JENSEN HUGHES

Advancing the Science of Safety

Historical Basis of Today's Code Requirements

Keith D. Calder

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Overview

Why?

Historical Basis

- Model Building Code of Canada
- Egress (Exit Width and Occupant Load)
- Building Size (Height and Area Limits)
- Spatial Separation

Why?

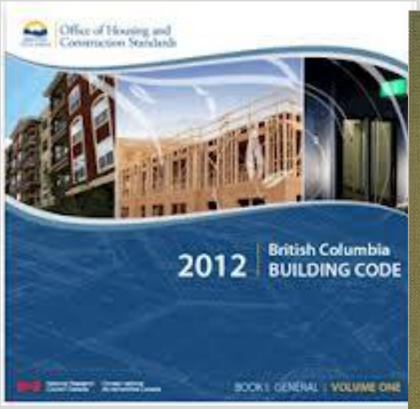
Why do we need an understanding of the historical basis of today's code requirements?

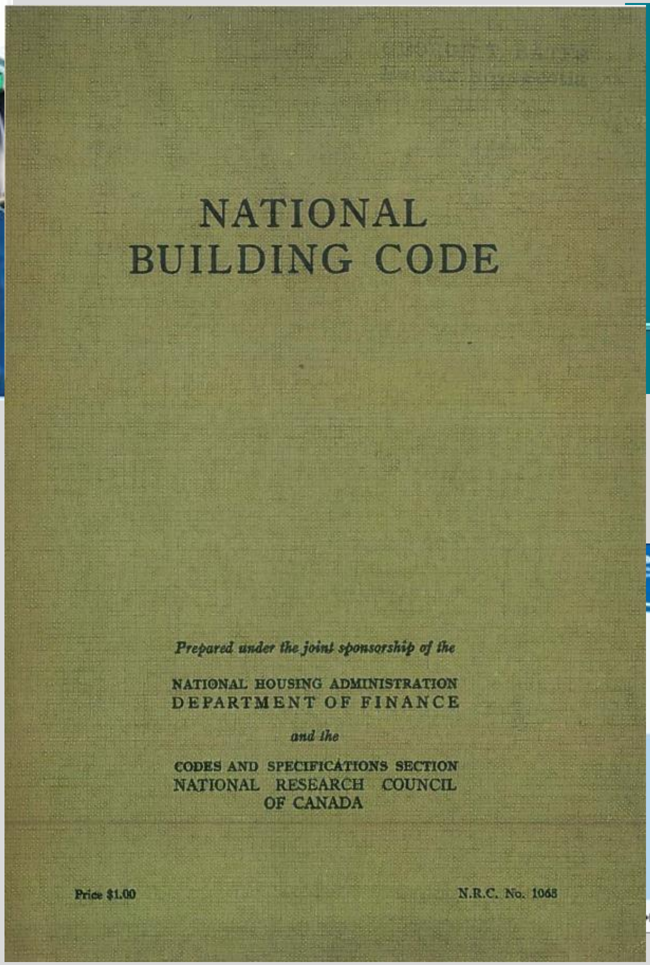
- Understand intent of code requirements
- Clarity
- Consistent interpretation
- Facilitates alternative solutions
- Basis to develop code change

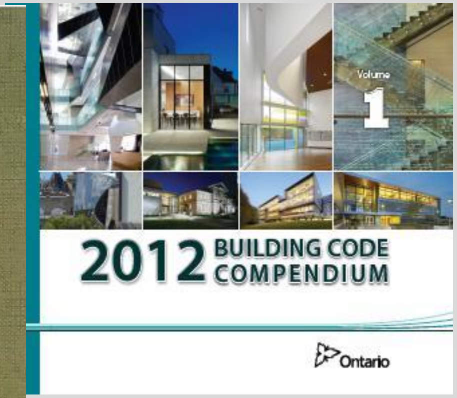
General History

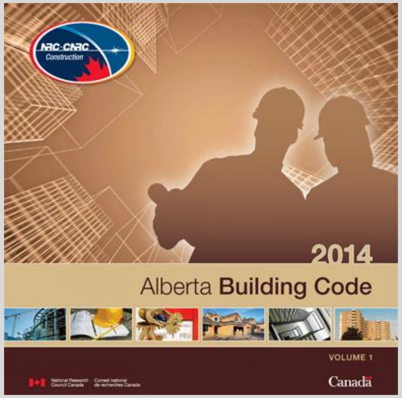
NATIONAL BUILDING CODE OF CANADA

Historical Basis – Model Code









Historical Basis – Model Code

- A model code was desired to unify construction practices across Canada
- Development of a National Model Building Code was first contemplated in Canada in the 1920's, abandoned due to limited resources to complete work.
- Large amount of work completed in the United States relative to a US model code from 1910 to 1935.
- Administrative Committee formed in 1932 by the National Research Council of Canada

Historical Basis – Model Code

- Development of Canadian Model Code re-initiated in 1937. Recommendation at that time:

  any building code authority in Canada could do no better than adhere to the procedure followed by American authorities and take advantage of their recommendations.

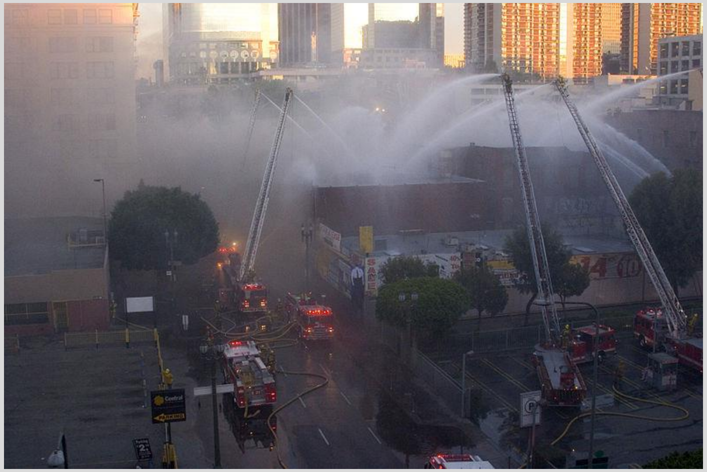
- First Edition of a Canadian Model Code: 1941 NBCC
- Substantially based on US model codes
- 13 editions since 1941 NBCC

General History

ANALYSIS APPROACH

Approach

- **Implicit Risk:** What is/was the risk that initiated the development of the specification(s)?
- **Mitigating Measures:** What knowledge, capability, materials and methods were considered in mitigating the risk?
- **Acceptable Risk:** To what level is/was the risk mitigated?



General History

EGRESS

Exit Width – Acceptable Solution, Objective, Functional Statement

- **Clause 3.4.3.2.(8):** The minimum width of exits shall conform to Tables 3.4.3.2.A and 3.4.3.2.B – generally 1100 mm.
- **Clause 3.4.3.2.(1)(c):** The aggregate width of 9.2 mm per person for stairs
- **Objective [OS3.7]:** To limit the probability that a person in or adjacent to the building will be exposed to an **unacceptable risk of injury due to hazards** caused by persons being **delayed** in or impeded from **moving** to a **safe place** during an emergency
- **Functional Statement [F10]:** To facilitate the timely movement of persons to a safe place in an emergency

Exit Width – Intent Statement

- **Intent:** to limit the probability that exits will be of insufficient width to permit efficient egress in an emergency situation, which could lead to delays in the evacuation or movement of persons to a safe place, which could lead to harm to persons.
- How do you develop an Alternative Solution for exit width based on this?

  *An effort must be made to demonstrate that an alternative solution will **perform as well as** a design that would satisfy the applicable acceptable solutions in Division B.*
- How do we demonstrate “as well as”?

Exit Width – Purpose

- Delay?:
  - What is the delay relative to?
  - What does the building code consider in terms of a value for delay?
- Moving?
  - How do we quantify "moving". Speed, distance?
- Safe place?:
  - The building code does not define "safe place"; however, exit facility, adjacent building and public thoroughfare could be interpreted as safe.
  - Is safe an ultimate term or a function of the growth and development of a fire?
- Need to establish original basis for development to answer these questions

Exit Width – Historical Basis

- 2010 NBCC: Width Per Person Basis:

c) 9.2 mm per person for
   i) ramps with a slope of more than 1 in 8, or
   ii) stairs, other than stairs conforming to Clause (b).

- 1985 NBCC: Metric Unit Width Basis:

(2) The aggregate width of *exits* from a room or *floor area* expressed as units of *exit* width (550 mm) shall be determined by dividing the *occupant load* of the room or *floor area* by the allowable number of persons per unit of *exit* width specified in Article 3.4.3.3.

(5) Except as provided in Sentences (2) to (4), the number of persons per unit of *exit* width shall be 60.

$$\frac{550\ mm\ (22\ in)}{60\ People} = 9.17\ {}^{mm}/_{Person}$$

Exit Width – Historical Basis

- 1953 to 1977 NBCC: Imperial Unit Width Basis:

(2) The aggregate width of *exits* from a room or *floor area* expressed as units of *exit* width (22 in.) shall be determined by dividing the *occupant load* of the room or *floor area* by the allowable number of persons per unit of *exit* width specified in Article 3.4.3.3.

- 1941 NBCC: Unit Width Basis

The clear width of *exits* (*stairways*, *passageways*, ramps, doorways, etc.) shall be expressed in units of 22 inches, and the least total number of such units required for any *floor-area* shall be determined by dividing the total population on the *floor-area* (see Item 4.6.5.1 and Table 1) by the figure given in Table 3 of this Section for the occupancy concerned. Twelve inches or more of width when added to one or more full 22-inch units may be considered as half a unit.

Exit Width – Historical Basis

- The 1941 NBCC exit requirements based on 1935 “Design and Construction of Building Exits” – National Bureau of Standards in the US:

1941 NBCC

Grade shall mean

(i) for buildings adjoining one *street* only, the elevation of the sidewalk at the centre of that wall adjoining the *street*;

(ii) for buildings adjoining more than one *street*, the average of the elevation of the sidewalk at the centres of all walls adjoining the *street*;

(iii) for buildings having no wall adjoining the *street*, the average level of the ground (finished surface) adjacent to the exterior walls of the building.

All walls approximately parallel to and not more than 15 feet from the *street line* are to be considered as adjoining a *street*.

1935 Design and Construction of Building Exits

Grade.—(a) For buildings adjoining 1 street only, the elevation of the sidewalk at the center of that wall which adjoins street; (b) for buildings adjoining more than 1 street, the average of the elevations of the sidewalk at centers of all walls adjoining streets; and (c) for buildings having no wall adjoining the street, the average level of the ground (finished surface) adjacent to the exterior walls of the building. All walls approximately parallel to and not more than 5 feet from a street line are to be considered as adjoining a street.

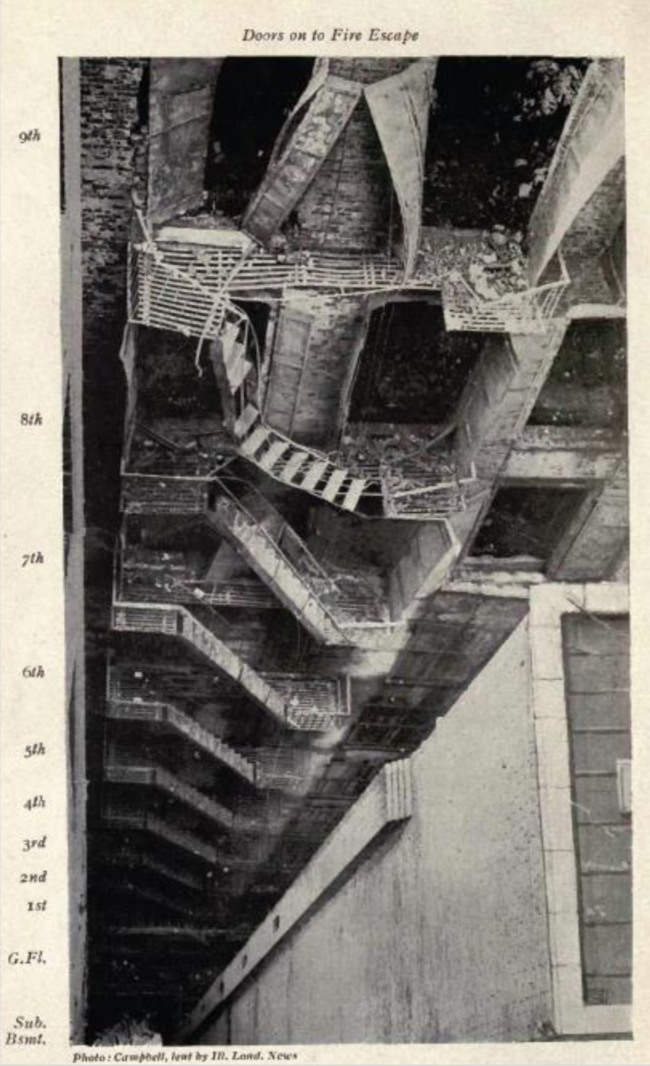
Exit Width – Historical Basis

- The exit width requirements in the 1935 “Design and Construction of Building Exits” are based on studies conducted in the United States between 1900 and 1930 relative to occupant flow.
- 1935 “Design and Construction of Building Exits” based on “Building Exits Code”, now called NFPA 101, “Life Safety Code”
- The first edition of the “Building Exits Code” was issued in 1927, following NFPA Life Safety Committee deliberations since committee inception in 1913
- Why was the Life Safety Committee formed?

Exit Width – Historical Basis

- Shirtwaist Factory Fire, New York City, 1911.
- Exits locked
- 146 workers dead
- Lead to Formation of Factory Investigation Committee, 1911.
- Initiated NFPA Life Safety Committee in 1913

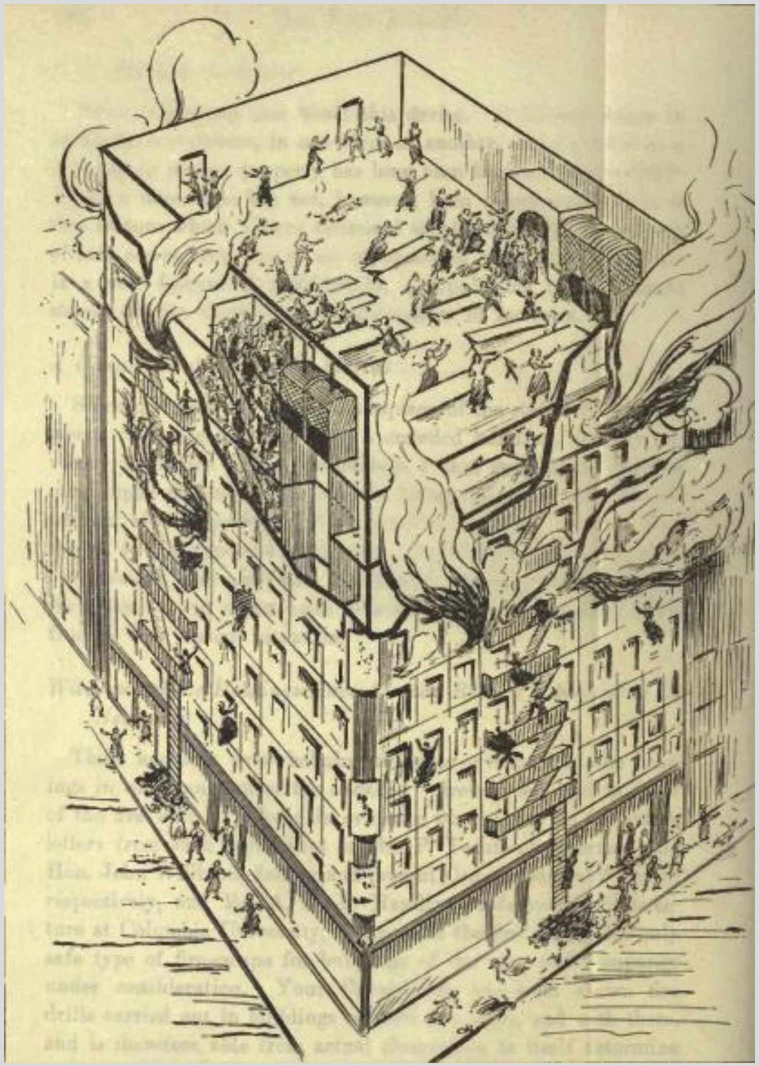
Exit Width – Historical Basis

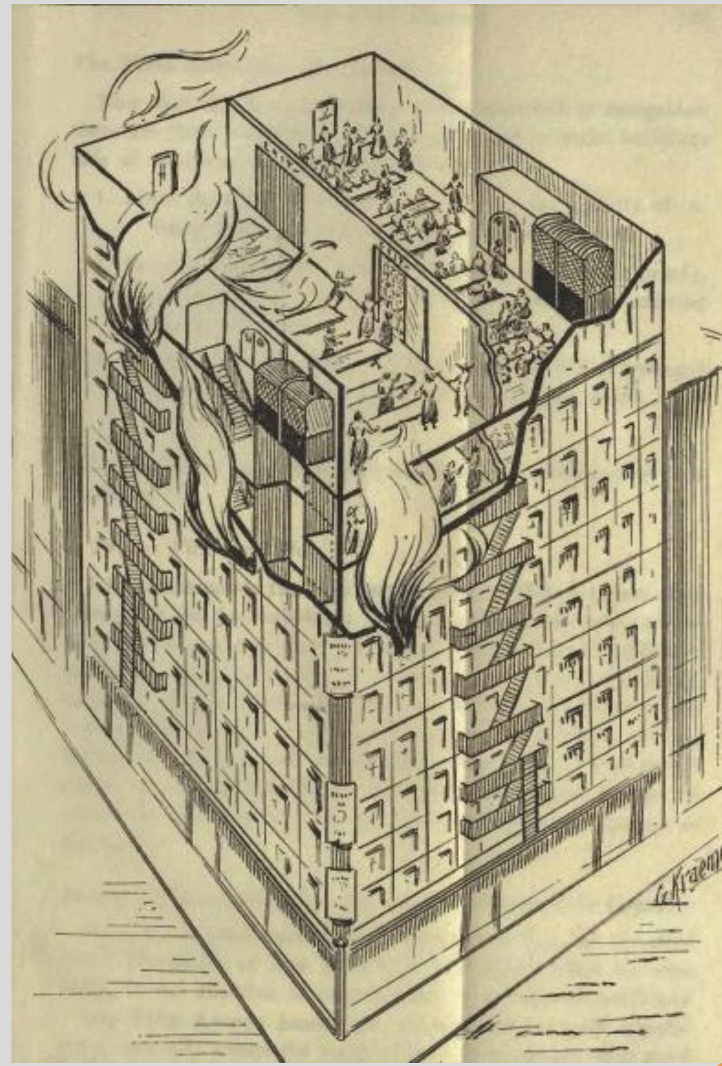


Exit Width – Historical Basis

- Initially a need to evacuate occupants from factory buildings within specific time period (3 minutes).
- Emptying time increased for increasing building height.
- Exit width based on stair capacity and flow to meet emptying time based on multiples of the 22 inch unit width
- Several methods suggested for adequate evacuation:
  - Provide adequate stair capacity
  - Provide horizontal exit to available floor area.
  - Combination of the above two methods.

Exit Width – Historical Basis





Exit Width – Historical Basis

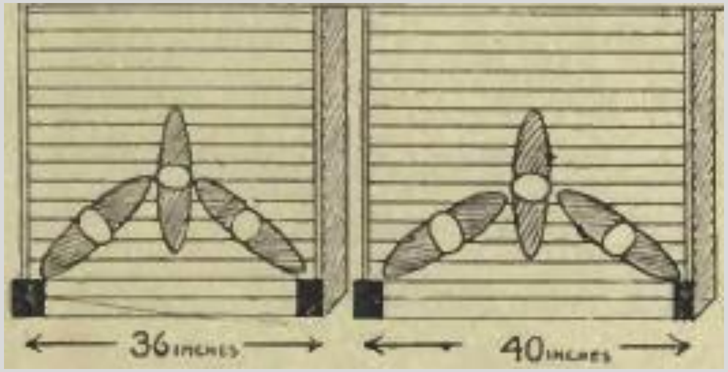
- Where does the 22 inch unit width come from?

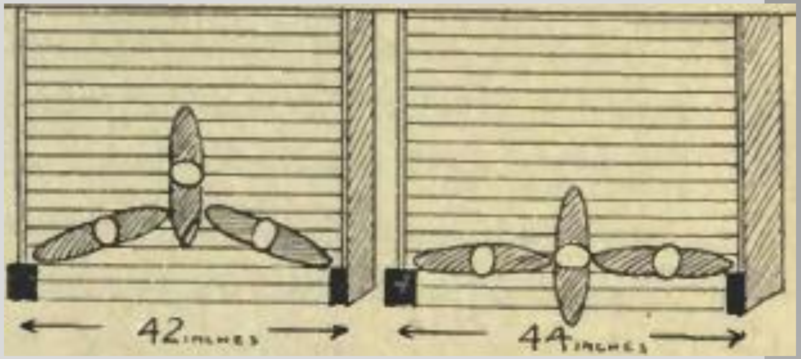
“ In the opinion of many who have studied the matter, 22 inches can be taken as the width of a file of people in motion. Its origin is said to be in experience gained in the Army. A stairway width of 44 inches will permit 2 files of people to move freely down the stairs at the same time.

- 1792 – Troop Formations: known values for troop formation widths rationalized for evacuating occupants

The platoon FALLS IN, in three ranks at cloſe order, with ſhouldered firelocks; the files lightly touching, but without crouding; each man will then occupy a ſpace of about 22 inches.

Exit Width – Historical Basis





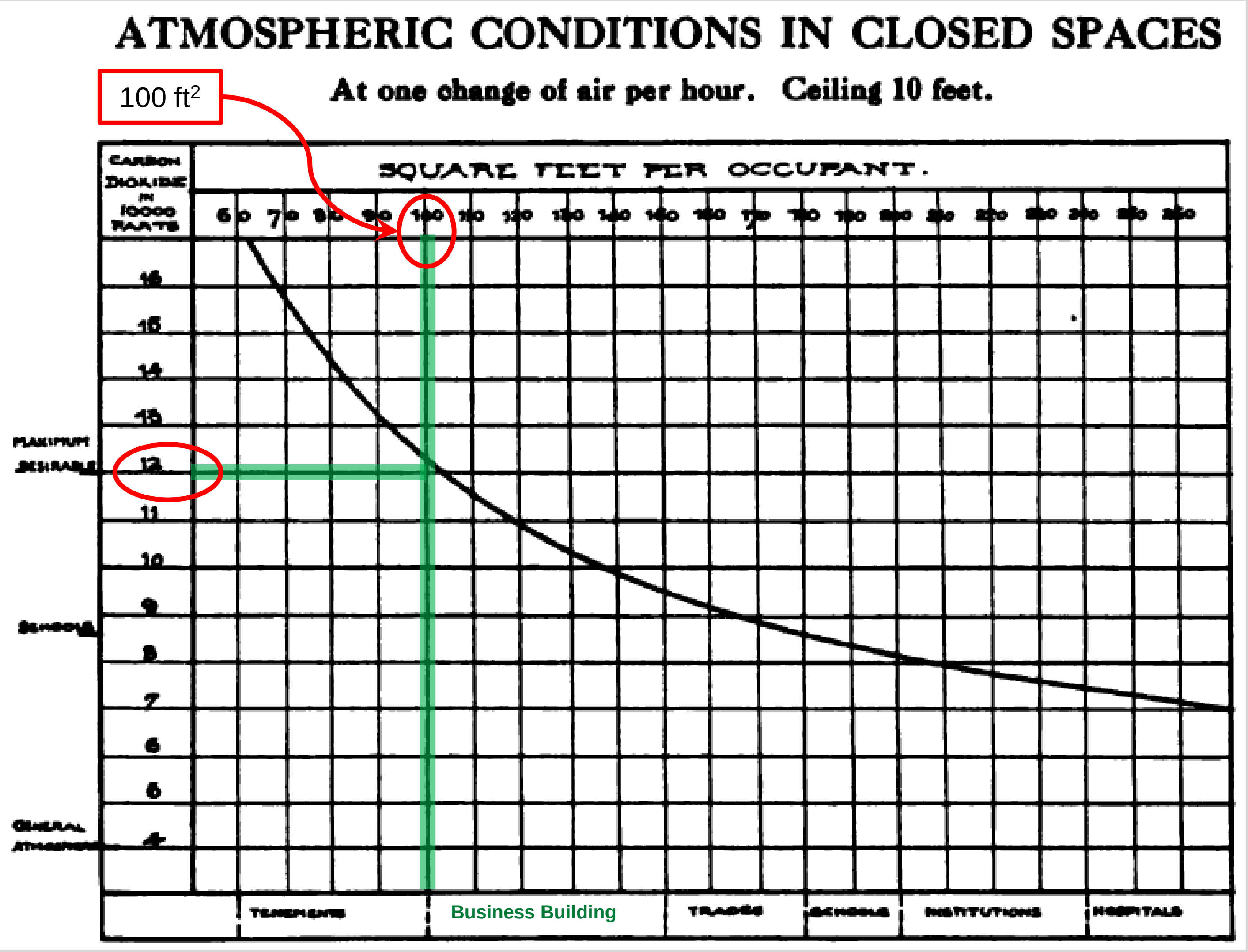
Historical Basis - Quantification

- Unit exit width confirmed based on statistical analysis of egress
- Results of exit flow analysis indicate:
  - 45 People/min for each 550 mm unit exit width for stairs
  - 60 People/min for each 550 mm unit exit width for doors
- Combining the values above with the limit to the number of occupants per unit of exit width (i.e., 60 People/550 mm stair/door width:
  - 1.33 minutes to clear a floor area based on stair capacity
  - 1.00 minutes to clear a floor area based on door capacity
- 1.00 to 1.33 minutes to clear a floor area assumes that a floor area is becoming untenable within that time period

Occupant Load – Historical Basis

- Large loss of life in barracks and hospitals
- Florence Nightingale proposed minimum volumetric space per person 1860's
- Ventilation requirements a function of:
  - room dimensions,
  - external and internal temperatures,
  - number of occupants in the room,
  - the time the room is occupied, and
  - the use of the room.
- Max von Pettenkofer – developed cubic limits for various occupancies as a function of exhaled carbonic acid

Occupant Load – Historical Basis (Ventilation)



Occupant Load - Elevator Service

- Required an understanding of maximum occupant load
- Bolton - office occupancies:
  - Existing ventilation requirements as basis for calculation
  - Confirmed calculation through statistical analyses of highest density offices in the City of New York

Occupant Load - Elevator Service: Ventilation and Statistics

SQUARE FEET OF OCCUPIED FLOOR AREA PER OCCUPANT

In buildings, or portions of buildings, occupied by	Under the busiest conditions	Where removed from main center of business	When occupying isolated positions
Stockbrokers, Exchange firms	100	110	115
Shipping, Railroads, and wherever many employes, or draftsmen, are employed	105	115	120
Lawyers, also where small offices are laid out, or where tenants are allowed to rent desk-room	110	120	130
City departments, public offices, large Insurance and Surety offices with numerous employes	115	127	135
Banks, large business corporations, where hours of arrival are not coincident	120	133	142
Real estate, general business agencies, hours of arrival scattered . . .	125	140	150

Occupant Load - Building Exits Code (Life Safety Code)

- Committee on Safety to Life established occupant loads on a statistical basis for Mercantile, School and Office Buildings.
  - 1918 to 1924: developed as a set of graphs and tables
- Developed complicated tables of egress relative to occupant loads, building height, protective features

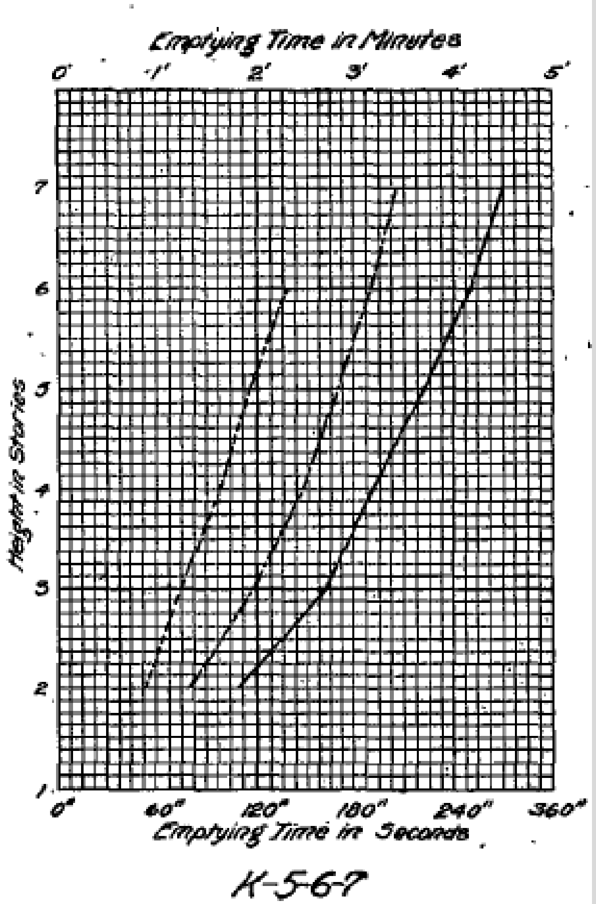


Fig. 10.

Occupant Load - Building Exits Code (Life Safety Code)

Based on Emptying Time, and on Construction, Sprinkler Protection, Protection of Vertical Openings, Height, and Character of Materials, Stored, Manufactured, or Used.

Column 1	Column 2	Column 3	Col. 4	Column 5		Column 6		Column 7		Col. 8
				Character of Material Stored, Manufactured, or Used						
				High Inflammability		Moderate Inflammability		Low Inflammability		
Type of Construction	Automatic Sprinkler Protection	Protection of Vertical Openings	Story Height of Bldg.	Emptying Time in Secs.	Persons per Floor	Emptying Time in Secs.	Persons per Floor	Emptying Time in Secs.	Persons per Floor	Line No.
High Combustibility	No	Required Exits Enclosed or Protected	2	15	15	25	25	40	40	1
			3	30	15	50	25	70	35	2
			4	45	15	60	20	90	30	3
			5	60	15	72	18	88	22	4
			6	75	15	75	15	90	18	5
			7	90	15	90	15	90	15	6
		All Vertical Openings Enclosed	2	15	15	30	30	40	40	7
			3	30	15	60	30	80	40	8
			4	45	15	75	25	120	40	9
			5	60	15	88	22	120	30	10
			6	75	15	90	18	120	24	11
			7	90	15	90	15	120	20	12
	Yes	Required Exits Enclosed or Protected	2	22	22	50	50	80	80	13
			3	44	22	100	50	140	70	14
			4	66	22	120	40	180	60	15
			5	88	22	148	36	180	45	16
			6	110	22	150	30	180	36	17
			7	132	22	150	25	180	30	18
		All Vertical Openings Enclosed	2	22	22	60	60	80	80	19
			3	44	22	120	60	160	80	20
			4	66	22	150	50	240	80	21
			5	88	22	180	45	240	60	22
			6	110	22	180	36	240	48	23
			7	132	22	180	30	240	40	24

Occupant Load - Building Exits Code (Life Safety Code)

- 1924: developed an occupant load formula to replace tables to simplify egress analysis.

$$N = \frac{A \times B \times C \times D \times E \times F^{*}}{H}$$

- 1925: customization of the occupant load formula for Institutional Buildings.
- 1927: occupant load of Assembly Buildings established based on a combination of number of seats and floor area basis.
- 1934: egress analysis simplified into basic table of values

Occupant Load - Life Safety Code

Occupancy	*Areas Per Person Sq. Ft.*
Dance hall, lodge room, and places of assembly (see par. below)	15
Store, street floor and sales basement	30
other floors	60
School, courtroom, restaurant and other similar public occupancy	40
Office, factory and workroom	100
Hotel and apartment	125
Institutional	150
Warehouse, storage and garage	300

Occupant Load - Modern Building Codes

- 1935: "The Design and Construction of Building Exits"

Occupancy	Maximum Area of Floor Space per Person, in Square Feet
Arenas, Auditoriums, Churches, Dance Halls, Exhibition Buildings, Lodge Rooms, Passenger Stations, *Theatres*, and similar *places of assembly* (see paragraph below)	15
Libraries, Schools, Courtrooms, Museums, and similar occupancies; *Restaurants*	40
Stores; Street floor and sales basement	30
Other floors	60
Offices, Factories, and Workrooms, *Stages* and 'Back-stage' Areas	100
Hotels and Apartment Houses	125
Institutional Buildings	150
Warehouses, *Garages*, Storage Buildings	300

- 1941: "National Building Code of Canada"

Occupancy:	Areas per person (square feet)
Dance hall, lodge room, and places of assembly	15
Store:	
Street floor and sales basement	30
Other floors	60
School, courtroom, and other similar public; restaurant	40
Office, factory, and workroom	100
Hotel and apartment	125
Institutional	150
Warehouse, storage, and garage	300

Exit Width – Historical Basis Considerations

- Exit width requirements were established based on the perceived risk of death by fire at that time
- Do they still apply today?
- Risk of death by fire in 1910’s versus today has been significantly reduced given:
  - Improved material performance and limits on surface finishes
  - Advanced detection and notification technology
  - Increased use of sprinklers
  - Advances in fire department apparatus and capabilities
  - Greater understanding of fire growth and development
  - Advances in building design beyond that intended by these early codes

Exit Width – Alternative Solution Considerations

- Delay/Impeded?:
  - What is the delay relative to?
  - Development of untenable conditions resulting from fire
  - What does the building code consider in terms of a value for delay?
  - 1:00 to 1:20 minutes for fire floor assuming untenable conditions occur within that period of time affecting the entire floor area (for a standard floor)
  - 3 minute building emptying time for lower buildings, up to 7 minutes for higher buildings
  - Compartment fire development, flashover and full room involvement were not fully understood in the early 1900’s

Exit Width – Alternative Solution Considerations

- Safe place?:
  - The building code does not define “safe place”; however, exit facility, adjacent building and public thoroughfare could be interpreted as safe
  - Is safe an ultimate term or a function of the growth and development of a fire?
  - The building code developed the concept of safe relative to the industry understanding of fire development in the early 1900’s (i.e., physically or spatially separated from the location of the fire such that the products of the fire will not impact on safety, or outside the building)
  - These concepts were based on the assumption of the Building as the unit of control

General History

BUILDING SIZE (HEIGHT AND AREA LIMITS)

Building Size – Acceptable Solution Example

- 2012 BCBC:

Table 3.2.2.52.
Maximum Building Area, Group C, up to 3 Storeys
Forming part of Sentence 3.2.2.52.(1)

No. of *Storeys*	Maximum Area, m^2		
	Facing 1 *Street*	Facing 2 *Streets*	Facing 3 *Streets*
1	1 800	2 250	2 700
2	900	1 125	1 350
3	600	750	900

- Where do these limits come from?

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

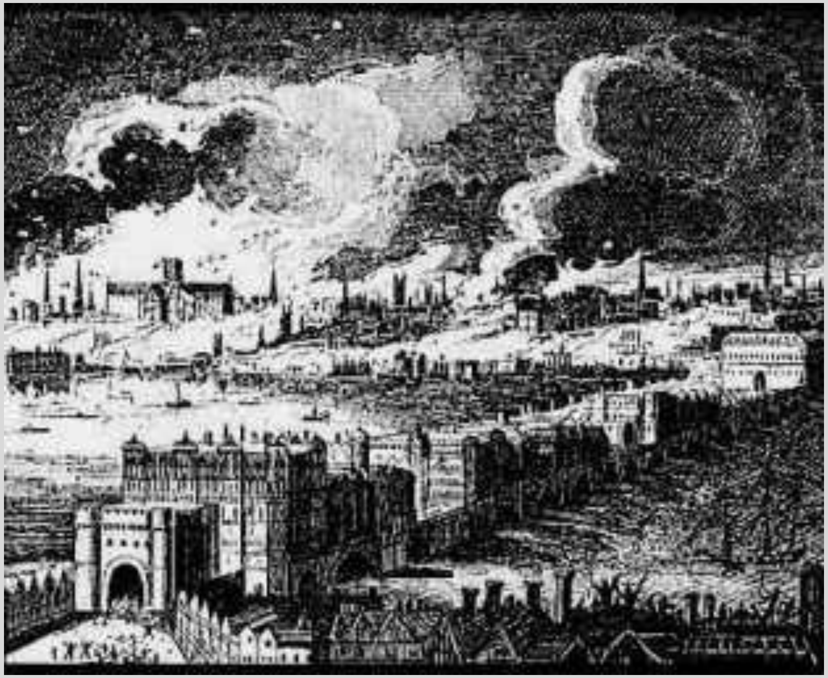
Construction Type Objectives, Functional Statements and Intent Statements

- 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.

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

Implicit Risk:	Fire spread from building to building resulting in conflagration.
Mitigation:	Stone wall between houses: 3 feet thick (party wall/firewall)
Intended Result:	Limit fire spread to individual buildings (primarily houses)

London – Great Fire: 1666

Building Size – London 1666 to 1774 Implicit Risk

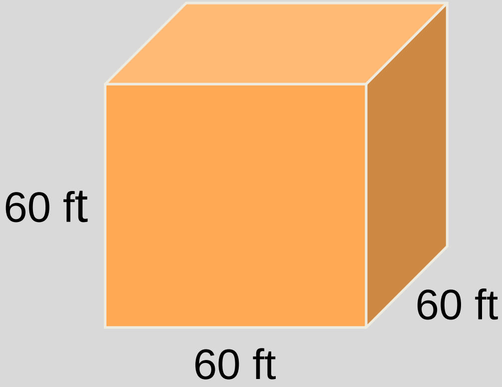
- Implicit Risk Considerations

Implicit Risk:	• Fire spread from building to building resulting in conflagration.
Mitigation:	• Brick or stone wall between houses: 13 inches thick and 18 inches above the roof (party wall/firewall) • Brick or stone exterior walls
Intended Result:	• Limit fire spread to individual buildings (primarily houses)

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.

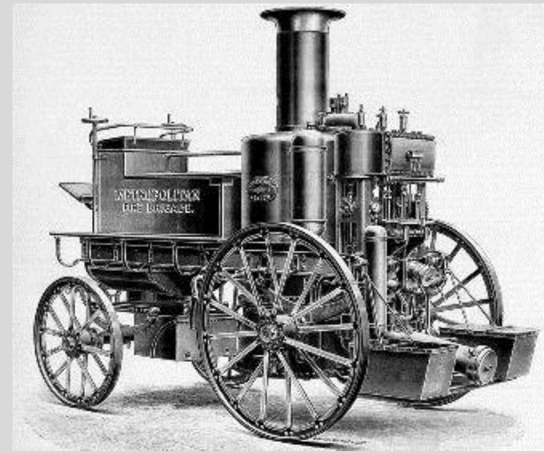
JAMES BRAIDWOOD.



London – Tooley Street: June 22, 1861

Building Size – London 1873 Implicit Risk

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 50 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.

Building Size – London: 1774 to 1873

- Implicit Risk Considerations

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

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.

9. HEIGHT to be not 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 ft^2 and height of 60 feet is 300,000 ft^3. This was the limit for existing warehouses in the City of London

Building Size –USA 1872 to 1930's Implicit Risk

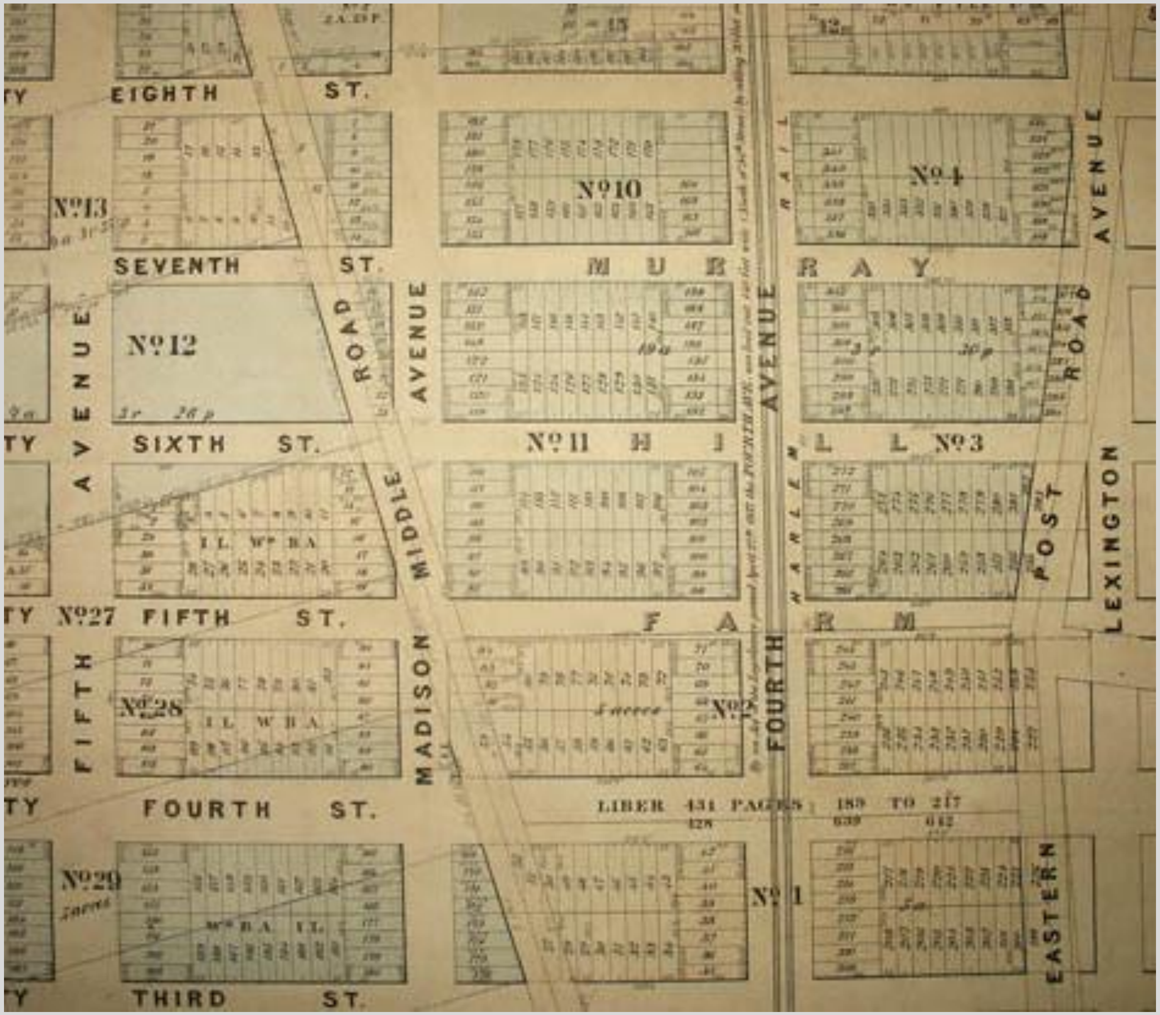
- Rationale for limits:

Restricting Undivided Areas

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 ft^2

Buildings covering multiple lots (typically 2)

5,000 ft^2

Building Size –USA 1872 to 1930's Implicit Risk

- Insurance rating system modifiers:

Feature	Modifiers
Occupancy:	A function of hazard level (experiential)
Type of Construction:	Fireproof and non-fireproof
Accessibility	Number of building sides facing a street
Sprinklering:	Gradual recognition of benefit with increased reliability
Area:	Incremental increases/decreases as a function of area
Height:	Incremental increases to a threshold level of 7 storeys then significant increases

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 ft^2
- Area modifiers:
  - Occupancy
  - Height
  - Type of construction
  - Streets Facing
  - Sprinklers

Non-Fireproof Construction.

Any occupancy, height limited to 55 feet.

Area, without Automatic Sprinkler Protection.

Fronting on one street only	5,000 sq. ft.
Fronting on two streets, that is, extending through from street to street	6,000 sq ft.
Corner building, fronting on two streets	6,000 sq. ft.
Fronting on three streets.	7,500 sq. ft.

Non-Fireproof Construction.

Any occupancy, height limited to 55 feet.

Area, with Automatic Sprinkler Protection (being an increase of 50 per cent. over the unsprinklered area).

One street front	7,500 sq. ft.
Two street fronts	9,000 sq. ft.
Corner building, two street fronts	9,000 sq. ft.
Three street fronts	11,250 sq. ft.

Fireproof Construction.

Occupancy, stores, warehouses and factories. Height when not exceeding 55 feet.

Area, without Automatic Sprinkler Protection.

Fronting on one street only	10,000 sq. ft.
Fronting on two streets, that is, extending through from street to street	12,000 sq. ft.
Corner building, fronting on two streets	12,000 sq. ft.
Fronting on three streets.	15,000 sq. ft.

Fireproof Construction.

Occupancy, stores, warehouses and factories. Height when not exceeding 55 feet.

Area, with Automatic Sprinkler Protection (being an increase of 33 1-3 per cent. over the unsprinklered area).

One street front	13,333 sq. ft.
Two street fronts	16,000 sq. ft.
Corner building, two street fronts	16,000 sq. ft.
Three street fronts	20,000 sq. ft.

Building Size –USA 1872 to 1930's Implicit Risk

- Implicit Risk Considerations

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

Major Occupancies	Fire Loads
Group A Assembly, Group B Institutional, Group C Residential, Group D Business, Group G Commercial and Industrial Division 3	10 pounds per square foot of *floor area*
Group E Mercantile and Group G Commercial and Industrial Division 2	20 pounds per square foot of *floor area*
Group F Hazardous and Group G Commercial and Industrial Division 1	30 pounds per square foot of *floor area*

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 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
- 1995 NBCC: Sprinkler and streets facing factor combined (2 x 1.5 = 3)

Building Size – Canada 1941 to Current Implicit Risk

- Implicit Risk Considerations

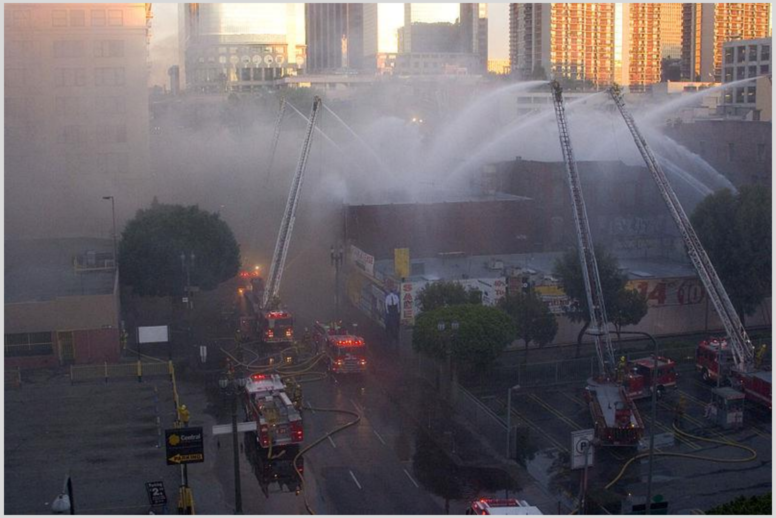
Implicit Risk:	• Inadequate evacuation
	• Full building involvement
	• Fire size beyond the capability of the responding fire department
	• Collapse of high buildings
	• Increased potential for conflagration
Mitigation:	• Height of 6 storeys (50 to 60 ft) and area limits as a function of occupancy, type of construction, fire-resistance, streets facing and sprinklering.
	• Maximum area of 5,000 square feet for basements in buildings otherwise sprinklers would be required.
	• Maximum area of 10,000 square feet for floor areas in high buildings otherwise sprinklers would be required.
Intended Result:	• Combustible buildings: Limit fire spread to building
	• Noncombustible buildings (no rating): Limit fire spread to building
	• Noncombustible buildings: Limit fire spread to storey

Building Size - Summary

- Occupancy: Fuel load/occupant evacuation
- Construction Type: Contributes to the fire?
- Area – total controllable fire size
  - Combustible construction: assumed entire structure could be involved.
  - Noncombustible construction: assumed only single storey could be involved.
- Height – access
  - Combustible construction: potential external attack
  - Noncombustible construction: primarily internal attack
- Mitigation: access, sprinklering

Building Size - Considerations

- Has capability improved?
- Have design and construction practices improved?
- Have material properties and capabilities improved?
- Has industry knowledge of fire science improved?
- Is a Building the proper unit of control?



General History

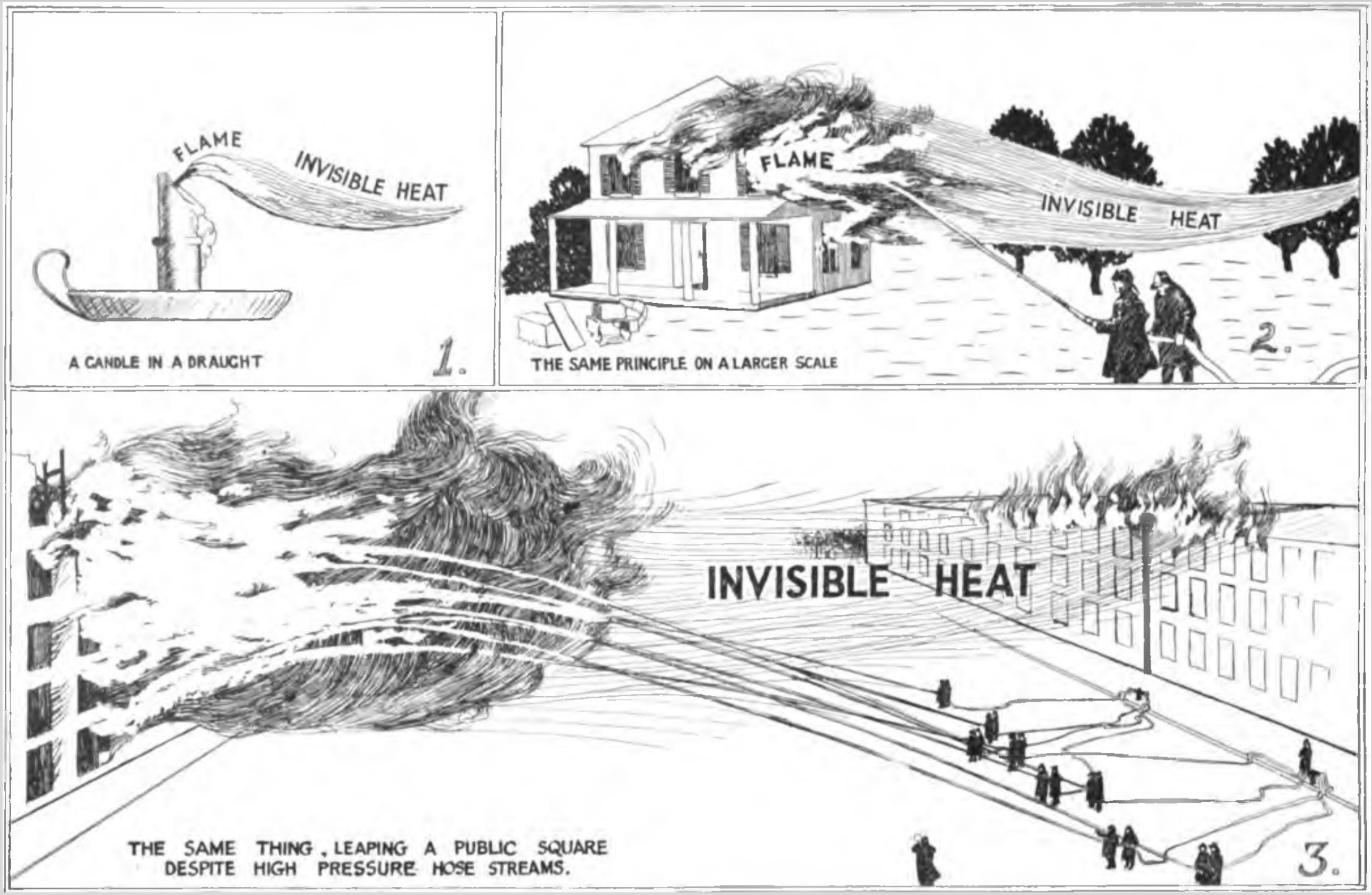
SPATIAL SEPARATION

Great Fire of Rome in 64 AD

Great Fire of London in 1666

Great Fire of Vancouver in 1886

"Invisible Heat"



Overview

- Early History of Development of Requirements
  - Limits

"(a) The First Class Fire Limits will be property within the following limits -

"The following defined area of the City of Calgary shall be known as the First Class Fire limits, that is to say, all the area lying within the following boundaries, namely:-

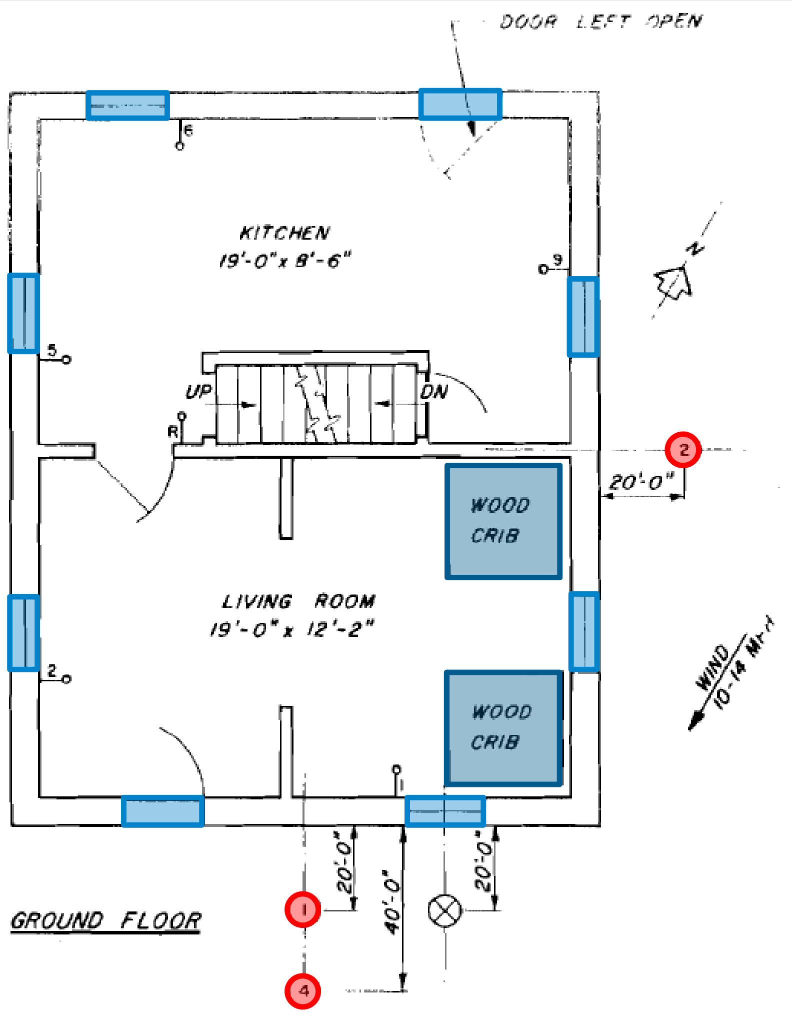
Commencing at the intersection of 6th Ave. and a point 125 feet West of 4th St. W., running easterly along 6th Ave., to the intersection of 2nd St. E. and 6th Ave., thence southerly along 2nd St. E. to the intersection of 7th Ave. thence easterly along 7th Ave. to the intersection of 4th St. E. thence southerly on 4th St. E. across the C.P.R. Right-of-way to the intersection of 11th Ave. and 4th St. E. thence westerly on 11th Ave. to the intersection of 4th St. W. thence northerly across the C.P.R. Right-of-way to the intersection of 9th Ave. thence westerly on 9th Ave to the intersection of 7th St. and 9th Ave. thence northerly on 7th St. W. to the intersection of 8th Ave. thence easterly to a point 125 feet west of 4th St. W. and 8th Ave. thence northerly to point of commencement."

  - Insurance Rating Schedule
  - Setbacks
- These requirements were challenging to enforce and typically city-specific
- Needed a better "building independent" system

St. Lawrence Burns

- Based on St. Lawrence burn tests:
  - Six 2-storey dwellings of similar size and layout and two larger structures (school and community hall)
  - One dwelling test eliminated due to problems
  - Current table values primarily based on results from Test No. 5

Burn Setup



DOOR LEFT OPEN
KITCHEN
19'-0" x 8'-6"
UP
DN
WOOD CRIB
LIVING ROOM
19'-0" x 12'-2"
WOOD CRIB
20'-0"
20'-0"
40'-0"
20'-0"
N
WIND 10-14 MPH
GROUND FLOOR

Ignition

Notification of Test Start

Burn No. 5

Burn No. 5 Observations

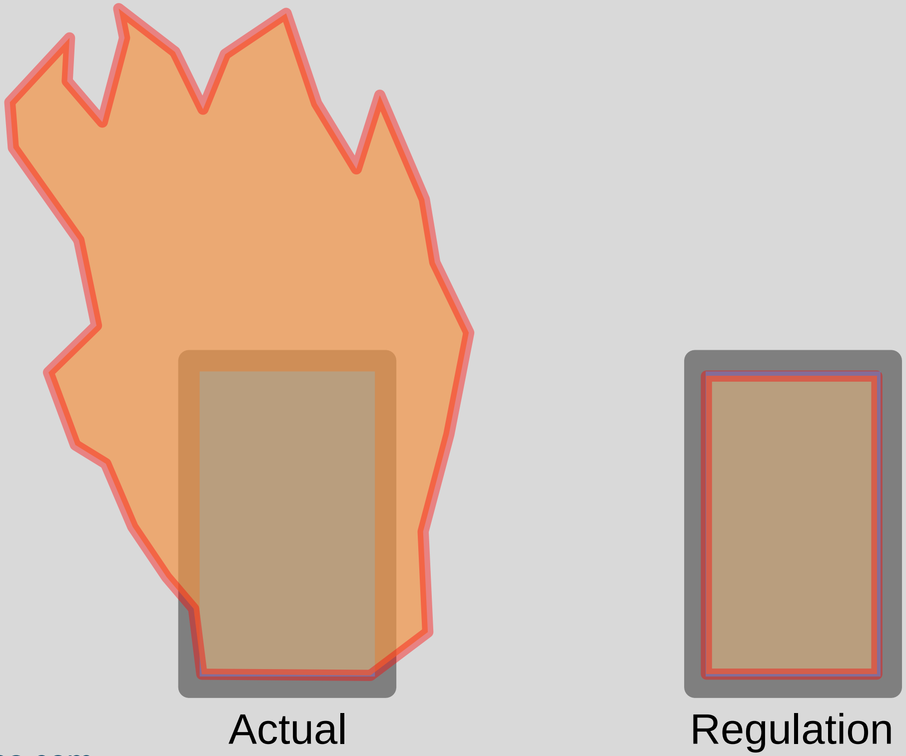
Time From Ignition Min Sec	Observations	
01:35	Glass in front window of ground floor cracked, smoke followed.	
02:00	Glass in window of living room between wood cribs blown out, smoke followed.	
02:30	Ceiling temperature at foot of stairs is 900°F. (482 ºC)	Flashover ~ 600 ºC
04:00	Glass in kitchen window near door to basement blown out, flames followed.	
04:30	Flames observed for first time on dining room side of house.	
05:00	Wood cladding on living room side of house ignited by flames from ground floor windows.	
07:00	Back shed well involved.	Additional fuel source
07:15	Eaves ignited on living room side of house.	
07:30	Rear wall of house burning. Flames out of small window at top of stairs.	
08:00	Flames out of front living room window.	
08:25	Exterior cladding and eaves at front of house ignited by flames out of living room window.	
08:30	Flames coming out of side living room window.	
09:15	Flame front extending to a distance of 4 ft in front of house.	Flame Front

Burn Results

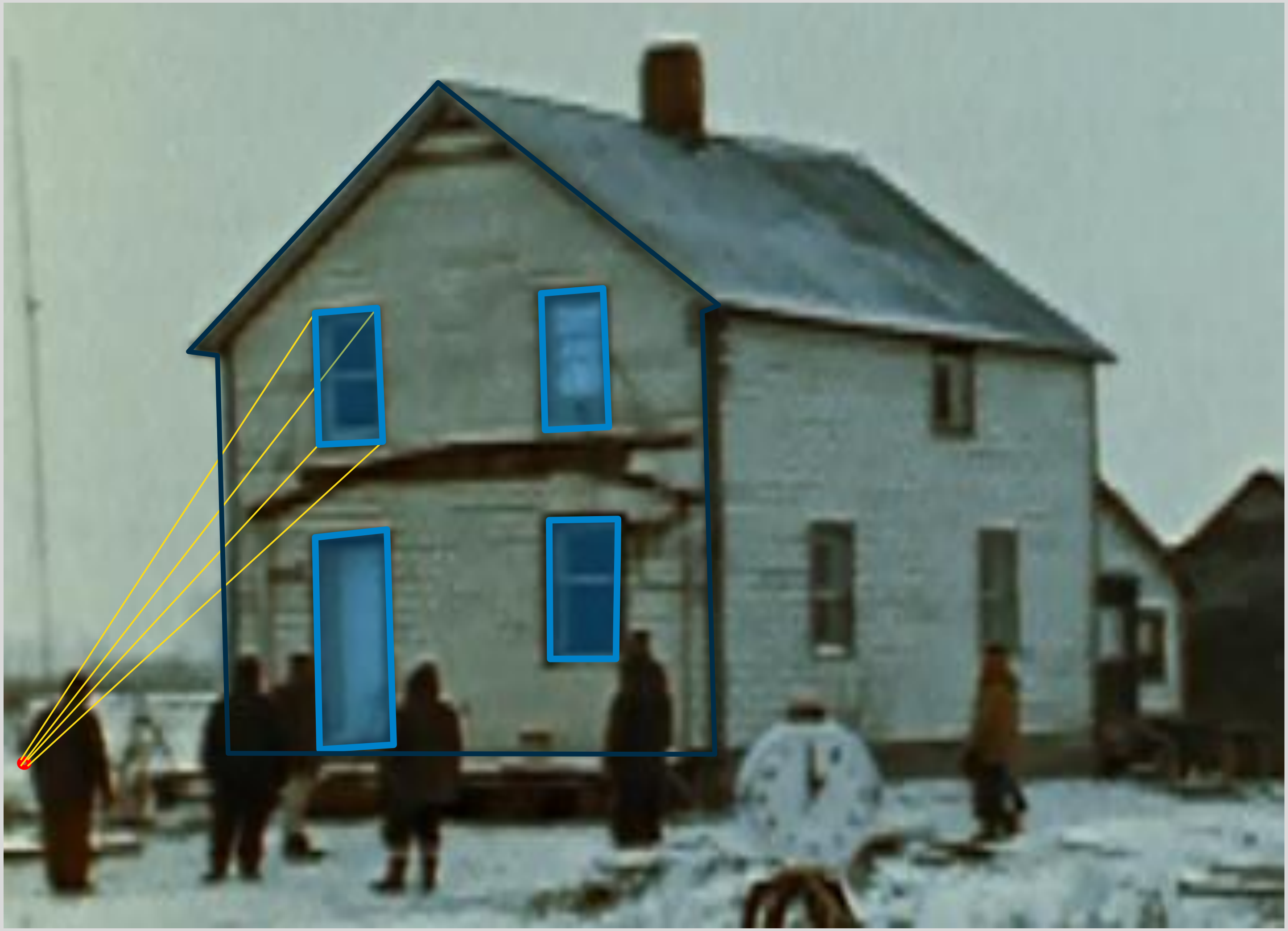
Building and Burn No.	Exterior Cladding	Interior Lining	Radiometer Location	Wind Speed	Intensity (I) cal/cm^2/sec	F Configu-ration Factor of Openings	I/F cal/cm^2/sec
2	Brick	Downstairs: fibreboard (walls & ceilings) except for plywood wainscot in kitchen Upstairs: plaster	15' leeward 30' leeward 15' windward	4-5 mph	0.47 0.18 0.08	0.05 0.016 0.04	9 11 2
3	Brick	Fibreboard	15' leeward 30' leeward 15' windward	13-14 mph	1.25 >0.18 0.46	0.034 0.013 0.034	37 >14 14
4	Clapboard (brick infilling to timber frame)	Plaster	20' leeward 40' leeward 20' windward	11-12 mph	0.56 0.17 0.46	0.032 0.011 0.028	18 15 16
5	Clapboard (on cedar shingles)	Pressed paper	20' leeward 40' leeward 20' side	10-14 mph	1.05 0.32 0.35	0.027 0.008 0.012	37 40 29
6 Fraternity Hall	Brick	Plaster, wooden ceiling and wainscot	20' leeward 40' leeward 20' windward	7-8 mph	0.9 >0.41 0.42	0.075 0.031 0.075	12 >13 6
7	Brick	Plaster	15' leeward 30' leeward 15' windward	13 mph	0.9 0.38 0.08	0.058 0.018 0.044	16 21 2
8 School	Brick	Plaster, wooden ceiling	20' east 40' east 20' west	very low	0.83 0.17 >0.5	0.049 0.019 0.088	17 9 > 6

Conversion into Regulations - Source

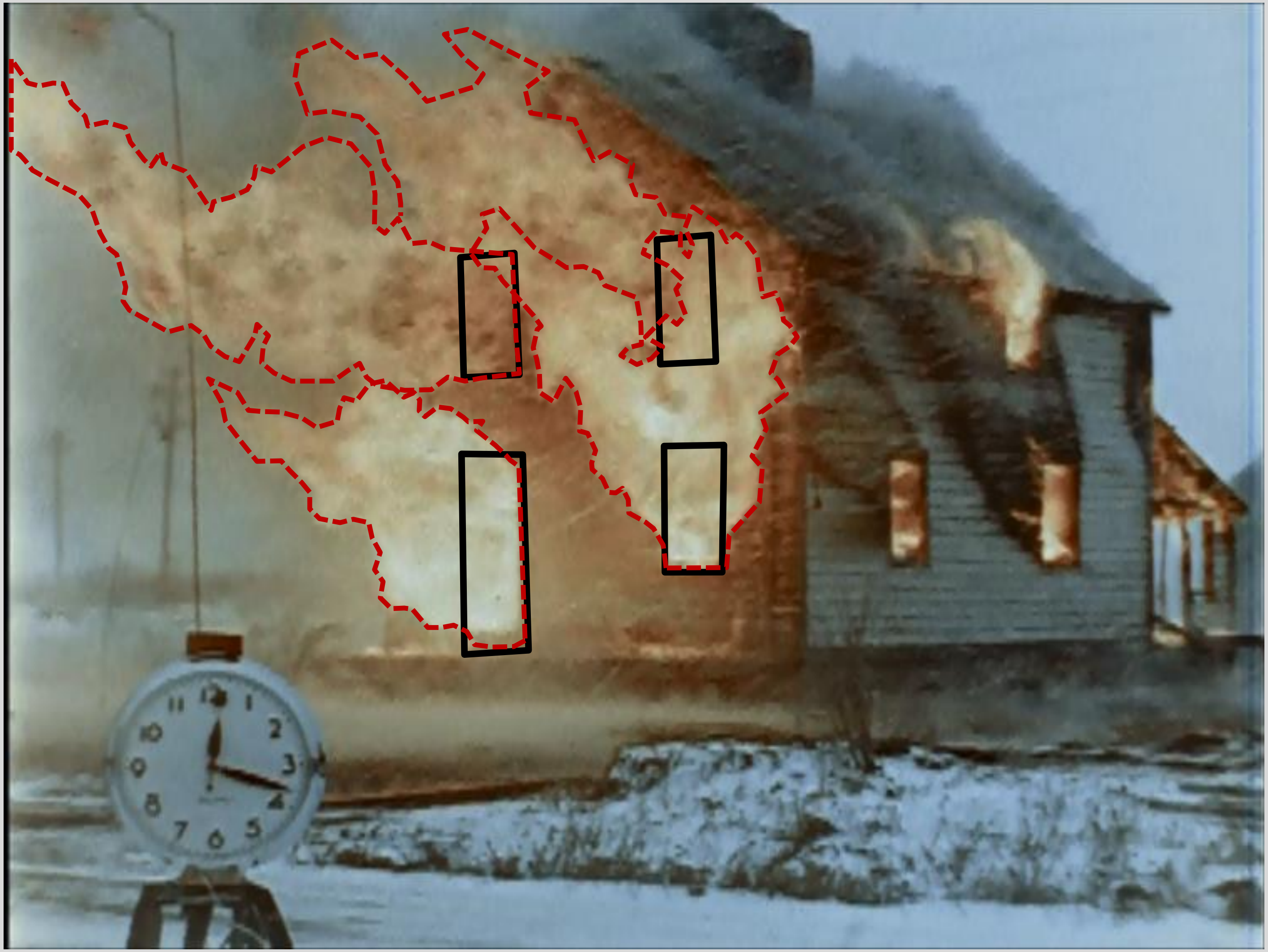
- Radiation Source (Windows)
  - Actual: Significant flame extension out windows
  - Regulation: Window area theorized as the only source of radiant heat for purposes of simplification



Conversion into Regulations - Source



Conversion into Regulations - Source



Conversion into Regulations – Peak Heat

- Peak Heat
  - Actual:
    - Burn No. 5 peak heat values of 29 to 40 cal/m^2·s (1214 to 1675 kW/m^2)
    - Burn No. 4 peak heat values of 16 to 18 cal/m^2·s (670 to 754 kW/m^2) – [approx. ½ Burn No. 5 values]
  - Regulation:
    - Building separations associated with peak heat not practical.
    - Assume fire department intervention when peak heat reaches approx. ¼ highest values measured.
    - Heat at 10 to 11 minutes for Burn No. 5
    - Approx. 356 kW/m^2

Conversion into Regulations – Peak Heat

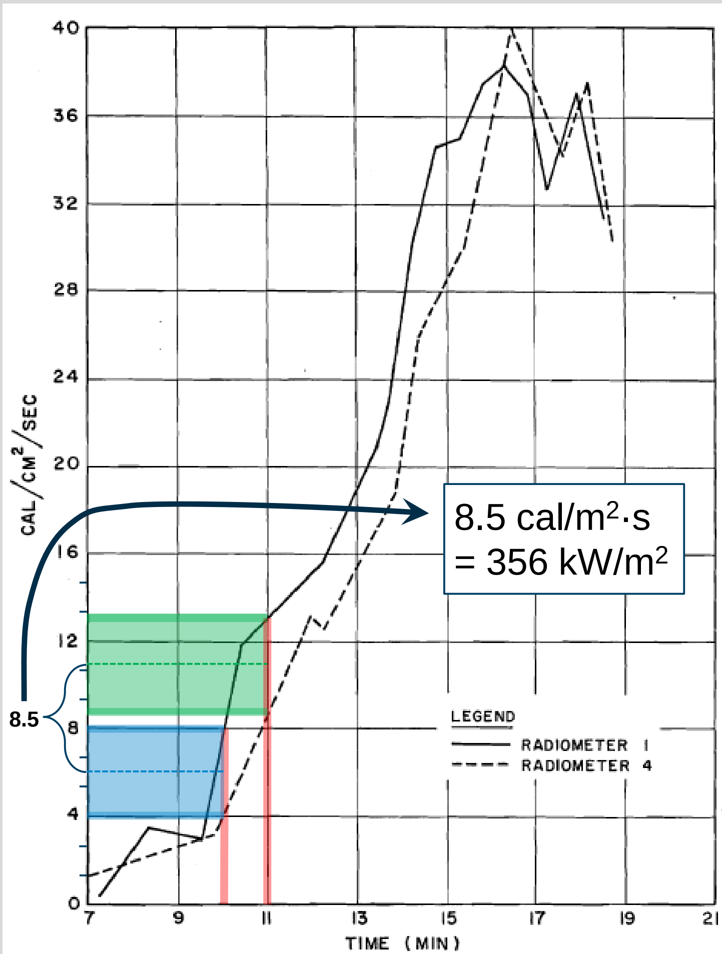
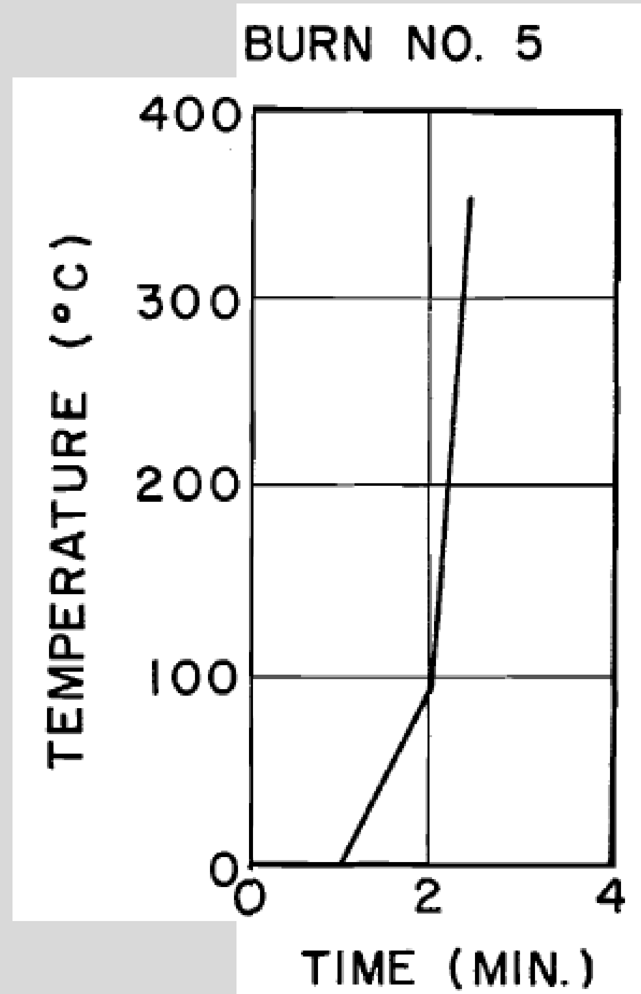


FIGURE 22 HYPOTHETICAL INTENSITIES AT WINDOW OPENINGS BURN No. 5



Conversion into Regulations – Target Criteria

- Acceptable heat flux at a target (Target Criteria):
  - 12.5 kW/m^2
  - Ignition of wood by open flame
  - Autoignition of wood ~ 30 kW/m^2
- Target criteria expressed as a ratio of target heat flux and peak heat
  - High hazard (combustible lining) - Table 3.2.3.1.C

$$\phi_c = \frac{12.5\ kW/m^2}{356\ kW/m^2} = 0.035$$

  - Low hazard (noncombustible lining) - Table 3.2.3.1.B

$$\phi_c = \frac{12.5\ kW/m^2}{\frac{1}{2} \times 356\ kW/m^2} = 0.07$$

Conversion into Regulations – Flame Front

- Flame Front
  - Actual: Varied 2 to 7 ft within first 10 minutes
  - Regulation: For simplification – 6 ft

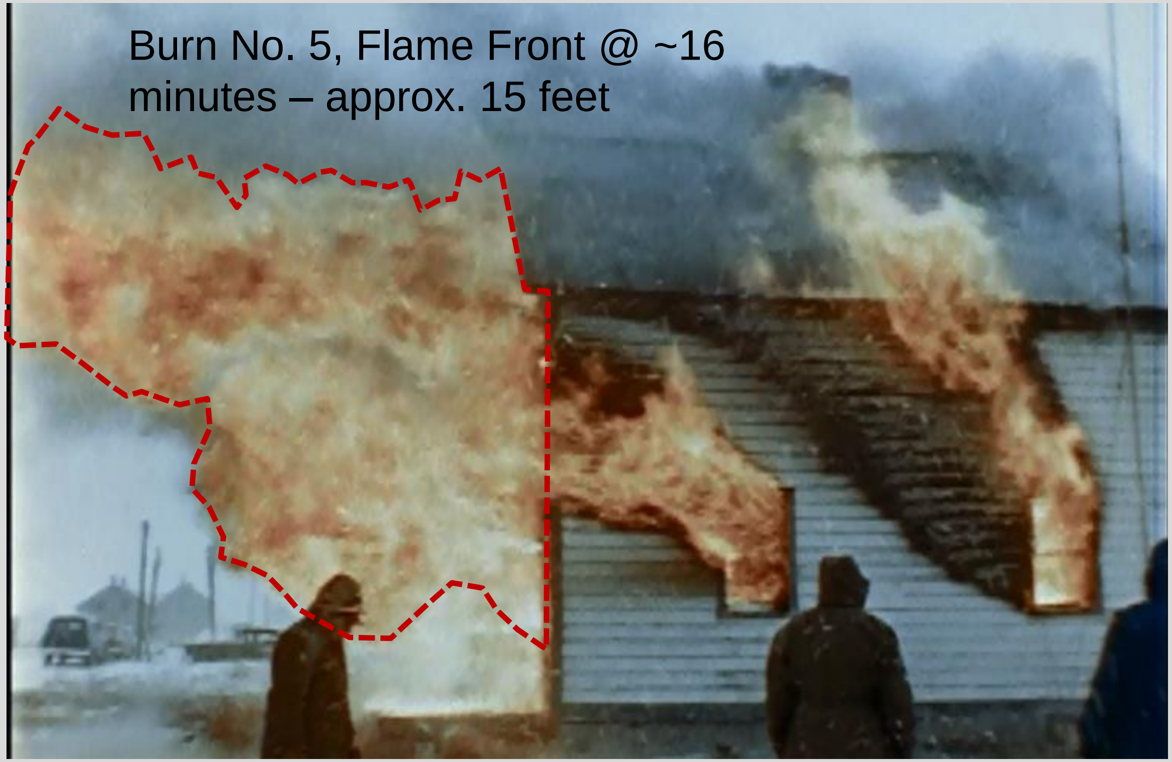


Table Equation - Unsprinklered

- Equation (unsprinklered):

$$\% \, openings = 100 \, \frac{\phi_c}{\phi}$$

$$\phi_c = 0.07 \, (A, C, D, F3) \; or \; 0.035 \, (E, F1, F2)$$

$$\phi = \frac{2}{\pi} \left\{ \sqrt{\frac{\frac{A}{S}}{\frac{A}{S} + 4}} \, arctan \left[\sqrt{\frac{A\,S}{\frac{A}{S} + 4}} \right] + \sqrt{\frac{A\,S}{A\,S + 4}} \, arctan \left[\sqrt{\frac{\frac{A}{S}}{A\,S + 4}} \right] \right\}$$

$$A = \frac{h\,w}{d^2}$$

$$d = 2 \, (LD - 0.9144)$$

$$S = \frac{h}{w} \; or \; \frac{w}{h} \; , whichever \; is \; greater$$

Table Equation - Sprinklered

- Equation (sprinklered):

$$\%\ openings = 100\ \frac{\phi_c}{\phi}$$

$$\phi_c = 0.14\ (A, B, C, D, F3)\ or\ 0.07\ (E, F1, F2)$$

$$\phi = \frac{2}{\pi}\left\{\sqrt{\frac{\frac{A}{3}}{\frac{A}{3}+4}}\ arctan\left[\sqrt{\frac{A\ 3}{\frac{A}{3}+4}}\right] + \sqrt{\frac{A\ 3}{A\ 3+4}}\ arctan\left[\sqrt{\frac{\frac{A}{3}}{A\ 3+4}}\right]\right\}$$

$$A = \frac{h\ w}{d^2}$$

$$d = 2\ \ (LD\ -\ 0.9144)$$

Table 3.2.3.1.B

- Spatial Separation in the National Building Code

Table 3.2.3.1.-B
Unprotected Opening Limits for a Building or Fire Compartment that is not Sprinklered Throughout
Forming Part of Article 3.2.3.1.

Exposing Building Face		Area of *Unprotected Opening* for Groups A, C, D, and F, Division 3 *Occupancies*, %																									
Max. Area, m^2	Ratio (L/H or H/L)[1]	*Limiting Distance*, m																									
		0	1.2	1.5	2.0	2.5	3	4	5	6	7	8	9	10	11	12	13	14	16	18	20	25	30	35	40	45	50
10	Less than 3 : 1	0	8	10	18	29	46	91	100																		
	3 : 1 to 10 : 1	0	8	12	21	33	50	96	100																		
	over 10 : 1	0	11	18	32	48	68	100																			
15	Less than 3 : 1	0	7	9	14	22	33	63	100																		
	3 : 1 to 10 : 1	0	8	10	17	25	37	67	100																		
	over 10 : 1	0	10	15	26	39	53	87	100																		
20	Less than 3 : 1	0	7	9	12	18	26	49	81	100																	
	3 : 1 to 10 : 1	0	8	10	15	21	30	53	85	100																	
	over 10 : 1	0	9	14	23	33	45	72	100																		
25	Less than 3 : 1	0	7	8	11	16	23	41	66	98	100																
	3 : 1 to 10 : 1	0	8	9	13	19	26	45	70	100																	
	over 10 : 1	0	9	13	21	30	39	62	90	100																	
30	Less than 3 : 1	0	7	8	11	15	20	35	56	83	100																
	3 : 1 to 10 : 1	0	7	9	12	17	23	39	61	88	100																
	over 10 : 1	0	8	12	19	27	36	56	79	100																	
40	Less than 3 : 1	0	7	8	10	13	17	28	44	64	89	100															
	3 : 1 to 10 : 1	0	7	8	11	15	20	32	48	69	93	100															
	over 10 : 1	0	8	11	17	24	31	47	66	88	100																
50	Less than 3 : 1	0	7	8	9	12	15	24	37	53	72	96	100														
	3 : 1 to 10 : 1	0	7	8	10	14	18	28	41	57	77	100															
	over 10 : 1	0	8	10	15	21	28	41	57	76	97	100															
60	Less than 3 : 1	0	7	8	9	11	14	21	32	45	62	81	100														
	3 : 1 to 10 : 1	0	7	8	10	13	16	25	36	49	66	85	100														
	over 10 : 1	0	8	10	14	20	25	38	51	67	85	100															
80	Less than 3 : 1	0	7	7	8	10	12	18	26	36	48	62	79	98	100												
	3 : 1 to 10 : 1	0	7	8	9	11	14	21	29	40	52	67	84	100													
	over 10 : 1	0	8	9	13	17	22	32	44	56	70	86	100														
100	Less than 3 : 1	0	7	7	8	9	11	16	22	30	40	51	65	80	97	100											
	3 : 1 to 10 : 1	0	7	8	9	11	13	18	25	34	44	56	69	84	100												
	over 10 : 1	0	7	9	12	16	20	29	39	49	61	74	89	100													

Summary

- Current codes are not entirely based on current technology or relevant fire data
- An understanding of the origin of current code requirements provides:
  - Clarity, uniform interpretation and a general understanding of the risk the requirements are intended to limit.
  - Facilitates development of alternative solutions and supports code changes

QUESTIONS?

Contact

Keith Calder

+1 604-295-3422

kcalder@jensenhughes.com

For More Information Visit

www.jensenhughes.com

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