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THE RISK BASIS FOR HEIGHT AND AREA LIMITS IN NORTH AMERICAN BUILDING CODES

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ABSTRACT: This document examines the development of the historical building height and area limits for North American building codes, identifying the risk factors upon which they were originally based and setting the stage for a re-examination of these factors in a current context. Height and area limits have developed over centuries, in conjunction with limits on types of construction, and were premised on a need to limit conflagrations and large loss of life. Over the last 80 years, these limits have remained relatively unchanged while technological advances and fire service capabilities have improved considerably. This paper covers the development of these limits from Nero's Rome to the development of more current limits in the modern model codes.

KEYWORDS: Height and Area, Building Size, Risk

1 INTRODUCTION

Recent initiatives by industry to facilitate greater use of wood in construction have considered a growing societal recognition of the importance of sustainable development, building affordability and aesthetics. These initiatives are supported by the advancement of wood-based products having unique properties and construction techniques that differ from conventional stick framing or heavy timber. However, the use of wood is limited in larger/taller buildings by the National Building Code of Canada (NBCC) based on concern of increased fire risk. This has led to a reconsideration of these limitations in light of current capabilities, materials and analytical methods; however, the re-assessment is complicated by a lack of information linking the actual risk attributed to building size to the existing requirements and limits.

The development of building code requirements to limit building size and type of construction have evolved following incidents of significant scale or impact, which due to the catastrophic circumstances, drew attention to specific building design issues. Investigation and analysis following the incidents identified specific conditions that led to the "unacceptable" occurrences, and new requirements were developed to limit future similar losses. This cycle of code change would continue following the next incident or other impetus for change, incrementally advancing the code without a reconsideration of the cumulative risk basis. Over time, the changes have become entrenched as accepted practice and recollection of the incidents and the specific risk context around the incidents have diminished. This cycle of change was described by the Head of the Building Standards Section of the National Research Council of Canada in the 1960's [1,2]:

> *In the broadest sense, building regulations develop from contingency to contingency. Each one represents an emergency measure taken with very little or no study. As the emergency recedes, the regulation tends to form part of traditional practice. It is added to the pile, which grows and grows.*
>
> *Progress towards better regulations in this country will be speeded when we have an understanding of the history of the regulations which are now enforced.*
>
> *R.S. Ferguson, Head of Building Standards Section (1960's), National Research Council of Canada*

The history of the NBCC has been one defined by a subtle balance between facilitation of innovation in building design, while keeping safety to life and property protection paramount. Building codes are intended to regulate the built environment and limit risks that may occur. They have existed for hundreds of years in various forms and have evolved to what they are today, very much through the process characterized above by Ferguson.

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Requirements and limits are formulated based on knowledge, capability, materials and methods available at the time of their development and represent a solution, which was deemed necessary and socially acceptable at the time, to achieving an objective. Quantification of the objective in terms of expected performance may have been known at the time a requirement or limit was developed, but can become lost over time where it is developed as a prescriptive solution and without a quantifiable link to the original objective. Establishing the knowledge, capability, materials and methods upon which a requirement or limit was formulated allows for quantification of the connection between the prescribed solution and the intended reduction in risk.

The primary properties of a building that define the allowable type(s) of construction are the building's occupancy, height and area, street access and provision of automatic sprinklers. The building height and area limits are considered the most defining of these factors, and knowledge of their origin allows industry to establish whether their application is appropriate in addressing the risk(s) associated with combustible construction today.

The development of the current height and area limits spans centuries and is implicitly connected with foundational fire and life safety provisions in the NBCC. Over the past several centuries, the industry's knowledge of fire science has evolved considerably, fire service equipment and capabilities have improved, detection and suppression systems have advanced, construction materials and techniques have changed significantly, and public awareness and education regarding fire safety has improved.

In order to facilitate an assessment of the merits of larger and/or higher buildings of combustible construction, it is necessary to verify the root foundation of the height and area limits, and provide the framework to reconsider those limits and their bearing on the use of combustible construction in buildings.

This paper summarizes research into the historical development of the building height and area limits in the NBCC, and covers the following:

- Ancient Rome and Early London from 64 A.D. to 1666.
- London from 1666 to 1874.
- The United States between 1871 and 1940.
- Early Canadian considerations between 1905 and 1920.
- The development of the NBCC from 1937 to the present.

The development of the height and area limits in the NBCC is founded on measures established to limit significant risks of the above geographic locations in the specified eras. While these individual locations have their own history of development of height and area limits, the focus of this paper is the development of those limits as they relate to the NBCC.

2 EARLY TIMES

The risk of conflagration in Rome (**Figure 1**) and Early London was addressed through limitations on building height and type of construction. Nero's regulations required every building to be enclosed by [3] "its own proper walls", which implied a degree of spatial separation in reducing the risk of fire spread. The Assize of Buildings [4] in early London, conversely, permitted neighbouring buildings to be connected provided they are separated by a common stone wall 3 feet thick. This wall was one of the earliest references to a firewall and was intended to act as a barrier to fire spread.

Figure 1: *Great Fire of Rome – 64 A.D. [5]*

Following the great fire of London in 1666 (**Figure 2**), an act was passed [6] for rebuilding the City of London, with requirements to reduce the risk of fire spread and conflagration. These requirements included noncombustible exterior walls and roofs, limits on location of hazardous occupancies, building height relative to type of construction, and party walls; and were intended to more precisely address the hazard of fire spread associated with differing conditions. These requirements were further refined and broadened in scope until the 1774 Act [7].

Figure 2: *Great Fire of London – 1666 [8]*

3 CUBIC CAPACITY CONCEPT

The Building Act of 1774 was the first in London to limit building area and height as a function of type of construction. These limits were revised and refined up to the Building Act of 1844 [9], which was the first act to limit cubical capacity of warehouses to 200,000 cubic feet, following several large warehouse fires. This cubic value was approximately equivalent to the combined height and area limit of warehouses in the 1774 Act. The intent of the development of the early height and area limits was not specified in any of the documentation reviewed. However, their development coincides with a general increase in building size and the proliferation of storage warehouses in London in the late eighteenth and early nineteenth centuries. The increase in building size resulted in fires growing beyond the ability of responding fire services to control, increasing the risk of conflagration.

The cubic capacity was further refined in the Building Act of 1855 in consultation with James Braidwood, the first Chief of the London Fire Brigade. Braidwood had been studying fire brigade capability and concluded that [10]:

> 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.

This was an important concept, providing a direct link between the limit in the Building Act and the capability of a “well organized” and “properly equipped” fire brigade. Braidwood does not qualify what is meant by “well organized” and “properly equipped”; however, given his affiliation at the time, the London Fire Brigade is assumed to be the benchmark in terms of “well organized” and “properly equipped”. This work done by Braidwood in setting building size limits would be carried forward and is reflected even in regulations existing to today.

A Bill in the early 1870’s [11] proposed an increase in the cubic capacity of buildings to 300,000 cubic feet and consideration of the concept of horizontal party-walls, which was a precursor to floor-to-floor fire separations. The Bill was eventually defeated in parliament; however, the greater cubic capacity became acceptable in the insurance industry relative to underwriting of existing warehouses and sheds. It would also become the basis for limits imposed by the insurance industry following the Chicago and Boston conflagrations in the early 1870’s.

4 INSURANCE RATING SYSTEM

The Chicago and Boston conflagrations (**Figure 3**) occurred just over a year apart in 1871 and 1872, resulting in insolvency of a large number of insurance companies.

Figure 3: *Destruction in Boston following the fire*

A large number of the remaining insurance companies were based in London and had significant influence over reforms to the system of rate setting relative to building construction, which was intended to reduce their losses. The reforms resulted in the development of a schedule of rates with an acceptable level of risk inherent to certain building characteristics. These combined characteristics were considered the standard to which basic rates were set and any building with these characteristics was referred to as a “standard building”. Any deviation from the standard was considered to increase the fire hazard of the building, resulting in higher rates. Design features, beyond those of a standard building, considered to reduce the fire hazard resulted in reduced rates. This was characterized as follows [12]:

> *It is entirely useless to appeal to an individual’s love of his city, and of the public weal, to cause him to substantially improve his buildings, for protection against fire, from causes not entirely plain to him; this is true of the majority:—it is equally true of the entirety that if you can show them where to save money while benefiting themselves, they will do it; we all go for the great American dollar; and the key to many a man’s attention is found in his pocket.*

The “standard Rate Schedule” was issued in January of 1873 by the New York Board of Fire Underwriters and defined a height limit of 60 ft and area limit of 5,000 square feet for a standard building (warehouse) as noted below [13]:

> 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.

These limits combined are volumetrically equivalent to the 300,000 cubic feet considered acceptable at that time by

London-based insurers relative to existing warehouses. At the time these limits were established, the city of New York had a standard lot size of 25 ft wide by 100 ft deep, and warehouse district buildings were permitted to cover 100% of a lot and in many cases covered more than one lot. Thus, buildings covering two lots could have maximum footprint areas of 5,000 square feet, which rationalized specifying the building size limits in terms of height and area rather than cubic capacity. The link between the London and New York requirements are summarized in the following statement [14]:

> An architect in this city said to me not long ago, speaking of large buildings—I think it was *apropos* of one of these large buildings that burned here: "A building that is more than 50 by 100 feet, or 5,000 square feet on the surface, is a dangerous building to insure." That is to say, it is dangerous, for it cannot be reached, and will be a total loss. He quoted the authority of the Chief of Brigade in London, for this very statement that 50 by 100 feet was as large a building as he wanted to cope with.

From 1873 to 1905, in addition to these height and area limits, the rating system evolved to consider additional features such as occupancy, type of construction, access and sprinklers and the rates associated with those features. Occupancies were classified as a function of hazard and attributed rates accordingly. Two types of construction developed; fireproof and non-fireproof. Fireproof buildings were attributed lower rates than non-fireproof, the difference being a function of contents and building materials. Accessibility (fire service) was identified as a key factor in reducing the consequences of fire and having an associated rate reduction on the basis that access to more than one side of a building enhanced the fire departments ability to reach and control the fire.

The efficiency of sprinklers took several decades to become fully appreciated by underwriters. Reductions in rates were initially small, but increased within a short period of time following the development of the first sprinkler standard (NFPA 13) in 1896. Design of systems in conformance with this standard increased reliability and permitted a 30 percent reduction in rates. This later became fifty percent for standard sprinkler equipment and up to sixty percent for a supervised system. This gradual increase in rate reduction was attributed to an increase in reliability and system experience.

Building area was attributed a rate as a function of type of construction and building height. The standard area for non-fireproof buildings was 5,000 square feet. The standard area for fireproof buildings was 10,000 square feet. Increases in area beyond the standard resulted in increased rates as a function of type of construction and building height. These increases were incremental and gradual. However, there were areas at which the risk was considered too high to insure. These were not explicitly stated, but based on underwriter judgment.

Building height was also rated as a function of type of construction. However, the risk was considered to increase significantly where the height exceeded the capability of the responding fire service. For non-fireproof buildings, the rating schedule considered heights above the seventh floor as beyond the reach of responding fire service and assumed that any contents above this level would perish in a fire. For fireproof buildings, the rating schedule considered heights at and above the 15th floor as hazardous and significantly increased the rate.

The rating system deterred substandard construction and associated risk through monetary penalties, which for many was a key motivating factor. Over 40 years of development and experience, the rating system evolved to address the specific risks associated with fire growth and spread, and more precisely link mitigating measures to those risks. These measures were translated into city-based regulations over the same time period, and would eventually become the basis of the requirements and limits in US and Canadian Model Codes.

5 US MODEL BUILDING CODES

The first US Model Code was developed between 1890 and 1905 [15-18] when it was published by the National Board of Fire Underwriters. The basis of the requirements in this Code was the set of mitigating measures developed as part of the insurance rating schedule, data from a survey of building regulations in foreign countries, fire loss experience and firefighting capability at that time. The resulting Model Code limits had the same base building height and area limits as the insurance rating schedule, but permitted a greater range of variations to those limits based on occupancy, type of construction, access and sprinklering. The base limits were 5,000 square feet for non-fireproof buildings, and 10,000 square feet for fireproof buildings, both at a maximum height of 55 feet. These limits were considered to be within the capability of most city fire departments. An example of the height and area limits for non-fireproof construction from the 1905 Model Code are as follows [18]:

Non-Fireproof Construction. Any occupancy, height limited to 55 feet. *Area, without* Automatic Sprinkler Protection.		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).	
Fronting on one street only	5,000 sq. ft.	One street front	7,500 sq. ft.
Fronting on two streets, that is, extending through from street to street	6,000 sq ft.	Two street fronts	9,000 sq. ft.
Corner building, fronting on two streets	6,000 sq. ft.	Corner building, two street fronts	9,000 sq. ft.
Fronting on three streets.	7,500 sq. ft.	Three street fronts	11,250 sq. ft.

A report prepared in 1913 by Ira H. Woolson [19], Consulting Engineer for the National Board of Fire Underwriters, summarized the results of a study of allowable heights and areas for factory buildings in the United States. The study was based on a survey of fire marshals and fire chiefs in the United States representing cities of over 20,000 population. The results were consistent with those of the insurance rating schedule, 1905 NBFU Model Code, New York City and Chicago City limits. The similarities were not surprising given the time since the development of the insurance rating schedule limits, the number of buildings constructed in conformance with those limits and the experience of the fire department fighting fires in those buildings. Woolson's results are shown below [19]:

TABLE 5 ALLOWABLE HEIGHTS AND AREAS IN FACTORY BUILDINGS

Type of Building	Stories in Height	Area between Fire Walls in Sq. Ft.
Brick and joist construction, not sprinklered.	3	6,000
Fireproof construction, not sprinklered.....	5	10,000
Brick and joist construction, sprinklered....	5	13,000
Fireproof construction, sprinklered.........	8	20,000

The National Board of Fire Underwriters published several editions of their Model Building Code between 1905 and the 1940's, and the base limits in all these editions remained relatively unchanged. The 1915 edition of the NBFU Model Code provided an important discussion linking firefighting capability to building size, noting that [20]:

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.

A handbook published at approximately the same time period [21] noted that 5,000 square feet, or a rectangle 50 by 100 feet "*is as large an undivided area as the experience of the New York Fire Department indicates to be within the capacities of effective fire department operations*".

6 CANADIAN HEIGHT AND AREA LIMITS

Mr. J. Grove Smith, Dominion Fire Commissioner of Canada, discussed height and area limits in his book "Fire Waste in Canada" [22]. Mr. Smith discussed the unit area approach, which was intended to confine a fire to a specific area and in doing so, limit the potential for conflagration. He suggested limiting areas out of concern that larger areas would result in greater fire intensity and spread and would require greater time for fire fighters to run hose lines, reduce visibility from smoke, making it difficult to reach the seat of a fire. Mr. Smith noted that once smoke or heat exposure reach untenable limits, responding fire fighters are required to take a defensive strategy and the fire becomes uncontrollable [22].

Mr. Smith suggested 5,000 square feet as the efficient operating area of a fire department with a limit of 100 feet in any direction, and a maximum area of 10,000 square feet for factories (typically of fireproof construction). These limits were consistent with those of the City of London at the time of 250,000 cubic feet (50 by 100 feet and 50 feet high).

Over this time period (1910's), a base area of 5,000 square feet was considered within the capability of a fire department with heights varying between 50 and 60 feet (5 to 6 storeys). Buildings of larger area and greater height were permitted, but with mitigating measures intended to limit fire size and/or facilitate fire department access.

Following the work conducted by Mr. Smith, uniform building regulations were first contemplated in Canada in the 1920's; however, this idea was abandoned because there was no Canadian organization in a position to write suitable specifications [23].

A model code, "Recommended Minimum Requirements for Fire Resistance in Buildings" [24] was developed by the National Bureau of Standards in the United States in the 1930's, and included height and area limits consistent with those published by the National Board of Fire Underwriters and National Fire Protection Association at that time. The height and area limits in the first National Building Code of Canada (1941 NBCC) were largely based on the limits in these documents.

The height and area limits were revised during the development of the 1953 NBCC based on the concept of risk associated with fire load and occupancy. The risk was addressed based on a methodology developed by B.L. Wood [25]. Wood differentiated height as a function of type of construction and linked height limits for combustible construction to firefighting capability. Wood noted that the height limit for noncombustible construction was not necessary where the structure was intended to withstand burnout. For combustible construction, Wood noted that 4 storeys was the limit associated with firefighting capability and above that height hose trajectory through a window was nearly vertical [25].

Wood's method considered the hazard of area as a combination of conflagration and life risks and developed a risk index to quantify the risk in a relative manner as a function of occupancy and type of construction. The conflagration risk was based on a quantification of occupancy (fuel load) and combustibility of structure balanced against measures to resist fire spread. The life risk was based on occupant load and ability to evacuate.

Wood's method was used as the basis to develop the initial table of height and area limits intended for the 1953 NBCC; however, the committee and industry were concerned with the resulting numbers. These limits were considered a significant departure from the limits in the 1941 NBCC. The result was a table of limits that were a combination of Wood's method with arbitrary alterations to address the concern of departure from the previous table of limits (1941 NBCC), and a commitment to review the limits during the 1960 NBCC code cycle. This was considered a temporary and reasonable compromise. Similar to the approach taken in the U.S. model codes, in the 1953 NBCC, height and area limits for seven different 'types of construction' were described.

Development of the 1960 NBCC considered several significant conceptual changes to the height and area limits including simplification of the arrangement of the limits to be more realistic, and consideration of short-term and long-term approaches to the limits [26]. The table of limits was changed into "spelled-out" versions [27], which allowed the deletion of unrealistic limits that previously existed for the purpose of filling in table squares. The spelled-out versions contained detailed construction specifications that eliminated the previous 7 types of construction in the 1953 NBCC, which were considered to be too rigid. The new construction specification format introduced the concept of 'combustible' and 'noncombustible' construction and definitions/standard tests to differentiate between the two types. In developing changes to the construction specifications, it was noted that fire resistive construction was intended to limit fire spread from floor to floor and where floors of buildings could be adequately separated, there was little reason to limit areas. At that time fire resistive construction was required to be noncombustible in addition to having a fire-resistance rating.

Two approaches to height and area limits were considered in the development of the 1960 NBCC in recognition of the fact that the 1953 Height and Area Limitations Table was a compromise [28]. A short term approach was developed to consider relatively minor revisions to the existing limits, and was considered to be achievable within the current code cycle [26]. A framework for a long term approach was developed and considered a major revision to the entire height and area limit format and values [26]. The long term approach was structured to directly address the hazards associated with building size, but was considered to require additional study that would carry beyond the current code cycle.

The long term approach to establishing limits was premised on identifying hazards known to exist. Four hazards related to building size were life, inaccessibility, excessive combustible materials, and danger of collapse for larger buildings. Several considerations were identified for each of the four hazards, and sample tables of limits provided to illustrate application of the approach. In developing the long term approach, a fundamental consideration was that the hazard of area is more gradual than height, which is considered to have more defined points of increased hazard. The points of increased 'building height' hazard primarily relate to firefighting capability and equipment.

Changes to the height and area limits during the 1965 NBCC code cycle were relatively limited as a result of an economic downturn and austerity measures implemented by the Government of Canada. It was determined that the 1965 NBCC would be [29] "an adjusted version of the 1960 Code and no major changes will be made". The changes were limited to minor adjustments to area limits for some occupancies and changes to the construction criteria for the "boxes" as a result of a change in the definition of the term "noncombustible". The two construction types introduced during the 1960 NBCC code cycle, were more definitively prescribed.

During the 1965 NBCC code cycle, Ferguson presented a workshop paper on the principles of fire protection at the 1964 Building Officials Conference [30]. Ferguson identified the complementary nature of fire protection and firefighting, and suggested that the structural integrity of a building be maintained for a period of time required for occupant escape and the protection of firefighters, but no specific times were noted. It was noted that greater structural stability is required for larger than for smaller buildings, particularly relative to height, and increased fire-resistance would provide the fire department with more time to operate. It was suggested that for buildings of a certain height, collapse is considered unacceptable and the risk of collapse be reduced to an "infinitesimal" quantity by providing a high degree of fire-resistance [30]. However, it was cautioned that risk be re-examined before taking further precautions beyond those initially developed to address the risk. This comment was specific to the consideration of sprinklering in addition to fire-resistance in addressing the risk of fire load in high buildings.

The development of the 1970 NBCC included provisions for covered malls, which required reconsideration of the definition of a building as a single unit. The provisions for a covered mall permitted the joining of two buildings by a protective cover/enclosure. In addition, areas were re-interpreted on a reduced storey basis as a function of building volume to reduce the potential for erroneous interpolations.

As part of the development of the 1975 NBCC, Ferguson committed to develop a guide to Part 3 and developed a hand-written draft version [31]. The draft included some basic concepts related to building size. Ferguson noted that the fire protection of buildings related to spaces:

- evacuating occupants from a space,
- confining fire to the evacuated space, and
- extinguishing fire in the space.

Ferguson further noted [31] that the building has historically been identified as the space upon which the control measures have been applied; however, the trend was moving away from the building as the control space to the compartment. He noted that a better fit between control and hazard is achieved as the space basis for regulation is reduced.

Two committees were formed in preparation of the 1975 NBCC to address structural requirements based on heights and areas and fire performance requirements for roof assemblies [32]. The committee dealing with roof assemblies developed several recommended changes, which were not adopted by the Standing Committee on Use and Occupancy. However, the Standing Committee did accept minor changes to roof assemblies to consider fire retardant treatment in lieu of a fire-resistance rating. No specific recommendations from the structural height and area committee were adopted.

In addition, it was recommended by the Standing Committee on Use and Occupancy and incorporated into the 1975 NBCC that all floor areas in high buildings exceeding 10,000 square feet be sprinklered recognizing the difficulty of fighting fires in large open floor areas in high buildings [33]. In addition, high buildings were required to be constructed of non-combustible construction.

Development of the 1977 and 1980 NBCC's included conversion from imperial to metric units, and minor revisions to the construction specifications associated with the height and area limits. In addition, unsprinklered basement and cellar fire compartments were limited to 5,000 square feet in area [34]. Areas larger than this were considered too large for effective firefighting and that the City of New York considered 6,000 square feet the largest area they could justify for effective firefighting [35]. A storage garage could be considered a separate building under certain conditions where separated from the remainder of the building by a substantial fire separation considered a "horizontal firewall" [36].

Development of the 1985 NBCC considered changes to the covered mall requirements [37] moving away from the concept of connecting two buildings to being a large public corridor in one single building. In addition, the determination of building height for residential buildings was considered relative to sloping sites [38].

A list of action items was developed during the initial stages of the 1990 NBCC cycle. These action items included review of structural requirements and terms and combinations of combustible construction in Subsection 3.2.2. The topic of combinations of combustible construction was considered a high priority item that could not be addressed within the time period of the development of the 1990 NBCC. It was noted that the 1995 NBCC code cycle was a more likely target.

A significant code change in preparation of the 1990 NBCC proposed Group C buildings of combustible construction be permitted to be 4 storeys in building height [39]. The proposal was based on provision of 1-hour floor and roof assembly fire separations, 1-hour suite to suite and suite to corridor fire-separations. The National Research Council of Canada at the time noted the following relative to this change [40]:

> *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.*

It was further noted by the Standing Committee on Fire Protection that [40]:

> *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.*

In addition to the increase in height, an increase in area was also permitted for 3 storey and lower where enhanced fire-resistance is provided. The proposal to permit 4 storeys in building height and increased area for 3 storey and lower buildings of combustible construction was permitted, but only where the building is sprinklered.

Development of the 1995 NBCC involved consideration of mandatory sprinklering requirements and increase in building height to 4 storeys for Group D and E occupancies in buildings of combustible construction [41]. In addition, as part of the mandatory sprinklering analysis, it was noted that sprinklered buildings that face three streets are given extra credit in permitting area, but the fire fighting access requirements are waived for sprinklered buildings. It was recommended that Subsection 3.2.2. be changed to permit the same total building area for facing three streets where the building is fully sprinklered, and the principal entrance is within 15 m of a street, but not require the three streets [42].

Development of the 2005 NBCC involved a substantial revision to the format of the Code to incorporate an objective based framework. As part of the development of this framework, several intent statements related to the construction requirements of the Code were developed and intended to provide additional information that could be used to better understanding the application of the height and area limits. These intent statements related to life safety within a storey, limiting fire spread from storey-to-storey, reducing the probability of collapse, reducing the probability of damage to property, and prevent conflagration [43].

Changes to the 2010 NBCC were limited to the addition of a new occupancy type, Group B, Division 3, Care Occupancies, and associated height and area limits, which ranged from 1 to unlimited storeys and 600 m^2 to unlimited area.

7 RISK BASIS

The compilation outlined in the previous sections of this paper provide a chronological summary of the development of the fire related building size limits in the North American building codes. This information is used to establish the risk basis upon which the limits were based, and is outlined in the following sections of this paper.

7.1 EARLY TIMES

Following great fires of Rome and London, building regulations were developed primarily to address the risk of conflagration and limit this risk by requiring noncombustible exterior construction, spatially separating structures, or physically separating structures with party walls constructed of stone or brick. The risk basis for this era is summarized in **Table 1**.

Table 1: *Risk Basis - Early Times*

Consideration	Overview
Implicit Risk:	• Fire spread from building to building resulting in conflagration
Mitigation:	• Stone or brick walls between houses and stone or brick exterior walls
Intended Result:	• Limit fire spread to individual buildings (primarily houses)

7.2 CUBIC CAPACITY CONCEPT

In the late 1700's with the proliferation of large warehouses, the risk was heightened as a result of the potential for a single building fire to grow beyond the capability of the responding fire brigade. This required an understanding of the capability of the fire brigade in order to limit building size, and consideration of building access, height and area related to this capability.

Based on judgment of the first 2 Chief Fire Brigade Officers of London, "sixty feet is the greatest height at which a building can be quickly protected", and the cube of 60 or 216,000 cubic feet is the greatest cubical capacity that can be quickly protected.

The risk basis for this era is summarized in **Table 2**.

Table 2: *Risk Basis – Cubic Capacity Concept*

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

7.3 INSURANCE RATING SYSTEM AND MODEL BUILDING CODES

An insurance rating system was developed following the Great Fires of Chicago and Boston to promote certain desirable city/building characteristics and reduce the risk of fire and conflagration to an acceptable level. The rating schedule defined characteristics of a standard city and standard building by which all cities and buildings were measured for insurance purposes. Substandard characteristics were discouraged through increased rates and additional protection was rewarded with rate reductions.

The rate schedule defined height and area limits, differing from the City of London's cubic capacity approach. The height limit was 60 ft, consistent with that of London, and the area limit was 5,000 square feet. The area limit was consistent with the size of two standard lots in the City of New York at the time, and combined with the height limit resulted in a cubic capacity of 300,000 cubic feet. This was consistent on a volume basis with what was being proposed as a change to the Metropolitan Act of London at the time as a compromise to erroneous interpretations of a party-wall, resulting in cubic capacities that were more than double or triple the 216,000 limit.

The rate schedule considered building size variations as a function of risks associated with occupancy and type of construction, balanced against measures intended to limit fire growth and spread.

In the early 1900's US Model Codes were developed, consistent with the insurance rating schedule. The Model Codes had the same base building heights and areas as the insurance rating schedule, but permitted a greater range of heights and areas with a broader combination of mitigating measures. These were confirmed by an analysis by Woolson in 1913 based on a survey of fire chiefs in the US relative to their capabilities and height and area limits.

A study of fire waste in Canada in 1918 suggested 5,000 square feet as the efficient operating area of a fire department with a limit of 100 feet in any direction, and a maximum area of 10,000 square feet for factories (typically of fireproof construction). These limits were consistent with those of the City of London at the time of 250,000 cubic feet (50 by 100 feet and 50 feet high).

Over this time period, a base area of 5,000 square feet was considered within the capability of a fire department for buildings of combustible construction with heights varying between 50 and 60 feet (5 to 6 storeys) and 10,000 square feet for buildings of noncombustible construction to greater heights. Buildings of larger area and greater height were permitted, but with mitigating measures intended to limit fire size and/or facilitate fire department access.

The risk basis for this era is summarized in **Table 3**.

__Table 3:__ Risk Basis – Insurance Rating System

Consideration	Overview
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 for buildings of non-fireproof construction • Height of 100 to 125 ft and base area of 10,000 square feet for buildings of fireproof construction • Increases in height and area based on type of construction, occupancy, streets facing and sprinklering
Intended Result:	• Limit fire spread to individual buildings

7.4 CANADIAN HEIGHT AND AREA LIMITS

The first Canadian model building code was published in 1941 and the building size limits were substantially based on a report published by the National Bureau of Standards (the predecessor to the National Institute of Standards and Technology).

The height and area limits were changed during the development of the 1953 and 1960 NBCC's based on the concept of risk associated with fire load. This risk was addressed with a corresponding fire-rated compartment intended to contain a burn-out. Certain fire loads were attributed to occupancy types and combustible construction was considered part of the fire load. However, this concept was difficult for the Committee to accept and it was suggested that areas be based primarily on firefighting capability.

It was suggested by the Committee that it would be impossible to prevent multi-storey buildings of wood joist construction from becoming involved in fire, and that where the fire load exceeded the fire-rating, 50 feet be the height limit. The result in the 1953 NBCC was a set of height and area limits established on the risk that some buildings may become completely involved and should be limited in height and area to a size within the capability of the responding fire department. Other buildings were considered sufficiently resistant to contain the complete burn-out of a storey, and permitted greater heights and areas accordingly.

Similar to previous Codes, the 1953 NBCC retained the area increases for number of streets facing and provision of sprinklers. In addition, increased areas and heights were permitted where the construction was considered more resilient (i.e., noncombustible and fire-resistant).

Preparation of the 1960 NBC considered further development of requirements associated with building size, including discussion relative to the firefighting assumptions and structural resilience. It was noted that combustibility and fire-resistance are important in buildings of such height and area to be beyond the capability of responding fire departments. It was suggested that buildings that cannot contain a burn-out pose a conflagration risk, endangering the lives of fire fighters and people within and adjacent to the building. Buildings greater than 6 storeys in height were considered difficult to fight and "virtually on their own". However, similar defining points did not exist for areas, which were considered more a degree of increasing hazard.

Building size limits further developed from the 1970's to today, however the risk basis remained relatively consistent with the concepts developed in the 1950's and 1960's.

The risk basis for this era is summarized in **Table 4**.

__Table 4:__ Risk Basis – Canadian Height and Area Limits

Consideration	Overview
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 4-6 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 single fire compartments
Intended Result:	• Combustible buildings: limit fire spread to the building of origin • Noncombustible buildings (no rating): limit fire spread to building of origin • Noncombustible buildings: limit fire spread to the storey of origin. • Reduce the probability of building collapse

8 CONCLUSIONS

The risk associated with building size has historically been the spread of fire to involve more than one building (conflagration). This risk has evolved to include full building involvement and collapse for high buildings, but has remained fairly constant for lower buildings of combustible construction where the assumption has been that smaller buildings may become fully involved.

The risk of building size has been addressed through a balance of passive fire protective features and active firefighting measures as a function of occupancy type, with the objective of limiting fire size such that it is within the capability of a responding fire department. This has been effected through limitation on building height and area and variations to those limits with additional beneficial features such as construction resilience, sprinklering and improved access.

The base height and area limits have remained relatively constant over the previous nearly 160 years, with some variation in concept recognizing containment of fire to a single storey under certain conditions and greater area in sprinklered buildings, but only required to face one street.

The basic height limit consistently specified over this period of time was 5 to 6 storeys or 50 to 60 ft (15 to 18 m) and primarily related to the reach of firefighting equipment from the building exterior. Beyond this height it was assumed that fire fighters would be required to fight the fire from the building interior, and require an additional degree of safety to do so. Similarly, the basis area limit consistently specified over this period of time was 5,000 ft^2 for buildings of combustible construction and 10,000 ft^2 for buildings of noncombustible construction and primarily related to experiential firefighting ability to control fire of a certain size.

Over the period of time upon which the building size limits have been established:

- firefighting techniques, equipment, response and overall capability has advanced significantly;
- construction methods and materials have advanced; and,
- analysis techniques have evolved significantly.

However, the building size limits have not been re-examined in light of these advances.

From the beginning, the building size limits have been founded on the assumption of the building as the unit of control. As noted by Ferguson, and discussed in this paper [31]:

> *The trend is toward the choice of smaller spaces for regulation purposes [and] as the space basis for regulation is reduced, a better fit between control and hazard is achieved.*

Ferguson further notes that this trend is in keeping with the purpose of the Code, and not that buildings be smaller, but that the concept of building as the control unit be abandoned and that the unit of control be smaller spaces within the building.

REFERENCES

[1] R. S. Ferguson, Building Regulations: Problems of Tradition and Knowledge. 1974: Ottawa.

[2] R.S. Ferguson, Letter to Mr. John Little, J. Little, Editor. 1961, National Research Council Canada: Canadian Codes Centre Archives.

[3] Cornelius Tacitus, Alfred John Church, and William Jackson Brodribb, Annals of Tacitus. Translated into English, with notes and maps. 1st ed. 1891, London, New York,: Macmillan and Co. xxvi p., 1 l.

[4] Corporation of London., John Carpenter, and Henry T. Riley, *Liber albus: the white book of the City of London*. 1861, London,: R. Griffin. x p., 1 l., 8.

[5] Hubert Robert, The Fire of Rome, 18 July 64 AD.

[6] Great Britain and D. Pickering, The Statutes at Large from the Magna Charta, to the End of the Eleventh Parliament of Great Britain, Anno 1761 [continued to 1806]. By Danby Pickering. 1763: J. Bentham.

[7] W. Woodall, Strahan, A., The Statutes at Large: From the Seventh Year of the Reign of King George the Third, to the Eighteenth Year of the Reign of King George the Third ... ; 8th. Vol. Vol. 8. 1786: Charles Eyre ... [et. al.].

[8] Unknown Painter, The Great Fire of London: 1666.

[9] Great Britain, The Metropolitan Buildings Act. 7th & 8th. Vict. Cap. 84. With Notes. 1844: Weale.

[10] E.M. Shaw, Fire surveys: or, A summary of the principles to be observed in estimating the risk of buildings. 1872: E. Wilson.

[11] Great Britain. Parliament and T.C. Hansard, Hansard's Parliamentary Debates. 1874: Hansard.

[12] Fire Underwriters Association of the Northwest, The Baltimore Underwriter: A Monthly Publication Devoted to the Interests of Insurance. Vol. XIV. 1875, Baltimore, MD: Sherwood & Company.

[13] New York Board of Fire Underwriters, Standard Rates. 1873, New York Board of Fire Underwriters: New York. p. 2.

[14] The Insurance Times. 1880. XIII(v. 11).

[15] The American Exchange and Review. 1891: Whiting & Company.

[16] United States. Bureau of Foreign Commerce, Fire and Building Regulations in Foreign Countries. 1892: U.S. Government Printing Office.

[17] National Board of Fire Underwriters, Proposed Building Law for Medium Sized Cities: As Drafted by a Commission Appointed Pursuant to Chapter 579, Laws of 1892 of New York State ... Issued June, 1893, by the Committee on Construction of Buildings of the National Board of Fire Underwriters. 1893: The Committee.

[18] American Insurance Association and National Board of Fire Underwriters, National Building Code. 1905: American Insurance Association, Engineering and Safety Service.
[19] Ira H. Woolson, Allowable Heights and Areas for Factory Buildings. Journal of the American Society of Mechanical Engineers. 1913: American Society of Mechanical Engineers.
[20] National Board of Fire Underwriters, Building code recommended by the National Board of Fire Underwriters, New York: An ordinance providing for fire limits, and regulations governing the construction, alteration, equipment, repair or removal of buildings or structures. 1915: J. Kempster printing company.
[21] J.K. Freitag, Fire prevention and fire protection as applied to building construction: a handbook of theory and practice. 1912: J. Wiley & sons.
[22] Smith Canada. Commission of Conservation, J.G., Fire waste in Canada. 1918: s.n.
[23] R.S. Ferguson, Short History of the National Building Code. 1948, National Research Council, Associate Committee on the National Building Code: Ottawa, Canada.
[24] United States. Dept. of Commerce. Building Code Committee, Recommended Minimum Requirements for Fire Resistance in Buildings. 1931: U.S. Government Printing Office.
[25] B.L.R. Wood, Fire Protection Through Modern Building Codes. 1945: American Iron and Steel Institute.
[26] Associate Committee on the National Building Code, Minutes of the Fifth Meeting of the Advisory Fire Group. 1959, National Research Council of Canada: Ottawa, ON.
[27] Associate Committee on the National Building Code, Minutes of the Second Meeting of the Revision Committee on Use and Occupancy. 1960, National Research Council of Canada: Ottawa, ON.
[28] Associate Committee on the National Building Code, Minutes of a Special Meeting Held to Discuss Proposed Table of Height and Area Limitations of Buildings Other Than 1 and 2 Family Dwellings. 1954, National Research Council of Canada: Ottawa, ON.
[29] The Associate Committee on the National Building Code of Canada, Minutes of the Thirty-Sixth Meeting of the Associate Committee on the National Building Code. 1963, National Research Council of Canada: Ottawa, ON.
[30] R. S. Ferguson, Workshop Session No. 1, Part 3 – Use and Occupancy, National Building Code, Principles of Fire Protection, in 1964 Building Officials' Conference of Canada, D.o.B.R. Building Standards Section, Editor. 1964, National Research Council of Canada: Halifax, NS.
[31] The Associate Committee on the National Building Code of Canada, Minutes of the Ninth Meeting of the Standing Committee on Use and Occupancy. 1971, National research Council of Canada: Ottawa, ON.
[32] The Associate Committee on the National Building Code of Canada, Minutes of the Tenth Meeting of the Standing Committee on Use and Occupancy. 1971, National Research Council of Canada: Ottawa, ON.
[33] The Associate Committee on the National Building Code of Canada, Minutes of the Fourteenth Meeting of the Standing Committee on Use and Occupancy. 1974, National Research Council of Canada: Ottawa, ON.
[34] The Associate Committee on the National Building Code of Canada, Minutes of the Fourth Meeting of the Coordinating Committee of the Standing Committee on Use and Occupancy in Preparation for the 1977 Code. 1975, National Research Council of Canada: Ottawa, ON.
[35] The Associate Committee on the National Building Code of Canada, Minutes of the Eighteenth Meeting of the Standing Committee on Use and Occupancy 1977, National Research Council of Canada: Ottawa, ON.
[36] Associate Committee on the National Building Code of Canada, Minutes of the Fifth Meeting of the Revision Subcommittee of the Standing Committee on Use and Occupancy. 1977, National Research Council: Ottawa, ON.
[37] Associate Committee on the National Building Code of Canada, Minutes of the First Meeting of the Task Group on Covered Malls and Public Concourses. 1980, National Research Council of Canada: Ottawa, ON.
[38] Associate Committee on the National Building Code of Canada, Minutes of the Twenty-Ninth Meeting of the Standing Committee on Housing and Small Buildings. 1984, National Research Council of Canada: Ottawa, ON.
[39] Associate Committee on the National Building Code of Canada, Minutes of the Tenth Meeting of the Standing Committee on Fire Protection. 1988, National Research Council of Canada: Ottawa, ON.
[40] Associate Committee on the National Building Code of Canada, Minutes of the Eleventh Meeting of the Standing Committee on Fire Protection. 1989, National Research Council of Canada: Ottawa, ON.
[41] Associate Committee on the National Building Code of Canada, Minutes of the Sixteenth Meeting of the Standing Committee on Fire Protection. 1991, National Research Council of Canada: Ottawa, ON.
[42] Canadian Commission on Building and Fire Codes, Minutes of the Nineteenth Meeting of the Standing Committee on Fire Protection. 1993, National Research Council of Canada: Ottawa, ON.
[43] Canadian Commission on Building and Fire Codes, Minutes of the Fourth Meeting of the Standing Committee on Fire Safety and Occupancy. 1998, National Research Council of Canada: Halifax, NS.