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Mass Timber Buildings
US Approach

Energy Storage Systems

NIBS
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Provider Number: G168

The UL Approach Regarding Concerns for Tall Wood Buildings and Lithium-ion Battery Energy Storage Systems

Course Number

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Date

January 9, 2019

Credit(s) earned on completion of this course will be reported to AIA CES for AIA members. Certificates of Completion for both AIA members and non-AIA members are available upon request.

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

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Course Description

Building construction that uses heavy timber has traditionally been limited to six stories in height, but, recently, efforts in the construction process are shifting to focus on renewable construction practices. This discussion on the expanded use of timber in the construction market has increased in the high-rise market. This presentation will review processes, including tests and resulting findings, and discuss current efforts within the International Code Council (ICC) code process in greater permitted heights and areas, including results of the *International Fire Code* (IFC) committee hearings. The speakers will also review questions and concerns from Underwriters Laboratories (UL) and members of the fire service, while having a discussion on potential next steps forward. Additionally, the presentation will review a second new technology trend in lithium-ion battery technology systems. Lithium-ion batteries utilize an electro-chemical technology to deliver high-energy capacities in a smaller footprint. Due to their small size, relative to their energy storage capacity, they are becoming more popular in various markets. The speakers will provide concerns of the responding fire service to these catastrophic failures and steps UL has taken, and in the process of taking, to address consumer protection and fire service response to battery product, battery-operated product and energy storage system failures.

CONTINUING EDUCATION AIA

Learning Objectives

At the end of the this course, participants will be able to describe:

1. Background – What is Cross-Laminated Timber
2. Research & Findings – Fire Protection Research Foundation
3. Design, Installation and Evaluation – US Codes
4. Energy Storage System Testing

Underwriters Electrical Bureau - 1894

The location was a small one room laboratory above Fire Patrol Station #1 on Monroe St. in downtown Chicago, IL.

Photo courtesy of Structurlam Products, Ltd

What is CLT?

Cross-laminated Timber

- Pre-fabricated, solid engineered wood panel
- Several layers of lumber boards stacked in alternating directions
- Bonded with structural Adhesive

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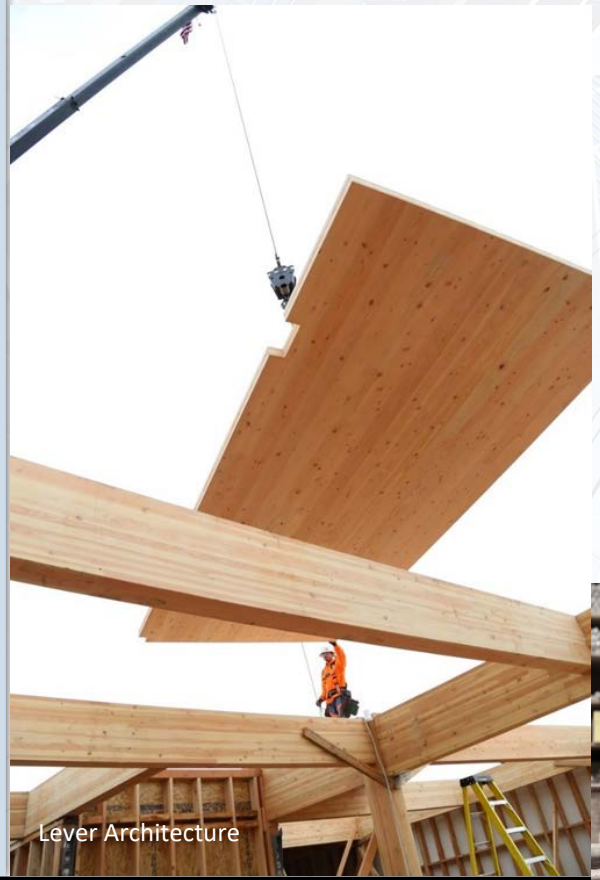
History of CLT

- 1985 First patent for CLT in France
- 1993 First projects in CLT in Switzerland and Germany
- 1995-1996 Development of press technology
- 1998 First multi-story residential building in Styria, Austria
- CLT use (Europe) increased significantly in the early 2000s
  - Driven by the green building movement
  - Due to better efficiencies, product approvals, and improved marketing and distribution channels
  - Over 500 CLT buildings in England
- US and Canadian use of CLT

IBC Principles for Mass Timber

Mass timber ≠ Conventional frame

CLT = Jinga



Lever Architecture

Nordic

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Current Structures

Muhlweg Apartments, Austria

Svartlamoen, Norway

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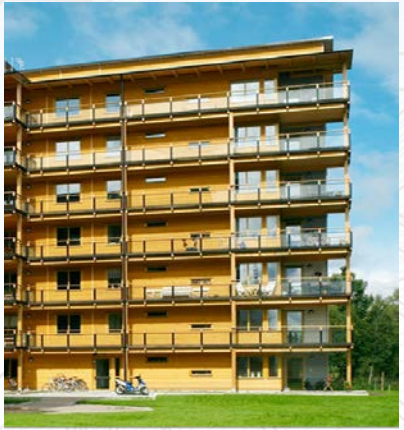

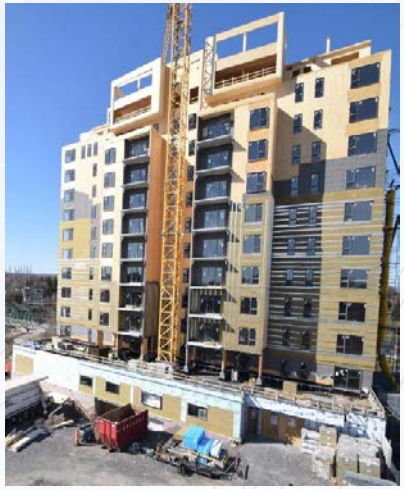

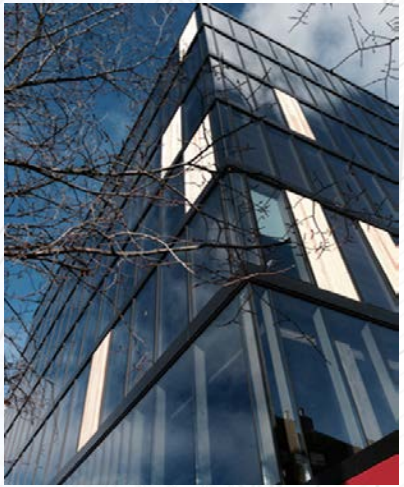

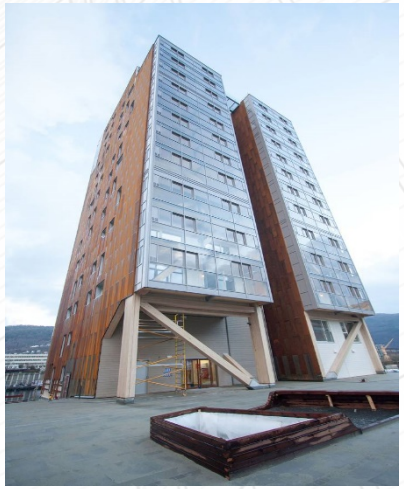

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Proposed Wood Towers

Modern Furniture

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Preliminary Results

FPRF's CLT Compartment Fire Tests

Joseph Su, PhD
Principal Research Officer, Fire Safety

CLT Compartment Fire Tests

Opening in W2	Interior dimensions 9.1 m x 4.6 m x 2.7 m					Test
	W1 9.1 m x 2.7 m	W2 4.6 m x 2.7 m	W3 9.1 m x 2.7 m	W4 4.6 m x 2.7 m	Ceiling 9.1 m x 4.6 m	
1.8 m x 2.0 m	3GB	3GB	3GB	3GB	3GB	1-1
	3GB	3GB	3GB	3GB	exposed	1-4
	exposed	3GB	3GB	3GB	3GB	1-5
	exposed	3GB	3GB	3GB	exposed	1-6
3.6 m x 2.0 m	2GB	2GB	2GB	2GB	2GB	1-2
	exposed	2GB	2GB	2GB	3GB	1-3

Baseline Test 1-1 (narrow opening)
Post test

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Sealing the Joints

Test 1-4 (exposed ceiling, narrow opening)
Post test

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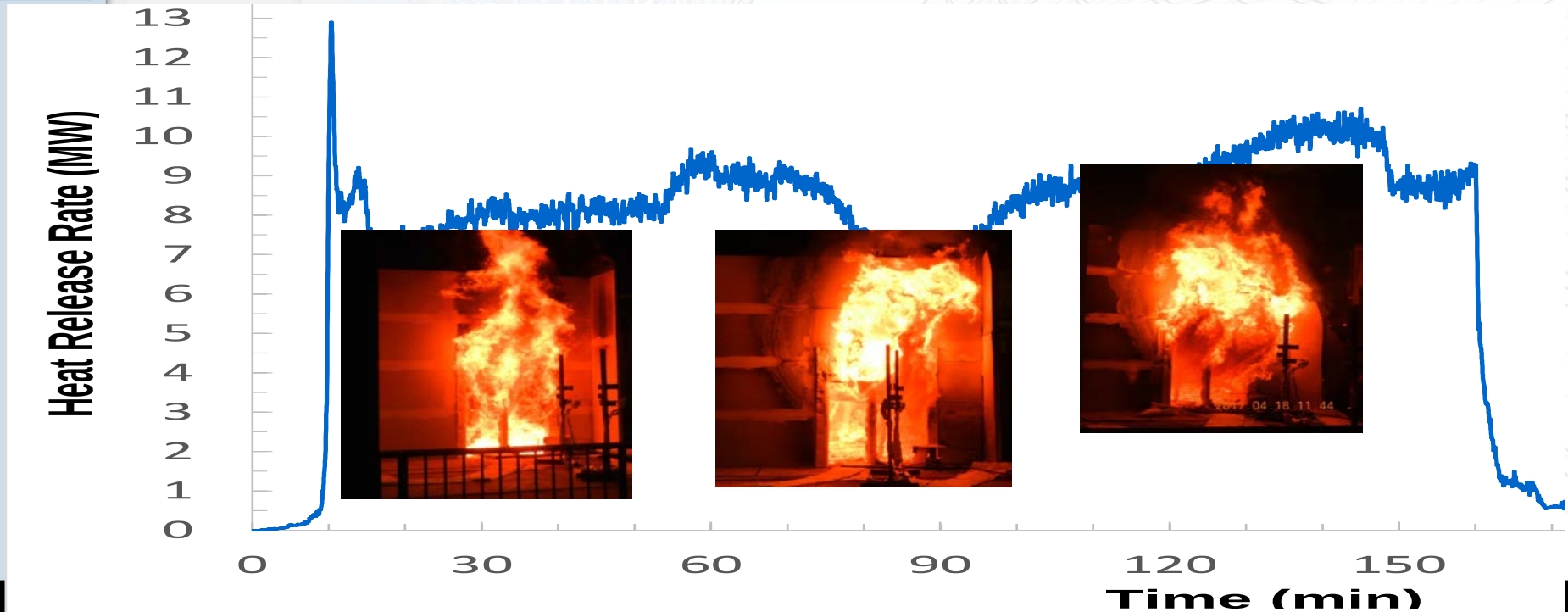
Ceiling Delamination

Test 1-6 (one wall & ceiling exposed, narrow opening)
Heat Release Rate (HRR)



Test 1-6 (one wall & ceiling exposed, narrow opening)
Post test

ICC TWB Ad Hoc Committee Meeting

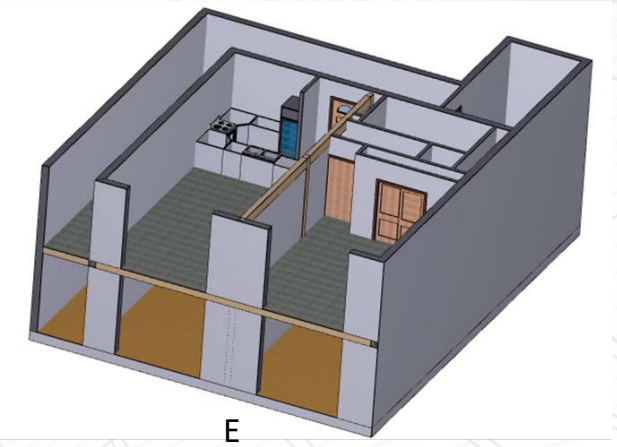
- Includes stakeholders, code officials and other interested parties
- Developed to study tall wood construction
- May develop code changes for the 2021 International Building Code
- Four workgroups
  - Fire
  - Structural
  - Standards/Definitions
  - Code: Height and Area

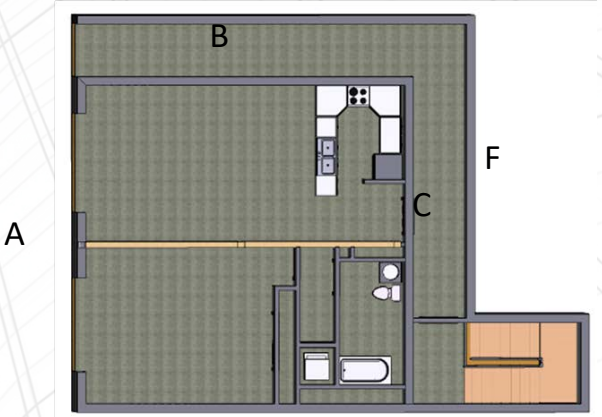
Objective of Fire Workgroup

- Develop and perform tests of realistic fire scenarios applicable to tall wood construction
- Evaluate occupant and firefighter tenability for egress and suppression efforts
- Provide data necessary for development of firefighter education literature

Structure

- Two Stories, one apartment per level
- Each apartment: 9 m x 9 m (30 ft by 30 ft)
- Ceiling height: 2.7 m (9 ft)
- Living room, kitchen, bathroom, bedroom
- Corridor around each apartment and a stairwell
- 5-ply CLT
  - Thickness: 175 mm (6.875 inches)
  - Douglas-fir – Larch species group
  - PURBOND Polyurethane Adhesive





Images courtesy of USDA FS Forest Products Laboratory

No.	Test Floor / Construction Type	Wall A	Wall B	Wall C	Wall D	Floor/Ceiling	Interior Partition	Active Protection
1	1st / IV-A Completed	60% openings with 2 layers Type X GWB elsewhere	2 Layers Type X GWB	2 Layers Type X GWB	2 Layers Type X GWB	Floor: 2 layers cement board Ceiling: 2 layers GWB	Non-fire rated ½" GWB on each side	None
2	2nd / IV-B Completed		2 Layers Type X GWB	2 Layers Type X GWB	2 Layers Type X GWB	Floor: 2 layers cement board Ceiling: 2 layers GWB with 30% exposed CLT		
3	2nd / IV-B Week of June 19		Livingroom: Exposed CLT Kitchen: 2 Layers GWB	2 Layers Type X GWB	Bedroom: Exposed CLT Bathroom: 2 Layers Type X GWB	Floor: 2 layers cement board Ceiling: 2 layers GWB		
4	1st / IV-C Week of June 26	60% openings with glazing with 2 layers Type X GWB elsewhere	Exposed CLT			Floor: 2 layers cement board Ceiling: Exposed CLT		NFPA 13, Ordinary Hazard
5	1st / IV-C Week of June 26					Floor: 2 layers cement board Ceiling: Exposed CLT		NFPA 13, Ordinary Hazard with 20-minute activation

Ceiling Damage - Replacement

Contents Fuel Load

- For each fire test, the apartment in which the test is to be conducted will be furnished with typical residential furnishings to achieve calculated fuel load densities of **807 MJ/m2 in the kitchen, 534 MJ/m2 in the bedroom, and 412 MJ/m2 in the living room**.*

- The furnishings will be as similar as possible, and arranged in the same manner, for each test. Thus, the total fuel load from combustible contents within the kitchen, bedroom and living room combined will be approximately 37,000 MJ in each test.

* These values represent mean fire load densities (FLD), as determined from a 2011 survey of typical multi-family dwellings in Canada (Bwalya, A., Lougheed, G., Kashef, A. and Saber, H. Survey Results of Combustible Contents and Floor Areas in Canadian Multi-Family Dwellings, Fire Technology, Volume 47, 2011, pp. 1121-1140).

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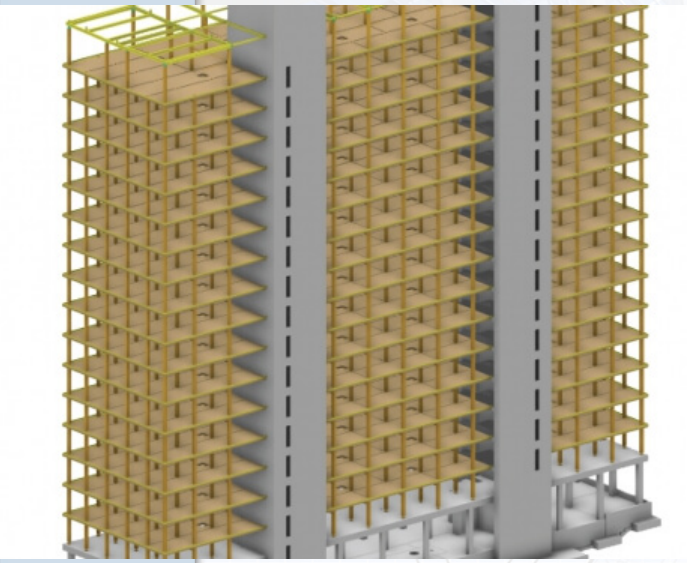
Brock Common Tower
British Columbia



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Portland, Oregon
12 Stories

Tall Wood CLT Winning Building Planned for New York City

A 10-story building in New York will be the first high rise there constructed with cross laminated timber.
475 W 18th Street

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ICC Code Development Just Completed

Photo courtesy of
www.iccsafe.org

Three New Construction Types

- **IV-A:** FRR same as I-A, fully encapsulated
- **IV-B:** FRR same as I-B, partially encapsulated
  - Up to 20% of ceiling or 40% of wall or ratio of combo with min separation
- **IV-C:** FRR same as IB, fully exposed

Height in Feet

- **Height in feet**
  - IV-C is equal to IV-HT
    IV-B is equal to I-B
  - IV-A is 1.5 times IV-B
  - Professional judgment reduces for specific occupancies
  - No additional height for non-sprinklered buildings

2021 International Code Council Edition Committee Actions - Height in Feet

Table 504.3
ALLOWABLE BUILDING HEIGHT IN FEET ABOVE GRADE PLANE[a, d]

Occupancy Classification	SEE FOOTNOTES	TYPE OF CONSTRUCTION											
		TYPE I		TYPE II		TYPE III		TYPE IV				TYPE V	
		A	B	A	B	A	B	A	B	C	HT	A	B
A, B, E, F, M, S, U	NS[b, d]	UL	160	65	55	65	55	65	65	65	65	50	40
	S	UL	180	85	75	85	75	270	180	85	85	70	60
H-1, H-2, H-3, H-5	NS[c, d]	UL	160	65	55	65	55	120	90	65	65	50	40
	S	UL											
H-4	NS[c, d]	UL	160	65	55	65	55	65	65	65	65	50	40
	S	UL	180	85	75	85	75	140	100	85	85	70	60
I-1 Condition 1, I-3	NS[d, e]	UL	160	65	55	65	55	65	65	65	65	50	40
	S	UL	180	85	75	85	75	180	120	85	85	70	60
I-1 Condition 2, I-2	NS[d, e, f]	UL	160	65	55	65	55	65	65	65	65	50	40
	S	UL	180	85								70	60
I-4	NS[d, g]	UL	160	65	55	65	55	65	65	65	65	50	40
	S	UL	180	85	75	85	75	270	180	85	85	70	60
R[h]	NS[d]	UL	160	65	55	65	55	65	65	65	65	50	40
	S13R	60	60	60	60	60	60	60	60	60	60	60	60
	S	UL	180	85	75	85	75	270	180	85	85	70	60

Height in Stories

- **Height in stories**
  - IV-C is increased over IV-HT (1.5 factor)
  - IV-B is equal to I-B
  - IV-A is 1.5 times IV-B
  - Professional judgment reductions for specific occupancies
  - No increase for non-sprinklered application

2021 International Code Council Edition Committee Actions - Stories

	NS=Nonsprinklerd S= Sprinklered	Type IV-A	Type IV-B	Type IV-C	Type IV-HT
H-3	NS	3	3	3	3
	S	4	4	4	4
H-4	NS	5	5	5	5
	S	8	7	6	6
H-5	NS	2	2	2	2
	S	4	3	3	3
I-1 (1)	NS	4	4	4	4
	S	12	10	5	5
I-1 (2)	NS	3	3	3	3
	S	12	10	4	4
I-2	NS	NP	NP	NP	NP
	S	7	5	1	1
I-3	NS	2	2	2	2
	S	7	5	3	3
I-4	NS	3	3	3	3
	S	9	6	4	4
M	NS	4	4	4	4
	S	12	8	6	5
R-1	NS	4	4	4	4
	S	18	12	9	5
R-2	NS	4	4	4	4
	S	18	12	9	5
R-3	NS	4	4	4	4
	S	18	12	5	5
R-4	NS	4	4	4	4
	S	18	12	5	5
S-1	NS	4	4	4	4
	S	10	7	5	5
S-2	NS	4	4	4	4
	S	12	8	5	5
U	NS	4	4	4	4
	S	9	6	5	5

Allowable Area

- **Building Area**
  - This is more complicated, as Type I-B construction is often permitted to be of unlimited area.

Note: The committee did not feel that unlimited area was a conservative approach, so all construction types are limited in area

- All area proposals based on current allowable areas for IV-HT
- IV-C is developed by using a 1.25 multiplier
- IV-B is 2.00 multiplier
- IV-A is 3.00 multiplier
- Professional judgment reductions for specific occupancies

2021 International Code Council Edition

Use Group	NS - non sprklrd S1 -1 story sprnklrd SM - >1 story sprklrd	Type I-A	Type I-B	Type II-A	Type II-B	Type IV-A	Type IV-B	Type IV-C	Type IV-HT	Type V-A	Type V-B
A-1	NS	UL	UL	15,500	8,500	45,000	30,000	18,750	15,000	11,500	5,500
	S1	UL	UL	62,000	34,000	180,000	120,000	75,000	60,000	46,000	22,000
	SM	UL	UL	46,500	25,500	135,000	90,000	56,250	45,000	34,500	16,500
A-2	NS	UL	UL	15,500	9,500	45,000	30,000	18,750	15,000	11,500	6,000
	S1	UL	UL	62,000	38,000	180,000	120,000	75,000	60,000	46,000	24,000
	SM	UL	UL	46,500	28,500	135,000	90,000	56,250	45,000	34,500	18,000
A-3	NS	UL	UL	15,500	9,500	45,000	30,000	18,750	15,000	11,500	6,000
	S1	UL	UL	62,000	38,000	180,000	120,000	75,000	60,000	46,000	24,000
	SM	UL	UL	46,500	28,500	135,000	90,000	56,250	45,000	34,500	18,000
A-4	NS	UL	UL	15,500	9,500	45,000	30,000	18,750	15,000	11,500	6,000
	S1	UL	UL	62,000	38,000	180,000	120,000	75,000	60,000	46,000	24,000
	SM	UL	UL	46,500	28,500	135,000	90,000	56,250	45,000	34,500	18,000
A-5	NS	UL	UL	UL	UL	UL	UL	UL	UL	UL	UL
	S1										
	SM										
B	NS	UL	UL	37,500	23,000	108,000	72,000	45,000	36,000	18,000	9,000
	S1	UL	UL	150,000	92,000	432,000	288,000	180,000	144,000	72,000	36,000
	SM	UL	UL	112,500	69,000	324,000	216,000	135,000	108,000	54,000	27,000
E	NS	UL	UL	26,500	14,500	76,500	51,000	31,875	25,500	18,500	9,500

Exterior Walls

- Permits exterior walls of mass timber
- Exterior walls are required to have 40 minutes of protection
- No combustible materials are permitted outside of mass timber
  - Except water barrier that meets the requirements of Exception 2 for Section 1402

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Water Barrier?

2021 International Code Council Edition Committee Actions – Special Inspections

Type	Continuous Special Inspection	Periodic Special Inspection
1. Inspection of anchorage and connections of mass timber construction to timber deep foundation systems.		X
1. Inspect erection and sequence of mass timber construction		X
1. Inspection of connections where installation methods are required to meet design loads		
a. Threaded fasteners		
1. Verify use of proper installation equipment.		X
1. Verify use of pre-drilled holes where required.		X
1. Inspect screws, including diameter, length, head type, spacing, installation angle, and depth.		X
a. Adhesive anchors installed in horizontal or upwardly inclined orientation to resist sustained tension loads	X	
c. Bolted connections		X
d. Concealed connections		X

2021 International Code Council Edition Committee Actions – Water Supply

- **403.3.2 Water supply to required fire pumps.** In all buildings that are more than 420 feet (128 m) in building *height,* and buildings of Type IVA and IVB that are more than 120' in building height, required fire pumps shall be supplied by connections to not fewer than two water mains located in different streets. Separate supply piping shall be provided between each connection to the water main and the pumps. Each connection and the supply piping between the connection and the pumps shall be sized to supply the flow and pressure required for the pumps to operate.

- **Exception:** Two connections to the same main shall be permitted provided that the main is valved such that an interruption can be isolated so that the water supply will continue without interruption through not fewer than one of the connections.

2021 International Code Council Edition Committee Actions – Annual Inspections

- **701.6 Owner's responsibility.** The owner shall maintain an inventory of all required fire-resistance-rated construction, construction installed to resist the passage of smoke and the construction included in Sections 602.4.1, 602.4.2 and Sections 703 through 707. Such construction shall be visually inspected by the owner annually and properly repaired, restored or replaced where damaged, altered, breached or penetrated. Records of inspections and repairs shall be maintained. Where concealed, such elements shall not be required to be visually inspected by the owner unless the concealed space is accessible by the removal or movement of a panel, access door, ceiling tile or similar movable entry to the space.

2021 International Code Council Edition Committee Actions – Under Construction

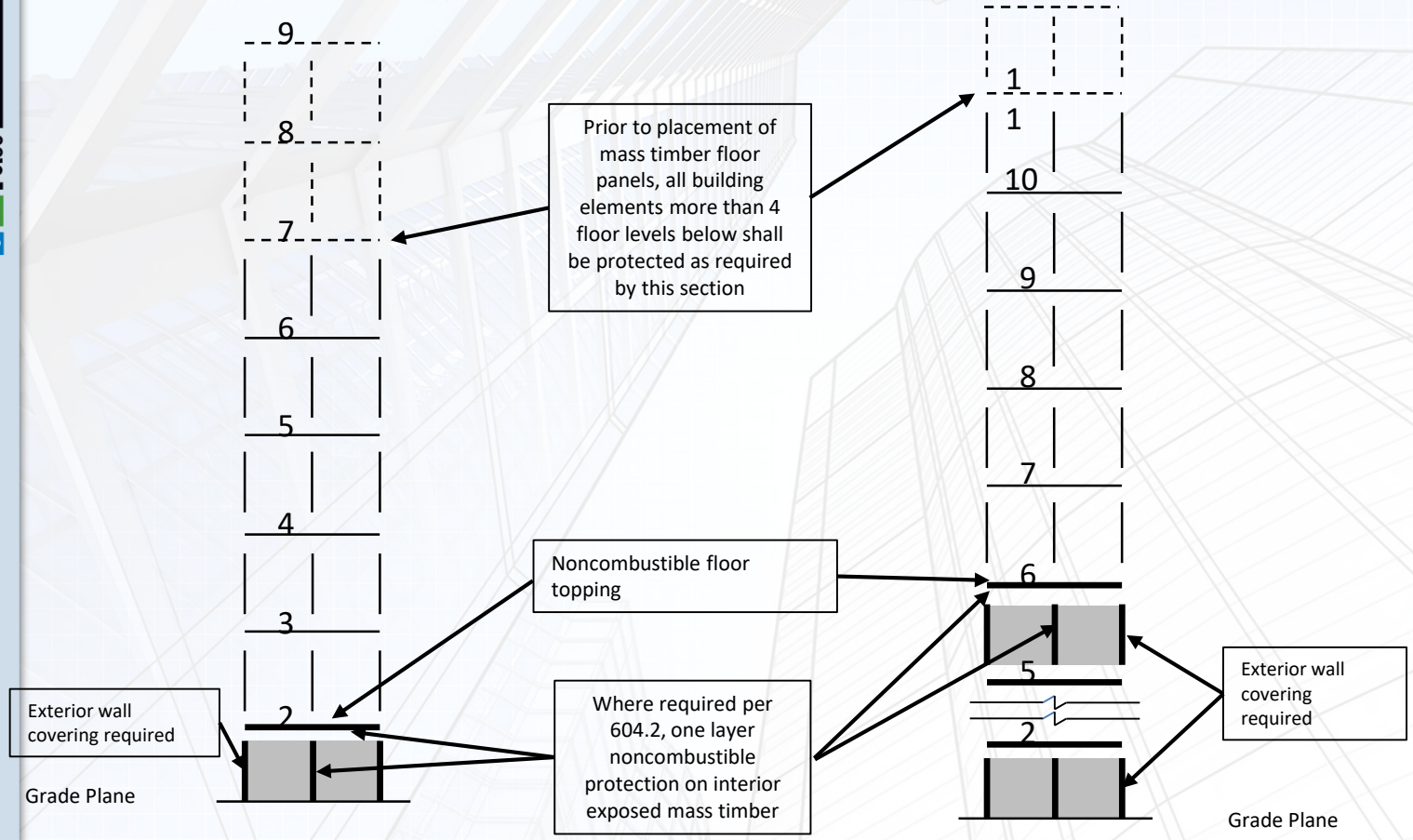
- 3314.7 Fire safety requirements for buildings of Types IVA, IVB, and IVC construction. Buildings of Types IVA, IVB, and IVC construction designed to be greater than six stories ABOVE GRADE PLANE shall meet the following requirements during construction unless otherwise approved by the fire code official.

1. Standpipes shall be provided during construction in accordance with Section 3311 .

2. A water supply for fire department operations, as approved by the fire chief.

3. Where building construction exceeds six stories ABOVE GRADE PLANE, at least one layer of the noncombustible protection where required by Section 602.4 shall be installed on all building elements more than 4 floor levels, including mezzanines, below active mass timber construction before erecting additional floor levels.

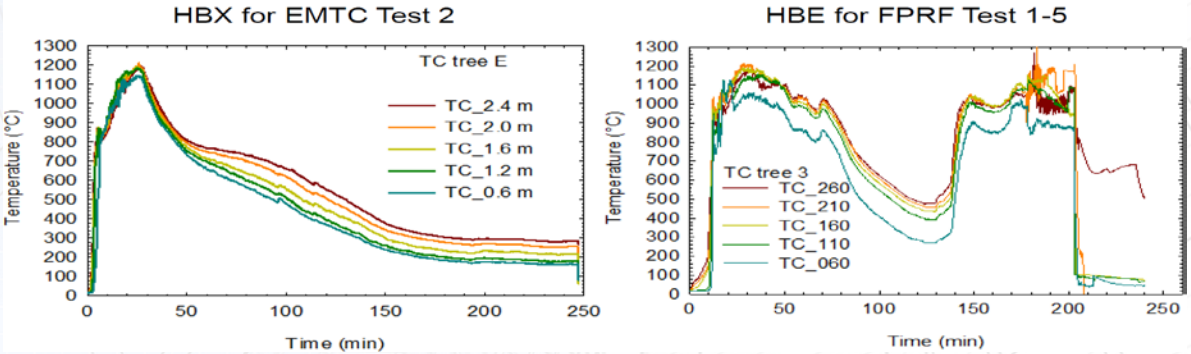
4. Where building construction exceeds six stories ABOVE GRADE PLANE required exterior wall coverings shall be installed on all floor levels more than 4 floor levels, including mezzanines, below active mass timber construction before erecting additional floor level.



Examples of Protection During Construction for Types IV-A, IV-B, and IV-C Mass Timber Buildings

Adhesives

- Address requirement for testing of adhesives used in CLT
- Code is presented using the DOC PS1 test in the previous PRG 320
- Recent update to PRG 320 (CLT standard) has included the introduction of a larger scale fire test
  - Modification may be required

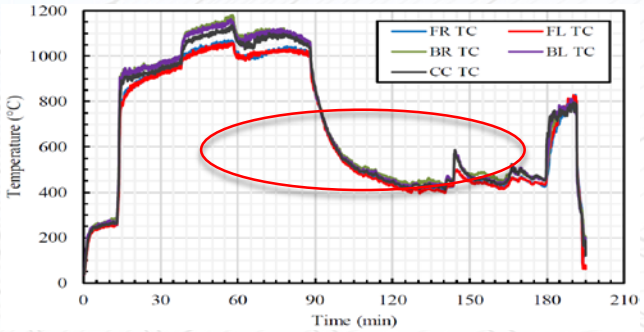


Note: FPRF testing shows improved performance of adhesives

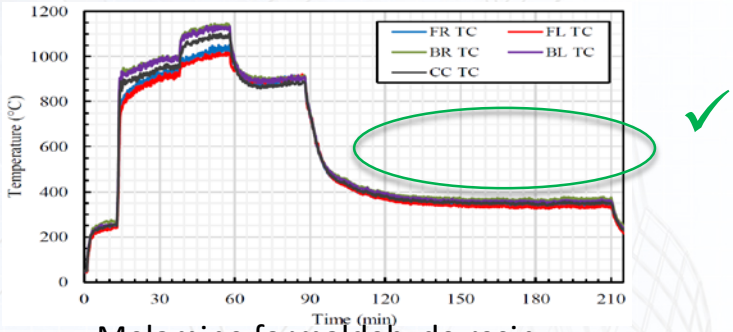
Adhesive Qualification Tests

Qualification tests performed on other adhesives

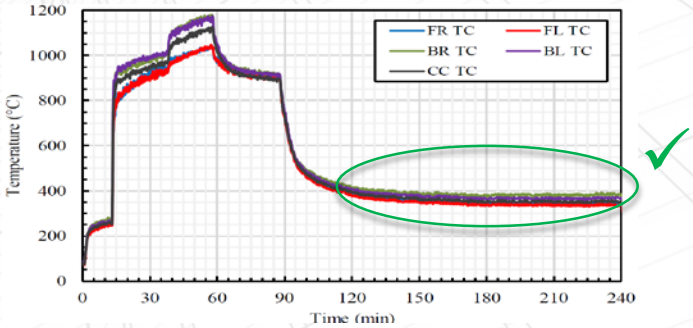
- Fire re-growth observed with PUR
- No fire re-growth observed with
  - Melamine formaldehyde resin
  - Improved PUR
- Test identifies acceptable performance



Heat-delaminating PUR



Melamine formaldehyde resin



Improved PUR

Courtesy American Wood Council

Applicable Code Requirements

- Annex B of PRG 320-2018
- Large-scale Compartment Test

ANNEX B. PRACTICE FOR EVALUATING ELEVATED TEMPERATURE PERFORMANCE OF ADHESIVES USED IN CROSS-LAMINATED TIMBER (MANDATORY)

B1 Scope

B1.1 This annex is to be used to evaluate the elevated temperature performance of adhesives used in cross-laminated timber (CLT).

B1.2 An unprotected CLT floor-ceiling slab is exposed to specified fire conditions representative of a real fire scenario.

B1.3 The unprotected CLT floor-ceiling slab shall sustain the applied load during the specified fire exposure for a period of 240 minutes without char layer fall-off resulting in fire regrowth during the cooling phase of a fully developed fire.

Courtesy American Wood Council

River Beech – Proposed
Chicago, IL

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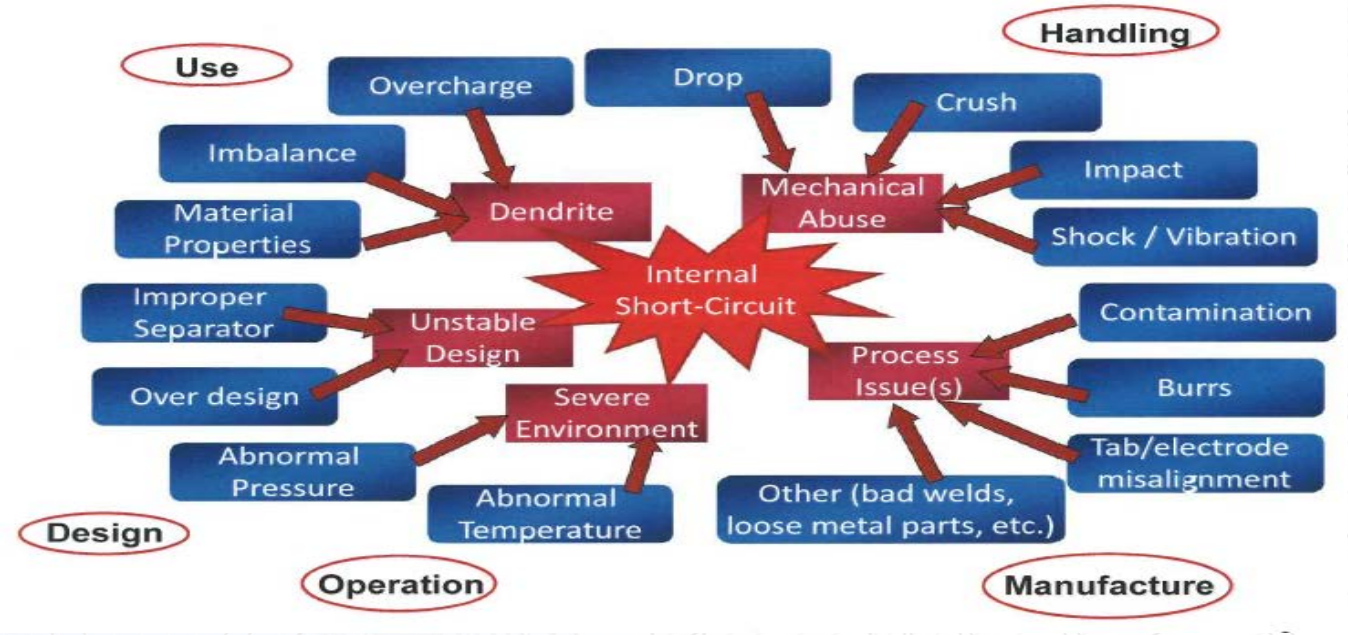
ARE WE READY FOR WHAT'S TO COME?

- 80 story Oakwood Tower
- London
- 984 ft. tall
- Similar Structure Proposed for Tokyo

INTRODUCTION

Energy Storage Systems

Causes of Cell Thermal Runaway



Note: UL's 9540A standard is conducted with thermal runaway induced in a module of the ESS.

Battery Installation Scenarios

Mixed Occupancy Building

Dedicated ESS Building

Rooftop Installations

Outdoors Near Building

Outdoors Remote

FIRE SAFETY APPROACH

Installation Codes

NEC: National Electric Code (NFPA 70)

NFPA 855: Standard for the Installation of Stationary Energy Storage Systems

ICC: The International Fire Code, International Residential Code

Battery Safety Certification

UL 1642: Lithium Batteries

UL 1973: Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications

UL 9540: Energy Storage Systems and Equipment

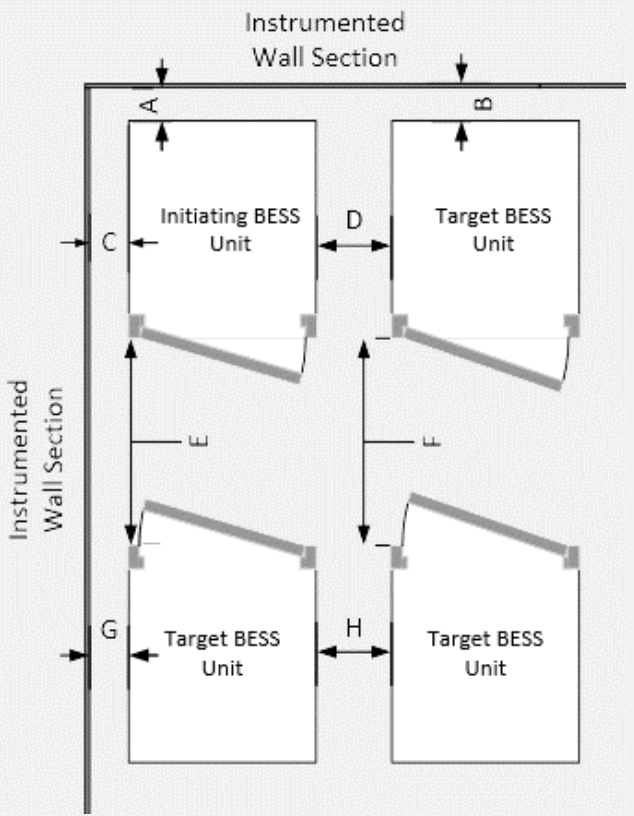
Testing for Performance

UL 9540A: Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

IFC CODE CONSTRAINTS

•Testing is required when one of the following requirements from the IFC Code is <u>not</u> met:

- Max. 50 kWh each
- Max. 250 kWh each for Listed systems
- Min. 3 feet spacing from other arrays and from walls
- Other arrangements/quantities as approved by AHJ based on large scale fire testing (UL 9540A)



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UL 9540A TEST STANDARD

Scope

Evaluate fire characteristics of a battery energy storage system that undergoes thermal runaway. Data generated will be used to determine the fire and explosion protection required for an installation of a battery energy storage system.

Match Fire Protection of Installation to Performance of BESS

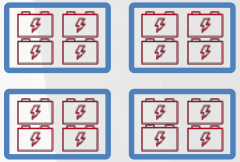
UL 9540A

Cell Level Test

- Whether cell can exhibit thermal runaway
- Thermal runaway characteristics
- Gas composition (flammability)

Module Level Test

- Propensity for propagation of thermal runaway
- Heat and gas release rates (severity/duration)
- Flaming/deflagration hazards



Unit Level Test

- Evaluation of fire spread
- Heat and gas release rates (severity/duration)
- Deflagration hazards
- Re-ignition hazards

Installation Level Test

- Effectiveness of fire protection system(s)
- Heat and gas release rates (severity/duration)
- Deflagration hazards
- Re-ignition hazards

UL 9540A – USE IN INDUSTRY

Energy Storage System

UL 9540A Test Method

Fire Test Report

Manufacturer/ Integrator/Sponsor

Fire Protection Consultant

Insurance Industry

Building Owner

Other AHJ

Fire Department

CELL LEVEL TESTING

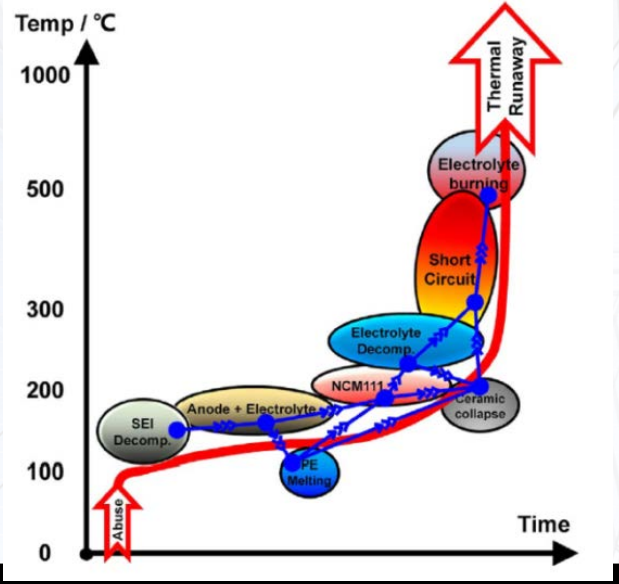
Purpose:

1.Cell thermal runaway methodology, instrumentation

2.Thermal runaway test parameters

3.Cell surface temp at venting and thermal runaway

4.Gas generation/composition ; characterize gas flammability hazards (LFL)



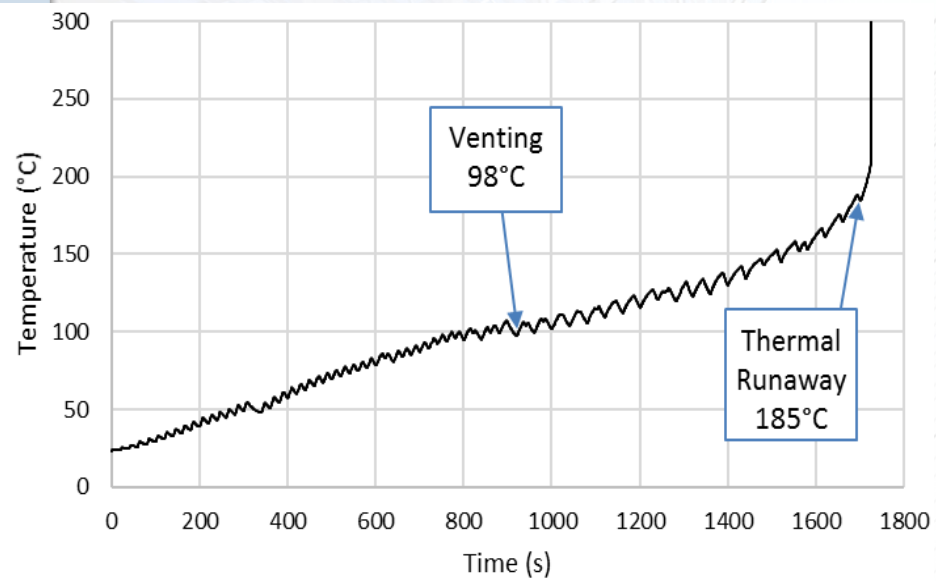
Cell Level Testing Apparatus

Important Data

- Thermal runaway method and parameters
- Temperature at venting
- Temperature at thermal runaway initiation
- Cell vent gas measurements:
  - Composition
  - Volume
  - Lower Flammability Limit
  - Burning Velocity
  - P_{max}

CELL LEVEL MOCKUP TEST

Example of generic li-ion cell heated to thermal runaway.
Cell venting and thermal runaway temperature are documented.



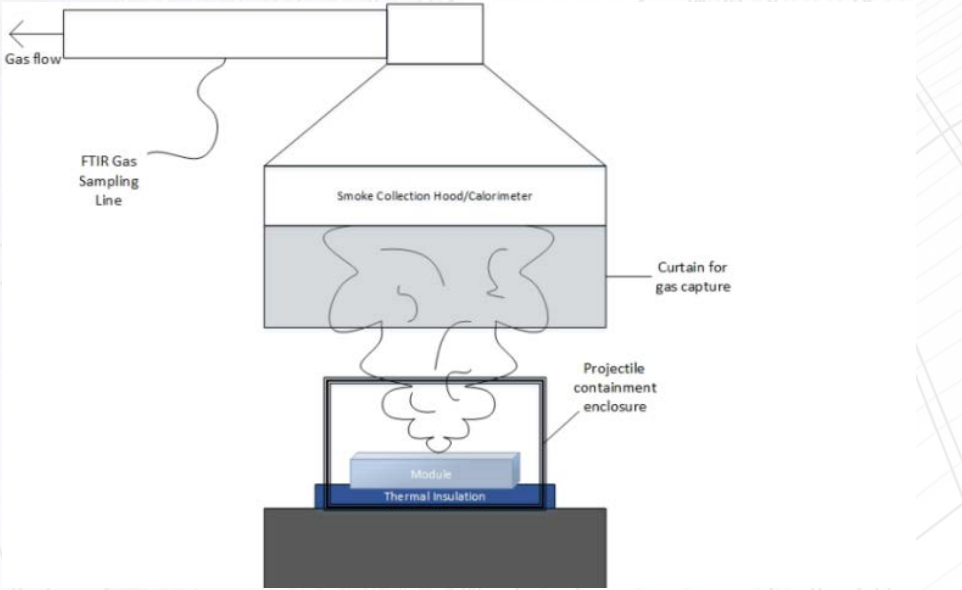
Gas	Composition (Vol %)
CO	36.2
CO_2	22.1
H_2	31.7
Hydrocarbons	~10%

Lower Flammability Limit: ~8.5%
Burning Velocity: 35 cm/sec

MODULE LEVEL TESTING

Purpose:

- Demonstrate the propensity for cascading thermal runaway propagation within a module
- Develop data on heat release rate and cell vent gas composition
- Document fire and deflagration hazards.

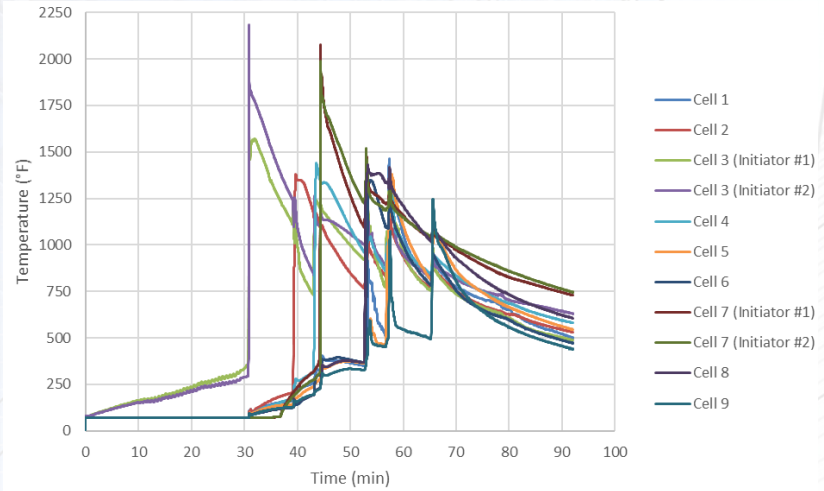


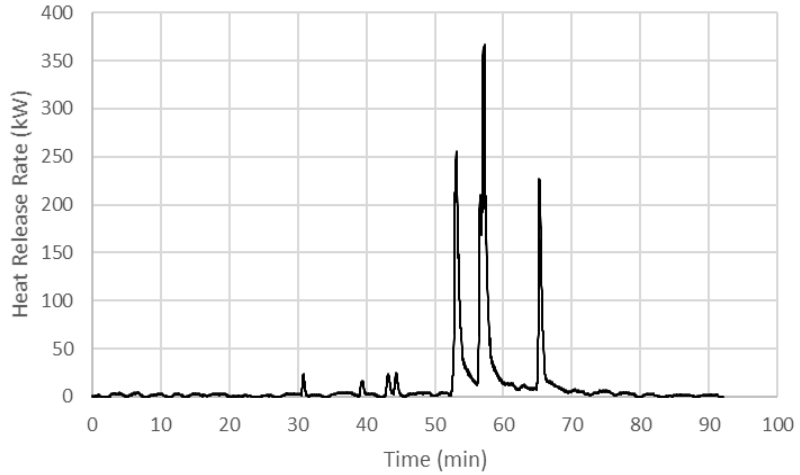
Important Data

- Thermal runaway propagation
- Heat release rate
- Deflagration hazards
- Cell vent gas measurements:
  - Gas composition and volumes
    - Hydrocarbons, H_2, THC, CO/CO_2, O_2, Halogens, etc.

MODULE LEVEL MOCKUP TEST

Example of generic li-ion propagation of thermal runaway.

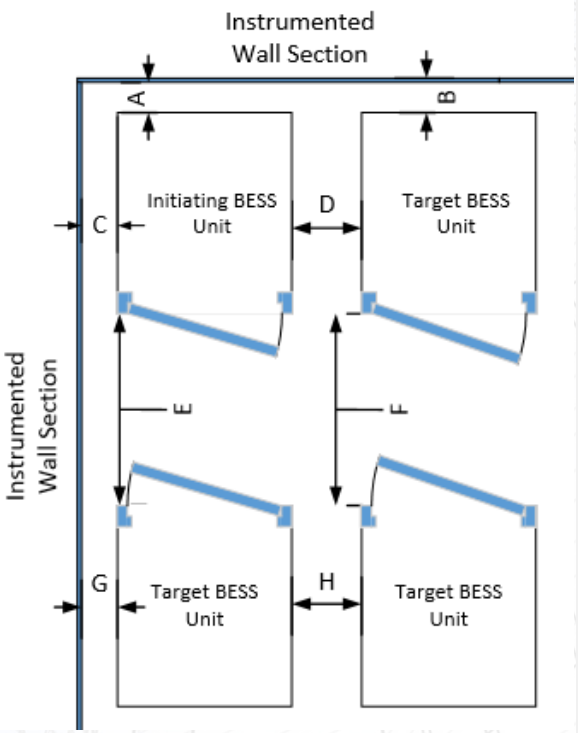




UNIT LEVEL TESTING

Purpose:

1. Document thermal runaway progression within a BESS unit;
2. Document if flaming occurs outside the BESS unit;
3. Measure heat and gas generation rates;
4. Measure surface temperatures and heat fluxes in target BESS units; and
5. Measure surface temperatures and heat fluxes on surrounding walls.



Important Data

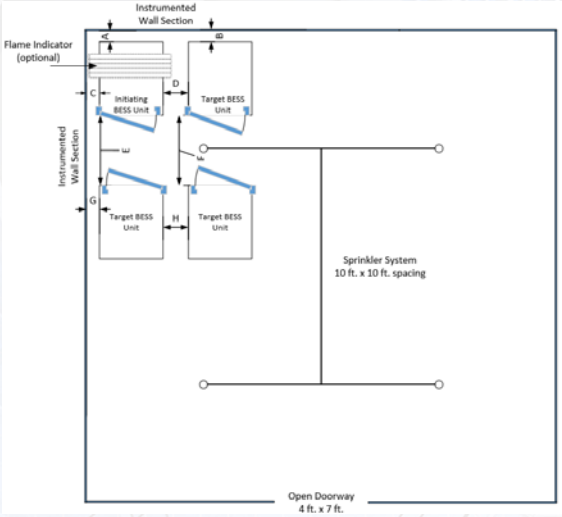
- Module to module thermal runaway propagation in Initiating BESS
- Heat release rate
- Gas composition and volume
- Wall temperatures and heat fluxes
- Target BESS temperatures and heat fluxes
- Deflagration hazards
- Re-ignition (on-going thermal runaway)

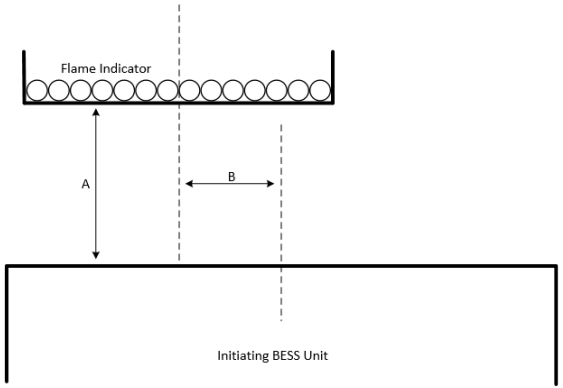
INTSTALLATION LEVEL TESTING (IF REQUIRED)

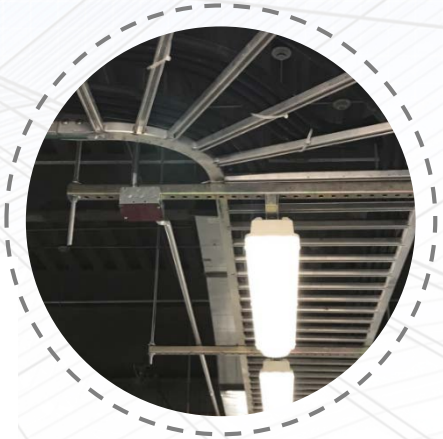
Methods:

1. Ceiling mounted automatic sprinklers; or
2. Designed Fire Protection Plan (open to manufacturer's design).

TEST METHOD 1 - EFFECTIVENESS OF CEILING MOUNTED AUTOMATIC SPRINKLER SYSTEM







- Type of sprinkler (make/model, activation temperature, Response Time Index)
- Design water density for sprinklers

Test may include overhead cabling is used in installation of units

The Goal No More Names

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This concludes The American Institute of Architects
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