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The CodeRed experiments - Evidence based fire safety solutions for timber buildings

Enabling safe and sustainable buildings

Dr Panos Kotsovinos

29/08/2022

Mass timber construction

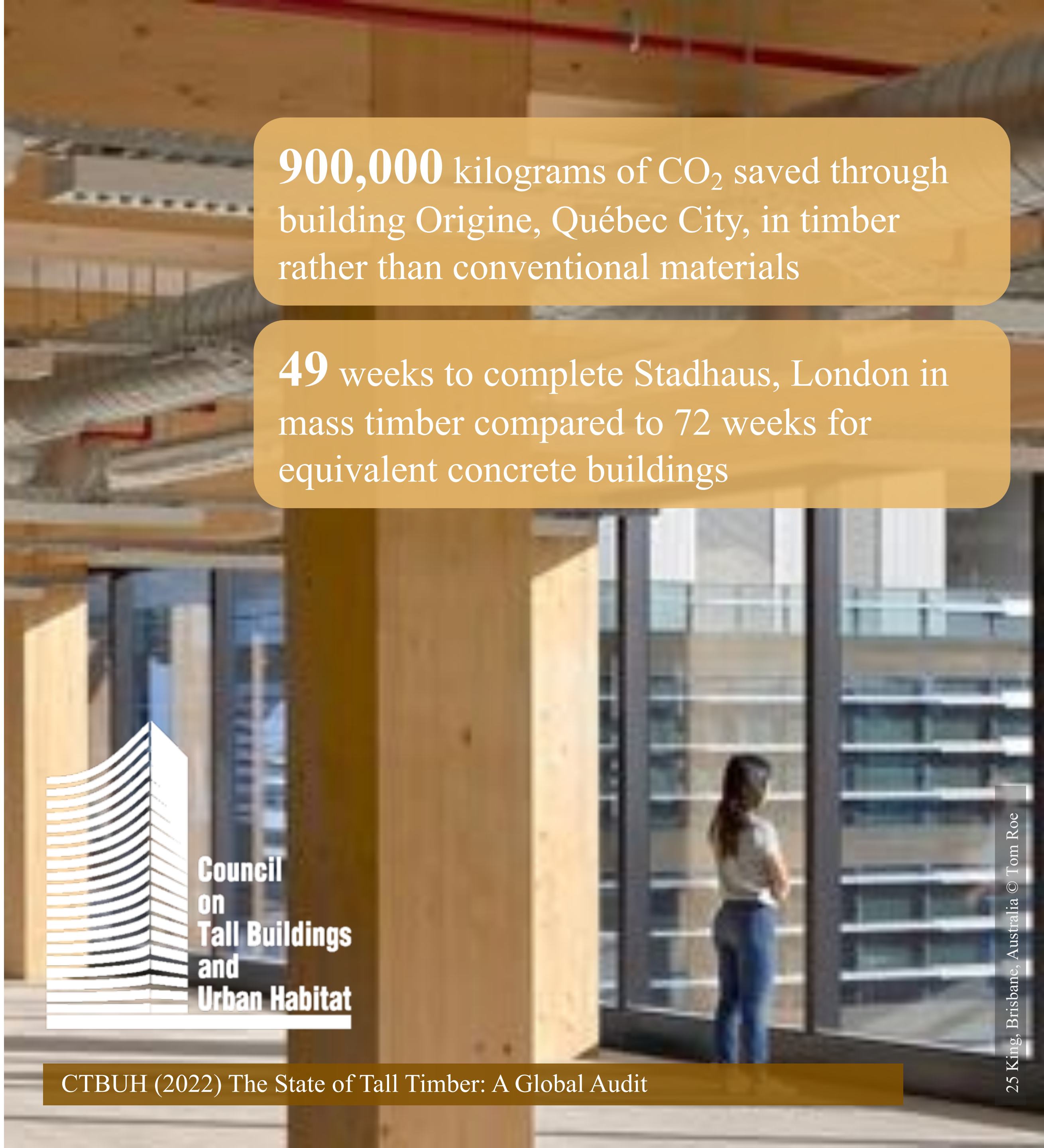
Increasing demand by governments, developers, suppliers

DRIVEN BY:

- Climate crisis

  Desire to reduce the embodied carbon in buildings and infrastructure

- Speed of construction
- Cost savings
- Architectural aspirations



900,000 kilograms of CO_2 saved through building Origine, Québec City, in timber rather than conventional materials

49 weeks to complete Stadhaus, London in mass timber compared to 72 weeks for equivalent concrete buildings

Council on Tall Buildings and Urban Habitat

CTBUH (2022) The State of Tall Timber: A Global Audit

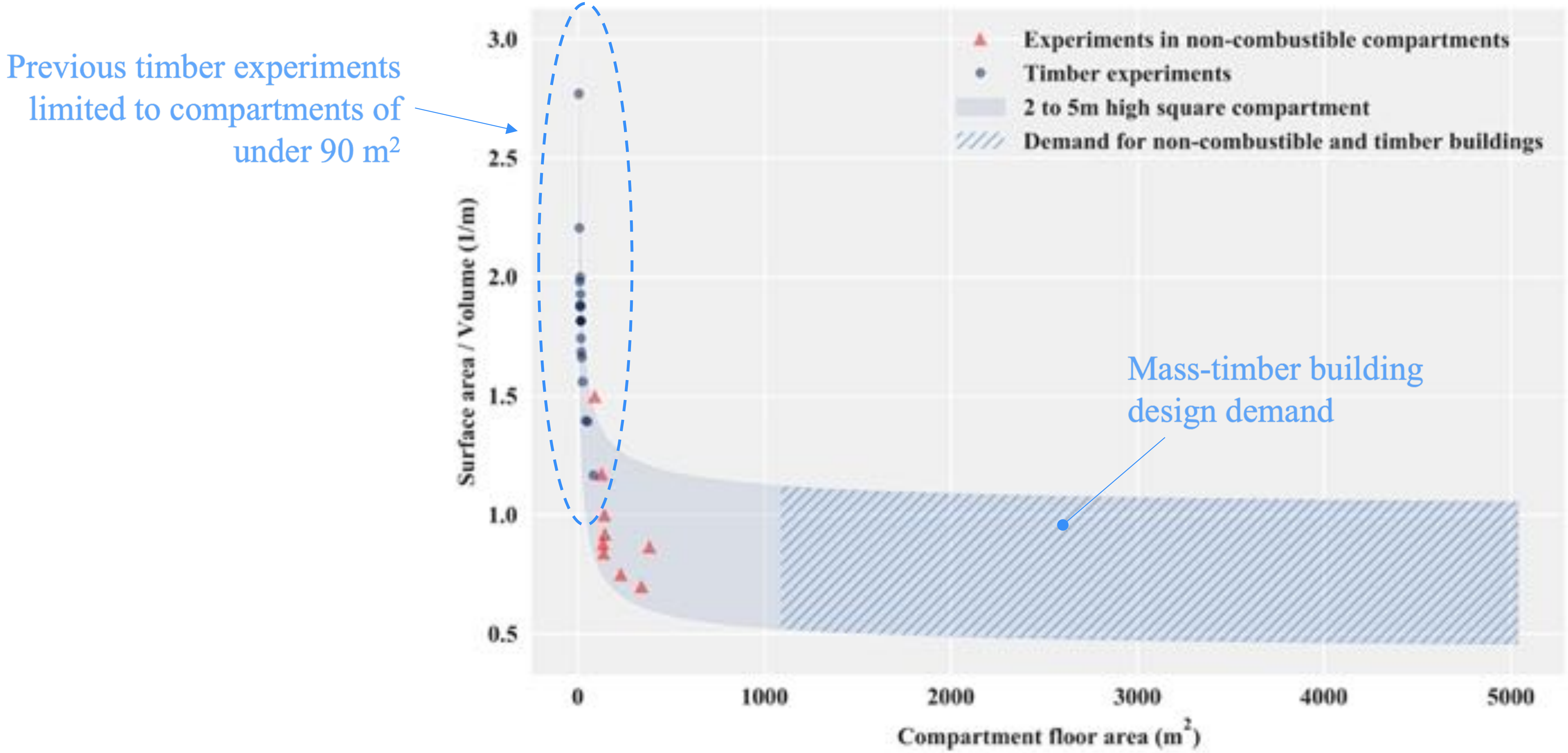
25 King, Brisbane, Australia © Tom Roe

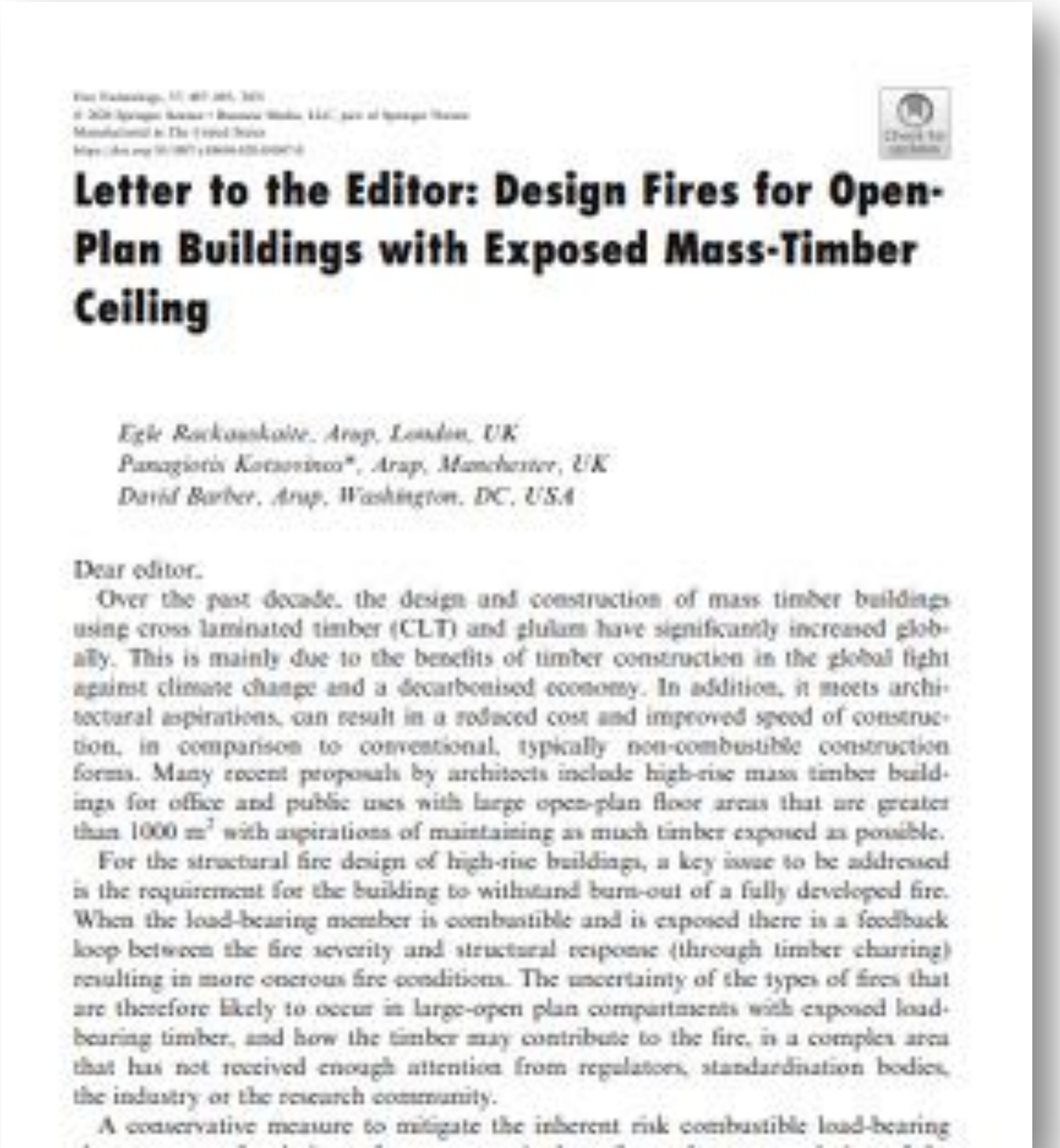
The challenge

Evidencing that the use of timber at scale can be safe

Current Knowledge

Observations in fire tests with exposed CLT





Letter to the Editor: Design Fires for Open-Plan Buildings with Exposed Mass-Timber Ceiling

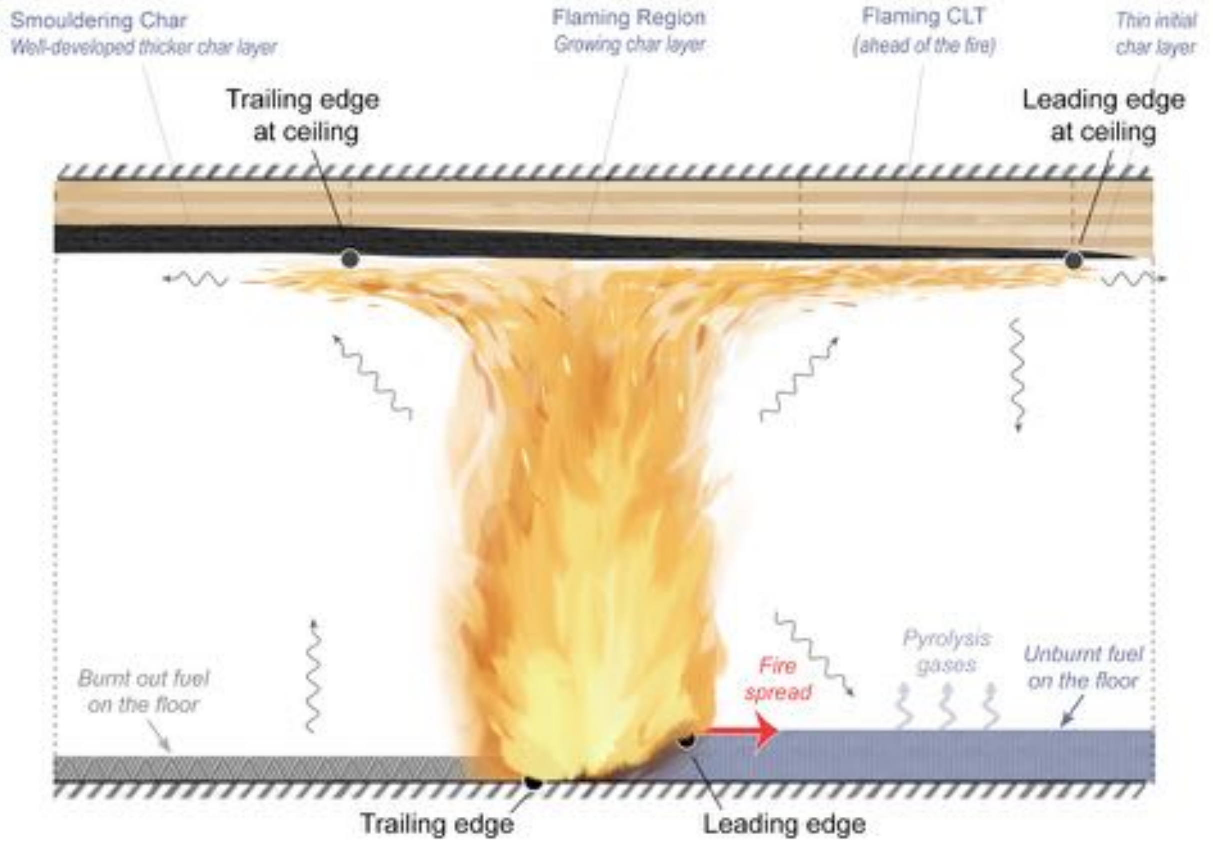
Egle Rackauskaite, Arup, London, UK
Panagiotis Kotsovinos, Arup, Manchester, UK*
David Barber, Arup, Washington, DC, USA

Dear editor,

Over the past decade, the design and construction of mass timber buildings using cross laminated timber (CLT) and glulam have significantly increased globally. This is mainly due to the benefits of timber construction in the global fight against climate change and a decarbonised economy. In addition, it meets architectural aspirations, can result in a reduced cost and improved speed of construction, in comparison to conventional, typically non-combustible construction forms. Many recent proposals by architects include high-rise mass timber buildings for office and public uses with large open-plan floor areas that are greater than 1000 m^2 with aspirations of maintaining as much timber exposed as possible.

For the structural fire design of high-rise buildings, a key issue to be addressed is the requirement for the building to withstand burn-out of a fully developed fire. When the load-bearing member is combustible and is exposed there is a feedback loop between the fire severity and structural response (through timber charring) resulting in more onerous fire conditions. The uncertainty of the types of fires that are therefore likely to occur in large-open plan compartments with exposed load-bearing timber, and how the timber may contribute to the fire, is a complex area that has not received enough attention from regulators, standardisation bodies, the industry or the research community.

A conservative measure to mitigate the inherent risk combustible load-bearing



- Fire design methodologies have been developed based on 84m^2 compartments and → *require further validation for large compartments*
- Travelling fires methodology not developed for application to timber structures
- Knowledge gaps and research needs to apply travelling fires to timber

CodeRed

Large scale CLT fire experiments

CodeRed

Research aims

SEEK TO UNDERSTAND:

1. The **effect of exposed timber on fire dynamics** in large open-plan compartments
2. The **decay behaviour** of exposed mass timber surfaces
3. How **observed fires compare to the standard fire exposure** (e.g. time-equivalence)
4. The **travelling fire spread rates** in large compartments when lined with timber construction
5. The **charring rates in natural fires** as a function of received radiation

CodeRed #02:

1. The **effect of reduced ventilation (50%)** in large open-plan compartments with exposed timber

CodeRed #04 :

1. The **effect of encapsulation (50%)** in large open-plan compartments with exposed timber

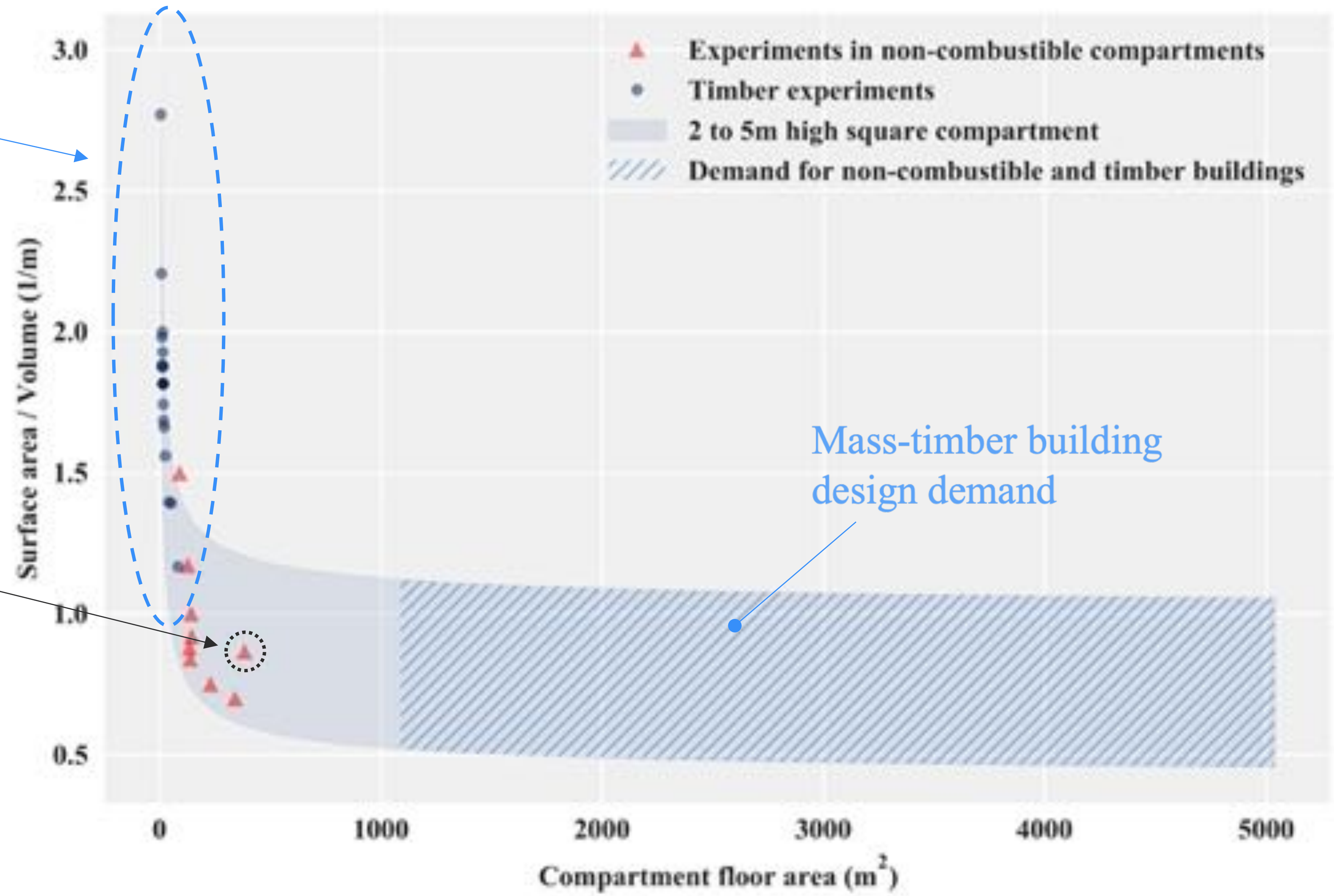
Images from construction of CodeRed #01

Previous travelling fire experiments

Observations in fire tests with exposed CLT

Previous timber experiments limited to compartments of under 90 m^2

x-ONE & x-TWO
Largest fire experiments in terms of compartment floor area (~**380m^2**) conducted to date worldwide



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Steering Group

Close academic and industry collaboration with oversight by steering group, and input from project application

Fabienne Robert

CERIB Project Director Fire Test House

David Barber

Global timber fire safety lead, EC5 committee

Prof. Andrew Lawrence

Steering Group – structural timber expert, EC5 committee

Prof. Guillermo Rein

Steering Group – ICL fire dynamics, smouldering expert

Alistair Murray

Steering Group – Arup Fire UK Leader

Dr. Clare Perkins

Steering Group – materials expert

Dr. Susan Lamont

Steering Group – global fire skills lead

Eoin O'Loughlin

Steering Group – global structural fire skills lead

Harry Mitchell

Steering Group – PhD student, ICL

Rikesh Amin

Steering Group – PhD student, ICL

Daniel Thomson

Fire UK Timber skills lead

The building

Experimental layout for CodeRed

- 352 m^2 | 10.27 m wide, 34.27 m long, 3.1 m high

The building

Experimental layout for CodeRed

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- CLT ceiling comprises 5-ply CLT with MUF adhesive
- Two timber columns (glulam)
- One protected steel column

The building

Experimental layout for CodeRed

- ~370 MJ/m^2 wood crib

Instrumentation

CodeRed #01 shown indicatively

PT - plate thermocouples

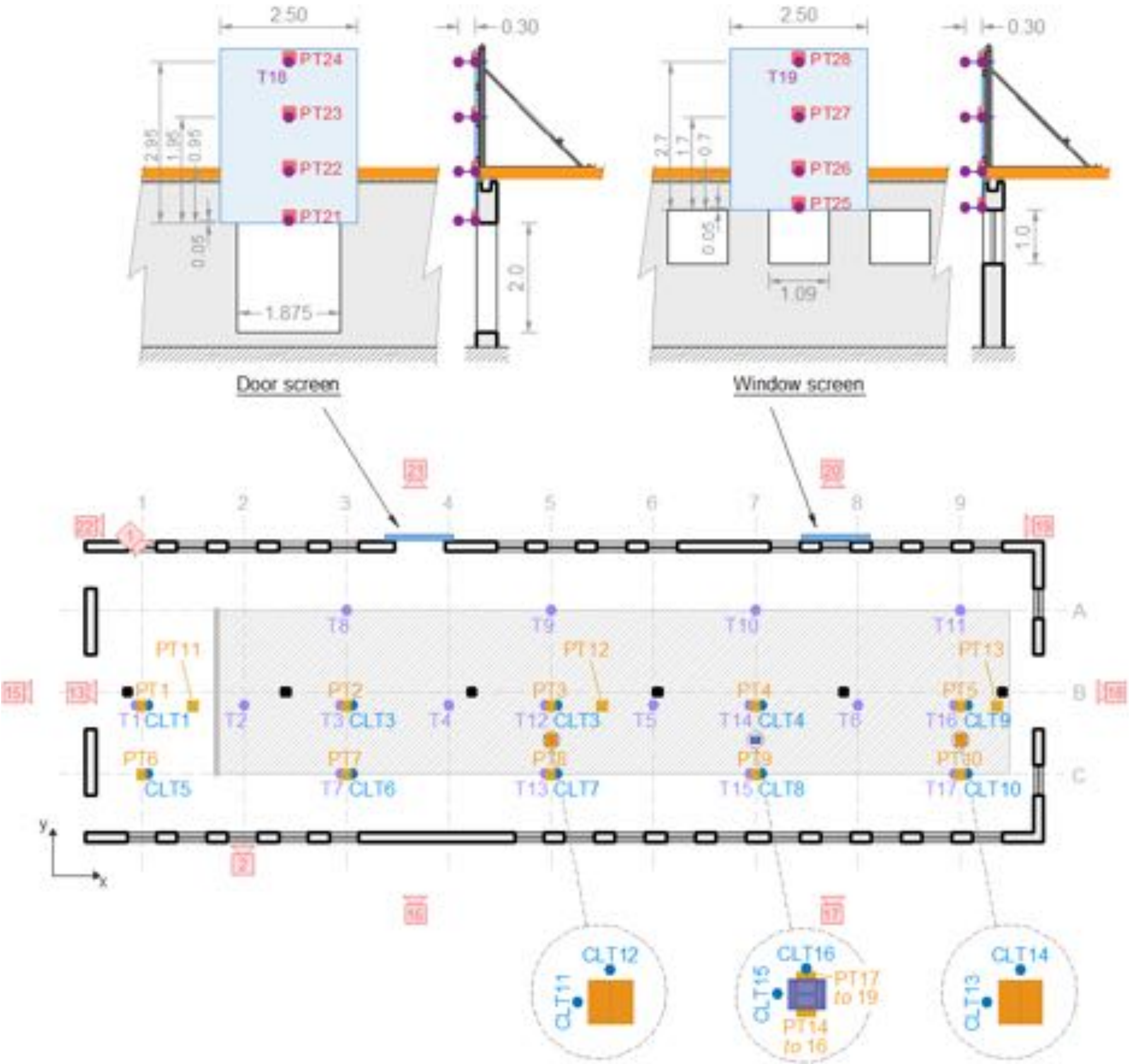
PT1 to 13: *100mm below the ceiling*
PT14 to 19: *100mm from the steel column at 100, 700 & 2100mm below the ceiling*
PT21 to 28: *fixed to the external screens*

CLT - Type-K thermocouples within CLT panels

CLT1 to 16: *embedded 20, 40, 60 & 80 mm from the exposed surface*

T - Type-K thermocouple trees

T1 to 11: *100, 700 & 2100 mm below the ceiling*
T2 to 17: *100, 700, 2100 & 2800 mm below the ceiling*
T18 to 19: *0 and 300 mm from the external screens*

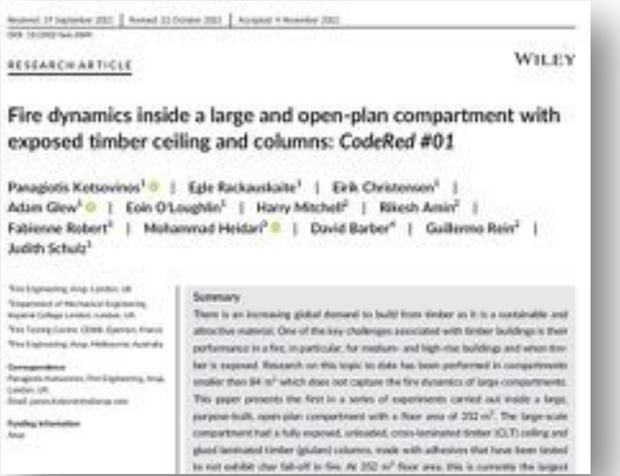


The CodeRed experiment series (2021)

Localised water mist system test

	CodeRed #01	CodeRed #02	CodeRed #03	CodeRed #04
Ventilation	21%	**10%**	10%	21%
Encapsulation	none	none	none	**50%**

Publication in progress



RESEARCH ARTICLE

WILEY

Fire dynamics inside a large and open-plan compartment with exposed timber ceiling and columns: *CodeRed #01*

Panagiotis Kotsovinos | Egle Rackauskaite | Eirik Christensen | Adam Glew | Eoin O'Loughlin | Harry Mitchell | Rikesh Amin | Fabienne Robert | Mohammad Heidari | David Barber | Guillermo Rein | Judith Schulz

RESEARCH ARTICLE

WILEY

Impact of ventilation on the fire dynamics of an open-plan compartment with exposed timber ceiling and columns: *CodeRed #02*

Panagiotis Kotsovinos | Eirik G. Christensen | Egle Rackauskaite | Adam Glew | Eoin O'Loughlin | Harry Mitchell | Rikesh Amin | Fabienne Robert | Mohammad Heidari | David Barber | Guillermo Rein | Judith Schulz

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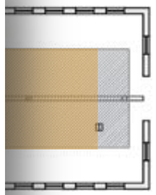
FROM THE PUBLISHER OF FIRE PROTECTION ENGINEERING MAGAZINE

The Effectiveness of a Water Mist System in an Open-plan Compartment with an Exposed Timber Ceiling: *CodeRed #03*



encapsulation

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CodeRed #01

Impact of adding CLT


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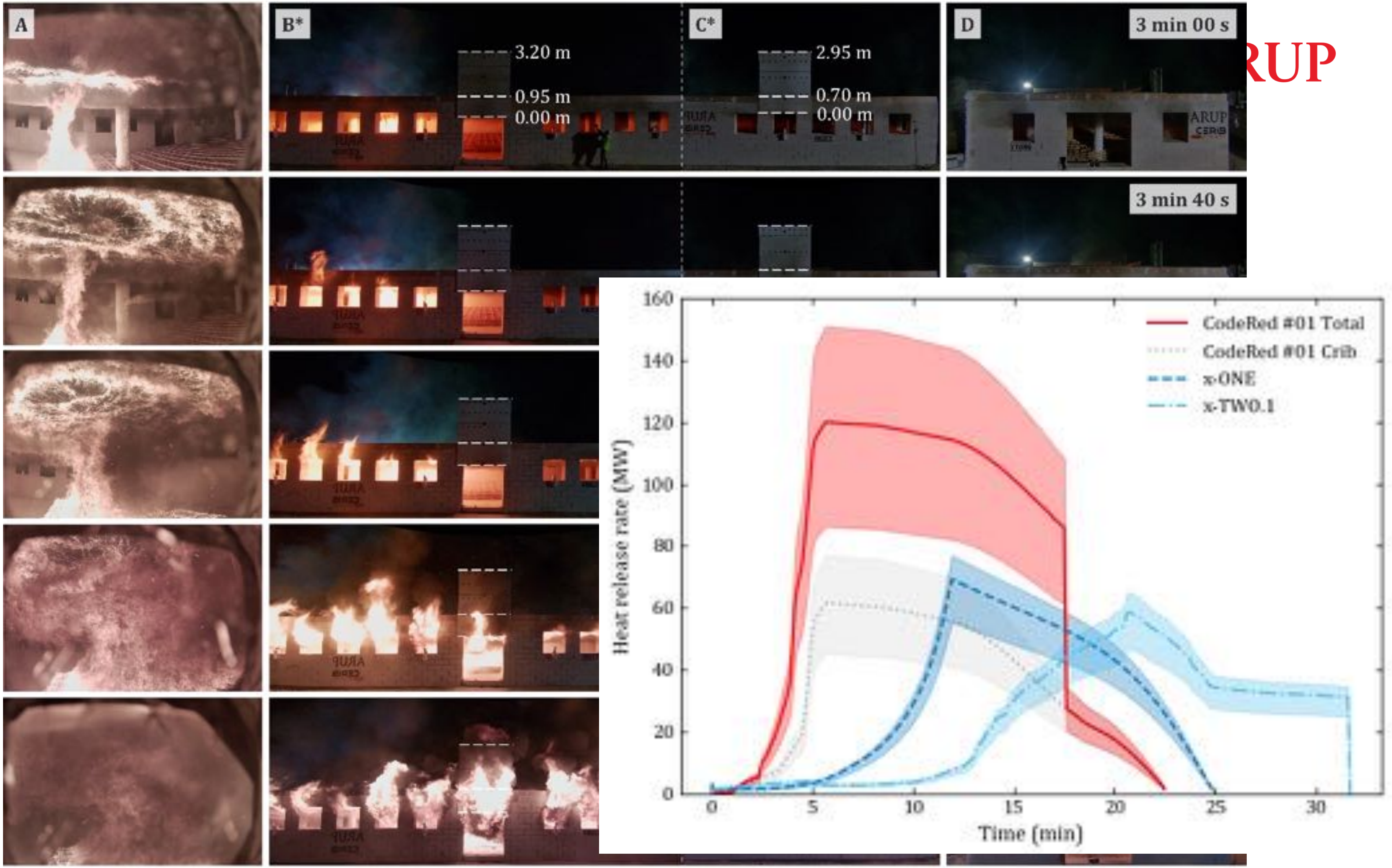
CERIB
Fire Testing Centre


~1.5 min


A
B*
3.20 m
0.95 m
0.00 m
C*
2.95 m
0.70 m
0.00 m
D
3 min 00 s
3 min 40 s
CodeRed #01 Total
CodeRed #01 Crib
x-ONE
x-TWO.1
Heat release rate (MW)
Time (min)
0
20
40
60
80
100
120
140
160
0
5
10
15
20
25
30

~6 min

AM – 10th March

AM – 10th March

Smouldering

CodeRed #01

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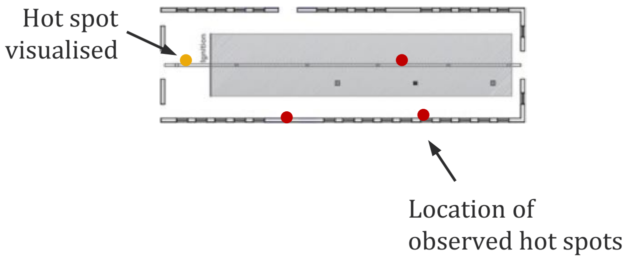
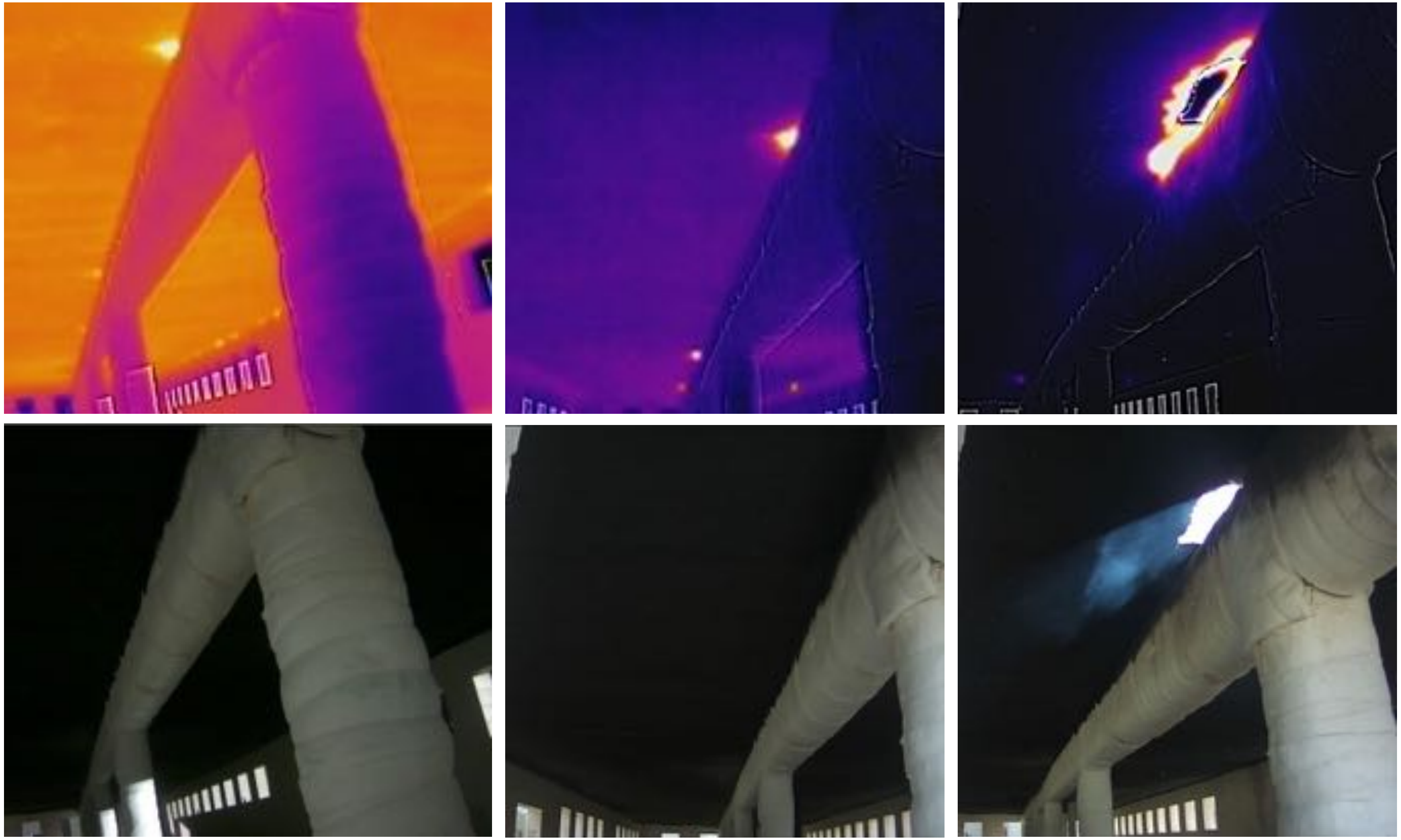


t = 3.18 h | t = 14.28 h | t = 38.08 h

Infrared

Visual



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RESEARCH ARTICLE

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Fire dynamics inside a large and open-plan compartment with exposed timber ceiling and columns: *CodeRed #01*

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Funding information

Arup

Summary

There is an increasing global demand to build from timber as it is a sustainable and attractive material. One of the key challenges associated with timber buildings is their performance in a fire, in particular, for medium- and high-rise buildings and when timber is exposed. Research on this topic to date has been performed in compartments smaller than 84 m^2 which does not capture the fire dynamics of large compartments. This paper presents the first in a series of experiments carried out inside a large, purpose-built, open-plan compartment with a floor area of 352 m^2. The large-scale compartment had a fully exposed, unloaded, cross-laminated timber (CLT) ceiling and glued laminated timber (glulam) columns, made with adhesives that have been tested to not exhibit char fall-off in fire. At 352 m^2 floor area, this is currently the largest

CodeRed #02

Impact of reduced ventilation

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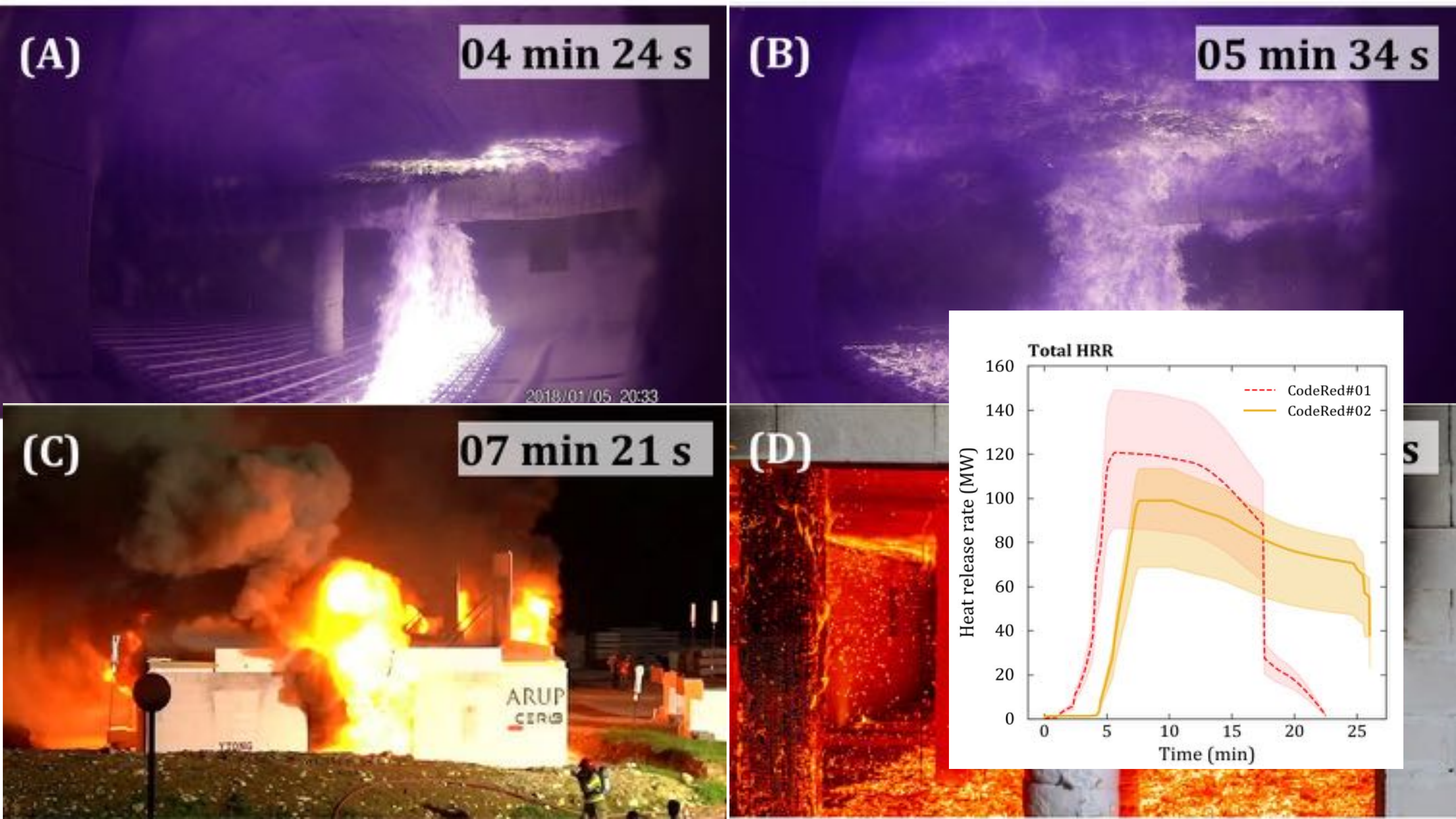
(A)
04 min 24 s
2018/01/05 20:33
(B)
05 min 34 s
Total HRR
Heat release rate (MW)
Time (min)
CodeRed#01
CodeRed#02
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
(C)
07 min 21 s
ARUP
(D)

External flaming

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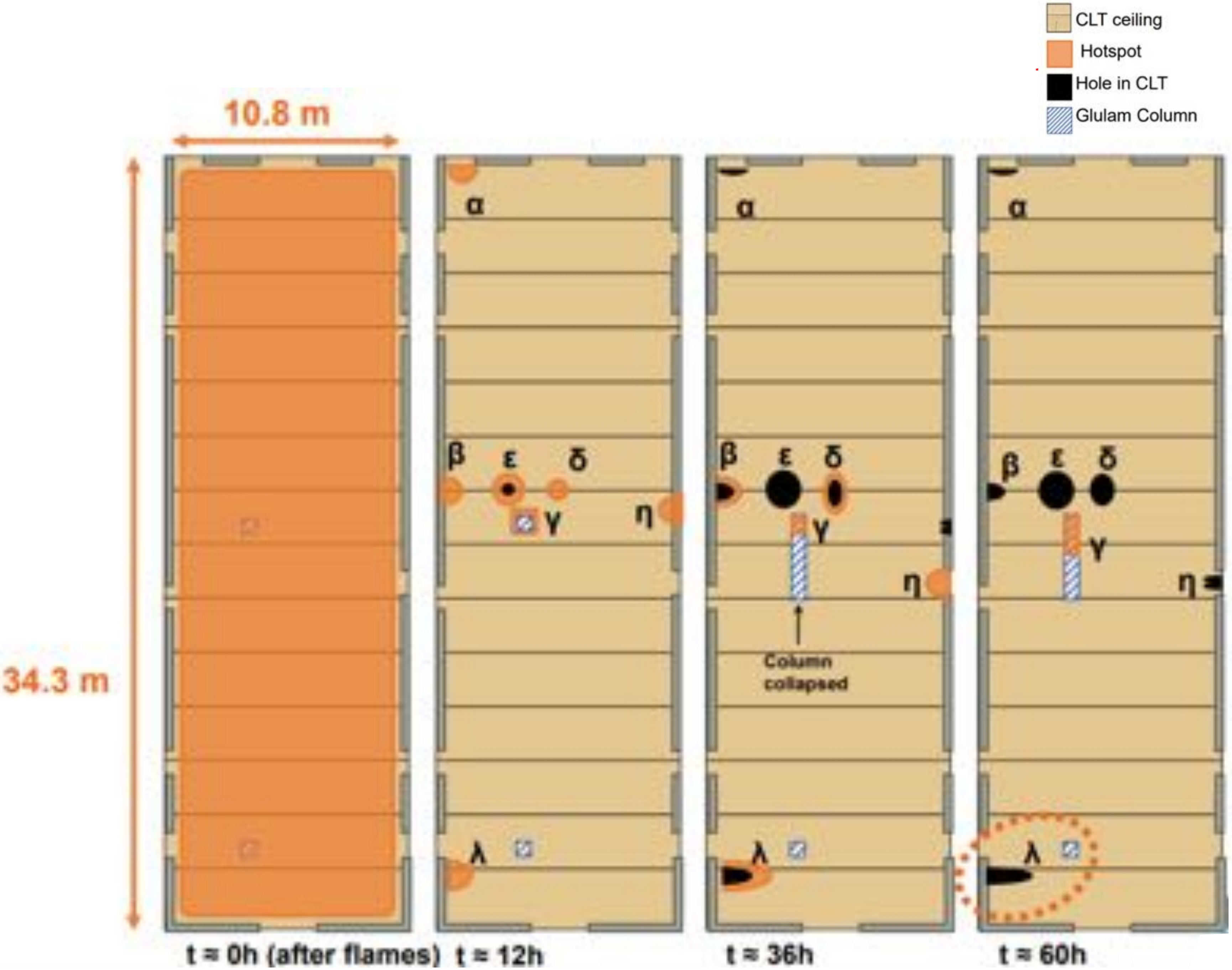
- Slightly **greater external flaming** height than CR #01;
  3 to 3.5 m in height
- Much ‘smokier’ (incomplete combustion)
- Pulsating flames
- Large lateral flame extensions

Smouldering

CodeRed #02



Mitchell, H., Amin, R., Kotsovinos, P., and Rein, G. (2022), *Structural Hazards of Smouldering in Tall Timber Buildings*, SFPE Annual Conference, Detroit

Imperial College London

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RESEARCH ARTICLE

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Impact of ventilation on the fire dynamics of an open-plan compartment with exposed timber ceiling and columns: *CodeRed #02*

Panagiotis Kotsovinos[1] | Eirik G. Christensen[1] | Egle Rackauskaite[1] | Adam Glew[1] | Eoin O'Loughlin[1] | Harry Mitchell[2] | Rikesh Amin[2] | Fabienne Robert[3] | Mohammad Heidari[3] | David Barber[4] | Guillermo Rein[2] | Judith Schulz[1]

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Abstract

The desire by developers and architects to build mass timber buildings using cross laminated timber (CLT) and glulam has significantly increased globally in the last decade due to its benefits with regards to sustainability as well as other architectural and commercial drivers. This paper presents novel experimental evidence from *CodeRed #02*, the second in a series of large scale fire experiments carried out inside a purpose-built, open-plan compartment to capture fire dynamics in large compartments with exposed timber. The experiment used a continuous wood crib (6 × 29 m) as a controlled movable fuel load. The aim of the *CodeRed #02* experiment was to study the impact of

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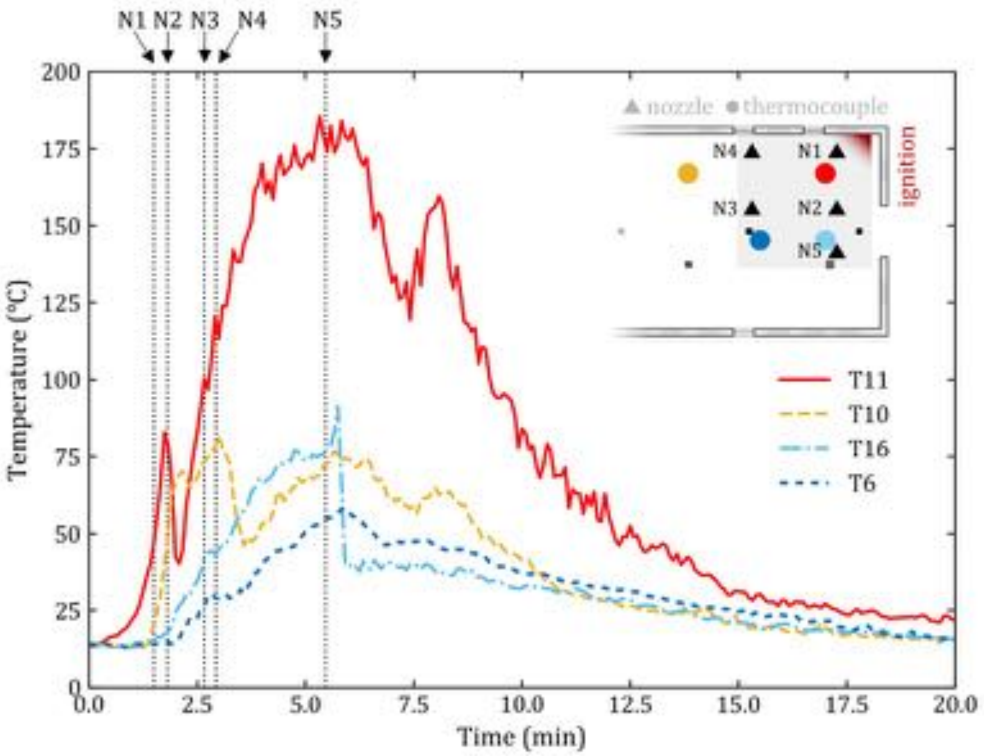
CodeRed #03

Effectiveness of water mist system

CodeRed #03



Nozzle*	Activation time	Average discharge density
N1	1 min 30 s	3.0 litres/m/min
N2	1 min 48 s	
N3	2 min 40 s	2.93 litres/m/min
N4	2 min 56 s	
N5	5 min 28 s	2.88 litres/m/min

Flame height and HRR

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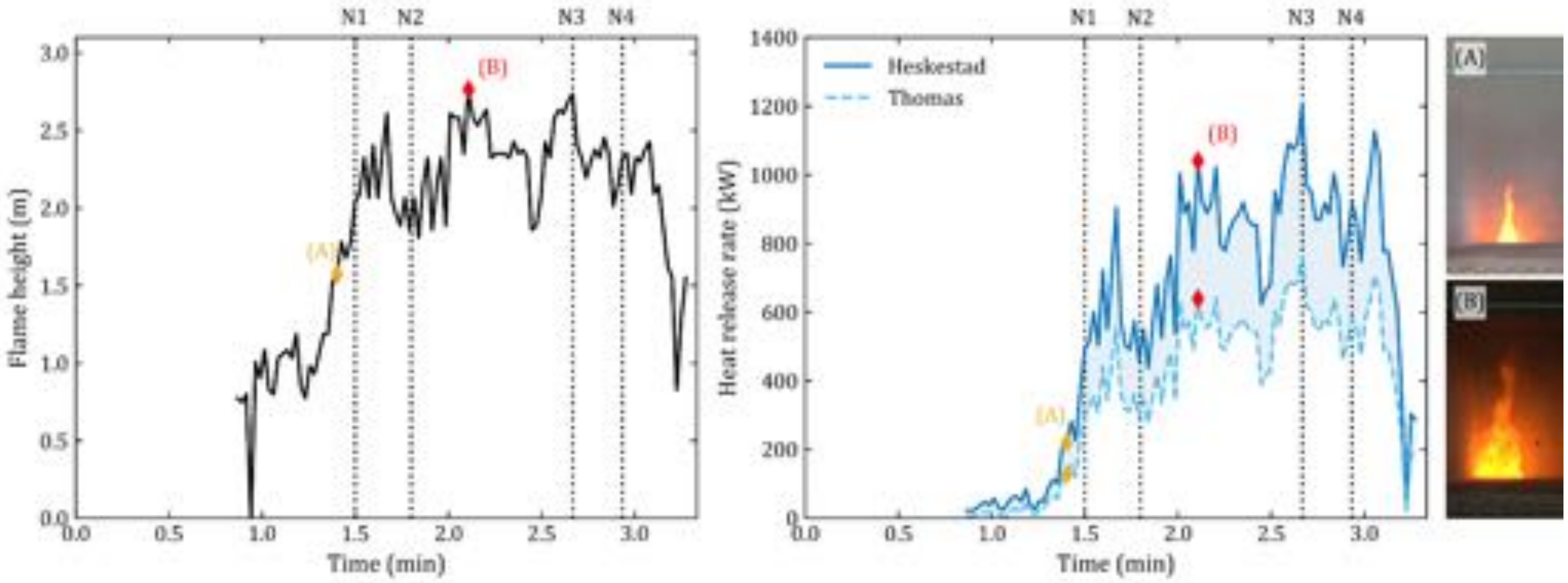

Peak heat release 762-1205 kW, based on the Thomas and Heskestad methods respectively
This was achieved 2 min 40 s after ignition, approximately simultaneously with the activation of the third nozzle

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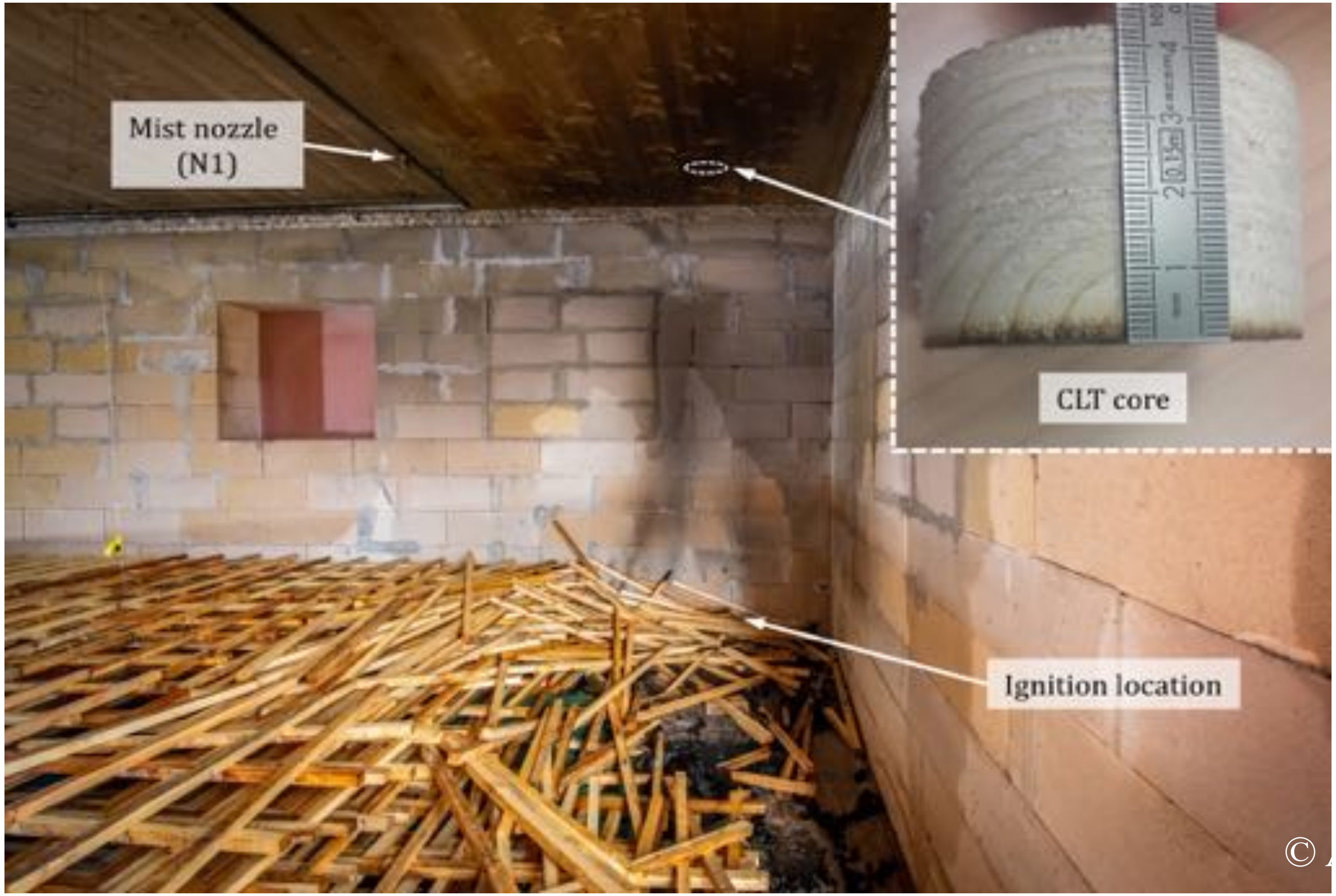
CodeRed #03



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FROM THE PUBLISHER OF FIRE PROTECTION ENGINEERING MAGAZINE

The Effectiveness of a Water Mist System in an Open-plan Compartment with an Exposed Timber Ceiling: *CodeRed #03*

By: P. Kotsovinos, E. G. Christensen, J. Gale, H. Mitchell, R. Amin, F. Robert, M. Heidari, D. Barber, G. Rein, and J. Schulz

In recent times, there has been a global surge in the design and construction of mass timber buildings due to their benefits, particularly regarding sustainability. Many of these buildings are proposed to be used in commercial premises with open-plan layouts. As discussed by Rackauskaite et al., [1] compartment fire experiments with exposed timber surfaces published at the time of the authors' review were limited to a compartment area of 84 m^2. In contrast, open floor office spaces often exceed 1000 m^2. To address this limitation in research and meet current design needs, researchers conducted a series of full-scale fire experiments in a very large purpose-built compartment of 352 m^2. To address this limitation in research and meet current design needs, the research team conducted a series of full-scale fire experiments in a very large purpose-built compartment of 352 m^2. The experiments were performed at CERIB's fire testing facility in France. These experiments aim to capture fire dynamics in large compartments with exposed timber and develop solutions for design [2], [3].

This article presents novel experimental evidence from the third experiment in the series, *CodeRed #03*. The aim of the first two experiments (*CodeRed #01 and #02*) were to capture fundamental fire dynamics, while the third experiment was to investigate the effectiveness of a standard water mist suppression system in both limiting fire growth as well as preventing the ignition of an exposed CLT ceiling. Providing an automatic suppression system is a common mitigation measure used in mass timber buildings that, with other protective measures (such as encapsulation, fire-fighting facilities, etc.), aim to address the additional risks introduced by the combustible nature of the structural frame.

Experimental Set-up

The facility where the experiment was undertaken is described in detail in [2]. The compartment has internal dimensions 10.27 × 34.27 × 3.1 *m* with a floor plate area of ~352 m^2. The *CodeRed #03* experiment has several open windows and doors to imitate possible ventilation conditions in an office environment with openable windows during the very early stages of a fire.

The equivalent theoretical fire load that would be present in buildings was replicated by constructing a wood crib in part of the enclosure with a fuel load density of ~ 570 MJ/m^2 and which covered a floor area of ~50 m^2 (7 m × 7 m). The fuel load density corresponds to the 80% fractile for offices as per PD 6688-1-2:2007 "Background paper to the UK National

CodeRed #04

Impact of partial encapsulation

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MEP considerations

MEP fixings included

Indicative of Unistrut support spacings expected for commercial office fitout

Fixing matrix

M8-10 fixings (loaded and unloaded)

Into bare CLT vs into protected CLT

Post fire investigation

Saw cut through fixings into CLT

CodeRed #04

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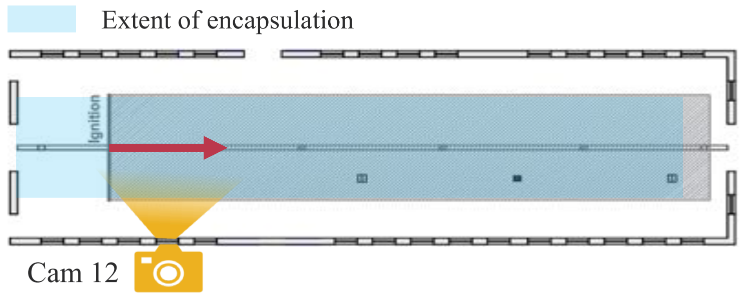
CodeRed #04

Notable events

Initial fire spread



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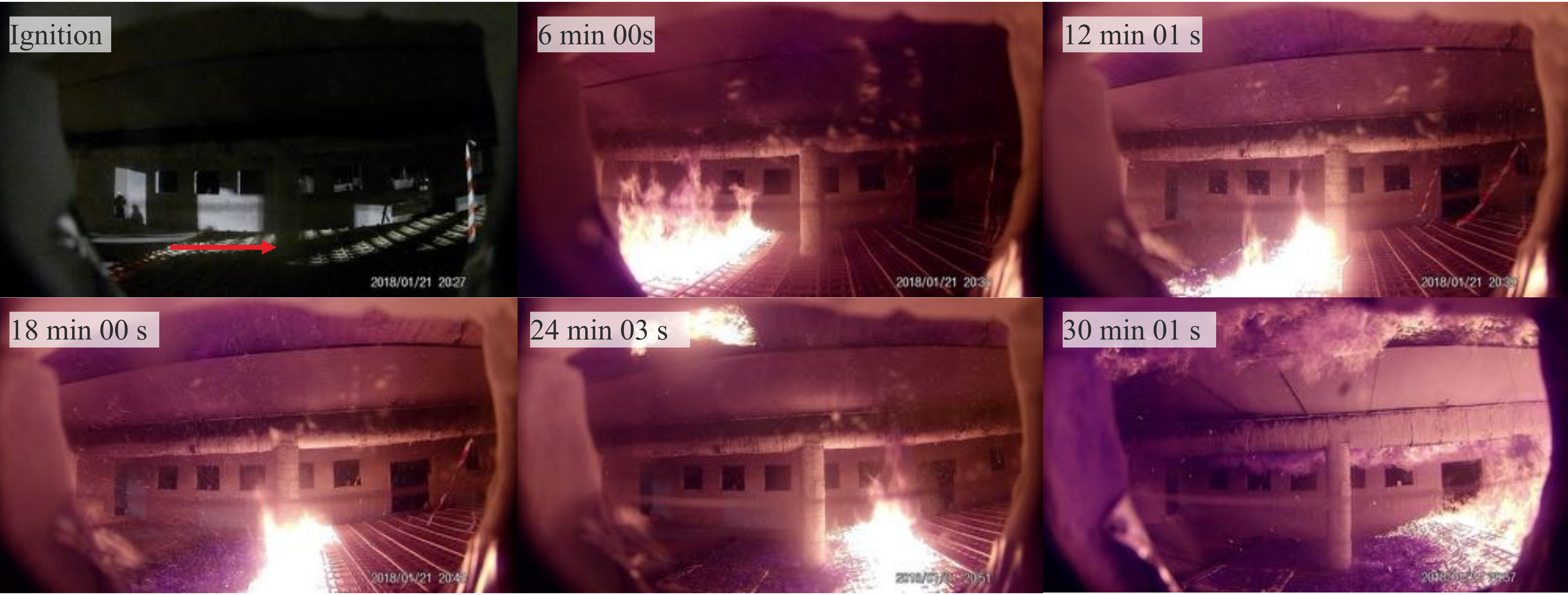
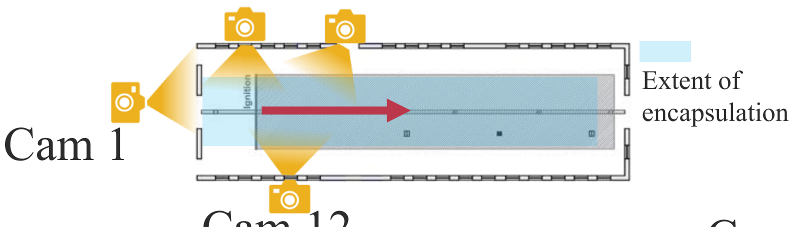


Steady spread of both leading and trailing edge – rapid acceleration post CLT ignition

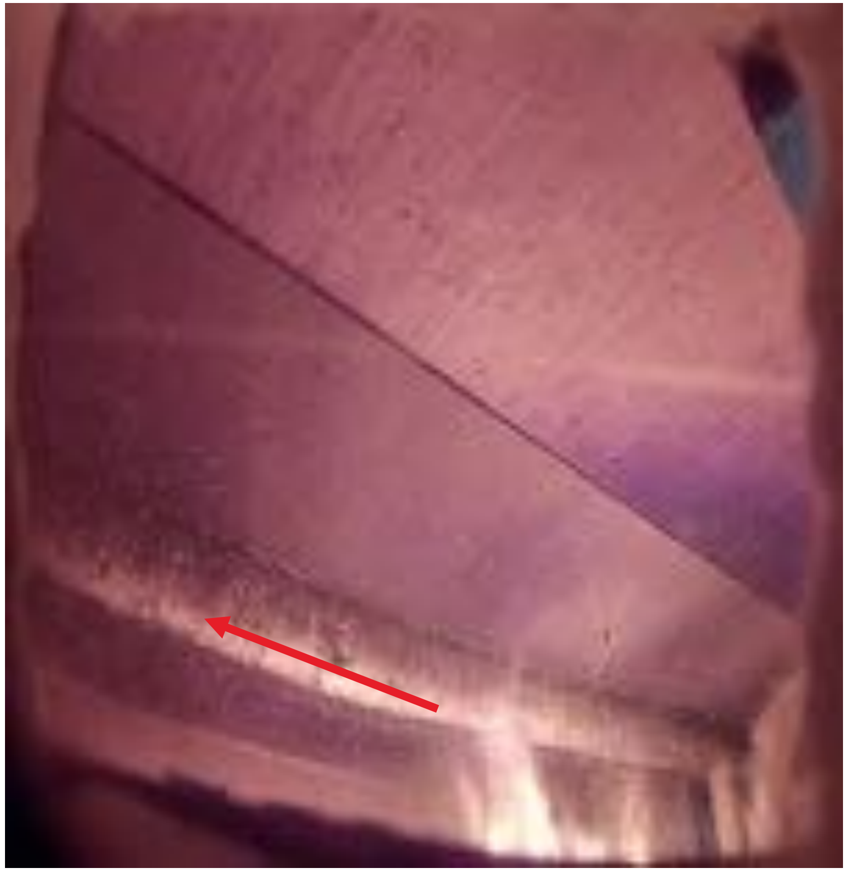
Note: preliminary results

Notable events

CLT ignition



Cam 2



23 min 52 s
Right side CLT ignites, glowing visible on left side! (started 18.47)

24 min 57 s
CLT on left side ignites

25 min 54 s
flaming on right side dies down

27 min 26 s
flaming on left side dies down, as right side grows

28 min 55 s
left sides grows again

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Peak heat flux and temperatures

- Peak heat fluxes are lower in CodeRed#04 than in #01
- Peak temperatures near the ceiling appear to similar between experiments
- Peak temperature close to the ground appear to be between those from a non-combustible and fully exposed timber structure.

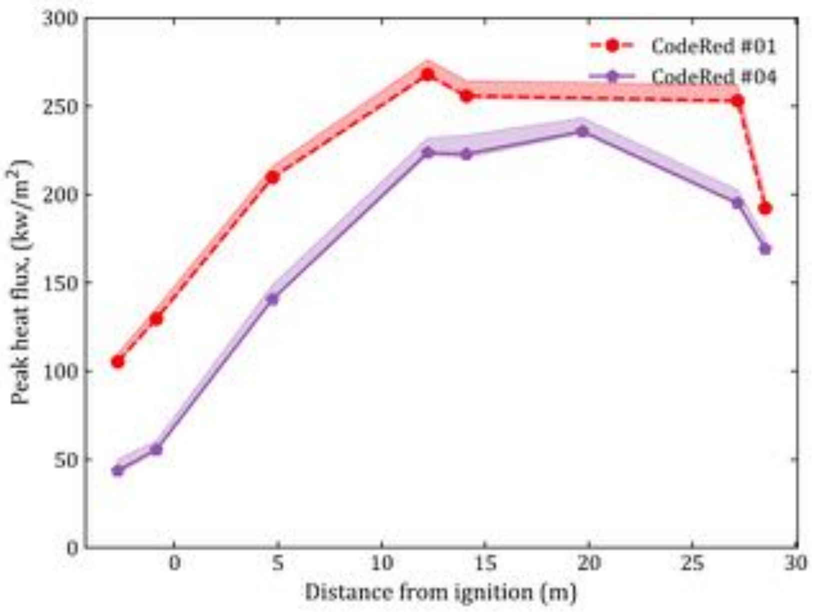


Figure – Peak incident heat flux values measured along the centreline of the compartment near the ceiling.

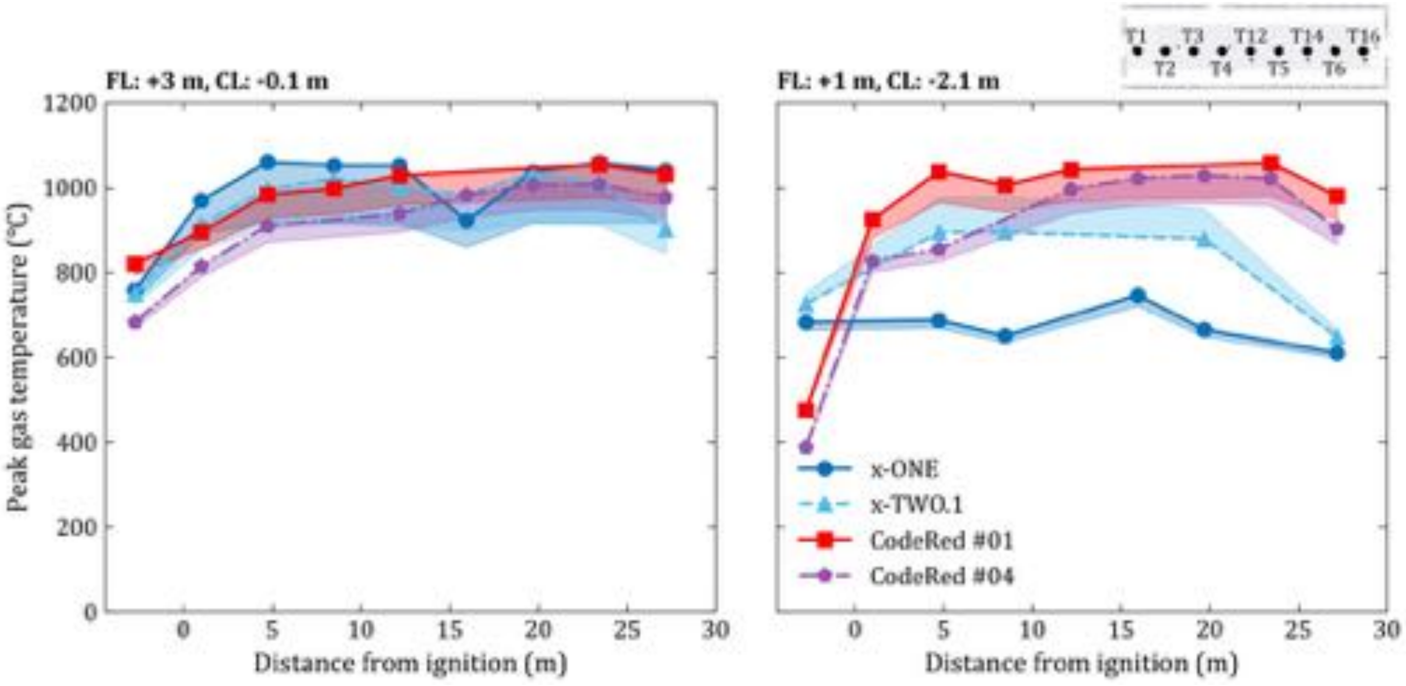
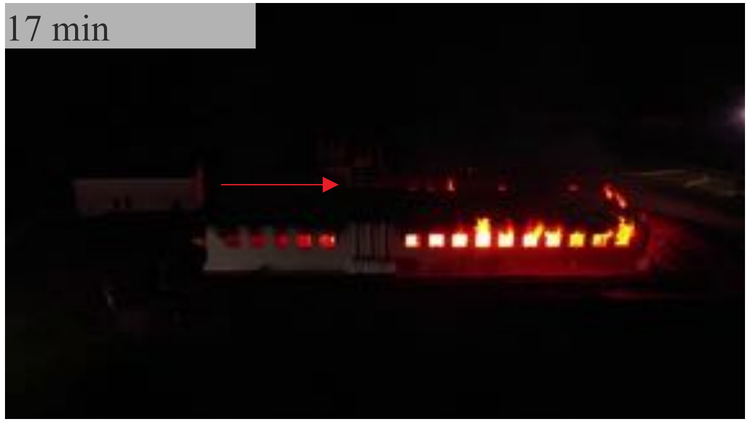


Figure – Peak temperatures measured along the centreline of the compartment.

Note: preliminary results

CodeRed #01



- 6 min

similar

fire travelled to far end
localised external flaming there
CodeRed #04 smaller flames
as expected due to reduced CLT fire load

+ 5 min

12 min and 36 min chosen as approx. mid-point of 'peak' external flaming for each experiment

CodeRed #04

Below encapsulation

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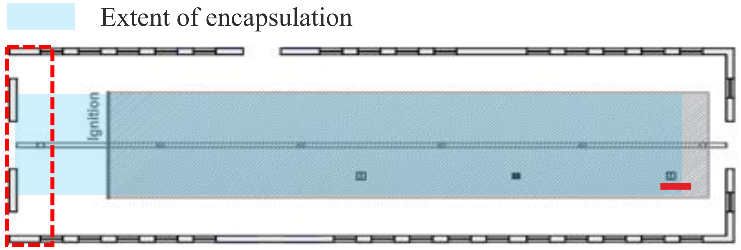
Some smouldering occurred below CLT encapsulation.

This is isolated to the first CLT slab.

Linked to location of smouldering near the junction



6th of January, 23 days after the experiment

At the end of encapsulation

Approximate encapsulation location

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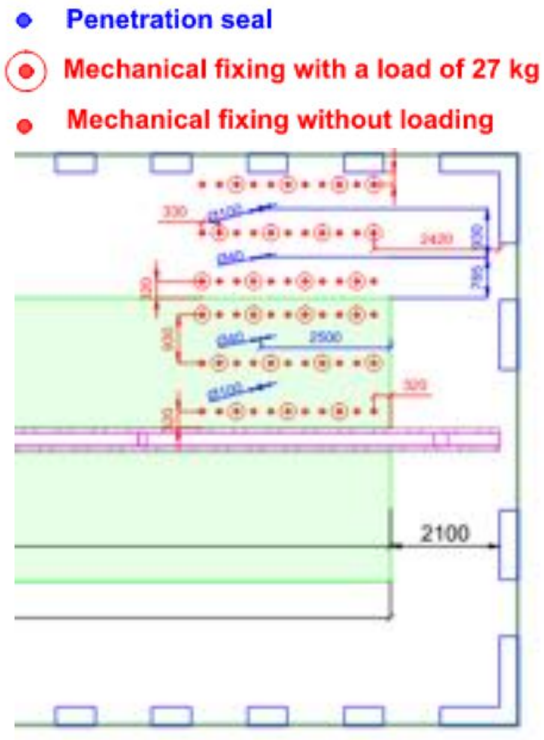
Mechanical fixings

- Included mechanical fixings representative of services hung from ceiling
- Informed by projects currently in concept design
- Half in CLT, half in encapsulated CLT



Key issues identified

These need to be addressed in tall mass timber buildings

- Fire spread across large areas of exposed timber is fast –
- External flaming and the likelihood that fire spread will occur
- The lower portion of exposed columns can be more vulnerable
- Smouldering will occur in joints and interfaces for days afterwards
- Current compartment fire models are not adequately reflecting fire behaviour in large compartments with exposed CLT

Thank you and questions

Dr Panos Kotsovinos
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RESEARCH ARTICLE

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Fire dynamics inside a large and open-plan compartment with exposed timber ceiling and columns: *CodeRed #01*

Panagiotis Kotsovinos[1] | Egle Rackauskaite[1] | Eirik Christensen[1] | Adam Glew[1] | Eoin O'Loughlin[1] | Harry Mitchell[2] | Rikesh Amin[2] | Fabienne Robert[3] | Mohammad Heidari[2] | David Barber[4] | Guillermo Rein[2] | Judith Schulz[1]

RESEARCH ARTICLE

WILEY

Impact of ventilation on the fire dynamics of an open-plan compartment with exposed timber ceiling and columns: *CodeRed #02*

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