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Alternative Solutions: 3.2.6 Assess Fire Spread in Floor Voids
Phase 1 – Literature and Code Review

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Abstract

Some innovative and structurally efficient uses of massive wood panels, such as cross-laminated timber (CLT), will result in hollow structural sections. Light-weight wood construction as well as heavy timber assemblies using dropped ceilings or raised floors to allow for the passage of building services, can also create horizontal concealed spaces in floor assemblies. Concealed horizontal spaces provide a potential path for fire to spread quickly throughout a building which could go undetected. The review of the NBCC and related standards, namely NFPA 13, identified several requirements that aim to limit the spread of fire in combustible concealed spaces.

This project is divided into 2 phases and is intended to address limitations of wood in regards to flame spread through the evaluation of fire spread in cavities of light-frame floor assemblies as well as in heavy timber assemblies.

Phase 1 of this project provides insight into the actual fire risk associated with combustible concealed spaces by reviewing the National Building Code of Canada and NFPA 13 requirements with respect to fire protection of combustible concealed spaces, fire blocks and sprinkler system requirements as well as reviewing existing test data and regulatory requirements in an attempt to identify the fire safety objectives and functional requirements.

Phase 2 of this project will consist in carrying out flame spread tests in accordance with ULC S102 standard on real-scale light-framed and heavy timber assemblies (with and without insulation) with surfaces protected with fire retardant (or intumescent) coatings.

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1 Objectives

This project is intended to address limitations of wood in regards to flame spread through the evaluation of fire spread in cavities of light-frame floor assemblies as well as in heavy timber assemblies. It also provides insight into the actual fire risk associated with combustible concealed spaces.

The objectives are to understand the fire spread behaviour in wood assemblies as well as understanding the 2010 National Building Code of Canada (NBCC) requirements aimed at limiting fire spread beyond its point of origin. Such evaluation may also allow revising and actualizing the current Building Code provisions with respect to fire blocks in horizontal concealed spaces.

The key activities include:

- Review of NBCC & NFPA 13 requirements for combustible concealed spaces, such as for fire blocks and sprinkler systems
- Review of existing test data and regulatory requirements to identify the fire safety objectives and functional requirements
- Carry out flame spread tests in accordance with ULC S102 standard on real-scale light-framed and heavy timber assemblies (with and without insulation) with surfaces protected with fire retardant (or intumescent) coatings.

This report addresses Phase 1 of this project which provides a literature review on fire protection of combustible concealed spaces.

2 Introduction

Some innovative and structurally efficient uses of massive wood panels, such as cross-laminated timber (CLT), will result in hollow structural sections. Light-weight wood construction as well as heavy timber assemblies using dropped ceilings or raised floors to allow for the passage of building services can also create horizontal concealed spaces in floor assemblies. One major concern with these combustible concealed spaces is the spread of fire.

The National Building Code of Canada (NBCC) [1] and NFPA 13 [2] set out requirements that aim to limit fire spread within these spaces, such as the use of an active sprinkler system, limited combustible materials, filling narrow cavities completely with noncombustible insulation, etc.

There is a need to identify a cost effective solution, other than installation of an active fire suppression system that will mitigate this risk. One possible approach is the use of surface treatments, such as fire retardants and intumescent coatings. To assess the effectiveness of this approach, it is necessary to quantify the relative performance of existing wood surface treatments to limit flame spread in floor voids

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4 Materials and Methods

Certain wood floor construction designs will result in horizontal combustible concealed spaces, which create the possibility for fire to spread quickly within an assembly. A comprehensive review of existing literature, test data, and regulatory requirements is performed in order to identify the fire safety objectives that need to be met, such as NBCC requirements that aim to limit fire spread beyond its point of origin (objectives OS1.2 and OP1.2 from NBCC, as described in Sections 5.1 to 5.3 of this report). This information can be used to determine a cost effective solution that limits flame spread in these spaces.

Code requirements that restrict the use of wood in floor applications are reviewed. This includes NBCC clauses that relate to fire blocking and fire stopping, allowable open concealed spaces, and NFPA 13 requirements relating to sprinkler systems in concealed spaces. Relevant fire safety objectives and functional statements from the NBCC are also identified.

Based on an analysis of this information and the relevant regulatory requirements, a series of flame spread tests in accordance with CAN/ULC S102, *"Surface Burning Characteristics of Building Materials and Assemblies"* [3] are conducted to evaluate the performance of existing wood surface treatments, such as fire retardants and intumescent coatings, which aim to limit flame spread, on various combustible construction floor assemblies. The results of these tests can be found in Part 2 of this report.

5 Review of Current NBCC Requirements

The fire safety provisions set forth in Part 3 of Division B of NBCC interrelate to four main objectives. They describe, in very broad and qualitative terms, the overall goals that the NBCC's requirements are intended to achieve. The four objectives are as follow:

1. Safety (OS);
2. Health (OH);
3. Accessibility for persons with disabilities (OA), and;
4. Fire and structural protection of buildings (OP).

The objectives describe undesirable situations and their consequences, which the Code aims to avoid occurring in buildings. The NBCC recognizes it cannot entirely avoid any undesirable event from happening or eliminate all risks. Therefore, its objectives are to "*limit the probability*" of "*unacceptable risk*". It is thus assumed, within the NBCC, that an undesirable situation may occur and means shall be provided to limit its consequences. Moreover, an "*acceptable risk*" is the risk remaining once compliance with the NBCC prescriptive solutions has been achieved [1].

Subsections 5.11 to 5.9 of this report provide a list of the relevant clauses from Part 3 of Division B of the NBCC with respect to limiting flame spread in horizontal combustible concealed spaces. Part 3 relates to fire protection, occupant safety, and accessibility. Relevant articles and information are summarized herein as well as the objectives and functional statements attributed to these articles, as provided by the "*Supplement to the NBCC 2010: Intent Statements"* [4]. The attributions to these relevant clauses provide useful information in regards to the intent aimed by these requirements.

5.1 OS1 Fire Safety Objective

This objective aims to limit the probability that a person in or adjacent to the building will be exposed to unacceptable risk of injury due to fire as a result of the design or construction of the building. The fire-related risks of injury are those caused by:

OS1.1 – fire or explosion occurring
OS1.2 – fire or explosion impacting areas beyond its point of origin
OS1.3 – collapse of physical elements due to a fire or explosion

OS1.2 is directly linked to fire spread in concealed spaces as it aims at limiting fire from impacting areas beyond the point of origin. Additional information on objectives can be found in Section 2.2 of Division A of NBCC.

5.2 OP1 Fire Protection of the Building

This objective aims to limit the probability that the building or adjacent buildings will be exposed to an unacceptable risk of damage due to fire or structural insufficiency, or the building or part thereof will be exposed to an unacceptable risk of loss of use also due to structural insufficiency as a result of the design, construction, or demolition of the building. The fire-related risks of damage are those caused by:

OP1.1 – fire or explosion occurring
OP1.2 – fire or explosion impacting areas beyond its point of origin
OP1.3 – collapse of physical elements due to fire or explosion

OP1.3 is directly linked to fire spread in concealed spaces as it aims at limiting fire from impacting areas beyond the point of origin. Additional information on objectives can be found in Section 2.2 of Division A of NBCC.

5.3 Functional Statements

The functional statements describe conditions in the building that help satisfy the objectives. They are more detailed than the objectives and, similarly, are entirely qualitative. The functional statements and objectives are interconnected. As such, there may be several functional statements related to any one objective and a given functional statement may describe a function of the building that serves to achieve more than one objective. The objectives of the NBCC are achieved by measures that are intended to allow a building or its elements to perform specific functions, such as:

F02 – To limit the severity and effects of fire or explosions
F03 – To retard the effects of fire on areas beyond its point of origin
F04 – To retard failure or collapse due to the effects of fire

F03 is directly linked to fire spread in concealed spaces as it aims at limiting fire from impacting areas beyond the point of origin. Additional information on functional statements can be found in Section 3.2 of Division A of NBCC.

5.4 Combustible Construction (3.1.4)

According to NBCC, combustible materials are those that do not meet the requirements of CAN/ULC S114, "Test for Determination of Non-Combustibility in Building Materials" [5]. Wood and wood-based products are considered combustible materials.

In a combustible construction, the flame spread rating (FSR) on any exposed surface of foamed plastic insulation, and on any surface that would be exposed by cutting through the insulation in any direction, shall not be more than 500.

5.4.1 Fire-Retardant-Treated Wood (3.1.4.5)

Fire-retardant-treated (FRT) wood is permitted to be used in a combustible construction and in some applications of noncombustible construction. However, when FRT wood is specified in NBCC, it shall be pressure impregnated with fire-retardant chemicals in accordance with CAN/CSA O80 Series, "Wood Preservation" [6] and shall also exhibit a flame spread rating (FSR) not more than 25.

5.5 Noncombustible Construction (3.1.5)

5.5.1 Nailing Elements (3.1.5.6)

Wood nailing elements used in combustible construction can be directly attached to a noncombustible backing, for the attachment of interior finishes, in noncombustible buildings provided the concealed space they create is not more than 50 mm thick.

5.5.2 Combustible Interior Finishes (3.1.5.10)

The following requirements are for interior finishes used in noncombustible construction, they do not apply to concealed spaces, but it is of value to make note of them in this review.

Combustible interior ceiling finishes (other than foamed plastics) are permitted in a noncombustible building provided they are not more than 25 mm thick, except for FRT wood battens, have a FSR not more than 25, or are FRT wood, except that not more than 10% of the ceiling area within each fire compartment is permitted to have a FSR not more than 150.

5.6 Fire Separations and Closures (3.1.8)

5.6.1 Continuity of Fire Separations (3.1.8.3)

A horizontal service space or other concealed space located above a vertical fire separation shall be divided at the fire separation by an equivalent fire separation within the service space. A shaft that penetrates a fire separation shall extend through any horizontal service space of any concealed space. Both of these situations require smoke tight joints where they intersect a floor, roof slab, or roof deck. The attributed objectives and functional statements for these requirements are [F03-OS1.2] and [F03-OP1.2].

5.7 Penetrations in Fire Separations and Fire-Rated Assemblies (3.1.9)

Penetrations of a fire separation or an assembly required to have a fire-resistance rating (FRR) shall be sealed with a fire stop. When subjected to the CAN/ULC S115, "Fire Tests of Firestop Systems" [7], the fire stop shall achieve an F rating not less than the fire protection rating required for closures in the fire separation, according to Table 3.1.8.4 (shown in Table 1 below), or be cast in place. The F rating is expressed in hours and indicates the specific time that the fire stop has withstood preventing the passage of flame through openings, or the occurrence of flaming on any element of the unexposed side of the fire stops.

Table 1 – Fire Protection Rating of Closures, Table 3.1.8.4 of NBCC [1]

FRR of Fire Separation	Minimum Fire-Protection Rating of Closure
45 min	45 min
1 h	45 min
1.5 h	1 h
2 h	1.5 h
3 h	2 h
4 h	3 h

Penetrations of a fire separation of horizontal service space or other concealed space above a vertical fire separation shall be sealed by a fire stop having an FT rating not less than the FRR of the fire separation. The FT rating is expressed in hours and indicates the specific time that the fire stop has met both the F and the T ratings. The latter indicates that the temperature rise on the unexposed surface of the fire stop, or on any penetrating item, is not more than 180°C above its initial temperature.

Automatic sprinklers are permitted to penetrate a fire separation or an assembly required to have a FRR without having to meet the above fire stop requirements when installed in accordance with NFPA 13 [2].

Moreover, fire dampers are permitted to penetrate a fire separation or an assembly required to have a FRR without having to meet the above fire stop requirements.

The attributed objectives and functional statements for these requirements are [F03-OS1.2], [F04-OS1.3], [F03-OP1.2] and [F04-OP1.3].

5.7.1 Combustibility of Service Penetrations (3.1.9.2)

Service penetrations, such as pipes, ducts, electrical outlet boxes, that penetrate an assembly required to have a FRR shall be noncombustible, unless the assembly was tested with them.

The attributed objectives and functional statements for these requirements are [F03-OS1.2], [F02, F04-OS1.3], [F03-OP1.2] and [F02, F04-OP1.3].

5.7.2 Combustible Piping Penetrations (3.1.9.4)

Combustible sprinkler piping is permitted to penetrate a fire separation provided the compartments on each side of the fire separation are sprinklered.

The attributed objectives and functional statements for these requirements are [F03-OS1.2], [F02, F04-OS1.3], [F03-OP1.2] and [F02, F04-OP1.3].

5.8 Fire Blocks in Concealed Spaces (3.1.11)

A fire block is a material, component or system installed in a concealed space in a building to restrict the spread of fire and often smoke in that concealed space, or from that concealed space to an adjacent space.

5.8.1 Separation of Concealed Spaces (3.1.11.1)

Concealed spaces in interior wall, ceiling and crawl spaces shall be separated from concealed spaces in exterior walls and attic or roof spaces by fire blocks.

The attributed objectives and functional statements for these requirements are [F03- OS1.2] and [F03-OP1.2].

5.8.2 Fire Blocks between Nailing and Supporting Elements (3.1.11.3)

In a noncombustible building fire blocks are required for concealed spaces created by wood members in a raised platform so that the maximum space is not more than 10 m^2. These combustible flooring elements must be greater than 50 mm but not more than 300 mm high and directly applied to a noncombustible floor slab.

The attributed objectives and functional statements for these requirements are [F03- OS1.2] and [F03-OP1.2].

5.8.3 Fire Blocks between Vertical and Horizontal Spaces (3.1.11.4)

Fire blocks are required at all interconnections between concealed vertical and horizontal spaces in interior covered ceilings, dropped ceilings and soffits as well as at the end of each floor level between stair stringers where the exposed construction materials in the space have a FSR not more than 25.

The attributed objectives and functional statements for these requirements are [F03- OS1.2] and [F03-OP1.2].

5.8.4 Fire Blocks in Horizontal Concealed Spaces (3.1.11.5)

Horizontal concealed spaces within a floor or roof assembly of combustible construction without sprinklers shall be separated by fire blocks into compartments not more than 600 m^2 if the exposed materials in the space have a FSR not more than 25 (with no dimension more than 60 m), or 300 m^2 if the materials have an FSR greater than 25 (with no dimension more than 20 m). This does not apply to crawl spaces.

The attributed objectives and functional statements for these requirements are [F03, F04-OS1.2] and [F03, F04-OP1.2].

A concealed space in an exterior cornice, a mansard-style roof, a balcony or a canopy where the exposed materials have a FSR more than 25 shall be separated by fire blocks into spaces with a maximum dimension not more than 20 m, where the concealed space extends across the ends of required vertical fire separations.

The attributed objectives and functional statements for these requirements are [F03, F04-OS1.2] and [F03, F04-OP1.2].

5.8.5 Fire Blocks in Crawl Spaces (3.1.11.6)

An unsprinklered crawl space that is not considered a basement shall be separated by fire blocks into compartments not more than 600 m^2, with no dimension greater than 30 m.

The attributed objectives and functional statements for these requirements are [F03, F04-OS1.2] and [F03, F04-OP1.2].

5.8.6 Fire Block Materials (3.1.11.7)

Fire blocks shall remain in place and prevent passage of flames for not less than 15 min when subjected to CAN/ULC S101, "Fire Endurance Tests of Building Construction and Materials" [8]. This does not apply to the following:

- gypsum board greater than 12.7 mm thick and sheet steel greater than 0.38 mm, or
- wood nailing elements attached to noncombustible construction for the attachment of interior finishes, provided the concealed space created is not more than 50 mm thick.

The attributed objectives and functional statements for these requirements are [F04-OS1.2] and [F04-OP1.2].

In a combustible roof system or raised platform of a combustible building, materials used to separate concealed spaces are permitted to be:

- solid lumber not less than 38 mm thick;
- phenolic bonded plywood, waferboard, or strandboard not less than 12.5 mm thick with supported joints;
- two thicknesses of lumber, each not less than 19 mm thick with staggered joints, where the width or height of the concealed space requires more than one piece of lumber not less than 38 mm thick to block off the space.

Moreover, openings through these materials shall be protected to maintain integrity of construction (attributions [F04-OP1.2] and [F04-OS1.2]).

Also, when these materials are penetrated by construction elements of service equipment, a fire stop is needed to seal the penetration (attributions [F03-OP1.2] and [F03-OS1.2]). A fire stop is a material, component or system, used to fill gaps between fire separations, between fire separations and other construction assemblies, or used around items which wholly or partially penetrate fire separations, to restrict the spread of fire and often smoke thus maintaining the integrity of a fire separation (refer to Section 5.6 of this report).

In a building of combustible construction, semi-rigid fibre insulation board is permitted to be used to block the vertical space in a double stud wall assembly formed at the intersection of the floor and walls when the width of the vertical space is not more than 25 mm. The board needs to have a density not less than 45 kg/m^3, be securely fastened to studs, extend from below the bottom of the top plate in the lower storey to above the top of the bottom plate in the upper storey, and completely fills the portion of vertical space between the headers and wall plates.

5.9 Flame-Spread Rating and Smoke Developed Classification (3.1.12)

FSRs and smoke developed classification (SDC) are evaluated using CAN/ULC S102 [3]. Several FSRs are available in Appendix D of the NBCC.

The attributed objectives and functional statements for these requirements are [F02- OS1.2] and [F02-OP1.2].

5.10 Interior Finish (3.1.13)

5.10.1 Interior Finishes, Furnishings and Decorative Materials (3.1.13.1)

Interior finishes are considered any part of the interior surface of a floor or ceiling. Article 3.1.13.1 from Division B of NBCC defines FSR requirements for ceilings, but these only apply to the interior most surface and do not apply to concealed spaces.

5.10.2 Flame-Spread Rating (3.1.13.2)

FSRs are defined for wall and ceiling finishes and shall not be more than 150, with exceptions given in Table 3.1.13.2 from Division B of NBCC. Non-sprinklered buildings require the use of materials with lower FSRs. These requirements do not apply to concealed spaces. FSR data for generic products is given in Table D-3.1.1.A of Appendix D of the NBCC, and is presented in Subsection 8.2 of this report (see Table 2).

The attributed objectives and functional statements for these requirements are [F02-OS1.2] and [F02-OP1.2].

5.11 Building Size and Construction Relative to Occupancy (3.2.2)

The extent of a building size (height and area) is dependent on its intended type of occupancy. These criteria also define further characteristics of the building, such as its type of construction, automatic sprinkler protection and fire-resistance rating of building elements. These criteria are defined in Subsections 3.2.2.20 to 3.2.2.88 in Division B of the NBCC.

A definition of the occupancy groups can be found in Article 3.1.2.1 from Division B of NBCC.

5.12 Automatic Sprinkler System Required (3.2.2.18)

When automatic sprinklers are required to be throughout a building they shall be designed, constructed, installed and tested in conformance with NFPA 13. The latter provides special requirements for fire protection of concealed spaces, as detailed in Section 6 of this report.

However, article 3.2.5.12 from Division B of NBCC provides special provisions where NFPA 13R [9] is allowed to be used for the design, construction and installation of automatic sprinkler system for residential occupancy (Group C) buildings having a building height not more than 4 storeys and for buildings of care occupancy (Group B-3) with not more than 10 occupants and not more than 3 storeys.

Lastly, the design, construction and installation of automatic sprinklers can be made in compliance with NFPA 13D [10] for residential occupancy buildings that contains not more than 2 dwellings or buildings of care occupancy that contains not more than 2 suites of care occupancy, not more than 5 occupants and provided that a 30 minutes water supply can be met.

Both NFPA 13R and 13D do not require fire protection of concealed spaces, attics and floor/ceiling spaces.

5.13 Horizontal Service Spaces (3.6.4)

This subsection includes ceiling spaces, duct spaces, crawl spaces, and attic or roof spaces.

5.13.1 Fire Separations for Horizontal Service Spaces (3.6.4.2)

A horizontal service space that penetrates a vertical fire separation shall be separated from the remainder of the building. If this space is located above a vertical fire separation (other than a vertical shaft) this space does not need to be divided at the fire separation as long as the construction is a fire separation with a FRR equivalent that that required of the vertical fire separation. The FRR cannot be less than 30 min if the vertical fire separation is not required to have a FRR more than 45 min.

The attributed objectives and functional statements for these requirements are [F03-OS1.2] and [F03-OP1.2].

5.13.2 Plenum Requirements (3.6.4.3)

A concealed space used as a plenum within a floor or roof assembly need not conform to 3.1.5.15.(1) or 3.6.5.1 (relating to being of noncombustible materials) if all of the materials in the concealed space have a FSR not more than 25 and a smoke developed classification not more than 50, with exceptions, as well as the supports for the ceiling membrane provided they are of noncombustible material having a melting point not below 760°C. The attributed objective and functional statement for these requirements is [F02-OS1.2].

If this concealed space is used as a return-air plenum and incorporates a ceiling membrane that forms part of the required FRR of the assembly, every opening through the membrane shall use a fire stop. This fire stop will stop the flow of air into the concealed space in the event of a fire and is supported in a manner than will maintain the integrity of the ceiling membrane for the duration of time required to provide the required FRR. The attributed objectives and functional statements for these requirements are [F03-OS1.2] and [F03-OP1.2].

5.14 Summary of NBCC fire block and fire stop requirements

Fire blocks are required:

- To separate adjacent concealed spaces;
- At all interconnections between concealed vertical and horizontal spaces;
- In an unsprinklered horizontal combustible concealed spaces creating compartments not more than 600 m² when surfaces have a FSR not more than 25, otherwise 300 m²;
- In an unsprinklered crawl space creating compartments not more than 600 m²; and
- To divide a horizontal concealed space above a vertical fire separation by an equivalent fire separation within the service spaces.

Fire stops are also required when construction elements are penetrated by service equipment, particularly for fire separations and fire-rated assemblies. They are particularly necessary when there is a penetration of a fire separation or an assembly required to have a FRR. In this case they require an F-rating not less than the FRR of the fire separation

5.15 Summary of Objectives and Functional Statements Attributions

Of the functional statements and objectives that are listed for the clauses relevant to fire spread in floor voids, the main identified objectives are OS1.2 and OP1.3, which aim to limit fire from impacting areas beyond its point of origin, specifically to limit impacting a person in or adjacent to the building or the structural sufficiency of the building or an adjacent building.

OS1.2 addresses impacts in and to adjacent buildings, therefore is applicable to limit flame spread within an assembly and to limit flame spread between buildings. The applicable functional statements related to OS1.2 are to limit the severity and effects of fire (F02), to retard the effects of fire on areas beyond its point of origin (F03) and to retard failure or collapse due to fire (F04).

In clauses which identify objective OP1.3, which relates to the fire protection of the building and adjacent buildings, only functional statements F03 and F04 are used which relate to retard the effects of fire on areas beyond its point of origin (F03) and to retard failure or collapse due to fire (F04).

6 Review of Current NFPA 13 Requirements (Sprinklers)

As mentioned in Subsection 5.12 of this report, when automatic sprinklers are required to be throughout a building they shall be designed, constructed, installed and tested in conformance with NFPA 13. The following paragraphs relate to specific requirements with respect to fire protection of combustible concealed spaces.

6.1 Concealed spaces requiring sprinklers

Sprinklers in combustible concealed spaces are discussed in NFPA 13 [2] under Section 8.15, entitled "Special Situations".

6.1.1 Concealed Spaces Requiring Sprinkler Protection (8.15.1.1)

All concealed spaces enclosed wholly or partly by exposed combustible construction shall be protected by sprinklers except in concealed spaces where sprinklers are not required to be installed in accordance with 8.15.1.2.1 through 8.15.1.2.16 and 8.15.6.

This clause applies to spaces with combustible construction or finish materials, areas for storage of combustible materials, and areas that can contain combustible building features, such as wiring or piping.

6.1.2 Concealed Space Design Requirements (8.15.1.3)

When sprinklers are required to be installed in concealed combustible spaces they shall be installed in accordance with requirements for light hazard occupancy, i.e. they are required to be quick-response sprinklers.

6.1.3 Heat-Producing Devices with Composite Wood Joist Construction (8.15.1.4)

When heat producing devices are located in joist channels above a ceiling directly applied to wood joists that would not regularly require sprinklers, sprinklers are required in that joist channel and the adjacent ones.

6.1.4 Localized protection of exposed combustible construction or exposed combustibles (8.15.1.5)

In localized areas of horizontal combustible concealed spaces the combustible elements shall be protected using sprinklers with light hazard spacing.

6.2 Summary

According to NFPA 13 sprinklers are required in concealed spaces in the following instances that relate to combustible construction:

- In any space that is wholly or partly enclosed by combustible construction, except in situations relating to articles 8.15.1.2.1 through 8.15.1.2.16 and 8.15.6 (discussed below);
- When heat producing devices are directly applied to wood joists.

6.3 Concealed spaces not requiring sprinklers

6.3.1 Concealed Spaces Not Requiring Sprinkler Protection (8.15.1.2)

The following are summaries of the articles in NFPA 13 that address situations when sprinklers are not required in concealed spaces. When a concealed space has an alternative protection measure, such as a CO_2 system, it is considered to be protected and therefore sprinklers are not required [11].

The following sub-clauses provide additional conditions where sprinkler protection is not required in concealed spaces.

8.15.1.2.2 Concealed spaces of limited-combustible construction having limited access that does not allow for occupancy or storage of combustibles. These spaces are permitted to have small openings for air plenum.

8.15.1.2.3 Concealed spaces formed by studs or joists with less than 6 in. (152 mm) between the inside or near edges of the studs or joists shall not require sprinkler protection. (see figure 8.6.4.1.5.1).

8.15.1.2.4 Concealed spaces formed by bar joists with less than 6 in. (152 mm) between the roof or floor deck and ceiling shall not require sprinkler protection.

8.15.1.2.5 Concealed spaces formed by ceilings attached directly to or within 6 in. (152 mm) of wood joist construction shall not require sprinkler protection. This applies to sheathed joist construction or similar narrow spaces formed by the attachment of a ceiling to, or within, 6 in. (152 mm) of joists. This exception is intended to apply only to joists with no opening in the members and with a nominal depth of up to 14 in. (356 mm).

8.15.1.2.3, 8.15.1.2.4, 8.15.1.2.5 These conditions do not require sprinkler protection because it is not physically practical to install sprinklers in this type of space. To reduce the possibility of uncontrolled fire spread in these areas the following methods could be used: 8.15.1.2.7, 8.15.1.2.10, and 8.15.1.2.12. These alternatives do not necessarily provide an equivalent level of fire safety, they are more to address the idea that sprinklers is physically impractical in these spaces.

8.15.1.2.6 Concealed spaces formed by ceilings attached to composite wood joist construction either directly or onto metal channels not exceeding 1 in. (25.4 mm) in depth, provided the joist channels are fire stopped into volumes each not exceeding 160 ft^3 (4.53 m^3) using materials equivalent to the web construction and at least 3 ½ in. (90 mm) of batt insulation is installed at the bottom of the joist channels when the ceiling is attached utilizing metal channels.

8.15.1.2.7 Concealed spaces entirely filled with noncombustible insulation shall not require sprinkler protection. Filling a cavity with insulation may be more cost effective than installing sprinklers.

8.15.1.2.8 Wood joist construction using noncombustible insulation to fill the space from the ceiling to the bottom edge of the roof joist or floor deck. This also applies to composite wood joist construction as long as joist channels are firestopped into volumes not exceeding 160 ft^3 (4.53 m^3) the full depth of the joist.

8.15.1.2.9 Concealed spaces over isolated small rooms not exceeding 55 ft^2 (5.1 m^2) in area shall not require sprinkler protection.

8.15.1.2.10 When rigid material is used and exposed surfaces have a FSR of 25 or less and the material does not propagate fire. For example, if the entire space were covered with gypsum board, with no combustible construction exposed inside the concealed space.

8.15.1.2.11 When the exposed material in the space is entirely of FRT wood (in accordance with NFPA 703 [12]).

8.15.1.2.13 Concealed spaces below insulation that is laid directly on top of or within wood joists or composite wood joists used as ceiling joists in an otherwise sprinklered concealed space, with the ceiling attached directly to the bottom of the joists, shall not require sprinkler protection.

8.15.1.2.14 Vertical pipe chases for non-combustible pipes that are under 10 ft2, are fire stopped at each floor, contain no sources of ignition, and where penetrations are properly sealed at each floor.

8.15.1.2.16 When noncombustible (or limited combustible) ceilings are suspended from wood joists, composite wood joists, wood bar joists, or wood trusses having insulation that fills all of the gaps between the bottom of the joists and sprinklers are present in the space above the insulation. As demonstrated in the figure below.

6.4 Spaces under ground floors, exterior docks, and platforms (8.15.6)

This addresses the fact that there would be maintenance problems involved with having sprinklers in spaces under ground floors, such as limited access and the danger of pipes freezing.

Sprinklers are required in spaces under all combustible ground floors, exterior docks, and platforms, except when the space:

- is not accessible for storage and is protected against wind-borne debris;
- contains no equipment;
- has the floor above of tight construction;
- has no combustible or flammable liquids or materials are processed, handled, or stored on the floor above.

6.5 Summary

According to NFPA 13 sprinklers are not required in concealed spaces in the following instances that relate to combustible construction:

- Concealed spaces of limited-combustible construction with limited access that do not allow for occupancy or storage of combustibles;
- Concealed spaces of limited-combustible construction having limited access that does not allow for occupancy or storage of combustibles when studs or joists are less than 6 in. (152 mm) apart;
- When a ceiling is direct applied to joists or within 6 in. (152 mm), provided members are not greater than 14" (356 mm) deep and there are no openings between members;
- When a ceiling is attached to composite wood joist construction either directly or onto metal channels not exceeding 1 in. (25.4 mm) in depth, provided the joist channels are firestopped into volumes each not exceeding 160 ft^3 (4.53 m^3). At least 3½ in. (90 mm) of batt insulation is installed at the bottom of the joist channels when the ceiling is attached utilizing metal channels;
- When a space is completely filled with noncombustible insulation;
- In wood joist construction where noncombustible insulation fills the space from the ceiling to the floor deck, this includes composite joist construction, provided that joist channels are firestopped into volumes not exceeding 160 ft^3 (4.53 m^3) the full depth of the joist;
- Over small rooms that are not greater than 55 ft^2 (5 m^2);
- When rigid construction materials that do not propagate fire are used and surfaces have an FSR of not more than 25;
- When the exposed material of the space is entirely of FRT wood;
- In spaces below insulation laid directly on top of or within wood ceiling joists, in an otherwise sprinklered concealed space, with the ceiling attached directly to the bottom of the joists;
- When noncombustible (or limited combustible) ceilings are suspended from wood joists having insulation that fills the gaps between the bottom of the joists and sprinklers are present in the space above the insulation;
- When the space is protected with an alternative protection measure, such as a CO_2 system;
- For spaces under combustible ground floors that have limited access which would result in maintenance problems. Where sources of ignition have been eliminated and combustible materials are limited to floor materials only.

7 Association of Professional Engineers and Geoscientists of BC (APEGBC)

The Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) has published a technical bulletin in regards to professional engineering services, including fire protection, for mid-rise residential buildings [13]. The document focuses on specific concerns for wood frame construction and addresses fire and life safety in regards to building materials as well as fire suppression systems.

Combustible concealed spaces are identified as a concern for fire spread and it is recommended that a fire protection engineer review any building design to identify and address fire risks associated with these spaces that are not specifically address in the building code.

8 Existing data and research

8.1 Fire Stops and Fire Blocks

Overtime, there has been a reduction in fire losses for certain fire scenarios. Particularly, the use of fire stops and fire blocks have helped in this reduction, by limiting fire spread to adjacent compartments or concealed spaces [14]. Several large fires brought this issue to the forefront of fire safety engineering, i.e. Brown's Ferry Nuclear Power Plant, the Inn on the Park and the MGM Grand Hotel, which lead to the implementation of fire stops and fire blocks in building codes.

In conjunction with these events, a study by the U.S. National Bureau of Standards in 1977 demonstrated the need to prevent unrestricted fire spread in concealed spaces in multi-family residences [15]. The study involved low-rise residential buildings mostly of wood-frame construction and concluded that the single greatest cause of extensive fire spread was the lack of fire stops and fire blocks.

Although building codes have been significantly revised since this time to provide better fire safety provisions for fire stops and fire blocks, it is important to recognize the potential hazard that fire spread in concealed spaces presents if not properly controlled.

8.2 Flame Spread

Surface burning characteristics, i.e. flame spread, of wood products has been studied extensively in the past. Flame spread is described by a dimensionless parameter: flame spread rating (FSR). FSRs in Canada are determined following the CAN/ULC S102 test standard. Similar international standards are ASTM 84, NFPA 255, and UL723. This test is also referred to as the Steiner Tunnel Test.

FSRs give an indication of how a material, product, or assembly responds when exposed to flames under the specific test conditions. It is important to ensure that materials are tested in the same arrangement that they will be installed in practice. Changes in orientation can significantly impact flame spread and combustibility of a material [2]. Also a FSR alone cannot be used to assess fire-hazard or fire risk of a material used in a given scenario, and therefore will not dictate how a fire would spread in a building.

As described in the previous sections of this report, certain clauses in the NBCC limit the use of combustible interior finishes based on thickness and FSR. According to the NBCC, FSRs can be determined either by following the CAN/ULC S102 test procedure or from values specified in Table D-3.1.1.A of Appendix D in the NBCC [1], shown in Table 2. FSR values given in the NBCC are typically conservative in order to be generic and be representative of a wide range of materials. FSRs typically decrease with increasing thickness for wood products [16].

Table 2 - Assigned FSR and smoke developed classifications - Table D-3.1.1.A of NBCC [1]

Materials	Minimum Thickness mm	Unfinished		Paint or Varnish not More than 1.3mm Thick, Cellulosic Wallpaper not more than 1 Layer [2,3]	
		FSR	SDC	FSR	SDC
Gypsum wallboard	9.5	25	50	25	50
Lumber	16	150	300	150	300
Douglas Fir plywood[4]	11	150	100	150	300
Poplar plywood[4]	11	150	100	150	300
Plywood with Spruce face veneer[4]	11	150	300	150	100
Douglas Fir plywood[4]	6	150	100	150	100
Fiberboard low density	11	> 150	100	150	100
Hardboard, Type 1	9	150	> 300	[2]	[2]
Hardboard,Standard	6	150	300	150	300
Particleboard	12.7	150	300	[5]	[5]
Waferboard	-	[5]	[5]	[5]	[5]
OSB	-	[5]	[5]	[5]	[5]

Notes:
[1] See Sentence D-1.1.1.(5) for standards used to assign FSR and smoke developed classifications
[2] FSR and smoke developed classifications for paints and varnish are not applicable to shellac and lacquer.
[3] FSR and smoke developed classifications for paints apply only to alkyd and latex paints.
[4] The FSR and smoke developed classifications shown are for those plywoods without a cellulose resin overlay
[5] Insufficient test information available.

The above table indicates that unfinished wood products typically have a FSR of 150, such as for lumber and plywood. A comprehensive selection of flame spread data for commonly used wood products in Canada is available from the Canadian Wood Council [16]. The American Wood Council (AWC) also provides more detailed information in regards to FSR of wood products tested mostly under ASTM E84 standard [17].

8.3 Fire-Retardants

The main goal of fire-retardant coatings is to reduce surface flammability, i.e. produce lower FSRs. Coatings can just be flame-retardant and fire-resistive (non-intumescent) or they can have intumescent properties. When exposed to high temperatures intumescent coatings are meant to expand and form a charred layer that will insulate and protect the material for a certain period of time. Even some conventional paints can be effective at reducing FSRs [18].

Fire retardant coatings applied to wood construction may be acceptable by some Authorities Having Jurisdiction (AHJ), but may not be accepted by others. Therefore more research is required to justify the performance of these coatings in actual real-scale fire scenarios.

8.3.1 Non-intumescent coatings

FRT wood is a wood product that has its surface-burning characteristics reduced through the impregnation of fire-retardant chemicals. It should be noted that fire-retardant coatings are different from FRT wood (refer to 5.4.1 of this report), where NFPA 703 [12] outlines specifications for fire-retardant coatings in the United States. According to this standard a coating reduces flame spread of combustible surfaces by at least 50% or to a flame spread index of 75 or less, whichever is the lesser value, and has a smoke developed index not exceeding 200. However, the main difference is that fire retardants are impregnated into FRT wood, whereas a coating is simply applied to the outer surface. Outdoor weathering of coatings will reduce their durability and will therefore need to be reapplied on a regular basis [19].

Fire retardant coatings are capable of delaying the ignition time of wood and decreasing the peak heat release rate (HRR) in the initial combustion stages, as demonstrated by tests conducted by Kozolowski et al. [20].

8.3.2 Intumescent Coatings

Recent advances in intumescent coating technology have resulted in coatings that have better fire retardancy, lower smoke emission, low hygroscopic properties, higher temperature resistance, and resistance to mildew and rot [21]. Coatings can be applied by spray, brush, or roller so that they can be applied on site or materials can be coated during manufacturing. Applying intumescent coatings is known as one of the most efficient methods of improving fire retardancy. These coatings can reduce flame spread and smoke emission while not impacting the material's performance. Clear coatings are ideal for exposed wood applications since they maintain the natural appearance of wood.

There are two types of intumescent coatings: traditional chemical coatings that rely on chemical fire retardancy and physical coatings that contain expandable graphite. The later type has the benefits of improving fire retardant efficiency (due to a greater degree of expansion which better insulates the material), weather durability, reducing smoke, volatile organic compound (VOC), and toxic gas emissions [21].

In tests conducted by Hao and Chow [21], the fire protection response (FPR), which is the time necessary for the unexposed surface of a sample to reach a specified temperature, was evaluated for timber products using an intumescent coating. The materials were exposed to a flame of 930^{o}C. Two coatings were tested and they improved the FPR by 2 to 4 times. When the two coatings were used together the FPR was improved by 6 to 10 times.

The wood products market has begun to respond to the increase in awareness of the importance of fire safety for construction. As a result, new technologies and products are coming available and aim at increasing the fire performance of building products. This can simplify design and construction of fire-rated assemblies, particularly those requiring a 1-hour FRR, through the use of pre-applied protection measures, such as intumescent coatings. These products can reduce the amount of gypsum board required for an assembly, for example using 1 layer instead of two, and the amount of noncombustible insulation.

However, there has been no definitive research indicating that coatings improve the fire resistance rating (FRR) of wood members [19].

8.4 Fire Spread in Combustible Concealed Spaces

Much theoretical research has been done on the flame spread of wood products as well as the use of fire retardant coatings on wood products. However, little research has been done to assess actual fire spread in concealed spaces. Concealed spaces are of particular concern because they can provide a passage for flames to spread quickly and undetected throughout a building.

Open horizontal spaces are increasingly being used to conceal utilities and ventilation since this design helps to maximize flexibility for different tenant requirements. Having services in these spaces allows easy access, lower construction costs and energy conservations for HVAC systems. There have been several large fires which involved combustible materials in concealed spaces [22], but not necessarily in concealed spaces of combustible construction. This indicates that there is an increased fire hazard associated with any concealed space that is not adequately protected with measures such as fire stops or sprinklers.

Horizontal concealed spaces in mid-rise and tall buildings are typically present because of the use of suspended ceilings or raised floors that are used to house services, cables, and utilities. In high-rise buildings these areas can be equivalent to the entire surface area of the floor and have an average depth of 0.5-0.6 m [23].

These spaces are of particular interest for fire safety for the following reasons [23]:

- Due to buoyancy they are a natural trap for hot combustible products;
- These spaces usually contain electrical and other services which may be a source of fire;
- They can consist of combustible materials and contain combustible insulation;
- If insulated, they encourage the rapid buildup of heat;
- These large open spaces may link to adjoining spaces if not properly fire stopped
- They provide ideal conditions for flashover to occur
- A fire could potentially go undetected in the early stages

In order to assess the hazard associated with fire spread in a combustible concealed space protected by sprinklers a testing series was conducted by National Research Council Canada (NRCC) [24]. At the time of the tests, according to NFPA 13, Subsection 4-4.4, sprinklers were required in combustible concealed spaces, except for combustible wood joist assemblies where the ceiling membrane was not more than 152 mm (6 in) from the joists. Previously, sprinklers were not required when the ceiling membrane was attached directly to the joists. The exception to ceilings 6 in from the joists was added in 1985 to address the idea that it was difficult to install sprinklers in spaces less than 152 mm (6 in) and is still in effect today.

Two tests were conducted on a 7.3 m x 9.8 m (24 ft x 32 ft) ceiling assembly constructed using 2 x 10 spruce joists spaced at 406 mm on centre (16 in). A 16 mm (5/8 in) waferboard subfloor was used, having a FSR of 232. The ceiling was suspended from aluminum T-bars 152 mm below the joists. The floor was supported on one side by a gypsum board wood stud wall, with the three other sides left open. Thermocouples were installed 51 mm (2 in) below the bottom surface of the flooring. The ignition source was a burner, similar to that used in the CAN/ULC-S102 [3], which ran for 3.5 minutes. The first test had a 6 mm (1/4 in) combustible plywood ceiling having a FSR of 211. The second test used a 9.5 mm (3/8 in) non-combustible gypsum board ceiling with a FSR of 17.

In the first test, the flame front moved rapidly along the ignited joist space with fire visible at the open end within 97 seconds. The criteria to determine the location of the flame front was 527ºC (980ºF), which is occasionally used for CAN/ULC S102 tests [3]. Flame spread across the joists was much slower. Once sprinklers were activated temperatures decreased rapidly in the direction perpendicular to the joists, reducing the extent of the fire, however they did not activate until after flames had reached the open end of the assembly.

The second test used a non-combustible gypsum board ceiling. Again, the flame front moved along the joist space ahead of sprinkler activation; the fastest movement was along the joist space where ignition occurred. However, in this test movement was much slower.

These tests demonstrated that the joist spaces acted as a channel to move hot gases to the open end of the assembly. For the first test, the rapid flame spread was enhanced by the combustible ceiling material. The fire in the second test had ventilation limited combustion which resulted in extended flames.

The sprinklers did not provide adequate protection against fire spread along the joist channels, especially when a combustible material was used for the ceiling. The sprinklers, however, did limit lateral fire spread and were effective for areas directly impacted by the sprinkler jet.

These results were similar to tests which observed flame spread along a corridor with combustible ceilings [25], which are described herein. This investigation, conducted by Hinkley et al. studied the behavior of flames spread beneath both combustible and non-combustible ceilings.

The tests simulated a corridor with a fire at one end, however the results are applicable to other scenarios where the flow beneath the ceiling is essentially unidirectional. The simulated corridor measured 7.3 m long by 1.2 m wide and used screens on either side to channel the hot gases. A burner was placed at one end of the channel and released varying degrees of heat output (140, 210, 300, 420, and 500 kW) at various heights beneath the ceiling (0.37, 0.66, 0.9, and 1.2 m). The combustible linings tests used cellulosic building boards nailed to 28 mm x 19 mm timber battens. The time it took for the boards to ignite, varied between 10 s and 2 min, depending on the material used. Longer times to ignition were observed for materials with a Class 1 or Class 2 flame spread test rating, thus for materials with FSR not more than 75. The time to maximum downward radiation was much longer for boards with a low index from the fire propagation test.

In the tests which used combustible ceiling linings longer flames were observed when compared with the non-combustible ceiling. The longer flames lead to an increase in the distance over which heat was radiated downwards at an intensity sufficient to promote fire spread and a faster rate of increase of radiation. When flames extend horizontally beneath a ceiling this strongly heats the contents and walls of a room by radiation over a much larger area than would flames extending vertically, which results in more rapid fire spread [25]. A ceiling lined with a combustible material will contribute to the flames which will increase the rate of fire spread.

Similarities between this series of tests and those conducted by NRCC are peak temperatures of 800ºC (1470ºF) in the joist channels of the combustible ceiling tests. A major difference in these tests is the close proximity of the ceiling with may limit the air flow to the fire located in the joist spaces. This may have resulted in ventilation limited combustion which would account for the slow flame spread rate observed in the second NRCC test which used (noncombustible ceiling material).

8.4.1 Fire tests on data cables in concealed spaces

Overtime, there has been increasing use of combustible concealed spaces for cabling. LAN cabling systems are being replaced every 3 to 5 years as computers become faster and more powerful. Because of this there are numerous concealed spaces that become filled with several generations of combustible cables that are not removed when new cabling is installed, which represents an additional fire load.

The Society of the Plastic Industry sponsored a series of intermediate scale and real scale tests to evaluate the fire performance of cables in horizontal concealed spaces above ceilings and below floors in commercial and industrial buildings [22].

The first series of tests were conducted in a concealed space structure measuring 7.4 x 5.7 x 4m high. The fire scenario, ventilation conditions, and cable configurations were varied. The cables were placed in a 1m deep space above a 2-hr fire rated suspended ceiling. The room was exposed to a 1 MW fire for 30 minutes where hot gas and smoke entered the cavity through a hole in the ceiling. The different cables performed in a variety of ways, with the most severe releasing large amounts of heat and developing large fire-balls, and large pool fires on the suspended ceiling.

The second series of tests were conducted in the Steiner Tunnel, and the cables demonstrated similar results to the full-scale tests, reinforcing that results in the tunnel test can be correlated to full-scale fire performance. These tests demonstrate the fire hazard associated with combustible materials in concealed spaces and the need to protect and mitigate the impact these materials could have in combustible concealed spaces.

Similar real-scale tests were conducted by Fei et al. [26] which demonstrated that for cable fires in a concealed space the HRR of the fire source ultimately decides the severity and hazard of the fire growth.

9 Conclusions

Concealed horizontal spaces provide a potential path for fire to spread quickly throughout a building which could go undetected. The review of the NBCC and related standards, namely NFPA 13, identified several requirements that aim to limit the spread of fire in combustible concealed spaces.

The functional statements related to these requirements aim to limit the severity and effects of fire and explosions (F02), to retard the effects of fire on areas beyond its point of origin (F03), and to retard failure or collapse due to the effects of fire (F04). The corresponding objectives aim to limit the probability that:

- a person in or adjacent to the building will be exposed to unacceptable risk of injury due to fire as a result of the design or construction of the building (OS1 - Fire Safety Objective)
- that the building or adjacent buildings will be exposed to an unacceptable risk of damage due to fire or structural insufficiency, or the building or part thereof will be exposed to an unacceptable risk of loss of use also due to structural insufficiency as a result of the design, construction, or demolition of the building (OP1 Fire Protection of the Building)

The risks associated with these objectives are caused by fire or explosion impacting areas beyond its point of origin (OS1.2), collapse of physical elements due to a fire or explosion (OS1.3), fire or explosion occurring (OP1.2), and fire or explosion impacting areas beyond its point of origin (OP1.3).

The NBCC requires fire blocks:

- To separate adjacent concealed spaces;
- At all interconnections between concealed vertical and horizontal spaces;
- In an unsprinklered horizontal combustible concealed spaces creating compartments not more than 600 m^2 when surfaces have a FSR not more than 25, otherwise 300 m^2;
- In an unsprinklered crawl space creating compartments not more than 600 m^2; and
- To divide a horizontal concealed space above a vertical fire separation by an equivalent fire separation within the service spaces.

Fire stops are required when construction elements are penetrated by service equipment, particularly for fire separations and fire-rated assemblies.

According to NFPA 13 sprinklers are required in certain instances of horizontal combustible concealed spaces. This includes:

- In any space that is wholly or partly enclosed by combustible construction, except in situations relating to articles 8.15.1.2.1 through 8.15.1.2.16 and 8.15.6 of NFPA 13;
- When heat producing devices are directly applied to wood joists.

Sprinklers are not required in horizontal combustible concealed spaces:

- Concealed spaces of limited-combustible construction with limited access that do not allow for occupancy or storage of combustibles;
- Concealed spaces of limited-combustible construction having limited access that does not allow for occupancy or storage of combustibles When studs or joists are less than 6 in. (152 mm) apart;
- When a ceiling is direct applied to joists or within 6 in. (152 mm), provided members are not greater than 14" (356 mm) deep and there are no openings between members;
- When a ceiling is attached to composite wood joist construction either directly or onto metal channels not exceeding 1 in. (25.4 mm) in depth, provided the joist channels are firestopped into volumes each not exceeding 160 ft^3 (4.53 m^3). At least 3 ½ in. (90 mm) of batt insulation is installed at the bottom of the joist channels when the ceiling is attached utilizing metal channels;
- When a space is completely filled with noncombustible insulation;
- In wood joist construction where noncombustible insulation fills the space from the ceiling to the floor deck, this includes composite joist construction, provided that joist channels are firestopped into volumes not exceeding 160 ft^3 (4.53 m^3) the full depth of the joist;
- Over small rooms that are not greater than 55 ft^2 (5 m^2);
- When rigid construction materials that do not propagate fire are used and surfaces have an FSI of not more than 25;
- When the exposed material of the space is entirely of FRT wood;
- In spaces below insulation laid directly on top of or within wood ceiling joists, in an otherwise sprinklered concealed space, with the ceiling attached directly to the bottom of the joists;
- When noncombustible (or limited combustible) ceilings are suspended from wood joists having insulation that fills the gaps between the bottom of the joists and sprinklers are present in the space above the insulation;
- When the space is protected with an alternative protection measure, such as a CO_2 system;
- For spaces under combustible ground floors that have limited access which would result in maintenance problems. Where sources of ignition have been eliminated and combustible materials are limited to floor materials only.

Horizontal combustible concealed spaces have been identified to present a fire hazard with respect to fire spread in floor voids. Fire can move quickly in these spaces and can go undetected in the early stages of a fire. Several methods have been identified that could potentially mitigate this hazard for combustible spaces.

Extensive existing research has shown that FSRs of wood products can be reduced through the use of fire retardants and intumescent coatings. This information will be used in the second phase of this project to evaluate how these treatments may perform in real-scale floor assemblies.

10 Recommendations

Research related to fire spread in floor assemblies is needed. The second phase of this study will include preliminary testing of various combustible construction floor assemblies to evaluate their relative fire performance. These tests will specifically evaluate how the use of different fire retardants, such as FRT wood and intumescent coatings, may limit the spread of fire.

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