Tall Wood

Performance Approach to Fire Safety

Seattle, May 2014

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Principal, **GHL** Consultants Ltd
Email: ah@ghl.ca

BASc, Queen's University at Kingston, Civil Engineering

M Eng, UBC's short lived Fire Science program

PE – Washington State, 2001

25 years' experience in Equivalencies and Alternative Solutions

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- Founded in 1992
- Building Code consultants
- Code reviews – assisting clients and authorities
- Fire engineering services
  - Performance-based fire engineering design
  - Risk analysis
  - Legal / expert opinion

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Fire Engineering

- Prefer “Fire Engineering”
  - Focus on Part 3
  - Fire hazard analysis
  - Fire risk analysis
  - Structural fire resistance
  - Heat transfer
  - Egress/evacuation
  - Smoke control design
  - Persons with disabilities / ADA work
  - No system design

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8 Principals + staff (total 21)

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Research Work

- BC Wood First Advisory Committee to Forestry Investment Innovations
- CAN 086 Task Group on Fire (Andrew Harmsworth)
- NEWBuildS Research Network (Andrew Harmsworth, Board of Directors) – 70 Master's and PhD Students
- Effectiveness of Sprinkler Systems after an Earthquake.

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Publications

- Lead Author, Tall Wood Guide with FP Innovations

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Message

To show that tall wood buildings are safe, feasible and practical

To show that Engineers have the tools to design these buildings

Earth Sciences Building at University of British Columbia
First 5 storey timber school building in Canada in 100 year

US / Canadian Codes & Standards

- Look different at first glance; however, surprisingly similar.
- Long history of parallel development.
- Lots of little differences, often just because 'the furnace was different'.
- Few big differences.

Conclusion: Same big picture

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6 Storey Wood - 1871

Wikipedia

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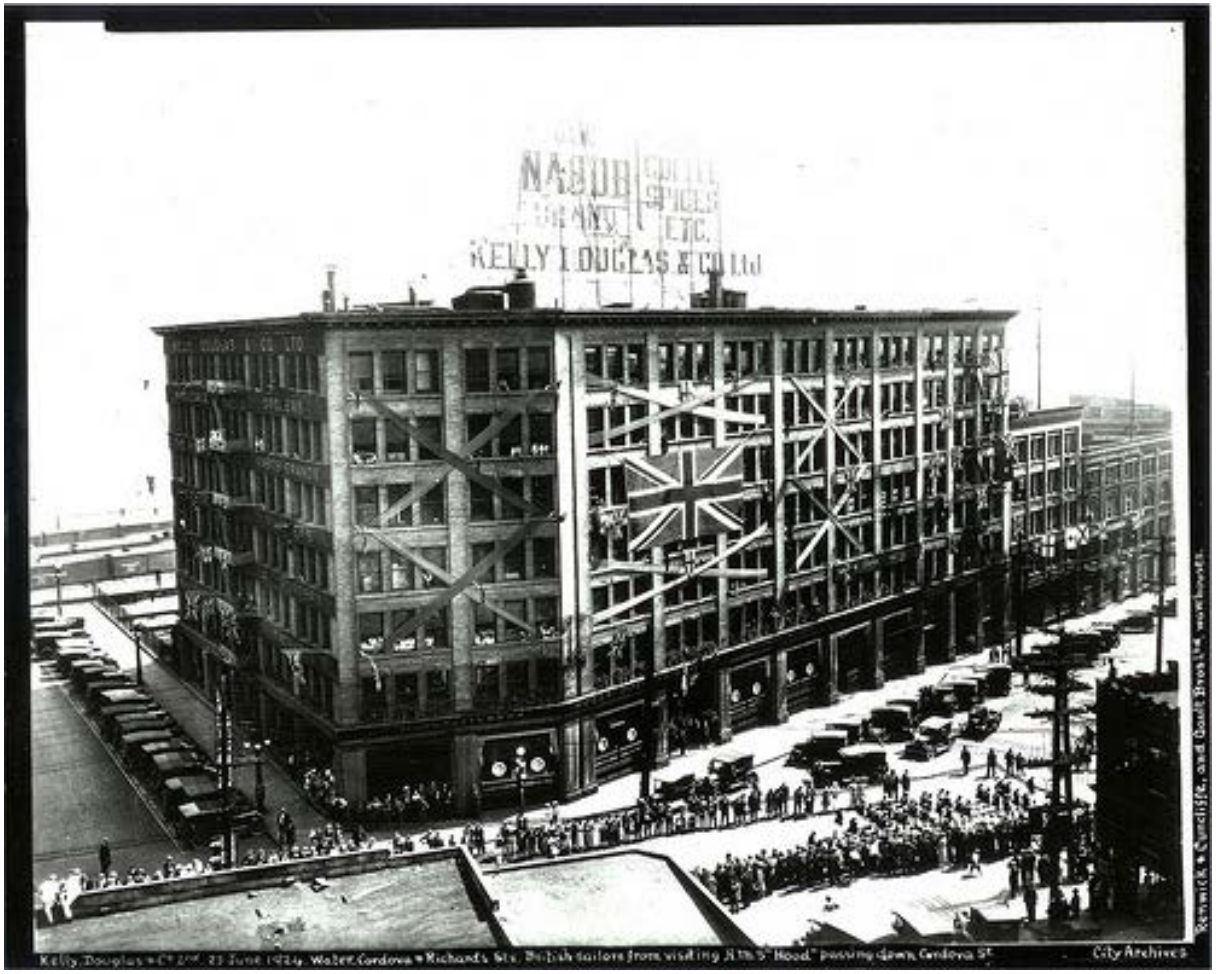
9 Storey Heavy Timber - 1905



Kelly Douglas Building, Vancouver

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Today

Wikipedia

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What Happened

- Greater concern with fire safety.
- Canadian National Building Code of 1941.
- Initially prefaces with the idea that it was a ‘Guide’.
- Over time it became a restrictive document.

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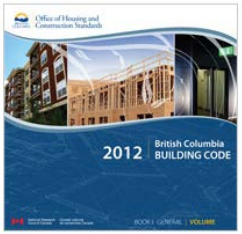
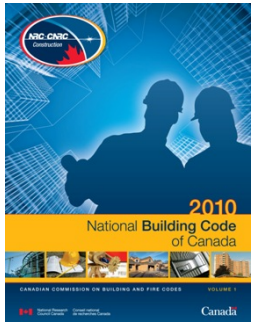
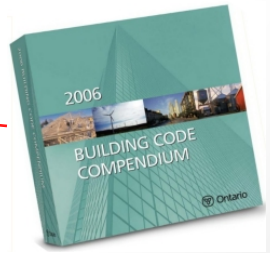
The Canadian Building Code System

- Started as a “guide”.
- Prescriptive , 1941 – 1995.
- Over time, it became a restrictive document.
- National Building Code is a **model code.**







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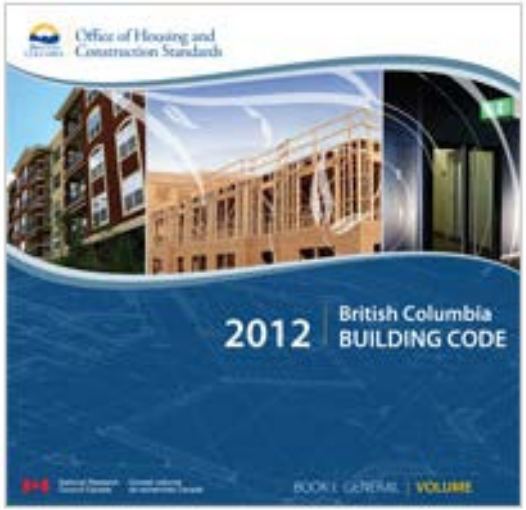

Buildings are subject to risks:

- Code compliance ≠ no risk.
- Code compliance = risks at acceptable level.

Entering a building is just like getting into a car, there is an acceptable level of risk.

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Codes and Mass Timber

1905 Pre-NBCC

1941 NBCC

2015 NBCC (Proposed)

1953…2010 NBCC

Vancouver

1941, 2015 NBCC

2010 NBCC

Québec City

Building Code Compliance

Acceptable Solutions

Alternative Solutions

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Courtesy FPInnovations

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Thoughts on Codes

- Code should not care what material you use.
- All materials and design methods should be required to meet the same performance level.
- Code should be based on science, not emotion.
- Designers and Owners should be able to choose the best material for the job.

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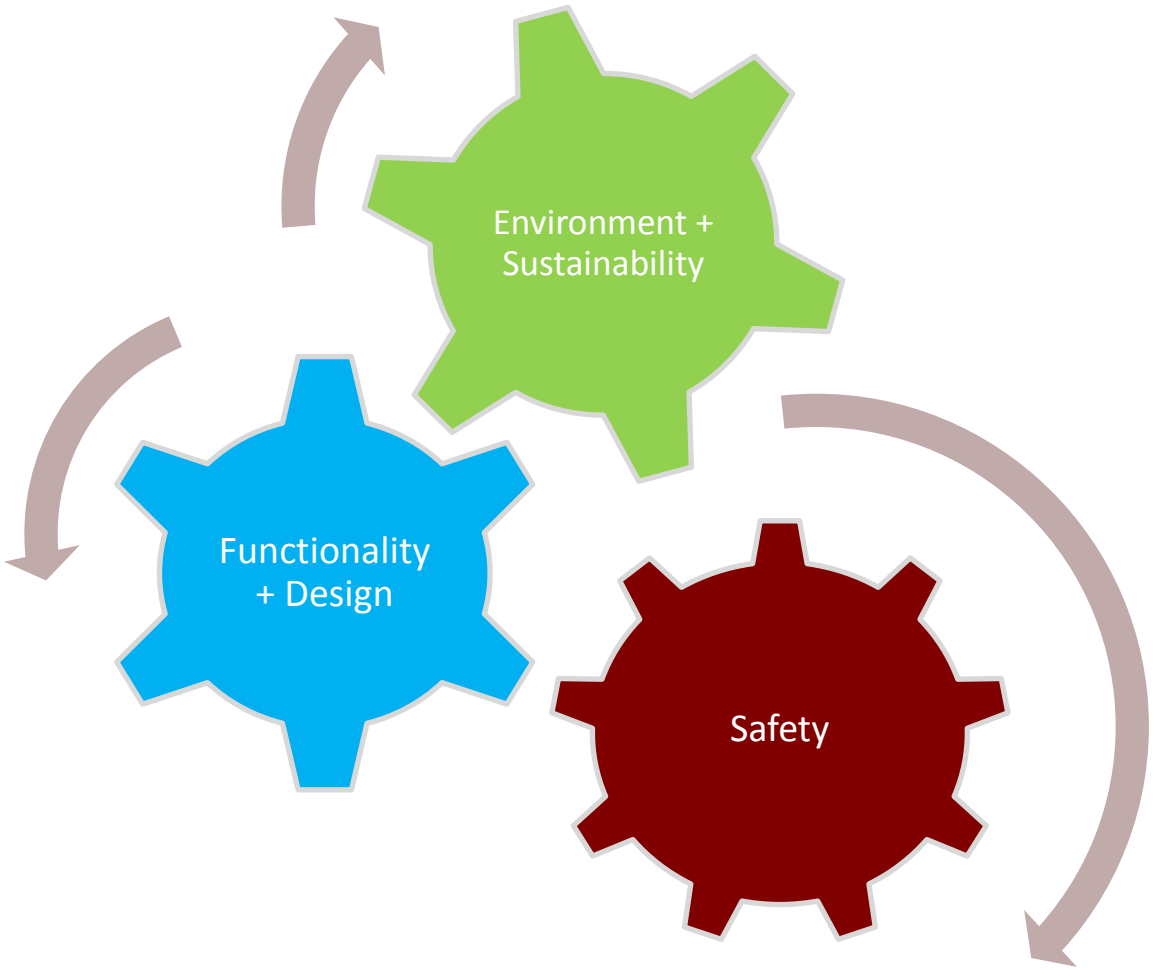
Safety Needs to Balance Other Goals



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Code Evolution

Prescriptive → Objective-based → Performance-based

- NBC up to 1995
- Many Codes around the world

- NBC since 2005

- UK, Australian & New Zealand codes

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Objective-based Code Framework

Building Code Compliance

↓

Objectives and Functional Statements

↓

Acceptable Solutions (Division B)

- Deemed-to-satisfy solutions
- Establish level of performance

Alternative Solution

- Meet the objectives and functional statements
- Provide the *same* level of performance relative to objectives and functional statements

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Why Non-combustible

Objective OS1 Fire Safety from 3.2.2

- Intent 1:
- To limit the probability that combustible construction materials within a storey of a building will be involved in a fire, which could lead to the growth of fire, which could lead to the spread of fire within the storey **during the time required to achieve occupant safety and for emergency responders to perform their duties,** which could lead to harm to persons.

- Other ~~Requirements~~ *Provisions of the Acceptable Solutions* are similarly worded.

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I Hope to Demonstrate to You

That we can design a building of mass timber that:

- Is equivalent or better in the overall level of safety for occupants and emergency responders to a noncombustible building:
  - **During the time required to achieve occupant safety and for emergency responders to perform their duties.**

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Facts

Population of 7 to 9 billion needs housing.

We are resolving most problems.

http://www.gapminder.org/videos/dont-panic-the-facts-about-population/

EXCEPT - Global warming.

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One Square Meter of Floor

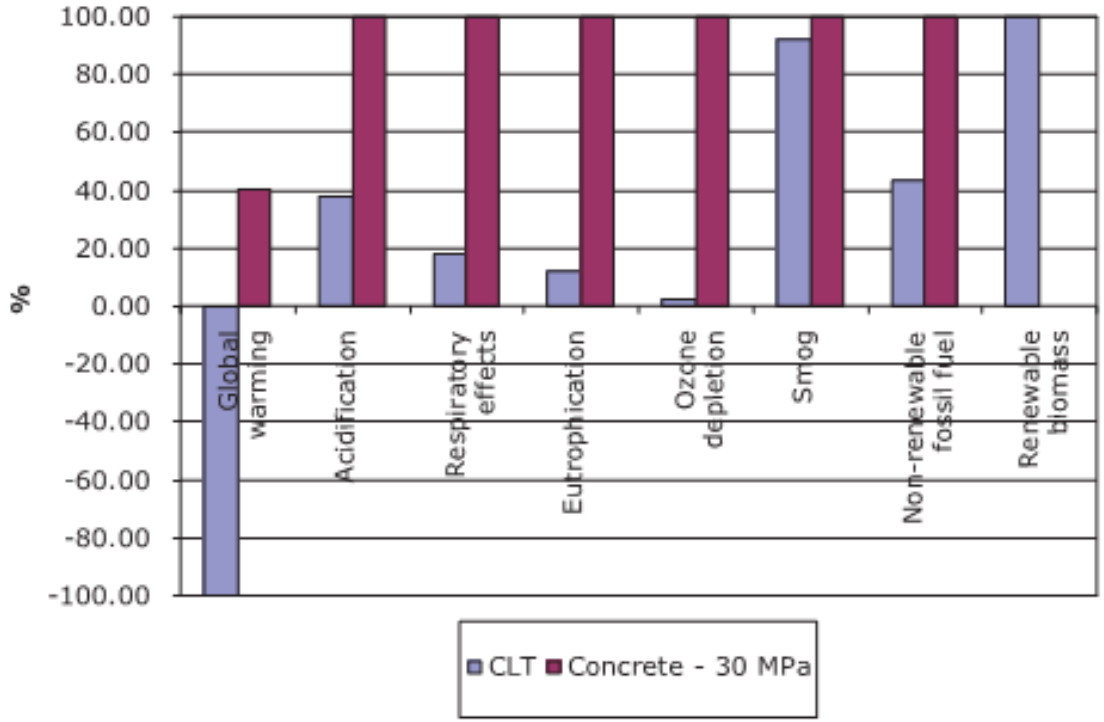

Figure 6

Comparative LCA between 1 square meter of CLT and concrete floor structure

Note: This Figure graphs the data shown in Table 1 on a percentage basis, with the baseline set at the highest number in each environmental performance category. For example, in fossil fuel consumption, the concrete system had the highest number and was set to 100%, with the CLT number shown as 43% of the fossil fuel use of concrete.

Courtesy F I CLT Handbook 2013

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Table 1

Comparative LCA results for CLT and concrete produced and used in Vancouver – absolute values

Impact Category	Unit	CLT 1m² of Floor	Concrete 1m² of Floor
Global warming	kg CO_2 eq.	-222.55*	90.12
Acidification	H+ moles eq.	8.77	23.00
Respiratory effects	kg PM2.5 eq.	0.010	0.058
Eutrophication	kg N eq.	0.014	0.115
Ozone depletion	kg CFC-11 eq.	7.15E-09	2.65E-07
Smog	kg NOx eq.	0.21	0.23
Non-renewable fossil fuel	MJ eq.	274.30	633.54

Note: *Net emissions, when taking into account forest carbon sequestration (248 kg CO_2 eq.) and reduction in carbon emissions from substituting wood residues for natural gas (21.8 kg CO_2 eq.).

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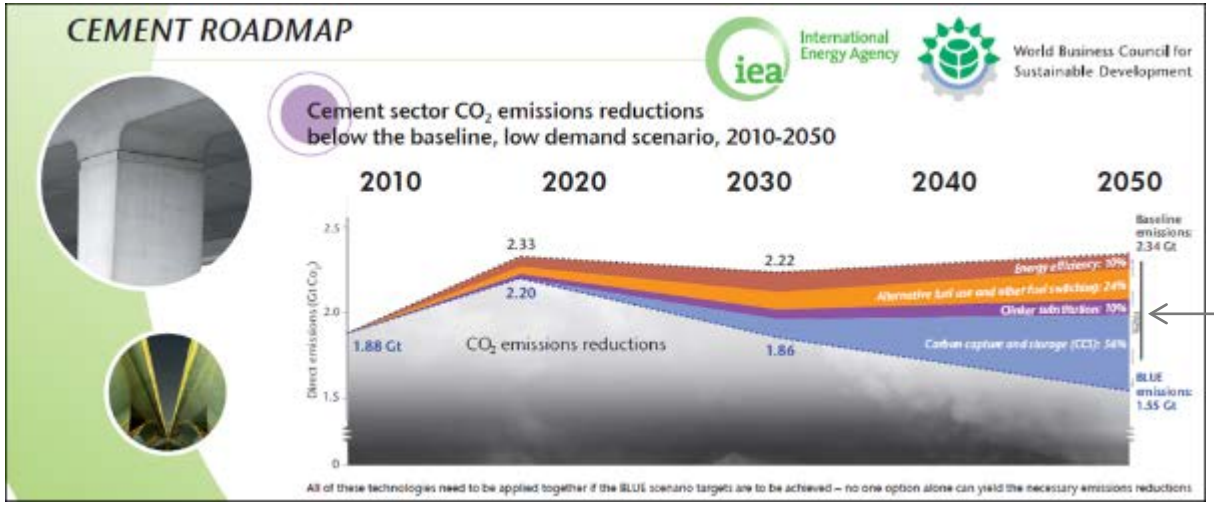
Carbon Capture and Storage



CCS

IEA.org Cement Industry Roadmap

No financially viable operating CCS of any size?

What about the forest?

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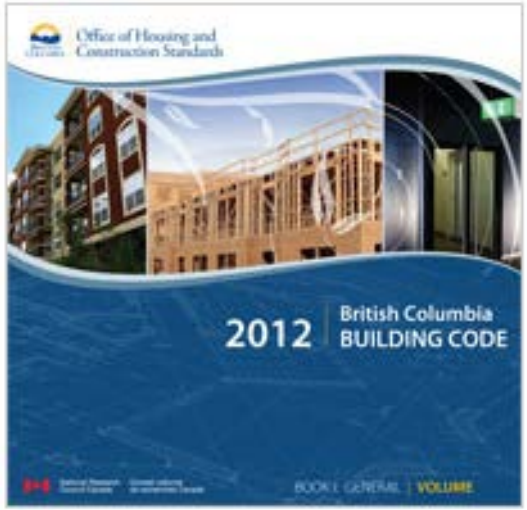
BC 6 Storey Residential



GHL prepared the risk analysis.

GHL recommended the code language.

Essentially an 'Alternative Solution' that was incorporated in the Code.

GHL argued that risks were equivalent to existing allowable building areas and heights if appropriate provisions were made.

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Where Are We Now?

BC Code allows 6 Storey Residential, limited area.

Quebec interim changes.

NBC 2015 proposed changes to allow 6 storey wood frame published for comment.

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Construction Fires

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Laminated 2x6 elevator shaft

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Mass Timber

Consensus is developing to use the term Mass Timber.

Includes HT, LVL, LSL and new forms.

Avoids confusion with the specified sizes for Heavy Timber in Division B.

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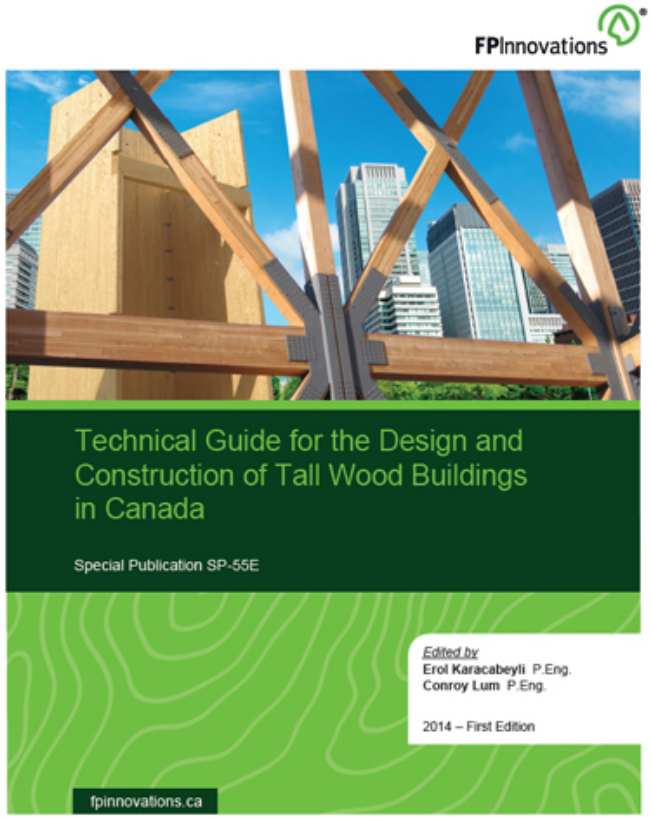
FPInnovations Tall Wood Guide



FPInnovations project funded by Natural Resources Canada (Federal Agency)

- 400 pages, 70 on fire.
- Fire section is the first to provide comprehensive review of fire issues in tall wood buildings.
- https://fpinnovations.ca/ResearchProgram/advanced-building-systems/Pages/promo-tall-wood-buildings.aspx#.U3Rc6fldWT0

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Approach Chosen

- Intent was to demonstrate that it CAN BE DONE.
- Nationally acceptable risk tolerance.
- Took a conservative approach.
- Recommends an approach of encapsulation of combustibles.

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Possible Approaches -

- Full performance based assessment
  - Lack of performance criteria/ inconsistent benchmarks
  - Time consuming

- Extend permitted combustible construction based on comparative risk analysis:
  - WIDC
  - BC 6 Storey

- Equivalent component performance
  - Protect components for equivalent performance

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Mass Timber Fire Resistance

Two methods:

- Encapsulation
- Char

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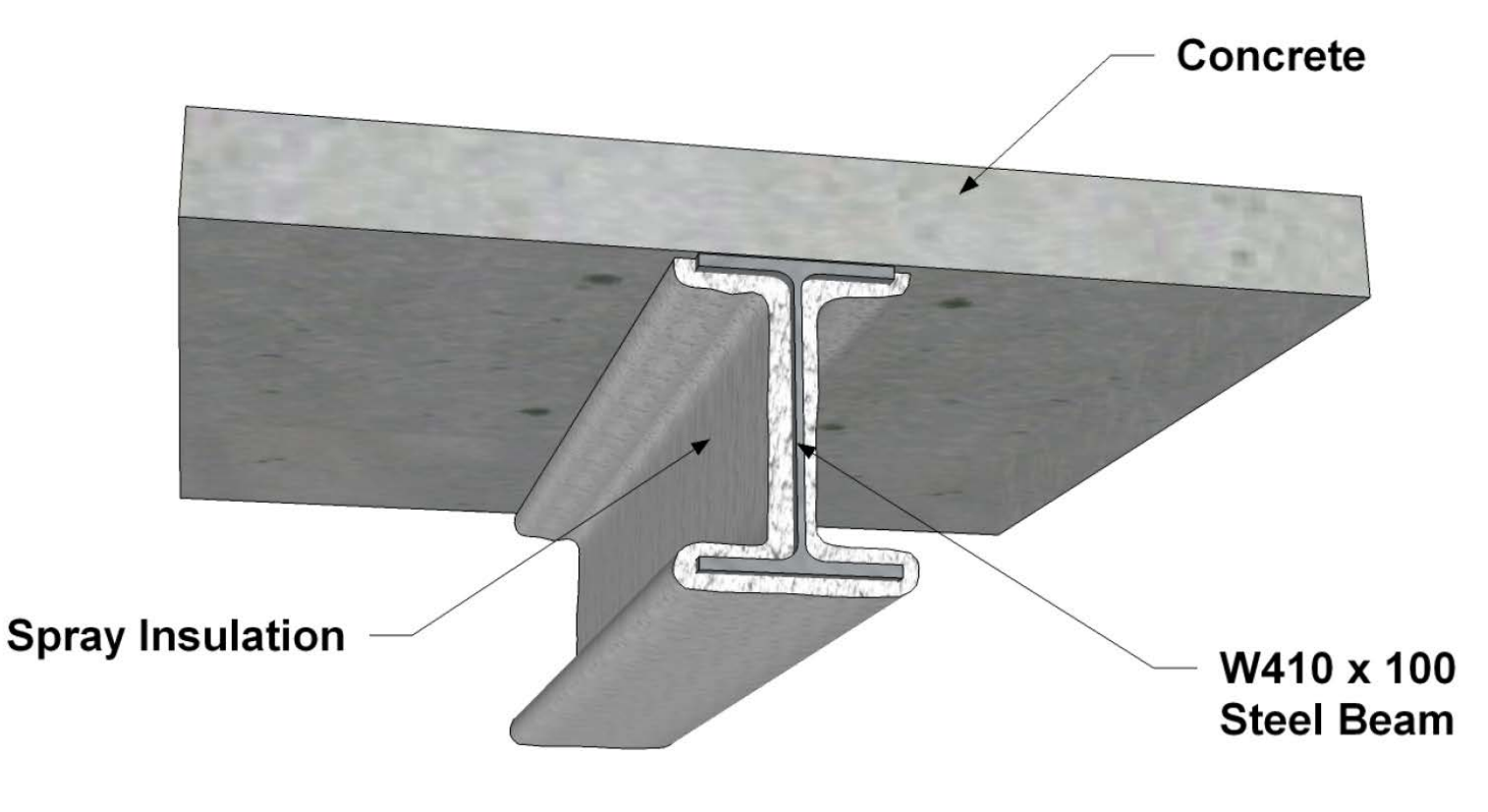
Encapsulation



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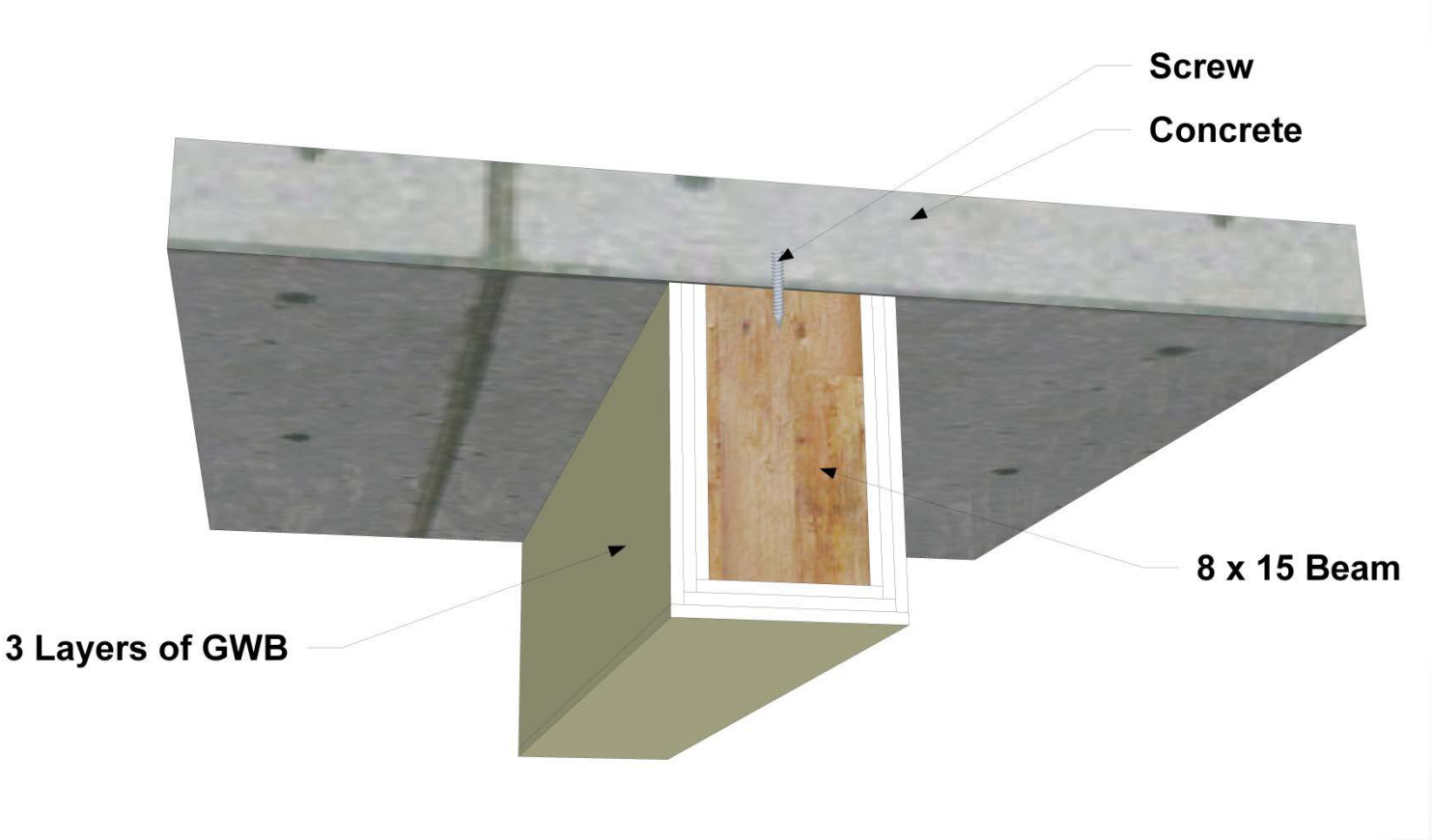
Encapsulation



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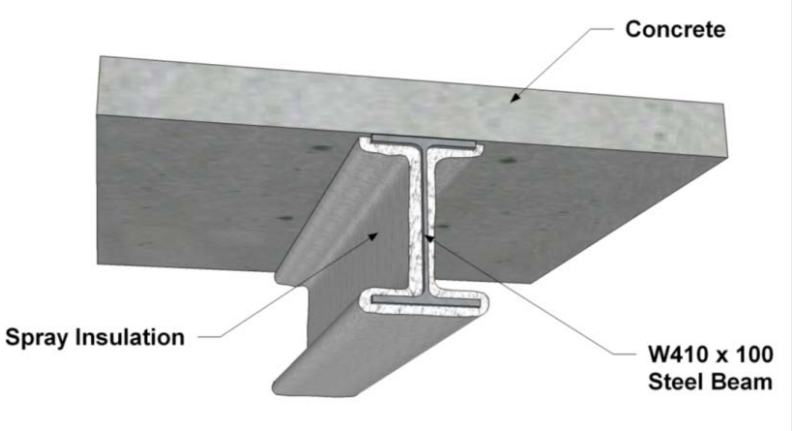
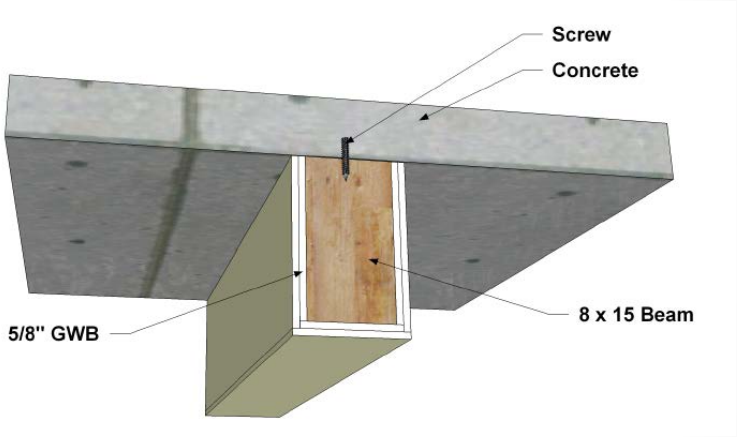
What is the Difference





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Complete Encapsulation

- Wood not affected by the fire for expected duration.
- Wood does not contribute to the fire for expected duration.
- 4 layers of ½in GWB.
- Makes the point that it CAN BE DONE.

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Fire Resistance Rating of Gypsum Board Membranes

Gypsum Board Members	Fire Resistance Rating
One layer of 12.7mm (½in) GWB	15min
One layer of 15.9mm (⅝in) GWB	30min
Two layers of 12.7mm (½in) GWB	40min
Two layers of 15.9mm (⅝in) GWB	60min
Three layers of 15.9mm (⅝in) GWB	90min
Four layers of 15.9mm (⅝in) GWB	120min

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Flame Spread Rating

- Multiple tests have been conducted
  - Consistently show FSR of 35 to 40

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Fire Testing

- Fire resistance rating developed from testing

WALL ASSEMBLIES						
# of Plies	CLT Thickness (mm)	Gypsum Board Protection	Load (kN/m)	Load Ratio (%)	Failure Mode	Fire Resistance (min)
3	114	2 x 12.7 mm (1/2")	333	52	Structural	106
5	175	Unprotected	333	25	Structural	113
5	105	Unprotected	72	21	Structural	57

FLOOR ASSEMBLIES						
# of Plies	CLT Thickness (mm)	Gypsum Board Protection	Load (kPa)	Load Ratio (%)	Failure Mode	Fire Resistance (min)
3	114	2 x 12.7 mm (1/2")	2.7	23	No failure *	77 *
5	175	Unprotected	11.8	38	Integrity	96
3	105	1 x 15.9 mm (5/8")	2.4	43	Integrity	86
5	175	1 x 15.9 mm (5/8")	8.1	100	Integrity	124
7	245	Unprotected	14.6	100	Structural	178

* Test was stopped due to equipment safety concerns. Failure was not reached.

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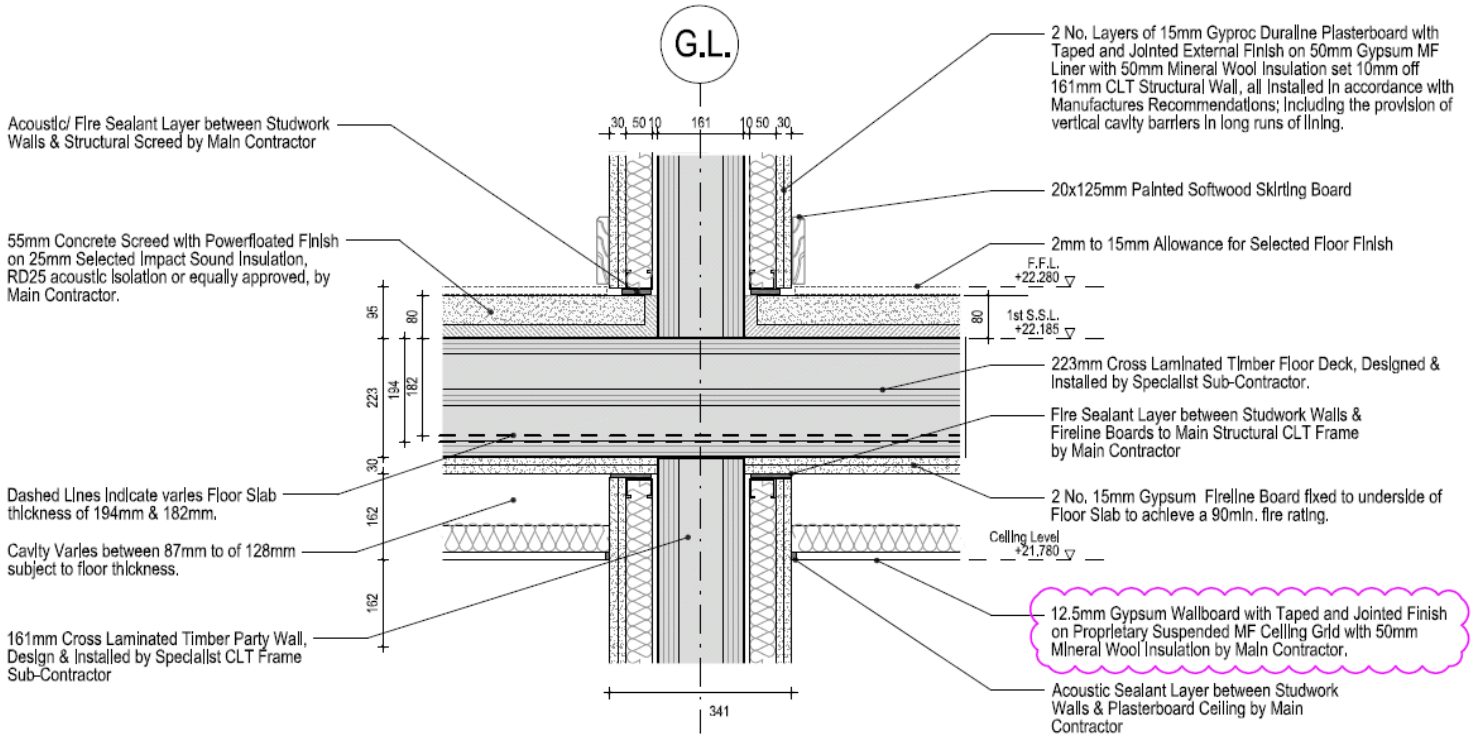
UK Early Example – Bridport House

Fire / Acoustic



D002
176-A-C-400-11

Junction of 1st-4th Floor & Party Wall
Scale 1:10

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Peel Off the Layers

Then, suggested we peel off the layers.

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Char → Fire Resistance

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Inherent Safety of Mass Timber

- Why do we use small wood sticks to start a campfire?

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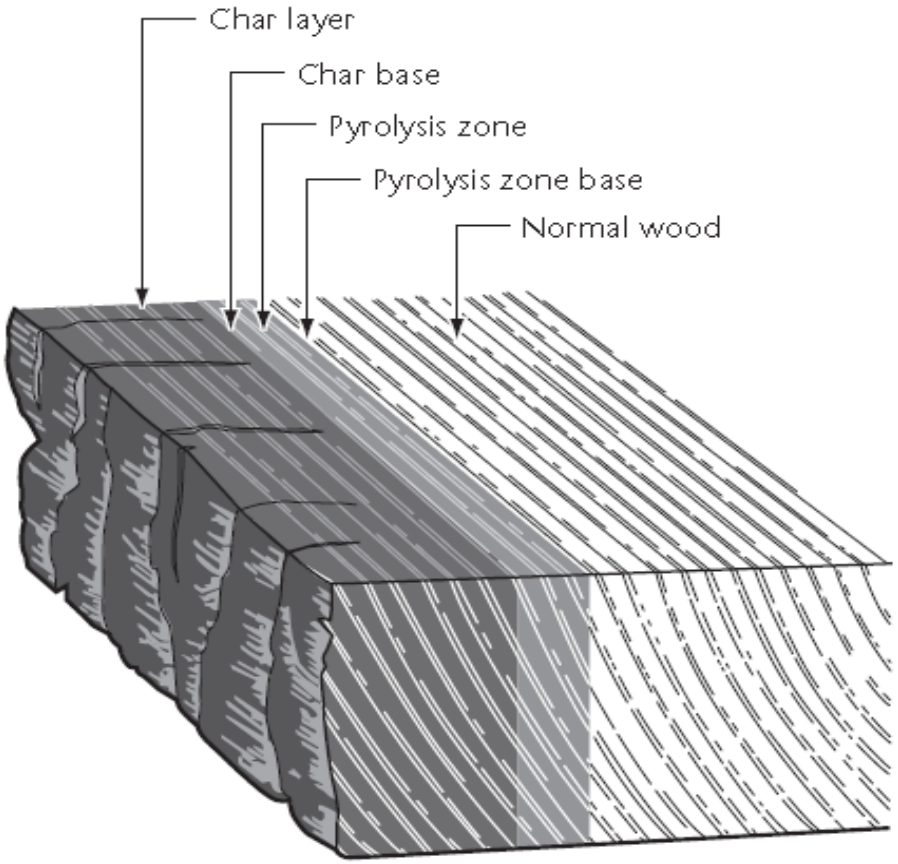
Char Layer – Small-Scale Flame Test



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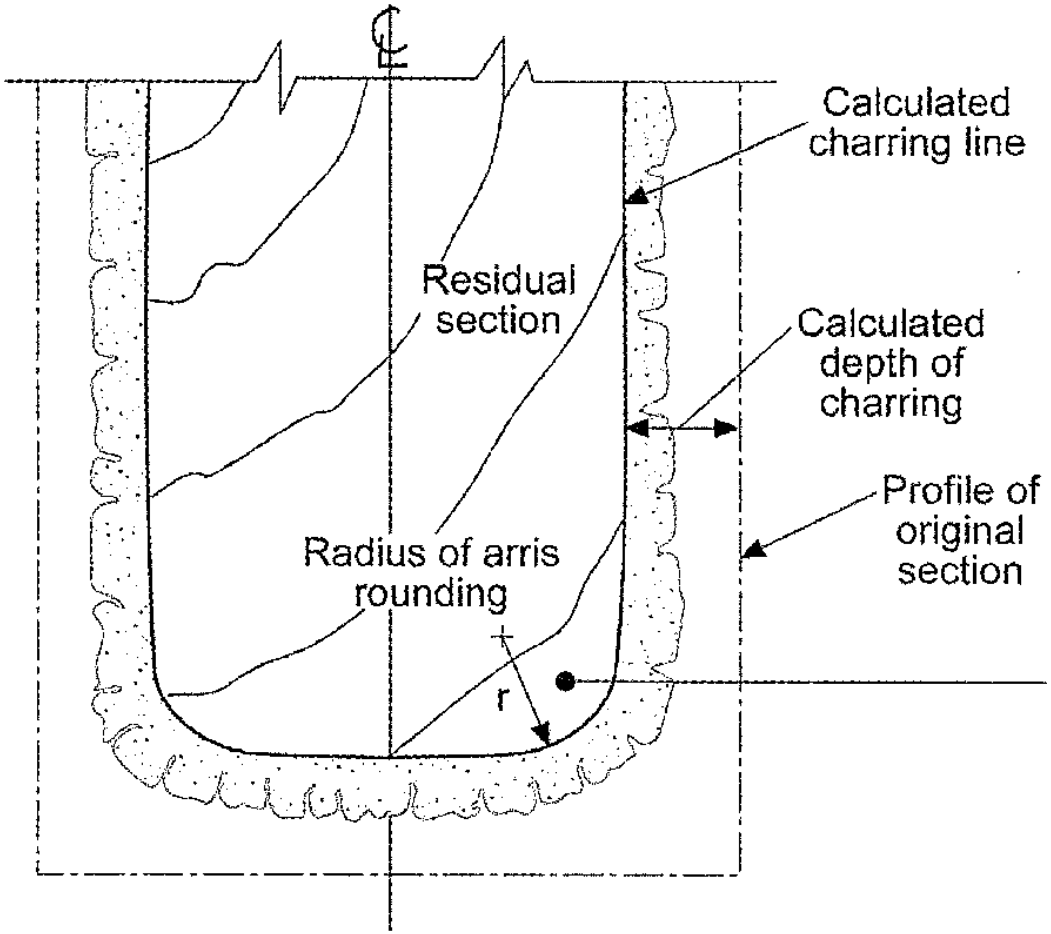
Concept of Mass Timber Design for Fire Resistance



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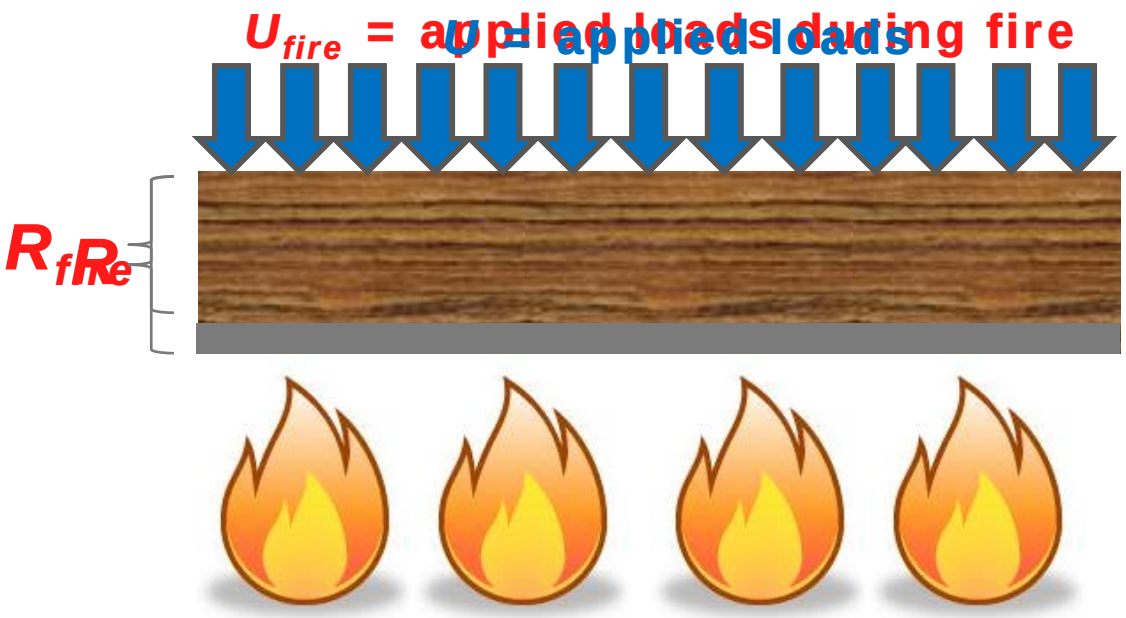
Limit State Design – for Fire

$$U_{fire} \leq \Phi_f R_{fire} \qquad (1)$$

where U_{fire} = the design action from the applied load at the time of the fire;
Φ_{fire} = the strength reduction factor for the timber material; and
R_{fire} = the nominal load capacity at the time of the fire, accounting for charring of wood members



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Size of Members

Upsize of members for fire.

But this refers to critical collapse loads only.

Often performance governs (vibration, deflection).

Members may not need to increase in size.

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What has the greater risk?

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2h Noncombustible

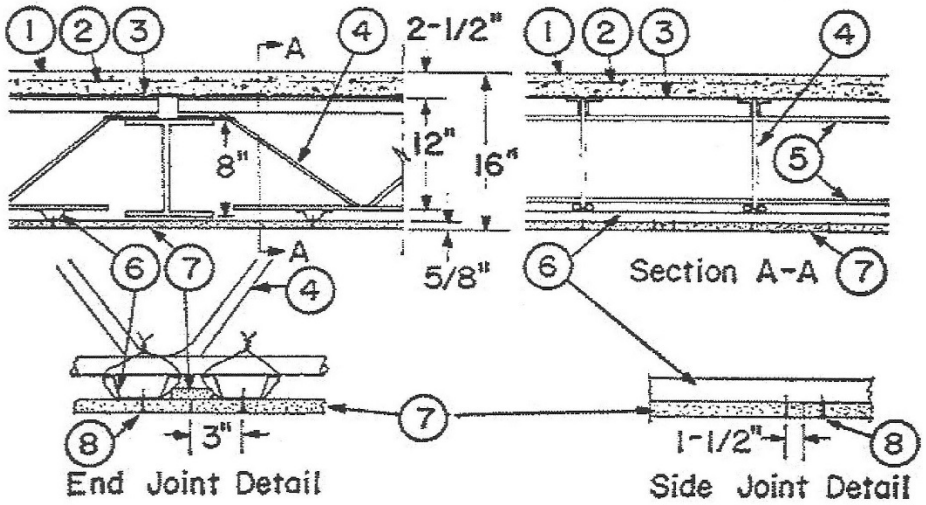
Fire Resistance Ratings - ANSI/UL 263

See General Information for Fire Resistance Ratings - ANSI/UL 263

Design No. G512

February 18, 2010

Restrained Assembly Rating — 3 Hr.
Unrestrained Assembly Rating — 3 Hr.
Unrestrained Beam Rating — 3 Hr.
Load Restricted for Canadian Applications — See Guide BXUV7



Beam — W8x35, min size.

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2h FRR

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This, especially if wrapped in 2 layers of GWB

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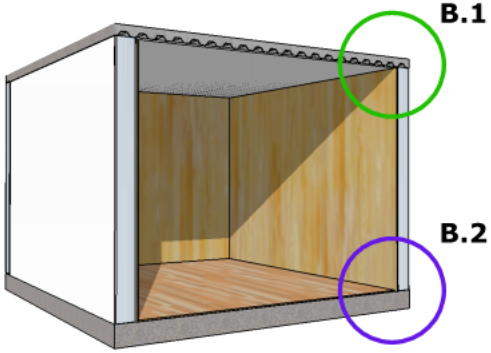
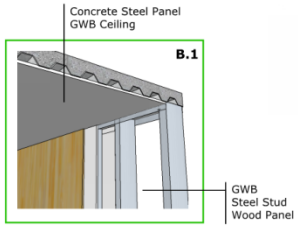
Simple Comparison Directly Permitted Room



B. Conventional Steel Stud Compartment



- Wood panelling 25mm thick permitted in a sprinklered building.
- Typical FSR 100 to 150.
- Burnout of panelling and contents:
- 25mm/0.8mm/min.
- Approximately 30min.

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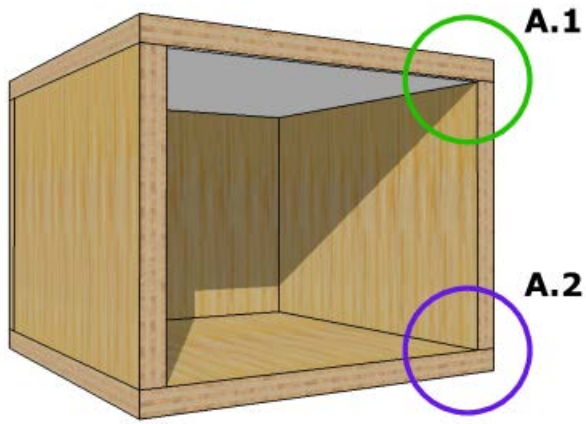
CLT Box



A. CLT Panel Compartment

- FSR 40 (FSR 37 and 38)

First 30 to 45min – Same as Wood Panels

Perhaps less than wood panels with FSR 40

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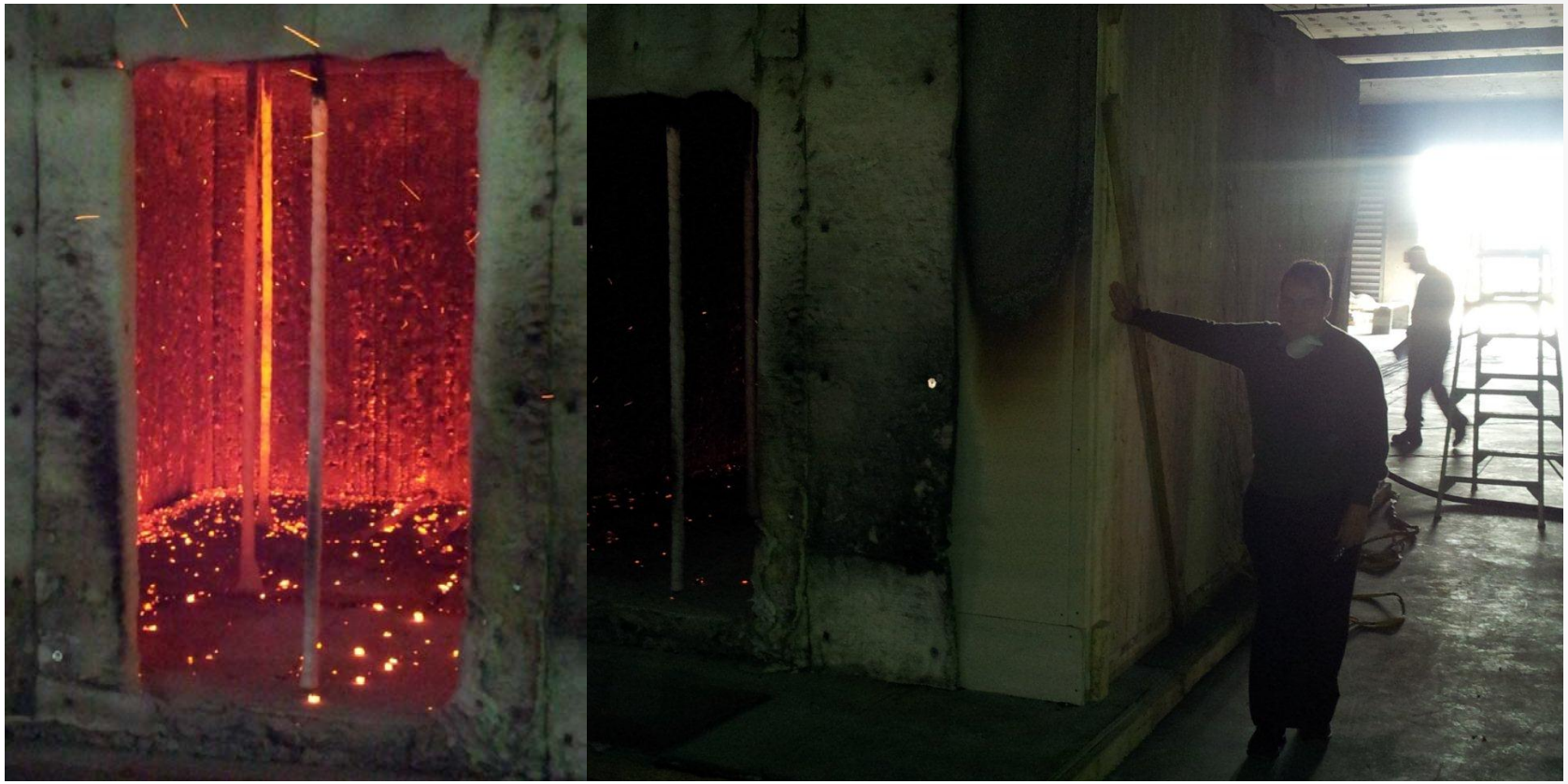

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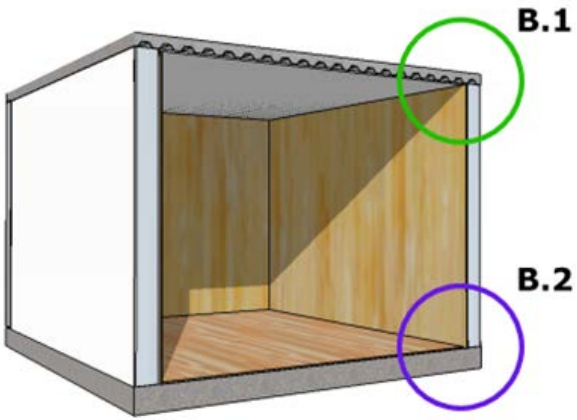
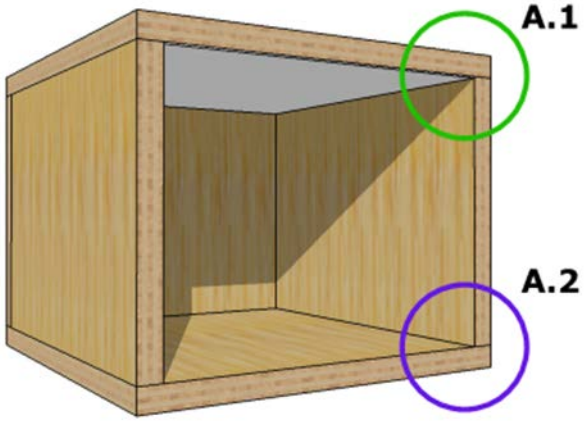
Which do you trust more



B. Conventional Steel Stud Compartment



A. CLT Panel Compartment

?

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NRC/CWC Research Consortium

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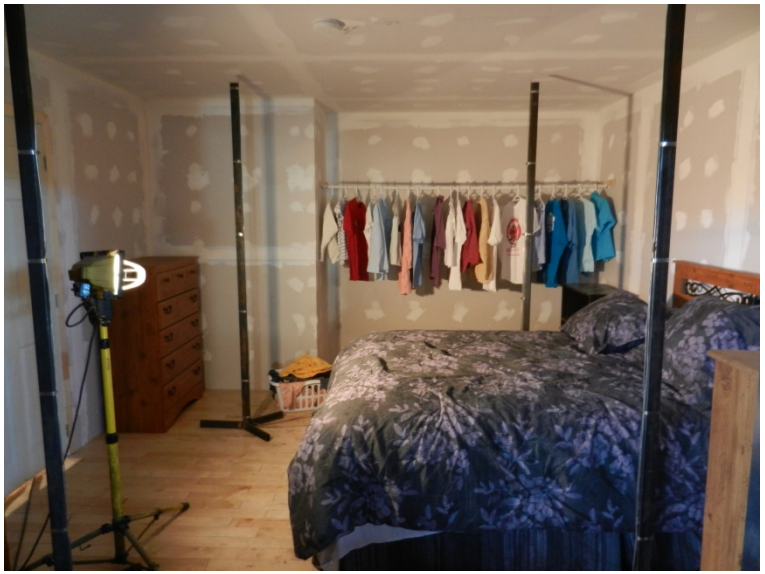

Fire Test Fuel

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NRC/CWC Research Consortium

LWF Start of Test

CLT Start of Test

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NRC/CWC Research Consortium

LWF Fire Test

CLT Fire Test

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NRC/CWC Research Consortium

LWF

CLT

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NRC/CWC Research Consortium

Steel

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Risk Analysis

CUrisk

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CURisk

- A quantitative fire risk assessment model.
- Developed at Carleton University by George V. Hadjisophocleous - Professor and NSERC-Forintek Industrial
  - Professor Hadjisophocleous is Research Chair in Fire Safety Engineering.

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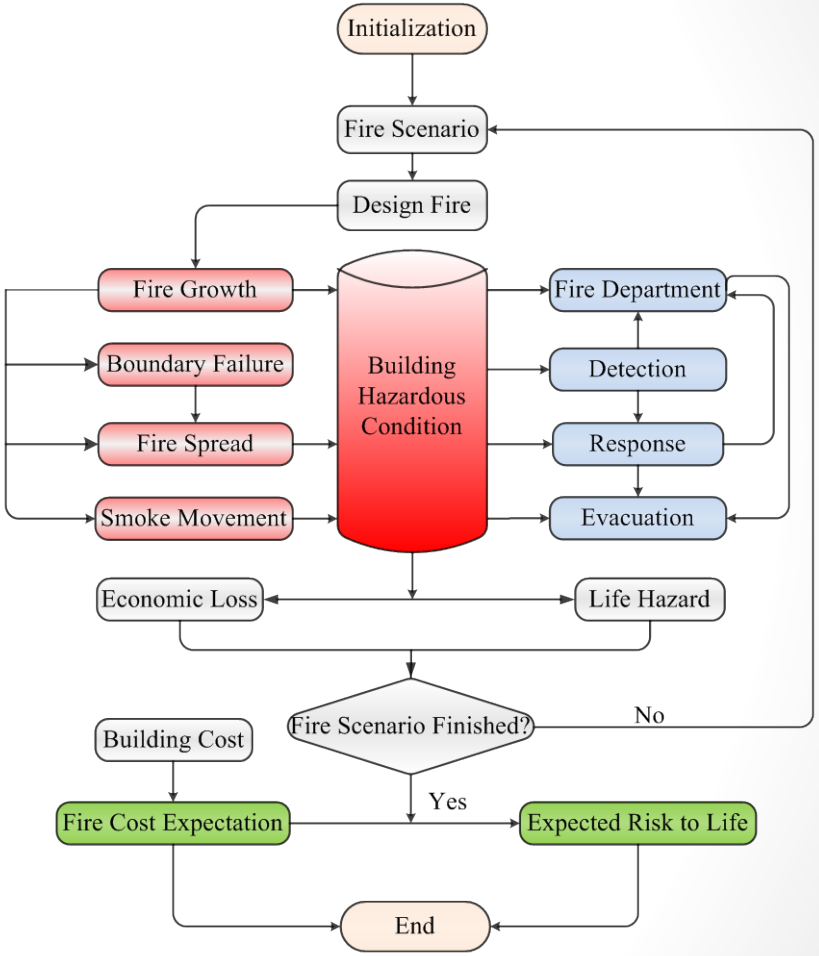
CUrisk

- It has a system model and more than 10 sub-models.
- Scenario-based fire risk analysis.
- Fire cost expectation and expected risk to life.



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Fire Risk Modeling Using CUrisk

- The objective - using CUrisk to compare the fire risk of the proposed building of mass timber construction with that of a prescribed non-combustible construction.
- Buildings for comparison:
  - The demonstration building :
    - The proposed mass timber construction.
    - With one wall of heavy timber panel unprotected (about 15% of the room surface area).
  - A comparable noncombustible construction:
    - Same design but a prescribed noncombustible construction.
    - Assumed with no combustible room linings.

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CUrisk Simulation

- Fire growth in the fire room under different room constructions.
- Effects of HTP wall exposure areas on the fire development.
- Effects of sprinklers and fire department on the fire development.
- Response and evacuation process:
  - Probability of evacuation following response.
  - Remaining percentage of building occupants.
  - Occupants' evacuation times.
- Scenarios-based fire risk analysis:
  - Comparison of the over fire risk.
- Effect of reliability of fire sprinklers on the fire risk.

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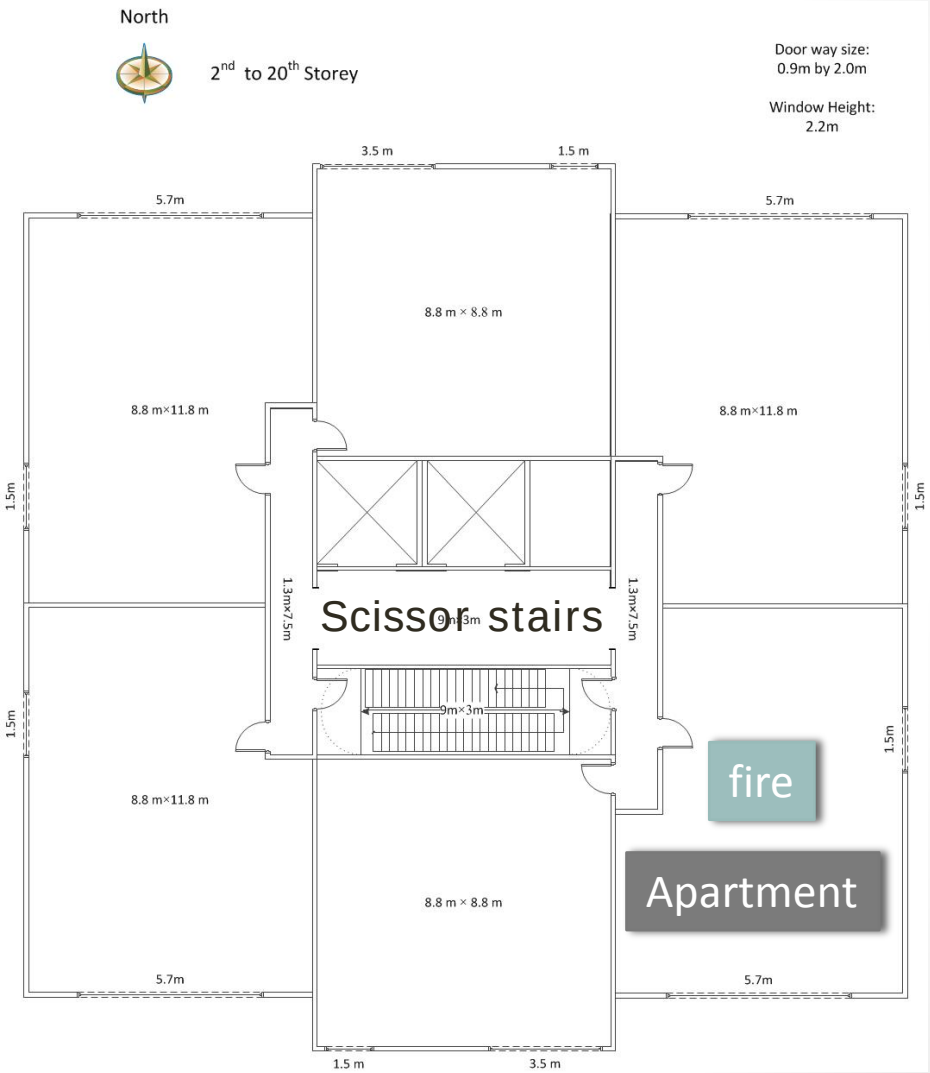
CUrisk input - Fire Scenarios

- Residential fires in all residential storeys:
  - One fire location each floor.
  - Covering all the residential floors.
- Extreme scenarios:
  - Fire in the lobby and night fires without fire suppression.
  - Discussion in the report.



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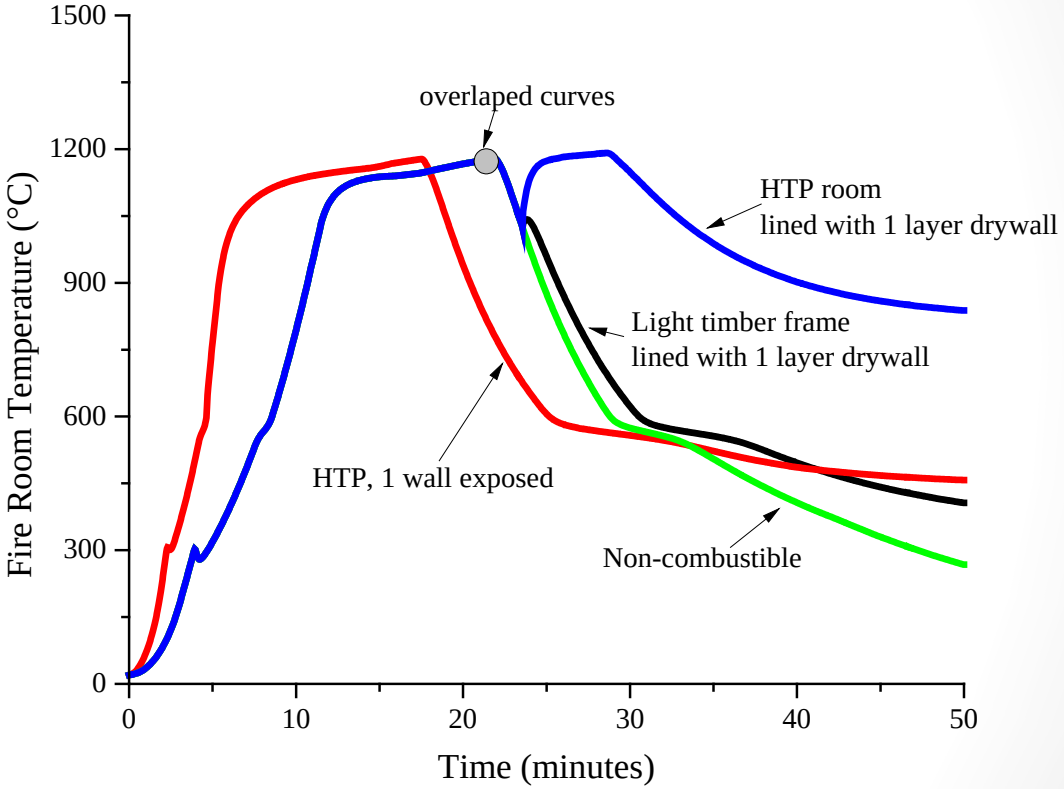
Comparison of Fire Curves

- No fire suppressions.
- Faster fire growth (> ultrafast).
- Continuous wall burning.
- Fully developed fire may occur after wall linings fail.



Room temperature in the fire room Apt.11 on 2nd floor

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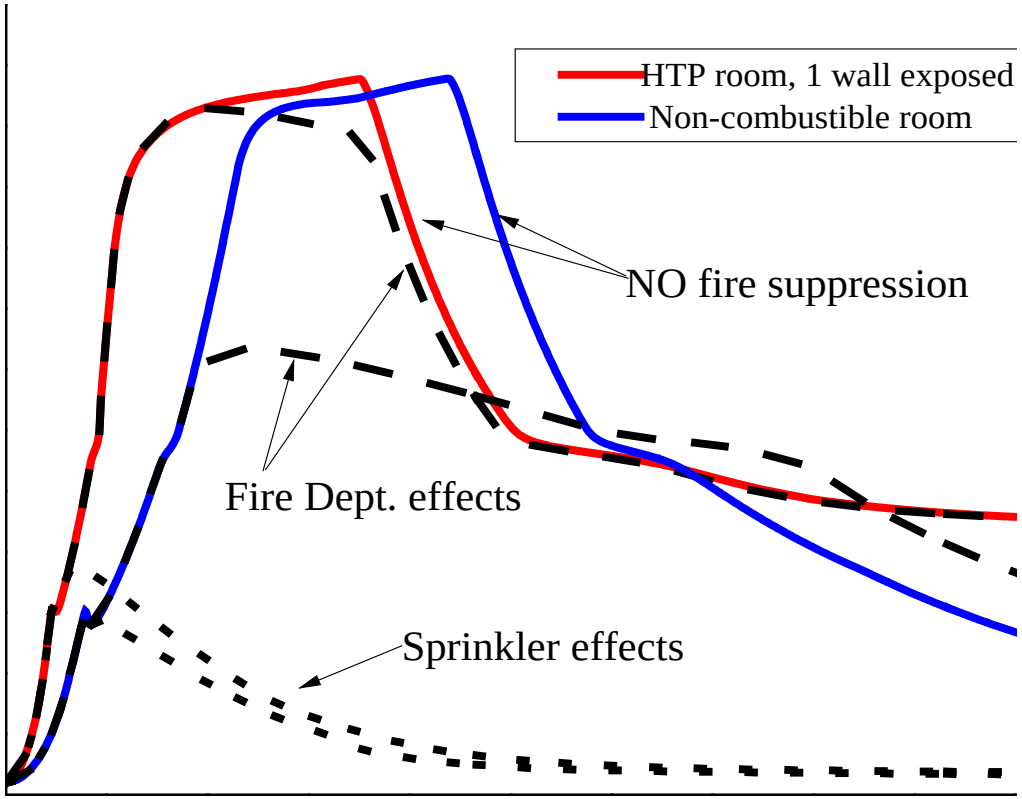
Effect of Sprinklers and Fire Department



Room temperature in the fire room Apt.11 on 2nd floor

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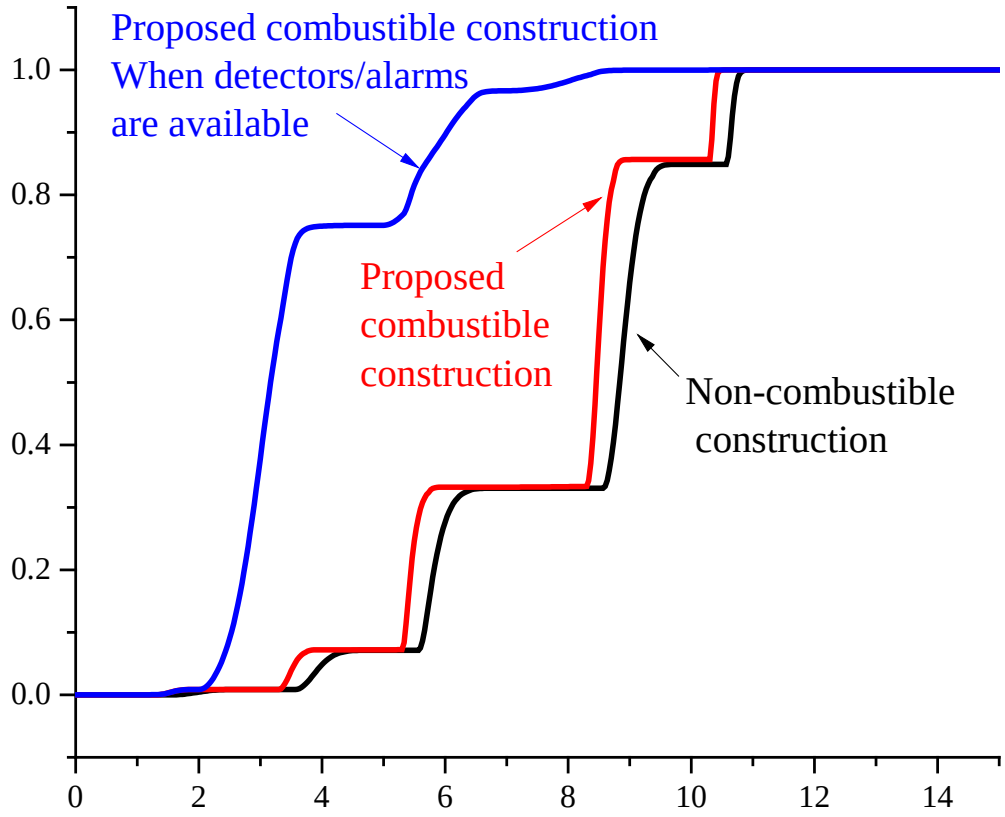
Occupant Response to Fire



Probability of evacuation initiation following occupant response time when fire occurs in room 11 on the 2nd floor. No fire suppression and detection and alarms (solid and dash lines)

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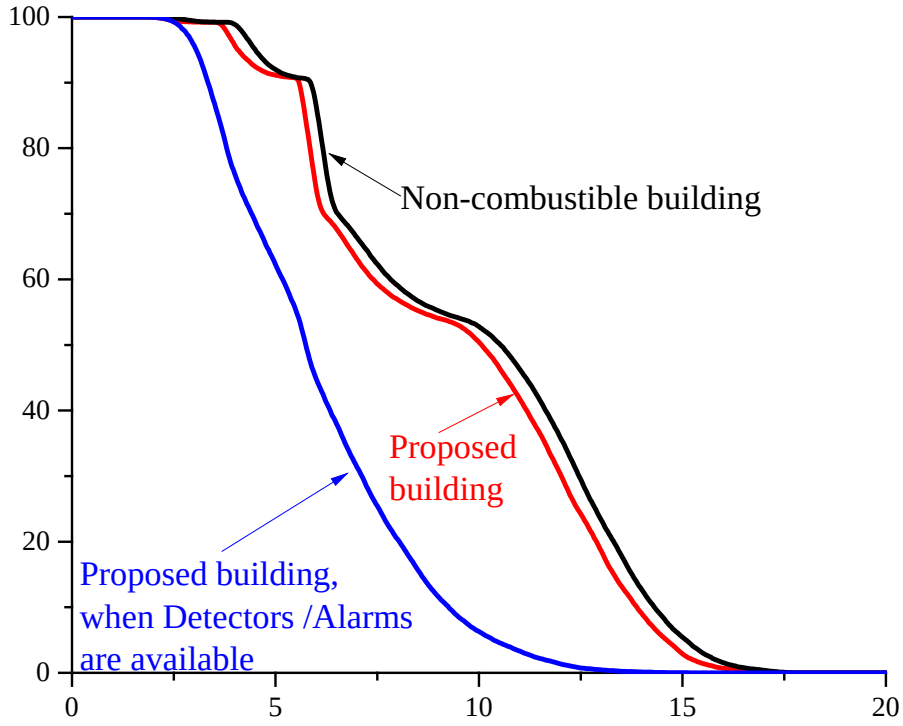
Evacuation Remaining Percentage



Occupant remaining percentage in the building versus time when fire occurs in room 11 on the 2nd floor. No fire suppression and no detectors and alarms (red and black).

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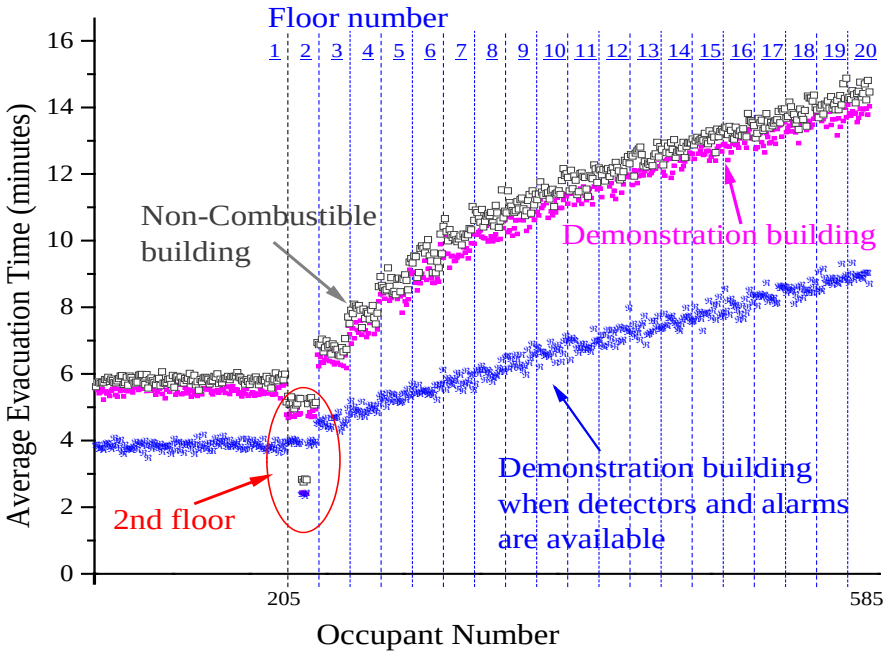
Occupant Evacuation Times



Average evacuation time of each occupant when fire occur on 2nd storey room 11. A comparison of the proposed combustible building and a noncombustible building.

Reliable fire detectors and alarms can provide quicker fire cues to occupants.

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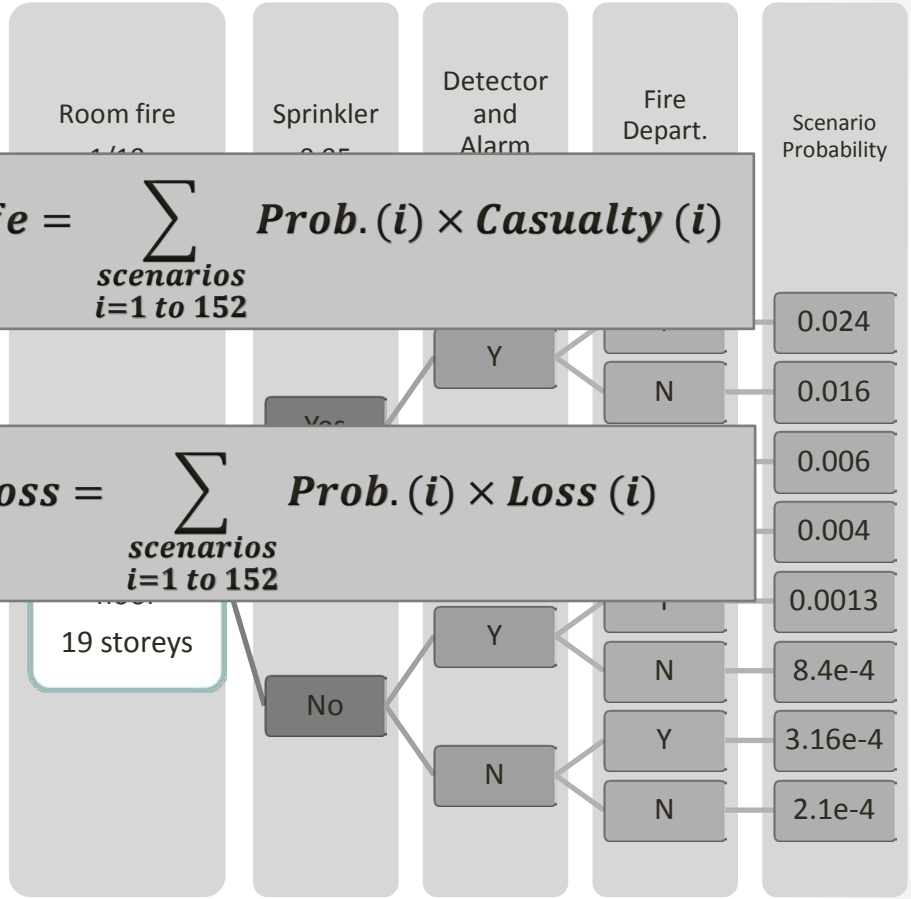
Fire Risk Comparison

- Considering possible fire scenarios on each residential floor
  - Same
    on ea
- Consid
  - Fire location
  - sprinklers
  - detec
  - Fire D
- Totally 152 fire scenarios for each type of building
  - The proposed building
  - Comparable non-combustible construction

$$\textit{Relative Risk to Life} = \sum_{\substack{\textit{scenarios} \\ i=1 \textit{ to } 152}} \textit{Prob.}(i) \times \textit{Casualty}(i)$$

$$\textit{Expected Fire Loss} = \sum_{\substack{\textit{scenarios} \\ i=1 \textit{ to } 152}} \textit{Prob.}(i) \times \textit{Loss}(i)$$



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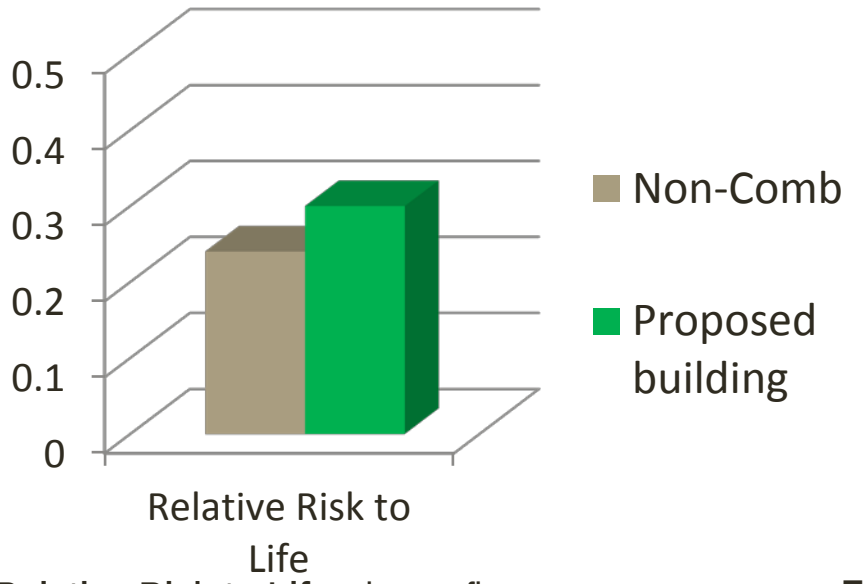
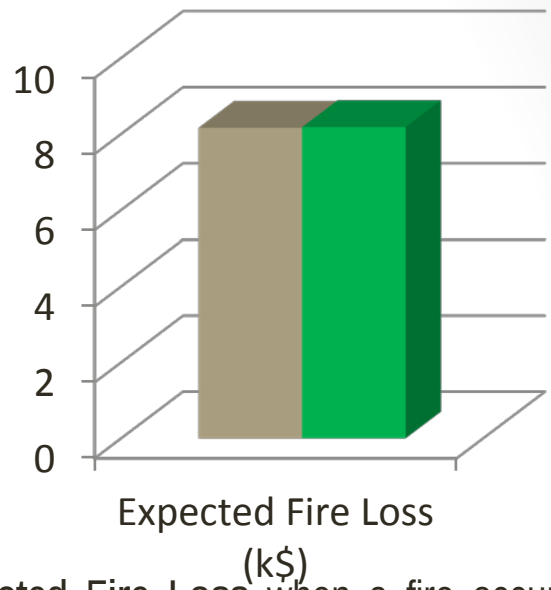
Expected Fire Risk Comparison



Relative Risk to Life when a fire occur on any residential storeys among all the occupants



Expected Fire Loss when a fire occur on any residential storeys in the whole building

- It is assumed that the non-combustible building does not contain wood panelling or any combustible linings. This fact would bring the life risk results into closer alignment.
- Beside, neither CUrisk nor ULC S101 recognizes the added reliability of HTP fire separations versus the permitted light steel fire separations.

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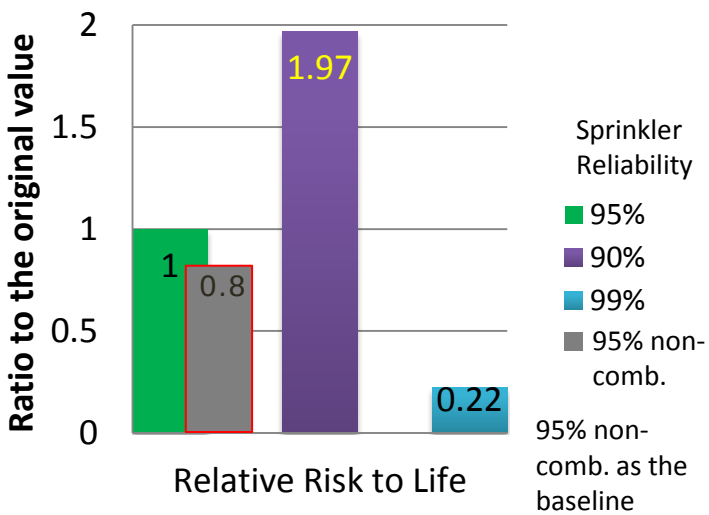
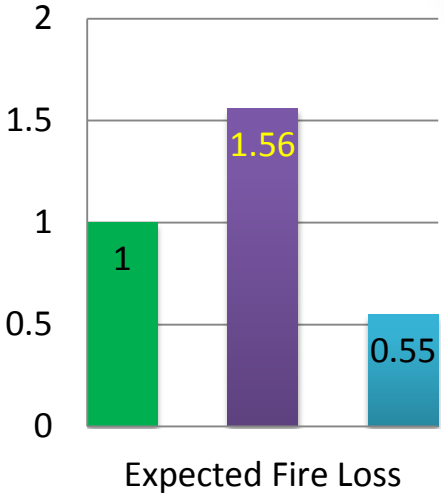
Effects of Sprinkler Reliability





The effect of sprinkler reliability on the fire risk of the demonstration building

- Reliability of sprinklers is the most important factor in reducing the fire risks. Slight increase in sprinkler reliability can greatly reduce the fire risk.
- In this respect, the difference between the non-combustible and the demonstration building is insignificant/ignorable.
- Fast response sprinklers with high reliability and suppression efficiency can dramatically reduce the risk.

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CUrisk Summary

- Scenarios-based fire risk assessment are conducted using CUrisk, and results showed that the demonstration building could provide the same level of fire safety as a directly permitted noncombustible construction.
- Evacuation simulation results showed that occupants can evacuate out of the building with a reasonable time frame; regarding to occupant evacuation times, the demonstration building is as good as the comparable noncombustible construction building.
- Higher reliability sprinkler system (good efficiency) can bring any combustible construction into close assignment with a noncombustible construction building.

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5 Storey A-2 Occupancy UBC Earth Sciences Building

Acceptable solution for A-2 occupancies:

- 1h noncombustible construction.
- Alternative solution to address 1h mass timber.

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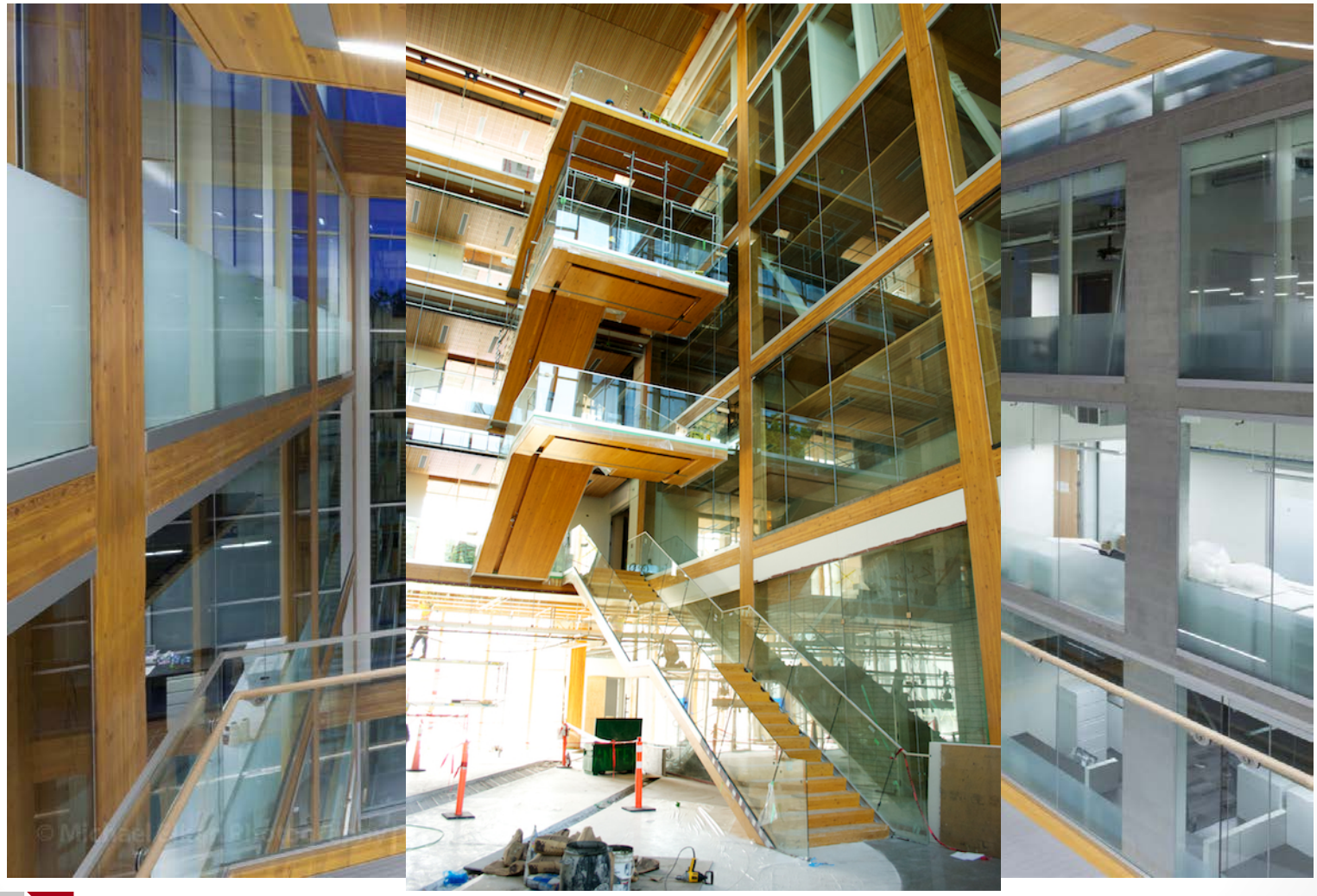
Earth Sciences Building



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Pre - Flashover

95% sprinkler reliability.

Only necessary to address 5% probability.

Low occupant load, extra fire separations.

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Approach

Risk Analysis

Pre-Flashover

Post-Flashover

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Peer Reviewed

GHL was the proponent.

Gage-Babcock & Associates Ltd was the reviewer.

All large UBC buildings done by peer review.

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Mass Timber vs Steel

Wood

- Highly reliable.
- Reproducible results.
- Contributes fire load.

Steel

- Cheap to protect.
- How reliable?
- How reproducible are the results?
- Burns out.

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Concrete

Concrete:

Agreed generally more fire safe than mass timber.

Are fire rating designs and cover still applicable?

Is 1/2in of cover acceptable (interpretation of IBC)

Spalling is unpredictable.

Concrete – how do you repair it - $30B loss in NZ.

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Firefighting Considerations

- If sprinklered – no difference from a sprinklered noncombustible building – 96%.
- Encapsulation == encapsulated steel.
- Performance in the first half hour will be the same as concrete or steel building of the same design.
- Evacuation the same.
- Difference may be clean-up, as mass timber may continue to burn and char.
- Difference – If the sprinklers fail, longer clean-up.

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Connections

Not specifically addressed for steel or concrete.

Especially intumescent – problems noted.

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Intumescent Paint

Most tested on steel beams – no movement or cracking.

Effectiveness on connections, steel or wood is not known.

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We Used to Know How to Do It

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Protected Connections for Enhanced Fire Performance

b) Connection covered with wood paneling

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Protected Connections for Enhanced Fire Performance

a) Fire-resistance test conducted on concealed plate
(credit: L. Peng (Peng, Hadjisophocleous, Mehaffey, & Mohammad, 2010))

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Issues

A few issues that came up worth discussing.

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Issues

Performance targets not clear.

Why 2h FRR? IBC is 3h, why the discrepancy?

Why does ULC S101 only require 1 test?

Is criteria set by residential 1h compartment rating?

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Sprinkler Reliability

To what degree can we rely on sprinklers?

Consensus of authors:

- On site water supply needed if exposed wood.

Addresses – seismic concerns:

- Fire after 2h?

US data confirms that sprinklers are 90% reliable; Canadian data, if monitored and supervised, reliability is much higher.

In my opinion, a fully sprinklered 2h combustible building can meet risk fully exposed, but not politically saleable in most areas.

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Seismic

"An internal report of the City of Vancouver concludes that, at present, an M-7 earthquake would render the Greater Vancouver Water District supply system completely dysfunctional with 1000 water main breaks and 1000 service breaks." (Robertson 2000)

Conclusion: We need an on site water supply.

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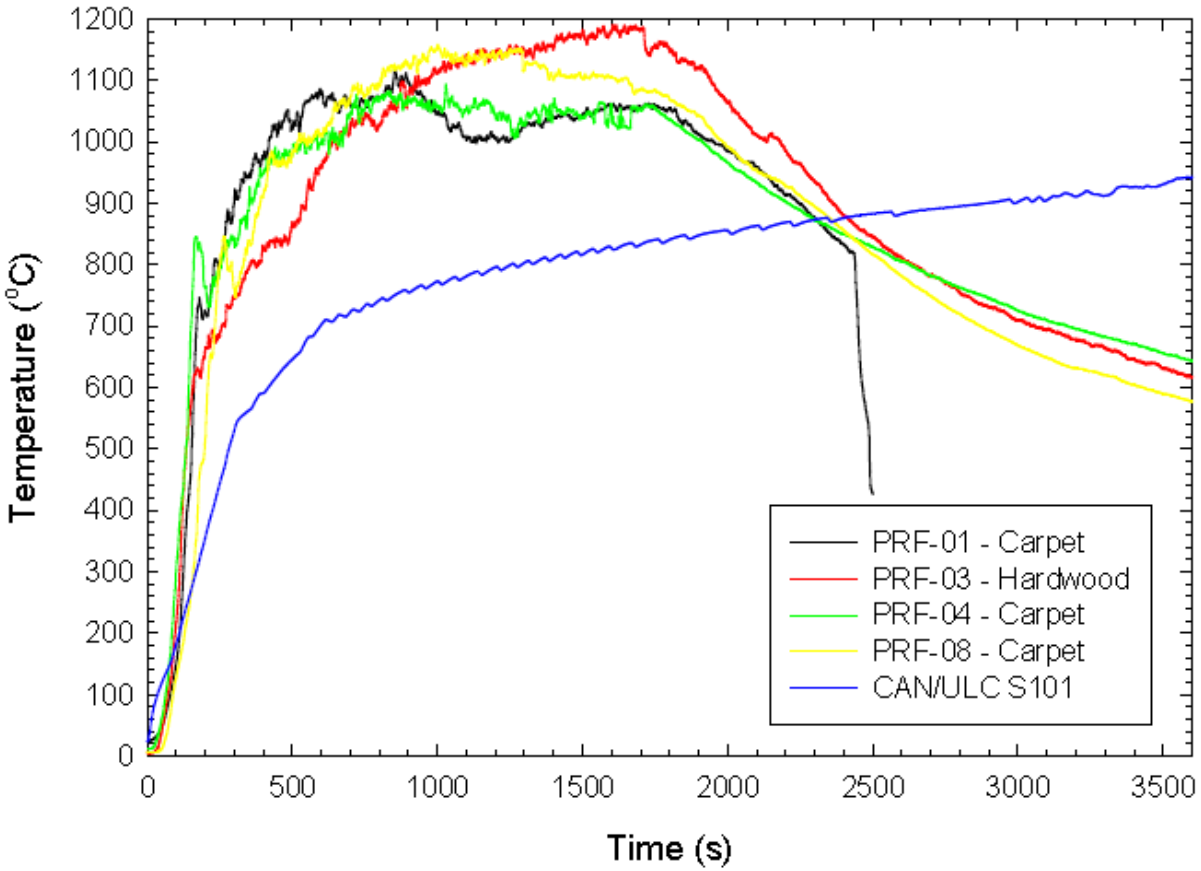
Standard Fire vs. Design Fire



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Design Fire

Is the standard fire acceptable, or do we need to look at real fires?

Conclusion:

- Office, Residential Occupancies – standard fire is acceptable as a yardstick.
- High hazard, should probably assess real fires.

Note, if using reduced load, must use 'natural fire'.

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Void Spaces

- Limited but they will occur.
- How big a void space is acceptable?
- Unsprinklered (NFPA 13 provisions applicable).
  - Sprinklered?

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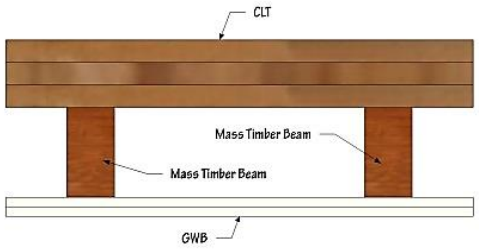
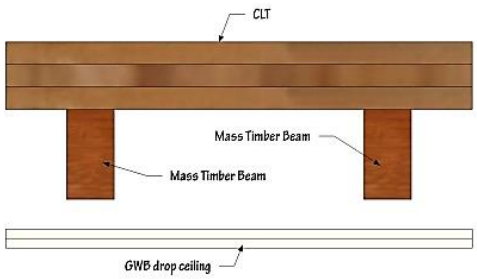
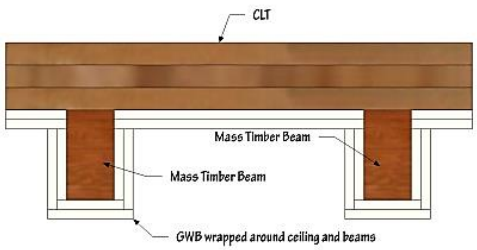
Approaches to Encapsulation Creating Concealed Spaces







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Mass Timber within Occupied Spaces

Mass Timber typically FSR 40 to 50:

- Wall and ceiling finishes up to 25 mm in thickness.
- Floor finishes of any thickness.
- Solid wood partitions that are not a part of floor-to-floor separations or exit separations.
- Light wood framing in partitions that are not a part of floor-to-floor separations or exit separations.

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Firestopping

Don’t see a lot of issues.

Some public testing being done for WIDC.

But, be careful.

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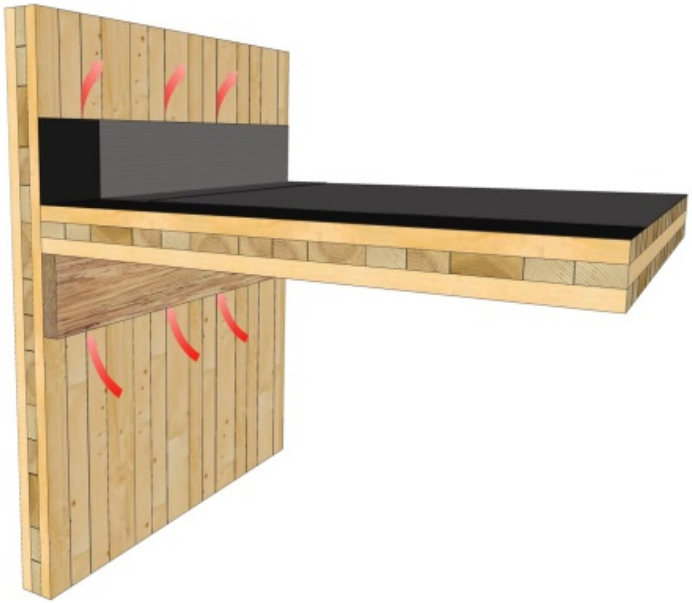
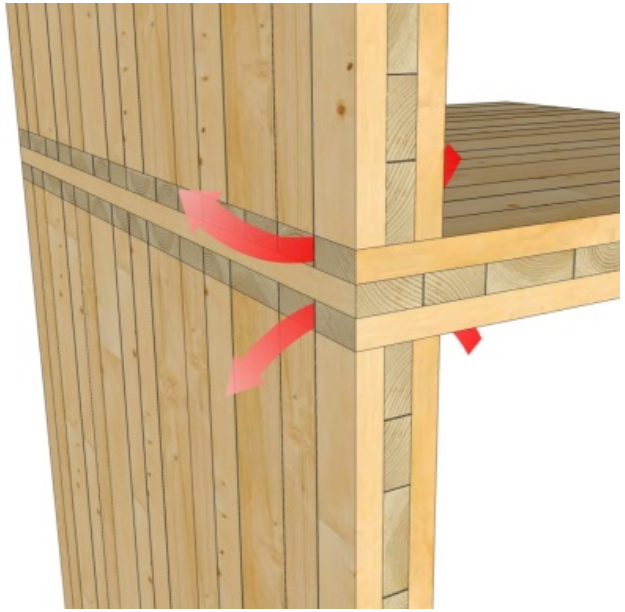
CLT Smoke Leakage Paths





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Fire Tests Not So Bad

Results to come

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Firestop Test 2013/02/04

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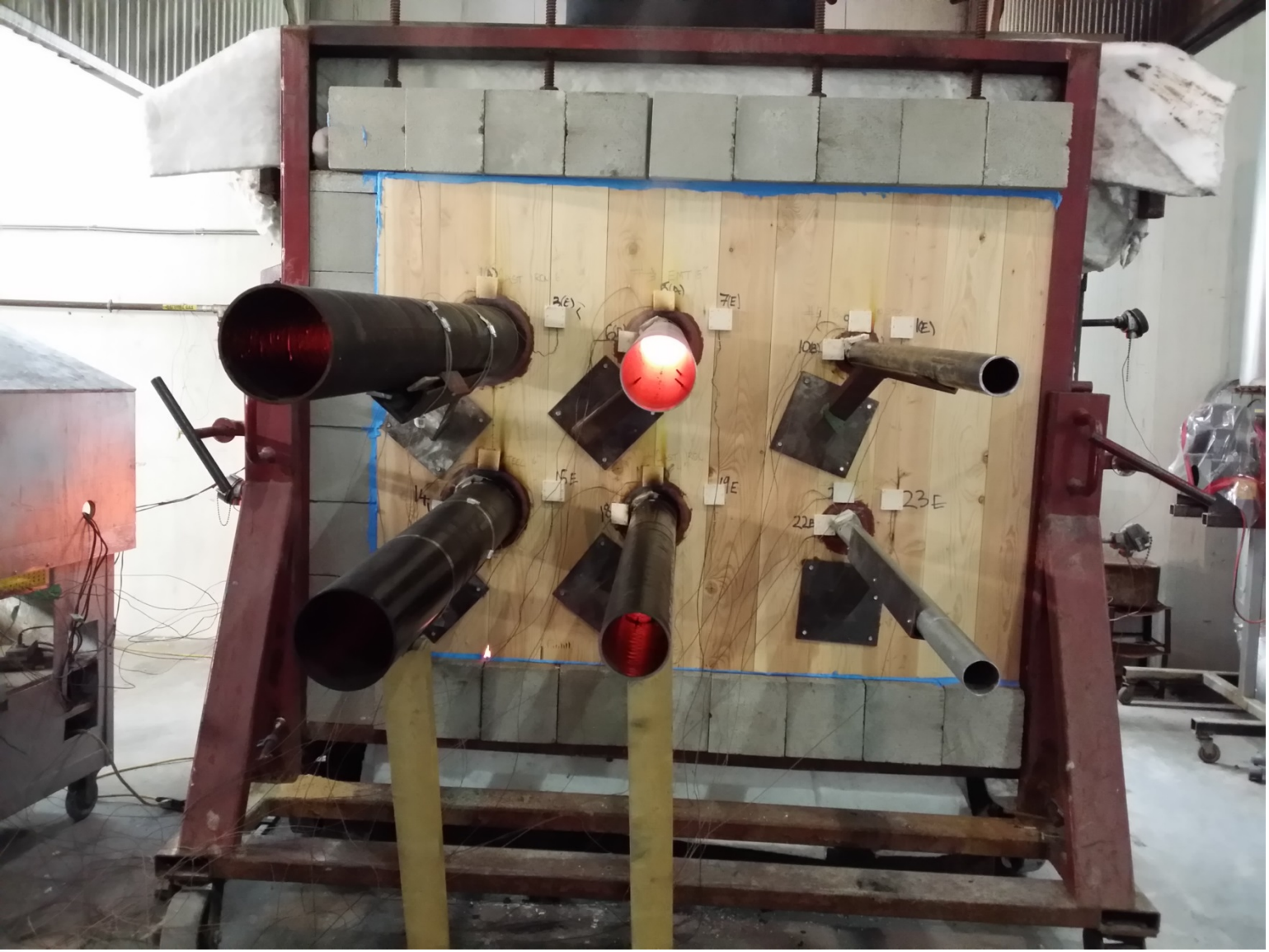

Firestop Test 2013/02/04

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Exterior Cladding

Unlikely to be fully exposed.

Take a walk in the forest – how much wood do you see?

Code has a nice performance Standard for this, just needs to be applied to the whole wall assembly.

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Cladding

Performance Standards

- Exterior:
  ULC S1.3.5 /Article 3.1.5.5
- Interior:
  Standard firestop
- If we meet that, why do we need additional provisions of noncombustible?

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Developments in Canada

NEWBuildS - Network for Engineered Wood-based Building Systems.

CAN/CSA O86 Task Group on Wood Fire Ratings.

NRC/CWC Research consortium on higher wood buildings.

FP Innovations CLT Development.

National Code Process.

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NEWBuildS

NEWBuildS - Network for Engineered Wood-Based Building Systems:

- History of the Code studies.
- Fire tests of CLT rooms.
- Hybrid construction (steel/wood and concrete/wood).

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NRC/CWC Research Consortium

Research consortium on higher wood buildings:

- Looking at 6 storey combustible frame construction.
- Learned group similar to Code Committee.
- Comparative performance testing (fire and sound).

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Useful Links

- GHL CONSULTANTS LTD: www.ghl.ca
  Tall Wood Presentation: http://www.ghl.ca/shared/Tall_Wood_Presentation.pdf

- Woodworks! National:
  ww.woodworks.org/index.php?option=com_content&view=featured&Itemid=112

- Woodworks! Alberta:
  www.wood-works.org/index.php?option=com_sobipro&sid=61:Wood-WORKS-Alberta&Itemid=228

- Woodworks! BC:
  www.wood-works.org/index.php?option=com_sobipro&sid=61:Wood-WORKS-Alberta&Itemid=228

- Canadian Wood Council: Mid-Rise Construction in BC:
  http://www.cwc.ca/documents/case_studies/Mid-Rise-Construction-in-BC.pdf

- Canadian Wood Council: Innovating with Wood:
  http://www.cwc.ca/documents/case_studies/Four%20demonstration%20Case%20Study_May_30.pdf

- Technical Guide for the Design and Construction of Tall Wood Buildings in Canada:
  http://ghl.ca/shared/Tall_Wood_Building_Technical_Guide.pdf

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Questions?

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