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### **A literature review of the state-of-art in fire protection of mid-rise wood buildings under construction**

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#### **Publisher's version / Version de l'éditeur:**

<https://doi.org/10.4224/23003386>

*Internal Report (National Research Council of Canada. Construction); no. A1-007070.01, 2016-03-29*

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CONSTRUCTION

# A Literature Review of the State-of-Art in Fire Protection of Mid-rise Wood Buildings under Construction

Alex Bwalya, Yoon Ko, Cecilia Lam, Andrew Kim, Gary Lougheed and Joseph Su

Internal Report

29 March 2016



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# A Literature Review of the State-of-Art in Fire Protection of Mid-rise Wood Buildings under Construction

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Report No: A1-007070.01  
Report Date: 29 March 2016  
Contract No: A1-007070  
Program: Mid-rise Wood Buildings

18 pages

Copy no. 1 of 3 copies

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## Executive Summary

This work was carried in support of NRC's Mid-rise Wood Buildings (MRWB) program, whose objective is to improve the performance of mid-rise and tall wood buildings. The main objective of the work was to determine the scope for future research to develop new technologies to prevent, fight and mitigate the impacts of fire during construction. The work involved an extensive literature review and some discussions with potential stakeholders to understand their views, concerns and research needs. The literature review covered approximately 115 publications (including magazine and newspaper articles). The current literature clearly identifies the significant fire risks faced by wood buildings during the construction phase and there are numerous examples of fires that have occurred at wood building construction sites.

The literature review revealed that the current state-of-the-art essentially encompasses the development and promotion of safe working practices and fire safety guidelines for mid-rise wood buildings under construction, which is being adequately addressed by many industry stakeholders. There is a lack of research and methods to address the critical areas of active and passive fire protection during construction. This is likely due to the fact that the acceptance of mid-rise and tall wood buildings has only happened recently and was largely based on the fact that the fire safety of finished buildings is assured by proven adequacy of their fire resistance design features, such as the encapsulation approach, and mandatory requirements for fire protection systems, such as sprinklers. Therefore, NRC can make a more valuable contribution in areas where its existing fire research expertise and unique test facilities can lead to the development of new knowledge to improve safety in mid-rise wood buildings under construction by undertaking research in the following areas identified by this study:

1. Characterization of construction site fires and evaluation of detection systems;
2. Evaluation and development of active fire protection systems/technologies applicable to construction sites;
3. Evaluation and development of passive fire protection systems/technologies applicable to construction sites;
4. Improvement of firefighting tactics using scientific knowledge of construction site fires and effective suppression technologies.

The research can be undertaken in phases, with Phase 1 focusing on the characterization of mid-rise wood construction site fires, evaluation and development of fire detection and suppression systems. Subsequent phases of the project could address the evaluation and development of cost-effective passive protection systems and the improvement of firefighting tactics using the fire scenarios developed in Phase 1.

Further details of the potential scope for research in the above areas are presented and discussed in this report.

# **A Literature Review of the State-of-Art in Fire Protection of Mid-rise Wood Buildings under Construction**

by

Alex Bwalya, Yoon Ko, Cecilia Lam, Andrew Kim, Gary Lougheed and Joseph Su

## **1 Background**

In recent years, there has been an increasing trend world-wide to embrace the design and construction of tall wood buildings. In Canada this is reflected in recent changes to building regulations and codes in some provinces and approved changes to the National Building Code of Canada (NBC) to allow the construction of mid-rise wood buildings of up to six storeys. These changes have resulted in new research needs to address various issues concerning the fire safety of mid-rise and tall wood buildings in communities. Many of these issues are centered on firefighting operations and tactics, and fire prevention measures at construction sites.

The construction stage is the period during which wood buildings are most vulnerable to fire. This is primarily due to the presence of substantial unprotected combustible materials, various hazardous construction operations, such as hot works, incomplete fire protection features and systems, and deficiencies in site security, as widely documented in the literature on construction site fire safety, for example (Garis et al. 2015b). Unprotected wood frame structures, and particularly light-frame construction, also present significant fire risks to adjacent buildings during the construction phase, prior to completion of fire resistive assemblies with the installation of sheathing protection, such as gypsum board. This also makes wood frame buildings under construction particularly vulnerable to arson.

In Canada, there have been numerous documented occurrences of large-scale construction site fires, such as Winnipeg, Manitoba in October 2015, Calgary, Alberta in March 2015, Kingston, Ontario in December 2013 and Richmond, British Columbia in 2011, that highlight the concerns expressed by the fire services and the public. The cost of fire losses in buildings under construction in the province of Alberta are reported to have been about \$70 million in the period 2000 - 2009 (Office of the Fire Commissioner, Public Safety Division, Alberta Municipal Affairs, 2015). Fire losses in 21 cities across Canada are reported to have been in excess of \$250 million in the period 2001 - 2014 (CWC, 2014b).

It is understood that the extent of damage that can occur from fires in buildings under construction can be significantly reduced if active and passive protection systems and measures are progressively implemented as the construction progresses. However, full implementation of these measures is hampered by a number of challenges related to construction practices, technological issues and cost effectiveness.

## **2 Objective**

To determine the scope for future research to develop new technologies to prevent, fight and mitigate the impacts of fire during construction, in support of the MRWB program's objective to improve the performance of mid-rise and tall wood buildings.

### **2.1 Methodology**

The following work was carried out:

1. Review of the state-of-the-art of fire protection technology and practices on mid-rise wood construction sites to determine gaps in the present knowledge;

2. Consultations with potential stakeholders to understand their views, concerns and research needs

This report also provides an overview of the current regulations, best practice guidelines and a review of research work conducted regarding active fire protection systems of relevance to construction site fire safety.

### **3 Literature Review**

The literature review covered approximately 115 publications (including magazine and newspaper articles). The literature clearly identifies the significant fire risks faced by buildings during the construction phase and provides numerous examples of fires involving wood building construction sites. Various publications by the Canadian Wood Council (CWC) and others reported fire incidents that have occurred in the past with their causes and lessons learnt (Canadian Wood Council, 2014b) and (Gerard & Barber, 2013). The following is a list of typical fire risks at construction sites; a more comprehensive discussion is provided by Garis et al., 2015b:

- a) Hazardous construction operations, such as hot works and roofing;
- b) Onsite storage of combustible materials;
- c) Presence of temporary heating equipment;
- d) Risk of incendiary fires due to limited security;
- e) Incomplete fire separations;
- f) Partial installation of fire detection and suppression systems;
- g) Incomplete provisions for firefighting, and;
- h) Inadequate water supply for firefighting.

The construction industry and regulatory authorities recognize that construction site fires are largely preventable; hence there has been a considerable amount of effort directed towards enhancing security measures and the development and promotion of safe working practices, fire safety guidelines and code requirements. The vast majority of publications found in the literature cover safe working practices and fire safety guidelines, and the following are good examples: NFPA 241; UKTFA, 2008; Garis et al, 2015; Canadian Wood Council, 2015; Garis et al., 2015b.

A summary of some of the typical best practices in construction site fire safety that were found in the literature is provided in Appendix A.

#### **3.1 Fire Detection Systems**

Fire detection systems are intended to provide early detection and alert occupants. Fast detection and alerting are key factors in reducing the fire services' response time and consequently minimising the potential fire damage in wood buildings that are under construction (Craft et al., 2013).

Implementation of a fire watch for construction sites during work hours is required by building codes and guidelines in Canada and other countries including USA, UK and Asia (Canadian Wood Council, 2014a, 2014b, 2015; Confederation of Fire Protection Associations in Europe, 2012; HSE UK, 2010). The Confederation of Fire Protection Associations (CFPA) European guide requires site fire safety plans that include general site precautions, fire detection and alarm systems, temporary emergency lighting and portable fire extinguishers (Confederation of Fire Protection Associations in Europe, 2012). To ensure that personnel at construction sites are quickly evacuated, the National Fire Code of Canada (NFC) also requires an alerting system, such as an air horn, that is capable of sounding an alarm that can be heard throughout the construction site in the event of a fire (Craft et al., 2013).

### 3.1.1 Requirements for Fire Detection

The current 2010 NBC, 2006 Alberta Building Code (ABC) and 2014 Vancouver by-laws do not require automatic detection systems to be installed in buildings under construction. The Ontario Health and Safety regulations do not require both the manual (fire watch) and automatic fire detection at construction sites.

In the UK, automatic fire detection systems are required to be installed in areas where flammable liquids and gases are stored, as well as in temporary buildings and temporary accommodation used for cooking or drying of clothes. In these cases, automatic fire detection systems are required to be linked to an alarm receiving centre, unless there is a 24-hour security presence on site (FRM Journal, 2012).

The early installation of fire detection systems can be an option to reduce the risk of fire in partially completed buildings. In this regard, it is recommended to bring fire detection and alarm systems into service progressively on each floor as construction takes place (Canadian Wood Council, 2015; HSE UK, 2010). However, NFPA 72 (NFPA 72, 2016) does not recommend early installation because of possible complications, such as:

- Damage from nearby construction tasks (NEMA, 2009)
- Special care and replacement necessary on each floor (Canadian Wood Council, 2015);
- Designing and planning the construction project in sequence to achieve the early installations of detection systems (Confederation of Fire Protection Associations in Europe, 2012)

### 3.1.2 Challenges of Early Installation of Detection Systems

Craft et al. identified the following challenges of utilizing current fire detection technologies in buildings under construction (Craft et al, 2013):

- a) False alarms: Some devices may be activated by normal operations conducted on site, such as hot works. The heat and smoke generated by hot works can trigger detection systems. Therefore, some construction sites require detection systems to be de-activated during work hours.
- b) Risk of Damage: Detectors can be physically damaged due to rough handling, dusty environments and other construction activities. To prevent physical damage, guards can be installed to protect detectors.
- c) Maintenance: Regular cleaning or check-up is necessary.

Despite the above challenges, in the literature, e.g. Craft et al, 2013, it is recommended to install fire protection systems, such as heat and smoke detectors, sprinklers, fire walls and doors, at an earlier stage during the construction process. However, it should be noted that smoke detectors are generally listed for operation above 0 °C. Operation at lower temperatures can result in false alarms due to condensation inside the detectors.

### 3.1.3 Available Technologies

Heat and smoke detection systems are often used in buildings. Currently, a temporary detection system employing spot-type heat detectors can be used. Wireless detection systems are also available. A line-type heat detection system can also be used due to its easy installation. In addition, it is reported that a line type heat detection system can locate the fire more closely and protect a larger area than the spot type heat detection system (NEMA, 2009). However, line

detectors can be easily damaged by construction site activities. Therefore, line type heat detectors require regular maintenance and protection from physical damage.

Smoke detection systems can provide early warning; however, their performances greatly depend on the construction site conditions.

Both the heat and smoke detection technologies rely on a localised build-up of heat and smoke for activation. Therefore, in a building under construction, these detection technologies are not suitable in the early stages of construction before compartmentation is completed.

## **3.2 Fire Suppression Systems for Wood Buildings under Construction**

### **3.2.1 Needs for early fire suppression**

Active fire protection systems are required to reduce the risk of fire during construction of wood buildings. Water supply to the construction site would be required when combustible construction materials arrive at the site (Ontario, 2015; RBA Engineering, 2013).

### **3.2.2 Current building codes, fire codes, occupational health and safety regulations, local by-laws and guidelines**

- a) **Requirements for portable extinguishers:** The Ontario Building Code (OBC) requires that portable extinguishers be provided in various locations in a construction site (Canadian Wood Council, 2015).
- b) **Requirements for standpipes:** The OBC requires that a permanent standpipe system be installed in the completed building. The OBC also requires that a temporary or permanent standpipe system be installed to within two storeys of the uppermost work level (Canadian Wood Council, 2015).
- c) **Requirements for sprinkler systems:** Temporary sprinkler systems are not required for construction sites (except for hazardous material storages, sleeping accommodations) in Canada, US, Europe and Asia. In Europe, permanent sprinkler systems are required to be brought in service as soon as applicable following completion of each storey (Canadian Wood Council, 2014b).

### **3.2.3 Potential challenges with early installation of suppression systems**

Similar to the problems of early installation of fire detection systems, fire suppression systems that are planned for the finished buildings are not suitable for use during construction. Flaming (2009) discussed the problems associated with the early installation of fire suppression systems in detail. Some of the problems discussed in Flaming (2009) are uncertain performance of partially completed systems and potential damage as well as accidental discharge of sprinklers.

## **3.3 Passive Fire Protection: Fire Compartmentation and Structural Stability**

Unprotected wood buildings under construction also present significant fire risks to adjacent buildings. Passive fire protection is considered to be the second line of defence after a fire has started. This includes the use of fire resistive elements and limiting the use of combustible materials within a building. Fire compartmentation is considered to be an effective strategy for slowing the spread of fire. This can be achieved by completing fire compartment boundaries as the construction process progresses. In addition, installation of temporary covers on exterior openings and fire resistant cladding on building faces are considered to be effective strategies for slowing the spread of fire.

For finished buildings, the NBC contains requirements for spatial separation between properties. However, these requirements do not explicitly address the potential fire risk during construction when the exterior walls offer no fire resistance (Richardson, 1999).

Many of the published literature and guidelines on improving construction site fire safety encourage the use of the following mitigation strategies:

- The inclusion of more demanding material specifications (e.g. external wall sheathing or cladding with limited or no combustibility);
- Installing closures in firewalls to effectively prevent the spread of fire;
- Completing fire resistive linings on exterior walls to reduce the impact of radiation from the exposing building sides;
- Risk mitigation through construction process improvements, such as avoiding top down completion of interior fire separation and active fire protection systems;
- Consideration for pre-insulated panels, reduced flame spread wood materials, including fire retardant (FR) treated wood, sheathing and decking;
- Consideration for pre-fabricated modules having significantly completed passive fire protection and reducing construction time and fire risk exposure, as demonstrated in the construction of a 14 storey wood building project in Norway (Abrahamsen, 2014).

Richardson explored various ways of improving fire safety at infill construction sites (Richardson, 1999). The methods included:

- a) Erection of a temporary fire barrier between the infill site and neighbouring buildings;
- b) Implementation of a water curtain by distributing water upward from piping;
- c) Constructing the exterior wall of the exposing building with sufficient fire resistance from the onset of construction to protect adjacent buildings for a given period until the fire services arrive. This was to be achieved by the use of exterior grade gypsum sheathing with no openings (window openings would be cut out at a later stage);
- d) Controlling the ignitability of the fuel elements by application of fire retardant treatments.

However, Richardson noted that erection of temporary fire barriers could be impractical due to high maintenance costs, while the use of fire retardants also has some practical limitations.

### **3.4 Security Measures**

It is reported that most construction site fires (about 40% according to NFPA fire statistics) are due to incendiary or suspicious causes. The following are some of the measures that are frequently recommended for improving security at construction sites:

- Covering windows and installation of temporary doors to prevent unauthorized access to the structure after hours;
- Installation of good lighting and security fencing around the perimeter of the construction site;
- Installation of monitoring and video surveillance systems.

The NBC 2010 and some by-laws in many Canadian cities require security fencing for construction sites to protect the public and limit unauthorized access to the construction site (Canadian Wood Council, 2014a). Numerous publications are available that provide further guidance on steps to enhance construction site safety (NFPA 241; UKTFA, 2008; Canadian Wood Council, 2015; Garis et al, 2015b).

### **3.5 Consideration of New Technologies**

An integrated fire detection and suppression system based on video surveillance is available. This system is based on widely available surveillance video cameras which are often adopted on construction sites for security. Once a fire is detected, the system will control the fire suppression module to automatically move a water gun to the fire and to suppress the fire (Yuan, 2010).

Water curtain and envelope systems are used in Japan mainly to protect wood structured temples and buildings for heritage conservation. The systems are usually installed outside of a building within the boundary setbacks so that the system can discharge water jets toward the building envelope. As the main purpose of these systems is to prevent fire spread to and from adjacent buildings, these systems might be suitable for infill construction sites.

### **3.6 Construction Site Fire Research**

The literature review revealed a lack of previous work on fire research aimed at improving fire safety at construction sites. The UK Timber Frame Association (UKTFA) published a design guide for determining separating distances during construction, which was based on the analysis of thermal radiation measured in actual fire tests (UKTFA, 2012). The publication also provided a methodology for assessing the fire risk to neighbouring buildings in the event of a fire occurring during construction prior to completion of the fire resistant finishes. The technical guide provides tables for determining the required separating distances for exposing and exposed buildings for different types of buildings.

Calder (2014) undertook an analytical study using the NIST Fire Dynamics Simulator (FDS) to evaluate the potential radiation exposure from construction site fires and the relative risk associated with various building heights. The results of the analysis indicated that without any mitigating measures, the probabilities of fires occurring in either a 4 or 6 storey structure were similar and that the consequences of a fire event was higher for both life safety and fire spread considerations for the 6 storey structure than for the 4 storey structure. Calder did not provide any discussion of model validation to justify the results.

Calder identified the following areas that needed further research:

- The lack of knowledge on structural involvement as the fire grows complicates quantification of the rate of spread to involve the entire façade.
- The lack of knowledge relative to localization of fire and geometrical involvement of the façade limits prediction of localized heating;
- The lack of knowledge related to fire spread on the façade at various stages of construction (i.e., with or without the full architectural and fire safety designs in place at the time of a potential fire event) limits the ability to predict distribution of emissive energy over the entire façade area.

### **3.7 Current Canadian Standards, Codes and Regulations**

Garis et al. (2015b) reviewed existing legislation, regulations, codes, standards and guidelines that address fire safety for construction sites in general. Part 8 of the NBC 2010 addresses construction site regulations, while the NFC covers construction site fire and life safety. The NFC has been adopted by eight provinces with little or no modifications. The exceptions are:

- British Columbia and Alberta provincial fire codes have their own construction and demolition safety sections, and;
- Ontario does not include requirements for fire and life safety at construction sites in its 2012 fire code.
- Nunavut and Prince Edward Island have not adopted fire regulations that address fire and life safety at construction sites.

The protection of adjacent buildings from construction site fires was considered to have a high priority in the revision of 2010 NBC (Calder, 2014).

The current Ontario Fire Code (OFC) does not address the fire safety of buildings under construction; it only caters to existing buildings and partially occupied buildings that are under construction. Therefore, there is an absence of the legislative and regulatory framework to authorize the necessary fire safety requirements for mid-rise wood frame building construction. In Ontario, the protection of workers on construction sites is under the jurisdiction of the Ministry of Labour, Occupational Health and Safety Act. A deficiency of these regulations is that they do not offer a comprehensive coverage of fire safety on construction sites. Currently, the province of Ontario is developing a voluntary guideline document for construction site safety (Ontario Ministry of Municipal Affairs and Housing, 2015). The guideline outlines best practices for fire safety during construction of five and six storey buildings of predominantly wood (combustible) construction.

#### **4 Discussions with Stakeholders**

Discussions were held with the following stakeholders:

- Canadian Wood Council (CWC);
- City of Ottawa, Fire Services;
- Edmonton Fire Rescue Services;
- Office of the Ontario Fire Marshal;
- FPInnovations;
- City of Surrey, Fire Services / University of the Fraser Valley;
- NRC Canadian Codes Center.

Most of the consulted stakeholders were involved in activities to promote safe working guides and fire fighter education on construction site fires. Following are some noteworthy highlights from the discussions:

- Without appropriate preventive and fire suppression strategies, fires in large combustible structures will present considerable challenges to the fire services and communities;
- Skeptical about the benefits of using fire retardant coatings for wood components due to unknown potential impact on building envelopes, such as health and moisture permeability;
- Supportive of temporary protection measures, e.g. deluge systems attached to scaffolding and consideration for alternative fire suppression technologies, such as nozzles integrated into security perimeter with fire service connections;
- Highlighted challenges with using smoke detectors and sprinkler systems designed for finished buildings;
- Fire services face challenges as many do not have equipment that will reach top floors;
- Interested in research to help enhance firefighting tools and tactics and preplanning;
- NRC can act as coordinator for research, bringing together a number of fire service experts as was done in the US at the National Institute of Standards and Technology (NIST);

- For buildings under construction, risk assessment is needed, as well as methods for mitigating risks, e.g. curtain walls similar to those used in the UK;
- Experimental and analytical studies of plume heights / heat flux from piled combustibles would be useful;
- Need to quantify heat exposure to adjacent buildings;
- Need to determine water requirements for fighting construction site fires, since heat release characteristics likely differ from those in finished room fires. Ideally requires characterization of construction site fire scenarios, which would be useful for improving firefighting tactics.
- The 2015 NBC contains construction site safety provisions that are largely based on NFPA 241.
- There are concerns about fire fighter access to construction sites. The current NFC only requires access to the building site but does not address adequacy.
- FPInnovations is conducting an internal project, involving a literature review on technologies to mitigate fire risks in mid-rise buildings. The focus of FPInnovations' work is on technologies to detect fires, such as video surveillance and various optical technologies.

## 5 Gap Analysis

As previously mentioned, the literature review revealed that the current state-of-the-art essentially encompasses the development and promotion of safe working practices and fire safety guidelines for mid-rise wood buildings under construction. There is a lack of research and methods to address the critical areas of active and passive fire protection during construction. This is likely due to the fact that the acceptance of mid-rise and tall wood buildings has only happened recently. The fire safety of finished buildings is assured by proven adequacy of their fire resistance design features, such as the encapsulation approach (Su & Lougheed, 2014), and mandatory requirements for fire protection systems, such as sprinklers. Although the implementation of construction site fire safety measures promoted in guidelines is a significant step towards reducing fire incidences, the consequences of any fire can be catastrophic and continues to be a source of concern from the perspective of risk to adjacent properties and higher insurance costs for builders.

### 5.1 Characterization of Fire Scenarios for Buildings under Construction

As with fires in finished buildings, a quantitative understanding of fire scenarios (initiation, development and evolution) is important in any effort to develop mitigating technologies and strategies, including determination of firefighting resources, such as water supply. Indeed, during the course of this work, stakeholders had indicated that the lack of knowledge on the evolution of construction site fires was a drawback, particular for firefighting operations.

### 5.2 Risk Assessment of Wood Buildings under Construction with and without Fire Protection Systems

There have been no studies conducted to investigate the effectiveness of the use of fire detection and suppression systems in wood buildings under construction. There have also been no studies conducted using quantitative methods to assess the level of fire safety inherent in wood buildings under construction with different types of construction systems. However, risk assessment of completed wood buildings has been conducted using the CURISK and FIRECAM models (Zhang, Mehaffey, & Hadjisophocleous, 2015; Garis, 2015). It is necessary to identify levels of risk associated with different types of construction. (Kilmartin, Behayeddin, & Chandler, 2012) discusses risk assessment of buildings under construction. An interesting analytical study

was undertaken by (Calder, 2014), in which the degree of heat exposures from a wood building under construction was quantified.

### **5.3 Effectiveness of Current Fire Detection Technologies Suitable for Wood Building Construction Sites**

As discussed previously, the heat and smoke detection systems designed for finished buildings are not particularly suitable for use during the construction stage. There was no information found on detection technologies that are suitable for use in harsh construction environments and severe climate conditions, where detection of free burning fires is also required.

### **5.4 Challenges in Detecting and Suppressing Fires in Wood Buildings under Construction**

No article has discussed the issue of suppressing fires in wood buildings under construction. The challenges in detecting and suppressing fires in wood building under construction need to be identified first, and then the current or new technologies can be tested using test protocols reflecting the characteristics of wood building fires under construction.

### **5.5 Passive Fire Protection**

Numerous suggestions for implementing passive fire protection in buildings under construction were found in the literature, such as installation of fire doors, speeding up construction to achieve compartmentation, closing off openings, and installation of fire resistant sheathing and barriers to protect adjacent buildings. However, there was no research quantifying the effectiveness of different approaches. The suggestions appear to have been provided from a general understanding of fire behaviour, such as limiting ventilation by closing off openings in order to restrict fire growth and intensity.

### **5.6 Water Demand Assessment**

The quantity of water required by the fire services needs to be identified for wood buildings under construction. The water demand could vary depending on the presence of fire protection systems on the site, the construction phases and the level of risk associated with the building. Benfer and Scheffey reviewed water flow methodologies for completed buildings (Benfer & Scheffey, 2014). However, no methods were found to estimate the water demand specific to wood buildings under construction. The Ontario Ministry of Municipal Affairs and Housing provides factors to be considered for the water supply analysis (Ontario Ministry of Municipal Affairs and Housing, 2015).

### **5.7 Firefighting Tactics**

The issue of firefighting tactics is of particular concern to the fire services, especially since many departments may not have the aerial capability to deal with fires in mid-rise and tall wood structures. There was no information found on firefighting tactics that are specifically directed towards mid-rise and tall wood buildings. As previously mentioned, this is likely due to the fact that the acceptance of mid-rise wood buildings has only happened recently. Any research conducted to address other fire safety aspects of mid-rise wood buildings will also be of benefit to the issue of firefighting tactics.

## **6 Research Needs**

From the literature review, it is quite clear that the aspect of construction site fire safety concerning safety procedures and guidelines is being adequately addressed by many industry

stakeholders, such as the Canadian Wood Council, as previously discussed. NRC Construction can make a more valuable contribution in areas where its existing fire research expertise and unique test facilities can lead to the development of new knowledge to improve safety in buildings under construction. Therefore, the following areas are recommended for further research:

1. Characterization of construction site fires;
2. Evaluation and development of active fire protection systems/technologies relevant to construction sites;
3. Evaluation and development of passive fire protection systems/technologies relevant to construction sites;
4. Improvement of firefighting tactics through construction site fire characterization and evaluation and development of suppression technologies.

## **6.1 Characterization of Construction Site Fires**

There is currently no information available on the characteristics of fires in wood buildings under construction. A quantitative understanding of fire scenarios (fuel load, initiation, development and evolution) is important in any effort to develop mitigating technologies and strategies, including determination of firefighting resources, such as water supply. Potential areas of research in this category include characterization of:

- a) Fuel loads and fuel configurations during the construction phase;
- b) Ignition scenarios, such as incendiary and accidental ignition sources;
- c) Fire development, and;
- d) Radiation and firebrand exposure to adjacent buildings.

The outcome of construction site fire characterization will feed into, and can take place concurrently with, some aspects of the active fire and passive fire protection research efforts.

## **6.2 Active Fire Protection**

Active fire protection deals with fire detection, alerting (using fire alarms) and suppression. Challenges of implementing active fire protection systems during the construction phase were discussed in Section 3.1.2. Potential areas of evaluation and development research for mid-rise wood buildings under construction include:

- Fire detection and alerting;
- Temporary fire suppression systems, and;
- Improved firefighting capabilities for the fire services.

### **6.2.1 Fire Detection Systems**

NRC conducted a multi-phase research project to investigate the performance of different detection technologies available for road tunnels. In this study, nine different detection technologies were tested at the NRC full-scale test facility and in the field. The nine technologies included linear heat detection, spot heat detection; smoke sampling detection, multi-infrared flame detection and video imaging detection systems. Some of these detection technologies may be suitable for use in buildings under construction. The following detection technologies could be included in a future study to investigate their detection capability and reliability, as well as ease of installation.

- Heat detectors: Linear heat detectors, radio heat detectors (wireless), spot heat detectors;
- Smoke detectors: Projected beam smoke detectors, spot smoke detectors, optical smoke detectors (wireless);

- Video imaging detection system coupled with IR cameras or surveillance cameras, and;
- Drone detection technology.

### **6.2.2 Fire Suppression**

For on-site fire protection systems, options include water based fire suppression systems, such as sprinklers or foam systems. These would not be sophisticated fire suppression systems such as required in NFPA13, but rather basic temporary systems. With sprinkler systems, the option of integrating nozzles into scaffolding or security perimeter fencing can be explored. This is supported by discussions with personnel from the Ottawa Fire Services.

Using sprinkler heads would provide some level of protection, but using foam nozzles may provide a higher level of protection, especially if a compressed-air-foam (CAF) system is utilized. CAF is generated by injecting air under pressure into a foam solution stream. One significant advantage of the CAF system is the increased momentum of the foam, enabling it to penetrate fire plumes and reach the seat of the fire. Therefore, a CAF system can provide a much larger coverage area with much better fire suppression performance. CAF technology could be a suitable system for installation around the security perimeter fencing of the construction site since it has a stronger momentum with larger coverage area. In addition, CAF also has better sticking characteristics, so it can prevent spread of fire by limiting ignition of adjacent materials from the fire, whereas water spray alone has a limited effect on this because water quickly evaporates due to radiation heat from the fire.

Further research is required to study the performance, cost effectiveness and optimization of the various suppression systems given the challenges of operating in construction sites. Optimization of suppression systems would require further development work and testing to optimize dispenser (sprinklers or nozzles) characteristics for suitable systems. In addition, the impact of winter weather on the performance of suppression systems and measures to maintaining systems operational need to be studied.

### **6.3 Passive Fire Protection**

Potential research to enhance passive fire protection can include:

- Identification and evaluation of materials for external wall sheathing or cladding with limited or no combustibility to limit fire spread to adjacent buildings;
- Consideration for pre-fabricated modules having significantly completed passive fire protection elements and reducing construction time and fire risk exposure;
- Evaluation of the effectiveness of temporary fire barriers between the infill site and neighbouring buildings;
- Evaluation of the effectiveness of measures such as water curtains;
- Controlling the ignitability of the fuel elements by application of fire retardant treatments;
- Analysis of construction processes to identify potential for early implementation of compartmentation and fire resistive barriers.

### **6.4 Firefighting Strategies and Water Flow Requirements**

The fire services are concerned about the large quantity of unprotected fuel load and exposing building face areas in mid-rise wood construction and whether they have adequate capability (such as aerial equipment) to fight such fires with current resources. An additional concern is whether there is adequate water supply and access routes to prevent fire spread to adjacent

structures, especially in infill situations. One of the issues for buildings under construction is that the peak heat production likely occurs differently than it would in a finished building. Therefore, the required fire flows during construction may be different than those required for finished buildings. Further research is required to characterize and quantify building site fire scenarios to help develop appropriate firefighting strategies.

One way to improve the fire services' firefighting capabilities is by developing water additives that can increase firefighting effectiveness for Class A fires. Class A fires result from ordinary combustibles such as wood, paper, fabrics, rubber and plastics. Another option is to consider the use of foam as an additional fire extinguishing medium. CAF is currently available to the fire services, and it has many advantages in fighting Class A fires. It has been shown that CAF can extinguish fires much faster and with less water. Also, since CAF has better sticking properties than water, it has a much better capability of preventing fire spread when it is sprayed onto an adjacent structure, which is an important consideration in infill fire scenarios. NRC has vast experience in evaluating the effectiveness of CAF in fighting Class A fires. Recently, several companies have developed mobile compressed-air-foam (CAF) systems for use by fire services.

An experimental study was carried out by NRC to compare the fire suppression effectiveness of a manually-applied CAF system with that of a hose stream application using water alone and using foam-solution, under similar conditions. These tests involved manual firefighting, and human factor was involved, thus it was difficult to get repeatable results (Kim, 2012). The effectiveness of the system depended on the firefighting technique used by the firefighters. However, it was clear from the test results that CAF is more effective than water alone or foam solution applications, in suppressing compartment fires. The difference in water consumption to knock-down the fire with the hose stream water and CAF is approximately 2-3 times. CAF, with 94.6 LPM flow rate, used 13.8 L of water to knock-down the fire, while hose-stream water used 39 L of water. With a 47.3 LPM flow rate, the CAF used 25 L of water to knock-down the fire and hose-stream water used 60 L of water. The difference in the total amount of water used to completely extinguish all flames in the fire compartment between the CAF and the hose-stream water was smaller than the difference in the amount of water used to knock-down the fire.

In these tests, the fire challenge was limited because the fire compartment was relatively small, but if the fire challenge is much greater, such as in real fire scenarios involving structural fires in the field, the effectiveness of CAF over water-only should be more evident. Further research is required to study the effectiveness of CAF in construction site fire scenarios.

The CAF system requires a different firefighting technique than hose-stream water application. It is important that firefighters are trained on the proper techniques of using the CAF system to optimize its performance.

## **7 Project Approach**

The research could be undertaken in phases, with Phase 1 focusing on the characterization of mid-rise wood construction site fires, fire detection and suppression. The scope of Phase 1 could include:

- a) Development of fire scenarios through a study of previous fire incidents involving both incendiary and accidental ignition sources related to construction processes;
- b) Analysis of construction site fuel loads and fire risks as construction progresses;
- c) Fire experiments to characterize selected ignition and fire growth scenarios. The experiments would be appropriately sized to be accommodated in existing test facilities and may involve simulation fires in a complete or partial compartment section;
- d) Evaluation of selected fire detection systems;

- e) Evaluation of selected fire suppression systems;
- f) Providing recommendations of viable cost-effective fire detection and suppression systems.

A subsequent phase of the project could build on the information developed in Phase 1 to address the following aspects:

- a) Evaluation and development of cost-effective passive protection systems, using fire scenarios developed in Phase 1.
- b) Evaluation and development of suppression technologies and tactics for firefighting, as well as firefighter training by conducting appropriately scaled demonstration fire experiments.
- c) Additional research needs identified in Phase 1.

## **8 Summary and Conclusions**

The vast majority of publications found in the literature cover safe working practices and fire safety guidelines. The literature review revealed that the current state-of-the-art essentially encompasses the development and promotion of safe working practices and fire safety guidelines for mid-rise wood buildings under construction. There is a lack of research and methods to address the critical areas of active and passive fire protection during construction. This is likely due to the fact that the acceptance of mid-rise wood buildings has only happened recently and was largely based on the fact that the fire safety of finished buildings is assured by proven adequacy of their fire resistance design features, such as the encapsulation approach, and mandatory requirements for fire protection systems, such as sprinklers.

NRC can make a contribution in many identified research-gap areas where its existing fire research expertise and unique fire testing capabilities can lead to the development of new knowledge to improve fire safety in buildings under construction. Therefore, the following research-gap areas are recommended for further study:

1. Characterization of construction site fires;
2. Evaluation and development of active fire protections systems;
3. Evaluation and development of passive fire protection systems;
4. Improvement of firefighting tactics through construction site fire characterization and suppression technologies.

The research could be undertaken in a number of phases, with Phase 1 focusing on the characterization of mid-rise wood construction site fires, fire detection and suppression. A subsequent phase of the project could address the evaluation and development of cost-effective passive protection systems and improvement of firefighting tactics using the fire scenarios developed in Phase 1 as well as addressing additional research needs arising from Phase 1

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## Appendix A: Construction Site Fire Safety Best Practices

Following is list of best practices summarized from a number of publications (provided at the end):

- Develop fire safety plan in advance
  - Update regularly
  - Work with local fire department
  - Key steps include: analysis of site risks and factors; development of policies/procedures/systems to manage risks; analysis of available resources (e.g. staff); development of protocol of emergency procedures (e.g. sound alarm, call emergency services, shut down hazardous operations/services)
- Designate fire safety coordinator (full-time)
  - Keep workers up to date on emergency procedures
  - Monitor site for fire safety issues, including compliance
  - Apply and update site's fire safety plan
  - Liaise with local emergency services
- Ensure adequate security
  - Proper fencing or barricades to prevent unauthorized entry
  - Good or motion-activated lighting
  - May include manned system, active detection system, security cameras, automated surveillance system, intrusion deterrents, sign-in/sign-out procedures
  - Install temporary doors and cover windows after 1st storey constructed to make unauthorized entry difficult
- Ensure adequate water supply for firefighting
  - Adequate supply available by the time combustibles arrive on site
  - Early installation of fire pumps where required for fire protection water supply
  - Install standpipe before construction is 40 feet above fire department access; extend standpipe during construction to within one floor of the highest point of construction having flooring
- Implement sprinkler system as soon as practical
  - Install and activate before introducing combustibles, before commissioning or hot testing operations are conducted
  - Activate sprinkler piping as soon as framing for each floor is finished
  - Activate sprinkler system two floors below the floor under construction
  - Keep sprinkler system charged and operational; could temporarily deactivate for specific zones while work is in progress in that area
  - Install sprinkler system as designed (wet/dry) but temporarily use as dry and convert to wet only when risk of freezing is no longer present
- Implement fire compartmentalization as soon as practical
  - Install fire doors and fire stopping as early as possible
  - Sequence construction to give priority to fire compartments, firewalls and closures in fire separations
  - Maintain 'bottom-up' completion of building interior (instead of 'top-down') so that fire protection systems are progressively installed together with rest of building interior/volume of combustibles
  - To retard upward fire spread through unstopped ducts and shafts, fit temporary horizontal fire retardant boarding as work progresses

- Face exposed timber construction and combustible insulation with non-combustible materials at earliest opportunity
- When multiple buildings involved, stagger sequence of construction to create physically separate fire areas, min 100 ft apart
- Maintain means of egress
  - Provide unobstructed and completed (with fire separations) exit stairway to each floor level
  - Install permanent escape stairs as early as possible
  - Exit stairs should be enclosed at the time when building is enclosed
  - Minimize reliance on scaffolding as escape route
  - There should normally be at least two escape routes offering escape in different directions
  - Provide and maintain clear signage
- Mitigate exterior exposure
  - Final cladding should be put in place as soon as is reasonable to prevent external fire spread
  - Prioritize completion of building faces adjacent to other buildings
  - Consider exterior fire barriers, control of outdoor combustibles, temporary exterior suppression or standpipe systems
  - If flexible materials are used to clad scaffolding, they shouldn't contribute to fire load or potential for fire growth and spread
- Ensure fire department access (vehicles and firefighters)
  - Vehicle access route should be available as soon as work commences at the site
  - Dead-end roads that are longer than 45 metres should be provided with a turn-around
  - Firefighters should be able to access each floor via stairway instead of construction ladder
- Restrict smoking
  - Designate smoking areas; cover these areas to prevent giving employees an excuse to smoke in the building during inclement weather
  - Use water-filled or metal container with self-closing lid for cigarette disposal
  - Equip smoking shelter with fire extinguisher
- Ensure access to fire extinguishers
  - Extinguishers located near exits on each floor; if in the open, protected from environment
  - Extinguishers at entrance to stores of flammable liquids/gas cylinders
- Store flammable liquids/gases safely
  - Store outdoors whenever possible
  - Store in container suitable for that liquid's hazards, in controlled access area that has sufficient window area to provide explosion relief to outdoors and that is remote from means of egress
  - Avoid/minimize presence of acetylene on site
  - Consider automatic flammable-gas detection equipment for enclosed storage areas
- Limit hot work
  - Adopt alternative methods to hot work wherever possible
  - Maintain clearance around heating/drying equipment; ensure ventilation
  - Fire watch required during and after hot work; fire watch should be trained in use of fire extinguishing equipment
  - When hot work performed in non-sprinklered areas, manned and charged fire hoses should be in place

- Remove or cover combustibles in area near hot work; alternative is thorough wetting of nearby surfaces
- Cover nearby openings to prevent hot sparks from entering or falling to a lower level
- Conduct in dedicated area away from main area of construction work or storage of materials; consider building fire-resistant enclosures for hot work processes
- Keep tar boilers at ground level wherever possible
- Strictly control hot processes/hot work by operating permit-to-work schemes
- Practice good housekeeping
  - Minimize combustible waste
  - Metal bins with close-fitting metal lids for flammable waste materials, e.g. oily rags
  - Reduce storage of combustible materials (e.g. just-in-time ordering)
  - Limit amount of flammable material to what is needed for half a day or a single shift and return unused material to the stores when the work is finished

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