Ulster University

Fire and Safety Conference
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The Institution of Fire Engineers
Republic of Ireland Branch

Performance of Modular Timber Assembly in Fire Conditions

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Introduction

Typical wall assembly

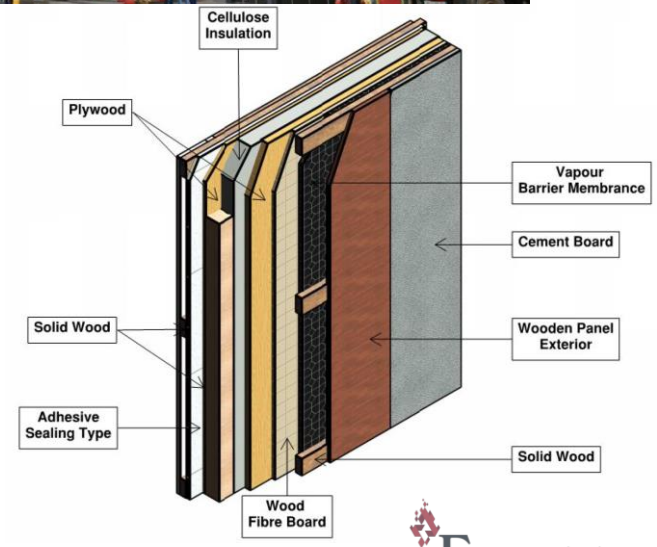
- Wooden panel
- Timber framing
- Insulation materials
- Weather proofing materials
- Cement board
- Gypsum Plasterboard or Fire board

Advantages

- Increased Construction Speed
- Low carbon emissions

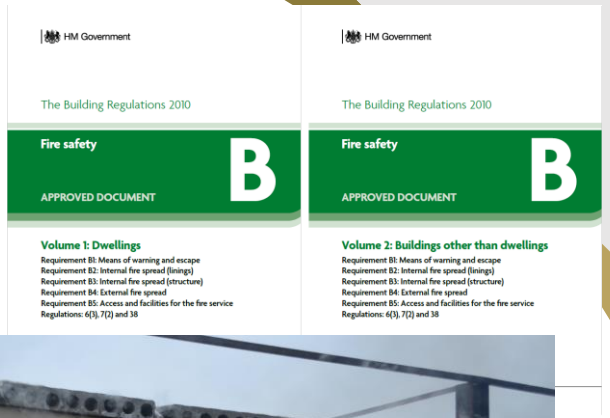
Associated Fire Risks

- Combustible nature
- Structural elements as a source of fuel
- Higher heat release rate
- Increased compartment temperature
- Prolonged fire duration
- Affects structural integrity



- **Stability: connections**

Absence of Regulation in Modular Timber Construction



No Approval Document B to Modern Method in Construction (MMC)

Lack of research and test data available to provide reassurance on the fire performance of buildings constructed using types of MMC

FRSs on construction methodology need to know to intervene in a fire event effectively and safety

Prescriptive fire calculation models and fire resistance tests do not account for the fuel load from the timber structure used for the construction

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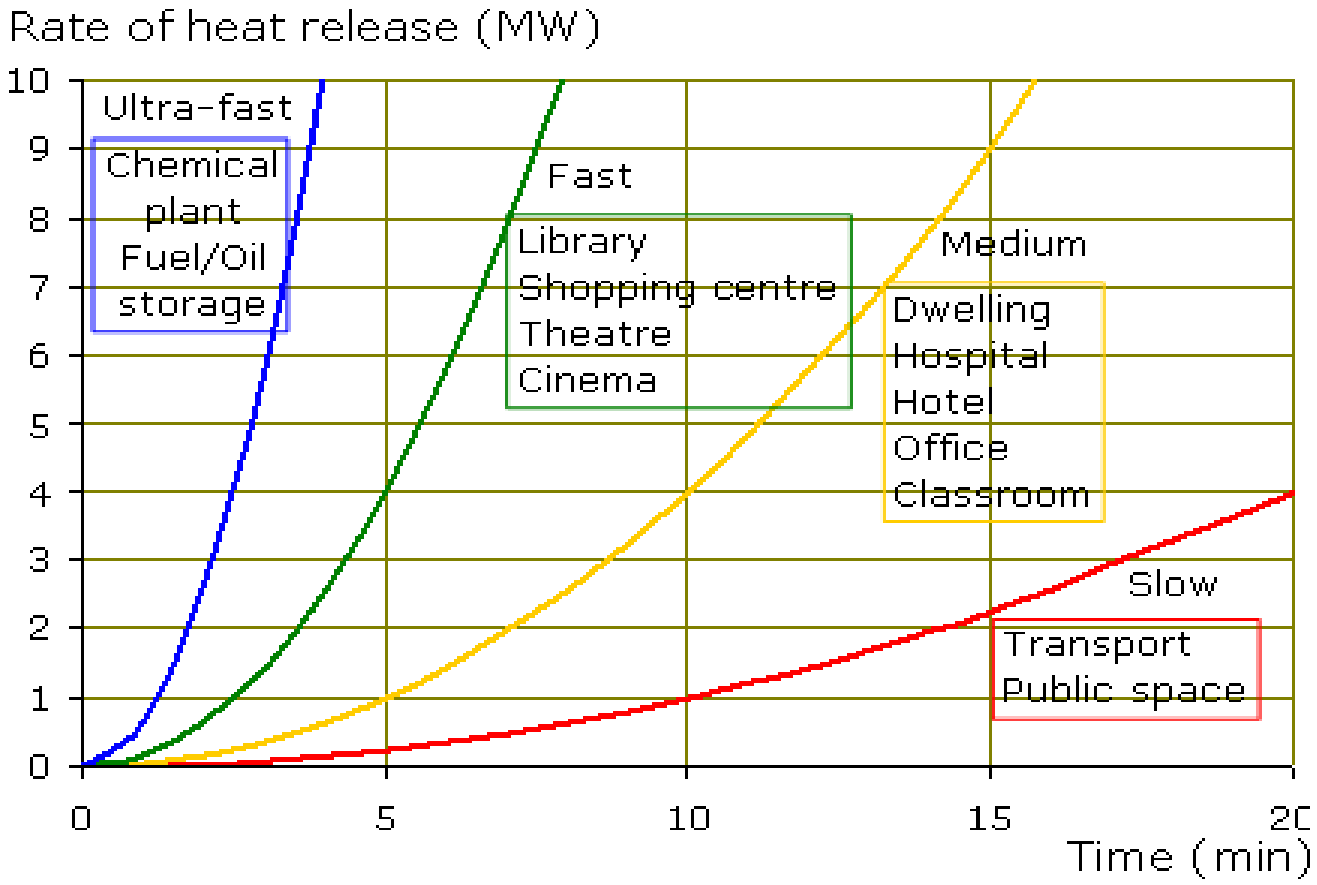
Compartment Failure

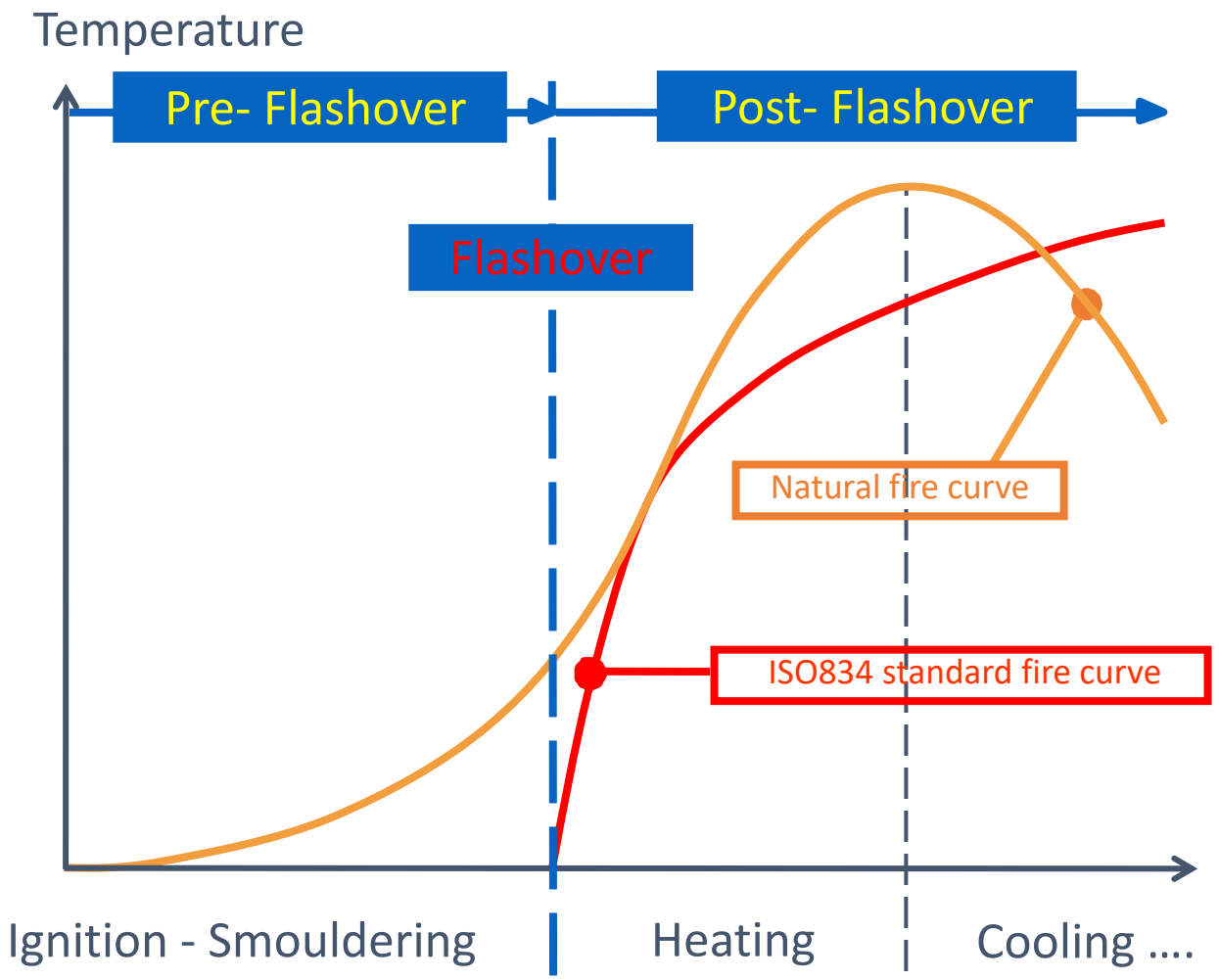
Primark fire: August 2018, Belfast

Grenfell tower June 2017



Heat Release Rates

Influencing parameters



Geometry

- ✓ Boundary properties
- ✓ Ceiling height
- ✓ Opening Area

Fire

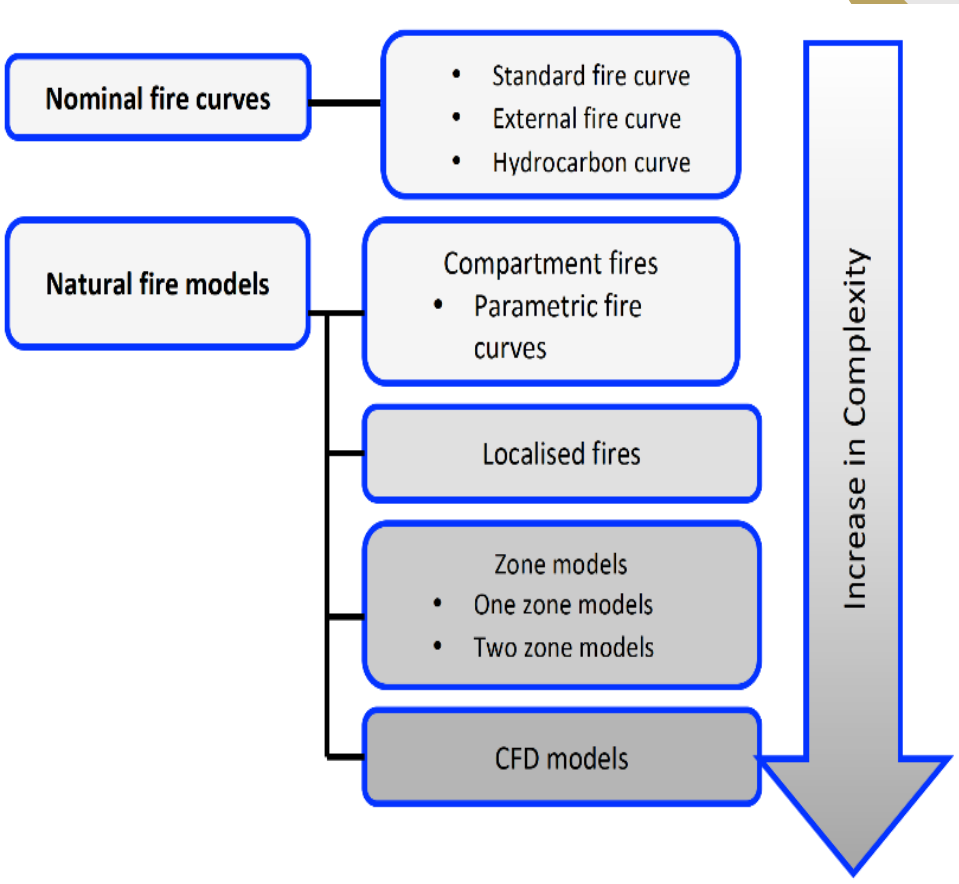
- ✓ Fire surface
- ✓ Rate of heat release

Modular Timber Assembly Design Approach

- Typical buildings - Prescriptive Design
  - Standard fire tests
  - Not actual representation of fire
  - Combustible fire load of timber is not considered

Combination of Prescriptive and Performance Based Design for Modular Timber Assembly

- Performance Characteristics using Experimental tests
- Analysis using natural Fire Models
  - Ozone models
  - CFD models for localized fire
  - CFD model for fully developed fire



(Nadjai Ali 2018)

Research Methodology

Specimen

Specimens procured and kept in temperature-controlled conditioning room

Testing

Moisture content determination

Thermogravimetric Analysis (TGA)

Fourier-transform infrared spectroscopy (FTIR) analysis

Cone Calorimeter

Results

TGA – Moisture content, Thermal degradation and mass loss characteristics

FTIR - Determination of functional group of the material

Cone Calorimeter - Ignition, burning time, heat release rate, mass loss rate, heat of combustion, smoke production etc.

Analysis of test data

Ozone analysis for analyzing compartment temperatures

FDS analysis for compartment temperatures and heat transfer through wall lining

Alternate design proposed for better future designs

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FireSERT Experimental Equipment

- Large, Medium and **Small** Scale

TGA (V&H), DSC, DTA, BC,
FTIR, GC, Micro CC
Rheometer

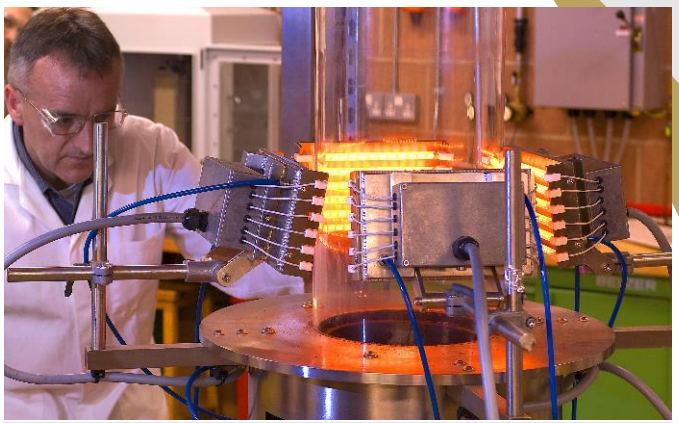
FireSERT Experimental Equipment

- Large, **Medium** and Small Scale

Ignitability Apparatus

Single Flame Source Test – BS EN ISO 11925-2

Cone Calorimeter Apparatus



Universal Flammability Apparatus

BS 476 Part 15
ISO 5660,
ASTM E1354,
ASTM E1474,
ASTM E1740,
ASTM F1550,
ASTM D6113,
CAN ULC 135,

Moisture Content Analysis

Fan Assisted Oven

Experimental Setup

- Apparatus – Fan assisted oven
- Standard – ISO 287 : 2017
- Temperature – 100 – 105 ^{0}C

Specimen

Specimen dimension – 100 mm X 100 mm

Result

Moisture content

Thermogravimetry Analysis

TGA Apparatus

Experimental Setup

- Apparatus : Perkin Elmer Pyris 1 TGA
- Standard : BS EN ISO 11358 - 2014
- Furnace atmosphere : Air / Nitrogen at 50 ml per minute
- Temperature : Up to 800 ^{0}C
- Hang down type specimen loading

Specimen

Weight of specimen : 4 – 9mg
Ceramic crucible for loading specimen

Result

- Moisture loss
- Mass loss
- Pyrolysis temperature
- Rate of decomposition

Fourier Transform Infrared Spectroscopy (FTIR)

Experimental Setup

- Apparatus : Thermo Nicolet Nexus

Specimen

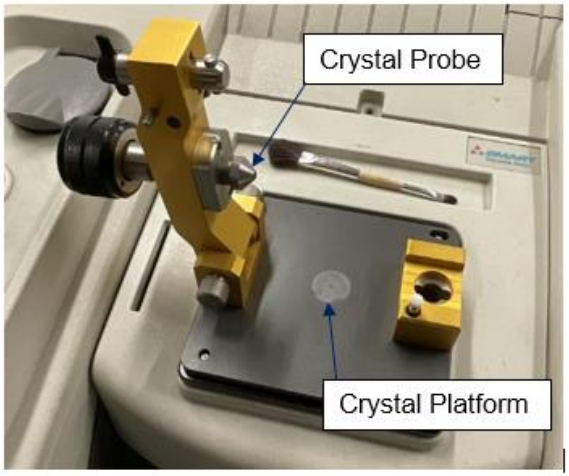
Less than 1 mg

Result

- Functional group determination from IR spectrum

Spectrum type	Spectrum range
Single bond region	2500 – 4000 cm^{-1}
Triple bond region	2000-2500 cm^{-1}
Double bond region	1500 – 2000 cm^{-1}
Fingerprint region	600 – 1500 cm^{-1}

(Nandiyanto, Oktiani et al. 2019)



Cone Calorimeter

Fire Reaction and Performance

Experimental Setup

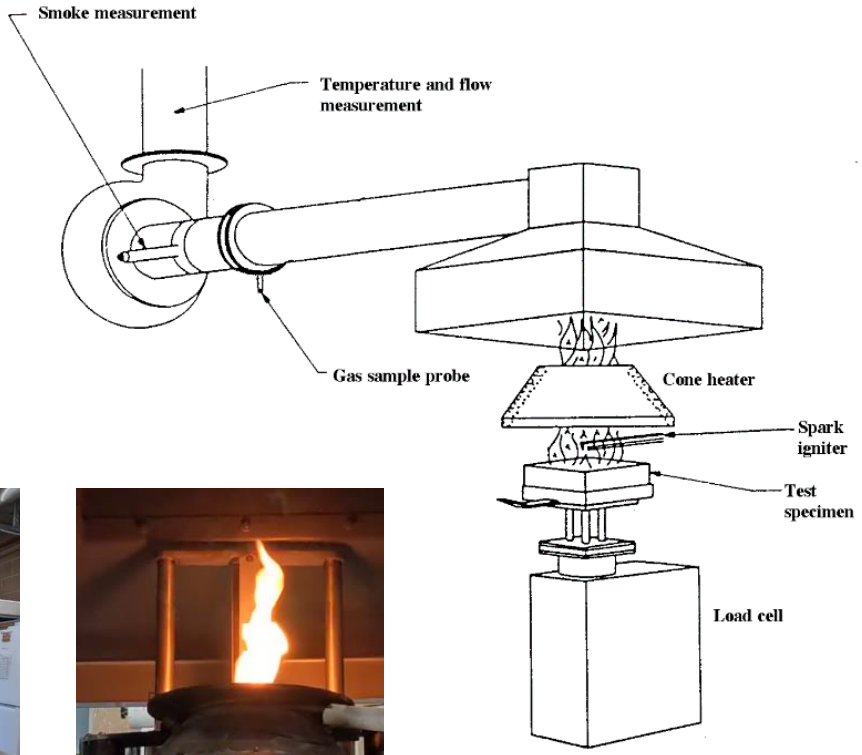
- Apparatus : Cone Calorimeter
- Standard : BS EN ISO 5660
- Asset number : EUI 066

Specimen

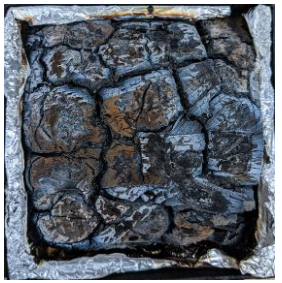
- Dimensions – 100 mm X 100 mm
- Specimen preparation as per BS EN ISO 5660
- Stainless steel holder

Result

- Heat release rate
  - Peak and average
- Time to ignition
- Burning time
- Average mass loss rate
- Smoke production rate
- CO and CO_2 yield

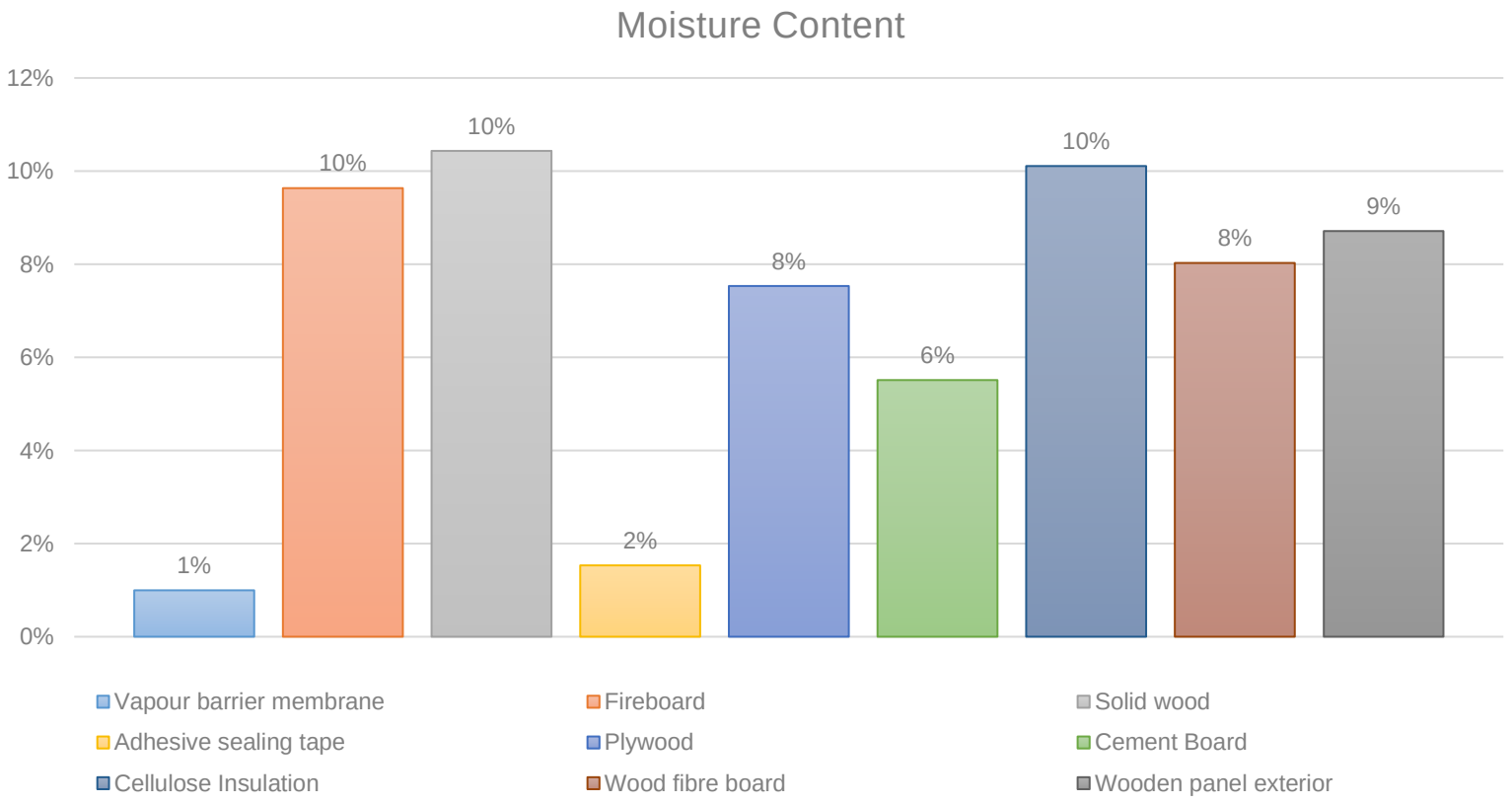


(Van Hees, Hertzberg et al. 2002)



Moisture Content

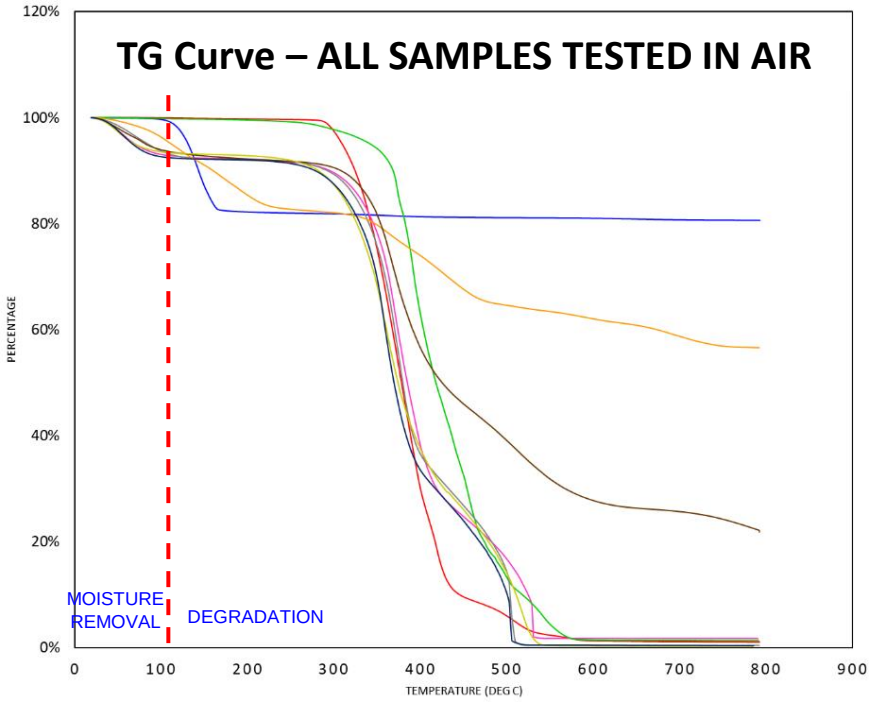
Results

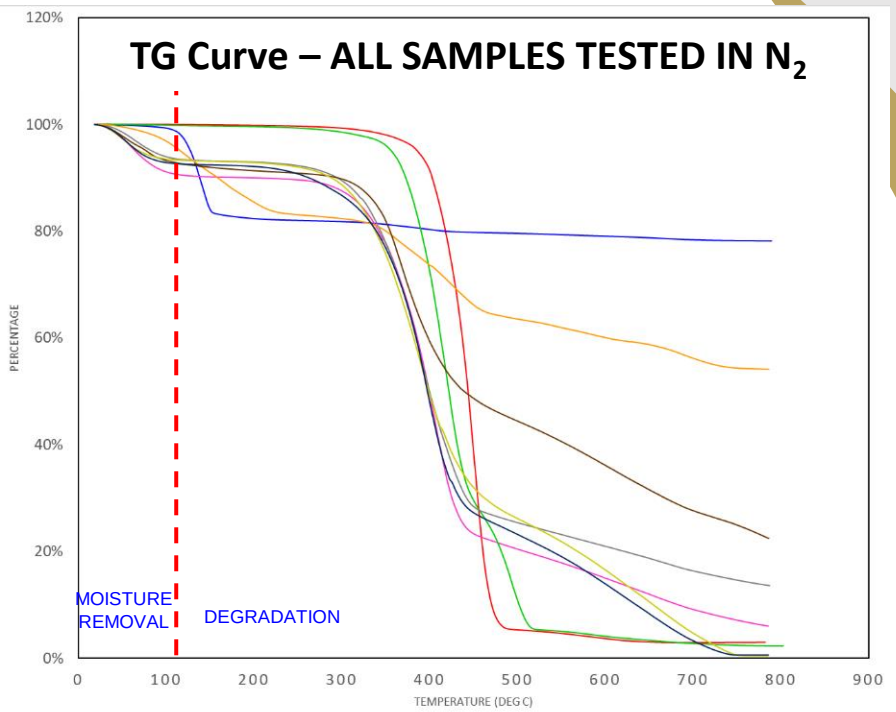


- Timbre material observed with 8 -10 % of moisture

Thermogravimetry Analysis (TGA)

Results





Sample 1 - Vapour Barrier Membrane
Sample 2 - Fire board
Sample 3 - Solid Wood
Sample 4 - Adhesive Sealing Tape
Sample 5 - Plywood
Sample 6 - Cement Board
Sample 7 - Cellulose Insulation
Sample 8 - Wood fibre board
Sample 9 - Wooden Panel Exterior

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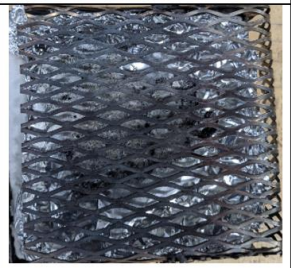
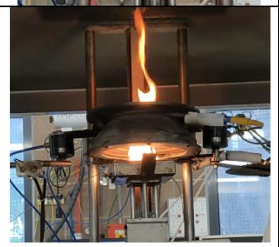
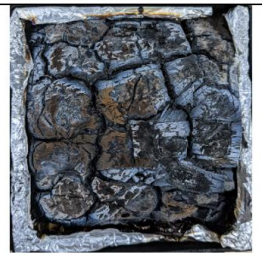
Cone Calorimeter

The cone calorimeter assessment was carried out for all the elements in the modular timber assembly at 50 kW/m^2.

Specimen	Flame pattern	Residue	Remarks
Vapour barrier membrane			The surface rise of the specimen was observed during the test. A very high flame was observed. Not much residue was observed after the test.
Fire board			No flame was observed as the material is non-combustible. Only the paper lining of the board burnt.
Solid wood			A very high flame was observed. The residue has charring material which has a crack line in one direction.

Specimen	Flame pattern	Residue	Remarks
Adhesive tape		No image	Immediate ignition. A very high flame was observed. Not much residue was observed after the experiment.
Plywood (OSB)			A very high flame was observed. The residue has charring material which is cracked in multi directions.
Cement board	No burning was observed.		No flame was observed as the material is non-combustible.
Cellulose Insulation			Immediate ignition. Low-level flame height.

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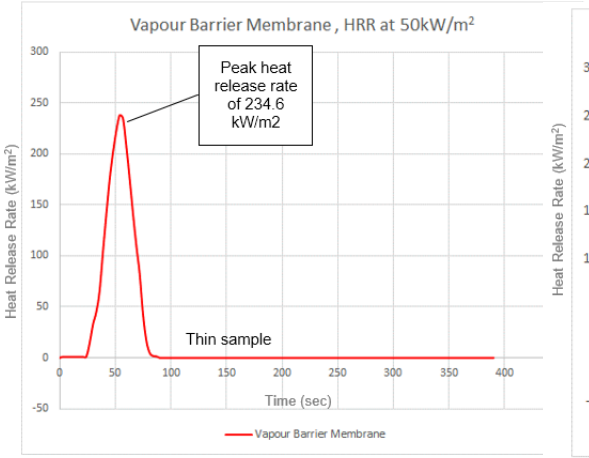
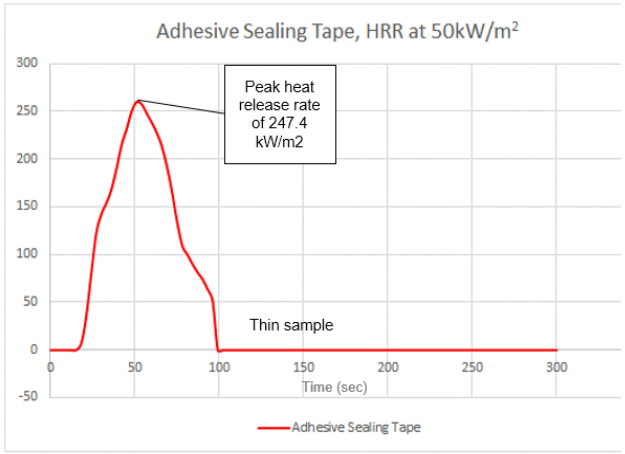
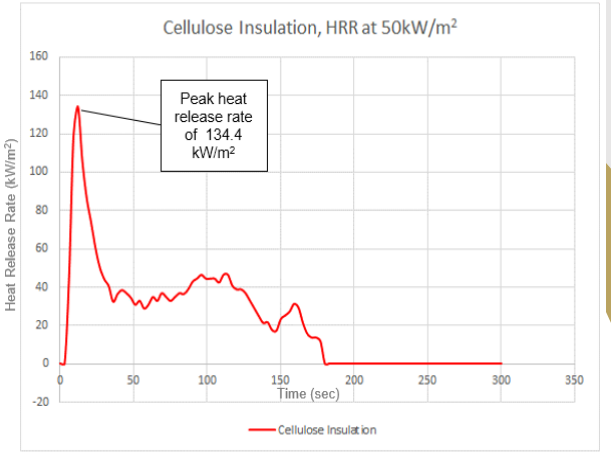
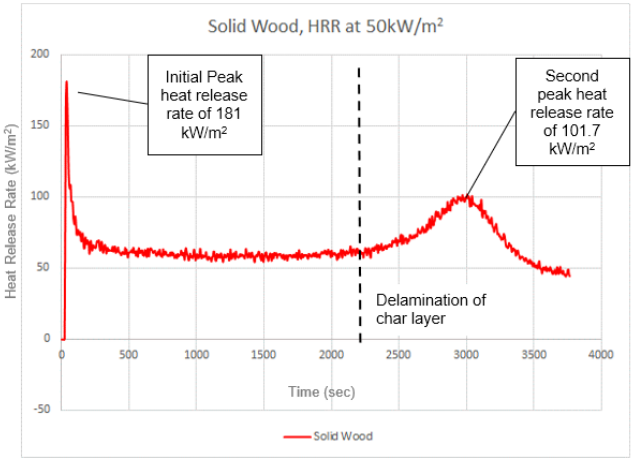
Cone Calorimeter

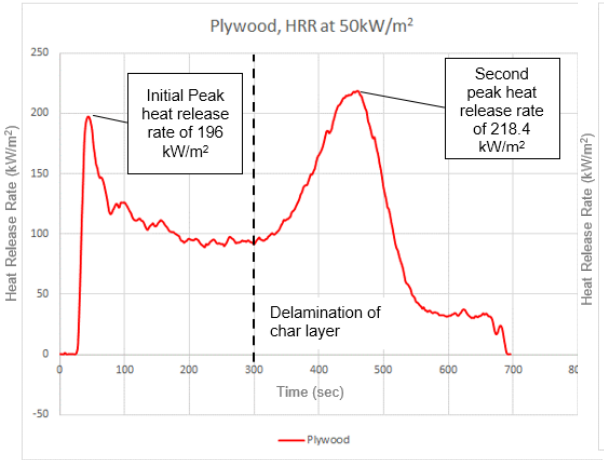
Heat Release Rate (HRR)

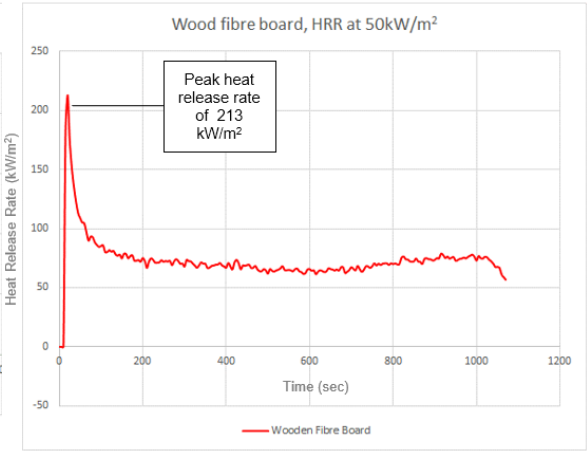












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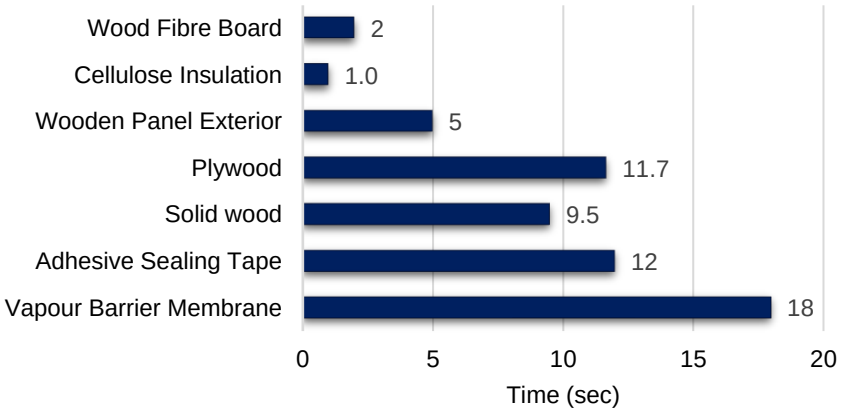
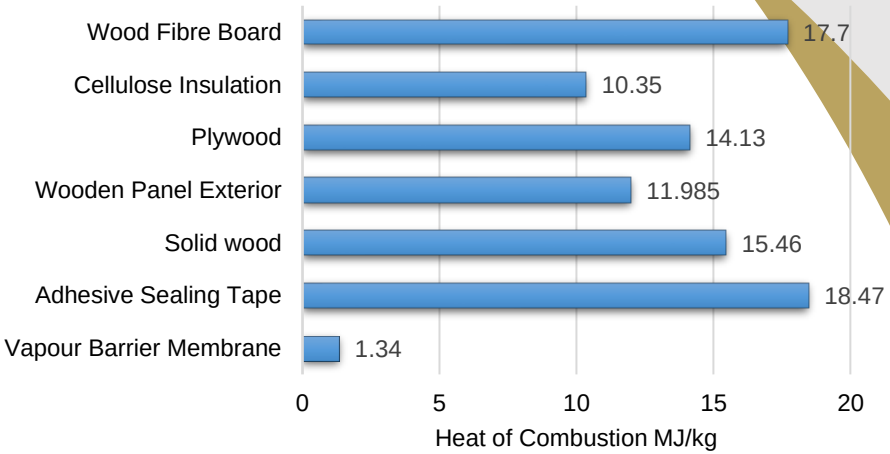
Cone Calorimeter

Results

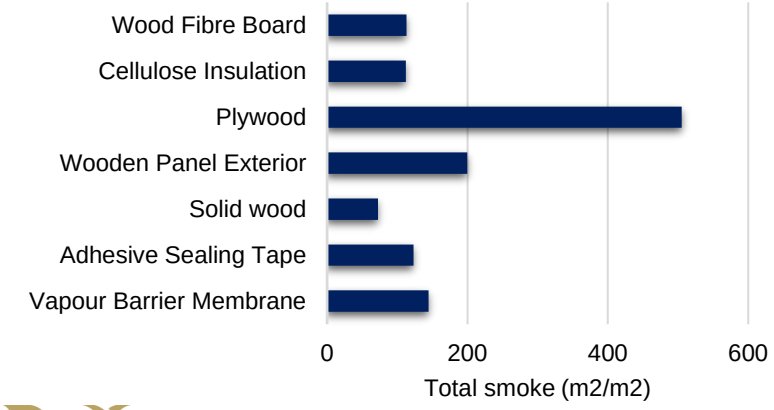
IGNITION TIME



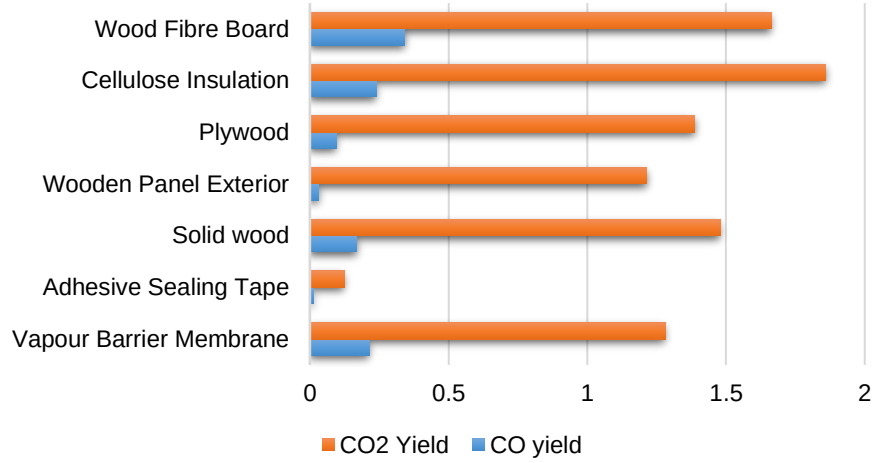
HEAT OF COMBUSTION (MJ/kg)



TOTAL SMOKE (m^2/m^2)



CO AND CO_2 YIELD(kg/kg)



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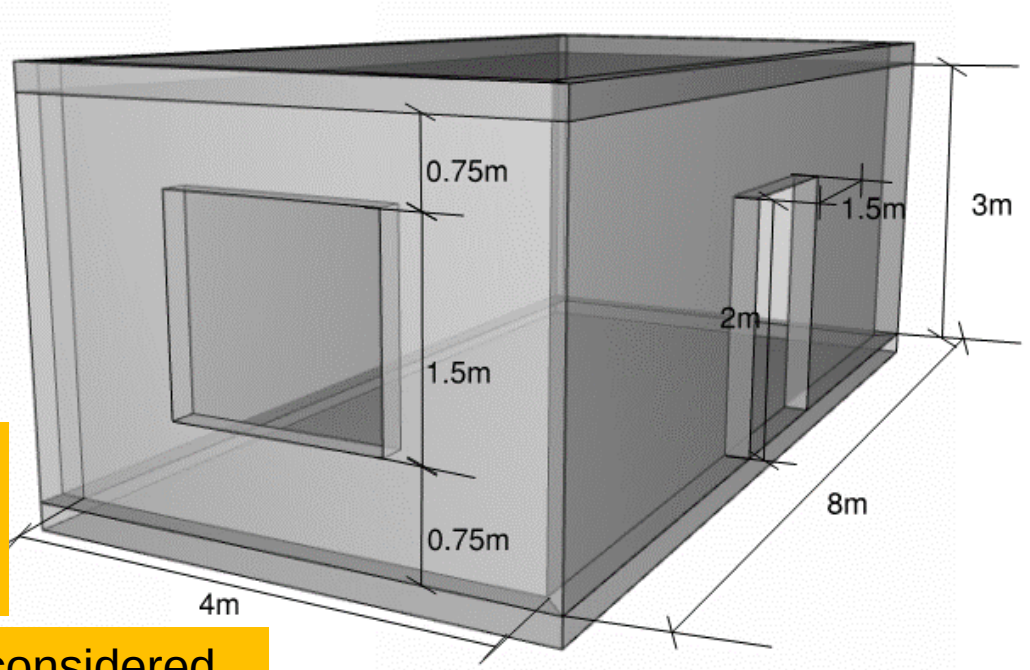
Ozone Analysis

The Ozone software is a numerical tool which is used to evaluate the development of gas temperature during a fully developed fire within a compartment.

A standard geometry was considered for the analysis of Ozone software.



The enclosure of the compartment considered are components of a modular timber wall.

Material	Thickness (mm)	Density (kg/m^3)	Conductivity (W/mK)	Specific heat (J/kgK)	Rel emissivity (hot surface)	Rel emissivity cold surface)
Fire board (Type A Plaster Board[1])	12.5	900	0.25	1000	0.8	0.8
Insulation (Gutex multitherm Insulation)[2]	40	140	0.040	2100	0.8	0.8
Plywood (OSB Board[1])	11	650	0.13	1700	0.8	0.8
Cement board[1]	12.5	1150	0.35	840	0.8	0.8

1. BS EN 12524 – 2000
2. Gutex Multitherm datasheet

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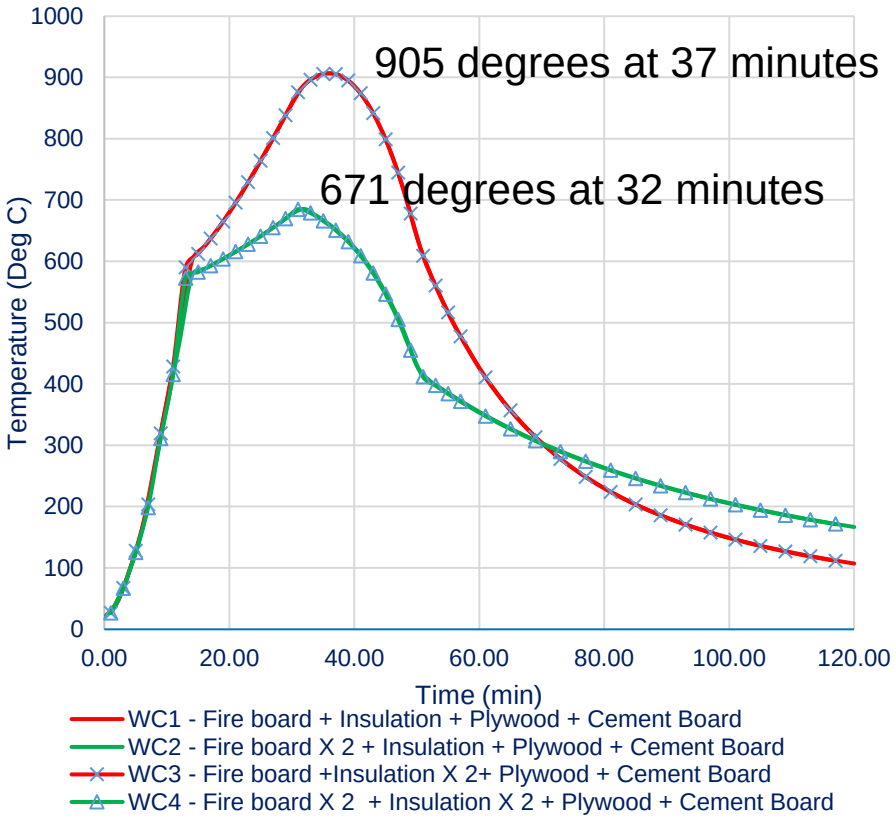
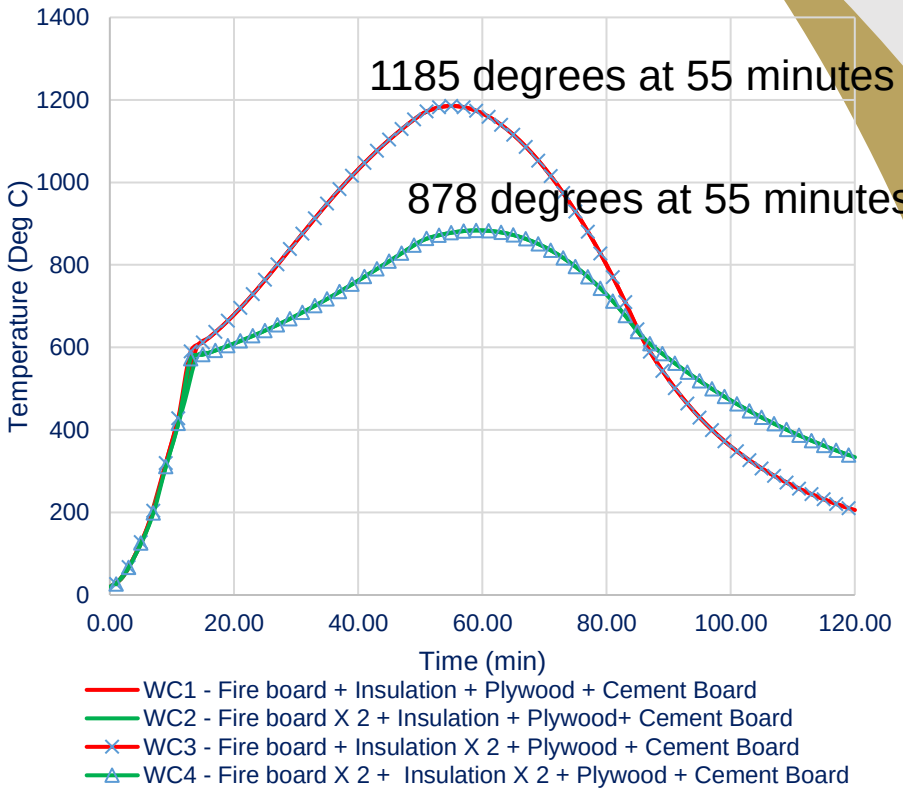
Ozone Analysis

Results – Temperature

Temperature evaluation in Office with Fire load 511 MJ/m^2



Temperature evaluation in Dwelling with Fire load of 948 MJ/m^2



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Different wall configurations were considered for office and dwelling occupancy.

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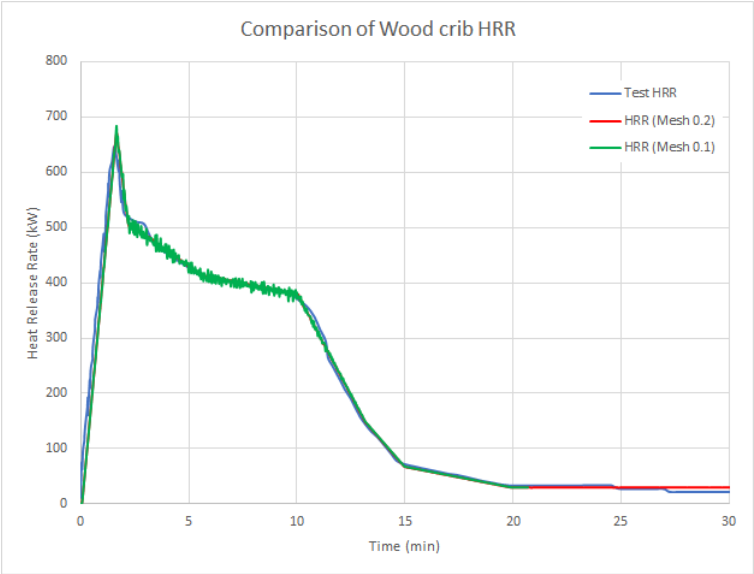
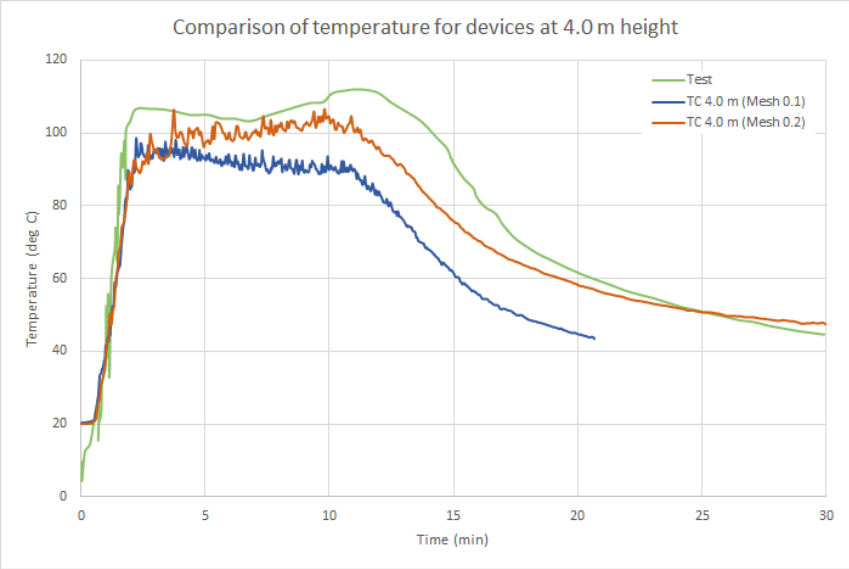
FDS Analysis

Model Validation

Compartment fire study by VTT technical research centre of Finland (Rinne, Hietaniemi et al. 2007) is considered

Temperature and HRR profiles of wood crib and heptane fire in experimental study are considered for validation





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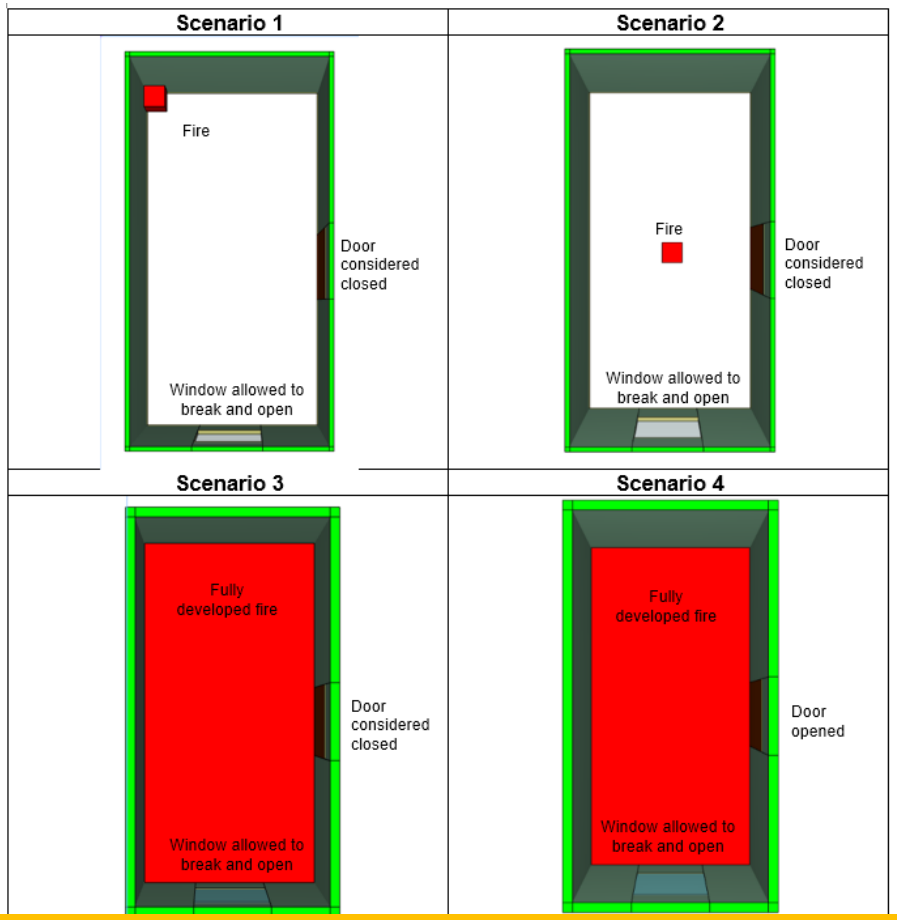
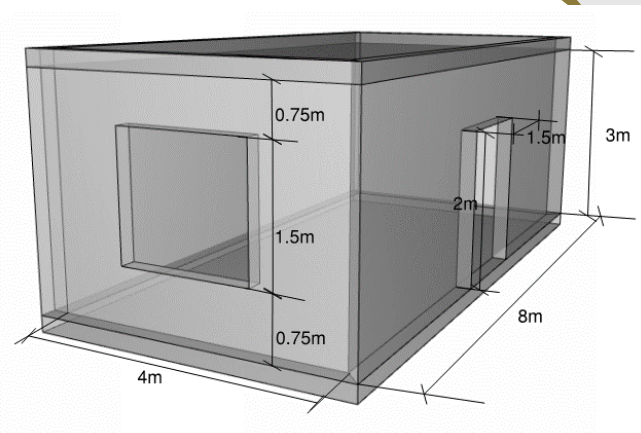
FDS Analysis

Model geometry and Fire locations

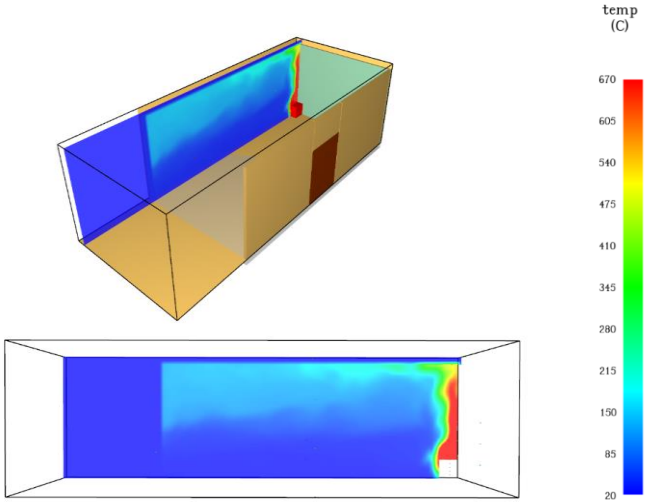


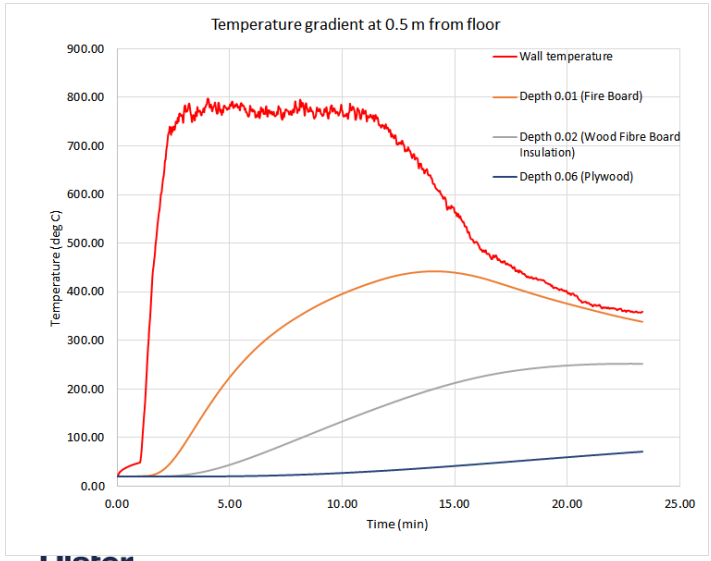


- Scenario 1 – Fire at the corner of the room with a wood crib to represent the worst scenario of flame exposure to the wall-lining materials.
- Scenario 2 – Fire at the centre of the room with a wood crib to represent a standard fire scenario
- Scenario 3 – Fully developed fire of 8MW - Eurocode office fire (*Euro Code 1 - EN1991-1-2.* 2002) with limited ventilation
- Scenario 4 – Fully developed fire of 8MW - Eurocode office fire (*Euro Code 1 - EN1991-1-2.* 2002) with adequate ventilation

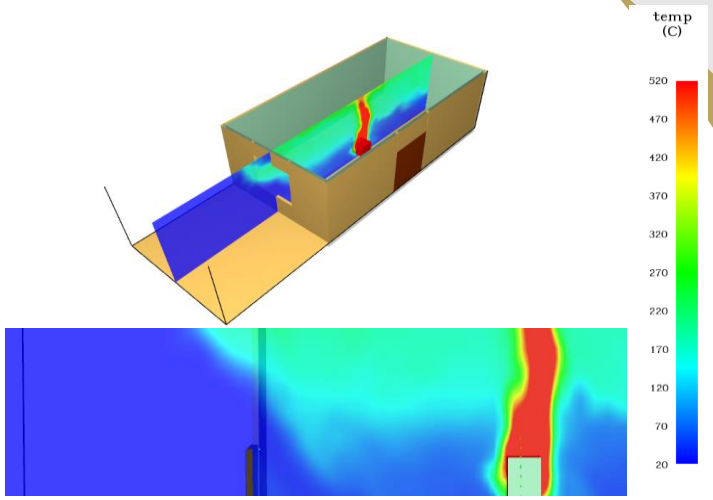
FDS Analysis

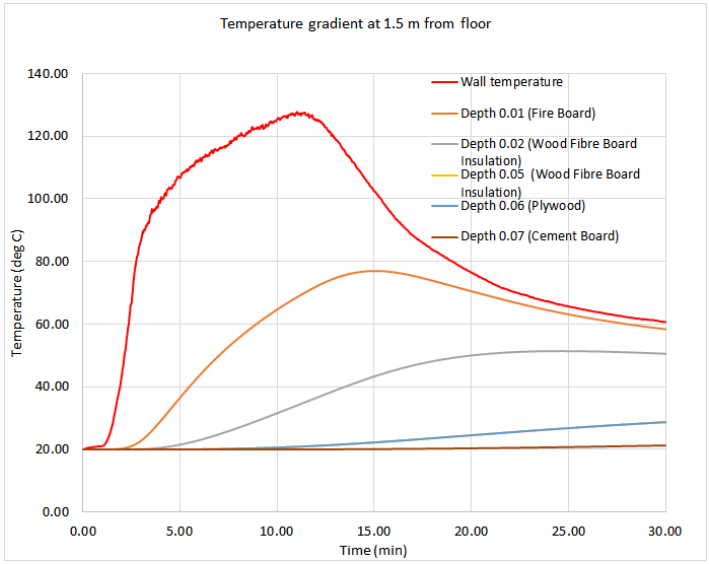
Scenario 1





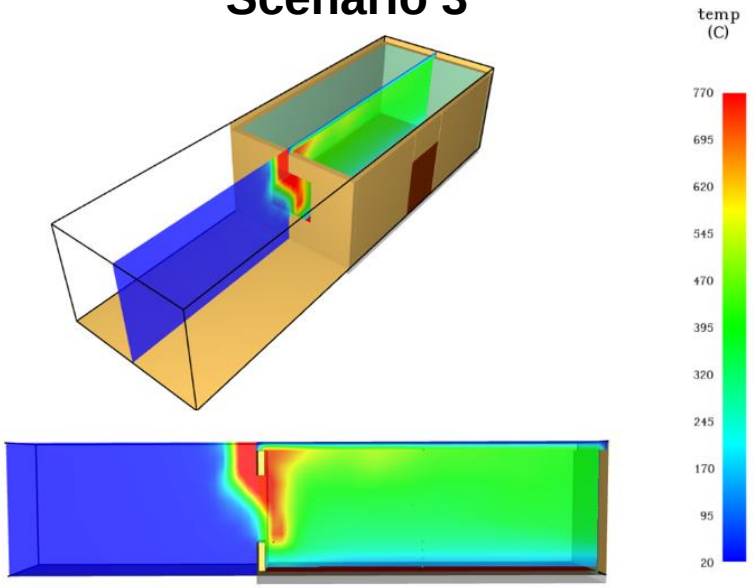
Scenario 2



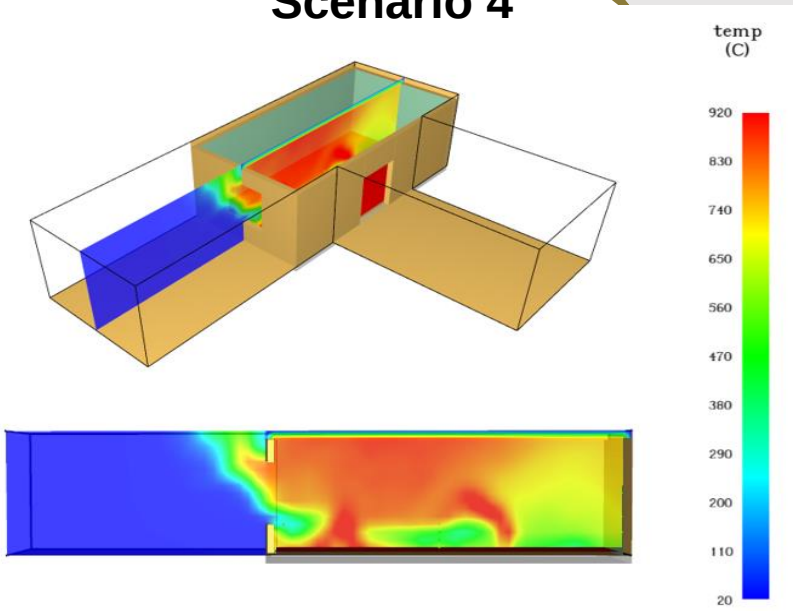


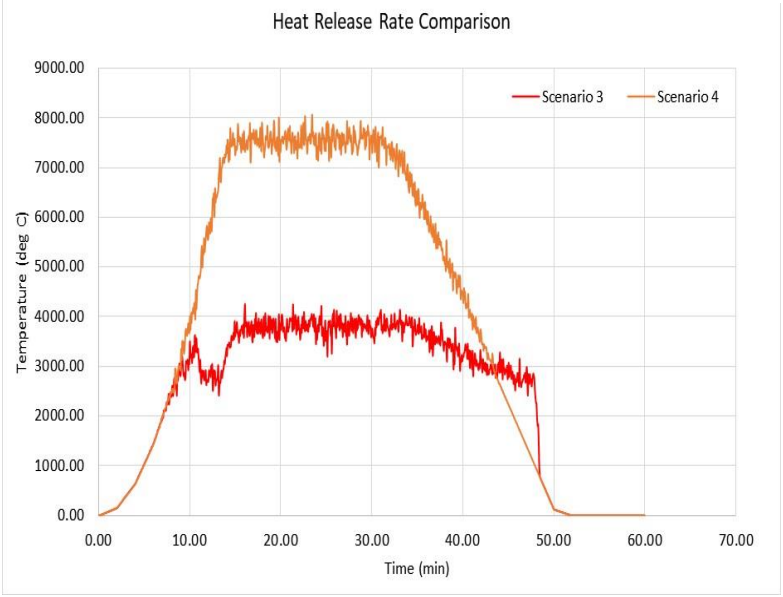
FDS Analysis

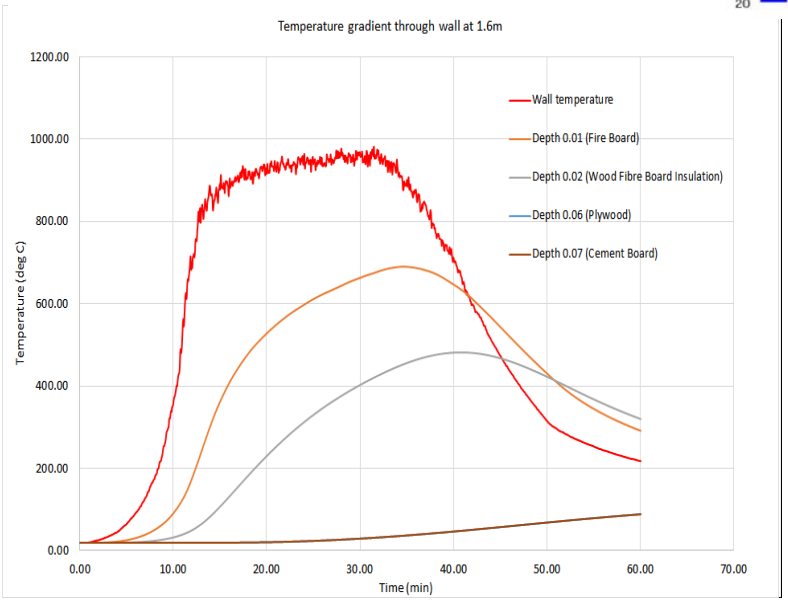
Scenario 3



Scenario 4



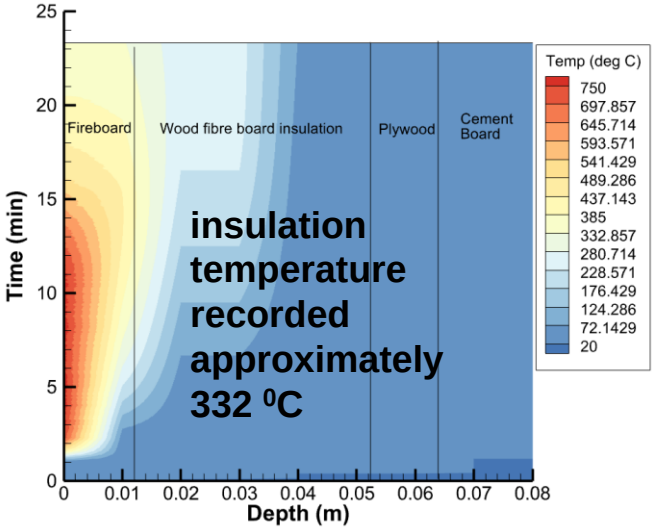




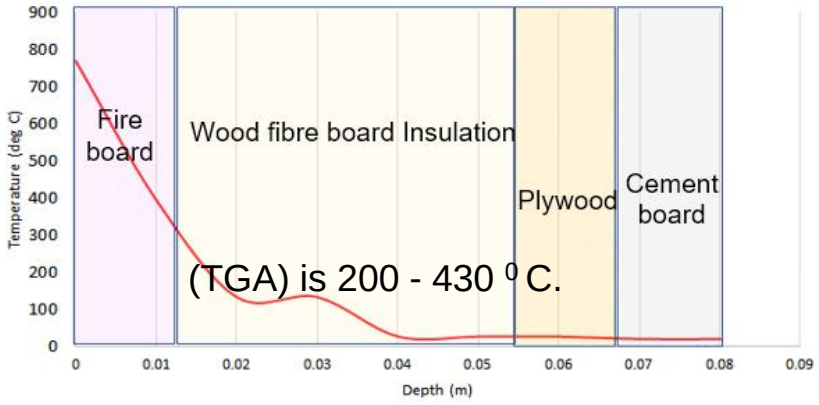
FDS Analysis

Temperature Gradient Wall Analysis

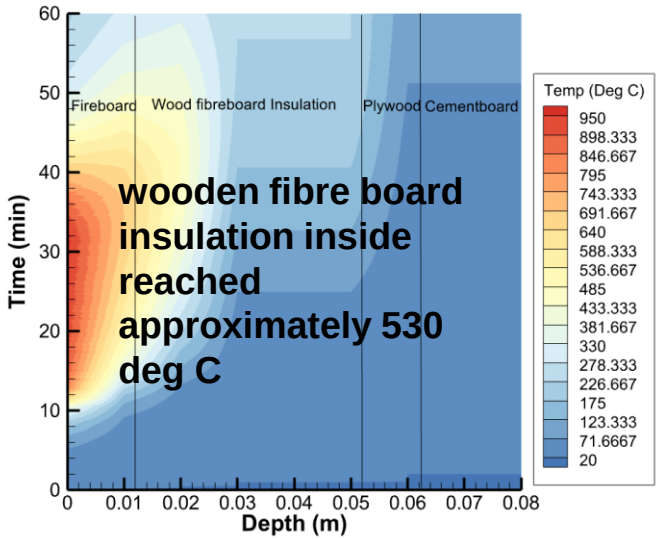
Scenario 1 – Corner Fire



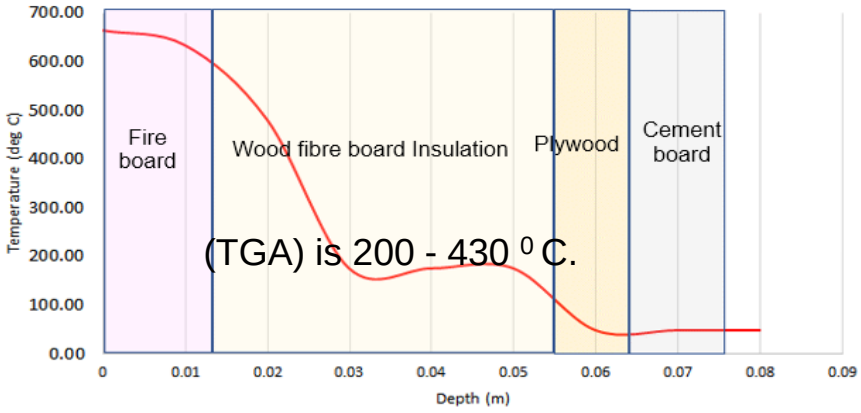
Temperature evolution through wall layers at 0.5 m from fire at 10 min



Scenario 4 – Fully developed fire



Temperature evolution through wall layers at 1.6 m from fire at 42 min



Conclusions

Modular timber assembly building cannot be designed prescriptively in accordance with typical regulatory building codes

A combination of prescriptive and performance-based approaches is to be considered while designing a modular timber building.

From the results of cone calorimeter tests, it can be easily concluded that the Insulation materials considered in the modular timber assembly tested are very fast ignitable materials

The majority of the mass loss happens between temperature ranges from 260 ^{0}C to 390 ^{0}C

The provision of a fire board encapsulation limits the temperature or flame spread to the inner layers of the assembly.

Any penetrations to the outer lining layer of the wall assembly are to be carefully sealed with adequate fire-stopping materials.

The heat of combustion identified for each material in the cone calorimeter test can be used for CFD modelling and determining the total combustion energy of the structural timber materials.

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Further buildings with larger floor areas or volumes with exposed timber aesthetic features could also result in additional fuel load to the compartment. These are also required to be evaluated as part of the fire engineering design.

From the results, it can be interpreted that the addition of two layers of fireboard reduced the compartment temperature significantly

The CFD study using FDS showed the high temperatures developed within a compartment during different fire scenarios and their effect on the lining of the modular timber assembly

The experimental analysis carried out as part of the study shows the high calorific value of timbre materials with the probability of a secondary flashover.

Hence, a timber building design cannot be typical as a non-combustible structural element building.

It is recommended to consider automatic sprinkler systems or other suppression systems in timber buildings to reduce the risk associated with high fuel load. This needs to be carried out as part of the performance-based design where the fire hazards are evaluated using proper fire risk assessment methods.

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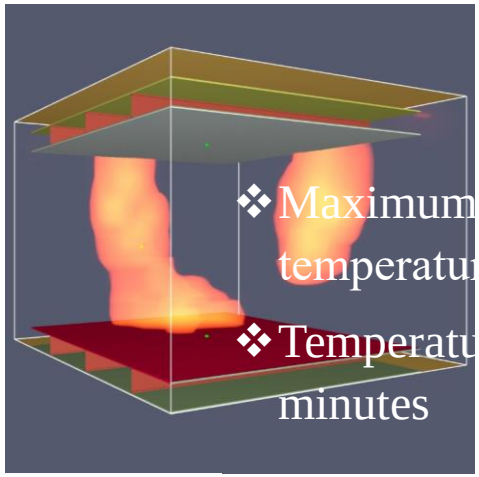
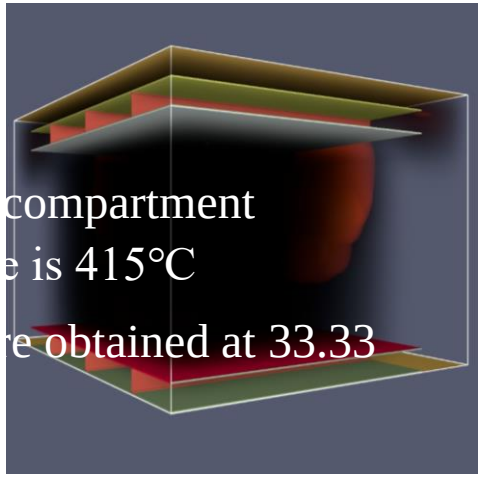
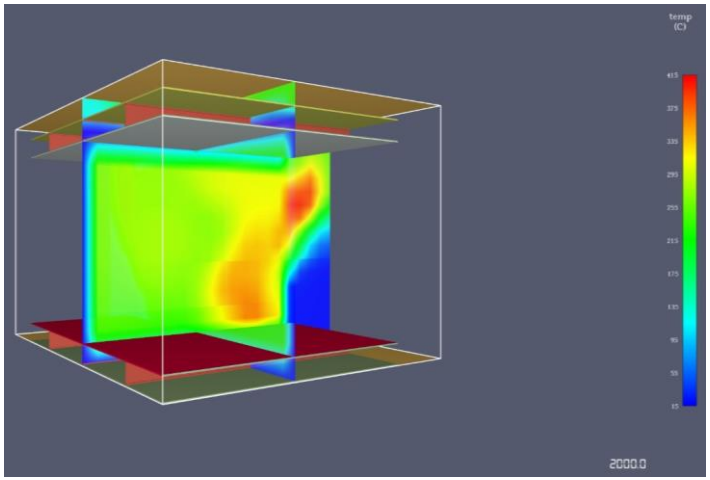
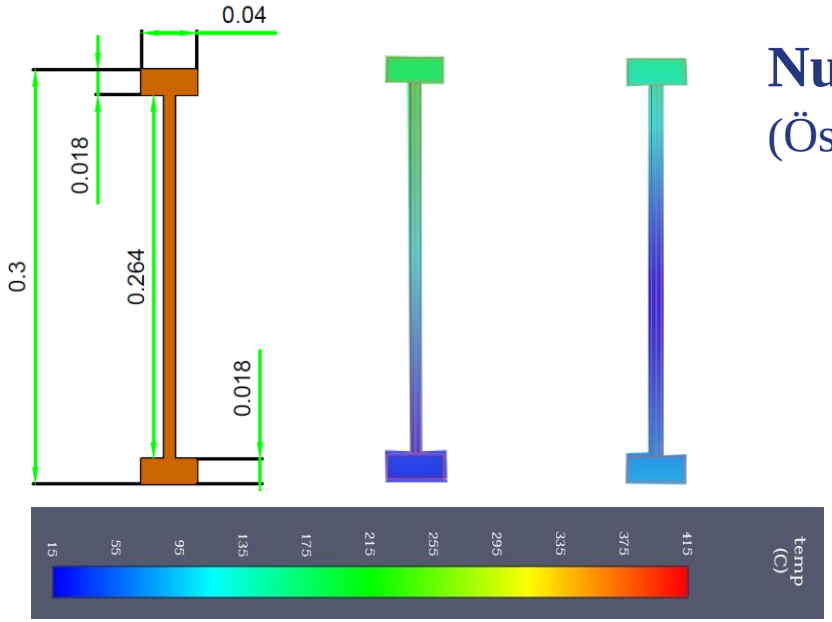
Engineers Beam Timber Flooring





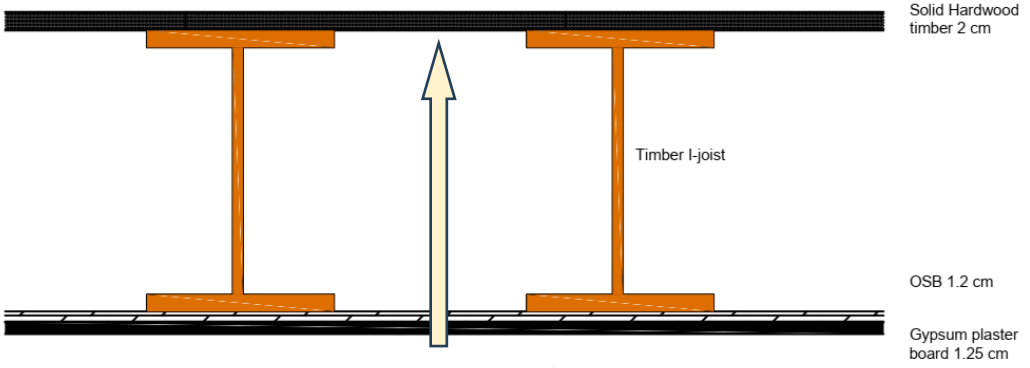


- Maximum compartment temperature is 415°C
- Temperature obtained at 33.33 minutes



Numerical calculations of fire resistance

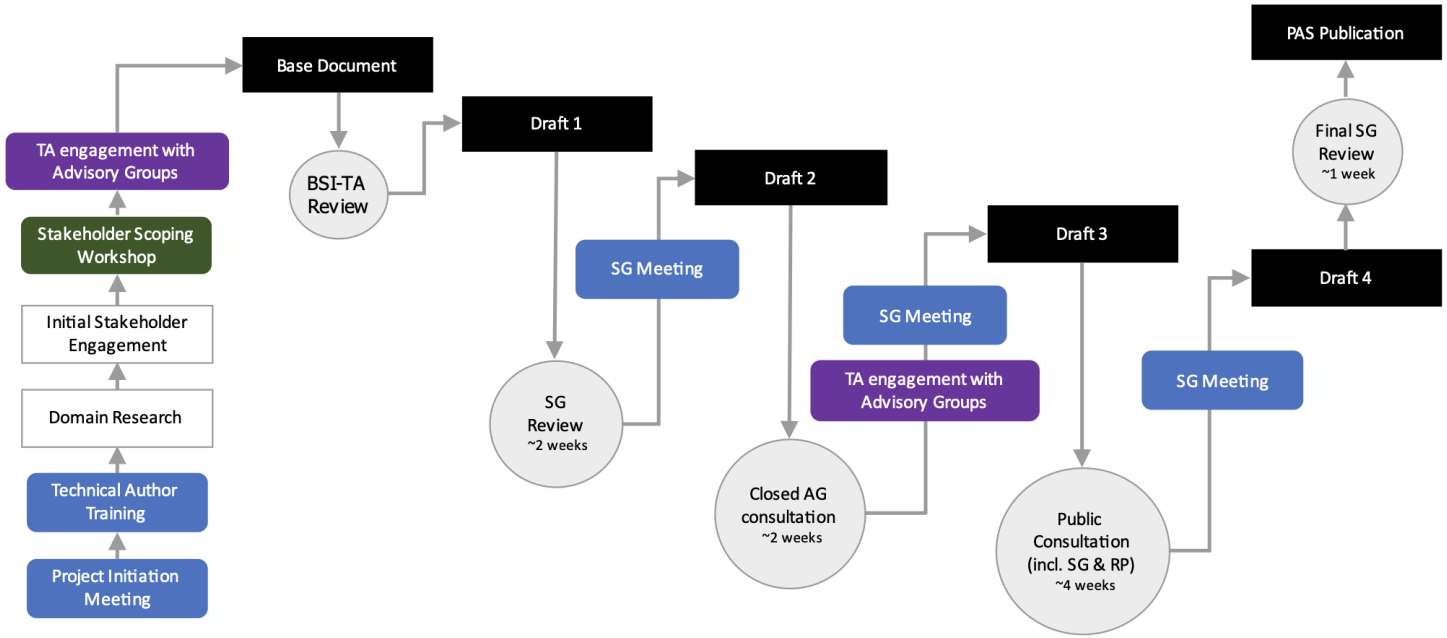
(Östman et al., 2010, chap.5)



$$Protection\ time, t_{prot,1} of\ Gypsum = (24.10 \times 1 \times 1) \times 1$$

What is going on now:

PAS process



This PAS specifies requirements for the use of modern methods of construction (MMC) in new build residential properties. It covers multiple build types and materials used in single use and mixed use residential MMC1.

Acknowledgements to Lidan Design Ltd – Ireland for the cooperation

Mr Manu Rajan my MSc Fire Safety Student for his involvement in the project