GHL CONSULTANTS LTD

409 GRANVILLE STREET, SUITE 950
VANCOUVER, BC V6C 1T2 CANADA

P 604 689 4449
F 604 689 4419
www.ghl.ca
Holder of AIBC Certificate of Practice

April 23, 2012

Via Email *Ben.Henzler@bcfii.ca*
Phone 604 685 7507

Mr. Ben Henzler, P Eng
Forestry Innovation Investment Ltd
1200 – 1130 West Pender Street
Vancouver, BC
V6E 4A4

STUDY OF 8 STOREY HEAVY TIMBER BUILDINGS
OF GROUP D (BUSINESS AND PERSONAL SERVICE) OCCUPANCY **GHL File BSP-3517.04**

Dear Ben:

Enclosed is our final Group D, 8 storey study concentrating on heavy timber. This study represents our opinion that an 8 storey, 1.5hour heavy timber building Group D building is feasible and can provide the level of performance intended by the BC Building Code 2010.

As you are aware this was complete as of the end of March, however John Ivison asked that we review his comments and incorporate them. We met with John and have reviewed and incorporated his comments as we feel appropriate.

We are submitting both electronic and hard copies to your office.

We look forward to discussing this and future work with you.

Yours truly,
GHL CONSULTANTS LTD

Andrew Harmsworth

Andrew Harmsworth, M Eng, P Eng, CP

Enclosure

cc	Bob Thompson	Building and Safety Standards Branch	P 250 356 8903	E bob.thompson@gov.bc.ca
	John Ivison	Wood Enterprise Coalition	P 604 222 5715	E johnivison@wecbc.ca

AH/lf P:\PRJ\35\3517.04 - Mid-Rise Wood, Group D\Report\Henzler - HT Report Cover (3517.04).doc

GHL CONSULTANTS LTD

409 GRANVILLE STREET, SUITE 950
VANCOUVER, BC V6C 1T2 CANADA

P 604 689 4449
F 604 689 4419
www.ghl.ca
Holder of AIBC Certificate of Practice

STUDY OF 8 STOREY HEAVY TIMBER BUILDINGS OF GROUP D (BUSINESS AND PERSONAL SERVICE) OCCUPANCY

Prepared for

Forestry Innovation Investment Ltd
1200 – 1130 West Pender Street
Vancouver, BC
V6E 4A4

April 23, 2012

GHL File BSP-3517.04

EXECUTIVE SUMMARY

This report examines the prospect of allowing 8 storey heavy timber 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 8 storey heavy timber 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. Within this framework, a qualitative risk analysis can be carried out to study the risk of the proposed 8 storey heavy timber building based on the acceptable risk in other types of construction categories currently permitted.

In this study, 8 storey heavy timber office occupancies are analyzed, assuming an interpolated 1.5 hour fire resistance rating and a maximum building area of $3600m^2$. 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. 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 8 storey heavy timber 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 8 storey heavy timber buildings of Group D occupancy, provided that the building area is restricted and certain measures are taken to address issues specific to heavy timber construction.

Certain areas of concern were identified such as exterior cladding construction, ceiling flame spread and concealed spaces and interconnected floor spaces.

Based on the outcome of the study, Code changes to permit 8 storey heavy timber buildings of Group D occupancy are proposed and areas of future work are identified, including provisions to mitigate the risks identified.

The report also notes that it is not suggested that 8 storeys is the limit for heavy timber or 1.5hour buildings, only that this was the conceptual building that was the subject of this study. Further research is needed in this area, and in the area of applicability of these ideas to highrise buildings.

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 8 storey heavy timber 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 8 storey heavy timber 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 8 storey heavy timber 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:

Mr. Ben Henzler
Director, Wood First
Forestry Innovation Investment Ltd
1200 – 1130 West Pender Street
Vancouver, BC
V6E 4A4

TABLE OF CONTENTS

1.0 BASIS OF REPORT

1.1 PURPOSE

GHL was initially requested by FII to perform a study of 6 storey wood frame Group D (Office) buildings. In the course of that study it was apparent that many of the concerns implicit in the Code for light timber frame buildings are not applicable to buildings of heavy timber construction. GHL has subsequently been requested by FII to revise the study on 6 storey buildings to address only light timber frame, and based on that study, to prepare this engineering report aimed at extending the maximum allowable building height for heavy timber buildings of Group D occupancy from 4 storeys to 8 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 8 storey heavy timber buildings of Group D occupancy in BC. The study focuses on fire safety requirements of the Building Code only. This study builds upon the separate study on 6 storey Group D occupancy.

1.2 HEAVY TIMBER CONSTRUCTION – HISTORY AND CURRENT STATE

Heavy timber construction has a long history of use in buildings up to and including 8 storey buildings still in use in both Vancouver and Toronto. The Landing building constructed at the turn of the century in Vancouver's Gastown is an example of an 8 storey heavy timber building of Group D occupancy.

The Landing in Vancouver Gastown, a multi-tenant building constructed at the turn of the century

Although the preferred material for construction of large buildings at the turn of the last century, heavy timber fell out of use in the middle of the last century. The 1953 edition of the National Building Code included specific construction categories for heavy timber with different allowable building sizes to those permitted for protected light timber or unprotected steel [21]; however, in an effort to simplify the Code, and probably recognizing the unavailability of large timber members as old growth timber became unavailable, this was removed from the Code.

1.3 MODERN HEAVY TIMBER CONSTRUCTION – HISTORY AND CURRENT STATUS

In recent years a number of new heavy timber products have emerged, initially in the form of glued-laminated timber, and more recently in the form of laminated veneer lumber (LVL), parallel strand lumber (PSL) and cross-laminated timber (CLT). Further analysis of the current status of heavy timber construction in Canada and the US is found in the CFT Engineering Report [21].

The introduction of these new heavy timber products provides opportunities to introduce the use of heavy timber construction in modern buildings. Large CLT buildings, up to 11 storeys are completed or under construction in Europe. Heavy timber elements are now incorporated in a 6 storey office building in Quebec, and the UBC Earth Systems Science Building, a 5 storey university building of mixed heavy timber and concrete construction, is nearing completion.

University of British Columbia, Earth Sciences Building

The Building Code currently assigns a 45 minute fire resistance rating to heavy timber construction when the minimum dimensions are met; however, greater fire resistance ratings can be afforded based on increasing the member's cross sectional area. Methods of calculating fire resistance ratings of modern heavy timber products have been developed for ratings up to and including 2 hour fire resistance ratings. Recent small and full scale loadbearing tests have also demonstrated that heavy timber elements can reliably achieve fire resistance ratings up to and exceeding 2 hours. Further details on current calculation methodologies can be found in various fire engineering textbooks; the draft CSA 086 document "*Fire Resistance Design of Solid Sawn and Glued Laminated Timber Members*" [22] provides a good summary; calculation methodologies for one form of modern heavy timber, cross laminated timber is found in the CLT Handbook [16].

1.4 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 8 storey heavy timber buildings of Group D occupancy, focusing on fire safety issues.
- Recommendation of appropriate Code changes to enable 1.5 hour fire rated heavy timber buildings of up to 8 storeys.

It is important to note that GHL was asked to address 8 storey 1.5 hour fire rated construction for non-highrise buildings. It is not within the scope of this study to examine what the appropriate high limit for a 1.5 hour fire rated building would be, or to address the added complications of a highrise (or high) building as defined in the BC Building Code.

1.5 GHL'S PREVIOUS STUDIES ON GROUP C AND D OCCUPANCIES

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]. This Group C study addressed the technical and process risks, which for clarity have been re-named designed risk and contingent risk respectively.

1.6 DEFINITIONS OF RISK

This study addresses two types of risk, 'Designed Risk' and 'Contingent Risk', 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 8 storey heavy timber buildings of Group D occupancy would have the same fire risk (or afford the same level of fire safety) as 1 hour 6 storey noncombustible Group D buildings currently permitted by the Building Code, assuming buildings can be built in full compliance with the Building Code. The earlier study referred to this 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. The earlier study referred to this as the process risk.

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 an 8 storey heavy timber building is compared to that of an 4 storey sprinklered light wood frame 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).

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
- Canadian Wood Council
- Wood Enterprise Coalition
- City of Vancouver

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 practice, it is possible for an assessment and decision to be made regarding greater allowance of heavy timber 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.

Should the BC government decide to proceed with amending the Code to permit 8 storey heavy timber buildings of Group D occupancy, further public consultation is recommended.

1.8 ASSUMPTIONS AND DEFINITIONS

This report is based on the following assumptions:

- **Heavy Timber Construction**

  This study uses the term heavy timber construction to refer to all forms of mass timber where the dimensions of the timber are sufficiently large as to provide a minimum fire resistance rating of 45 minutes. This is consistent with the Building Code definition of "*Heavy timber construction means the type of combustible construction in which a degree of fire safety is attained by placing limitations on the sizes of the wood structural members and on thickness and composition of wood floors and roofs and by the avoidance of concealed spaces under floors and roofs*".

It is noted that during the lifetime of a heavy timber building, some concealed spaces may inevitably be created through renovations and installation or modification to the ceiling; however, heavy timber construction, by the manner in which it is constructed (with mass timbers utilized as floor decking, beams and columns similar to reinforced concrete and steel construction), effectively has very few or no concealed spaces relative to conventional light wood frame construction, in which the floor and wall systems are based on an assembly of small dimensional lumbers.

- **Traditional Heavy Timber Construction**

  Heavy timber, as defined in the Building Code, is considered to have a 45 minute fire resistance rating and unprotected steel connections.

- **Engineered Heavy Timber or Mass Timber Construction**

  Heavy timber or mass timber construction calculated in accordance with generally accepted engineering methodology, has the required fire resistance rating of more than 45 minutes, complete with fire protected connections.

- **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**

  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 real and perceived 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 currently required to use noncombustible construction with 2 hour 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	Maximum Building Height	Construction Type	Floor and Support Fire Resistance Rating	Sprinkler Protection
Low-Rise	3 Storeys	Combustible	45 minute	Yes and No
Low-Rise	4 Storeys	Combustible	1 hour	Yes
Mid-Rise	6 Storeys	Noncombustible	1 hour	Yes and No
High-Rise	Unlimited	Noncombustible	2 hour	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. The Code does not distinguish between conventional light wood frame construction and heavy timber construction.

The high-rise category in Table 1 relates to construction requirements only and does not relate to the high building requirements to Subsection 3.2.6 of the Code.

Although an examination of the history of the Code development for construction requirements is outside the scope of this study, it can generally be 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 the basis of the construction requirements 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 3.2.2.49	Article 3.2.2.50	Article 3.2.2.51	Article 3.2.2.52/54
Construction	Noncombustible	Noncombustible	Noncombustible	Combustible
Sprinkler Protection	Yes	No	Yes	Yes
Fire Rating of Floor and Structural Supports	2 hour	1 hour	1 hour	45 minutes or 1 hour
Maximum Building Height	Unlimited	6 storey	6 Storeys	4 Storeys
Maximum Allowable Building Area (facing one street)				
1 Storey	Unlimited	Unlimited	Unlimited	14400m^2 (45 minutes)
2 Storey	Unlimited	7200m^2	Unlimited	7200m^2 (45 minutes)
3 Storey	Unlimited	4800m^2	14400m^2	4800m^2 (45 minutes)
4 Storey	Unlimited	3600m^2	10800m^2	3600m^2 (1 hour)
5 Storey	Unlimited	2880m^2	8640m^2	Not Permitted
6 Storey	Unlimited	2400m^2	7200m^2	Not Permitted

* Note: It is necessary to combine the requirements of Articles 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 wood construction used in practice: light wood framing (also known as platform framing) using dimensional lumber and engineered wood; and ‘heavy’ timber framing. In light wood frame construction, lumber is framed to form walls and floors. Light wood frame construction is generally covered by gypsum board to conceal insulation and services within the framed assemblies, as well as to meet fire safety requirements such as flame spread rating, integrity of fire separation and fire resistance rating. In heavy timber construction, large mass timbers are used to form a structural frame and are generally left exposed as their large mass provides an inherent degree of fire resistance and resistance to ignition. In some cases, they may be surface treated by fire retardant chemicals to meet flame spread rating requirements or covered by gypsum board to provide higher fire resistance ratings.

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 resistance to ignition 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 is 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 combustible 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, light steel framing construction is generally 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 wood for fire safety reasons without taking into account differences in performance of light wood frame, conventional heavy timber or engineered heavy timer systems [5].

2.3 DEVELOPMENTS IN TECHNOLOGY

The restrictions for use of wood in building construction remains, in our opinion, disproportionately conservative in comparison to other construction materials and does not necessarily reflect the state-of-the-art fire engineering designs available today. As the prescriptive Codes in Division B are generally written in anticipation of construction with the lowest level of performance, which in the case of 'combustible construction' means light wood frame construction, the Code seems to unfairly penalize the superior performance expected in heavy timber construction, which also falls into the 'combustible construction' category. This point is discussed further in Section 2.6.

2.4 COMBUSTIBLE CONSTRUCTION AND COMPARTMENT FIRE

The general concern with wood construction is that as a combustible material, it 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 the 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.

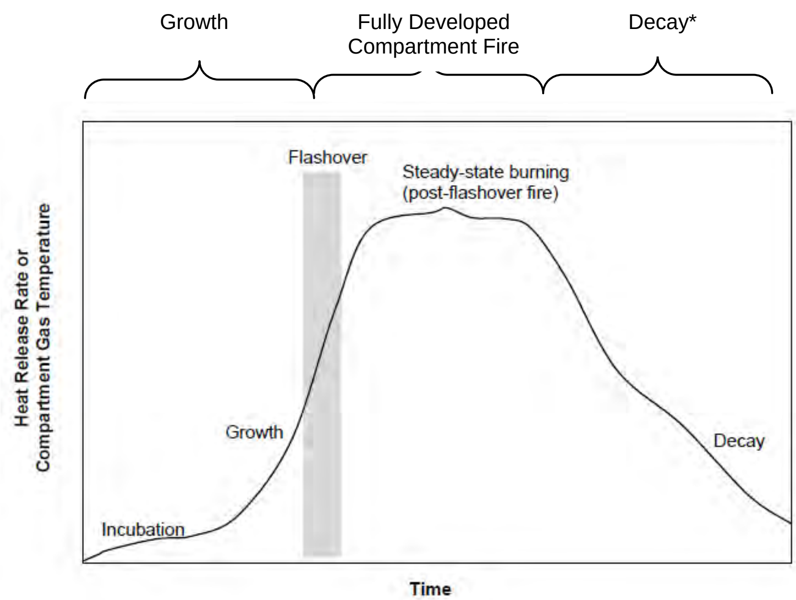


Figure 1. Schematics of a typical compartment fire history [6]. *The decay phase is not currently addressed by the Building Code.

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 forms the majority of the 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 intentionally general, this statement makes no reference to the acceptable level of combustion. Light wood frames, when exposed to fire, will contribute significantly to a fire, whereas massive wood members of heavy timber will have relatively minimal contribution.

In the event that the fire does progress to reach flashover, where 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].

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 heavy timber buildings of Group D occupancy, the following key questions need to be considered:

1. How are heavy timber buildings designed to limit the involvement of wood during the pre-flashover stage?

2. How are heavy timber buildings designed to limit spread of fire and smoke beyond the compartment of fire origin?

3. How are heavy timber 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 heavy timber buildings designed to remain structurally sound should the compartment fire become fully developed?

5. How are heavy timber 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 mid-rise buildings of Group D occupancy identified in Table 2, and compares their performance in these areas to the proposed 8 storey heavy timber building of Group D occupancy presented in Section 3.4. This forms the core of the analysis of designed risk presented in the next section of this report.

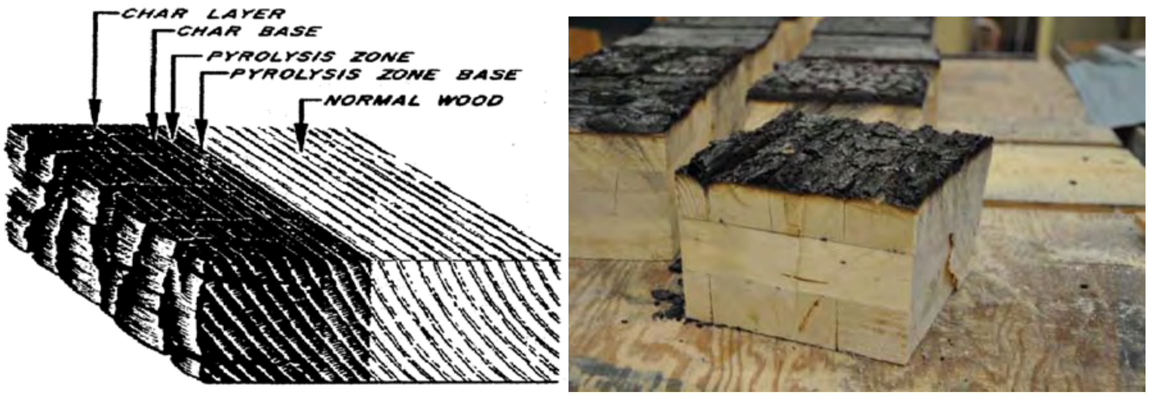
2.5 FIRE RESISTANCE RATING

The performance of assemblies required to have a fire resistance rating, such as walls, columns and beams, 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 ¾ hours, 1 hour, and 2 hours. 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 1 hour 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.

2.6 FIRE RESISTANCE OF HEAVY TIMBER CONSTRUCTION

A heavy timber member has an inherent level of fire resistance based on its relatively large mass to surface area ratio. When exposed to fire, wood undergoes a thermal decomposition process known as pyrolysis [4, 11]; within the pyrolysis zone, combustion takes place between the hydrocarbon gases released from the pyrolysis process with oxygen in the air. However, because of the inefficiencies associated with the combustion process, not all wood cellulose undergoes combustion; the decomposed wood that did not participate in combustion forms a zero-strength layer called the char layer, which exhibits significant thermal insulation properties. The formation of the char layer limits the extent of the overall combustion process as it limits the exposure of the wood to the fire and oxygen.

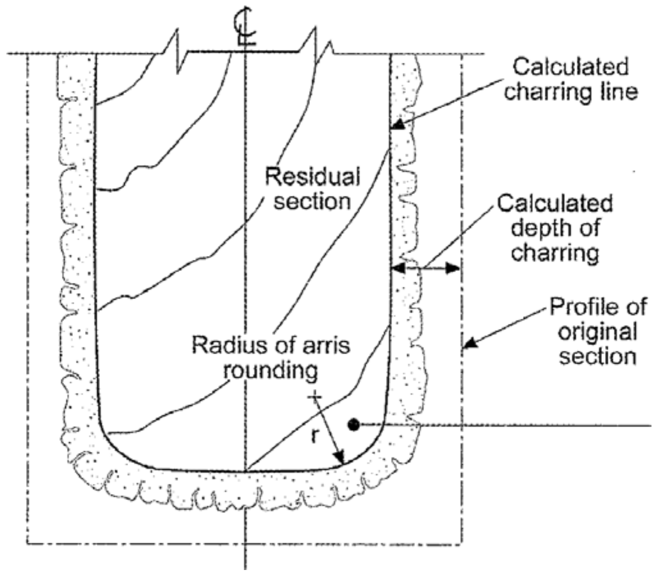
Because large timber members have greater strength, heavy timber construction is fundamentally different from light wood frame construction. Heavy timber construction is in fact more similar to steel / concrete construction where structural members are each a structural element and are generally strong enough to be positioned significantly apart to support larger spans. As such, the charring of wood coupled with greater separation of structural members allow heavy timber construction to afford significantly better fire performance. In contrast, light wood frame construction has an inherently lower level of performance in fire due to the use of 2 by 4 members in close proximity to form wall or floor assemblies. Even though wood chars in fire, the close-proximity of the framing members allows significant radiation and convection heat transfers between the framing members such that the net effect is more rapid combustion of the assembly. Therefore, light wood frame construction only affords practical fire resistance ratings when protected by fire resistive membranes such as gypsum board.



(a) Schematic illustration of and (b) photograph of the char layer in a wood member underwent combustion.

The Building Code currently provides methods of calculating fire resistance ratings for solid wood walls, floors and roofs and glued-laminated timber beams and columns in Appendix D. Appendix D already recognizes laminated timber walls and floors and glue laminated timber up to 1 hour.

The calculation methodology for wood members is generally based on the fact that wood, in a standard fire test, chars at a relatively constant rate, with wood below the char level heating with a sharply dropping temperature profile, such that wood 7 to 15mm below the char level can be considered unaffected by fire. This is illustrated in the following diagram.



Char Methodology of Calculating Fire Resistance

The calculation methods for wood in Appendix D of the Building Code, while valid, have not been updated to account for various other modern engineered heavy timber products currently available in the market, such as LVL and CLT. In addition, the empirical equations presented in Appendix D for glued-laminated timber beams and columns are organized in a fashion that do not rationally express the fire and structural physics relating to timber members under structural and fire loading.

Notwithstanding this, a more generalized methodology for calculating the structural fire resistance of heavy timber structures is being developed by the CSA 086 Task Group on Design for Fire Resistance. In addition, for one form of modern heavy timber, Cross-Laminated Timber, FPInnovations has provided a design guide on calculating fire resistance for that specific material, and is performing fire tests to confirm and refine this calculation methodology. Essentially, the methodology for structural fire-resistance is one of satisfying the limit states criterion during fire as given by:

$$U_{fire} \leq \Phi_f R_{fire} \tag{1}$$

where U_{fire} is the design action from the applied load at the time of the fire; Φ_f is the strength reduction factor for the timber material; and R_{fire} is the nominal load capacity at the time of the fire, which is required to be calculated based on a reduction in the member's section factor due to charring. Depending on building occupancy, type of timber material, type of structural member, and fire loading, the variables in Eq. (1) will be determined by the designer.

2.7 RECENT TESTING OF HEAVY TIMBER

One particular form of modern heavy timber, Cross Laminated Timber, has been subject to a series of full scale tests up to and exceeding 2 hours by FPInnovations, including load bearing walls and floors, both directly exposed to the furnace and protected by gypsum wallboard membranes and incorporating joints. At the time of the writing of this report, the full series of full scale tests have not been completed, nor have the results been published; however the author can confirm that these tests have generally confirmed the char rate analysis methodology, and it is anticipated that the results of these tests will be made available to fire engineers working with heavy timber.

2.8 HIGH BUILDING REQUIREMENTS

This report does not address the implications of high buildings. High buildings are a category of building where the building height, in combination with high occupant loads can require more complicated fire fighting techniques including potential staging of firefighting operations within the building.

Sentence 3.2.6.1.(1) of Division B of the Code contains a formula that provides for the classification of a building as a high building, taking into account the height and occupant load for buildings between 18m and 36m in height as follows:

This Subsection applies to a building

a) *of Group A, D, E or F major occupancy classification that is more than*

i) *36 m high, measured between grade and the floor level of the top storey, or*

ii) *18 m high, measured between grade and the floor level of the top storey, and in which the cumulative or total occupant load on or above any storey above grade, other than the first storey, divided by 1.8 times the width in metres of all exit stairs at that storey, exceeds 300,*

This report has not reviewed this formula, and it is suggested that further study is appropriate as to whether the 1.5 hour classification proposed should be equally applicable to buildings classified as high buildings.

3.0 ANALYSIS OF DESIGNED RISK

The risk analysis performed in this study evaluates an 8 storey heavy timber 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 currently available.

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.

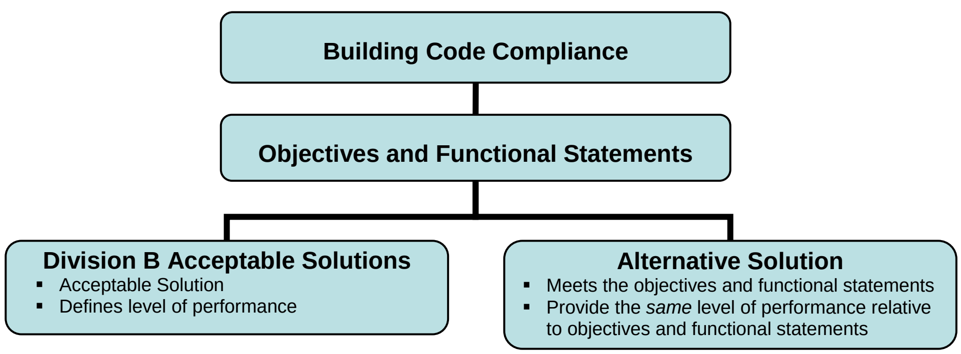


Figure 2. Summary of the two approaches available for Building Code compliance.

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 (i.e. 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 practical to provide a quantitative analysis to evaluate the risk of an 8 storey heavy timber 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 8 storey heavy timber 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 type 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 an 8 storey heavy timber 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 currently exist in the Building 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 an 8 storey heavy timber building of Group D occupancy having a maximum building area of $3600m^2$. The proposed maximum building area is based on doubling the construction volume permitted by Article 3.2.2.50 for an unsprinklered Group D building of noncombustible construction. Article 3.2.2.50 would permit a gross area of a 6 storey building to be $14400m^2$ (6 storeys $\times$ $2400m^2$). Multiplying this figure by a factor of 2 then divided by 8 storeys yields the proposed $3600m^2$ maximum allowable building area for an 8 storey building. As the building area limitations in Subsection 3.2.2 appear to have limited technical justification, the proposed building area is simply based on doubling the gross area of what is permitted by Article 3.2.2.50, which is regarded as reasonable given the higher 1.5 hour fire resistance rating and sprinkler protection in the proposed building as summarized in Table 3.

Table 3. Comparison of the proposed 8 storey heavy timber building characteristic versus a building permitted by Article 3.2.2.50.

	Article 3.2.2.50	Proposed
Construction Type	Noncombustible	Combustible – Heavy Timber
Occupancy	Group D	Group D
Building Height	6 Storey	8 Storey
Building Area	$2400m^2$	$3600m^2$
Gross Floor Area	$14400m^2$	$28800m^2$
Fire Resistance Rating	1 hour	1.5 hour
Sprinkler Protection	No	Yes

3.5 INTERPOLATION OF FIRE RATINGS

GHL was specifically asked to review the possibility of 8 storey engineered heavy timber buildings.

The current Code has a substantial jump from 1 hour fire ratings to 2 hour fire ratings. As a function of the fact that a char rate analysis, or the addition of protective material, is typically linear, a doubling of the required fire rating from 6 storeys to 7 or 8 storey implies a significant increase in the quantity of fire protective material, whether sacrificial wood or added membrane protection in the form of gypsum wallboard.

With many occupancies, the majority of buildings exceeding 6 storeys would be high buildings, within Group D, the Code provides a method of calculation for buildings between 18m and 36m where such buildings are not considered high buildings. The distinction between a high building and a building that is not a high building relates to both the time and ability to evacuate the building and the need for interior fire fighter staging operations.

It is clear that a building of unlimited height poses a significantly greater consequence and risk of failure due to fire than a building of 6 storeys, but commensurately, a building of 7 or 8 storeys would only pose a proportionally slightly greater risk of failure than a building of 6 storeys.

This report therefor proposes interpolating between the 2 hour fire rating requirement for 6 storey Group D building and an unlimited height Group D building with a 1.5 hour fire rating requirement for 7 and 8 storey Group D buildings.

It is important to note that GHL was asked to address 8 storey 1.5 hour fire rated construction for non-highrise buildings. It was not within the scope of this study to either examine what the appropriate high limit for a 1.5 hour fire rated building would be, or to address the added complications of a highrise (or high) building as defined in the BC Building Code.

Although this approach is primarily based on interpolation of the existing requirements of the BC Building Code, it is significant that many other jurisdictions use a maximum required fire resistance of 90 minutes for office buildings, including the United Kingdom's Building Regulations 2000 (effective 2007) and other European countries.

3.6 COMPARISON BUILDINGS

In our analysis, we compared the proposed 8 storey heavy timber 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 1 hour fire resistance rating for floors and supporting structures (see Table 2). It is assumed that the building will have structure, floor and exit fire separations of 1.5 hour fire resistance ratings based on heavy timber construction. Within the proposed heavy timber building, the following elements would likely be of light timber framing.

- Exterior wall infill framing
- Interior walls
- Interior fire separations other than floors (with gypsum wallboard protection)
- Dropped ceilings and bulkheads
- Roof infill framing

It is noted that NFPA 13 has specific requirements for sprinkler protection and compartmentation of wood spaces within light frame buildings.

Consistent with larger buildings and the 6 storey residential construction of Article 3.2.2.45, exterior cladding for the proposed building would be that permitted for noncombustible buildings in Article 3.1.5.5.

This report contemplates exterior walls of infill framing between heavy timber floors only. Curtain wall or balloon framing of wood is not contemplated.

3.7 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 heavy timber 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 heavy timber office building would be the same as that of a noncombustible office building of the same size and area.

It is not within the mandate of this report to compare a heavy timber office building with a 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.

3.8 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.

3.9 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, 3.2.2.52 for Group D, Up to 4 Storeys, Combustible Construction, Sprinklered, and 3.2.2.49, Group D, Unlimited Height.

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.

3.10 ANALYSIS

3.10.1 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.

Based on the use of sprinklers and fire separations, an 8 storey heavy timber building with a 1.5 hour fire resistance rating protected by a sprinkler system is expected to have a lower risk of fire spread than a 6 storey noncombustible building with 1 hour fire resistance rating without a sprinkler system. For the comparison building of Article 3.2.2.50, as there is no sprinkler system, the only mechanism in place to limit fire spread within the building is through fire separations; therefore, there is a greater reliance on the fire separation system. In a typical steel stud building, the fire resistance rating of the separation is derived principally from the gypsum board.

In comparison, the proposed 8 storey heavy timber building will have inherent fire resistance based on the heavy timber walls, which is more reliable than a steel stud wall; or based on non-load bearing light wood frame partition walls serving as a fire separation, which also relies on the gypsum board membrane, but is no different than a steel stud wall. In addition, the 8 storey heavy timber building will be protected by sprinklers such that the thermal stress on the fire separations will be low, based on sprinklers lowering the compartment temperature. On a probabilistic basis, fire separations will only be expected to be stressed thermally at their design capacity in the 5% to 1% range when sprinklers fail. In comparison, a 6 storey unsprinklered building will have fire separations potentially exposed to their design limit 100% of the time.

For the proposed 8 storey heavy timber building, it is likely that the heavy timber construction will be left exposed. In our opinion, this should perform no differently than a compartment within a noncombustible building permitted to have up to a 25mm thick wood wall finish. With respect to exposed wood ceiling, in order to maintain the same level of performance as a noncombustible building (which permits up to a 25mm thick wood ceiling finish, provided it has an FSR of 25 on any surfaces that could become exposed by cutting), the exposed wood ceiling in the proposed heavy timber building will be fire retardant treated to reduce the FSR to not more than 25. With respect to the requirement for FSR of 25 on any surfaces that could become exposed (fire retardant impregnation treatment), in our opinion, this requirement is not required if it is the heavy timber floor that is exposed, as fire retardant treatment subsequent to the erection of the structure will be reliable and there will be minimal cutting to the structure once it has been constructed. On the other hand, if additional wood interior finish that is not part of the heavy timber structure is introduced, then the additional wood interior finish would need to be fire retardant treated to reduce the FSR to 25 on any surfaces that may become exposed.

In our opinion, based on the foregoing assessment and measures, the use of heavy timber in an 8 storey building of Group D occupancy will therefore not likely increase the risk of flashover related fire spread.

Should the fire progress to flashover and become fully developed, the sprinklered 8 storey heavy timber building is expected to perform in a superior manner to a 4 storey sprinklered light wood frame building or 6 storey unsprinklered noncombustible building based on 1 hour rated fire separations. The use of 1.5 hour rated fire separations in an 8 storey heavy timber building will offer an enhanced 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.

It should be noted that for an 8 storey heavy timber building, the use of combustible insulation may have a material impact on the risk of interior fire spread and could attribute to flashover. Without further experimental study, this report assumes that combustible insulation will be protected in accordance with Article 3.1.5.12 for buildings of noncombustible construction.

In conclusion, the risk of fire spread beyond point of origin within the 8 sprinklered storey heavy timber building will be less than in a 6 storey noncombustible building.

3.10.2 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 type 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 of fire and smoke migration 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]:

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

2) 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.

3) 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.

With regard to the proposed 8 storey heavy timber 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 an 8 storey heavy timber 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 found in 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 8 storey heavy timber 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.

Larger multi-level floor openings described in Clause 3.2.8.1.(1)(b) are currently permitted in heavy timber buildings, provided heavy timber construction is used. As the construction Articles in Subsection 3.2.2 do not specifically specify heavy timber construction, but rather combustible or noncombustible construction, a building permitted to use combustible construction could be of light wood frame construction. In allowing large interconnected floor spaces of Clause 3.2.8.1.(1)(b) for heavy timber construction, the Code recognizes the inherent difference in performance between light wood frame and heavy timber construction. That is, with respect to vertical fire and smoke spread through floor openings in a large atrium, the Code deems heavy timber construction as having the same degree of performance and reliability as noncombustible construction.

In large interconnected floor spaces, the general concern is the rapid spread of smoke to multiple storeys. This is currently addressed by the Building Code through smoke protected vestibules for exits, protected floor spaces and elevators if required, and cumulative exiting, which are aimed at evacuating the occupants in a tenable environment. In a large open space, heavy timber construction will not likely have a significant contribution to the production of smoke based on the charring phenomenon and the fact that timber members will be situated in a large open space with significant heat loss, which limits the extent of heavy timber construction becoming involved in the fire. Based on the use of smoke protected vestibules for exits, protected floor spaces and elevators if required, and cumulative exiting, in our opinion, heavy timber construction will not likely have a material impact on smoke protection during the early stages of the fire when evacuation is expected to take place. Notwithstanding this, in buildings over 6 storeys, the effects of stack action driven by the difference in interior and exterior temperatures, particularly in certain regions of BC during winter months, can be significant. Without additional modelling and experimental study, it is difficult to estimate the impact of heavy timber construction.

With respect to fire spread, the Building Code currently acknowledges the effectiveness of sprinklers for up to 8m in Article 3.2.8.9, where the combustible content limitation comes into effect if the floor to ceiling height exceeds 8m. The Code requirement, which was developed prior to the availability of quick response sprinklers, deems sprinklers to be ineffective if they are positioned more than 8m from the floor, and as such requires the combustible content to be limited. In light of the fact that a heavy timber building will be permitted to have combustible construction in general, such as a wood stairway, without being considered as the building content, we see some increase in fire spread risk if the effectiveness of the sprinkler system cannot be ascertained. Therefore, based on this consideration, and the concern for stack effect on smoke spread in higher timber buildings, and the lack of available experimental data to provide an informed engineering judgment on the expected performance of large interconnected floor spaces in large heavy timber buildings, the extent of the interconnected floor space permitted by Clause 3.2.8.1.(1)(b) should be limited to 4 storeys or maximum 12m, from the floor of the lowest storey to the ceiling of the uppermost storey within the interconnected floor space. It may be possible to permit a larger extent of the interconnected floor space, for example, to 8 storeys or 24m, if features such as enhanced sprinkler protection through increased sprinkler design density and limitation on flame spread rating to not more than 25 for all wall and ceiling finishes are proposed. In our opinion, these features could be addressed through alternative solutions.

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 exempted in Article 3.2.8.2 and will not likely increase for interconnected floor spaces of Clause 3.2.8.1.(1)(b) when additional measures are implemented.

3.10.3 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 in comparison to an unsprinklered 6 storey noncombustible building through the requirement for full sprinkler protection of 8 storey heavy timber construction. Previous editions of the Code contained specific provisions, such as spandrels, to address this concern for mercantile occupancies; however, these provisions were removed as part of the Code changes that introduced the requirement for sprinkler protection of all larger mercantile and industrial buildings; that is, the Code recognizes that provision of sprinkler protection is an appropriate method to address the risk of flame spread on the exterior of the building.

In conclusion, provided the cladding meets the existing requirements for control of flame spread on the exterior of the building, the risk of fire spread beyond point of origin via the exterior will not likely increase over that of a 6 storey noncombustible unsprinklered building, and will significantly decrease due to internal control by sprinklers.

3.10.4 Risk of Fire Spread to / within Concealed Spaces

A building of heavy timber construction would not be required to conform to Subsection 3.1.5 (except for protection of combustible insulation as discussed in Section 3.9.1) and could contain significant additional combustible elements in comparison to a noncombustible building. As such, the probability of fire spread within concealed spaces is higher than for a noncombustible building.

Discussions at the NRC consultation group, and with fire engineers involved in fire investigation indicate that current sprinkler and fireblocking requirements of the 2010 NBC, when implemented correctly, are effective. Similarly sprinkler protection of all void spaces, or the more onerous fireblocking requirements of NFPA 13 will provide effective and appropriate protection from such an event.

Therefore, the probability of fire spread in void spaces is higher than in a noncombustible building. However, compared to a 4 storey sprinklered wood frame building, the consequences of such fire spread are minimal. In the event of fire spread within the void spaces of a 4 storey wood frame building (that is, failure of sprinklers, gypsum membrane and fireblocking), a fire will directly affect the structural members of the building, and can potentially lead to rapid collapse, as wood truss and joist members can be expected to retain the load carrying ability in the range of 5 to 15 minutes [13]. Hence the consequence of fire spread in void spaces in a light frame building is potential rapid collapse. On the other hand, in an 8 storey heavy timber building, the number of void spaces can be expected to be minimal, inherent with the nature of heavy timber construction. Further, as the heavy timber and connections will have inherent 1.5 hour fire resistance ratings, even if fire does spread within the void spaces, unlike a 4 storey wood frame building, such fire spread will not have an immediate impact to the structure of the building as the fire resistance rating is inherent with the charring of the wood in heavy timber construction.

In other words, the lowest level of acceptable risk and consequence is set by the 4 storey sprinklered building and the proposed 8 storey building has both a lower probability of fire spread to voids (fewer voids) and a lesser consequence (no collapse).

Therefore, while the probability of fire spread within void spaces may be marginally greater than in a noncombustible building, the consequence of fire spread, in terms of threat to life safety and property damage, will significantly less than the consequence of fire spread in an unsprinklered 6 storey building, or a sprinklered 4 storey wood frame building.

Therefore the risk (probability and consequence) of fire spread within void spaces is less than the acceptable minimum level of risk, namely that set by a sprinklered 4 storey combustible building of light wood frame construction.

3.10.5 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 heavy timber for an 8 storey building undermines the exit strategy that the Code has in place.

Based on mandatory sprinkler protection, a sprinklered 8 storey heavy timber building of Group D occupancy, with the commensurately increase fire rating 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. The maximum travel distance in an unsprinklered floor area is 30m, compared to the maximum travel distance in a sprinklered floor area of 45m; however, 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 via a sprinklered floor area with longer travel path of 45m than via 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], it would take 53 seconds to traverse 45m, and 35 seconds to traverse with 30m. This 18 second difference is negligible 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. The additional 2 storeys of exit travel is insignificant, as it relates to less than 1 minute of additional exit time, and occurs within the 1.5 hour protected stair shaft.

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 heavy timber 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 8 storey heavy timber building offers significantly greater level of safety in terms of providing a tenable environment for evacuation than an unsprinklered noncombustible building.

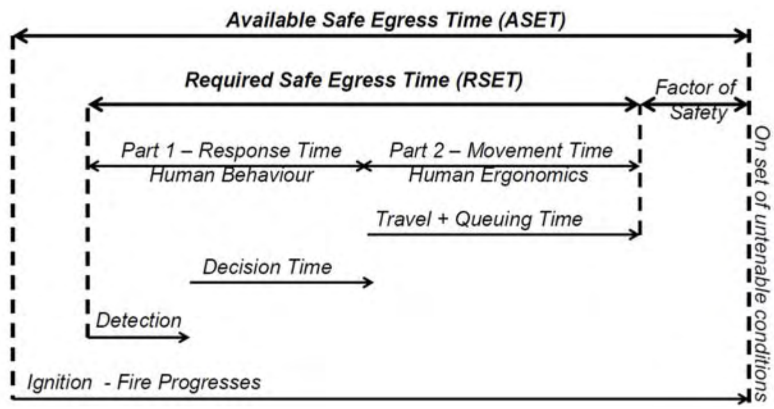


Figure 3. Schematic illustration of evacuation timelines

In conclusion, the risk of occupants not being able to evacuate the building will not likely increase compared to a fire in an equivalent 6 storey noncombustible building. In addition, a sprinklered heavy timber building is fundamentally safer; this reduces the risk to occupants in case of evacuation and offsets the minor additional vertical travel distance.

Therefore the lowest level of performance is provided by the unsprinklered 1 hour fire rated 6 storey Group D building. The proposed 8 storey 1.5 hour fire rated heavy timber building will provide a lower level of risk of occupants being unable to evacuate, than the 6 storey unsprinklered noncombustible Group D building.

3.10.6 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 an 8 storey heavy timber 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 and the provision of 1.5 hour fire separations to stair and elevator enclosures.

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 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 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.

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.

A critical risk to firefighters in wood frame construction is fire spread within voids attacking structural elements resulting in premature and unexpected collapse of floor assemblies. Although the fact that the fire rating is inherent to the heavy timber, this risk related to 4 storey wood frame buildings does not exist in heavy timber buildings. As noted in Section 3.9.4 above, the probability of fire spread within void spaces is reduced. Further, the consequence of fire spread within void spaces in a 4 storey light wood frame building is the potential for collapse, whereas the consequence of fire spread within void spaces of a heavy timber building does not include the probability of collapse.

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 1 hour 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 buildings and recognizes the reliability and effectiveness of automatic sprinkler systems.

There is a very significant benefit to firefighting operations afforded to an 8 storey Group D heavy timber building with full sprinkler protection in that it would require significantly less firefighting resources than an unsprinklered noncombustible 6 storey building with a 1 hour fire resistance rating.

In conclusion, the risk of the fire service being unable to conduct effective operations is less than in an 8 storey sprinklered building than in a 6 storey noncombustible building.

3.10.7 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 an 8 storey heavy timber 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 heavy timber and the probability of the compartment reaching flashover.

The use of heavy timber for structural purposes will not have a significant impact on the severity of a post-flashover compartment fire. First, while heavy timber may become involved in the fire in a post-flashover event, this will generally be limited in a properly constructed building. 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 heavy timber in the building's construction will not make a significant contribution to overall compartment temperature.

While the use of heavy timber will not have a significant impact on the maximum compartment temperature, an 8 storey sprinklered heavy timber 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 keep 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 of sprinklers, a sprinklered heavy timber building 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 8 storey heavy timber building of Group D occupancy.

In conclusion, the risk of fire spread to neighbouring buildings will be less than in a 6 storey noncombustible unsprinklered building.

3.10.8 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, 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 an 8 storey heavy timber building is required to have the greater 1.5 hour fire resistance rating compared to the 1 hour fire rating of 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 fire spread beyond the compartment will be the same.

In conclusion, the risk of fire spread beyond the compartment of fire origin will be less than in a 6 storey unsprinklered noncombustible building.

3.10.9 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 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.

For timber buildings of 7 and 8 storeys in building height, our review of Subsection 3.2.2 requirements and assessment of the heavy timber performance is that it may be appropriate to create a 90 minute fire resistance rating category for these tall, non-high buildings. This fire resistance rating category, which would equally apply to steel and concrete construction, is explained as follows.

The current Code has a substantial increase from 1 hour fire resistance rating for mid-rise buildings in the 4 to 6 storey range to 2 hour fire resistance rating for buildings over 6 storeys. As a function of the fact the addition of protective material, which in the case of wood is the formation of the char layer, is typically linear, a doubling of the required fire resistance rating from 1 hour for 6 storeys to 2 hours for 7 storeys implies a material increase in fire risks from 6 storeys to 7 storeys, which does not appear to be rational.

For many 'higher hazard' occupancies, the majority of buildings exceeding 6 storeys would be high buildings; however, for 'lower risk' occupancies such as Group D, the Code provides a method of determining the high building classification for buildings between 18m and 36m based on the exit capacity and occupant loads. Under this provision, the distinction between a high building and a non-high building relates to both the time and ability to evacuate the building and the need for interior fire fighter staging operations.

It is clear that a building of much greater height, for example 50 storeys, poses a significantly greater risk of failure due to fire than a building of 6 storeys, but commensurately, a building of 7 or 8 storeys would only pose an incrementally elevated risk of failure than a 6 storey building.

This report therefore proposes interpolating between the 1 hour fire resistance rating requirement for a 6 storey Group D building and 2 hour fire resistance rating for an unlimited height Group D building to yield a 1.5 hour fire resistance rating for 7 and 8 storey Group D buildings.

It is important to note that GHL was asked to address 8 storey 1.5 hour fire rated construction for non-highrise buildings. It is not within the scope of this study to examine what the appropriate high limit for a 1.5 hour fire rated building would be, or to address the added complications of a highrise (or high) building as defined in the BC Building Code.

Although this approach is primarily based on interpolation of the existing requirements of the BC Building Code, it is significant that many other jurisdictions use a maximum required fire resistance of 90 minutes for office buildings, including the United Kingdom's Building Regulations 2000 (effective 2007) and other European countries.

In addition to the time rating of the fire resistance rating, another important aspect of performance, in our opinion, is the reliability of the fire resistance rating, which is a topic that has not been discussed in the Building Code or subject to rigorous studies. Because of the framework for testing for fire resistance rating, an assembly is permitted to be tested for as many times as possible and will receive the fire resistance rating based on one successful test. In addition, as an allowance for margin of error in the furnace temperature, an assembly can be subject to a fire exposure permitted within the error margin that is the least intensive during the fire test. Therefore, in recent years, there have been numerous light-wood and light-steel frame structures receiving significant fire resistance ratings with one layer of 15.9mm Type X gypsum board protection while experimental data from research institutions such as NRC are suggesting conflicting performances. While all of this can be considered to be account for as an acceptable risk in the current Building Code regulatory framework, it is important to note that within the fire resistance testing protocol, certain type of construction is inherently more reliable – such as heavy timber and reinforced concrete – than others – such as light wood frame and light steel frame; however, the reliability of the fire resistance rating is not currently considered for the purpose of assessing the risk of structural failure due to fire.

An example of the reliability of heavy timber construction can be found in the recent Remy 6 story residential building fire in Richmond BC. As can be seen from the CBC television footage below, at the end of the construction fire (approximately 4 to 6 hour fire) the heavy timber elevator shaft remained standing, despite complete destruction of the adjacent, at that point in construction, unprotected light wood frame structure. The elevator shaft consisted of nail laminated nominal 2x6 members with a plywood inner lining. This illustrates the relative performance of heavy timber in a fire.

Therefore, provided an 8 storey heavy timber building is required to have a commensurate 1.5 hour fire resistance rating compared to the 4 storey wood building currently permitted in Article 3.2.2.52 and the unsprinklered 6 storey 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 no greater than that envisioned by the Code.

Remy Fire, May, 2011

3.10.10 Connections Between Structural Elements

Connections are a critical part of a structural framework as they are responsible for transferring the loads to the ground. Therefore, their performance in fire is critical to the performance of the overall structure in fire. While the current fire resistance test, CAN/ULC-S101, does not include a category for structural connections, it is expected by fire engineers that they are designed or otherwise protected to meet an acceptable level of performance in fire.

The proposed 1.5 hour fire resistance rating in the preceding Section is based on the assumption that connections between structural elements provide the assumed 1.5 hour fire resistance ratings. This can generally be achieved with the use of internal connections (connections concealed by the timber structural members) or connections protected by sacrificial wood or gypsum wallboard.

It is noted that another common practice is to protect exposed steel connections with intumescent paint; however, there is a lack of test data on this and what preliminary data that is available indicates that this approach may not work due in part to charring of wood exposing unpainted steel. Significant further analysis and testing is required before the use of intumescent paint on connections in these buildings. The author is not aware of any manufactures of intumescent coatings that that have tested their product on metal connection of a heavy timber building.

3.11 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, requiring 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 Section 3.4 to provide adequate exit capacity for the anticipated occupant load.

At the 8 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 or heavy timber construction. That is, many 8 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 likely compensate for the minimum Code-permitted exit capacity; however, review of this was not within the scope of this report.

3.12 SUMMARY

Generally, it is determined that there is no substantial increase in fire risk in a 1.5 hour fire resistance rated 8 storey heavy timber building given the inherent fire rating provided by heavy timber construction. When properly constructed, there is no effective difference between a heavy timber building and a noncombustible building in both pre- and post-flashover fires, with the only significant difference being the presence of some concealed spaces in wood construction. However, for heavy timber construction, while the risk of fire spread within voids remains, similar to a wood frame building, the inherent fire rating of the heavy timber means that the consequence of fire spread in void spaces is minimal in comparison to a wood frame building.

It is noted that the 1.5 hour fire rating was based on interpolation between the 1 hour fire rating required for a 6 storey unsprinklered building and the 2 hour fire rating required for a building of unlimited height. It was not with the mandate of this report to examine the question of how high a 1.5 hour fire rated building would meet the level of performance required by the Code, nor whether this was applicable to a highrise building.

In fact, based on the presence of sprinkler protection, the risks are significantly reduced in comparison to an unsprinklered 6 storey noncombustible building of 1 hour construction.

Therefore, a 8 storey heavy timber building of Group D occupancy designed in accordance with the Code with a 1.5 hour fire rating will not pose an increase in fire risk when benchmarked against the performance of 6 storey unsprinklered noncombustible construction.

4.0 ANALYSIS OF CONTINGENT RISKS

The previous section discussed the proposed 8 storey heavy timber 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, whether of combustible or noncombustible construction, are subject to contingent risks. However, it is important to recognize that similar to 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.

When properly constructed, it is not believed that the contingent risk of a heavy timer building is different from a noncombustible building; however, one specific area of concern is worth noting:

- **Fire Protection of Structural Connections**

  One contingent risk related to heavy timber buildings is the proper design and protection of structural connections to achieve the required fire resistance rating. The Building Code and the referenced CAN/ULC-S101 fire test standard currently do not address fire resistance rating for connections. The current approach to structural fire safety is based on a "component-qualifying" system whereby individual structural members such as a beam or a column are tested to demonstrate fire resistance performance, while giving no consideration for the connections. As structural connections form an integral part of the structural system and recent research has revealed the significant importance of their role in assembled frameworks in fire, it is important that good fire protection engineering practice be exercised to ensure connections are designed or protected for exposure to fire. Some common approaches to fire protection of steel connections used in heavy timber buildings include application of intumescent coating, spray-applied fire-resistive material (commonly referred to as 'fire proofing'), and using gypsum board to form a membrane protection. Because there is a lack of fire testing on connections and their protection mechanisms in fire, analytical calculations to ascertain the connection performance in fire may be required. Alternatively, connections may be designed such that they are concealed within the wood member, which can utilize the charring behaviour of heavy timber as an inherent fire protection.

Specific caution is noted with respect to intumescent and spray applied coatings as the authors are unaware of any specific testing of such protection on steel connections in heavy timber buildings. What recent testing has occurred has indicated that intumescent coating may not perform as well as expected when used for protection of steel connections in heavy timber buildings.

It is also noted that the historic good experience with unprotected steel connections in traditional heavy timber buildings may not be applicable to modern connections, as historically such connections were significantly more massive than modern connections, and generally consisted of column caps providing load distribution rather than connections relying on tensile strength.

5.0 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 Design and Practice Bulletin [19]. The proposed Code changes are underlined.

5.1 Building Area and Building Height

Article 3.2.2.5X, "Group D, Up to 8 Storeys, Sprinklered"

1) A building classified as Group D is permitted to conform to Sentence (2) provided

a) the building is sprinklered throughout,

b) it is not more than 8 storeys in building height,

c) it not defined as a high building per Subsection 3.2.6 and

d) it has a building area not more than

i) 28,800m^2 if not more than 1 storeys in building height,

ii) 14,400m^2 if not more than 2 storeys in building height,

iii) 9,600m^2 if not more than 3 storeys in building height,

iv) 7,200m^2 if not more than 4 storeys in building height,

v) 5,760m^2 if not more than 5 storeys in building height

vi) 4,800m^2 if not more than 6 storeys in building height

vii) 4,114m^2 if 7 storeys in building height, or

viii) 3,600m^2 if 8 storeys in building height.

2) The building referred to in Sentence (1) shall be of noncombustible construction or heavy timber construction used singly or in combination, and

a) floor assemblies shall be fire separations with a fire resistance rating not less than 1.5 hour,

b) mezzanines shall have a fire resistance rating not less than 1 hour,

c) loadbearing walls, columns and arches shall have a fire resistance rating not less than that required for the supported assembly

5.2 Exterior Cladding

Article 3.2.2.5X, "Group D, Up to 8 Storeys, Sprinklered"
3) Except as required in Sentence (4), a building referred to in Sentence (1) and more than 4 storeys in building height 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 3.2.2.5X.(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] and in the accompanying light frame Group D report. 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 8 storey heavy timber buildings of Group D occupancy.

5.3 Protection of Combustible Insulation

Article 3.1.4.2, "Protection of Foamed Plastics"
1) Except as required by Sentence (2), foamed plastic that forms part of a wall or ceiling assembly in combustible construction shall be protected **2)** Combustible insulation used in a building permitted to comply with Article 3.2.2.5X and is more than 4 storeys in building height shall comply with the requirements of Article 3.1.5.12.
Comments
The proposed Code change is intended to address use of combustible insulation in a heavy timber building exceeding 6 storeys permitted by Article 3.2.2.5X.

5.4 Combustible Ceiling Finish

Article 3.1.4.6, "Heavy Timber Construction"
13) Except as permitted by Sentence (14), combustible interior ceiling finishes in a building permitted to comply with Article 3.2.2.5X and is more than 6 storeys in building height shall have a flame spread rating not more than 25 on any exposed surface, or on any surface that would be exposed by cutting through the material in any direction, or are of fire retardant treated wood. **14)** Exposed combustible interior ceiling finish that is formed by the underside of a heavy timber floor in a building permitted to comply with Article 3.2.2.5X and is more than 6 storeys in building height shall have a flame spread rating not more than 25, provided there is no other combustible decorative element below the ceiling.
Comments
The proposed Code change is intended to require flame spread rating of 25 on combustible interior ceiling finishes in a heavy timber building exceeding 6 storeys in building height on the same basis as a noncombustible building, except that when the ceiling finish is the underside of the heavy timber floor, the flame spread rating is permitted to be achieved at the surface only; i.e., the "any surface that would be exposed by cutting through the material" does not apply. This is to recognize the superior performance of heavy timber construction in fire, provided that there are no other combustible decorative elements constructed below the heavy timber floor. This recommendation relates to a lack of evidence. It is hoped that testing, some of which is currently underway, may demonstrate that the probability of flashover is not increased with a heavy timber ceiling.

5.5 Interconnected Floor Space

Article 3.2.8.3, "Construction Requirements"
1) Except as required by Sentence (2), a building constructed in conformance with Articles 3.2.8.4. to 3.2.8.9 shall be of noncombustible construction, except that heavy timber construction is permitted if Subsection 3.2.2 permits the building to be constructed of combustible construction. **2)** Interconnected floor spaces in a building constructed in conformance with Articles 3.2.8.4 to 3.2.8.9 and of heavy timber construction shall not consist of more than 4 storeys or have a floor to ceiling height more than 12m, unless the effects of fire and smoke spread have been accounted for based on good fire engineering practice. (See Appendix A)
Comments
The proposed Code change is intended to permit large interconnected floor spaces of Clause 3.1.8.1.(1)(b) in a building of heavy timber construction provided the extent of the interconnected floor space is not more than 4 storeys, which is the maximum height for Group D combustible construction permitted by Article 3.2.2.52. The proposed Sentence (2) is not intended to restrict the extent of interconnected floor space if good fire engineering practice is employed to address the effects of fire and smoke spread. The Appendix A reference would include a discussion on areas of fire risk that larger interconnected floor spaces in a heavy timber building should be addressed.

6.0 FUTURE WORK

The foregoing sections have provided GHL's study on the designed and contingent risks of 8 storey heavy timber 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 and simple interpolation 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 National Research Council of Canada Task Groups. Some of this work has recently been started as found in the paper, "*Rationalization of Life Safety – Code Requirements for Mid-Rise Buildings*", by Michael Kruszelnicki as part of the NSERC funded NEWBuildS project.

  In particular, consideration should be made of heavy timber buildings of greater than 8 storeys; it is our opinion that an appropriately probabilistic risk and reliability study would likely demonstrate that 1.5 hour heavy timber construction could reasonably be extended to 10 or 12 storeys or unlimited as in Europe or Australia and New Zealand.

- **Applicability to Highrise Buildings**

  In conjunction with the review of building height and area limits for heavy timber buildings, a review of the applicability of such an approach to buildings defined by Subsection 3.2.6 of the Code is appropriate as this was excluded from the scope of this study. In the authors' opinion that such a study would likely demonstrate that the approach in this report could be extended to significantly higher buildings including buildings that are classified as high buildings.

- **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.

- **Mixed-Construction**

  It would be appropriate to review mixed construction, light timber floors or roofs in conjunction with heavy timber frames.

- **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 noncombustible 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.

7.0 CONCLUSION

This 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 8 storey heavy timber buildings of Group D occupancy with 1.5 hour fire ratings.

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 an 8 storey heavy timber 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, 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 note that further analysis and research may allow fire rated heavy timber buildings to be extended to higher buildings including highrise buildings.

Prepared by,
GHL CONSULTANTS LTD

Andrew Harmsworth

Andrew Harmsworth, M Eng, P Eng, CP

Reviewed by,

Gary Chen

K. M. Gary Chen, MASc, P Eng

GC/AH/jm/lf P:\PRJ\35\3517.04 - Mid-Rise Wood, Group D\Report\FII-6 Storey Grp D Report - Heavy Timber (3517.04).doc

REFERENCES

[1] GHL Consultants Ltd, **http://www.housing.gov.bc.ca/building/wood_frame/reports.htm**

GHL Stage 1 Report - Building Code Provisions for Residential Buildings and Identification of Technical and Process Risks

GHL Stage 2 Report - Recommended Building Code Changes to permit 5 and 6 Storey Wood-Frame Buildings of Residential Occupancy

GHL Stage 3 Report - Technical and Process Risks in 5 and 6 Storey Wood-Frame Buildings of Residential Occupancy.

[2] Ontario Ministry of Municipal Affairs and Housing. 2010. Appendix A: Mid-rise Wood Frame Construction. http://www.mah.gov.on.ca/Page9293.aspx (last accessed March 16, 2011).

[3] NRCC (National Research Council of Canada). 2006. *British Columbia Building Code 2006*. Ottawa: National Research Council of Canada.

[4] Buchanan, A. 2001. *Structural Design for Fire Safety*. West Sussex: John Wiley & Sons Ltd.

[5] Skulsky, A. 2008. *Multi-Level Wood framed Structures: Requirements for Building beyond Four Storeys – A Scoping Review*. Ministry of Labour and Citizens' Services.

[6] Drysdale, Dougal. 1998. *An introduction to fire dynamics, 2nd edition*. West Sussex: John Wiley & Sons Ltd.

[7] Interview and follow-up email correspondence with Resort Municipality of Whistler Building Department. March 2, 2011.

[8] Babrauskas, V. 1976. *Fire Endurance in Buildings*. PhD Thesis. Berkeley: University of California.

[9] ULC (Underwriters Laboratory of Canada. 2004. *CAN/ULC-S101 Standard Method of Fire Endurance Tests of Building Construction and Materials*. Toronto, Ontario: ULC

[10] SFPE (Society of Fire Protection Engineers). 2003. *Engineering Guide: Human Behaviour in Fire*. USA: Society of Fire Protection Engineers.

[11] SFPE. 2002. *SFPE Fire Protection Engineering Handbook, 3rd Edition*. Bethesda: Society of Fire Protection Engineers.

[12] Hall, J.R. 2010. *US Experience with Sprinklers and Other Automatic Fire Extinguishing Equipment*. National Fire Protection Association.

[13] Sultan, M.A. et al. 2005. *Results of Fire Resistance Tests on Full-Scale Floor Assemblies – Phase II*. Ottawa: National Research Council of Canada.

[14] Sultan, M.A. et al. 2002. *Results of Fire Resistance Tests on Full-Scale Gypsum Board Wall Assemblies*. Ottawa: National Research Council of Canada.

[15] Enjily, V. *The TF2000 Project and its impact on Medium-rise Timber Frame Construction in UK*. United Kingdom: Building Research Establishment.

[16] FPInnovations. 2011. *Cross-Laminated Timber Handbook*. Ottawa: FPInnovations.

[17] Proulx, G. and Pineau, J. 1996. *Differences in the Evacuation Behaviour of Office and Apartment Building Occupants*. Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting.

[18] Harmsworth, A. "Fire Spread in Concealed Space" Email to Helen Griffin. 10 March 2011.

[19] APEGBC (Association of Professional Engineers and Geoscientists of BC). 2011. *Structural, Fire Protection and Building Envelope Professional Engineering Services for 6 Storey Wood Frame Residential Building Projects (Mid-Rise Buildings)*. Vancouver, BC: APEGBC.

[20] Kruszelnicki, Michael, "Rationalization of Life Safety – Code Requirements for Mid-Rise Buildings."

[21] CFT Engineering Report of November 29, 2011 entitled '*Review of Heavy Timber Requirements in the National Building Code 2010 and Potential Additional Heavy Timber Requirement*'.

[22] CSA O86 Draft Document "*Fire Resistance Design of Solid Sawn and Glued Laminated Timber Members*".

[23] FP Innovations Presentation at New Brunswick CLT Conference, October, 2011.