Analyzing history and forensics to support fire safety in future wood buildings

A look at the history of development of our codes and safety opportunities to facilitate wood design initiatives.

Presented on November 7, 2014 by Peter Senez, Sereca Fire Consulting Ltd.

Disclaimer: This presentation was developed by a third party and is not funded by WoodWorks or the Softwood Lumber Board.
Current Code Solutions

› Compliance –
  – Typically 3 – 6 storeys
  – Area limitations – cubic capacity concept
    • 7,500 ft² - 18,000 ft²
    • 3 – 4 storeys (some 6 – 8)
› Equivalency, Variance, Alternative Solution ...
  – A solution that affords an equivalent level of safety to the acceptable solutions in the Code.
Minimum Performance

› What is the minimum level of performance to demonstrate compliance with the Code using an alternative solution?:
  – targets are not necessarily precisely defined
    • Height, area, contribution, egress
  – equivalency is expected to perform as well as a design that would satisfy the applicable acceptable solutions
Code solutions

Generally address the following solutions:
- Fire-resistance rating
- Flame-spread
- Protection of wood
  • Limits contribution of wood to fire growth
- Fire-service access

Do these solutions address the fundamental concerns?
Development of Solutions

› How do you demonstrate “as well as”?
   - Identification of the underlying intent
   - Define the nature and degree of risk the Building Code is intended limit
   - Demonstrate that the proposed design will provide an equivalent or lower risk

› Risk qualification/quantification is key
Building Size – Acceptable Solution Example

› 2010 National Building Code of Canada:

3.2.2.50. Group C, up to 4 Storeys, Sprinklered

1) A building classified as Group C is permitted to conform to Sentence (2) provided
a) except as permitted by Sentences 3.2.2.7.(1) and 3.2.2.18.(2), the building is
sprinklered throughout,
b) it is not more than 4 storeys in building height, and
c) it has a building area not more than
   i) 7200 m² if 1 storey in building height,
   ii) 3600 m² if 2 storeys in building height,
   iii) 2400 m² if 3 storeys in building height, or
   iv) 1800 m² if 4 storeys in building height.

2) The building referred to in Sentence (1) is permitted to be of combustible
construction or noncombustible construction used singly or in combination, and
a) except as permitted by Sentences (3) and (4), floor assemblies shall be fire
   separations with a fire-resistance rating not less than 1 h,
b) mezzanines shall have a fire-resistance rating not less than 1 h, and
c) loadbearing walls, columns and arches shall have a fire-resistance rating not
   less than that required for the supported assembly.

› What is the purpose of these limits?
Building Size – Objective, Functional Statement and Intent Statements

› 3.2.2. – Requirements that a building be of noncombustible construction.

› Applies to portion of Code text: “... the building referred to in Sentence (1) shall be of noncombustible construction ...”

› F02: To limit the severity and effects of fire or explosions.

› OS1.2: fire or explosion impacting areas beyond its point of origin
Construction Type Objectives, Functional Statements and Intent Statements

Intent:

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 or damage to the building.
Considerations

› Specification-based requirements are time-relative “snapshot” solutions to address risk

› Changes or alternatives to specification-based requirements can be challenging without basis information

› Key considerations:
  – What is/was the risk that initiated the development of the specification(s)? [Implicit Risk]
  – What capability, materials and methods were considered in mitigating the risk? [Mitigating Measures]
  – To what level is/was the risk mitigated? [Acceptable Risk]
  – Is the risk still relevant? [Current Context]
Building Size – Implicit Risk

› Questions to be answered relative to building size requirements in the NBCC:
  – What is/was the implicit risk?
  – What was the knowledge, capability, materials and methods upon which the specifications were developed?
  – What was the intended result of the application of the specifications (Acceptable Risk)?
Building Size - Great Fire of Rome in 64 AD
Building Size - Great Fires of London in 1135 and 1212
Building Size – Early Times Implicit Risk

- Conflagrations in 1087 and 1135 resulting in destruction of most of the City of London
- Majority of buildings at that time were constructed of wood, roofed with straw.
- High building density

<table>
<thead>
<tr>
<th>Implicit Risk:</th>
<th>Fire spread from building to building resulting in conflagration.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitigation:</td>
<td>Stone wall between houses: 3 feet thick (party wall/firewall)</td>
</tr>
<tr>
<td>Intended Result:</td>
<td>Limit fire spread to individual buildings (primarily houses)</td>
</tr>
</tbody>
</table>
Building Size – London 1666 to 1774 Implicit Risk

Implicit Risk Considerations

<table>
<thead>
<tr>
<th>Implicit Risk:</th>
<th>• Fire spread from building to building resulting in conflagration.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitigation:</td>
<td>• Brick or stone wall between houses: 13 inches thick and 18 inches above the roof (party wall/firewall)</td>
</tr>
<tr>
<td></td>
<td>• Brick or stone exterior walls</td>
</tr>
<tr>
<td>Intended Result:</td>
<td>• Limit fire spread to individual buildings (primarily houses)</td>
</tr>
</tbody>
</table>
Building Size – London 1850’s Implicit Risk

With a well organized and properly equipped fire brigade it is found that sixty feet is the greatest height at which a building can be quickly protected, and that the cube of 60, or 216,000 cubic feet, is the largest cubical capacity which can be protected with reasonable hope of success after a fire has once come to a head.
By the Act of 1855 the limitation of the cubic contents of a building was fixed at 216,000 feet; but the magistrates had decided that that amount of cubical space might be contained on each separate floor. The Bill proposed that the 216,000 feet should be extended to 300,000 feet, but that the 300,000 feet should comprise the whole building.

1050. What is practically the highest maximum to which water can be thrown with effect by a steam engine?—That is a question which very seldom arises with us, but it can be thrown to 80 or 90 feet, although not with good effect.

1051. What is the extreme height to which fire escapes and ladders can be reasonably carried for the protection of life and the saving of life?—About 60 feet.

1120. What limit, according to you, would be a fair and safe limit to impose?—I should say that the limit applied in Liverpool is about the best for this country; 60 to 65 feet.
## Implicit Risk Considerations

<table>
<thead>
<tr>
<th>Implicit Risk:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Single buildings (warehouses) increasing in size resulting in fire size</td>
<td>beyond the capability of the responding fire department.</td>
</tr>
<tr>
<td>• Increased potential for conflagration.</td>
<td></td>
</tr>
<tr>
<td>Mitigation:</td>
<td></td>
</tr>
<tr>
<td>• Containment by limiting height/volume assuming fire service intervention</td>
<td></td>
</tr>
<tr>
<td>• Height of 60 to 65 ft and cubic capacity of 216,000 cubic feet.</td>
<td></td>
</tr>
<tr>
<td>Intended Result:</td>
<td></td>
</tr>
<tr>
<td>• Limit fire spread to individual buildings.</td>
<td></td>
</tr>
</tbody>
</table>
Chicago 1871

Map showing the Burnt District in Chicago,

Published for the benefit of the Relief Fund by

Building Size – USA 1872 to 1930’s Implicit Risk

› Great Fire of Chicago – October 10, 1871
› Great Fire of Boston – November 9, 1872
› These fires called attention to the substandard conditions of construction in cities across the United States
Building Size – USA 1872 to 1930’s Implicit Risk

› “Standard Building” and associated limits based on insurance rating system:
  – Defined building characteristics upon which insurance rates could be set
  – Deviations from the standard resulted in higher rates
  – Improvement of the standard resulted in discounted rates

› Variations to the “Standard Building” features were later quantified in greater detail
Building Size – USA 1872 to 1930’s Implicit Risk

› New York Board of Fire Underwriters – January 1873: “Standard Building” height and area limits

3. **Area.**—There shall not be more than 5,000 square feet of ground covered by the building, unless it be subdivided by one or more fire or party walls extending from the foundation to and through the roof and coped.

2. **Height.**—There shall not be over 60 feet.

**Note.**—The highest part of the front from the top of the gutter to the level of the sidewalk in all cases to be taken, and when fronting on two streets, the lowest front to be measured.

Note that the volumetric limit based on an area of 5,000 ft² and height of 60 feet is 300,000 ft³. This was the limit for existing warehouses in the City of London.
Building Size – USA 1872 to 1930’s Implicit Risk

› Rationale for limits:

The foregoing considerations point to the desirability of reducing all excessive areas in buildings by fixing, as a maximum, the efficient operating area of the fire department. As a working unit, 5,000 square feet has been suggested, with a limit of 100 feet in any direction (or a rectangle 50 x 100 feet), which is the largest undivided area within the capacity of the best fire departments.

Note 1.—It is generally conceded that five stories is the maximum height to which water can be thrown effectively by a fire department from the street level, and that 50 feet is the maximum distance inside a building which can be reached by a stream through a window. These facts have been a governing consideration in the establishment of the limits of heights and areas in this Code. In addition, the width of the street upon which a building fronts and the height of the building should be considered; a building endangers adjacent property in proportion to its size and proximity to other property.
Building Size – USA 1872 to 1930’s Implicit Risk

- Lot Size:
  - 25 ft x 100 ft
  - 2,500 ft²
- Buildings covering multiple lots
Building Size – USA 1872 to 1930’s Implicit Risk

- **Insurance rating system modifiers:**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Modifiers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupancy:</td>
<td>A function of hazard level (experiential)</td>
</tr>
<tr>
<td>Type of Construction:</td>
<td>Fireproof and non-fireproof</td>
</tr>
<tr>
<td>Accessibility:</td>
<td>Number of building sides facing a street</td>
</tr>
<tr>
<td>Sprinklering:</td>
<td>Gradual recognition of benefit with increased reliability</td>
</tr>
<tr>
<td>Area:</td>
<td>Incremental increases/decreases as a function of area</td>
</tr>
<tr>
<td>Height:</td>
<td>Incremental increases to a threshold level of 7 storeys then significant increases</td>
</tr>
</tbody>
</table>
Building Size – USA 1872 to 1930’s Implicit Risk

- Insurance rating schedule translated into regulation
- Published by the National Board of Fire Underwriters in 1905
- Base area: 5,000 ft²
- Area modifiers:
  - Occupancy
  - Height
  - Type of construction
  - Streets Facing
  - Sprinklers
Sprinkler modifier example (140 year history):
- **1874**: first successful commercial automatic automatic sprinkler was patented by Henry Parmelee.
- **1880’s**: 7.5% to 10% reduction of insurance rates
- **1890’s**: 20% reduction in insurance rates
- **1896**: First edition of NFPA 13 – increased reliability, 30% to 33⅓% reduction in insurance rates
- **1905**: 50% reduction in rates for standard systems and 66⅔% reduction in rates for supervised systems.
- **1905**: Credit of 50% to 66⅔% for sprinklers translated into Code context in 1905 NBFU Model Code by allowing an increase in area of 50% to 66⅔% where sprinklers are provided.
Building Size – USA 1872 to 1930’s Implicit Risk

- **1915**: 100% increase permitted for Mill construction
- **1921**: NFPA Proceedings

Mr. Boone: On the subject of area, 66 2/3% increase, I note, is allowed where sprinklers are installed. I feel that in a sprinklered office building cut up in small sections, with numerous partitions on each floor, the area could be very materially increased. As a matter of fact, I have always held the opinion that considerations of area are almost blotted out by standard automatic sprinkler protection, and in view of this light occupancy in offices with small sections and numerous partitions, I thought that, perhaps, the area might be increased to more than 66 2/3%, possibly 100%.

Mr. Woolson: The Chairman appreciates the significance of that criticism. May I ask if you make the suggestion of 100%?

Mr. Boone: I would make that suggestion as a motion.

The motion was adopted.

It was noted that sprinklered buildings that face three streets are given extra credit in permitted area (normally permitted on the basis of increased access for fire fighting) and yet the fire fighting access requirements are waived for sprinklered buildings. It is recommended that Subsection 3.2.2. be changed to permit the same total building area for facing three streets, but not require the three streets.
Building Size – USA 1872 to 1930’s Implicit Risk

- Woolson 1913: Survey of fire marshals and fire chiefs in the United States representing cities of over 20,000 population

<table>
<thead>
<tr>
<th>Type of Building</th>
<th>Stories in Height</th>
<th>Area between Fire Walls in Sq. Ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick and joist construction, not sprinklered</td>
<td>3.2</td>
<td>5,200</td>
</tr>
<tr>
<td>Fireproof construction, not sprinklered</td>
<td>5.3</td>
<td>9,300</td>
</tr>
<tr>
<td>Brick and joist construction, sprinklered</td>
<td>4.8</td>
<td>10,500</td>
</tr>
<tr>
<td>Fireproof construction, sprinklered</td>
<td>7.5</td>
<td>21,600</td>
</tr>
</tbody>
</table>

**TABLE 5 ALLOWABLE HEIGHTS AND AREAS IN FACTORY BUILDINGS**

<table>
<thead>
<tr>
<th>Type of Building</th>
<th>Stories in Height</th>
<th>Area between Fire Walls in Sq. Ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick and joist construction, not sprinklered</td>
<td>3</td>
<td>6,000</td>
</tr>
<tr>
<td>Fireproof construction, not sprinklered</td>
<td>5</td>
<td>10,000</td>
</tr>
<tr>
<td>Brick and joist construction, sprinklered</td>
<td>5</td>
<td>13,000</td>
</tr>
<tr>
<td>Fireproof construction, sprinklered</td>
<td>8</td>
<td>20,000</td>
</tr>
</tbody>
</table>
Building Size – USA 1872 to 1930’s Implicit Risk

 Implicit Risk Considerations

<table>
<thead>
<tr>
<th>Implicit Risk:</th>
<th>Mitigation:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Fire size beyond the capability of the responding fire department</td>
<td>• Height of 5 to 6 storeys (50 to 60 ft) and base area of 5,000 square feet</td>
</tr>
<tr>
<td>• Significant property loss</td>
<td>• Increases in height and area based on type of construction, occupancy, streets facing and sprinklering</td>
</tr>
<tr>
<td>• Increased potential for conflagration</td>
<td></td>
</tr>
</tbody>
</table>

Intended Result: • Limit fire spread to individual buildings.
Building Size – Canada 1941 to 1965 NBCC
Implicit Risk

› 1941 NBCC: height and area limits substantially based on limits from a model US Model Code

› 1953 NBCC: height and area limits, balancing of risk associated with conflagration and occupancy hazards

<table>
<thead>
<tr>
<th>Major Occupancies</th>
<th>Fire Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A Assembly, Group B Institutional, Group C Residential, Group D Business, Group G Commercial and Industrial Division 3</td>
<td>10 pounds per square foot of floor area</td>
</tr>
<tr>
<td>Group E Mercantile and Group G Commercial and Industrial Division 2</td>
<td>20 pounds per square foot of floor area</td>
</tr>
<tr>
<td>Group F Hazardous and Group G Commercial and Industrial Division 1</td>
<td>30 pounds per square foot of floor area</td>
</tr>
</tbody>
</table>

This value is used in the Code to determine the amount of fire protection which is necessary. It is obvious that the greater the severity of fire the greater must be the protection if the fire is to be contained. It has been found in actual burn out tests that a fire load of ten pounds per square foot can be contained by fire-resistive construction of roughly one hour. A fire load of twenty pounds can be contained by construction of two hours and so on. The values of resistance required for certain fire loads in the Code are based on these findings.
Building Size – Canada 1941 to 1965 NBCC
Implicit Risk

1960 NBCC:
- Height and area limits changed from table format to “spelled-out” format
- Types of construction reduced from 7 types to “combustible” and “noncombustible”

The combination of non-combustibility and fire resistance is important in buildings which are of such height and/or area as to be beyond the capabilities of the fire department to control the fire. Large or high buildings which cannot contain a burn-out of their contents could become conflagration hazards, dangerous to the lives of fire fighters and to people outside the building as well as to those who are sometimes caught unaware inside the building.
Building Size – Canada 1941 to 1965 NBCC
Implicit Risk

1965 NBCC:

(1) Compartmentation: A building may be designed as a series of fire compartments, each capable of containing a fire for a minimum period. The size of the compartment will depend on, the danger to life, the value of the contents and the cost of the enclosure.

(2) Integrity: The structural integrity of the building must be maintained for a period that is determined by the time needed for escape of the occupants and the protection of the firefighters.
Building Size – Canada 1941 to 1965 NBCC
Implicit Risk

1965 NBCC

Fire protection is complementary to fire fighting. The protection given to the building assists the Fire Department in much the same way as military fortifications assisted the armies of old.

In fire engineering parlance these two complementary functions are known as Active Defence (the part of the Fire Department) and Passive Defence (the part of the Building Department). This relationship is shown in Figure 1.

<table>
<thead>
<tr>
<th>Passive Defence</th>
<th>Active Defence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Regulations</td>
<td>Fire-fighting</td>
</tr>
<tr>
<td>Major Tasks</td>
<td></td>
</tr>
<tr>
<td>1. Means of egress</td>
<td>1. Evacuation</td>
</tr>
<tr>
<td>2. Stability under fire</td>
<td>2. Extinguishment</td>
</tr>
<tr>
<td>3. Control of fire spread</td>
<td>3. Control of fire spread</td>
</tr>
</tbody>
</table>
Building Size – Canada 1975 to 1980 NBCC Implicit Risk

1975 NBCC

"(d) every floor area exceeding 10,000 sq ft except when the floor area is divided into fire compartments not exceeding 10,000 sq ft in area and separated from the remainder of the floor area by fire separations having at least a 1 hr fire resistance rating."

**Reason**

Fires in large open floor areas is considered difficult to fight in high buildings. It is considered necessary to have sprinkler assistance when the area exceeds 10,000 sq ft.

(7) Sentence 3.2.2.11.(2) - Reduction of Open Areas from 10,000 to 5,000 sq. ft.

Mr. McConnell objects to the reduction of 10,000 sq. ft to 5,000 sq ft. as he is of the opinion that fire fighting techniques have improved and he does not think that 10,000 sq. ft. is too large for effective fire fighting.

It appears that the main concern is whether the 5,000 sq ft. area is too small. It was pointed out that the New York Fire Department considered 6,000 sq ft. was the largest area they could justify for effective fire fighting. After considerable discussion it was agreed that no action be taken as the 5,000 sq ft. appears adequate.
Building Size – Canada 1990 to 2010 NBCC Implicit Risk

› 1990 NBCC: 3 to 4 Storey (Sprinklered) combustible construction – Group C

Currently there appears to be little evidence of fires spreading beyond the suite of fire origin. The proposal to permit 4 storey combustible residential buildings allows for 15 minute increase in the level of structural fire-resistance rating and other fire protection systems will also be required. In discussion, the Committee observed that it is evident that the compartment to compartment fire separations are performing as intended and that the problem associated with fires in residential occupancies is that of life loss in the room of fire origin.

› 1995 NBCC: 3 to 4 Storey (Sprinklered) combustible construction – Groups D and E

› 1990 NBCC: Sprinkler and streets facing factor combined (2 x 1.5 = 3)
Building Size – Canada 1941 to Current Implicit Risk

Implicit Risk Considerations

<table>
<thead>
<tr>
<th>Implicit Risk:</th>
<th>Mitigation:</th>
<th>Intended Result:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Inadequate evacuation</td>
<td>• Height of 6 storeys (50 to 60 ft) and area limits as a function of occupancy, type of construction, fire-resistance, streets facing and sprinklering.</td>
<td>• Combustible buildings: Limit fire spread to building</td>
</tr>
<tr>
<td>• Full building involvement</td>
<td>• Maximum area of 5,000 square feet for basements in buildings otherwise sprinklers would be required.</td>
<td>• Noncombustible buildings (no rating): Limit fire spread to building</td>
</tr>
<tr>
<td>• Fire size beyond the capability of the responding fire department</td>
<td>• Maximum area of 10,000 square feet for floor areas in high buildings otherwise sprinklers would be required.</td>
<td>• Noncombustible buildings: Limit fire spread to storey</td>
</tr>
<tr>
<td>• Collapse of high buildings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Increased potential for conflagration</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Initiatives from last century – did they work?
Wood-frame

Roof Level Damage
Exterior Fire 2
Course of Construction
Statistical Summary

- **Number of Fires**
- **Increasing Damage**
- **Course of Construction**
  - Compartment: 57%
  - Concealed: 43%
Implicit Risk: Height Summary

› Unacceptable risk – noncombustible construction:
   - Fire spread to more than one storey
   - Whole building involvement
   - Building collapse
   - Fire spread to other buildings
   - Conflagration
Implicit Risk: Area Summary

› Basic area limit:
  – Total combustible content within the capability of a responding fire department (access, equipment, water supply, training)
  – Combustible construction: 5,000 square feet
  – Noncombustible construction: 10,000 square feet

› Variations in area as a function of occupancy, occupant load and level of protected construction
  – Fuel load <> protection provided
  – The Code assumes combustible construction will contribute to fire
  – Area limited as a function of occupant evacuation
Implicit Risk: Height Summary

› The basic height limit for “combustible” construction:
  – has remained relatively consistent of the previous approximately 160 years at 5 to 6 storeys of 50 to 60 feet (15 to 18 m)
  – has had some variation in concept recognizing containment of fire to a single storey

› Combustible construction/unprotected noncombustible: building height limited assuming the potential for whole building involvement and fire fighting from exterior

› Noncombustible construction: assumes fire fighting from interior and burn-out where firefighting is ineffective. Intent is to contain fire to a single storey
Implicit Risk Considerations

› Existing limits set long ago when understanding of fire engineering was limited

› Since then:
  – Firefighting techniques, equipment, response and overall capability has advanced significantly
  – Construction methods and materials have advanced
  – Analysis techniques have evolved significantly
  – Sprinkler effectiveness has increased
  – Studies have shown that fires tend to be contained to fire compartment of origin (sprinklered and unsprinklered)
Other Macroscopic Risk Considerations

› Spatial Separation:
  – Time to fire service intervention and ability to protect against radiant heat

› Construction:
  – Security
  – Staged protective measures
  – Hot work

› Public Perception
Expectations

› Not necessary to demonstrate wood is equivalent to noncombustible material.

› Expectation - Demonstration that the proposed design can perform “as well as” a building constructed of noncombustible construction relative to the risks associated with building size:
  – Appropriate identification and quantification of risk related to building size and combustible building structure
  – Provision of appropriate measures to address the risk
  – Appropriate demonstration that mitigating measures reduce risk to an “acceptable” level (i.e. “as well as”).
Goals

› Design and construct a “safe” building
› Demonstrate “as well as” performance relative to the Building Code
› “Sleep at night”
Thank You!