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STUDY OF 6 STOREY WOOD FRAME BUILDINGS OF GROUP D (BUSINESS AND PERSONAL SERVICE) OCCUPANCY

Prepared for

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February 1, 2012

GHL File BSP-3517.04

EXECUTIVE SUMMARY

This report examines the prospect of allowing 6 storey wood frame buildings of Group D occupancy (business and personal service occupancies) in British Columbia. The purpose of this report is two-fold. First, to present the designed and contingent risks related to 6 storey wood frame office buildings; second, to provide Code change recommendations to enable an acceptable solution to be incorporated in the Building Code for these buildings, addressing the designed risks identified.

The objective-based Building Code that came into effect in 2006 provides compliance via 'acceptable solutions' in Division B or by 'alternative solutions'. Without specific performance targets, the acceptable solutions constitute the acceptable minimum level of performance required by the Building Code. Fundamentally, the Building Code requires compliance with the objectives and functional statements of the Code, with the acceptable solutions deemed as automatically meeting the objectives and functional statements.

In this study, 6 storey wood frame office occupancies are analyzed. The exercise involves analyzing the risks in areas identified by the objectives and functional statements for construction requirements in Subsection 3.2.2 of Division B. Because the objective-based Code does not provide performance targets, GHL's analysis is based on a qualitative risk analysis. Two comparison buildings built in conformance with Article 3.2.2.50 for buildings of noncombustible construction, up to 6 storeys, unsprinklered and Article 3.2.2.52 for buildings of combustible construction, up to 4 storeys, sprinklered are used to establish the acceptable minimum level of performance for the purpose of evaluating proposed 6 storey wood frame buildings of Group D occupancy.

Based on GHL's analysis, review of literature and interview with certain stakeholders it is concluded that risks related to fire safety objectives and functional statements will not likely increase in 6 storey wood buildings of Group D occupancy, provided that the building area is restricted and certain measures are taken to address issues specific to wood frame and heavy timber construction.

Further, as 6 storey wood frame buildings will be fully sprinklered, many risks are significantly reduced in comparison to the currently permitted unsprinklered 1h fire rated 6 storey Group D buildings. Based on the outcome of the study, Code changes to permit 6 storey wood buildings of Group D occupancy are proposed and areas of future work are identified.

DISCLAIMER

This technical report has been prepared by **GHL** CONSULTANTS LTD (GHL) for Forestry Innovation Investment Ltd (FII). The purpose of this report is to study the prospect of changing the Code to permit 6 storey wood buildings of Group D (office) occupancy. GHL's study is based on our fire engineering expertise, understanding of fire science and fire engineering practice, as well as a review of the Building Code and literature during the limited timeframe in the month of March, 2011 and has been revised in October, 2011 to address wood frame only. Work of this nature would normally require substantial research for a significantly greater duration. GHL's work shall not be construed as exhaustive. There may be other relevant considerations for the Code change proposal not identified by GHL. At the time of report writing, GHL has recommended that FII retain qualified professionals to perform a peer review of GHL's work as well as making the work part of a public consultation process prior to any formal adaptation of the Building Code to permit 6 storey wood buildings of Group D occupancy.

The Building Code represents the generally accepted level of risk in buildings. This study is based on a comparison of risk between different construction types that are currently permitted by the Building Code. Therefore, GHL does not purport that there is no risk; rather, our study is aimed at demonstrating that a proposed 6 storey wood building of Group D occupancy can be built to be 'as good as' construction types that are currently permitted.

It is the government's sole discretion to adopt, consider or accept, in part or in full, the work of GHL contained in this report. GHL shall not be responsible for any loss of any kind that may arise due to any construction, building, or structure as a result of GHL's work or any Building Code or construction regulation change. Should this report be made available to other organizations that have regulatory capacity in construction of buildings and structures, this disclaimer shall equally apply. By preparing this report, GHL does not express explicitly or implicitly any social, economic or political opinion, or any other non-technical opinion, as it relates to the Code change proposal. This report is intended to be purely technical in nature. Any inquiries on this report shall be directed to FII:

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1.0 BASIS OF REPORT

1.1 PURPOSE

GHL has been requested by FII to conduct an engineering study aimed at extending the maximum allowable building height for wood frame buildings of Group D occupancy from 4 storeys to 6 storeys. This report has been prepared to document GHL's analysis. The scope of the study is to identify and comment on the designed and contingent risks relating to a potential Code change to allow 6 storey wood frame buildings of Group D occupancy in BC. The study focuses on fire safety requirements of the Building Code only.

1.2 OBJECTIVE

The objective of this study is to provide the following:

- A summary of the fire safety provisions that currently exist in the Building Code for buildings of Group D occupancy.
- Identification and analysis of designed and contingent risks associated with the Code change to permit 6 storey wood frame buildings of Group D occupancy, focusing on fire safety issues.
- Preliminary comments on approach to addressing designed and contingent risks.

The report was finalized on March 31, 2011 to include the proposed Code changes that are aimed at addressing the designed and contingent risks identified. Subsequent revisions were made in October, 2011 to focus the report on wood frame buildings, rather than all combustible construction systems. A separate report will be prepared shortly on heavy or mass timber systems.

1.3 GHL'S PREVIOUS STUDY ON GROUP C OCCUPANCY

GHL was engaged by the Building Safety and Policy Branch (BSPB) of the Ministry of Housing and Social Development to perform a similar study on 6 storey wood buildings of Group C occupancy (the Group C study) in 2008. The Group C study is summarized in 3 reports that are available at the Ministry of Housing website [1]. Readers of this report are encouraged to read the reports on the Group C study to gain an understanding of the work relating to mid-rise wood buildings. This Group C study addressed the technical and process risks, which for clarity have been re-named designed and contingent risk respectively.

1.4 THE ONTARIO STUDY

The Province of Ontario recently initiated a study aimed at permitting 6 storey wood buildings of Group C, Group D and Group E occupancies. As part of this study, GHL reviewed the publically available Ontario Code change proposals [2]. As of December, 2011, we have not received permission to review the consultants' report to the Ontario government on the Code change proposals.

1.5 NRC/CWC CONSULTATION GROUP

The National Research Council of Canada, in conjunction with the Canadian Wood Council, has established a consultation group to assess the feasibility of extending the National Building Code to permit 6 storey wood frame buildings, along with other types of heavy timber construction. To this end, NRC staff have performed a ‘scoping study’ to identify issues that may arise in 6 storey wood frame construction. Although the NRC study is in the early stages, the first meetings on March 8, 2011 and December 16, 2011 provided GHL an opportunity to consult with NRC staff, FPInnovations staff and Canadian Wood Council staff along with stakeholders from other interested parties. The issues identified in the scoping study and initial meetings have been considered in this study.

1.6 DEFINITIONS OF RISK

The original Group C study addressed two types of risk, referred to in that study as technical and process risk, as defined by the currently named Building Safety Standards Branch for the purpose of the Group C study. Since the initial work, a more generalized understanding on these terms has been realized. For the purpose of this study, the terms ‘Designed Risk’ and ‘Contingent Risk’ are broadly defined as follows:

Designed Risk - Designed risk means the residual risk associated with a building that is built in full compliance with Division B without significant defect. In this study, designed risk is used to evaluate whether 6 storey wood buildings of Group D occupancy would have the same fire risk (or afford the same level of fire safety) as 6 storey noncombustible Group D buildings currently permitted by the Building Code, assuming buildings can be built in full compliance with the Building Code. In the Group C study, this was referred to as the technical risk.

Contingent Risk - Contingent risk means the residual risk arising from the process of designing and constructing a building to comply with the Code. In this study, contingent risk is used to identify real-world concerns about designing and constructing wood buildings that may hinder them from performing as intended by the Building Code, and methods of addressing these concerns. In the Group C study, this was referred to as the process risk.

In addition, it has been noted that there is a significant difference between residential occupancies and office occupancies as a consequence of their use. This is discussed under ‘Occupancy Factors’ in Section 5 of this report.

For the purpose of this report, ‘risk’ refers to fire-related risk unless otherwise indicated.

1.7 SCOPE OF STUDY AND METHODOLOGY

The analysis of designed risk in this study is based on the fire safety objectives contained in the BC Building Code 2006. The risk analysis is qualitative in nature, whereby the risk associated with a 5 or 6 storey wood building is compared to that of a 4 storey sprinklered frame wood building permitted in Article 3.2.2.52 and a 6 storey unsprinklered light steel-frame building permitted in Article 3.2.2.50. No quantitative risk analysis was performed given that the National Building Code of Canada and the adopted BC Building Code are not performance-based Codes (i.e., they do not have explicit performance targets).

The contingent risks are identified based in part on GHL’s professional experience. As most contingent risks are not a function of occupancy type, the risks identified in GHL’s Group C study equally apply here. This report identifies the additional contingent risks that were encountered from GHL’s experience in the past two years working on 6 storey wood frame projects of Group C occupancy, as well as addressing the occupancy related risks.

During the writing, GHL also conducted consultation with key stakeholders for the purpose of establishing the designed and contingent risks that are identified in this report. Organizations that we have consulted include:

- Resort Municipality of Whistler, Building Department and Fire Rescue Service
- FPInnovations
- National Research Council of Canada – Institute for Research in Construction
- Arencon Inc (Code consultant on the Ontario Code change to permit 6 storey wood buildings of Group D occupancy)
- Canadian Wood Council
- Wood Enterprise Coalition

Should the BC Government decide to proceed with amending the Code to permit 6 storey wood buildings of Group D occupancy, further public consultation is recommended.

Acknowledgment is due to John Ivison, P Eng of the Wood Enterprise Coalition for his review and comment on the draft report.

1.8 ASSUMPTIONS

This report is based on the following assumptions:

- **Combustible Construction**
  The study assumes wood frame construction conventionally used in BC. That is, construction that is primarily based on nominal 2in sawn lumber, plywood and similar dimensioned manufactured lumber products. It is noted that Division B Part 3 of the Code classifies building construction based on “combustible” and “noncombustible” construction; it is not the intent of the Code to prohibit other types of combustible construction, although currently other types of combustible construction may not be possible due to restrictions in other parts of the Code, such as in Part 4 (structural design). GHL has only been retained to study Division B Part 3 requirements with respect to conventional wood frame construction in this study.

- **The Building Code**
  The terms “Building Code” and “Code” in this report generally refer to the British Columbia Building Code 2006 (BCBC) unless otherwise indicated. Code references made in this report generally refer to the acceptable solutions found in Division B of the Code unless otherwise indicated. The BCBC 2006 is based on the National Building Code of Canada 2005 (NBCC) with no substantial changes related to this study.

- **Alternative Solutions**
  This report relates to acceptable solutions of Division B of the Code. This report is not intended to preclude alternative solutions to address elements outside the scope of this report, or different solutions to that provided in Division B.

- **New Research**
  The recommendation provided in this report is not intended to preclude alternative solutions or professional engineering practice based on research which is not available at the time of this writing.

- **High Buildings**
  It is assumed that 6 storey wood frame buildings being studied will not be high buildings as defined in the Building Code. High buildings imply significantly more complex firefighting techniques, including staging of firefighting operations within the building, which are

outside the scope of this study. High buildings are defined in Division B, Clause 3.2.6.1.(1)(d) for Group D occupancy buildings as buildings with the uppermost floor level between 18m and 36m above grade based on exit capacity relative to total occupant load.

2.0 BACKGROUND REVIEW

2.1 CURRENT REQUIREMENTS FOR BUILDINGS OF GROUP D OCCUPANCY

The 2006 BCBC currently allows buildings of Group D occupancy to be of combustible and noncombustible construction [3]. Generally, as the building area and building height increase, the construction requirements become more stringent to reflect the elevated risks to life safety and of property loss; noncombustible construction and sprinkler protection are two key provisions to address the higher risks.

Although it is not defined in the Code, in general, buildings of Group D occupancy can be summarized into 3 generic categories: low-rise, mid-rise and high-rise as summarized in Table 1. It is noted that the definition of 'high rise' building in the Code is based on a set of criteria in Article 3.2.6.1, which is not related to construction requirements in Subsection 3.2.2; however, buildings over 6 storeys are required to use noncombustible construction with 2h fire-resistance rating and they also generally fall into the high-rise classification.

Table 1. Summary of general construction requirements for buildings of Group D occupancy [3].

Category	Max. Building Height	Construction Type	Floor and Support Fire Resistance Rating	Sprinkler Protection
Low-Rise	3 Storeys	Combustible	3/4h	Yes and No
Low-Rise	4 Storeys	Combustible	1h	Yes
Mid-Rise	6 Storeys	Noncombustible	1h	Yes and No
High-Rise	Unlimited	Noncombustible	2h	Yes

In the mid-rise category, the Code currently permits combustible construction for buildings of Group D occupancy up to 4 storeys, sprinklered per Article 3.2.2.52. The Code also provides two options for using noncombustible construction; under Article 3.2.2.50, a building of Group D occupancy can be built up to 6 storeys without sprinkler protection; under Article 3.2.2.51, the same building can be built with greater allowable building area with mandatory sprinkler protection. Table 2 is a summary of the construction requirements for the mid-rise category.

Although an examination of the history of the Code development for construction requirements is outside the scope of this study, it can be generally stated that building area, building height, building construction type and sprinkler protection are the four interrelated factors used in determining the risks of building construction, which form basis of the construction requirements seen in the Code. These four factors determine the likelihood of fire spread, the impact on life safety during a building fire, the efficiency and effectiveness of firefighting operations, and the ultimate limitation of property loss due to the fire.

Table 2. Summary of current Building Code provisions for mid-rise buildings of Group D occupancy. Note the maximum allowable building area for Article 3.2.2.50 is based on facing 3 streets. [3]

	Article 3.2.2.50	Article 3.2.2.51	Article 3.2.2.52/54	Article 3.2.2.53
Construction	Noncombustible	Noncombustible	Combustible	Combustible
Sprinkler protection	No	Yes	Yes	No
Fire rating of floor and structural supports	1h	1h	3/4 or 1h	3/4h
Max. building height	6 Storeys	6 Storeys	4 Storeys	3 Storeys
Max. allowable building area (facing one street)				
1 Storey	Unlimited	Unlimited	$14400m^2$ (3/4h)	4800
2 Storey	Unlimited	Unlimited	$7200m^2$ (3/4h)	2400
3 Storey	$7200m^2$	$14400m^2$	$4800m^2$ (3/4h)	1600
4 Storey	$5400m^2$	$10800m^2$	$3600m^2$ (1h)	Not Permitted
5 Storey	$4320m^2$	$8640m^2$	Not Permitted	Not Permitted
6 Storey	$3600m^2$	$7200m^2$	Not Permitted	Not Permitted

* Note: It is necessary to combine the requirements of Article 3.2.2.52 and 3.2.2.54 in order to obtain the permitted building areas, as Article 3.2.2.54, although limited to 3 storeys, permits larger areas than Article 3.2.2.52 which only addresses 4 storey construction.

2.2 COMBUSTIBLE VS. NONCOMBUSTIBLE CONSTRUCTION

The Code in Division B, Part 3 categorically permits 'combustible' and 'noncombustible' construction of buildings; however, the basic building materials used in practice are wood for combustible construction, and steel and concrete for noncombustible construction. These materials are used in buildings because they have been well studied, used historically in buildings, and have well developed design guidelines and standards. Therefore, while other types of materials may be possible under Part 3, they are / may not be used due to other design restrictions outside of Part 3 (e.g., lack of structural design standard). Accordingly, this study focuses the discussion on wood, steel and concrete materials.

In BC, there are generally two types of combustible construction used in practice: platform framing, using dimensional lumber (nominal 2x members) and similar engineered wood members, and heavy timber construction. In mid-rise buildings, wood frame construction is generally covered by gypsum board to conceal insulation and services within the framed structures, as well as to meet fire safety requirements such as flame spread rating, integrity of fire separation and fire resistance rating. Alternatively, 'heavy timbers' are generally left exposed as their large mass provides an inherent degree of fire resistance. This report deals with wood frame construction only.

With respect to noncombustible construction, steel and concrete are used; their choice in building construction is generally related to building height, cost and architectural effects. Steel is a noncombustible material that has an inherent degree of fire resistance due to its properties; however, it begins to lose strength and stiffness at elevated temperatures. Therefore, in mid-rise buildings, like wood frame construction, steel buildings are protected by gypsum board, spray applied fire-resistive material or protective coating, depending on the type of steel construction [4]. Concrete (steel reinforced concrete) is another type of noncombustible construction where both concrete and steel are utilized to take advantage of their respective compression and tension properties. Reinforced concrete construction generally does not require additional fire protection because concrete provides significant inherent fire resistance [4].

As stated previously, the Code does not distinguish types of construction materials available in the industry; it categorically permits “combustible” and “noncombustible” construction in Part 3 of Division B. While steel, light steel framing and reinforced concrete construction all satisfy the requirement for noncombustible construction, generally, light steel framing construction is used for the purpose of the risk analysis as it establishes the minimum level of performance acceptable by the Code. Further discussion on this is provided in Section 3 of this report.

While the aforementioned construction materials each have their own benefits and drawbacks, the Code currently restricts the size of buildings using combustible material for fire safety reasons [5] as found in Part 3 of the Building Code. These restrictions have been in the Building Code since its earliest edition based on the conception that combustible construction poses a greater fire risk due to its combustible nature when exposed to heat or fire. While at the material level, wood does pose a greater risk of ignition than steel and concrete, when utilized in building construction, wood frame construction has been shown to afford a publically acceptable level of fire safety for many applications.

Modern knowledge of fire science and engineering practice are allowing wood buildings to perform much better in fire than traditional wood frame buildings, and in some cases better than noncombustible buildings. However, the state-of-the-art fire protection for wood construction has yet to be fully integrated into the Building Code. While some of the advancements have been captured in past Code changes, many of them have not / may not have been fully recognized in the Code. Features that have evolved over the last 40 years that have led to a substantially improved level of fire safety include:

- improved gypsum board
- introduction of fire blocking
- improved firestopping of service penetrations
- sprinkler protection – and more recently, fast response technology
- supervised sprinkler systems
- addressable fire alarm systems
- better developed fire protection engineering expertise
- improved elevators

With respect to sprinklers, it is noted that the use of sprinklers in other than industrial buildings was rare when the allowance for doubling building area was introduced into North American building codes in the 1920’s; such systems were not typically monitored and supervised. It appears that this was the opinion of a Code Committee without extensive technical risk analysis.

While there has been wide acceptance of this factor of 2, there has been no re-examination as to whether this factor is too conservative, although there has been some increase of a single storey in building height and reduction in the level of fire department access.

The restrictions for use of wood in building construction remains, in our opinion, overly conservative and does not necessarily reflect the state-of-the-art fire engineering practice.

It should be noted that this study is not aimed at re-evaluating the accepted level of risks that are fundamental to the Building Code, although it should be an area of research. The study is aimed at demonstrating that with modern fire engineering technology, it is possible for an assessment and decision to be made regarding greater allowance of wood in buildings to the extent following the level of performance established in the acceptable solutions (Division B) from a fire safety perspective.

It is noted that this study does not examine the costs and benefits of the different construction materials / methodologies that are available. This study is prepared in the context of Part 3 fire safety requirements only.

2.3 COMBUSTIBLE CONSTRUCTION AND COMPARTMENT FIRE

The general concern with combustible construction is that combustible material may be exposed to and subsequently support the spread and/or growth of fire. Therefore, not only would the integrity of the combustible construction be affected by fire, the construction material itself may also become fuel. However, to scientifically understand and discuss the risk of combustible construction in fire, it is important to first discuss the physics of compartment fires and the general strategies that have been implemented in the Building Code for combustible buildings in addressing the risks posed by compartment fires. This would allow for a more systematic approach to examining the fire risks.

Fire is the exothermic reaction of fuel with oxygen that takes place at a critical temperature which releases heat as one of its products [6]. In buildings, compartment fires are generally the fire of consideration. The construction of walls, floors and ceilings create thermal boundaries that confine the fire to an enclosure (the compartment). Accordingly, the behaviour of the fire follows a set of unique physics commonly referred to as compartment fire dynamics. The progression of a compartment fire can generally be depicted by the heat release rate versus time curve shown in Figure 1.

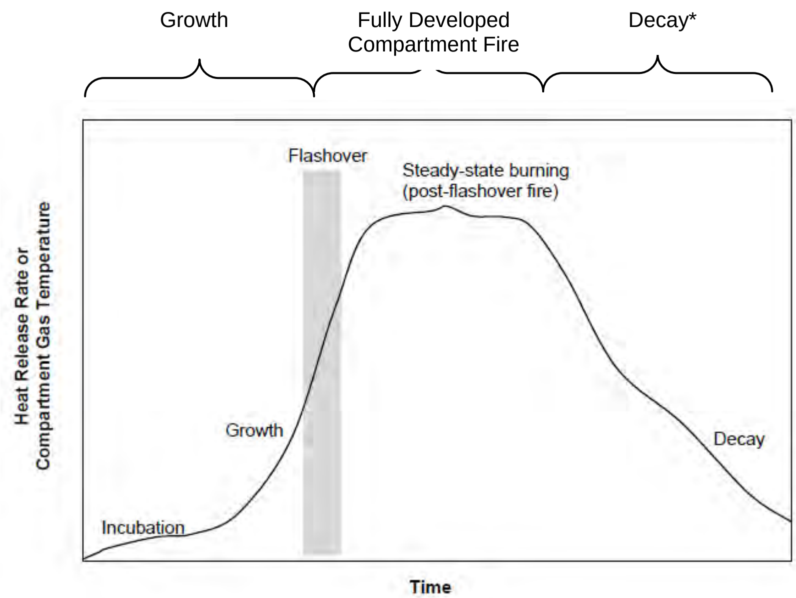

Figure 1. Schematics of a typical compartment fire history [6]. *The decay phase is not currently addressed by the Building Code.

During the growth stage, the fire is a localized phenomenon, where heated gas and products of combustion rise and form a 'smoke layer' at the ceiling. As the fire progresses, the smoke layer thickens and begins to descend along walls. During this stage, the building's construction materials may have a significant influence on the advancement of the fire. This includes interior finishes and the exposed construction material of the building. The general strategy employed by the Building Code for the growth stage is to limit spread and growth of fire, evacuate the occupants for life safety, and initiate firefighting for life safety and, if possible, property protection. This generally includes: (a) fire detection through sprinklers and smoke detectors to notify occupants of the fire, and to notify emergency responders; (b) limited flame spread rating in certain parts / assemblies of the building to limit fire spread and growth; (c) provision of sprinklers to control fire and smoke; and (d) fire separations to control spread of fire and its effects, which are principally heat and smoke.

As building size increases, the occupant load and the value of the property generally increase proportionally. Commensurate with this, the requirements for fire safety in the Code becomes more stringent to reflect the higher risk (higher probability of injury / loss of life due to fire and/or greater financial loss due to failure of the building). In larger and higher buildings, the Code generally requires lower flame spread rating for the interior finishes used and/or noncombustible construction material. The objective is to minimize the probability of combustible materials contributing to the pre-flashover fire, thereby increasing the chance of the fire protection strategy being successful. It is significant that the Code does not and cannot regulate contents, which form the majority of a fire load.

Although the Building Code does not explicitly discuss the fundamental fire protection strategies, the concern regarding combustible construction is noted in the intent statement of the Code. For example, the intent statement for Sentence 3.2.2.50.(2) states the requirement for noncombustible construction material is [3]:

> "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".

While combustible construction materials are subject to risk of fire, properly engineered and constructed buildings have a high degree of resistance against the threat of fire. This is generally achieved by concealing the wood members behind gypsum board. Use of sprinkler systems can also greatly enhance the building's overall level of fire safety, and in some cases exceeds the level of fire safety attained by unsprinklered noncombustible buildings.

In the event that the fire does progress to reach flashover, the fire is fully developed, which is a rare event, the fire protection strategy shifts towards preventing fire spread outside the compartment and preventing partial failure or collapse of the building's structural elements within a given timeframe. Although survival within the fire compartment is not expected in a post-flashover environment (at temperatures above 600C), the building's endurance in post-flashover environments is important as it provides time for evacuation of occupants outside the compartment of fire origin (i.e., at different floor levels or in exits), as well as for firefighters to complete their operations in those areas.

Fire endurance in fully developed fires is generally implemented by requiring a fire resistance rating for the building's fire separations, including floors and exits, and for structural supports. It is important to note that when a compartment reaches the fully developed stage, the fire is not growing in terms of severity as the fire size is governed by the available ventilation to the fire compartment; that is, the burning rate is governed by the amount of oxygen available, not the fuel load itself [6]. When a building compartment reaches the fully developed stage, firefighting may become a defensive operation where the objective is to let the fire reach burn-out within the compartment while protecting the adjacent properties [7].

It is significant to note that to obtain a fully developed compartment fire in a typical light timber building requires that the majority of the fuel be supplied by the contents; in a fire compartment, even with a wood floor, with the ceiling and walls lined with gypsum wallboard, there is insufficient fuel to sustain combustion. The wood framing, protected by gypsum wallboard, is essentially isolated from involvement in the fire for a significant period of time.

Understanding the compartment fire dynamics allows one to strategically design buildings to perform in an acceptable manner in the different stages of a fire. In the context of allowing greater building height for wood buildings of Group D occupancy, the following key questions need to be considered:

1. How are wood buildings designed to limit the ignition of wood during the pre-flashover stage?
2. How are wood buildings designed to limit spread of fire and smoke beyond the compartment of fire origin?
3. How are wood buildings designed to provide an acceptable environment for emergency responders to conduct their operations outside the compartment of fire operations during the fully developed stage?

4. How are wood buildings designed to remain structurally sound should the compartment fire become fully developed?

5. How are wood buildings designed to limit the spread of fire to neighbouring buildings should the compartment fire reach flashover?

To respond to these questions, this study examines the three mid-rise buildings of Group D occupancy identified in Table 2, and compares their performance in these areas to a potential 6 storey wood frame building of Group D occupancy. This forms the core of the analysis of designed risk presented in the next section of this report.

2.4 FIRE RATINGS

The performance of fire separations is measured by the standard fire test, CAN/ULC-S101 *Fire Endurance Tests of Building Construction and Materials* [9]. The test, which represents a fire rapidly progressing to a fully developed fire, exposes an assembly to a fire based on a standard time-temperature curve and assigns a fire resistance rating based on the time for which the assembly can resist the fire as set out in the passing criteria of the test. The fire resistance ratings found are categorized into periods of 3/4h, 1h, and 2h.

For load bearing elements, this test is performed under full load. This standard test is a performance test that enables the fire resistance rating of the element to be determined; the result is not predicated on whether the assembly's construction is combustible or noncombustible. Stated otherwise, when the test determines a fire resistance rating of 1h for a wood stud wall, it has the same fire endurance in a fully developed fire to that of a steel stud wall, or a concrete wall when tested in accordance with the CAN/ULC-S101 test.

3.0 ANALYSIS OF DESIGNED RISK

The risk analysis performed in this study evaluates a 6 storey wood building of Group D occupancy against the comparison buildings that are currently permitted in the Building Code. The comparison is made with respect to the specific fire safety objectives that are currently recognized in the Building Code. For the purpose of discussion, a brief summary of the objective-based Code is first presented, followed by the risk analysis.

3.1 OBJECTIVE-BASED CODE

The BC Building Code regulates building construction in the province of British Columbia. The Code represents the consensus reached by the public regarding the minimum level of standard required in buildings through the legislative process of adopting the Code [3]. The Code has traditionally been "prescriptive" in that Code requirements are directly stated in the regulation. While the Code is revised in each Code change cycle, some of the fundamental requirements such as building height and building area remain much the same as in the first edition of the Code. These requirements are historic in nature and do not necessarily reflect the modern engineering practice and construction technologies that are available now.

In 2005, the NRC released the National Building Code of Canada 2005, which is an objective-based Code. This was later adopted as the BC Building Code 2006. The benefit of the objective-based Code is that for the first time, specific Code objectives and functional statements are available, allowing practitioners, builders and Code regulators alike to understand the intent of the Code and its application. The objective-based Code allows one to comply with the Code through 'acceptable solutions' which are the previous prescriptive requirements of the Code or through alternative solutions that demonstrate equivalent level of performance in the areas identified by the objectives. Figure 2 depicts the roadmap to compliance with the objective-based Building Code.

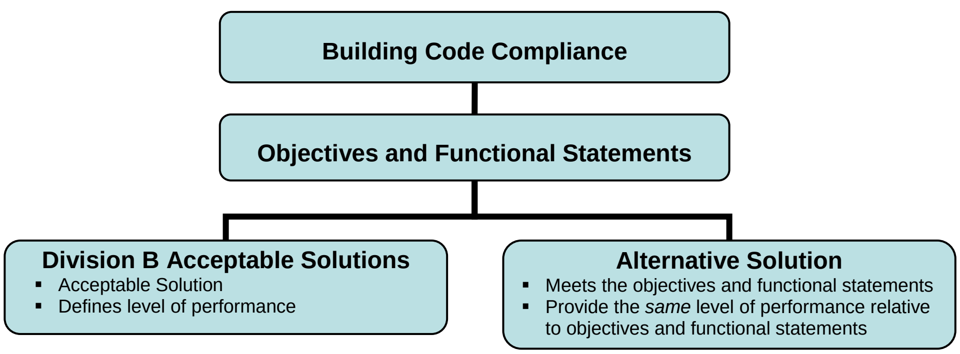

Figure 2. Summary of the two approaches available for Building Code compliance.

The Code objectives and functional statements associated with a particular requirement identify the risk areas that the Code is addressing in that requirement. Risks that are not part of the objectives are outside the Building Code framework and are therefore not considered (ie. the risk of failure due to terrorist attack is currently not a risk area recognized by the Code).

In the objective-based Code, the performance targets for the Code requirements are implicit in the requirements themselves; the performance attained by the acceptable solutions in Division B constitutes the *minimum* level of performance required. For example, Sentence 3.4.2.5.(1) requires a maximum travel distance to an exit of 45m in a sprinklered Group D floor area. The objective of Sentence 3.4.2.5.(1) is [F10-OS3.7], which is to facilitate the timely movement of persons to a safe place in an emergency in order to limit the risk of injury due to persons being delayed in or impeded from moving to a safe place during an emergency. The performance target is the measure of time for occupants to reach an exit within the 45m maximum distance relative to the onset of unsafe conditions. If an alternative solution is proposed, one would need to demonstrate that a different travel distance to exit meets or exceeds the performance attained by the 45m travel distance scenario with respect to [F10-OS3.7], assuming all other factors remain unchanged.

3.2 WHAT IS RISK?

In general terms, risk is a measure of a certain action or activity that will lead to an undesirable outcome. The magnitude of a fire risk is determined by (a) the likelihood of a fire event occurring and (b) the consequence of the event occurring [10]. The likelihood of an event is described by its frequency or probability of occurrence. In fire safety, the likelihood of a certain fire event occurring can generally be determined from studying statistical data, from past experience, or subjectively on the prevalence of certain conditions deemed to present a known risk. The consequence of an event occurring is concerned with measuring the extent of the undesirable outcome. In fire safety, this is generally measured in terms of injury, fatality and property damage.

It is important to recognize that buildings are subject to risk of failure, even buildings that are built in full conformance to the acceptable solutions of the Building Code. As it is not possible to completely eliminate fires from occurring and their consequences, the basic approach to combatting fire risk in the context of Building Codes and engineering practice is to find a practical solution that appropriately balances the risk of an undesirable outcome and the cost of implementing the solution. Through due-process, public input and scientific research, Building Codes are developed to manage risks to a level deemed to be acceptable by societies.

The acceptable level of risk, while in part a public policy decision, is complicated by the fact that some risk that has a relatively high probability of occurrence but low consequence may be acceptable (for example, noise transmission), whereas a very low probability event with higher consequence may not be acceptable (for example, collapse of a building).

3.3 RISK ANALYSIS APPROACH

Given that the objective-based Code does not provide specific performance targets, it is not possible to provide a quantitative analysis to evaluate the risk of a 5 or 6 storey wood building of Group D occupancy. However, the objective-based framework allows a *qualitative* risk analysis to be undertaken. Recognizing that Division B defines the boundary between acceptable and unacceptable risks, one can assess the proposed 5 or 6 storey wood building of Group D occupancy against the relevant construction types currently permitted in Subsection 3.2.2. The comparison using fire engineering principles and experience from the field allows one to determine whether the proposed building is ‘better’, ‘equivalent’ or ‘worse’ than the comparison buildings. This kind of analysis is in fact the common approach employed for developing alternative solutions (further discussion on qualitative risk analysis and development of alternative solutions is found in Appendix A A-1.2.1.1.(1)(b) of the Code).

It is important to note that the product of this risk analysis will only answer the question of whether a 5 or 6 storey wood building of Group D occupancy is as safe as the buildings currently permitted in the Building Code. It will, however, not answer the question 'are the existing Code provisions appropriate, too conservative or too relaxed'. In other words, the result of the analysis is only relative to the provisions that exist in the current Code.

In summary, the steps of the qualitative risk analysis used in this study are as follows:

1. Identify the area of risk being analyzed; in this case, the risks are defined by the objectives and functional statements associated with the requirements founds in Division B.
2. Evaluate the level of performance of the relevant Division B requirements which are deemed as the 'minimum level of performance' that achieves the Code objectives.
3. Evaluate the performance of the alternative solution relative to the objective.
4. Compare the performance between the Division B solution and the alternative solution.

3.4 PROPOSED BUILDING

For the purpose of discussion, the building being studied (the proposed building) is a 6 storey wood building of Group D occupancy having a maximum building area of 2400m^2.

3.5 COMPARISON BUILDINGS

In our analysis, we compared the proposed 6 storey wood building of Group D occupancy to a sprinklered 4 storey wood frame building permitted in Article 3.2.2.52 and an unsprinklered 6 storey light steel-frame building permitted in Article 3.2.2.50 (the comparison buildings), both of which require 1h fire resistance rating for floors and supporting structures (see Table 2).

3.6 EFFECT ON OCCUPANTS, CONTENTS AND PROBABILITY OF IGNITION

This report is a comparison of Group D occupancy buildings and does not include a comparison to other occupancies. For the purposes of this analysis, it is reasonable to assume that the contents of a wood frame office building would be the same as the contents of a noncombustible office building of the same size and area. Similarly, it is reasonable to assume that the probability of ignition of a wood frame office building would be the same as that of a noncombustible office building of the same size an area.

It is not within the mandate of this report to compare a wood frame office building with a wood frame building of other occupancies, such as residential. There are various factors, such as contents, degree of compartmentation, occupant characteristics and frequency and extent of damage and repair, some of which increase, and some of which decrease the level of risk. Notwithstanding this, GHL's opinion on this is discussed in Section 5 of this report.

3.7 EFFECTIVENESS OF SPRINKLER PROTECTION

Sprinklers have been shown to have an effectiveness of 95% to 99% [11] in limiting the growth and spread of fire. Recent advancements in fast response and quick response sprinklers, along with monitoring and supervisions of systems have substantially increased the reliability of such systems.

Notwithstanding this effectiveness, the Code has limited the reliance on sprinkler systems, possibly due to concern for over-reliance on a single system. That is, although the probability of failure of sprinkler systems to control a fire is very small, the consequence of such failure, should there be an over-reliance on sprinklers, may not be acceptable. Further assessment as to what degree of reliance on sprinkler systems is appropriate in the Code is not within the mandate of this report.

3.8 IDENTIFICATION OF FIRE RISK

The objectives of the Code are found in Division A, Part 2 and the functional statements are found in Division A, Part 3. The applicable construction Articles are 3.2.2.50 for Group D, Up to 6 Storeys, Unsprinklered, and 3.2.2.52 for Group D, Up to 4 Storeys, Combustible Construction, Sprinklered.

The related objectives and functional statements are [F02, F03, F04 – OP1.2, OP1.3] and [F02, F03, F04 – OS1.2, OS1.3], which can be paraphrased as:

a) To limit the severity and the effects of fire and to limit the extent of the fire to the point of origin so as to limit the risk of injury to occupants and damage to the building; and

b) To retard the failure or collapse of the building due to the effects of fire so as to limit the risk of injury to occupants and damage to the building.

Although emergency response, operation of sprinkler system and evacuation are not explicit in the Code objectives and functional statements, they are *implicit* in the objectives in that achieving OS1.2, OS1.3, OP1.2 and OP 1.3 requires the sprinkler system to be operational when needed to provide a tenable environment for evacuation, and that intervention by firefighters will facilitate evacuation and limit damage to the building.

Therefore, in summary, the analysis needs to examine the following fire safety risks:

1. Risk of fire spread beyond point of origin
2. Risk of occupants not able to evacuate the building.
3. Risk of firefighters not able to conduct effective firefighting operations.
4. Risk of fire spread to neighbouring buildings
5. Risk of fire spread beyond the compartment of fire origin
6. Risk of building collapse due to fire

3.9 ANALYSIS

3.9.1 Risk of Fire Spread beyond Point of Origin - Interior:

Generally, there are two mechanisms for fire spread in a building: interior and exterior (through unprotected openings such as windows). The Code addresses interior fire spread by requirements for sprinklers and fire separations. Sprinklers are active fire protection systems which are reliable and effective in controlling the growth and spread of a fire. On the other hand, fire separations are passive; they provide a barrier against spread of fire, with or without the operation of sprinklers.

In the early stages of fire, the risk of fire spread to structural elements is generally low based on the presence of fire separations and, in many cases, sprinklers. The use of wood in a 6 storey building of Group D occupancy will not likely increase the risk of fire spread. In wood frame construction, the wood is concealed behind gypsum board. Based on the lower compartment temperature in pre-flashover fires, gypsum board will be able to protect the wood from exposure to heat. Therefore, the contribution of the wood-framing to the fire is generally not possible.

When comparing the proposed building to a 6 storey building of noncombustible construction under Article 3.2.2.50, which does not require sprinkler protection, a 6 storey wood building provided with sprinkler protection will actually perform better with respect to fire spread. This is particularly true in open floor areas (i.e., the entire floor level is one suite). Without compartmentation, fire can spread via the combustible contents in the building. In Group D occupancies, this typically includes tables, chairs, office supplies and other furniture and furnishings. While the 6 storey building is constructed of wood, the wood has limited contribution to the fire due to the protection of the gypsum board. In this case, the wood building will outperform a noncombustible building not protected by sprinklers because there is no mechanism in place to control the fire size in the absence of fire compartments.

With respect to interior finish, for sprinklered buildings, the Code permits significant quantities of wood finish in terms of unlimited millwork and wood panelling on floors and walls up to 25mm thick. Hence, with respect to exposed wood, the amount of permitted exposed wood is the same in a building of noncombustible construction as in a building of combustible construction. The solutions in the Code, however, require that ceilings have a flame spread of less than 25, which can be achieved by impregnation or painting to reduce flame spread.

In a fully sprinklered building, the risk of flashover is minimized.

Should the fire progress to flashover and become fully developed, the 6 storey wood building is expected to perform the same as a 4 storey wood building or 6 storey noncombustible building based on 1h rated fire separations. The use of 1h rated fire separations in a 6 storey wood building will offer the same level of protection against spread of fire from a fully developed compartment as that of a 4 storey wood or a 6 storey noncombustible building.

In conclusion, the risk of fire spread beyond point of origin within the 6 storey wood frame building will not likely increase over the noncombustible building.

3.9.2 Risk of Fire Spread beyond Point of Origin for an Interconnected Floor Space:

It is common for buildings of Group D occupancy to have atria or interior convenience stairways for design and functionality purposes. This kind of design creates openings in the floor assemblies which are commonly referred to as interconnected floor spaces (IFS). Because each storey of a building is intended to function as a compartment, the creation of IFS presents a threat for fire and smoke to travel between floor levels, which may have an adverse impact on the fire protection strategies intended to be carried out during pre-flashover. To address this, the Code currently provides three acceptable solutions for designing IFS; namely [3]:

i. Provide vertical fire separations around the floor opening to maintain the floor-to-floor fire separation – Clause 3.2.8.1.(1)(a);

ii. Permit small floor openings when certain conditions are met on the basis that the small floor openings constitute an acceptable level of risk – Article 3.2.8.2.

iii. Permit large floor openings and requiring fire and smoke protection features as outlined in Articles 3.2.8.3 to 3.2.8.9 to manage the risks to an acceptable level – Clause 3.2.8.1.(1)(b). This includes the requirement to use heavy timber or noncombustible construction in combustible buildings and precludes wood frame construction.

iv. With regard to the proposed 6 storey wood frame building of Group D occupancy, application of Clause 3.2.8.1.(1)(a) will maintain the accepted level of risk given that the integrity of the fire separation is maintained and is not affected by whether the separation is constructed of noncombustible material or wood; refer to further discussions in Section 3.7.1 on CAN/ULC-S101.

With regard to small floor openings, the application of Article 3.2.8.2 will not affect the accepted level of risk in a 6 storey wood frame building of Group D occupancy as the applicable exemptions in Article 3.2.8.2 are based on limiting the size of the opening or the building area. The key exemptions are Sentence 3.2.8.2.(5) where floor openings not more than $10m^2$ are permitted in a sprinklered building, and Sentence 3.2.8.2.(6) where there is no limitation on the floor opening itself, but the opening is required to be between the 1st and 2nd storey or the 1st storey and the basement, and the building area is limited to not more than 50% of the maximum allowable permitted in Subsection 3.2.2. Given that the proposed 6 storey wood building of Group D occupancy will have a limitation of building area (instead of 'unlimited' in certain categories of Subsection 3.2.2), the application of Sentence 3.2.8.2.(5) and 3.2.8.2.(6) will not result in an increased risk of fire spread.

With regard to larger multi-level floor openings described in Clause 3.2.8.1.(1).(b), this level of interconnection is not currently permitted in a wood frame building and is not further discussed in this report. Further discussion will be found in the accompanying report on Heavy Timber Group D buildings.

In conclusion, the risk of fire spread beyond point of origin for an interconnected floor space will not likely increase subject to the current limitations in the Code for interconnected floor spaces.

3.9.3 Risk of Fire Spread beyond Point of Origin - Exterior Spread:

When a compartment fire reaches the fully developed stage, the fire may spill out of unprotected openings, resulting in a risk of spread to other parts of the building (generally the storeys above the fire level due to the buoyant nature of heated gas). Use of combustible cladding may contribute to fire spread as the cladding could ignite and become involved in the fire. However, this risk can be addressed by requiring noncombustible cladding or cladding of limited combustibility such as that permitted in Article 3.1.5.5 for noncombustible buildings.

Further, the risk will be significantly reduced through the requirement for full sprinkler protection of 6 storey wood frame construction in comparison to an unsprinklered 6 storey noncombustible building. It is significant that previous editions of the Code contained specific provisions, such as spandrels, to address this concern for mercantile occupancies; however, this was removed as part of the Code changes that introduced the requirement for sprinkler protection of all larger mercantile and industrial buildings be sprinklered; that is, the Code recognizes that provision of sprinkler protection is an appropriate method to address this risk.

In conclusion, the risk of fire spread beyond point of origin via the exterior will not likely increase, and will significantly decrease due to internal control by sprinklers.

3.9.4 Risk of Fire Spread to / within Concealed Spaces:

In comparison to a 4 storey wood frame building of Group D occupancy, a 6 storey wood frame building *may* pose some increased risk of fire spread within concealed spaces. While the probability of fire spread is considered to be the same as a 4 storey wood frame building (based on the application of NFPA 13, which requires sprinkler protection in concealed spaces), the consequence of fire spread, in terms of threat to life safety and property damage, *may* be greater in a 6 storey wood frame building. However, an observation of the building area and building height requirements in Article 3.2.2.52 appears to indicate that such risk is negligible and is accepted by the Code.

Currently, Article 3.2.2.52 of the Code permits up to 4 storeys for a wood frame building of Group D occupancy, as shown in Table 2. Unlike other Articles such as Article 3.2.2.45 for mid-rise wood frame building of Group C occupancy where the building area decreases with an increase in building height, Article 3.2.2.52 provides a 3600m^2 area limitation irrespective of the building height. Therefore, as an Article 3.2.2.52 wood frame building becomes higher, a greater overall volume / gross area results, as shown in Table 3.

Table 3. Comparison of Article 3.2.2.52 and Article 3.2.2.45 [3].

No. of Storeys	Article 3.2.2.52 Group D Occupancy		Article 3.2.2.47 Group C Occupancy	
	Building Area (m^2)	Gross Floor Area (m^2)	Building Area (m^2)	Gross Floor Area (m^2)
1	3600	3600	7200	7200
2	3600	7200	3600	7200
3	3600	10800	2400	7200
4	3600	14400	1800	7200
5	-	-	1440	7200
6	-	-	1200	7200

While there is no reliable data to associate the consequence of fire spread to and within concealed spaces with respect to the volume of the wood frame construction, it is generally considered that with increase in building volume, there is a greater *consequence* of fire to life safety and property damage as an increase in building volume is generally commensurate with a higher occupant load and property value. Given the Code currently does not require the building area to decrease with an increase in building height in Article 3.2.2.52, this would appear to indicate that the increase in risk to life safety and property damage with increase in wood frame volume is deemed to be acceptable by the Code.

Although review of the Building Code and related User's Guide provided no explanation on the difference in the allowable building area assignment in Articles 3.2.2.52 and 3.2.2.47, it would appear that the "relaxation" is provided to the Group D occupancy based on some of the generic advantages of Group D occupancy, such as occupants generally being awake and in a focused state of mind as opposed to sleeping or in a relaxed state of mind in the Group C occupancy, and greater overall evacuation performance [17].

To this end, a conservative measure to address the *consequence* of fire spread to / within concealed spaces in 6 storey wood frame buildings of Group D occupancy would be to restrict the gross floor area to 14,400m^2, the maximum gross floor area currently permitted in Article 3.2.2.52 as shown in Table 3.

It is noted that at the time of this writing, GHL has suggested, as part of the study of higher wood buildings, that the Canadian Wood Council and National Research Council of Canada provide further research or information on fire spread in concealed spaces [18].

It is noted that the requirements and standards for both fireblocking of concealed spaces and for firestopping of service penetrations have improved over the last few decades; however, no studies or statistical date is available to assess how this has impacted the overall risk and this has therefore not been included in this analysis. While there may be an increased risk of firespread due to the use of lightweight wood elements such as wood or joists, NFPA 13 provides requirements to deal with fireblocking of these spaces and other provisions to address these risks.

In conclusion, the risk of fire spread to and within concealed spaces will not likely increase subject to building area limitations.

3.9.5 Risk of Occupants Not Being Able to Evacuate the Building

The Code's general approach to evacuation of buildings is based on controlling occupant load, providing sufficient means of egress, and managing accessibility, availability and integrity of exit systems. In the context of this study, the question is whether the use of wood undermines the exit strategy that the Code has in place.

Assuming the gross floor area of 14,400m^2, the maximum gross floor area for a 4 storey sprinklered building of Group D occupancy currently permitted in Article 3.2.2.52 (see Table 2), is maintained in a 6 storey wood building of Group D building, the evacuation performance would remain unchanged relative to a 4 storey wood building of Group D occupancy. First, the total occupant load will not change while the occupant load per floor will generally decrease. Second, the travel time to an exit within a storey will likely decrease due to smaller building area and lesser queuing at exits as a result of fewer occupants per floor. Travel time within exit stairs would increase due to the 2 additional storeys; however, as exits are separated by 1h fire separations (and travel time within exits will be the same as that of a 6 storey noncombustible building), the exit stairs will provide the same level of performance as the noncombustible mid-rise buildings currently permitted by the Code. The 1h fire separation at exits would offer the same level of protection against fire, irrespective of the material of construction as aforementioned, which will afford an acceptable time for evacuation and for firefighting operations.

Based on mandatory sprinkler protection, a sprinklered 6 storey wood building of Group D occupancy will offer a safer condition for evacuation in comparison to an unsprinklered 6 storey noncombustible building of Group D occupancy as permitted under Article 3.2.2.50. While the maximum travel distance in an unsprinklered floor area is 30m, which is shorter than the maximum travel distance of 45m in a sprinklered floor area, sprinkler protection offers a much greater level of fire safety which more than offsets the 15m additional travel distance. It is far better for occupants to be evacuating a sprinklered floor area with longer travel path of 45m than an unsprinklered floor area with a slightly shorter travel path of 30m. This is because the travel time to exit is actually only a proportion of the overall evacuation time; within a floor area the difference in travel distance between 30m and 45m will generally not result in a significant difference in the time required to reach an exit. Based on a conservative average travelling speed of 0.85m/s [10], travel time would be 53s in a floor area with 45m travel distance versus 35s in a floor area with 30m travel distance, which is of negligible difference in the overall evacuation time. The significant portion of the overall evacuation time is actually the pre-movement time, which is a combination of the fire detection and decision making times that occur prior to the actual movement to the exits as depicted by Figure 3.

During a fire, precious opportunity for successful evacuation may be lost if the fire progresses rapidly leading to a faster onset of untenable conditions or reduction in the available safe egress time. The installation of sprinklers will allow the fire to be controlled, restricting fire spread and creating more favourable conditions for evacuation. The use of wood in the structure has limited impact on evacuation performance as the wood would be protected by gypsum board, such that the potential for participation in the fire is limited. In this regard, a sprinklered wood building offers significantly greater level of safety in terms of providing a tenable environment for evacuation than an unsprinklered noncombustible building.

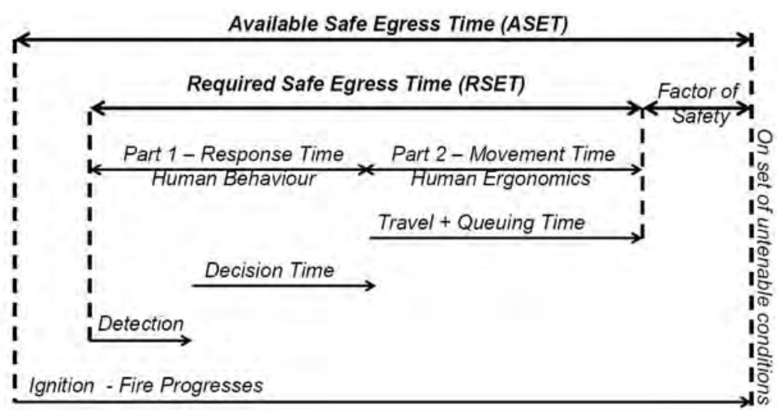

Figure 3. Schematic illustration of evacuation timelines

In conclusion, the risk of occupants not being able to evacuate the building will not likely increase compared to a fire in an equivalent noncombustible building. Also, a 6 storey sprinklered wood frame building is fundamentally safer; this reduces the risk to occupants in case of evacuation.

3.9.6 Risk of Fire Service Being Unable to Conduct Effective Operations:

In comparison to a sprinklered 4 storey wood or an unsprinklered 6 storey light steel-frame building, the risk of fire service not being able to conduct effective operations will not likely increase for a 6 storey wood building of Group D occupancy, provided the building is not a high building. This is primarily due to the benefit of sprinkler protection and controlling the maximum allowable building area to reflect the firefighting challenge.

Traditionally, unsprinklered construction relied on exterior firefighting operations. With the advent of buildings protected with monitored and supervised sprinkler systems and related firefighting practices, the Code has shifted to reliance on sprinkler systems and interior firefighting access.

In sprinklered mid-rise buildings, firefighting operations can be conducted from the interior of the building due to the reduced internal fire risk in comparison to unsprinklered buildings. In fact, a sprinkler system is considered to be the greatest asset for firefighting as such systems have been shown to be reliable, effective and typically they operate automatically well before firefighters arrive at the fire scene. In the Group D occupancy mid-rise category, the benefit of the sprinkler system is in fact recognized by the Code as seen in the much greater building area allowed in the comparison of Article 3.2.2.50 and Article 3.2.2.51 as summarized in Table 4.

As shown, for a 6 storey, unsprinklered noncombustible building of Group D occupancy facing 1 street, as the building height increases, the building area decreases to reflect the greater firefighting challenge. On the other hand, the Code allows the building area to be increased by 25% if it faces 2 streets and by 50% if it faces 3 streets given that facing additional streets is a benefit to firefighting. However, when a noncombustible building is sprinklered, as per Article 3.2.2.51, the increase in allowable building area is much more significant – at 3 times the allowable building area.

This relationship indicates that the Code considers sprinkler protection as an important asset and significantly more beneficial than facing additional streets. It also indicates the expectation for interior firefighting in a sprinklered building as the building is only required to face 1 street.

Table 4. Comparison of Article 3.2.2.50 and Article 3.2.2.51 requirements indicates that the maximum allowable building area increase is commensurate with a decrease in firefighting challenges [3].

	Article 3.2.2.50 Group D Noncombustible Unsprinklered			Article 3.2.2.51 Group D Noncombustible Sprinklered
No. of Storeys	Maximum Building Area (m^2)			
	Facing 1 Street	Facing 2 Streets	Facing 3 Streets	Facing 1 Street
1	No limit	No limit	No limit	No limit
2	7200	No limit	No limit	No limit
3	4800	6000	7200	14400
4	3600	4500	5400	10800
5	2880	3600	4320	8640
6	2400	3000	3600	7200
3 - 6	Base	25% more	50% more	300% more

Additional examples of other Code provisions that recognize the benefits of sprinkler systems in firefighting operations include:

- Eliminating the requirement for fire rated roofs in sprinklered buildings;
- Eliminating the requirement for firefighting access openings for firefighting in sprinklered buildings;
- Introduction of 4 storey 1h combustible building of Group C occupancy with a 9m height limit in the BC Building Code 1992 and the subsequent removal of the 9m height limit in the BC Building Code 1998.

The aforementioned provisions all indicate that the Code does not anticipate exterior firefighting for sprinklered wood buildings (or any sprinklered building) and recognizes the reliability and effectiveness of automatic sprinkler systems. Therefore, the primary change from 4 to 6 storeys is traveling up an additional 2 storeys of interior stairs. However, the use of wood as the construction material will not have a significant impact on firefighting operations as the structural materials will be concealed in gypsum board or treated in exits and public corridors. Therefore, operations would be carried out the same as in an unsprinklered 6 storey noncombustible building.

There may be a risk of fire spread via the exterior of the building due to combustible exterior cladding on a 6 storey wood building; however, as discussed, this can be addressed by imposing measures to limit the burning characteristics of the cladding system (such as the kind permitted for noncombustible buildings) or requiring noncombustible cladding.

In rural areas, some regions have limited firefighting capabilities. the BC Building Code Appendix A notes that this can be addressed through either requiring mandatory sprinklers or imposing restrictions through Municipal Zoning By-laws [3].

Considering the very significant benefit to firefighting operations that full sprinkler protection affords a 6 storey Group D building would require significantly less firefighting resources than an unsprinklered noncombustible building of 1 hour fire resistance. With respect to the sprinkler protection, where the region lacks adequate or reliable water supply infrastructure, additional measures such as emergency power, fire pump(s) and on site water supplies can be used to enhance the reliability of sprinkler system, in conjunction with enforcement of proper maintenance of systems.

Comments on High Buildings

The Code recognizes that, due to building height and occupant characteristics, certain buildings represent additional challenges for firefighting and require certain additional features. The height at which a building is defined as a high building varies in the Building Code according to occupancy due to the characteristics of the occupancies. The occupancies can be classified into two separate groups. The first group are occupancies in Groups A, D, E, and F, where occupants are normally awake and active, requiring less search and rescue efforts; the second group are occupancies in Groups B and C, where occupants may be incapable of self-preservation or are sleeping, require greater search and rescue efforts.

For buildings of Group B major occupancy, high buildings requirements apply to buildings over 18m in height to the uppermost storey; however, specific to Group B-2 (care and detention) occupancies, where a high proportion of occupants may have limited mobility, a high building is defined as a building over 3 storeys in building height. For buildings of Group C (residential) occupancy, where occupants may not be alert (i.e. may be sleeping), have some mobility limitations, or be slow to respond to fire cues, a high building is defined as a building 18m in height to the uppermost storey.

In contrast, in a Group D occupancy, the majority of occupants are expected to be mobile and alert; therefore, Group D buildings are defined as a high building if they (a) exceed 36m, or (b) exceed 18m if the total occupant load above the 1st storey divided by 1.8 times the width of exit stairs in metre exceeds 300. Although not explicitly stated in the Building Code, criterion (b) is intended to capture the effects of emergency responders sharing exit stairs with evacuating occupants, given that each floor level is still required by Subsection 3.4 to provide adequate exit capacity for the anticipated occupant load.

At the 6 storey maximum proposed, and assuming a 3m height per floor, only large buildings of Group D occupancy with minimal exiting would be considered a high building; this is regardless of whether the building is of noncombustible, wood frame or heavy timber construction. That is, most 6 storey buildings of Group D occupancy, by the nature of the formula, would not be defined as a high building due to the low ratio of total occupant load to exit capacity. Should the designers opt to design a wood frame building of Group D occupancy as a high building, additional features, such as enhanced alarm systems and emergency power to elevators, would compensate for the minimum Code-permitted exit capacity. Accordingly, there would be no significant change in the risk level for firefighting in a 6 storey building of Group D occupancy, whether it is of noncombustible, wood frame or heavy timber construction.

In conclusion, the risk of the fire service being unable to conduct effective operations will not likely increase. Further, in comparison to a 6 storey noncombustible unsprinklered building, the risk of fire services being unable to conduct effective operations is significantly reduced.

3.9.7 Risk of Fire Spread to Neighbouring Buildings:

The Code assumes fire spread to neighbouring buildings by means of radiation heat transfer [3]. This phenomenon is generally more prevalent in post-flashover fires when the compartment has attained high temperatures. The effects of radiation heat transfer are amplified as the compartment temperature increases; in fact, this relationship is to the 4th power of temperature as indicated by the following power relationship [11]:

$$Q \propto T^4 \qquad (1)$$

where Q is the radiant heat flux in kW/m^2 and T is the compartment gas temperature in degrees Kelvin.

The risk of fire spread to neighbouring buildings will not likely increase in a 6 storey wood building of Group D occupancy over a 4 storey wood building currently permitted, and will in fact be lower than in an unsprinklered 6 storey noncombustible building. The risk of fire spread to neighbouring buildings can be evaluated based on the consequence of fire due to the use of wood and the probability of the compartment reaching flashover.

The use of wood for structural purposes will not have a significant impact on the severity of a post-flashover compartment fire. First, while wood may become involved in the fire in a post-flashover situation (for instance, following failure of gypsum wallboard membranes), this will generally be limited in a properly constructed building. In wood frame buildings, the use of gypsum board, firestopping and fireblocking will limit the exposure of wood framing to the fire. Secondly, given that the maximum burning rate of a post-flashover fire is generally governed by the ventilation factor (oxygen) and not the volume of combustibles (fuel), the use of wood in the building's construction will not make a significant contribution to overall compartment temperature.

While the use of wood will not have a significant impact on the maximum compartment temperature, a 6 storey sprinklered wood building will perform better than an unsprinklered building of noncombustible construction as sprinklers will significantly reduce the probability of the fire reaching flashover and therefore keeping the compartment temperature low. As an illustration of the benefit of keeping the compartment temperature low, a calculation using Eq. (1) assuming T = 900C for a flashover compartment and T = 300C for a pre-flashover compartment indicates that the flashover compartment emits 18 times more thermal radiation than the non-flashover compartment (with all other factors being equal):

$$\frac{Q_{flashover}}{Q_{pre\_lashover}} = \frac{T_{flashover}{}^4}{T_{pre\_flashover}{}^4} = \frac{(900+273)^4}{(300+273)^4} = 18 \qquad (2)$$

Based on the high reliability rate of sprinklers, a sprinklered wood building with wood properly protected or treated has a much lower probability of flashover developing compared to an unsprinklered noncombustible building. In this regard, it can be concluded that the risk of fire spread to neighbouring buildings is actually higher in an unsprinklered 6 storey noncombustible building of Group D occupancy than a sprinklered 6 storey combustible building of Group D occupancy.

In conclusion, the risk of fire spread to neighbouring buildings will not likely increase. Further, in comparison to a 6 storey noncombustible unsprinklered building, the risk of fire spread to adjacent buildings is significantly reduced.

3.9.8 Risk of Fire Spread beyond the Compartment of Fire Origin

The spread of fire beyond the compartment of fire origin is achieved by requiring fire resistance ratings for fire compartment boundaries. This typically includes floors, and exits, corridors and suite separations. The fire resistance rating is established through the standard fire test CAN/ULC-S101. The standard fire test is a performance test that measures the assembly’s ability to resist the spread of fire. The test does not distinguish the assembly’s fire resistance based on its construction material; the fire resistance rating is assigned purely based on the timeframe for which the assembly can continue to carry the gravity load. Therefore, provided a 6 storey wood building is required to have the same 1h fire resistance rating as the 4 storey wood building currently permitted in Article 3.2.2.52 and the unsprinklered noncombustible building currently permitted in Article 3.2.2.50, it can be concluded that the risk of building collapse due to fire loading will be the same. It is noted that the Code permits reliance on sprinkler systems for certain assemblies, namely corridor walls and suite walls. That is, such separations do not require a fire resistance rating for such assemblies in a sprinklered building. However, this exemption is equally applicable to combustible or noncombustible buildings.

In conclusion, the risk of fire spread beyond the compartment of fire origin will not likely increase compared to the same fire in an equivalent noncombustible building.

3.9.9 Risk of Building Collapse Due to Fire

The structural integrity of buildings in fire is regulated by requiring fire resistance ratings of different elements of the structural system. This typically includes floors, beams and the supporting columns or walls. The fire resistance rating is established through the standard fire test CAN/ULC-S101. The test exposes a structural member to the standard time-temperature curve, which is intended to mimic a post-flashover fire, while carrying the required gravity load. The standard fire test is a performance test that measures the assembly’s ability to carry the gravity load when exposed to the fire. The test does not distinguish the assembly’s fire resistance based on its construction material; the fire resistance rating is assigned purely based on the timeframe for which the assembly can continue to carry the gravity load.

Therefore, provided a 6 storey wood building is required to have the same 1h fire resistance rating as the 4 storey wood building currently permitted in Article 3.2.2.52 and the unsprinklered noncombustible building currently permitted in Article 3.2.2.50, it can be concluded that the risk of building collapse due to fire loading will be the same.

3.10 SUMMARY

Generally, it is determined that there is no substantial increase in fire risk in a 6 storey wood frame building given that this type of construction involves concealing the wood with gypsum board. When properly constructed, there is no effective difference between a wood building and a noncombustible building in both pre- and post-flashover fires, with the only significant difference being the presence of concealed spaces in wood frame construction. However, this risk can be addressed by limiting the overall building area to globally limit the risk to occupant safety and property damage. The risk is also considered acceptable where the building is sprinklered in accordance with NFPA 13.

In fact, based on the presence of sprinkler protection many of the risks are significantly reduced in comparison to an unsprinklered 6 storey non-combustible building of 1h construction

Therefore, a 6 storey wood building of Group D occupancy of conventional light timber framing designed in accordance with the Code with a 1h fire rating will not pose an increase in fire risk when benchmarked against the performance of unsprinklered noncombustible construction of the same height.

4.0 ANALYSIS OF CONTINGENT RISKS

The previous section discussed the proposed 6 storey wood building of Group D occupancy in terms of 'Designed Risk', which is the residual risk that is generally deemed to be acceptable when the building is properly built. However, it is accepted that in reality, buildings cannot be built in full compliance with the Building Code. For example, while fire separations can be built to achieve the required rating per the Code requirement, real-world issues that occur in the field will generally result in the actual construction being somewhat different from ideal. The measure of the fire safety risk arising from this anomaly is addressed in this report as contingent risk.

It is noted that the Code currently does not address contingent risk. The Code is silent on what constitutes acceptable construction practice. This is generally managed by the design professionals through regular field reviews to ascertain the quality / acceptability of the construction, review by municipal building inspectors, as well as the builders being ultimately able to obtain insurance for their buildings upon completion.

Buildings are subject to contingent risks. However, it is important to recognize that just like designed risks, the key is to determine what constitutes an acceptable level of risk. For example, if a fire separation is built with good workmanship and there is no visually apparent defect from the listing, it is generally considered that the fire separation has been built in substantial compliance with the Code – even if the fire separation does not 100% comply with the ideal laboratory condition to the ultimate level of detail.

Much of the contingent risks for constructing a 6 storey wood building of Group D occupancy will be the same as that of a 6 storey wood building of Group C occupancy. This is because contingent risks are associated with the construction of the building, not the occupancy type. As the contingent risks have been previously identified in GHL's study on the Group C occupancy in 2008, they are not repeated here. However, an excerpt of the contingent risk discussions in the Group C study report is attached in *Appendix A.* These contingent risks have been addressed through the APEGBC Design and Practice Bulletin [19]; although the bulletin was prepared for Group C occupancy, they will equally apply to Group D occupancy.

However, this report notes the following two additional contingent risks that have been encountered through GHL's experience in 6 storey wood frame buildings of Group C occupancy in the past 2 years:

- **Reliability of Membrane-based Fire Separations**

  Although already identified in GHL's Group C study, the reliability of fire separation and fire protection of structural members are considered to be important in Group D wood buildings, if not more important than Group C wood buildings. This is because in the Group D occupancy, there is a greater likelihood of open-plan office spaces resulting in larger compartments or less compartment density than in Group C buildings. As a result, fire can potentially have a larger impact on the building's structural system in comparison to a Group C building that is highly compartmentalized. While all structural systems and fire separations are required to have a 1h fire resistance rating, which measures their performance in a post-flashover fire environment, the *reliability* of the 1h fire resistance rating becomes more important in a Group D wood building due to potentially larger spans.

With respect to wood frame construction, there is some concern regarding the reliability of membrane-based fire separations as when the wood frame is exposed to fire, the frame, being combustible, would directly fuel a fire. Laboratory tests have shown that a single layer of gypsum board on wood joists can achieve a 1h fire resistance rating; however, there is little validation of actual constructed separations in the field. Recent testing by the National Research Council of Canada has shown that for floor fire separations, minor variations in gypsum wallboard attachments can significant reduce fire resistance [13, 14]. Further, the recent full scale 6 storey timber-frame project in the UK [15] has indicated the need for increasing the durability of gypsum board-based fire protection. In view of this, it is considered that reliability of fire separations needs to be addressed. Some of the potential solutions include better craftsmanship of GWB installation, greater reviews during construction, and mandatory use of two layer wall and floor assembly systems.

- **Protection of Header Joists above Window**

Recent experience with the construction of 6 storey wood frame buildings in BC has revealed the importance of providing a fire resistance rating to the exterior wall on both sides at window openings where the wood joists and the header joists can be exposed (see Figure 4). Where a building contains a large opening and the exterior wall (which are not required to have a fire resistance rating <u>from the exterior</u> for spatial separation purposes), this type of fire exposure can potentially threaten the structural integrity of the building. This risk can be addressed by requiring the wood joists over windows to have a fire resistance rating on all sides (i.e., fire rating in the interior and from the exterior).

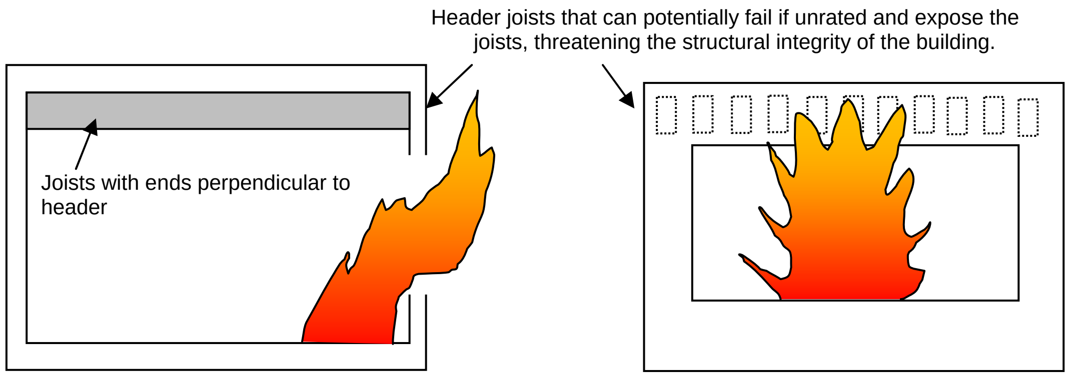

Figure 4. Schematic illustration of fire affecting the ends of the joists in a wood building

5.0 OCCUPANCY FACTORS

Although the objective based format of the Code requires comparison of permitted Group D construction classifications with 6 storey Group D combustible construction, some comments on the comparison to the permitted 6 storey combustible Group C classification are appropriate.

Occupant characteristics are substantially different. Group D occupants are generally alert, healthy and mobile (although some may use mobility aids such as walkers and wheelchairs and be unable to navigate stairs). Even in a doctor's office, where a patient may be significantly incapacitated, typically there is at least one able bodied person who is dedicated to assisting that person. In comparison, in a Group C occupancy, occupants may be alone and significantly incapacitated for periods of time due to sickness, age or injury. On this basis, Group D occupancies are less hazardous in life safety terms than Group C occupancies.

Similarly, with respect to contents, Group C occupancies are unregulated and are subject to occupants storing or using hazardous materials or performing hazardous operations without supervision. In contrast, in Group D occupancies, there is typically more control of hazardous contents, and such occupancies are usually subject to at least some form of fire inspection and fire safety standards. Further, the accumulation of combustibles is more easily controlled by fire inspectors as the objections to fire officials entering residential suites does not generally apply to Group D occupancies.

On the other hand, in Group D occupancies, there is an increased likelihood of major renovations due to change of tenancy and potential damage to fire separations and fire safety systems. Historically, this has not happened as frequently as Group C; however, it is noted that such wood frame buildings have been 3 storey rental buildings. With the large number of owner occupied condominium complexes, many reaching the 20 to 30 year mark, there is an increasing trend for occupants to renovate these buildings such that the risk of the renovations compromising required fire separations or fire safety systems is increasing. It is GHL's opinion that, while in the past the frequency of renovations for Group D has been higher, given the trend towards owner occupied condominiums, for this issue, it should be considered that there is less difference between Group C and Group D buildings.

The final significant difference is that Group D buildings are frequently 'open floor plate' type buildings with few intermediate walls. The impact of this is less compartmentation, both that required and that inherently provided, and the potential for longer span joists where collapse may be more critical than for the multiple short spans found in residential buildings.

Therefore it is our opinion that the risks in occupancy in Group D buildings is significantly less than in Group C buildings. This is recognized by the Code in that non-combustible 6 storey buildings of Group C occupancy require sprinkler protection, whereas Group D buildings are permitted to be unsprinklered.

6.0 RECOMMENDED CODE CHANGES

This section presents the proposed Code changes based on the designed risks presented in Section 3. There is no proposed Code change for the contingent risks as they are more appropriately addressed through design guidelines such as the APEGBC Designed and Practice Bulletin [19]. The proposed Code changes are underlined.

6.1 Building Area and Building Height

Option 1 – Article 3.2.2.52, "Group D, Up to <u>6</u> Storeys, Sprinklered"
1) A building classified as Group D is permitted to conform to Sentence (2) provided a) except as permitted by Sentences 3.2.2.7.(1) and 3.2.2.18.(2), the building is sprinklered throughout, b) it is not more than <u>6</u> storeys in building height, c) <u>it has a maximum height of less than 18 m measured between grade and the uppermost floor level of the top storey,</u> and d) it has a building area not more than i) <u>3600m^2 if not more than 4 storeys in building height,</u> ii) <u>2880m^2 if 5 storeys in building height, or</u> iii) <u>2400m^2 if 6 storeys in building height.</u>
Option 2 – Article 3.2.2.52, "Group D, Up to <u>6</u> Storeys, Sprinklered"
1) A building classified as Group D is permitted to conform to Sentence (2) provided a) except as permitted by Sentences 3.2.2.7.(1) and 3.2.2.18.(2), the building is sprinklered throughout, b) it is not more than <u>6</u> storeys in building height, c) <u>is not a high building in accordance with Sentence 3.2.6.1.(1)</u>, and d) it has a building area not more than 3600m^2.
Comments
Two possible Code changes to Article 3.2.2.52 are proposed. For both options, the maximum building height is limited to 6 storeys and 18m measured between grade and the uppermost floor level of the top storey. The 18m limit is intended to address exterior fire spread and firefighting challenges that higher wood buildings may pose, as well as to prevent a mid-rise wood building from being considered as a high-rise building as noted in the designed risk discussion and also in the Group C study reports [1]. Where the two options differ is the allowable building area. For Option 1, the proposed building areas for 6 storey buildings are based on maintaining the gross floor area of 14400m^2, which is the maximum gross floor area that a combustible building of Group D occupancy is currently permitted by Article 3.2.2.52 (i.e., 4 storeys × 3600m^2).

Option 1 is the more conservative of the two options proposed. As certain aspects of the designed risks cannot be definitively analyzed at this stage, such as the consequence of fire spread into concealed spaces in taller wood frame buildings, the conservative approach of keeping the gross floor area (the volume of wood construction) per building the same as is currently permitted ensures that the impact of the uncertain risks on life safety and ultimate property loss is not significantly different from what is currently deemed as acceptable risks.

The Code change proposal in Option 2 is based on keeping the allowable building area at the constant 3600m^2 for all building heights up to 6 storeys. This proposal is based on not exceeding the allowable building area currently permitted for an unsprinklered 6 storey noncombustible building of Group D occupancy in Article 3.2.2.50. The rationale is that given two buildings of the same building height, building area and occupancy classification, it is considered that the building of combustible construction with sprinkler protection affords at least the same level of fire safety as the building of noncombustible construction but with no sprinkler protection. That is, sprinkler protection is viewed as an effective and reliable measure to offset the risks associated with wood construction. Therefore, keeping the proposed building area the same as the maximum 3600m^2 permitted in Article 3.2.2.50 is considered reasonable. This option also recognizes GHL's experience of improvements in fire blocking and firestopping noted in Section 3.9.4.

In our opinion the second, less conservative option would provide a slightly higher level of risk than provided by a 4 storey sprinklered wood building (currently permitted by Article 3.2.2.52), but a lower level of risk than a 6 storey unsprinklered noncombustible light steel frame building (currently permitted by Article 3.2.2.50). The decision as to which option is appropriate may warrant public consultation.

6.2 Exterior Cladding

Article 3.2.2.52 "Group D, Up to 6 Storeys, Sprinklered"

3) Except as required in Sentence (4), a building referred to in Subclause 3.2.2.52.(1)(d)(ii) or (iii) shall

a) have an exterior wall cladding which

i. is noncombustible,

ii. has the exterior wall assembly constructed such that the interior surfaces of the wall assembly are protected by a thermal barrier conforming to Sentence 3.1.5.12.(3), and the wall assembly satisfies the criteria of Sentences 3.1.5.5.(2) and (3) when subjected to testing in conformance with CAN/ULC-S134, "Fire Test of Exterior Wall Assemblies", or

iii. is fire-retardant treated wood tested for fire exposure after the cladding has been subjected to an accelerated weather test as specified in ASTM D 2898 "Accelerated weathering of Fire-Retardant-Treated Wood for Fire Testing."

4) Sub-clauses 3.2.2.52.(3)(a)(ii) and (iii) are not permitted where an exposing building face is required by Article 3.2.3.7 to have noncombustible cladding.

Comments
The proposed Code change is intended to address exterior fire spread, fire spread to neighbouring buildings and firefighting challenges. The proposed solution is the same as that in Article 3.2.2.45 for Group C occupancy, which was presented in GHL's Group C study reports [1]. Essentially, it is thought that the performance criteria for combustible cladding mandated for noncombustible buildings sets the minimum level of performance and such performance would be appropriate for 6 storey wood buildings of Group D occupancy.

7.0 FUTURE WORK

The foregoing sections have provided GHL's study on the designed and contingent risks of 6 storey wood buildings of Group D occupancy. The following areas of additional study / research are recommended as future work concerning combustible construction requirements in Division B Part 3 are outside of the scope of the current study.

- **Building Height and Area**
  The foregoing analysis is based on the allowable building area limits that currently exist in the Building Code in Articles 3.2.2.50, 3.2.2.51 and 3.2.2.52. Our review of previous editions of the Building Code and related Code change documents indicates no clear scientific basis for the existing limitations. It would be appropriate as additional work to re-examine the building area and building height limits for combustible construction for all occupancies. Our understanding is that this question is being addressed by a National Research Council of Canada Task Group. Some of this work has recently been started as found in the paper, " by Michael Kruszelnicki as part of the NSERC funded NEWBuildS project.

- **Construction Fire Safety**
  As established in our study, a properly built wood building can afford a level of safety equivalent to other types of construction permitted in the Building Code. However, one area where wood buildings may pose a greater risk is the risk of fire during the construction stage when wood members are exposed without protection (no gypsum board or sprinkler system). Given that the building is under construction, construction fire risk will generally have very limited impact on life safety. With respect to property loss control, provided the maximum gross floor area of $14400m^2$ is maintained (the maximum gross volume currently permitted for a 4 storey combustible building of Group D occupancy per Article 3.2.2.52 (3)), we do not see an increased risk of construction fire on the basis that the same amount of combustible materials would be used. However, if a greater building area / building height were to be explored, then a complementary study on the issue of construction fire safety would be necessary as the combustible load will be effectively increased during the construction stage. It is noted that the National Fire Code of Canada 2010 has included additional requirements to address construction fire safety. The area of fire risk in construction is under review by several agencies, including FII.

- **Fire spread into and within concealed spaces**
  A study of the effects of fire spread into concealed spaces and fire spread through concealed spaces would enable better analysis of the impact of combustible concealed spaces and the effectiveness of measures to provide fire control of spaces that are difficult or expensive to provide with sprinkler protection. The relationship of this issue to building area also warrants study given that fireblocking of concealed spaces was not a Code requirement when the fundamental size and area limits for combustible buildings were set in the earliest versions of the National Building Code of Canada.

- **Reliability of Sprinkler Systems**
  A study into the reliability of sprinklers and their application in the Building Code (by acceptable or alternative solutions) would also be beneficial. Currently, a number of Code requirements are predicated upon the building being sprinklered. For example, the allowable building area is generally doubled when a building is sprinklered; however, there

is no clear information as to the extent designers can rely on sprinklers, whether the Code requirements already appropriately accounts for the risk of sprinkler failure or even if doubling the building area is unreasonably conservative. A study of this nature would benefit the formulation of alternative solutions and allow designers and authorities alike to understand when the benefits of sprinklers can be considered.

- **Appropriate Sprinkler Protection**
  It is noted that experience with 6 storey wood frame construction has indicated that the costs of sprinkler protection of concealed spaces is significant. In conjunction with the study above, a study on possible additional exceptions to required sprinkler protection, or of implementation of an appropriate sprinkler standard, such as was developed for 4 storey wood frame buildings as per NFPA 13R, may be valuable. Additional research is required on the effectiveness of the fireblocking requirements currently in NFPA 13 to establish whether fireblocking provides an equivalent level of protection to sprinkler protection of the void space, or is a relaxation from the level of protection intended.

- **Appropriate Sprinkler Protection – additional exemptions**
  It is noted that experience with 6 storey wood frame construction has indicated that the costs of sprinkler protection of concealed spaces is significant. In conjunction with the study above, a study on possible additional exceptions to required sprinkler protection, or of implementation of an appropriate sprinkler standard, such as was developed for 4 storey wood frame buildings as NFPA 13R, may be valuable. Further study of the impact of the new NFPA 13R requirements and possibility of developing standards similar to NFPA 13R appropriate to office buildings would be appropriate.

- **Probabilistic Fire Model**
  In order to fully assess wood building performance, a probabilistic fire risk assessment model is recommended to be developed. This would identify all failure modes in buildings and would construct an event tree analysis to enable the probability of acceptable performance to be determined. As both noncombustible and combustible buildings may often have the same likelihood of occurrence of certain events, the relative performance of one building to another will enable the performance of wood buildings to be appropriately compared to currently allowable non-combustible buildings. This would include the reliability of all building measures including automatic sprinkler systems. This study should include an assessment as to the level at which reliance can be placed on any one building measure, such as structural fire protection, fire alarms, sprinklers.

8.0 CONCLUSION

This designed report has been prepared by GHL for Forest Innovation Investment to identify and provide our opinion on the designed and contingent risks regarding the prospect of permitting 6 storey wood frame buildings of Group D occupancy.

Designed risks are identified by the Building Code objectives. GHL's analysis has focused strictly on the risk areas addressed by the Code objectives. We have taken a qualitative approach to analyze the risks by comparing a 6 storey wood building of Group D occupancy to that of a 4 storey wood or a 6 storey light steel-frame building of Group D occupancy currently permitted in the Code. In general, our finding is that provided the same gross floor area of $14400m^2$ is maintained, the risks will not likely increase. We did find that in order to limit exterior fire spread, noncombustible or limited combustible exterior cladding should be considered. Further, in order to address firefighting, the building should not be a high building as defined by the Code without further analysis of holistic building performance.

We have also identified contingent risks which are not addressed by the Building Code. GHL has identified contingent risks in addition to those identified in the Group C study based on our experience as fire protection engineers on mid-rise wood projects of Group C occupancy in the past two years.

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