 and the fire performance of cladding materials study (by the BRE)

The horizontally jointed cedar (CD-Virgin-19mm) produced the lowest fire growth rate and peak heat release rate. The slatted configuration at Samuel Garside House (PS-Virgin) produced the highest growth rate, particularly in the early phases of the tests once the crib had ignited the cladding. The vertically joined pinus sylvestris (PS-Virgin-19mm) produced the highest peak heat release rate, which was realised after the burn-through of the cladding and once the fire had come to involve the 'cavity side'.

In seeking to mitigate the envelopment of a building clad with timber, it is apparent that some configurations are more likely to deliver higher fire growth rates that others, with discontinuous virgin timber cladding, like that observed at Samuel Garside House, presenting a greater hazard than that of flat continuous timber surfaces. Discussion of the Phase 1 results suggest that this hazard can be substantially mitigated through fire retardant coatings, subject to establishing their longevity. It is also observed that, whilst at least in the early phases of fire development, flat timber surfaces have lower fire growth rates, they can be susceptible to 'burn-through' and involvement on the 'cavity side' and external surface simultaneously. One would logically postulate that this is a function of the cladding thickness, with it evidenced here that thicker cladding performs better than thinner. However, it is also noted that substantially different behaviours were observed for cladding of the same thickness but jointed in different orientations. This suggests that thickness should not be the only determinant of fire performance, even for flat continuous timber surfaces, i.e. configuration matters.

12 CONCLUSIONS

This report has set out a study that has aimed to better understand the hazards associated with timber cladding through experimentation and testing across several scales. This study was motivated by the fire at Samuel Garside House and is intended to inform future technical policy, i.e., Approved Document B guidance, on the matter of timber cladding. Conclusions are structured to speak to the specific research questions identified, the potential implications for fire safety technical policy and what further work might be warranted.

12.1 Response to research questions

The study identified four core research questions. These are reproduced below along with relevant associated conclusions:

1. Does thermal modification of timber result in a greater external fire spread hazard than virgin timber, and how does this change with ageing / weathering?

- Contrasting PS-Virgin and PS-TM-New samples at small-scale, i.e., the mass loss cone, there is no appreciable different in the burning or ignition characteristics.
- When aging was introduced, i.e., PS-TM-Aged, the critical heat flux for piloted ignition reduced, indicating that it would typically be easier to ignite compared to PS-TM-New. Given aged virgin timber was not subject to investigation, it has not been possible to establish if thermally modified timber is unduly affected by ageing in terms of its burning rate or ignition characteristics.
- At the scale of the SBI and BRE intermediate rig, thermally modified timber (both new and aged) resulted in slightly increased peak heat release rates, which would indicate a marginally greater extent of fire spread. However, this heat release rate was substantially below that of PE-ACM.

2. Does the slatted configuration of timber cladding, the like of which was observed at Samuel Garside House, result in a greater external fire spread hazard than more traditional flat / lapped timber cladding?

- EU Commission Decision 2006/213/EC notes that flat timber cladding configurations would be considered, without further testing, to achieve Euroclass D in terms of the expected fire spread index (FIGRA). This is subject to field of application limits, such as minimum thicknesses and timber density. The slatted configurations without fire retardant treatment, be that thermally modified or virgin, achieved Euroclass E, suggesting a greater rate and extent of fire spread at the scale of the SBI.
- The benchmarking of the tests undertaken in the BRE intermediate scale rig against flat cedar cladding reference configurations identifies that the peak heat release rate of slatted configurations was substantially higher. This was the case whether using virgin or thermally modified timber. This increase in heat release rate is attributed to a greater extent of fire spread in the test.

- Slatted timber cladding results in a greater external fire spread hazard when compared to traditional flat / lapped timber cladding.

3. To what extent can the external fire spread hazard associated with timber cladding be mitigated through the application of fire-retardant treatments?

- The results presented in Section 7 at the scale of the SBI demonstrate that, with the application of a fire-retardant treatment, a configuration like that adopted at Samuel Garside House can achieve Euroclass B in terms of fire growth when new. This study has not evaluated how the FIGRA might be influenced by ageing and weathering. However, the current classification system does not require explicit consideration of the durability of products and systems, be that in terms of reaction-to-fire or fire resistance.
- At the intermediate rig scale, Section 8 demonstrates that thermally modified timber with a fire-retardant treatment result in a heat release rate much below that of an untreated equivalent. It is also less than a flat cedar cladding of 19 mm thickness. Again, the implications of ageing / weathering on the treatment were not investigated.
- The application of a fire-retardant treatment reduces the external fire spread hazard from new timber cladding. No statement can be made on the likely performance of aged / weathered timber cladding.

4. Is the guidance in ADB able to capture and differentiate any such hazards that might arise from material changes (e.g., thermal modification) or configurational changes (e.g., slats).

- Despite the relatively small heating source in the SBI test, the impact of the configuration is apparent in the classification, with all slatted cases (virgin or thermally modified) demonstrating high FIGRA values. Therefore, the SBI can seemingly differentiate the hazard of a slatted timber cladding surface versus that of a flat homogeneous timber cladding surface, despite the heat source not being of intensity reflective of façade fire exposure.
- Table 12.1 of ADB expresses external surface performance expectations in terms of Euroclasses. Except for EU Committee Decisions, a Euroclass would typically be expected to be evidenced for a particular application / system and not generalised to materials.
- Whilst Euroclass based guidance exists in Table 12.1, it is potentially undermined by three things: (i) footnote (3) and the imprecise definition of "timber cladding", (ii) the lack of any provision for external surfaces within certain purpose groups, heights or for portions of buildings, and (iii) the limitation of balcony guidance to residential cases. Items (i) to (iii) may lead to a situation where timber cladding that supports rapid fire spread can be present and, within some of these building situations, could undermine the fire safety strategy by, for example, allowing compartmentation to be easily circumvented.
- The guidance in ADB only partially captures the hazards from material and / or configurational changes to timber cladding.

5. Can generalised guidance for timber cladding justifiably be included in ADB, such as Note 3 to Table 12.1 of Approved Document B?

- Phase 2 of this study has shown that for flat continuous timber cladding surfaces, thickness is a variable that influences the fire spread characteristics by influencing the time taken for burn-through to occur and for the cladding to ignite on the 'cavity side'.
- For the same thickness of cladding, it is also shown that the configuration of the joints between cladding elements is a factor influencing if burn-through occurs and, thus, the fire spread characteristics.
- This suggests that thickness should not be the only determinant of fire performance for timber cladding, even for flat continuous timber surfaces. The configuration has a substantial influence and should be considered when products are specified that comply with the requirements of the Building Regulations.
- Generalised guidance for timber cladding in ADB is not adequately justified by the inclusion of Note 3 to Table 12.1.

12.2 Recommendations for fire safety technical policy

Based on this study, OFR would make the following recommendations:

- Footnote (3) to Table 12.1 should be removed, leaving the external surface classifications presented only in terms of Euroclasses. This would prevent thickness being used as the sole determinant of performance and would include the effect of configuration as the SBI requires the testing of more 'end-use' representative samples.
- The relationship between Table 12.1 and its role in potentially facilitating rapid circumvention of compartmentation in some situations should be considered. This may require some separate guidance in the context of Regulation B3(3), given the historical emphasis of B4(1), and the associated guidance, has been on space separation.
- Where rapid circumvention of compartmentation has the potential to undermine the fire safety strategy for a building, consideration should be given to the inclusion of a minimum reaction-to-fire classification in cases where there is currently no provision. A similar classification could be extended to elements forming balconies.
- Whilst, except for EU Committee decisions, general material reaction-to-fire classifications do not exist, it is observed that actors within the construction industry can assume they do. This can extend to building control bodies. To this end, the BSR should consider issuing a clarification within ADB that reaction-to-fire classes should not be generalised and reflect the behaviour of products used in the as tested configuration.

12.3 Potential areas of further investigation

Three areas have been identified for potential further investigation:

- It is highlighted that aged thermally modified timber supported fire spread more rapidly than new thermally modified timber. It is not known whether this is an artefact of the thermal modification process or the aging process. Therefore, consideration should be given to exploring the impact of aging on the reaction-to-fire characteristics of unmodified timber cladding.
- It has been established that fire retardants are effective in mitigating the burning rate of timber cladding systems, even under challenging configurations, such as those present at Samuel Garside House. However, this conclusion is drawn based upon fire retardant treated timber that is both new and has not been subject to an external environment or aging. If reliance were to be placed on such coatings to improve the reaction-to-fire performance of timber cladding, it would be prudent to undertake research with the aim of establishing its long-term efficacy.
- The study has not been able to explore other important variables that could impact the burning characteristics of timber cladding, including: the impact of species, moisture content and seasonal variations, other treatments such as varnishes or weatherproofing, nor the impact of different fire-retardant treatments.

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APPENDIX A: PHASE 1 – INTERMEDIATE SCALE IMAGES

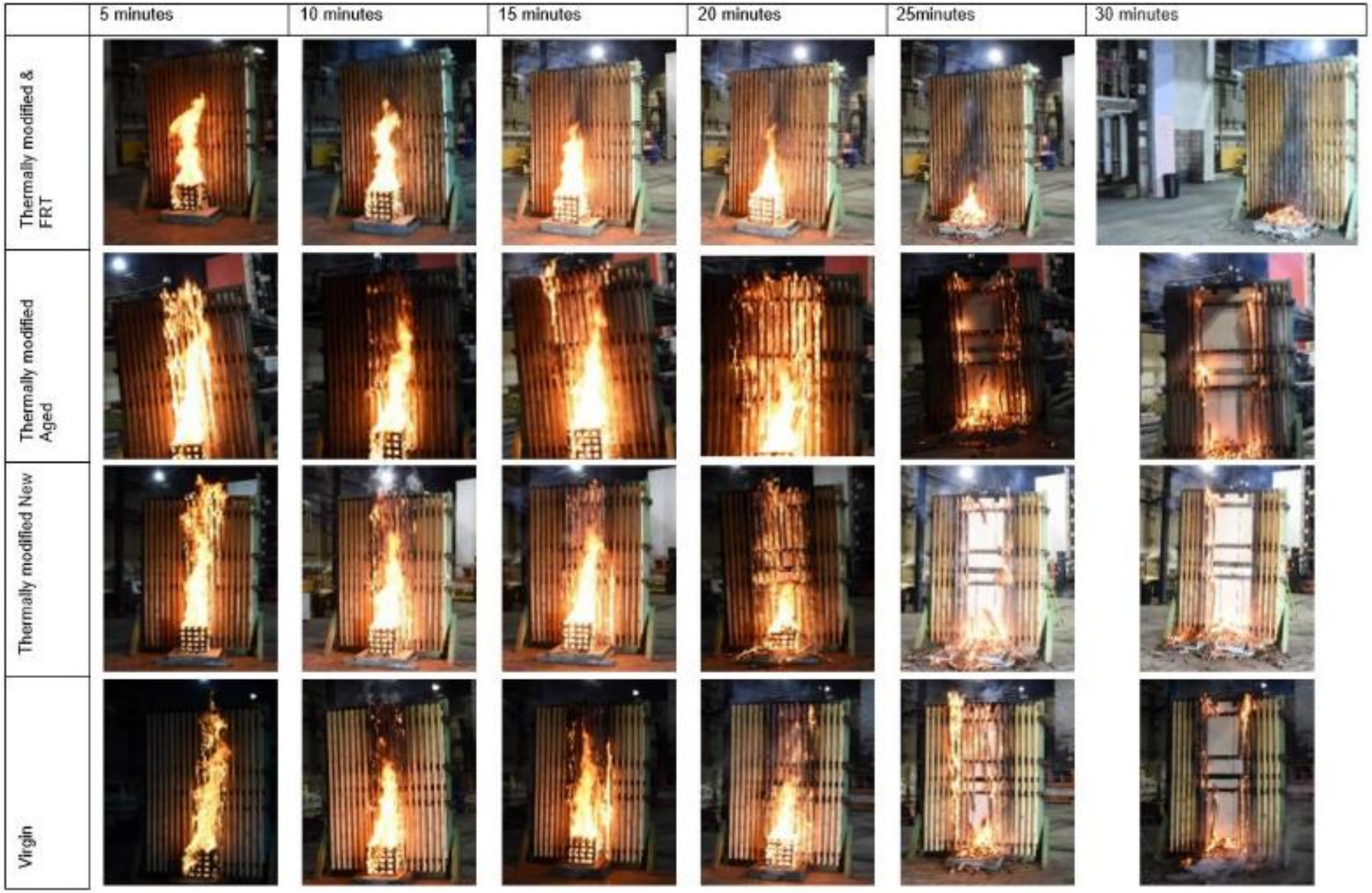

Figure 22. The four timber material states, every 5 min during testing, for visual comparison.

APPENDIX B: PHASE 2 – INTERMEDIATE SCALE IMAGES

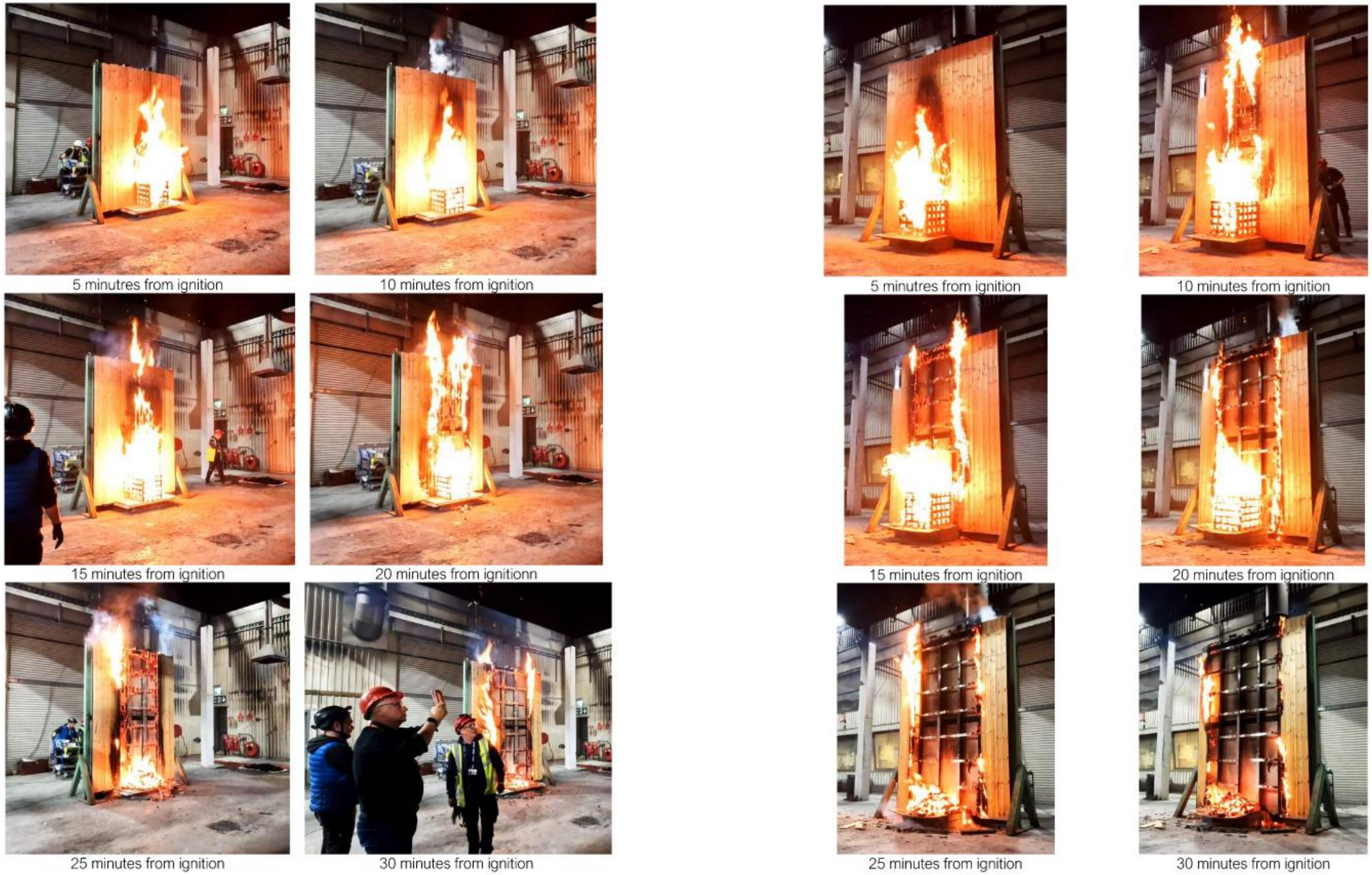

Figure 23. Visual comparison of fire spread for Phase 2: (left) CD-Virgin-9mm, and (right) PS-Virgin-19mm