Preventing firefighter & evacuee entanglement, electrocution, and obstruction risks in timber buildings on fire

A study for the Fire Service Research & Training Trust investigating and solving the problem of early loss of loadbearing capability of fixings holding M&E services to timber ceilings

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FOR AND ON BEHALF OF ASBP AND THE FIRE SERVICE RESEARCH & TRAINING TRUST

Versioning

Date	Changes made	By
2nd February 2026	Version 1.0 Issue – initial release DRAFT	Dr Jim Glockling
26th May 2026	Finalisation follow delivery and presentation to the FSRTT on 15th May 2026	Dr Jim Glockling

Dr James Glockling is a Principal Fire Protection Engineer within the Naval Engineering Team of BMT, consultant, and is the current Chair of BSI FSH/16 'Hazards to life from fire'. He has a degree in Chemical Engineering and PhD in nuclear engineering. Following post-doctorate study, he worked as, a lecturer in Chemical Engineering and Fire Safety Engineering, a forensic fire investigator, and ran research laboratories at the Loss Prevention Council (LPC), Building Research Establishment (BRE), and the Fire Protection Association (FPA) where he ran the UK insurance research scheme, RISCAuthority. Jim's principal areas of expertise are in suppression and detection technologies and complex risk mitigation scenarios. Jim is also visiting Professor at the University of Central Lancashire and continues to work promoting resilience with the commercial built environment and maritime sectors. (LinkedIn: www.linkedin.com/in/jim-glockling-15a9525)

Executive summary

This study aims to pre-emptively address a believed inevitable detrimental outcome of the necessary move to net-zero construction methods that may significantly raise the risk of firefighter and occupant harm from 'entanglement', 'electrocution' and 'crush' risks caused by detachment of ceiling mounted M&E structures in mass timber buildings. Such detachment of services also has the capability to render other fire protection systems (lighting, detection, smoke removal, alarm, suppression) inoperative, break down passive fire boundaries as large ventilation fall from their boundary interfaces, and even damage gas fuel lines.

Unresolved, it is believed that this is a problem waiting to happen and as such there is a duty to act upon this knowledge. In demonstrating and highlighting the problem, the project aims to educate those who can influence change to put in place the necessary training to reduce risk and inform on new standards required for the specification of anchoring equipment and methods in timber buildings to reduce the risk at point of source. Firefighting in buildings of combustible structure, particularly those of height, is associated with many new complex challenges for fire services. This study specifically addresses a potential terrible scenario of 'rapid' collapse of M&E systems in fire which might be impossible to risk assess on the spot.

In respect of FSR&TT objectives this project addresses:

a) Prevention of risks to attending firefighters, occupants and evacuees
b) Training of FRS personnel and standards makers by bringing this issue to front of centre
c) Ensuring firefighter effectiveness by highlighting a previously unknown risk, and in the longer term putting in place the standards and infrastructure that should lead to permanent change.

The study was prompted by a coincidental finding by Dale Kinnersley (FPA and RISCAuthority), whilst investigating how pipework attachment rules for fire sprinkler systems might have to be adapted in mass timber buildings.

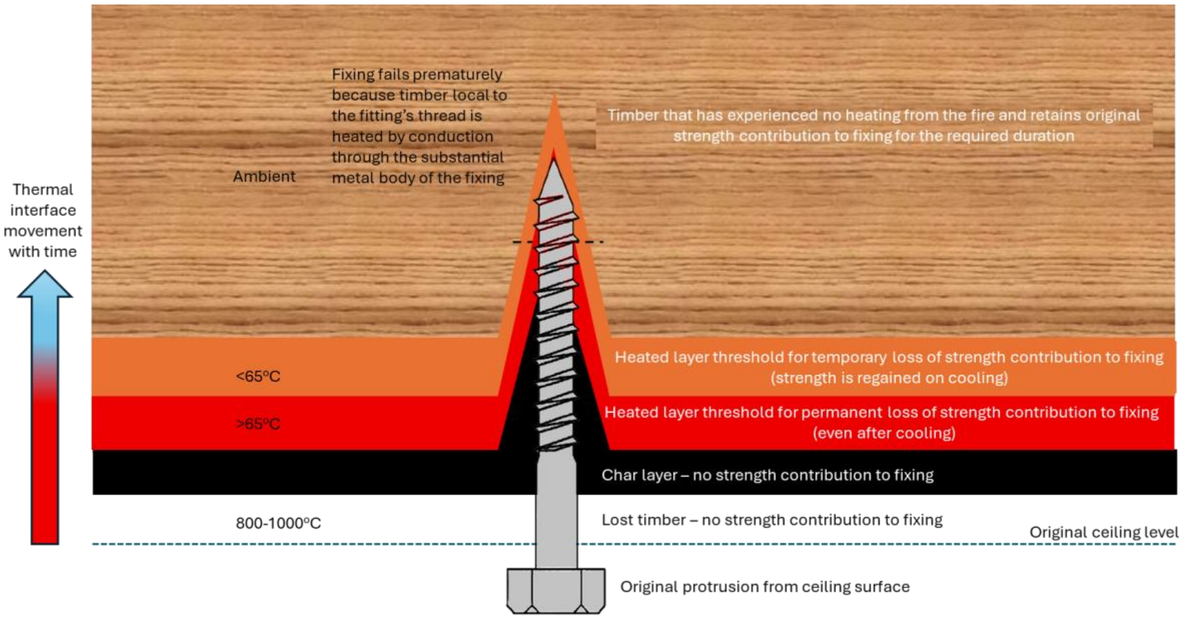
Outcomes:

This study investigated the contribution that each discreet fixing parameter made to the loss of load bearing capability under fire conditions including, embedment depth, diameter, material, thread pitch, loading, fire challenge, and contact surface area. Counterintuitively, whilst larger fixing had greater native load bearing capacity, when subject to fire, their weakening was faster and more dramatic than smaller fixings.

To explain the disproportionate loss of strength in fixings a 2-model approach is presented by way of explanation defined by the ability of the fixing to conduct heat along its length to impact the wood where the thread grips.

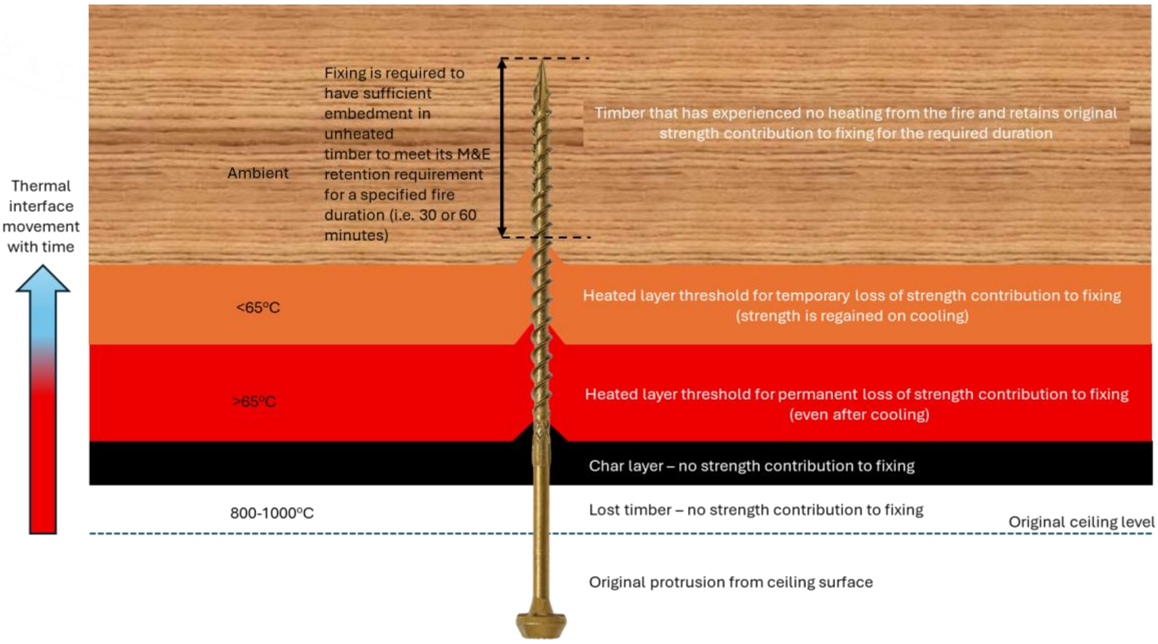
'Fat' Fixing model

In this model, the 'fatter' fixing is able to conduct heat deep into the wood raising its temperature between the threads so there is a loss of retention strength at the grip points. Wood weakens at surprisingly low temperatures. Whilst we recognise easily the loss of strength associated with charring, lower temperatures that impact moisture content exert great influence even before the wood undergoes pyrolysis.



'Skinny' Fixing model

In this model, the geometry of the fixing is less capable of conducting heat deep within the wood and the increased length ensures that the thread necessary for full retention remains in unheated wood for the duration that it must remain effective.



Whilst the ambient load bearing capacity of 'skinny' fixings is less that for their large diameter counterparts there are certain advantages in their use, specifically not requiring pilot-holes to be drilled, that might greatly offset the additional effort required to install greater numbers of fixings.

This study has shown that the assurance of fixing performance under fire conditions demands:

- Knowledge of the 'critical time' for which M&E is required to stay in place to support safe evacuation of occupants, and intervention by the fire service.
- An understanding of the heat uptake rate of the timber ceiling so that the interface depth of the unheated wood is known at the 'critical time'
- The selection of a fixing whose embedment of thread at depths greater than the unheated interface at the critical time assures full retention of the ambient load bearing capability of the fixing at the 'critical time'
- The selection of the fitting performs as a 'skinny' fixing – minimising conduction along its length
- The fitting is made of hardened steel and will not melt or break in fire.

Whilst other solutions to the problem are certainly plausible, such as the angling of fixings into the timber, in conversation with suppliers and installers this simple set of requirements is practical, can be supported by existing products, and on balance requires little greater effort than the measures already taken but warranting significant performance enhancement under fire.

The adoption of these simple measures will significantly improve firefighter safely in the conduct of their duties in the already complex environment of mass timber buildings.

For and on behalf of FSRTT and ASBP great thanks are extended to:

KLH®	For supply of CLT to this project
MIDFIX building better solutions	For the supply of fixings and technical support to this project
RISCAuthority	For financial support to the project

Contents

1 Background

1.1 Net-zero and fire safety

Natural materials (organic, renewable, and often carbon-sequestering) have for many years been integrated into the construction of buildings for reasons of material availability, the improvement of green credentials, cost, speed of construction, and architectural embellishment. The requirement for their use in the wholesale replacement of majority principle components in the structure, insulation, and cladding of large commercial and residential buildings in pursuit of net-zero, is a much more recent phenomenon and building codes and standards, produced against a history of non-combustible material use, may currently be under-developed for supporting this change, and be insufficient for assuring safety of occupant and responders, or securing the necessary insurance and investment provisions.

The need for reduced carbon emissions is obvious and must be supported, and it is not the intention to repeat those reasons here. Suffice to say however that energy related CO_2 construction is reported to account for around 34% of global emissions according to the UN Global Status report[a] which includes both operational emissions (from heating, cooling, and powering building), and embodied emissions (from materials like cement, steel, and glass in construction).

This wholesale change to the use of combustible natural materials presents many potential protection challenges that need to be addressed as part of the switch to a net-zero future. A simple back-to-basics review might surmise these to be:

a. **Greater fuel availability**: In addition to the contents of the building, the fabric of the building may be able to participate in both the early, and later stages of fire[b].

b. **A greater risk of building collapse**: Where the structural elements of the building are combustible (in panel or post form), their consumption by fire could lead to collapse, greatly impaired fire service support, reduced safety and greatly increased damage[c].

c. **More rapid fire development**: Research has shown[c] that fires in timber lined enclosures have a greater rate of acceleration than enclosures with non-combustible surfaces.

d. **Greater flame projection from windows**: Research has shown[c] that flame projection from timber compartments through windows and other openings is greater and may promote spread to the façade and storeys above by direct flame application, and neighbouring buildings though higher radiative emissions.

e. **A need for a very fast and effective response to fire**: In addition to the need to respond to higher fire development rates, the need for fast intervention also stems from a need to prevent fire travelling into inaccessible spaces[d]. Many natural materials can burn in both flaming and smouldering form allowing fires to burrow deep within the material and into inaccessible voids, to emerge once again elsewhere as fire, possibly hours or even days later, to continue its destruction. IF fire is allowed to spread into inaccessible locations, the question of 'how' such a fire is then extinguished becomes very difficult to answer. Historical fires indicate resolution using a range of blunt approaches including the need for internal demolition of sometimes

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[a] GlobalABC, UNEP. 2023. *Global Status Report for Buildings and Construction 2023*. Nairobi: United Nations Environment Programme.

[b] BUCHANAN, Andrew H. and ABU, Anthony K. *Structural Design for Fire Safety*. 2nd ed. Chichester: Wiley, 2017. ISBN 978-1-119-34192-5.

[c] MCGRATTAN, Kevin, HOSTIKKA, Simo, FLOYD, Jason, et al. *Fire Safety Challenges of Tall Wood Buildings – Phase 2: CLT Compartment Fire Tests*. NIST Technical Note 1996. Gaithersburg, MD: National Institute

[d] KÖNIG, J. and WALLEIJ, L. *Timber Frame Assemblies Exposed to Standard and Parametric Fires*. SP Report 1999:50. Borås: Swedish National Testing and Research Institute (SP), 1999.

structural walls to access fire in voids[e], to complete demolition of the building after days of repeated fire outbreaks.

f. **A need to review which areas of the building need fire protection**: The location of spaces adjacent to substantial combustible voids and communicating service ducts might warrant greater levels of protection.
g. **A need to consider the sensitivity of many natural materials to water exposure**: Estimates on the quantities of water used for fighting fires in larger residential and commercial buildings by fire services vary greatly[e], and range from tens of thousands to hundreds of thousands of litres applied over periods of 30 minutes to some hours. Water exposure of natural materials can quickly lead to both aesthetic and structural damage incurring large remediation effort and should be minimised.
h. **A need to consider extent of damage and methods and cost of repair**: Where the structure of the building is provided by natural materials which may participate in, and be consumed by the fire, the type of damage incurred may be difficult and disproportionately costly to repair.
i. **A need to consider insurability**: against the background of the aforementioned new risks, un-ameliorated, insurers may be confronted with being asked to cover buildings that[f]:
    - Are formed largely of combustible materials
    - May not court the same level of intervention from the fire service
    - May suffer more extensive fire damage that is difficult to quantify the extents of
    - May spread fire to other buildings
    - May suffer greater levels of consequential damage
    - May be more costly to repair
i. A need to support Fire Service effectiveness: given the aforementioned challenges, it is unthinkable that, without specific measures being taken that ensure firefighter safety in this new situation, they will not be able to be as effective as they are in buildings of traditional non-combustible structure … yet their timely participation is essential as the only measure that may assure the ending of the fire event.

In recognition of these challenges the UK insurance industry, via RISCAuthority (the UK insurance industry research funding scheme) sponsored a programme of research focussed on the optimisation of fire sprinkler systems for use in the mass-timber environment. Fire sprinkler system design continuously evolves with changing construction and storage methods to ensure they stay relevant to the modern world. In mass timber buildings fire sprinklers can provide a response that addresses many of the key challenges presented, especially the support of fire service intervention.

Part of the fire sprinkler system design and installation rulesets[g] specifies the requirements for the attachment of sprinkler pipe to ceilings and this was investigated during the study. The result from that study have now been published[h] and form the starting point for this research as it revealed an

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[e] HOME OFFICE. *Fire and Rescue Incident Statistics: England*. London: Home Office, annual publication. Latest edition: 2023. ISBN 978-1-5286-4234-9.

[f] ALLIANCE FOR SUSTAINABLE BUILDING PRODUCTS (ASBP). *Mass Timber Insurance Playbook*. London: ASBP, 2021. ISBN 978-1-9164583-4-4.

[g] FIRE PROTECTION ASSOCIATION**.** *LPC Rules for Automatic Sprinkler Installations 2015: Incorporating BS EN 12845:2015+A1:2019 and associated Technical Bulletins.* Moreton-in-Marsh: Fire Protection Association, 2015 (regularly updated).

[h] KINNERSLEY, R., GLOCKLING, J. and HULL, T.R. Fire spread via fixings and interfaces in timber construction. *Fire Safety Journal*, 2023, 134, 103747. DOI: 10.1016/j.firesaf.2023.103747.

overlooked safety issue that, if unaddressed, would lead to a future foreseeable loss of firefighter's lives for reasons akin to those of the Shirley Towers fire event[i] (see later).

1.2 Previous research

Recent research conducted by Dale Kinnersley at the Fire Protection Association and now published formally in the Fire Safety Journal entitled '*Fire spread via fixings and interfaces in timber construction*' [Dale Kinnersley, Richard Hull, James L D Glockling, Stuart Campbell] investigated the fire performance of standard sprinkler pipe fixings when used under timber ceilings. An important operational function of fire sprinkler systems is that the fixings are capable of supporting the substantial weight of water pipe distribution arrays; can tolerate impulse forces when in operation; and do not detach during fire – all with appropriate safety factors. Whilst standards exist for the specification of fixing into concrete ceilings, none exist for timber ceilings.

The structural ability of wood to withstand fire is complex and impacted by:

- Loss of material
- Formation of a char which has no intrinsic strength but can insulate the underlaying wood to a degree
- Permanent loss of some strength if heated above a threshold temperature
- A temporary loss of strength if heated up to a certain temperature threshold that drives off moisture that can be recovered upon cooling

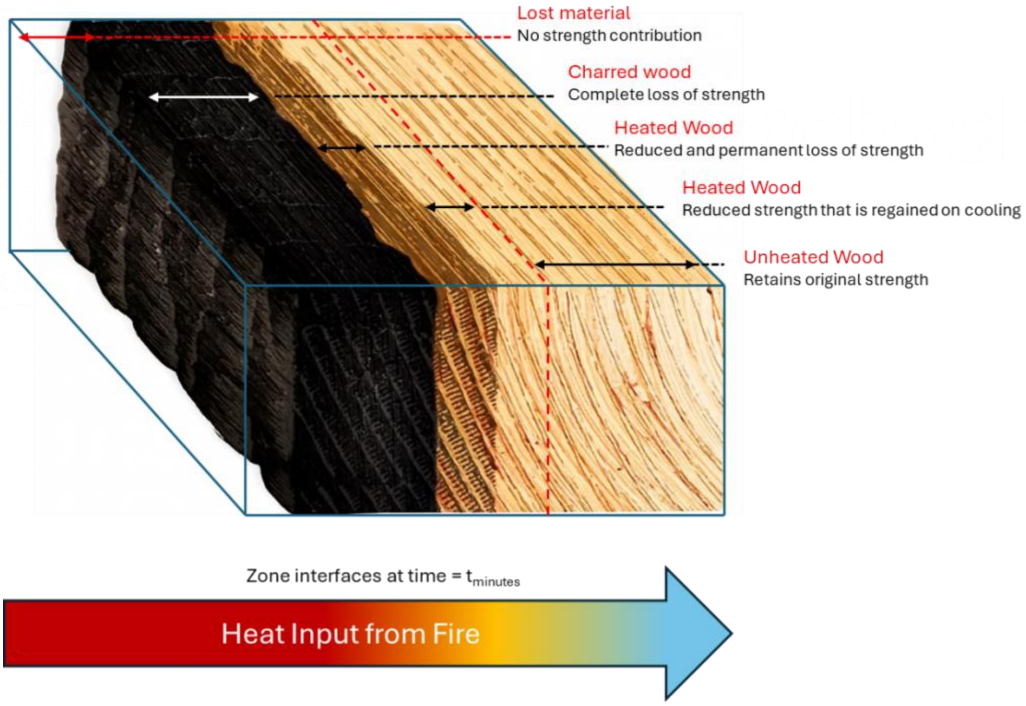

Figure 1 Mechanisms of strength loss in timber during fire

The study subjected a great number of common fixing types to a fire designed to mimic a developed room fire as might be expected in a mass timber building constructed of Cross Laminated Timber (CLT). The majority of tests were conduct unloaded and pull-out strength tests were conducted before fire, and after being subjected to fire exposures of 30 and 60 minutes.

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[i] HAMPSHIRE FIRE AND RESCUE SERVICE. *Fatal Fire Investigation Report: Firefighters Alan Bannon and James Shears, Shirley Towers, Southampton, 6 April 2010.* Hampshire Fire and Rescue Service, 2013.

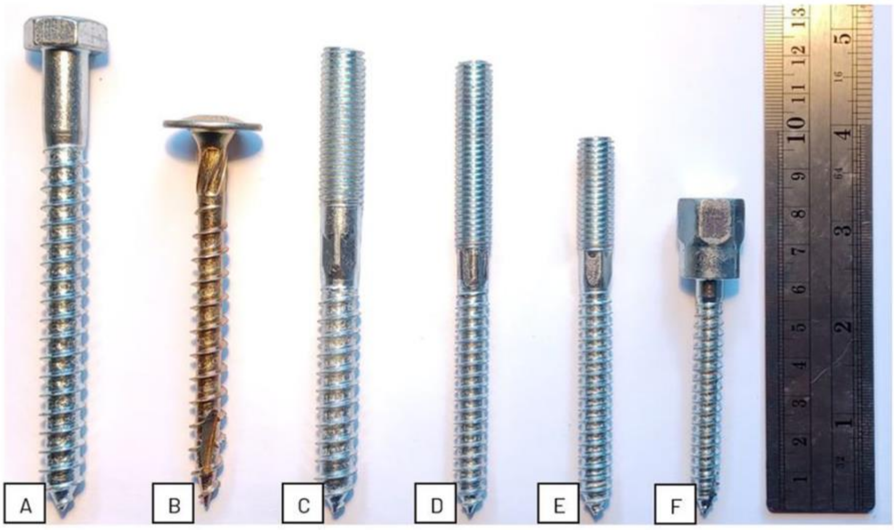


Figure 2 Tested screw fixing types [A] - M12 Hex Coach Screw [B] - M10 Flanged Structural Timber Screw [C] - M12 Stud Screw [D] & [E] - M10 Stud Screws [F] - M10 Rod Hangar

The results showed a marked loss of strength by the fixing before and after fire that was disproportionate to the amount of surface charring of the CLT in comparison to the fixings embedment depth in the timber. Whilst char formation as described in Figure 1 is a relatively slow process, large screw fixings are able to conduct the fire heat deep into the CLT to raise temperatures and weaken wood local to the fixing's screw threads. To this end, for large diameter fixings, such as those specified in many M&E applications only millimetres of heated wood and char around the threads must form to for complete loss of retention capacity to occur as shown in Figure 3.

Figure 3 Post test cutaway showing heating and charring of wood around the bolt threads

It is also interesting to note the greater amount of heating that has occurred around the larger M12 screw than the smaller M10 screw.

A summary of all tests run is given in Figure 4 showing that, in the unloaded condition, strength loss is significant and occurs on a timescale meaningful to evacuation and fire service intervention.

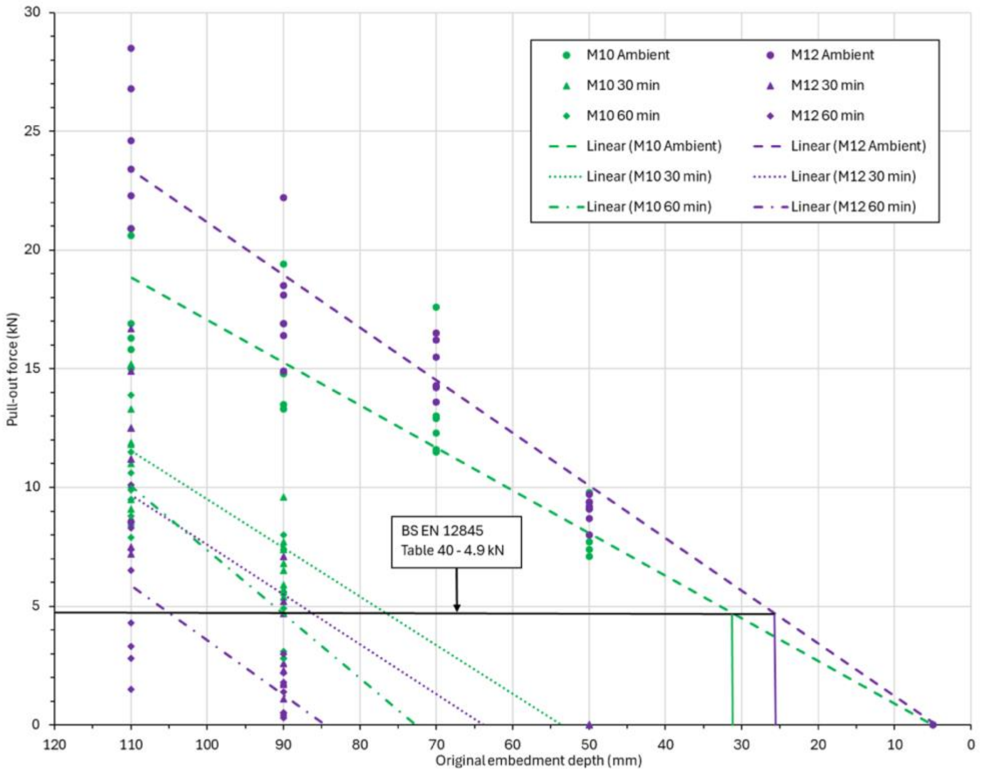


Figure 4 Strength reduction of all tests conducted in the unload condition before and after fire

It was identified late on in the programme that the true evaluation of performance needed to be made under loaded conditions because a post-fire hardening of the timber may occur due to cooling of the timber, cooling of the CLT glues, and timber moisture recovery.

The results of the research concluded:

- Fixings in wood are much weaker post-fire.
- There is a high risk that Mechanical and Electrical (M&E) services could fall during or after a fire.
- Char formation around the screw thread reduces fixing strength.
- Load capacity during fire appears to decrease with increasing bolt diameter.
- Changes to fixing choice and specification could greatly improve performance under fire conditions.
- Only fire testing under load can accurately describe the retention capability of fixings during a fire.

Whilst a functioning fire sprinkler system would ‘self-protect’ its own fixings from experiencing high fire temperatures, the risk of early detachment of heavy M&E systems in the unprotected situation is all too clear and could result in:

- Entanglement, crush, and electrocution risks to people
- Breakdown of fire compartmentation if sealed systems break on falling, such a ventilation ducts
- Damage to other safety systems on falling, such as smoke ventilation systems, detection and alarm system wiring, emergency lighting, and fire sprinkler system pipework.
- Damage to energy bearing systems such as gas pipes and electrical cabling
- Damage to water supplies that might be needed for firefighting purposes

1.3 Shirley Towers

The tragic fire at Shirley Towers in Southampton on 6 April 2010 led to the deaths of two firefighters, Alan Bannon and James Shears. The incident occurred in Flat 72 of the 15-storey residential block, which featured a complex ‘scissor section’ layout that made navigation difficult. The fire began when curtains ignited from contact with an uplighter lamp. As crews entered the flat, they encountered extreme heat (over 1,000°C), zero visibility, and a disorienting layout. The situation was worsened by falling electrical cables, which had melted from the heat and obstructed escape routes. These conditions contributed to the firefighters becoming trapped and ultimately succumbing to the intense heat.

Figure 5 Fallen cable at Shirley Towers

Following the incident, Hampshire Fire and Rescue Service launched a comprehensive investigation. The coroner’s inquest identified multiple contributing factors, including building design, cable management, and operational challenges. A ‘Rule 43’ letter was issued to recommend changes aimed at preventing future deaths. These included improved training for high-rise incidents, better understanding of complex building layouts, and national changes to fire safety regulations - especially regarding electrical cable containment. One major outcome was the push for non-combustible cable supports to prevent entanglement hazards during fires which was implemented in the revision of the IET Wiring Regulations (BS 7671) - specifically Regulation 521.10.202 – Cable Support in Fire Conditions in the 18th Edition, which came into force on 1 January 2019. It mandates that:

- Cables must be supported by fire-resistant fixings (e.g. metal clips or ties).
- Plastic-only fixings are no longer allowed as the sole support method.
- The rule applies to all wiring installations, not just escape routes.

This change directly addresses the hazard that contributed to the deaths of firefighters at Shirley Towers, where plastic trunking melted, causing cables to fall and entangle crews trying to escape.

In respect of fixing M&E to mass timber ceilings the problem is ‘the same but different’. In the case of Shirley Towers, a traditionally constructed building, the issue was one of fire-weak (plastic) fixings secured into a strong substrate (concrete). For timber ceilings, the fixings are very strong (steel) but the timber substrate weakens greatly under the action of fire. The causes are different, but the outcome is the same and sadly, the amendments to wiring regulations made following the Shirley Towers incident do nothing to protect against this new challenge – that will require further regulation change.

2 Project specification

This project seeks to put in place the research that will ultimately lead to methods and standards for the assurance of fixings performance during the critical periods of occupant evacuation and fire service search and rescue. The attachment of often heavy M&E services, including HVAC, pipework, and fire suppression systems, to ceilings is catered for in standards for traditional concrete floor slab structures (BS 8539), but not timber. Through this work it is hoped to pre-emptively prevent predicable harm to firefighters resulting from changing building methods – an area hitherto neglected in the enthusiasm for net-zero construction.

The major objectives of this study are:

1. To experimentally demonstrate and publicise the extent of the problem
    - Design and construction of a suitable test rig that may in future serve as the basis of a test standard for fixings approval if required.
    - Generation of a dataset that shows the extent of the problem.
    - Presentation of the issue through FRS, ASBP, FSRTT, HSE, BSI and all stakeholder networks
2. To engage with industry to find engineered solutions (fire resistant fixings into timber)
    - To work with the mass timber products supply industry to find products and methods that do not weaken so readily under the action of fire
    - To present the findings to British Standards in support of formalising the requirement
3. To educate and lobby building regulations to implement change
    - Public speaking
    - Open webinars
    - Articles in appropriate journals
    - Formal paper publication
    - Presentation to BRAC / HSE if required

This report forms the foundation work of the study and describes the outputs of Part 1 & 2 of the specification.

3 Technical design considerations

The ability of fixings to maintain strength is complex and influenced by many factors. An appropriately designed rig should be able to assess the impact of each of these as single variable changes:

- Fixing length (embedment depth)
- Fixing diameter (conduction into the timber)
- Fixing connection to metal that might act as heat sink or heat barrier to conduction (conduction into timber)
- Mass loading
- Pilot hole size
- Thread pitch
- Fire challenge size

To build upon the previous study and extend it to find solutions to the problem there was a need to address perceived shortcomings of the original study. These are identified below:

a) **Rig robustness and usability** – the rig was formed of temporary materials (such as Unistrut) appropriate for the purposes of prototyping but not for use in a possible future standards rig. As part of the redesign, as well as fire-hardening the structure, greater attention was given to improving usability, repeatability, and test sample turnaround times to reduce laboratory costs.

b) **Fire size** – Reviewers of the paper noted that fire temperatures and char rates were lower than had been experienced in full-scale fire testing suggesting that the environment experienced by the fixings was potentially less onerous than it should be. To this end the impacting gas fire size was increased.

c) **Loaded testing of fixings** – for the reasons previously discussed, all fixings must be tested in the loaded condition.

d) **Extension of sample suite** – to include fittings that might structurally survive fire better (hardened steel), which will conduct less heat (skinnier), and will have more of the thread embedded in timber that remains unchanged on timescales relevant to evacuation and response (longer).

4 Test facility, equipment, and instrumentation

4.1 Test rig

The test rig was designed to allow for the simultaneous testing of 3 independently loaded fixings during each test. A crude diagram of the rig is shown below with detailed frame schematics given Annex A.

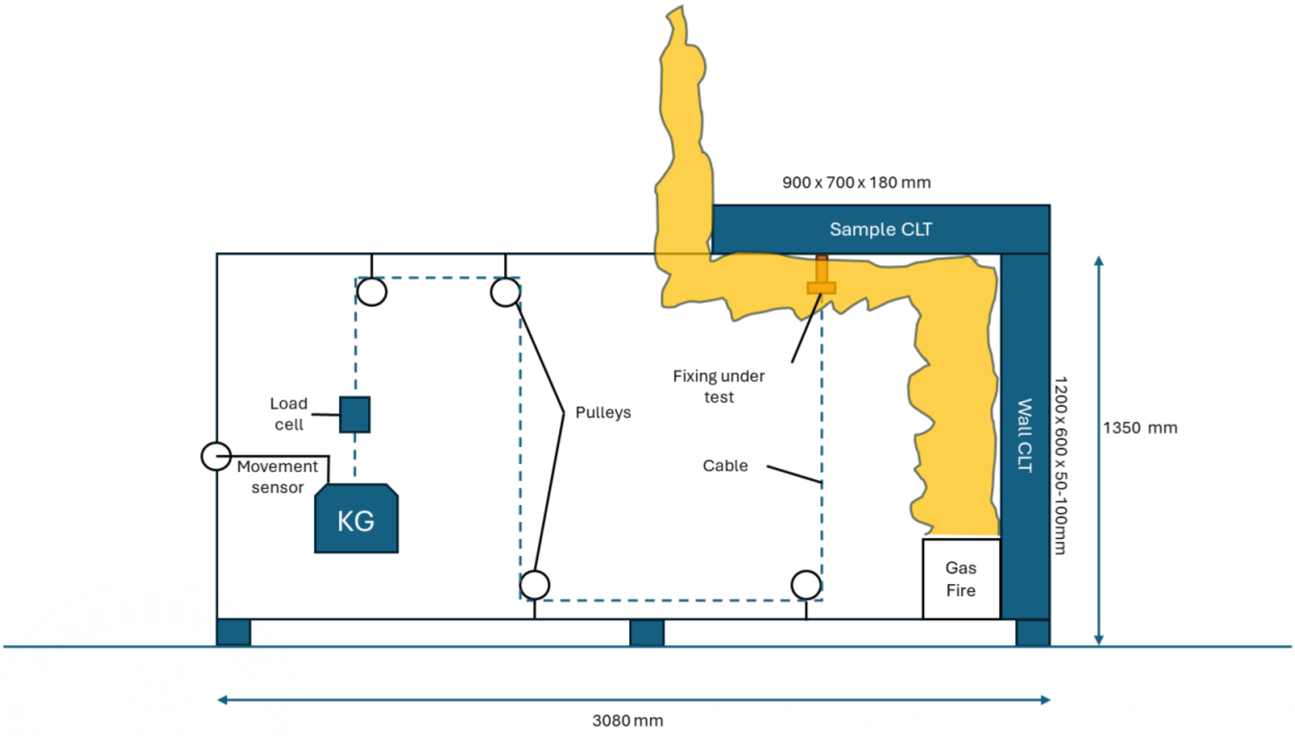


Figure 6 Schematic of test rig

4.2 Instrumentation

Instrumentation was installed to:

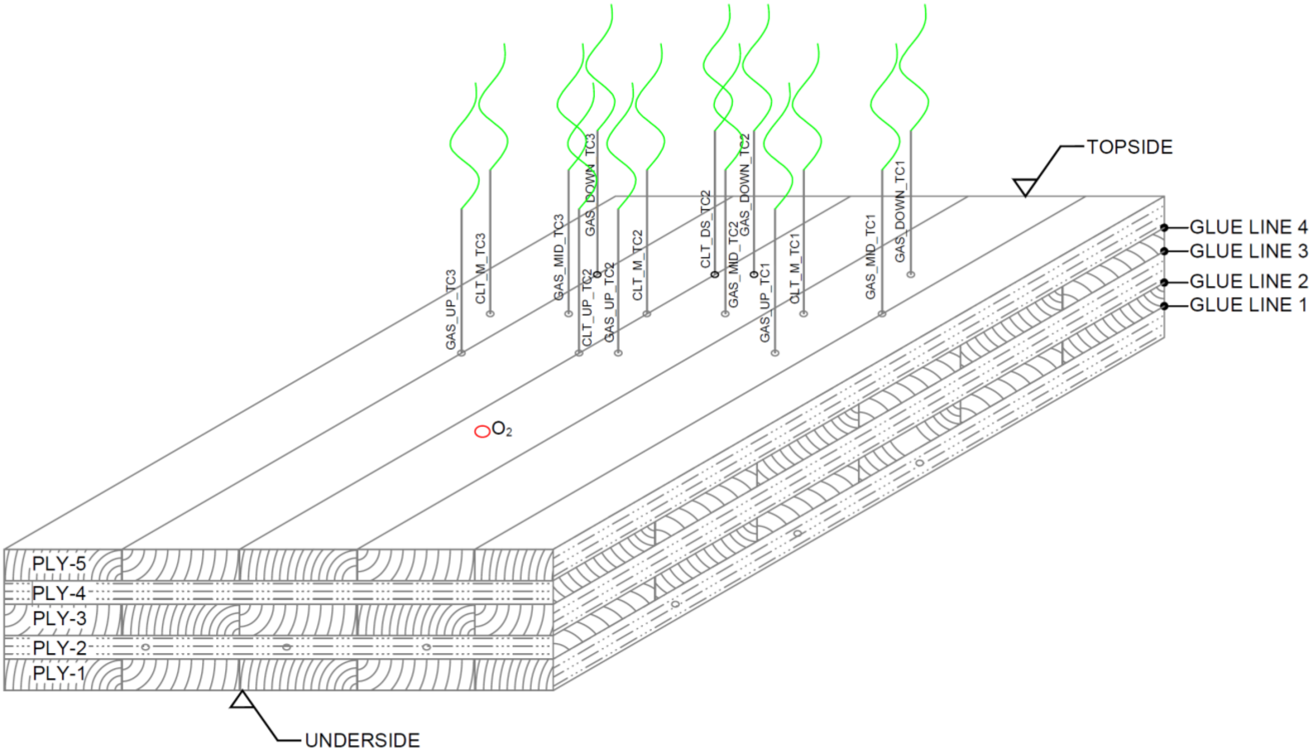
- Measure the challenge presented to the fixings
    - Flame temperature
    - Applied load
    - Heat flux measurement from wall and ceiling
- Confirm repeatability
    - Flame temperatures
    - Gas flowrate
    - CLT temperatures
    - Surface oxygen concentrations at CLT ceiling and wall samples
- Measure impact on fixing
    - Cable movement sensors
- Understand atmospheric conditions
    - Air temperature
    - Air humidity
- Understand timber condition
    - Moisture content

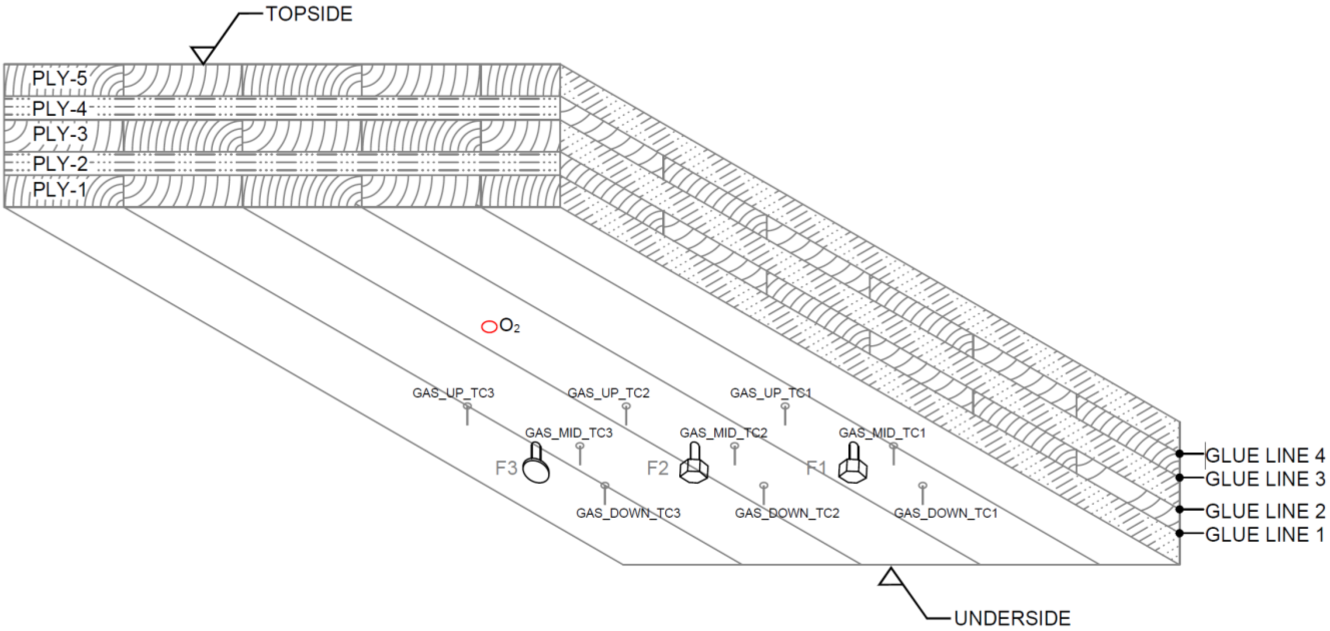
All data was collected by a high speed datalogger

Channel no.	Location	Label	Description
0	Laboratory	Lab_Hum	Laboratory Humidity
1	Laboratory	Lab_Hum_TC	Laboratory Temperature
2	Fire	Fire_TC	Fire temperature above burner
3	Below CLT	Gas_Mid_TC1	Gas temperature near Fixing 1
4	Below CLT	Gas_Mid_TC2	Gas temperature near Fixing 2
5	Below CLT	Gas_Mid_TC3	Gas temperature near Fixing 3
6	Below CLT	Gas_Up_TC1	Gas temperature upstream of Fixing 1
7	Below CLT	Gas_Up_TC2	Gas temperature upstream of Fixing 2
8	Below CLT	Gas_Up_TC3	Gas temperature upstream of Fixing 3
9	Below CLT	Gas_Down_TC1	Gas temperature downstream of Fixing 1
10	Below CLT	Gas_Down_TC2	Gas temperature downstream of Fixing 2
11	Below CLT	Gas_Down_TC3	Gas temperature downstream of Fixing 3
12	In ceiling CLT	CLT_Mid_TC1	Timber temperature near Fixing 1
13	In ceiling CLT	CLT_Mid_TC2	Timber temperature near Fixing 2
14	In ceiling CLT	CLT_Mid_TC3	Timber temperature near Fixing 3
15	In ceiling CLT	CLT_Up_TC2	Timber temperature upstream of Fixing 2
16	In ceiling CLT	CLT_Down_TC2	Timber temperature downstream of Fixing 2
17	Ceiling CLT	O2_Ceiling	Oxygen measurement ceiling surface
18	Wall CLT	O2_Wall	Oxygen measurement wall surface
19	Cable 1	Mass_F1	Load cell mass on cable to Fixing 1
20	Cable 2	Mass_F2	Load cell mass on cable to Fixing 2
21	Cable 3	Mass_F3	Load cell mass on cable to Fixing 3
	Cable 1	Movement_F1	Movement measurement on cable to Fixing 1
23	Cable 2	Movement_F2	Movement measurement on cable to Fixing 2
24	Cable 3	Movement_F3	Movement measurement on cable to Fixing 3
25	Wall	HFM_Ceiling	Heat flux meter pointing to fire ceiling CLT
26	Ceiling	HFM_Wall	Heat flux meter point up to wall CLT
27	Event Marker	Event_01	Event marker (Button Box)
28	Event Marker	Event_02	Event marker (Button Box)
29	Event Marker	Event_03	Event marker (Button Box)
30	Event Marker	Event_04	Event marker (Button Box)

Additional measurements made manually were:

- Pull out force pre-fire
- Char depth post test
- Video recording during test





4.3 CLT specification

The CLT for the project was generously provided by KLH Limited, specialists in the production and supply of Cross Laminated Timber for the building industry. The panels were supplied already cut to size for fitting to the test rig which greatly assisted test turnaround times and test repeatability.

The supplied panels had the following specification:

Ceiling panels:	Width	700mm
	Length	900mm
	Thickness	180mm
	Ply	5 (40/30/40/30/40mm)
	Lamina	Surface ply to be running across the sample width
Wall Panels	Height	1200mm
	Width	600mm
	Thickness	100mm
	Ply	3 (40/20/40mm)
	Lamina	Surface ply to be running across the sample width

Figure 7 CLT samples

4.4 Fire details

During the original FPA study a gas fire size of 100kW was used delivered via a 150mm x 150mm gravel box burner to the foot of the timber wall. Analysis of temperatures below the CLT were shown to peak at around 800°C which is lower than that measured during full-scale CLT fire tests and char formation were also found to be lower. To this end a new fire gas fire gravel bed of increased proportions was produced capable of delivering around 150kW and sized to involve the whole of the CLT wall width.

Gas flow was continuously monitored using a Bronkhorst mass flow controller calibrated to propane. Eight 47kg propane bottles connected in series were required to provide stable gas delivery for the maximum design test time of 60 minutes. The gravel bed design and measurement system is shown in Figure 8.

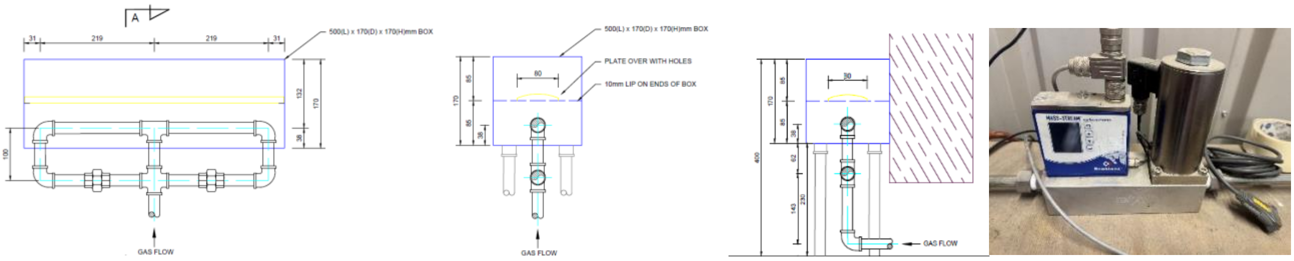


Figure 8 Gas burner design and measurement system

4.5 Gallery

Figure 9 to Figure 25 show images of the test equipment, rig, samples, and operation.

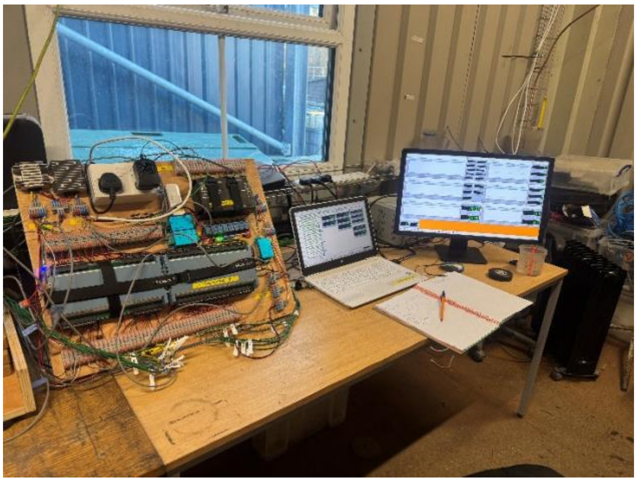


Figure 9 Instrumentation data logging and display

Figure 10 Data logging system

Figure 11 Gas analysis and conditioning system

Figure 12 Side view of view with winch loading system installed

Figure 13 CLT ceiling panel

Figure 14 CLT samples

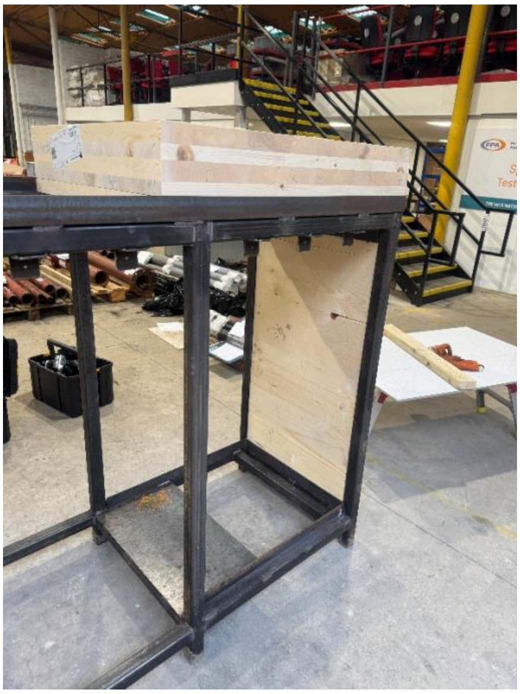


Figure 15 CLT ceiling and wall in position

Figure 16 Fixing load hanger

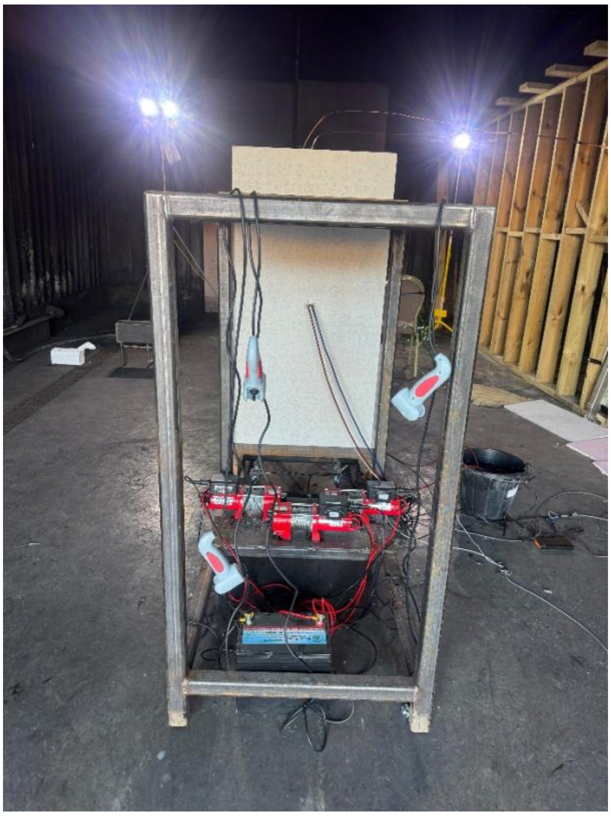


Figure 17 Loading end of rig with winch system

Figure 18 Loading end of rig with static weights

Figure 19 Rig in operation

Figure 20 Loaded fixings under fire

Figure 21 View of gas fire

Figure 22 Ceiling panel post fire

Figure 23 Wall panel post fire

Figure 24 Load pull out equipment

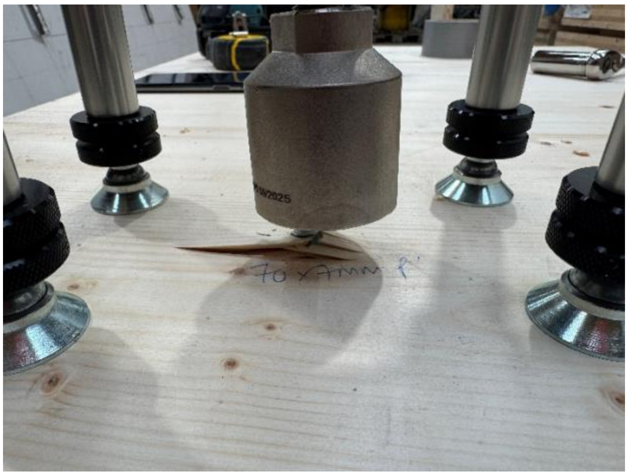


Figure 25 Load pull out close up

5 Fixings Inventory

Fixings for the project were generously provided by MidFix, a major UK provider of M&E fixings. Pertinent to the mass timber environment three specific types were supplied:

- Hex Coach Screws
- Flanged Structural Timber (FST) Screws
- Countersunk Structural Timber (CST) Screws

5.1 Hex Coach Screws

Hex Coach Screws are not engineered specifically for deep penetration into CLT or LVL. They are used on the presumption that ‘bigger is stronger’ and are extensively used for the attachment of M&E in buildings and in some cases are even specified in codes (such as those for fire sprinkler systems), but this is against a background of use in concrete buildings.

They are made of non-hardened steel and are characterised by having a coarse thread, hexagonal bolt head, and for all but the smallest sizes (M6 and below) require the drilling of a pilot hole. Photographs of the ones used in this study are shown in Figure 26. For the purposes of testing, where shorter samples were required, they were cut to size and sharpened as shown so the amount exposed to flame remain constant.

Figure 26 Hex Coach Screws

5.2 Flanged Structural Timber (FST) Screws

FST Screws are hardened steel fixings with a large diameter head suitable for the securing of channel to timber. The thread depth is greater and marginally wider than that of hex coach screws and are inserted with a Torx drive tool. They cover a similar size range to hex coach screws.

Figure 27 Structural Timber Screws

5.3 Countersunk Structural Timber (CST) Screws

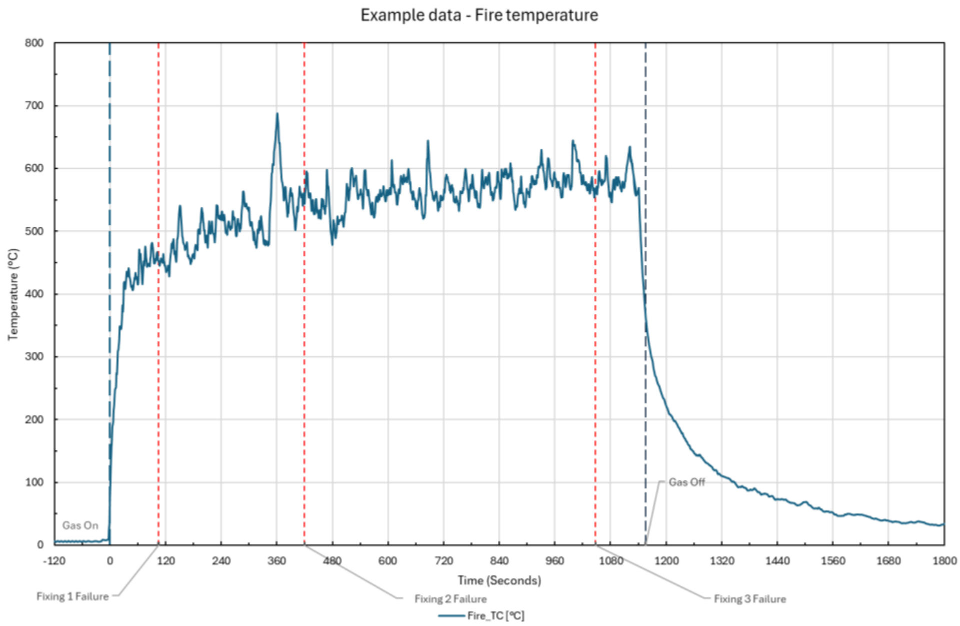
CST Screws are a high performance fixing for timber construction with high load bearing capacity. They are made of hardened steel and require no pre-drilling. Inbuilt into the design, to assist with insertion of these often-long fixings, is a torx drive, cutter point, milling thread, and glide coating.

6 Sample data set

This section provides a complete set of data that was collected for each test with associated content description to aid in the interpretation of test results.

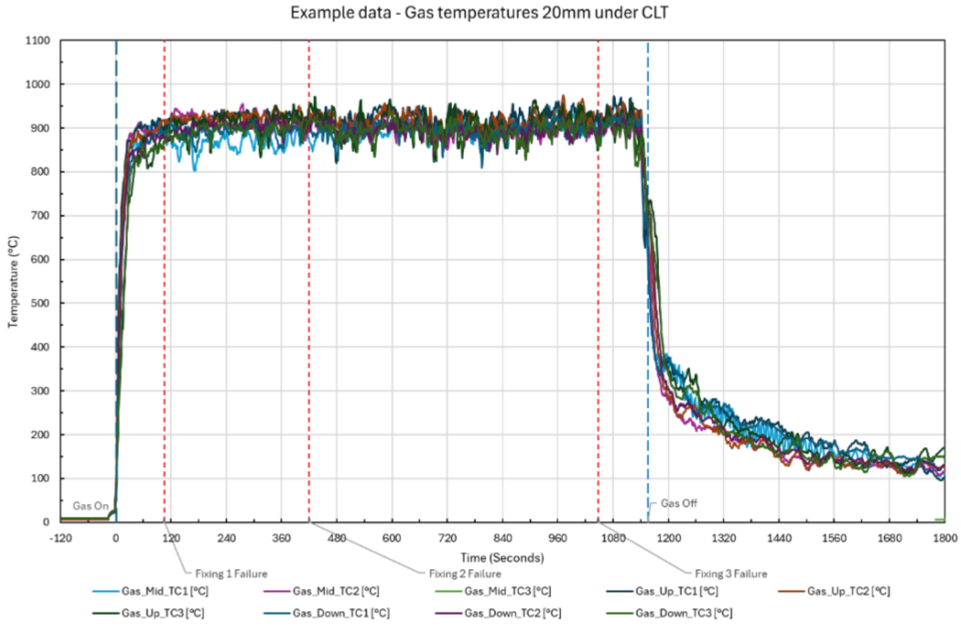
6.1 Fire temperature

The gas fire temperature is measured by a thermocouple mounted directly above the gravel bed. Its purpose is to define the time between the gas being turned on and ignited, and being turned off.



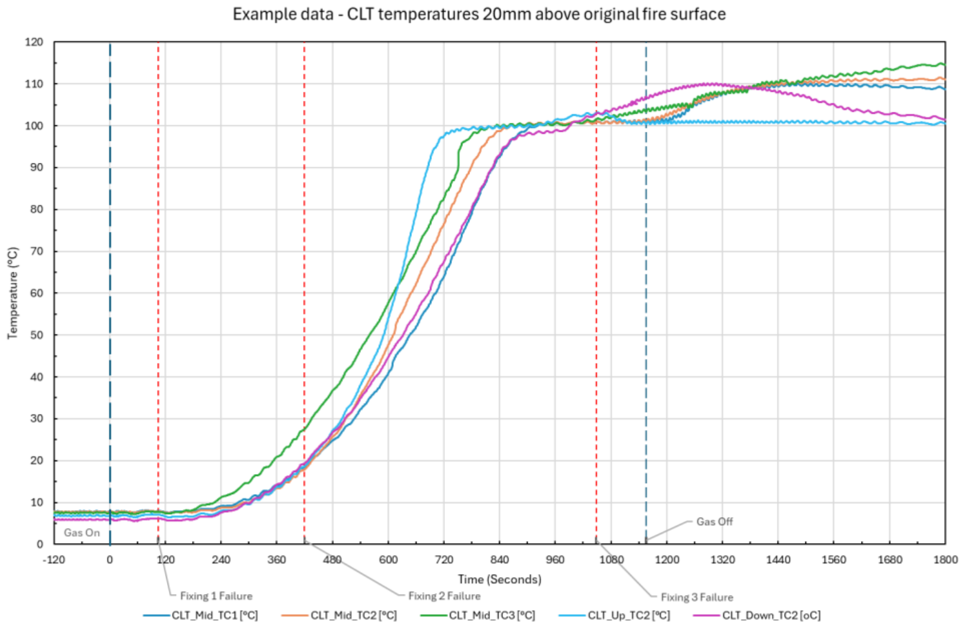
6.2 Under-ceiling gas temperatures

Gas temperatures 20mm under the original surface of the ceiling are measured by thermocouples mounted down through the CLT from the top surface via pilot holes. This is a key value for determining uniformity of fire challenge over the CLT surface and providing a key comparison value with historically conducted full-scale tests.



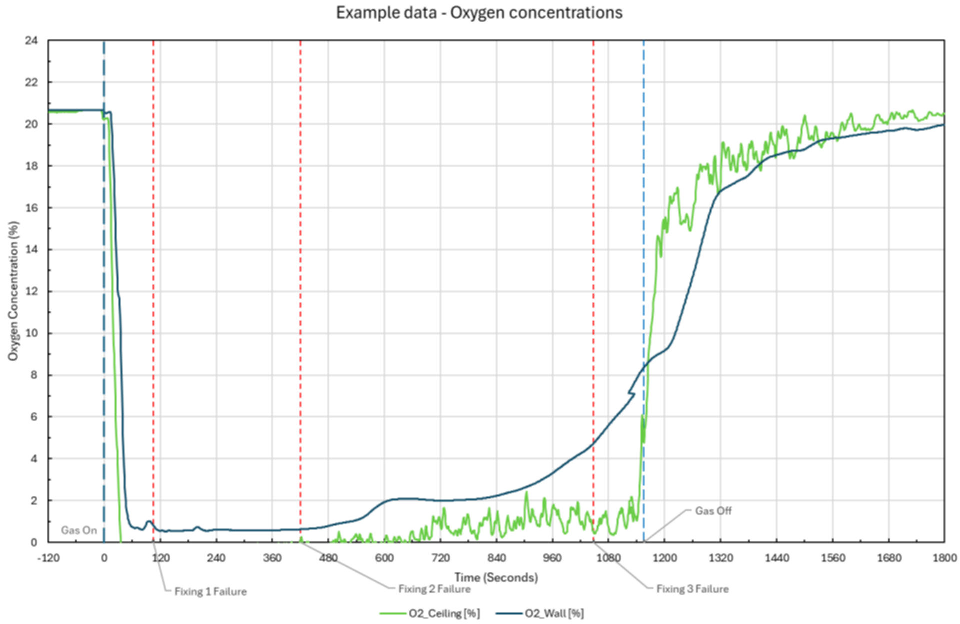
6.3 In CLT temperatures

CLT temperatures 20mm from the original surface of the ceiling are measured by thermocouples mounted within the CLT from the top surface via pilot holes. This is a key value for determining uniformity of fire challenge over the CLT surface and understand the rate of heat absorption into the CLT that influences timber's load bearing capacity. These values can be compared to the insertion depth of the fixings under test.



6.4 Oxygen measurement

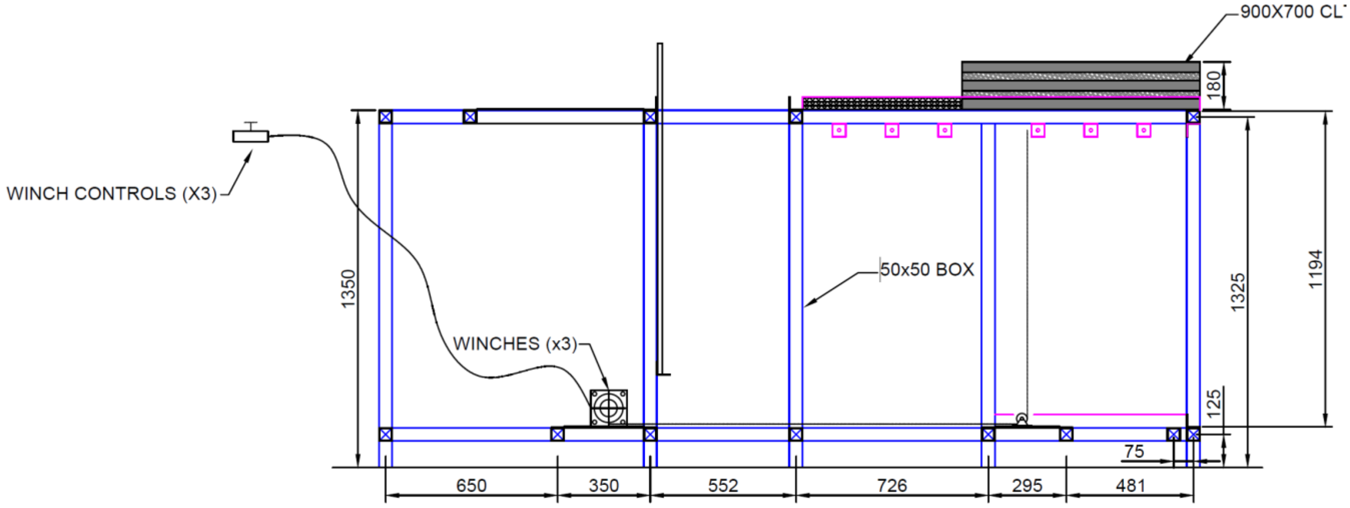
The measurement of oxygen at the CLT's surface assists with the understanding of factors that influence rate of burning.



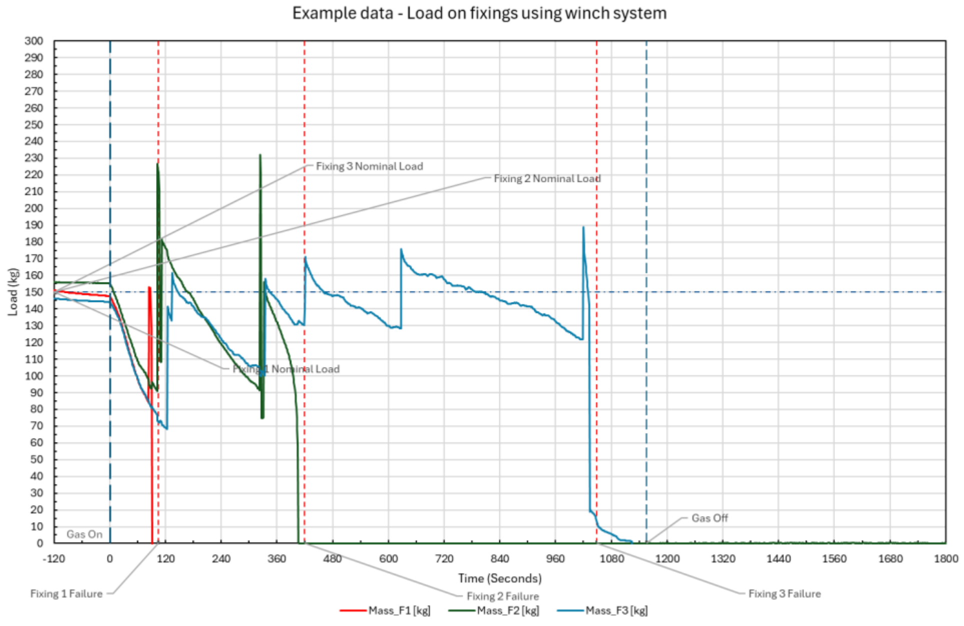
6.5 Load measurement

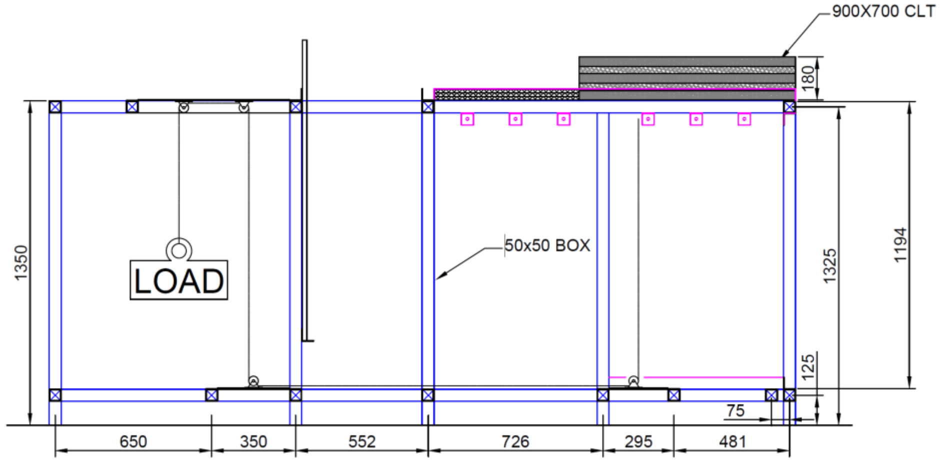
The loading of the fixings under test were made by 2 discreet methods; using winches, that required on-going adjustment; and by the application of suspended static loads. The winch system was used where high loads needed to be applied because the rig was unable to physically accommodate suspended weights of the size required. Tests conducted at lower loads used static weights as described below. With practice the adjustment of the winch loading became more accurate.

Measurement of load was made by S-Type load cells connected in line with steel cable between the load and the ceiling mounted fixings.

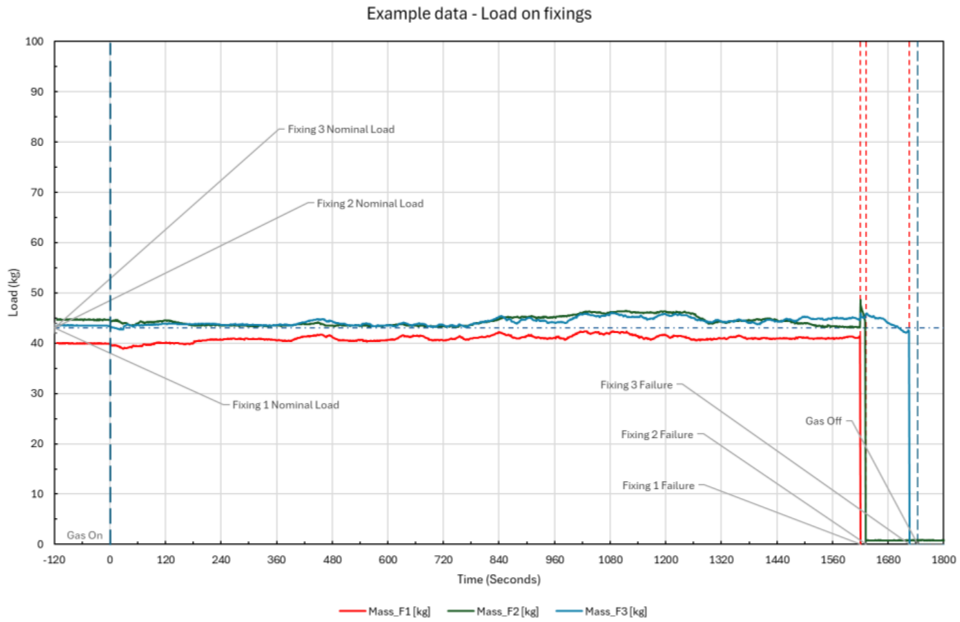


SIDE ELEVATION OF TEST RIG WITH WINCH SYSTEM



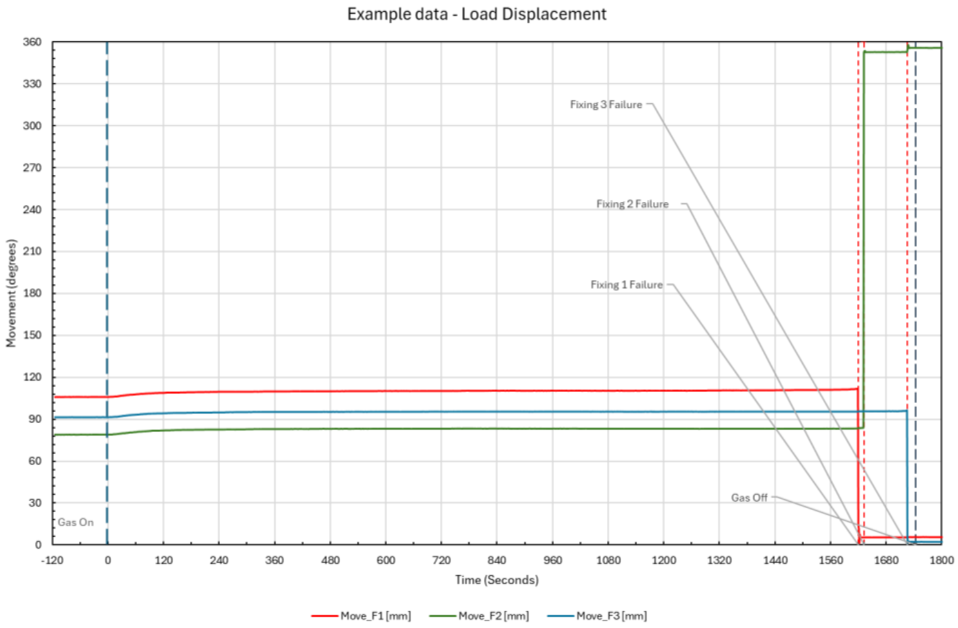


SIDE ELEVATION OF TEST RIG WITH WEIGHT PULLEY SYSTEM



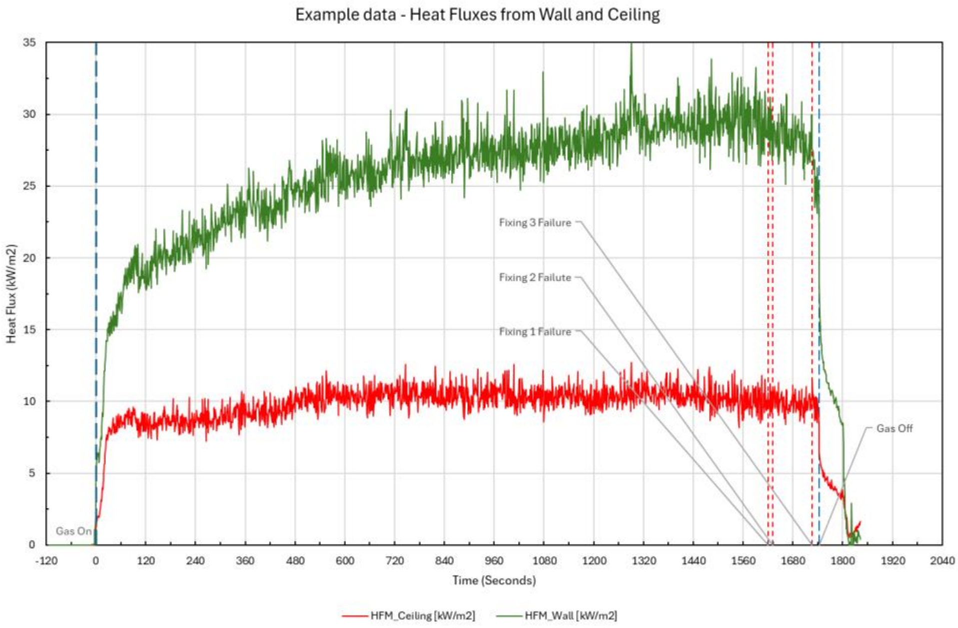
6.6 Load displacement

In an attempt to ascertain the mode of failure of the fixings rotational sensors were attached to each of the three steel cables via pivot bars. The intention was to understand better if fixing pull out was a gradual or sudden process. These results provided the most accurate timing for fixing failure.



6.7 Heat fluxes

Heat flux sensors pointed at the ceiling and wall CLT sections recorded heat flux from the surface as an aid to understanding the challenge presented and the consistency of rig operation.



7 Test scenarios and methods

The rig enabled each test to simultaneously compare 3 variations of a configuration feature thought to be important to contributing to load bearing capacity under the action of fire. The intention is to determine the factors that exerted the greatest influence so that solutions could focus on addressing these areas.

The tests are presented in the order best suited to describing to the reader the process and outcomes, rather than the order in which they were done as follows:

a) Characterisation of heat transfer into the timber ceiling
b) Non-fire pull-out testing of all fixings used
c) Impact of fixing embedment depth on load capability reduction (current fixings)
d) Impact of fixing diameter on load capability reduction
e) Impact of baffles / heat shields on load capability reduction
f) Impact of loading on load capability reduction
g) Impact of pilot hole size on load capability reduction
h) Impact of thread pitch on load capability reduction
i) Solutions testing

8 Results

Only the graphs appropriate to supporting the narrative of each test are provided within each section.

8.1 Characterisation of heat transfer into the timber ceiling

To support a better understanding of the thermal response of the CLT itself to fire the instrumentation was initially configured to assign all thermocouple resource to the detailed analysis of heat conduction into the timber at 10mm intervals in the same horizontal linear position that the fixings would be mounted in. This test was conducted once the repeatability of the fire challenge had been confirmed so the results could be considered appropriate to all test conducted under the same conditions.

The test was conducted for a full hour.

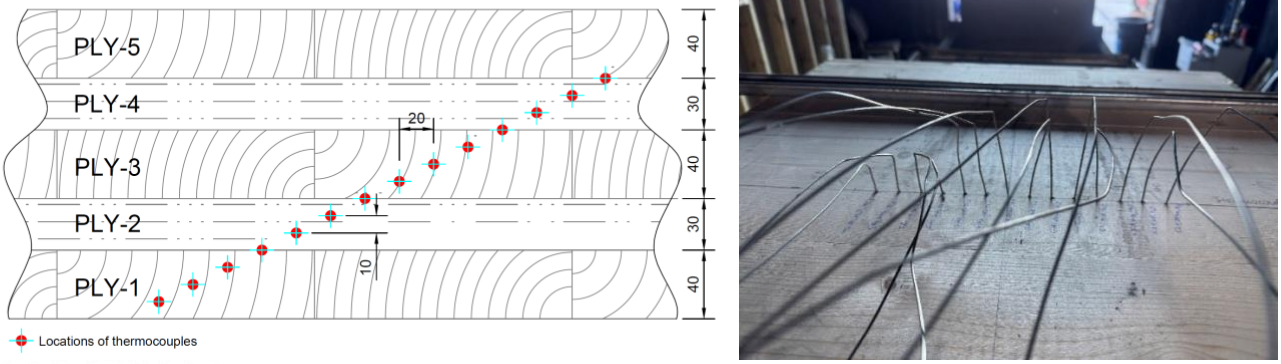


Figure 28 Position of thermocouples within the CLT for detailed thermal analysis

Figure 29 Wall and Ceiling samples post-test with some char cleared for measurement

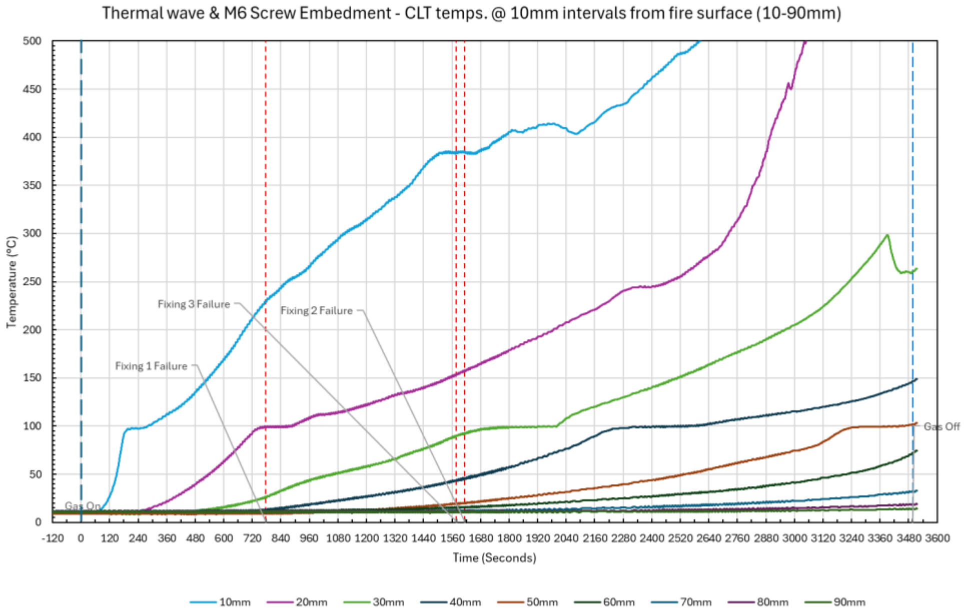


Figure 30 Temperature profile within CLT for thermocouples mounted between 10mm and 90mm from the original ceiling surface

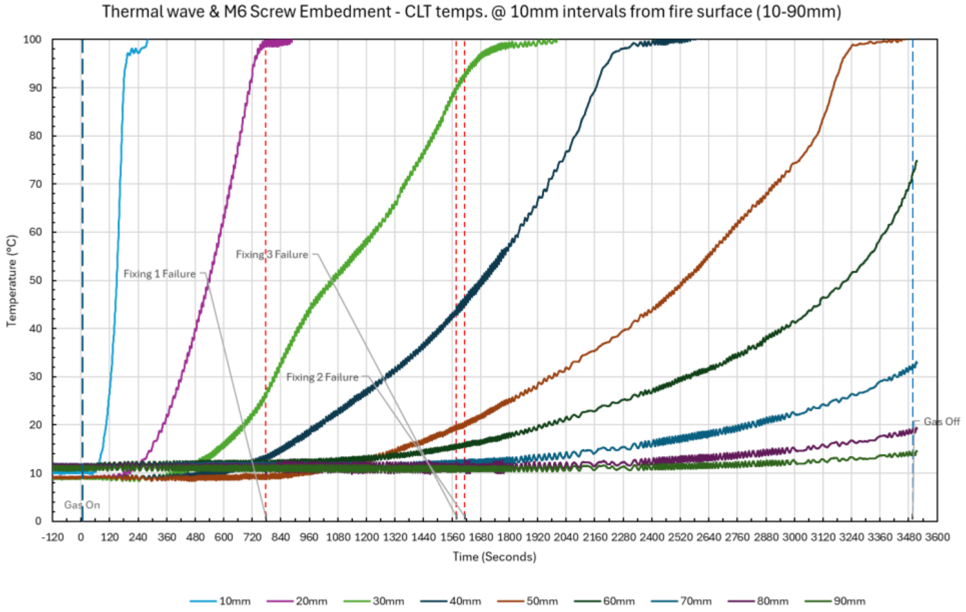


Figure 31 Temperature profile within CLT for thermocouples mounted between 10mm and 90mm from the original ceiling surface (zoomed in)

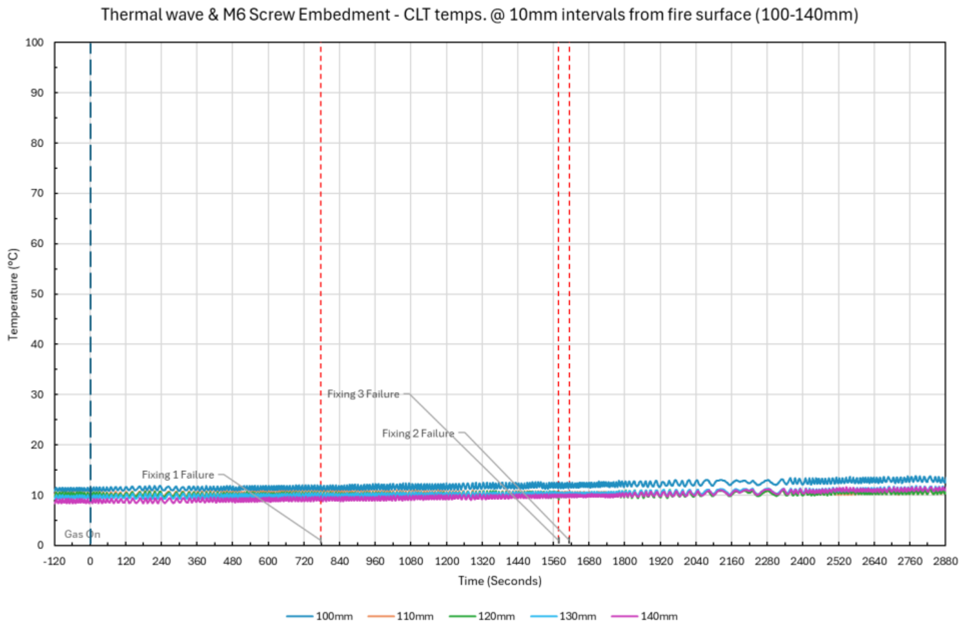


Figure 32 Temperature profile within CLT for thermocouples mounted between 100mm and 140mm from the original ceiling surface

Notable from these results is:

- The pause in heating at 100°C from moisture being driven from the timber is very apparent
- Within the time period of 1 hour the 100°C threshold is never reached for depths greater than 50mm
- Above 100mm depth there is no measurable change in the temperature of the CLT meaning that at this time the original hold capability of any part of a fitting at this depth would be unaltered subject to there being no conduction of heat down the fitting.

In the context of this study this data is very important. It is unreasonable to expect any fitting to last in a fire indefinitely so a cut off time, relevant to the evacuation of occupants, and attendance of the fire service needs to be chosen. By selecting that period from the above graphs, the depth of thermally unimpacted wood becomes known and may form the basis of understanding potential fixing solutions.

8.2 Non-fire fixing load capability performance

As a benchmark, the load retaining capability of all tested fixings and configurations, was appraised using an industry standard pull-out tester hired for the purposes of this study. The device provides for a stable attachment to the surface, a means of gripping the fixing head and applying force, and a load cell to measure that force. The device records the maximum value attained before the load drops following failure and dislodgment.

6

Figure 33 Load pull out equipment

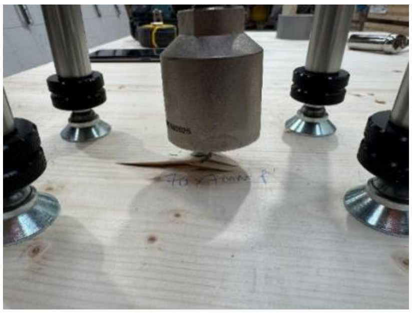


Figure 34 Load pull out close up

Table 1 Ambient (no fire) pull-out strengths of all fixing combinations tested with installation parameters

Fixing Type	Fixing Size	Fixing length (mm)	Embedment depth (mm)	Pilot hole size (mm)	Lamina contacted	Ambient Capacity (kg)
Hex Flanged Structural Timber Screw	M12	40	30	7	1	326
Hex Flanged Structural Timber Screw	M12	70	60	7	2	1040
Hex Flanged Structural Timber Screw	M12	100	90	7	3	1906
Hex Flanged Structural Timber Screw	M8	100	80	0	3	1295
Hex Flanged Structural Timber Screw	M10	100	80	5	3	1560
Hex Flanged Structural Timber Screw	M12	100	80	7	3	1641
Hex Flanged Structural Timber Screw	M10	100	70	5	2	1274
Hex Flanged Structural Timber Screw	M10	100	70	5	2	1274
Hex Flanged Structural Timber Screw	M10	100	70	5	2	1274
Hex Flanged Structural Timber Screw	M10	100	80	5	3	1560
Hex Flanged Structural Timber Screw	M10	100	80	5	3	1560
Hex Flanged Structural Timber Screw	M10	100	80	5	3	1560
Hex Flanged Structural Timber Screw	M10	100	80	5	3	1560
Hex Flanged Structural Timber Screw	M10	100	80	5	3	1560
Hex Flanged Structural Timber Screw	M10	100	80	5	3	1560
Hex Flanged Structural Timber Screw	M10	100	80	5	3	---
Hex Flanged Structural Timber Screw	M10	100	80	5.5	3	---
Hex Flanged Structural Timber Screw	M10	100	80	6	3	---
Flanged Structural Timber Screw	M10	100	80	5.5	3	1478
Hex Flanged Structural Timber Screw	M10	100	80	5.5	3	1835
Flanged Structural Timber Screw	M8	100	80	0	3	1070
Countersunk Structural Timber Screw	M6	100	90	0	3	775
Countersunk Structural Timber Screw	M6	120	110	0	3	989
Countersunk Structural Timber Screw	M6	150	140	0	4	1019
Flanged Structural Timber Screw	M10	100	80	5	3	1469
Flanged Structural Timber Screw	M10	100	80	3	3	1366
Flanged Structural Timber Screw	M10	100	80	0	3	1346
Countersunk Structural Timber Screw	M6	100	50	0	2	571
Countersunk Structural Timber Screw	M6	100	60	0	2	907
Countersunk Structural Timber Screw	M6	100	70	0	2	1101
Countersunk Structural Timber Screw	M6	150	130	0	4	917
Flanged Structural Timber Screw	M8	100	80	0	3	989
Flanged Structural Timber Screw	M8	120	100	0	3	1244
Flanged Structural Timber Screw	M8	160	140	0	4	1529

Fixing load bearing capability is shown to be a strong function of both embedment depth and fixing diameter with values ranging from 326kg to 1920kg.

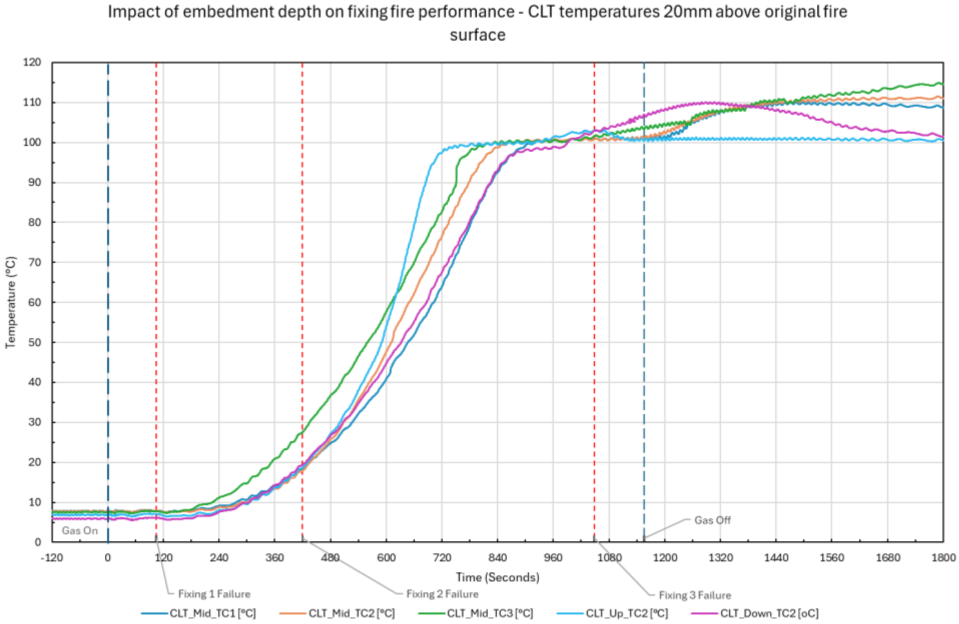
8.3 Impact of embedment depth (current fixings)

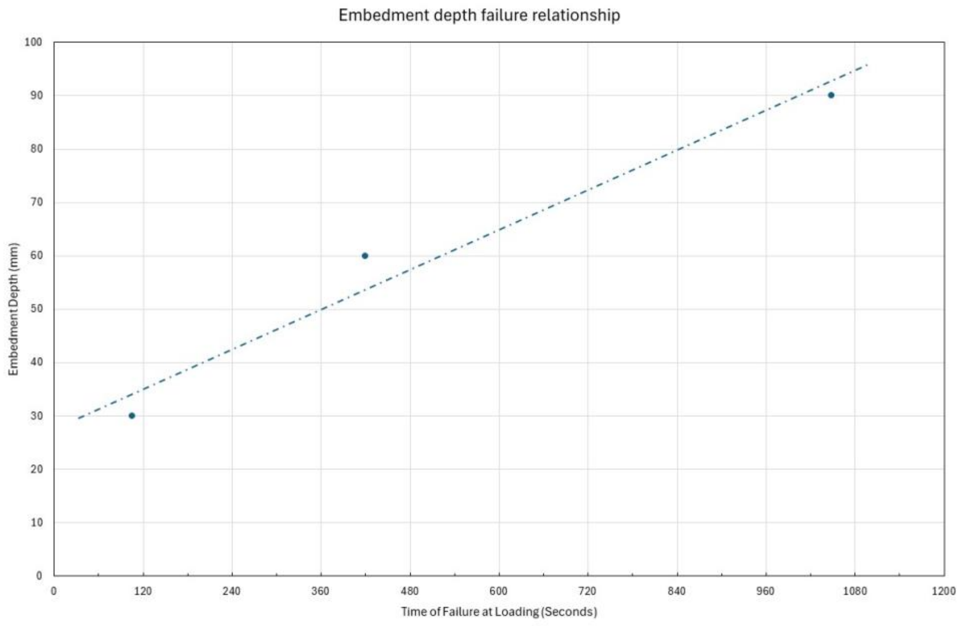
The impact of embedment depth was assessed using 100mm M12 Hex Coach screws cut down to size to give the same amount of protrusion (10mm) below the CLT ceiling. This is necessary to ensure that the results are not influenced by any differences in heat collection from the flame zone resulting from different protrusion lengths.

Figure 35 M12 embedment test Hex Coach Screw fixings

The parameters of the fixings are as shown in the table below along with measured failure details.

Impact of embedment depth (current fixings)	**Fixing**	40mm M12 Hex Coach Screw	70mm M12 Hex Coach Screw	100mm M12 Hex Coach Screw
	Loading Mass	150kg	150kg	150kg
	Pilot dia. / depth	7mm/30mm	7mm/60mm	7mm/70mm
	Embedment	30mm	60mm	90mm
	Failure Time	105s	420s	1048s
	Failure Mode	Pull-out	Pull-out	Pull-out
	Ambient retention	326kg	1040kg	1926kg





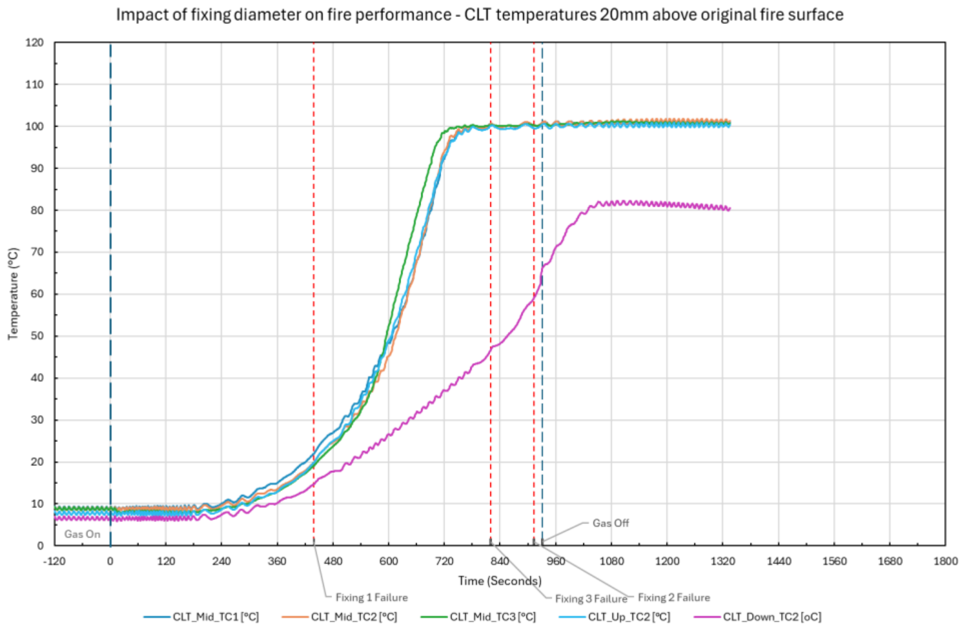
A clear relationship is shown of increasing retention capability with embedment depth but in every case:

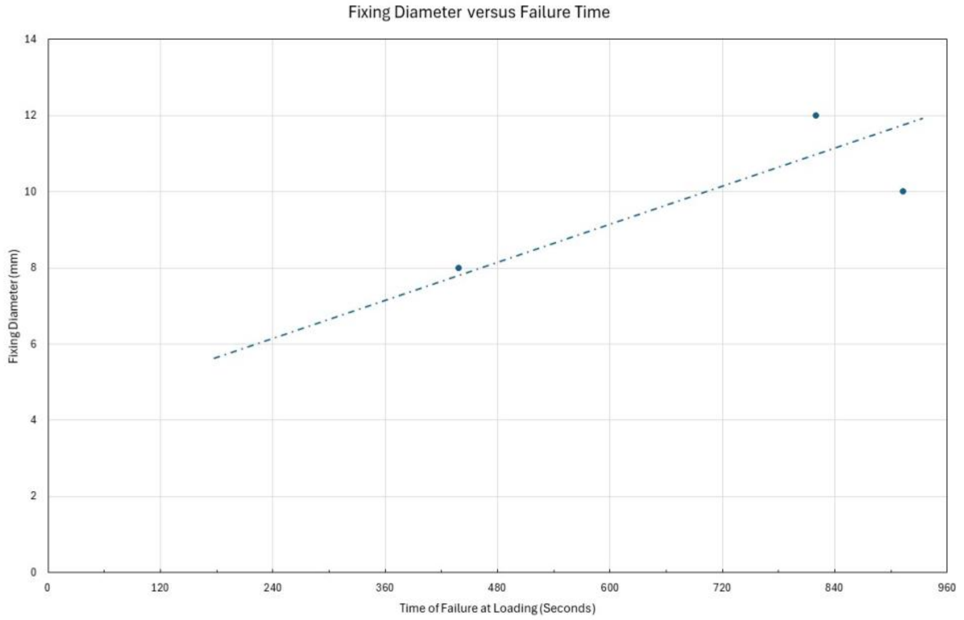
- The fixing fails when restraining only a fraction of its non-fire measured capacity
- CLT temperatures are low or unchanged at the time of fail suggesting that timber heating that leads to loss of strength is occurring local to the fixing and its threads

8.4 Impact of fixing diameter

The impact of fixing diameter was assessed using 100mm M8, M10, and M12 Hex Coach screws mounted to give the same amount of protrusion (20mm) below the CLT ceiling. The parameters of the fixings are as shown in the table below along with measured failure details.

Impact of fixing diameter	**Fixing**	100mm M8 Hex Coach Screw	100mm M10 Hex Coach Screw	100mm M12 Hex Coach Screw
	Loading Mass	150kg	150kg	150kg
	Pilot dia. / depth	0mm/70mm	5mm/70mm	7mm/70mm
	Embedment	80mm	80mm	80mm
	Failure Time	439s	913s	820s
	Failure Mode	Melted and pulled through	Pull-out	Pull-out
	Ambient retention	1295kg	1560kg	1641kg





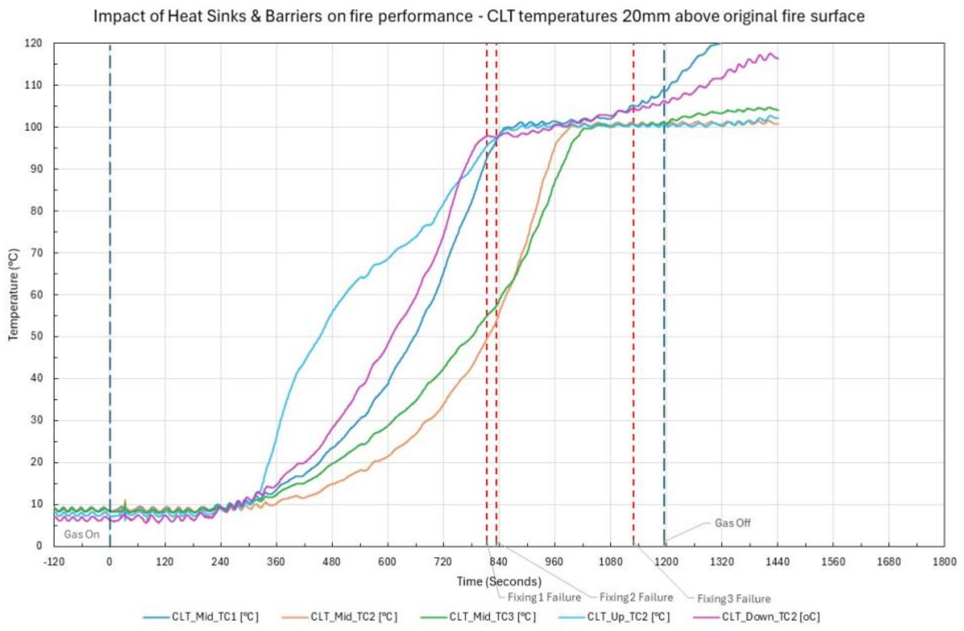
A clear relationship is difficult to discern because the smallest diameter fixing failed through a different mechanism to the other two, melting as opposed to pull-out (an important finding). That said, again all fixings failed whilst supporting only 1/10th of their ambient (non-fire) load bearing capacity. It the time when the two larger diameter fixings failed timber temperature along their length would have ranged from 250°C at their insertion point, to ambient at their tips (see Figure 30). The impact of conduction down the shank of these bolts is explored later.

8.5 Impact of contacted metal mass / baffles

Historic work has shown that what the fixing is connected to can exert a great impact on its performance under fire. Intimate contact with thin metal structures may enhance heat collection thereby promoting conduction of heat along the fixing and deep into the time resulting in accelerated failure. Larger metal, and non-metal insulating structures may act as heat sinks or baffles that act to delay or prevent the collection of heat, and subsequent conduction into the wood via the fixing.

In this test varying quantities of Unistrut were attached to the ceiling with a single 100mm M10 Hex Coach Screw with all other installation parameters preserved. The parameters of the fixings are as shown in the table below along with measured failure details.

Impact of contacted metal mass / baffles	**Fixing**	100mm M10 Hex Coach Screw	100mm M10 Hex Coach Screw	100mm M10 Hex Coach Screw
	Loading Mass	150kg	150kg	150kg
	Pilot dia. / depth	5mm/70mm	5mm/70mm	5mm/70mm
	Embedment	70mm	70mm	70mm
	Configuration	1 slot Unistrut	3 slot Unistrut	5 slot Unistrut
	Failure Time	813s	834s	1129s
	Failure Mode	Pull-out	Pull-out	Pull-out
	Ambient retention	1274kg	1274kg	1274kg

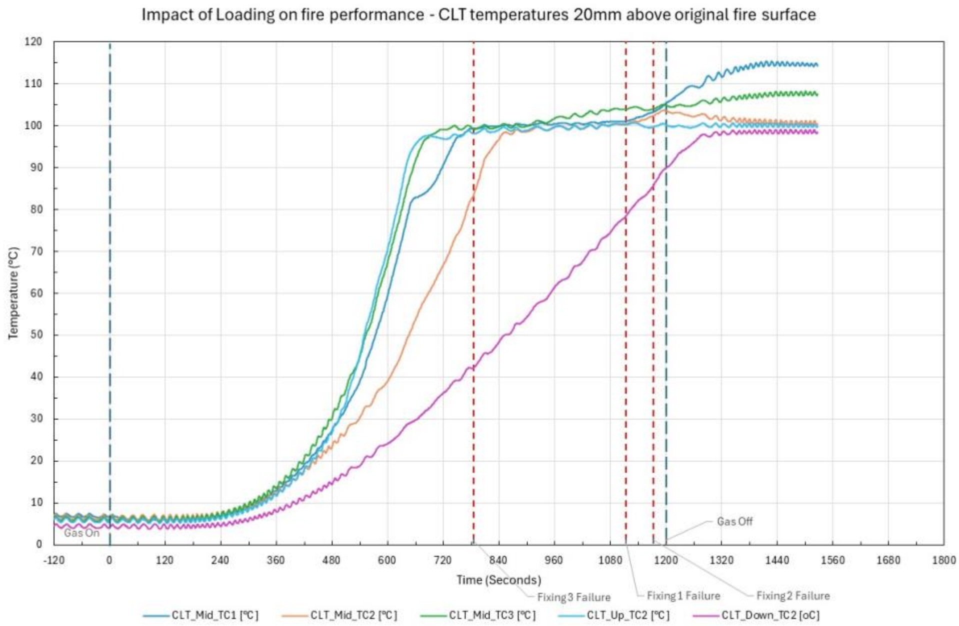


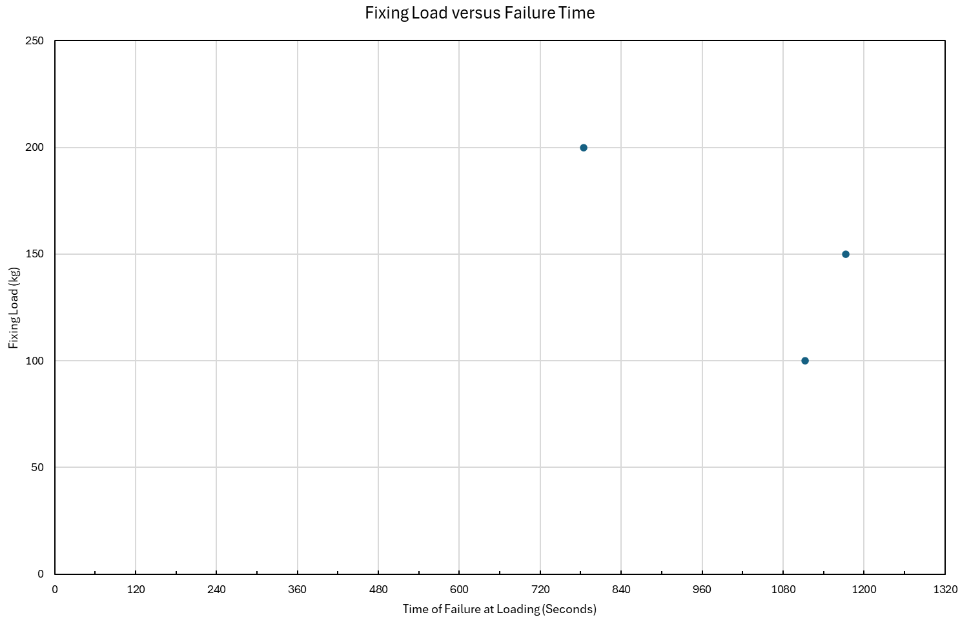
The data suggests that in this configuration the steelwork attached to the fixing is acting as a baffle against heat uptake by the fixing or having only a minor impact. Failure time for the smaller baffles is noted to be very similar to that of a previous test with no metalwork in place. The largest baffle which shielded the fixing from flame to the greatest degree appears to afford some protection leading to an increased retention period. However, again it is noted that all fail whilst holding in place only a small fraction of the mass they are capable of holding in the non-fire condition.

8.6 Impact of mass loading

The impact of fixing loading was assessed using 100mm M10 Hex Coach screws with each loaded individually to 100, 150, and 200kg, respectively. The parameters of the fixings are as shown in the table below along with measured failure details.

Impact of high mass loading	**Fixing**	100mm M10 Hex Coach Screw	100mm M10 Hex Coach Screw	100mm M10 Hex Coach Screw
	Loading Mass	100kg	150kg	200kg
	Pilot dia. / depth	5mm/70mm	5mm/70mm	5mm/70mm
	Embedment	80mm	80mm	80mm
	Failure Time	1113s	1173s	784s
	Failure Mode	Pull-out	Fixing broke	Fixing broke
	Ambient retention	1560kg	1560kg	1560kg

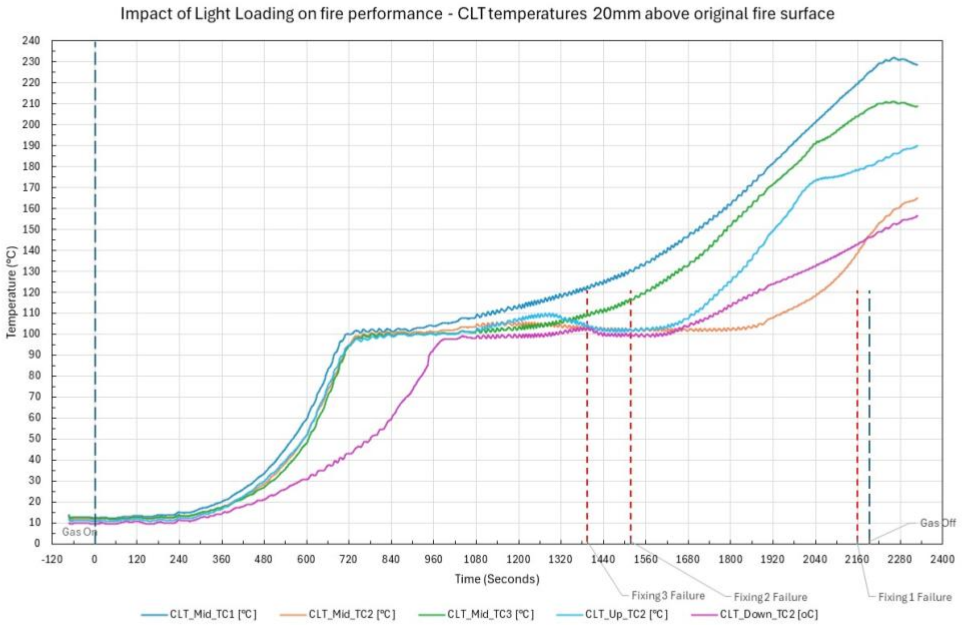


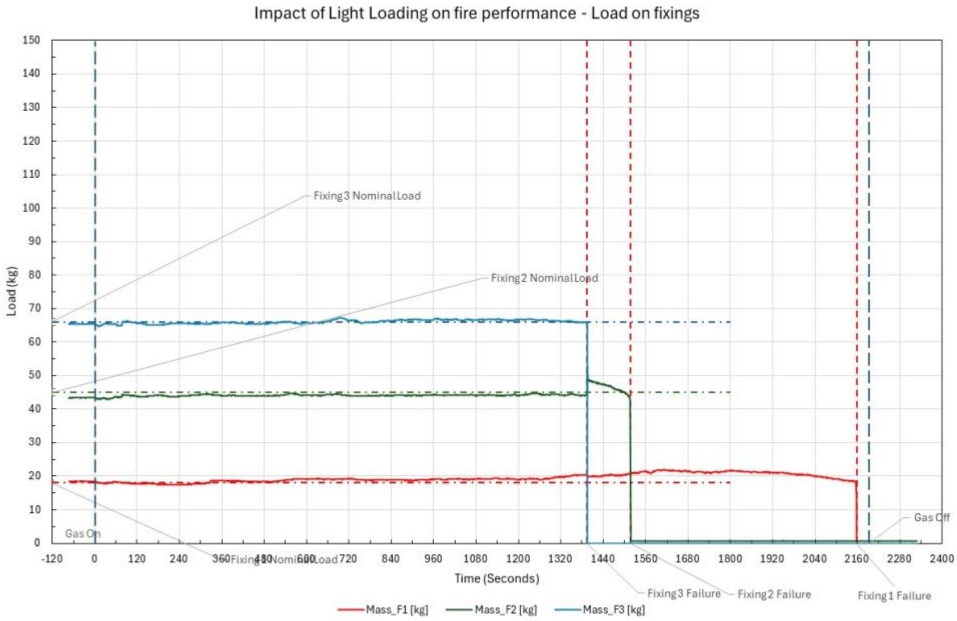


In this test the fixings with the greater loading of 150kg and 200kg are observed to break during the test. This introduces another interesting considering for this project. Whilst the majority of failures are due to the weakening of timber around the fixing under the action of heat, there is also a need for the fixing itself to remain intact for the fire's duration. In spite of the fixings having an ambient loading capacity of 1560kg, they all experience either pull-out or structural failure at loads of under 200kg under the action of fire and within a short period of under 20 minutes.

To investigate the implications of mass further without the likelihood of fixing structural failure, a further series of test were conducted at lighter loads as follows:

Impact of low mass loading	**Fixing**	100mm M10 Hex Coach Screw	100mm M10 Hex Coach Screw	100mm M10 Hex Coach Screw
	Loading Mass	18kg	44kg	66kg
	Pilot dia. / depth	5mm/70mm	5mm/70mm	5mm/70mm
	Embedment	80mm	80mm	80mm
	Failure Time	2158s	1518s	1395s
	Failure Mode	Pull-out	Pull-out	Pull-out
	Ambient retention	1560kg	1560kg	1560kg



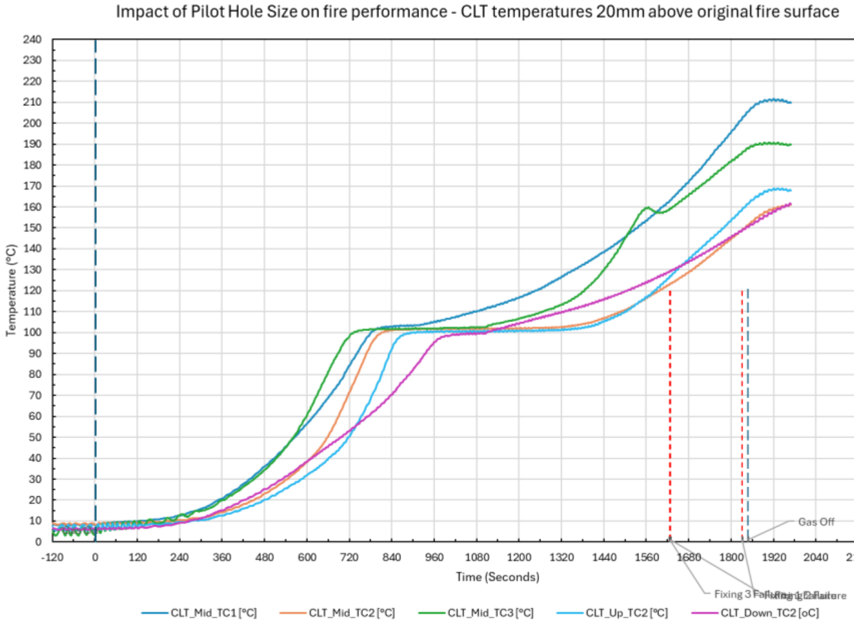


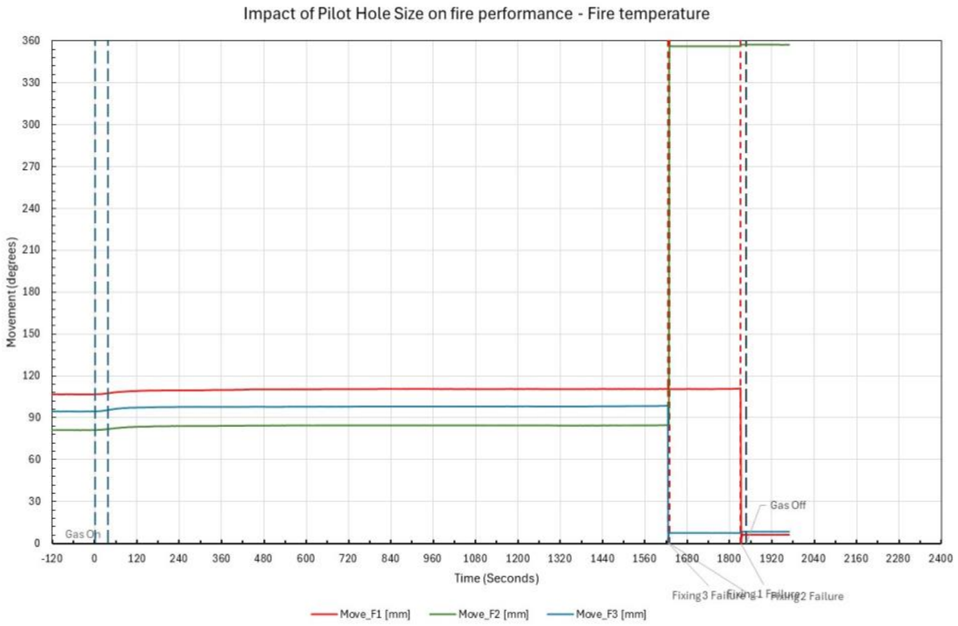
Whilst a relationship does exist between the load the fixing is carrying and the time to failure it is not a strong one. When the high loading and low loading data is taken together it would seem that failure of fittings loaded to 20kg and 200kg fails on a similar timescale, and certainly with a period relevant to evacuation and fire service response.

8.7 Impact of pilot hole size on Hex Coach Screws

The impact of pilot hole size was assessed using 100mm M10 Hex Coach screws with each pre-drilled to 5, 5.5, and 6mm respectively, respectively. The parameters of the fixings are as shown in the table below along with measured failure details.

Impact of pilot hole size on Hex Coach Screws	**Fixing**	100mm M10 Hex Coach Screw	100mm M10 Hex Coach Screw	100mm M10 Hex Coach Screw
	Loading Mass	44kg	44kg	44kg
	Pilot dia. / depth	5mm/70mm	5.5mm/70mm	6mm/70mm
	Embedment	80mm	80mm	80mm
	Failure Time	1832s	1629s	1626s
	Failure Mode	Pull-out	Pull-out	Pull-out
	Ambient retention	---	---	---

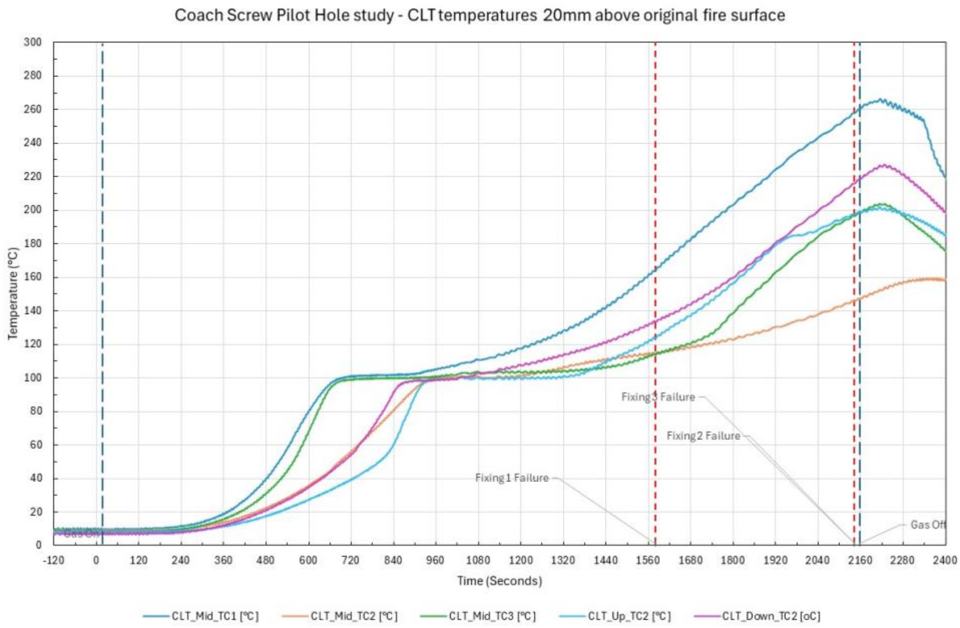


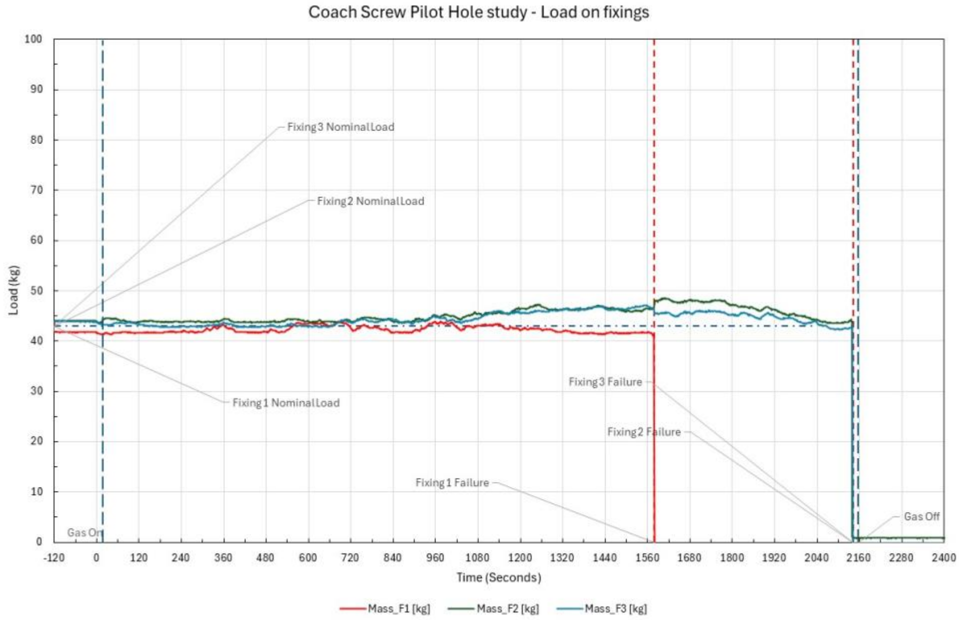


The size of pilot hole would be expected to exert an influence on both the ambient load bearing capability of the fixing, and during fire as this will impact the compression of wood around the thread of the fixing. It is clear from the data that the over-sizing of the pilot hole is deleterious to retention strength, but under-sizing it provides little or no additional benefit.

To investigate this more a further series of tests were conducted using Flanged Structural Timber Screws that could be inserted without a pilot hole being drilled.

Impact of pilot hole size on FST Screws	**Fixing**	100mm M10 FST Screw	100mm M10 FST Screw	100mm M10 FST Screw
	Loading Mass	44kg	44kg	44kg
	Pilot dia. / depth	5mm/80mm	3mm/80mm	0mm/0mm
	Embedment	80mm	80mm	80mm
	Failure Time	1579s	2142s	2142s
	Failure Mode	Pull-out	Pull-out	Pull-out
	Ambient retention	1469kg	1366kg	1346kg





In this instance, a notable increase in performance was observed from the reduction of pilot hole size from 5mm to 3mm, but thereafter no improvement was observed when no pilot hole was used.

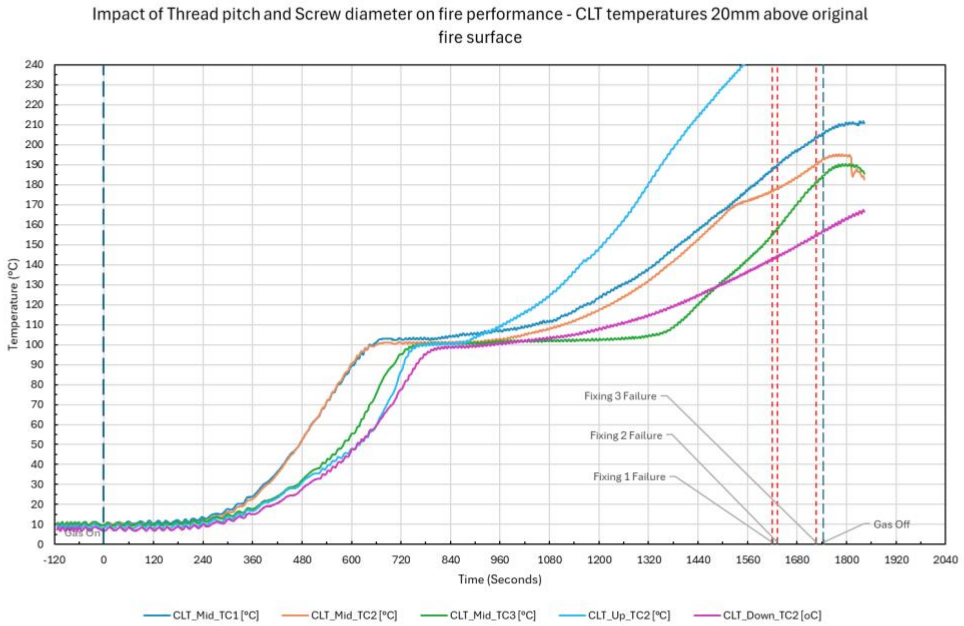
It is interesting to note that under ambient conditions use of the fixing with the correct 5mm pilot hole gave the highest load bearing capability over smaller pilot holes – the inverse of fire results. Also to be recognised is that in all instances the fixings failed with a load of just 44kg under fire, when their ambient strength was up to 1500kg – just 3% of its original load bearing capacity.

8.8 Impact of thread pitch and fixing diameter

The impact of thread pitch/depth was assessed by comparison the performance of 100mm M10 FST Screw with that of 100mm M10 Hex Coach screw. Whilst similar the Flanged structural Timber Screw is notable in having a thinner shaft with deeper cut and more widely spaced threads. This comparison was made on the presumption that fixings with a deeper and wider thread might perform better in fire.

Having a test bay spare, the test was also used to make a direct comparison of M10 and M8 FST performance.

Impact of thread pitch and fixing diameter	**Fixing**	100mm M10 FST Screw	100mm M10 Hex Coach Screw	100mm M8 FST Screw
	Loading Mass	44kg	44kg	44kg
	Pilot dia. / depth	5.5mm/80mm	5.5mm/80mm	0mm/0mm
	Embedment	80mm	80mm	80mm
	Failure Time	1620s	1632s	1726s
	Failure Mode	Pull-out	Pull-out	Pull-out
	Ambient retention	1478kg	1835kg	1070kg



Most notable from this test is the similarity of results from the M10 FST and M10 Hex Coach Screws indicating that that, on a like-for-like basis, thread pitch and depth makes little difference to the improvement of load retentional capacity under fire conditions. Of more interest is the improvement achieved by the use of the 'skinnier' M8 FST screw over the large M10 FST screw, which, whilst the improvement is not meaningfully great in terms of FRS response times, does point to the relevance of using skinnier fixings to reduce conduction into the parts of the wood where grip is to be found.

Again, it is interesting to note that the fixing with the weakest ambient hold capability gave the best fire performance of the three fixings tested.

8.9 Solutions testing – Long Countersunk Structural Screws

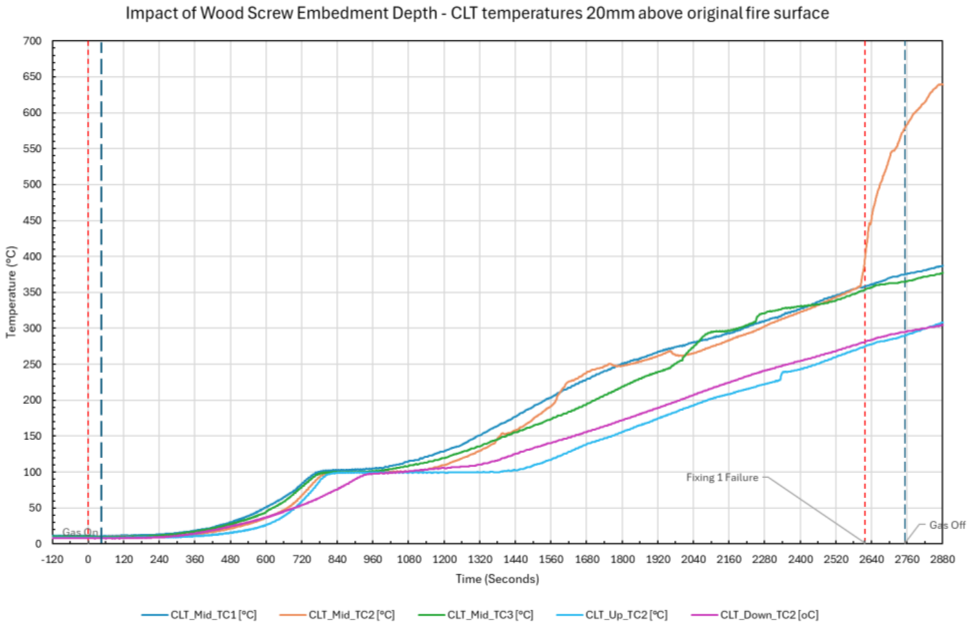
Having established that desirable features for fire resilient fixings in timber are:

- They should be long – with thread embedded into timber that remains unaltered and unheated at the maximum relevant time period considered
- They should be 'skinny' – to reduce conduction into the gripped wood around the screws
- They should be made of hardened steel – so that the skinny fixings itself will not melt or break under the action of heat

Two tests were run as shown below to give a span of embedment between 50mm and 140mm. In understanding the data it is important to remember that the thread does not run the entire length of the fixing (typically only 60-70mm back from the tip with the remainder in bar).

Impact of embedment depth of solution using 'skinny' fixings (1)	**Fixing**	100mm M6 CST Screw	120mm M6 CST Screw	150mm M6 CST Screw
	Loading Mass	44kg	44kg	44kg
	Pilot dia. / depth	0mm/0mm	0mm/0mm	0mm/0mm
	Embedment	90mm	110mm	140mm
	Failure Time	2618s	Did not fail	Did not fail
	Failure Mode	Pull-out	----	----
	Ambient retention	775kg	989kg	1019kg

Impact of embedment depth of solution using 'skinny' fixings (2)	**Fixing**	100mm M6 CST Screw	100mm M6 CST Screw	100mm M6 CST Screw
	Loading Mass	44kg	44kg	44kg
	Pilot dia. / depth	0mm/0mm	0mm/0mm	0mm/0mm
	Embedment	50mm	60mm	70mm
	Failure Time	777s	1614s	1578s
	Failure Mode	Pull-out	Pull-out	Pull-out
	Ambient retention	571kg	907kg	1110kg



With embedment depths over 110mm the M6 CST Screws did not fail before the test was ended at 45 minutes which indicates that the use of long skinny fixings, used in greater numbers to provide the equivalent ambient load capability, points to a tangible solution to the premature failure of shorter fixings of greater diameter. The information lacking is what the residual strength on the fixings was, which is addressed in the text test.

8.10 Unloaded post-fire strength assessment of short wide fixings vs. long thin fixings

To assess the retained load capacity post-fire a selection of long ‘skinny’ fixings were subjected to a half hour fire which was then stopped. Upon cooling the fixings were assessed to

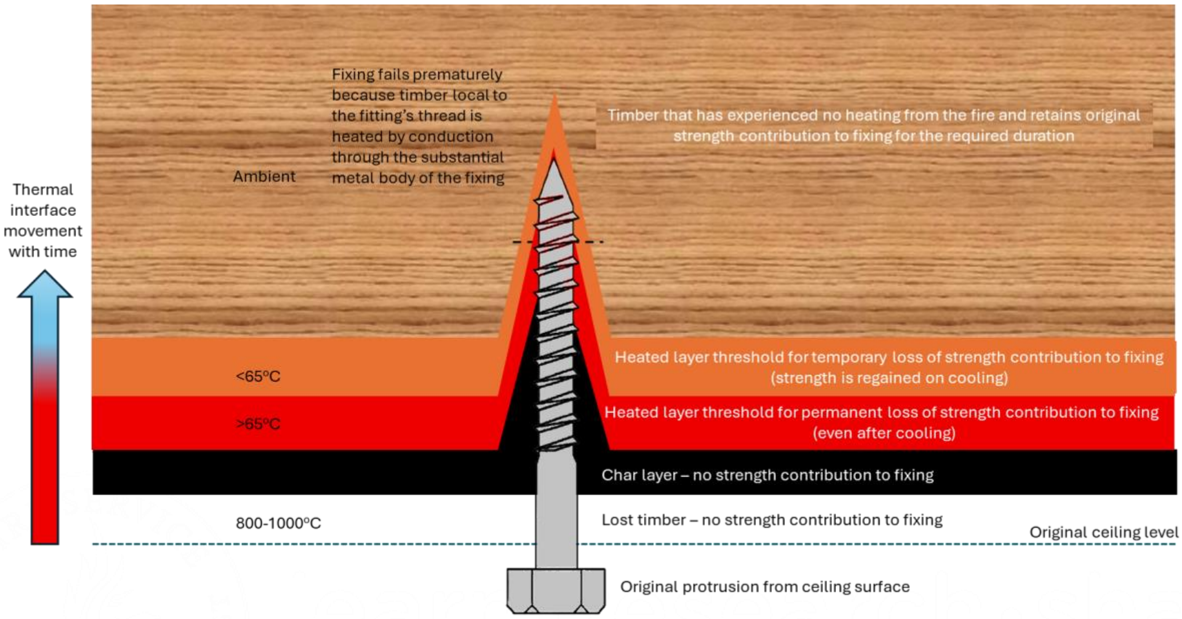
Unloaded post-fire strength assessment of short wide fixings vs. long thin fixings	**Fixing**	150mm M6 CST Screw	100mm M8 FST Screw	120mm M8 FST Screw	160mm M8 FST Screw
	Loading Mass	0kg	0kg	0kg	0kg
	Pilot dia. / depth	0/130mm	0/80mm	0/100mm	0/140mm
[*]On pull-out testing the head broke off due to twisting of the load testing device on the uneven charred CLT surface so retention would actually be better than the value supplied	**Embedment**	130mm	80mm	100mm	140mm
	Failure Time	----	----	----	----
	Failure Mode	----	----	----	----
	Ambient retention	917kg	989kg	1244kg	1529kg
	Post-fire capacity	785kg[*]	510kg	795kg	1325kg
	Capacity retention after 30min fire	86%[*]	52%	64%	87%

This test confirms the capability of long skinny fixings to retain a much greater proportion of their load bearing capability than shorter larger alternative fixings that have much higher ambient loading capability.

9 Discussion

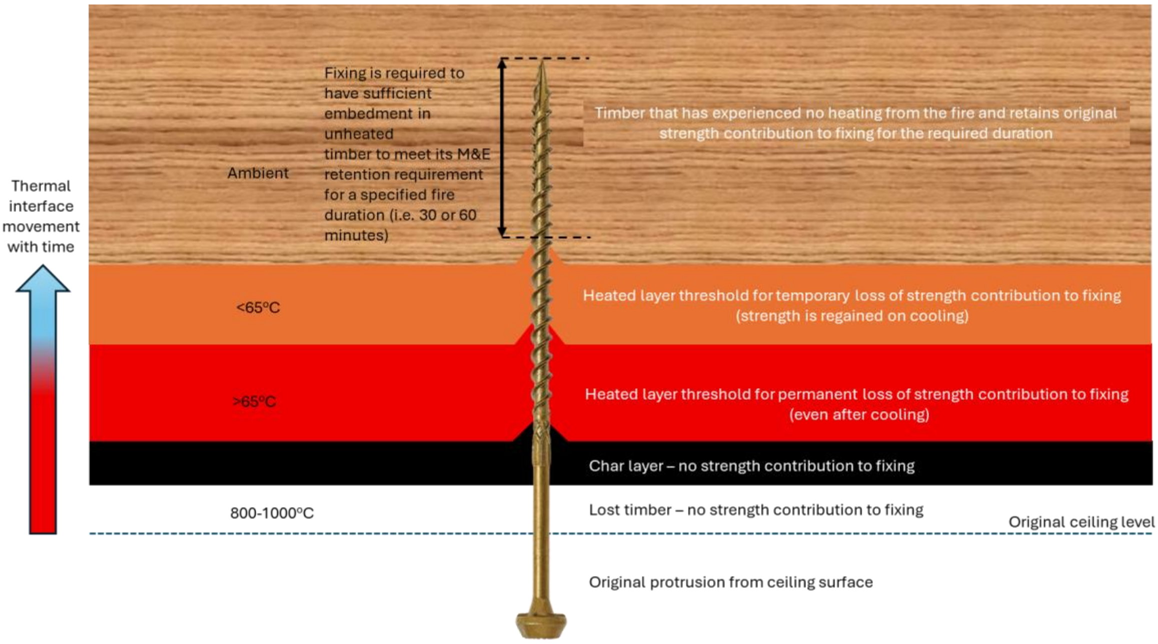
The ability of longer fixings to retain their strength for longer under fire conditions is in keeping with expectation. What is less obvious is the improvement in fire capability that results from the use of 'skinnier' fixings and shows that there are more forces in play than just that of the loss of timber to char with time and the change in effective embedment depth that this results in. To explain the disproportionate loss of strength in fixings demands a 2-model appropriate defined by the ability of the fixing to conduct heat along its length to impact the wood where the thread grips.

'Fat' Fixing model



In this model, the 'fatter' fixing is able to conduct heat deep into the wood raising its temperature between the threads so there is a loss of retention strength at the grip points. Wood weakens at surprisingly low temperatures. Whilst we recognise easily the loss of strength associated with charring, lower temperatures that impact moisture content exert great influence.

'Skinny' Fixing model



In this model, the geometry of the fixing is less capable of conducting heat deep within the wood and the increased length ensures that the thread necessary for full retention remains in unheated wood for the duration that it must remain effective.

Whilst the ambient load bearing capacity of ‘skinny’ fixings is less that for their large diameter counterparts there are certain advantages in their use, specifically not requiring pilot-holes to be drilled, that might greatly offset the additional effort required to install greater numbers of fixings.

10 Conclusions

This study has shown that the assurance of fixing performance under fire conditions demands:

- Knowledge of the ‘critical time’ for which M&E is required to stay in place to support safe evacuation of occupants, and intervention by the fire service.
- An understanding of the heat uptake rate of the timber ceiling so that the interface depth of the unheated wood is known at the ‘critical time’
- The selection of a fixing whose embedment of thread at depths greater than the unheated interface at the critical time assures full retention of the ambient load bearing capability of the fixing at the ‘critical time’ (all material may be lost up to the interface but the fixing maintains 100% of its design capability)
- The selection of the fitting performs as a ‘skinny’ fixing – minimising conduction along its length
- The fitting is made of hardened steel and will not melt or break in fire.

Whilst other solutions to the problem are certainly plausible, such as the angling of fixings into the timber, in conversation with suppliers and installers this simple set of requirements is practical, can be supported by existing products, and on balance requires little greater effort than the measures already taken but warranting significant performance enhancement under fire.

The adoption of these simple measures will significantly improve firefighter safely in the conduct of their duties in the already complex environment of mass timber buildings.

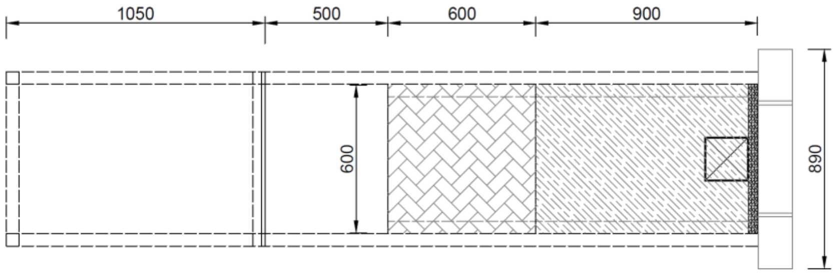
11 Next steps

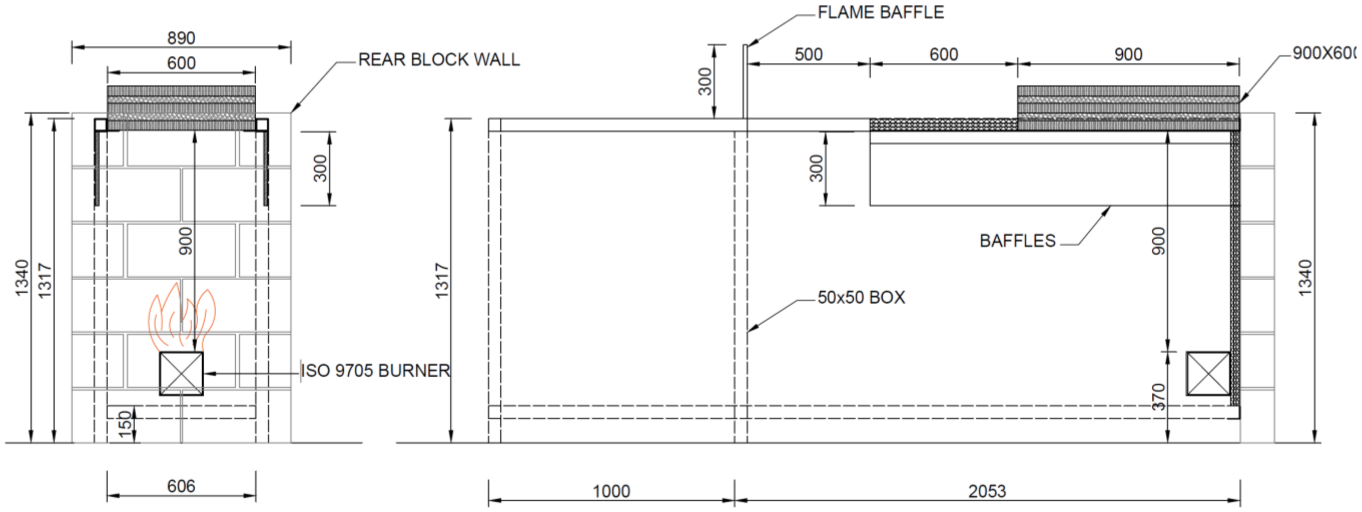
- Production of a short form briefing bulletin
- Presentation of findings to:
  - NFCC
  - BSI
  - M&E suppliers and installers
  - Installers and manufacturers of mass timber buildings and associated products
- To inform CROSS by anonymous submission (Collaborative Reporting for Safer Structures UK & International)

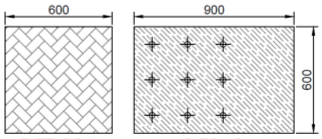
12 Acknowledgements

Many thanks the Fire Service Research and Training Trust for recognising the need for this study and the investment they have made. Thanks too for the additional funding provided by RISCAuthority, and the support provided by FPA Laboratories where the tests were conducted. The generosity of KLM and Midfix in product and expertise was also greatly valued. On a personal note, it was a pleasure working in the laboratory with Dale Kinnersley and with Simon Corbey of ASBP on bid and programme management.

Appendix A – Test Rig Design Details

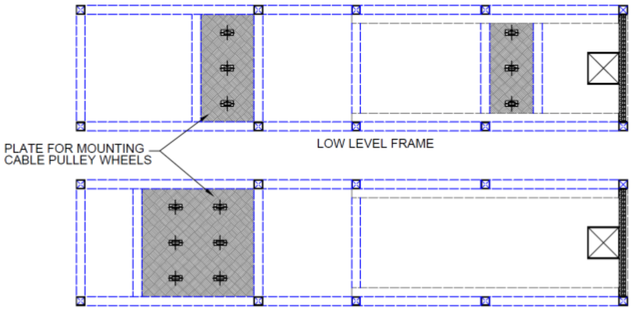






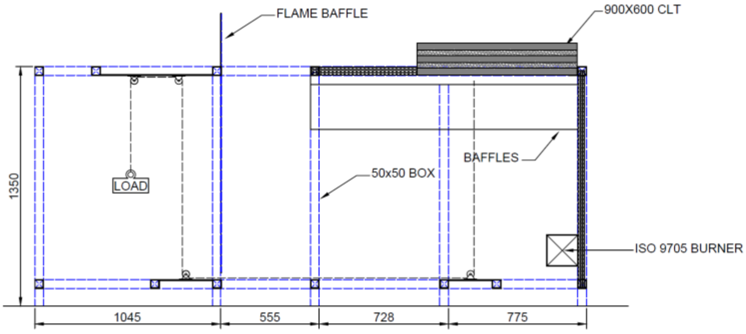
EXTENSION

CLT SLAB

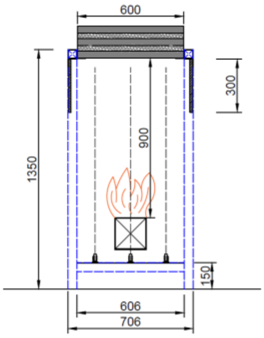


LOW LEVEL FRAME

HIGH LEVEL FRAME



SIDE ELEVATION



FRONT ELEVATION