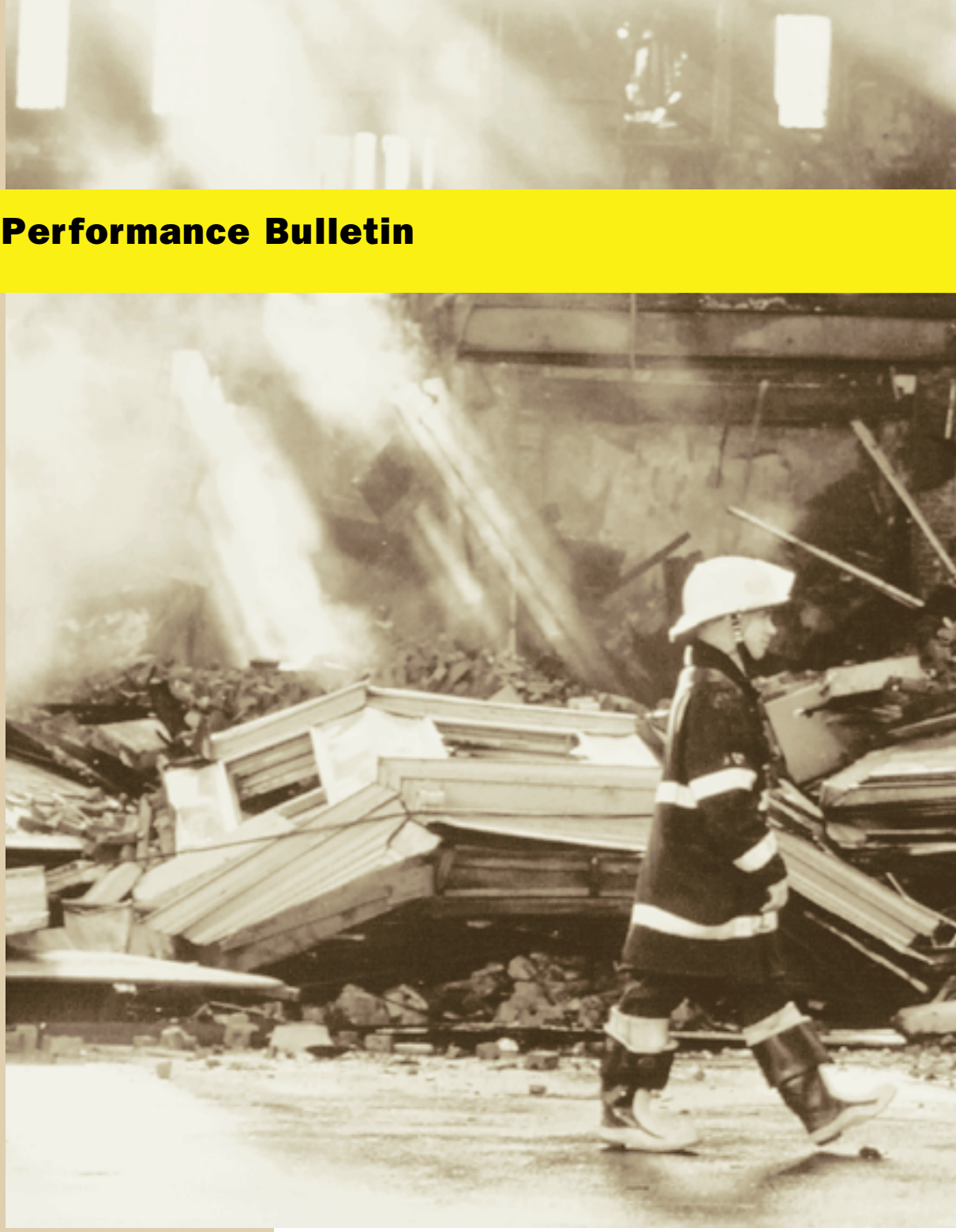
Canadian Wood Council

Conseil canadien du bois

Fire Safety in Residential Buildings

Building Performance Series: No. 2

Building Performance Bulletin



Fire is an ever-present danger for building occupants. Understanding and applying code requirements will enhance occupant safety regardless of the materials used to construct a building. This bulletin explains the principles of fire safety and demonstrates how wood-frame buildings meet code requirements for fire safety.

1. INTRODUCTION

Since wood-frame construction was first used in the early 1800's, North Americans have developed and been sheltered by wood-frame building technology -- from single family homes and progressing over the decades to larger, multi-storey apartment buildings and townhouses. In fact, over 90% of the 1.5 million homes built in North America each year are constructed using wood-frame construction.

Wood-frame construction provides North Americans with the world's highest housing standards. There are many reasons for the success of the wood frame system:

- It is easy to build
- It has a proven track record
- It delivers excellent value
- It has a high strength to weight ratio
- It is energy efficient
- It is one of the safest building systems in extreme conditions like earthquakes
- Wood is an abundant renewable resource

In addition, modern wood-frame construction provides a comparable level of fire safety to non-combustible construction. This technical bulletin will discuss some of the basic principles of fire safety, and dispel some myths about what makes residential buildings fire-safe for both single family homes and multi-family residential buildings.

2. FIRE SAFETY DEFINED

The National Building Code of Canada[1] (NBCC) defines fire safety as "*an objective to reduce the probability that a person in or adjacent to a building will be exposed to an unacceptable fire hazard as a result of the design and construction of the building.*" [2]

In simpler terms, fire safety is the reduction of the potential for harm to life as a result of fire in buildings. Although the potential for being killed or injured in a fire cannot be completely eliminated, fire safety in a building can be achieved through proven building design features intended to minimise the risk of harm to people from fire to the greatest extent possible.

Designing a building to ensure minimal risk or to meet a prescribed level of safety from fire is more complex than just the simple consideration of what building materials will be used in construction of the building. [3, 4, 5, 6] Many factors must be considered including the use of the building, the number of occupants, how easily they can exit the building in case of a fire and how a fire can be contained.

"There is no well defined method of assessing life safety from fire in buildings. Life safety is a concept, and no formula can identify or guarantee that a building is safe from fire." [7]

Fire Protection Handbook, National Fire Protection Association

3. MINIMISING FIRE RISK

The National Fire Protection Association (NFPA) developed a basic approach to minimise fire risk by applying the principles that are embodied within the *Fire Safety Concepts Tree* [8] (Figure 1). In order to achieve the basic objective of life-safety, the *Fire Safety Concepts Tree* applies a combination of measures intended to:

- prevent fires
- detect fires
- allow time for people to exit
- minimise the spread of fires
- facilitate extinguishment of fires

Most of the fire safety requirements contained in building codes can typically be categorised under one or more of the Fire Safety Tree's measures. The two fundamental principals of the *Fire Safety Concepts Tree* for minimising risk are:

- Prevent Fire Ignition
- Manage Fire Impact.

Prevent Fire Ignition

Obviously, preventing fires from starting in the first place is an important safety goal. Although fire prevention can never be completely assured, the chances of preventing a fire are increased by ensuring that:

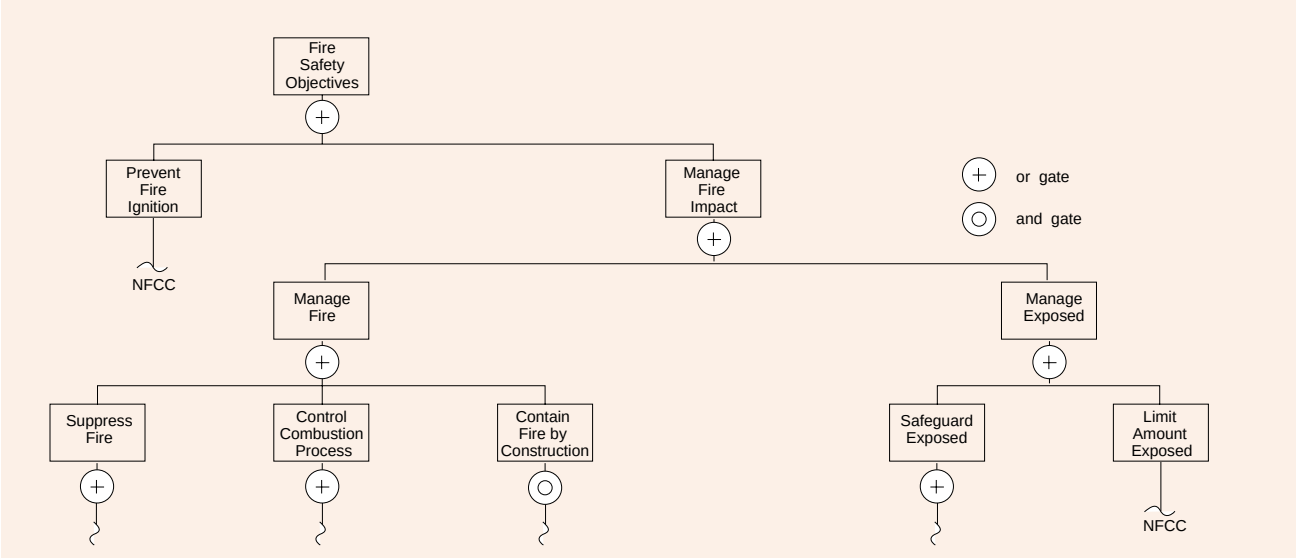
- the design and construction complies with the building codes
- the operation complies with the regulations in the fire codes

These codes apply to all residential buildings, regardless of the type of materials used to build the building.

Certain code-required features are intended to minimise the risk of fire ignition. For example, electrical systems must be installed according to the referenced national electrical codes so that fire ignition from electrical sources is minimized.

The main factors for ensuring that a fire does not start are related to the operation of a building. The fire regulations establish the fire safety requirements during the use of the facility. In Canada, the National Fire Code [9] is the model for the local fire regulations, and in the US, state or local provisions typically reference NFPA's *Life Safety Code* [10] or *Fire Prevention Code* [11]. An example of a fire code prevention measure is the requirement for the separation of combustible materials (such as refuse) from furnaces and other heat-generating devices.

Figure 1 Fire Safety Concepts Tree



Manage Fire Impact

Preventing fire ignition is the first line of defense in fire safety. The second line of defense, if ignition does occur, is to manage the fire's impact and minimise the risk. The two main methods for managing the impact of a fire are *Manage the People Exposed* and *Manage the Fire* itself.

Manage the People Exposed means getting the occupants out of the building and away from the hazard before they are injured. Most injuries or deaths are caused by the toxic fumes from the smoke so it is important that people be alerted to the fire quickly and can then get out of harms way by exiting the building.

Building Codes require building facilities or systems that are intended to limit the exposure of people to fire by facilitating their escape. Fire safety measures in this category include:

- detectors and/or fire alarm systems to warn people and cause them to evacuate
- window and door openings to allow people to escape or provide access for fire fighters to evacuate people
- exits such as corridors and stairs to allow people to evacuate safely

Manage the Fire involves measures intended to limit the spread and severity of the fire. In smaller buildings, this can be as simple as ensuring that there is a fire extinguisher available. In larger buildings, such as multi-storey apartment buildings, managing the fire becomes more complex and more critical. In a multi-family residential building, the built-in fire safety features related to managing the fire include such things as:

- fire resistant walls and floors built to contain fire to a single dwelling unit
- fire resistant walls and floors built to ensure that structural members continue to function under fire attack long enough for the people to escape or be evacuated
- limits on the flammability of wall, ceiling and floor finishes to reduce the potential for fire growth in a room
- sprinkler systems installed to control or extinguish fires

These measures will allow the occupants more time to become aware of the fire and escape the hazard.

All the foregoing measures related to both *Manage the People Exposed to Fire* and *Manage the Fire* itself are used in buildings to minimise the risk, regardless of the type of construction materials in the building.

4. Building Code Requirements

A builder or designer considering fire safety in a residential building must consider an intricate balance of measures, many of them contained in the building and fire codes, to achieve minimal risk to the occupants of the residence.

In Canada, the NBCC[1] is the model for provincial or municipal building regulations. In the US, in addition to three regional model building codes, [12, 13, 14] the recently published International Building Code (IBC) [15] is now an option that can be referenced by state and local jurisdictions.

The safety measures specified in building codes for the design of buildings vary with the size of the building and also by how the building is used. For example, indoor stadiums that will accommodate thousands of people require sophisticated fire safety systems including smoke control systems and sprinkler systems to ensure that the large amount of occupants can be evacuated. High-rise apartment buildings have similar requirements for sprinklers and other smoke control measures. On the other hand, smaller buildings such as single family houses, which have fewer occupants who can readily evacuate, do not require the same complexity of design and safety systems.

Research studies examining major causes of fatalities in residential buildings concluded that only 0.2% of the deaths were attributable to fires where a floor or wall collapsed. These studies also show that the combustible contents are the first materials to be ignited in residential fires and that the smoke and heat generated by these burning contents cause about 90% of the deaths. [16, 17, 18, 19]

Figure 2 Four Storey Wood Frame Residential Construction

The fire safety requirements for single family houses in Canadian and US Model Building Codes are the same regardless of the type of construction used. These requirements focus on ensuring that the occupants can evacuate if there is a fire because research has shown that it is the contents of the building that pose the greatest fire risk. Building codes do not require any prescribed level of structural fire resistance for floors and walls in houses. Typically, houses are finished with regular gypsum wallboard (drywall) that inherently provides some minimum protection from fire for the structural assemblies. Even without a prescribed minimum fire resistance for floors and walls in single family homes, structural fires or structural collapse do not play a major role in the deaths and injuries that occur.

The NBCC allows multi-family residential buildings up to three stories in height using any construction material. Safety measures include requiring the floors and walls separating apartments to have a required fire resistance rating. As the buildings get larger, the NBCC requires additional safety measures such as sprinkler systems and higher fire resistance ratings on the load-bearing structure. This reflects the increased risk of having more occupants and more floors for them to descend to evacuate. The NBCC mandates that four storey residential buildings be sprinklered and that the structure have a one-hour fire resistance rating regardless of whether the structure is wood, steel or concrete.

High-rise apartment buildings pose a higher risk because of the time involved for alerting and evacuating the occupants. Even though the NBCC mandates that the load-bearing structural systems be non-combustible, strict requirements including sprinklers or other form of smoke control measures along with much higher fire resistance requirements must also be met.

5. Fire Loss Statistics

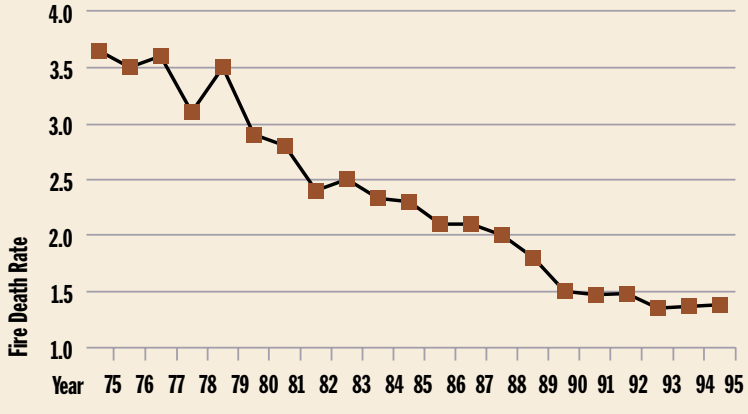
In Canada, 85% of fire deaths occur in residential buildings, the majority of which are single-family homes. This is no surprise, given that Canadians spend more than two-thirds of their time at home and, for a significant portion of that time, they are sleeping and thus at greater risk due to decreased awareness.

The high number of residential fire deaths is sometimes incorrectly linked to the extensive use of wood-framing in residential construction. An examination of annual fire loss statistics in Canada and the U.S. dispels this myth.

Canadian Experience

Figure 3 shows that fire deaths in Canada have been dropping for the last two decades. [20] This is mainly due to increased use of smoke detectors, improvements in electrical and heating systems, changes in life-style habits of the inhabitants (non-smoking/ reduced alcohol consumption/dining out), and public awareness (education programs).

Figure 3 Annual Fire Death Rate per 100,000 Residents



Effect of Residential Building Type

Table 1 contains data on Canadian residential fire deaths from 1993-1995. The data shows no significant difference in comparing the rate of deaths and injuries for 1- and 2-family houses (typically wood-frame) and the rates for other residential building types such as low-rise and high-rise multi-family apartment and hotel/motel buildings (typically steel or concrete).

Table 1 Fire Losses in Canadian Residential Buildings for 1993-1995 [21]

Occupancy	Fires	Deaths	Deaths per 100 Fires	Injuries	*Injuries per 100 Fires
1 & 2 Family	51,423	609	1.18	3,999	7.78
Apartment	17,677	181	1.02	2,396	13.65
Boarding	812	23	2.83	193	23.77
Hotel	803	7	0.87	101	12.58
Motel	293	4	1.37	24	8.19
Dormitory	195	0	0.00	6	3.08
Mobile Home	2,326	53	2.28	112	4.82
Miscellaneous	3,784	34	0.90	164	4.33
Total	77,313	911	1.18	6,995	9.05

**Includes firefighters*

Effect of Items First Ignited

Tables 2 and 3 indicate that contents and furnishings are the items first ignited and representative of the most deadly fires.

Table 2 Annual Fire Loss Record for Single-Family Dwellings – Items First Ignited [22]

Item First Ignited (list not complete)	Deaths Per 100 Fires	Injuries Per 100 Fires
Upholstered Furniture	5.11	9.24
Mattress or Bedding	1.94	7.48
Multiple Forms	1.94	4.47
Gas or liquid	1.47	8.61
Floor covering	1.32	3.88
Structural Members	0.75	1.78

Table 3 Annual Fire Loss Record for Apartment Buildings 1-4 Storeys – Items First Ignited [22]

Item First Ignited (list not complete)	Deaths Per 100 Fires	Injuries Per 100 Fires
Upholstered Furniture	4.16	15.73
Mattress or Bedding	2.16	12.21
Multiple forms	1.91	10.00
Interior Wall Covering	1.65	6.53
Gas or liquid	1.56	10.94
Structural Members	1.38	4.94

Effect of Construction Type

Tables 4 and 5 show that there is no clear indication in fire loss information that the risk from fire is significantly greater in any one type of construction.

Table 4 Residential Deaths and Injuries by Construction Type – When Fire Spreads to Entire Structure [22]

Construction Type	deaths per 100 fires		injuries per 100 fires	
	1&2 Family Dwellings	Apartments	1 & 2 Family Dwellings	Apartments
Heavy Timber	1.70	3.35	2.70	5.69
Fire Resistive	2.08	4.10	4.62	18.80
Unprotected Noncombustible	2.23	5.69	4.01	13.15
Protected Wood Frame	2.95	3.28	6.39	13.52
Unprotected Ordinary	2.97	4.00	6.03	13.15
Protected Ordinary	3.00	4.62	6.80	14.30
Unprotected Wood Frame	3.00	4.07	5.31	11.65
Protected Noncombustible	3.72	4.62	5.22	21.00
Other	4.01	15.00	5.60	25.00

Table 5 Residential Deaths and Injuries by Construction Type – All Fires [22]

Construction Type	deaths per 100 fires		injuries per 100 fires	
	1&2 Family Dwellings	Apartments	1 & 2 Family Dwellings	Apartments
Fire Resistive	.60	.60	2.90	5.85
Protected Noncombustible	.68	.70	3.45	6.90
Protected Wood Frame	.71	.70	3.95	6.32
Heavy Timber	.80	.52	2.08	4.30
Protected Ordinary	.80	.84	4.37	6.32
Unprotected Noncombustible	.71	.83	3.00	5.45
Unprotected Ordinary	.92	.97	4.01	6.01
Unprotected Wood Frame	.95	1.07	3.32	5.95
Other Construction Type	1.45	1.91	3.88	5.00

Notes for Tables 4 and 5:

1. Protected Construction has exterior walls, interior bearing walls, party walls, floors, and roofs that have a minimum one-hour fire resistance rating.
2. Fire Resistive Construction has non-combustible load-bearing building elements with a high degree of fire resistance, typically two to three hours.
3. Ordinary Construction has masonry exterior walls; floors, interior walls and roof can be wood framing.

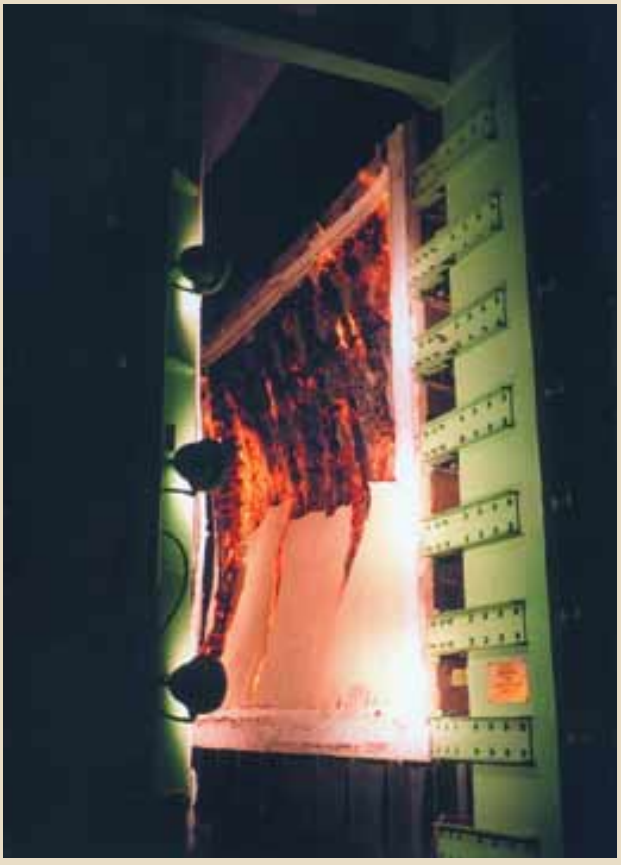
6. Wood Compared to Steel and Concrete

The fire safety of a building is far more complicated than whether the materials are combustible or non-combustible – the characteristics of the entire system must be taken into account.

Although wood is a combustible material, when it burns, a layer of char is created which helps to protect the wood and maintain the strength and structural integrity of the wood inside. This is the reason why a heavy timber system can be left exposed and still achieve a fire-resistance rating of up to 90 minutes. Wood frame walls, floors and roofs using conventional wood framing, wood trusses and wood I-joists can be designed to provide fire resistance ratings up to 2 hours.

" Most building fires are started by heat sources and ignitable materials that are brought into the building, not built into it." [3]

Fire Protection Handbook, National Fire Protection Association



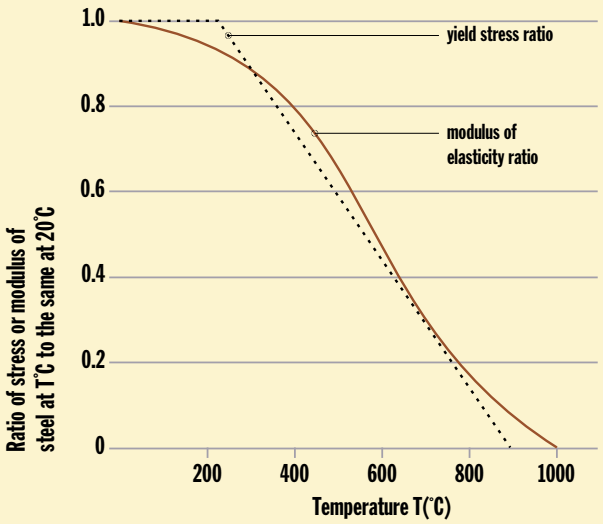
The fire resistance rating of a structural assembly is determined by subjecting the assembly to a standard fire, ranging from 1000°F at 5 minutes to 1700°F at one hour. The assembly, if designed to be loadbearing, must support the full design load for the duration of the fire test without allowing any flames to pass through.

Fire testing of loadbearing and non-loadbearing wood stud and sheet metal stud wall assemblies protected with gypsum wallboard show that fire rated wood stud wall assemblies prevent fire spread through the wall for as long as, if not longer than, identical walls built with sheet metal studs. [23, 24, 25]

Figure 4 Wood Stud Wall Assembly After 1 hour Test.

Steel is a non-combustible material but quickly loses its strength when exposed to the high temperatures of a fire (Figure 5). Like wood frame assemblies, steel must also be protected from direct exposure to fire, often by gypsum wallboard, to prolong the time before collapse occurs in a fire.

Figure 5 Steel Loses Strength at Elevated Temperatures



Source: Fire Engineering Design Guide, University of Canterbury, New Zealand, 1994

Concrete is also a non-combustible material but newer residential insulated concrete form systems use flammable foam on the exterior of the concrete as the insulation and the form. This foam generates toxic gases and intense heat in a fire. These newer ICF systems also need gypsum wallboard or some other form of protection to retard the spread of fire when used between dwelling units in multi-family residential buildings. ICF's also must be protected by a thermal barrier to protect all combustible foam insulation materials.

7. Conclusion

As demonstrated by the research, fire safety is determined to a much higher degree by the contents that homeowners bring into their residences and by their personal living habits than by the structural composition of the residence itself.

"Several patterns become apparent when we examine the various factors that lead to ignition. Perhaps the most obvious is that many people are simply oblivious to the fact that the way they interact with various items in their environment can lead to fire." [26]

NFPA Journal, National Fire Protection Association

Designers and builders, and lately even homeowners, are sometimes bombarded with terms such as "fire safe", "fire proof" and "non-combustible" in relation to residential fire-safety. Fire safety is a complex science that is not simply explained by only using such terms. No building can be completely "fire-proof" because it is the contents and the occupants that create the greatest risk.

How a building performs is not a factor of the materials used, but of how the building is designed and constructed. It is wrong to claim that sheet metal (steel stud) frame construction provides better fire safety than wood-frame construction. Building codes require that all building systems perform to the same level of safety, regardless of material used. Wood-frame construction meets, and in many cases exceeds these requirements to provide safe housing for North Americans.

North America has the best and most affordable housing in the world. North American wood-frame construction technology is being adopted in both emerging and developed economies throughout the world that want to achieve the same level of comfort and security. Wood-frame construction has the ability to meet code requirements for fire safety and all other criteria, and the flexibility and technical support to adapt to new requirements as codes continue to evolve.

This document has focussed on fire safety issues related to residential buildings. Readers are encouraged to refer to Canadian Wood Council's publication *Fire Safety Design in Buildings* [27] which provides a much broader commentary and background on the fire safety requirements of the NBCC for all buildings and construction types.

References Cited

References

1. National Building Code of Canada, National Research Council, Ottawa, ON, 1995.
2. Objective-Based Codes: A Consultation on the Proposed Objectives, Structure and Cycle of the National Building Code, National Research Council of Canada, Ottawa, ON, 2000.
3. Fitzgerald, Robert W., Fundamentals of Fire Safe Building Design, Fire Protection Handbook, National Fire Protection Association, Quincy, MA, 1997.
4. Watts, J.M. (Jr); Systems Concepts For Building Fire Safety, Fire Protection Handbook, National Fire Protection Association, Quincy, MA, 1997.
5. Rowe, W.D.; Assessing the Risk of Fire Systemically ASTM STP 762, Fire Risk Assessment, American Society for Testing and Materials, West Conshohocken, PA, 1982.
6. Linville, J. et al, SFPE Engineering Guide to Performance-Based Fire Protection, Analysis and Design of Buildings, Society of Fire Protection Engineers, Washington, D.C. and National Fire Protection Association, Quincy, MA, 2000.
7. Watts, J.M. (Jr.); Assessing Life Safety in Buildings, Fire Protection Handbook, National Fire Protection Association, Quincy, MA, 1997
8. NFPA 550 – Guide to the Fire Safety Concepts Tree, National Fire Protection Association, Quincy, MA, 1995.
9. National Fire Code of Canada, National Research Council, Ottawa, ON, 1995.
10. NFPA 101 – Life Safety Code®, National Fire Protection Association, Quincy, MA, 2000.
11. NFPA 1 – Fire Prevention Code, National Fire Protection Association, Quincy, MA, 2000.
12. Standard Building Code, Southern Building Code Congress International, Birmingham, AL, 1999
13. National Building Code, Building Officials and Code Administrators International, Country Club Hills, IL, 1999
14. Uniform Building Code, International Conference of Building Officials, Whittier, CA, 1997
15. International Building Code®, International Code Council, Falls Church, VA, 2000
16. Christian, W.J., The Effect of Structural Characteristics on Dwelling Fire Fatalities, Fire Journal, Vol. 68, No. 1, National Fire Protection Association, Quincy, MA 1974.
17. Harwood, Beatrice and Hall, J.R., What Kills in Fires: Smoke Inhalation or Burns?, Fire Journal, National Fire Protection Association, Quincy, MA, May/June 1989.
18. Miller, Alison, What's Burning in Home Fires, NFPA Journal, National Fire Protection Association, Quincy, MA, Sept/Oct 1991.
19. Ahrens, Marty, Selections From The U.S. Fire Problem Overview Report, Leading Causes and Other Patterns and Trends, Homes, National Fire Protection Association, Quincy, MA, April, 2000.
20. Fire Losses in Canada, Annual Report 1995, Association of Canadian Fire Marshals and Fire Commissioners, Ottawa, ON.
21. Mehaffey, J.R., Fire Loss Statistics for Single Family Dwellings in Canada, Proceedings of Canada-Japan Housing Committee Symposium, 1999.
22. Rohr, K.D., Custom Analysis: Examining Fires in Selected Residential Properties, National Fire Protection Association, Quincy, MA, 1998.
23. Gosselin, G.C., Impact of Wood Framed Partitions on Severity of Fires in Noncombustible Buildings, Committee Paper, Standing Committee on Fire Protection, National Research Council of Canada, Ottawa, ON, 1988.
24. Sultan, M.A., et al, Temperature Measurements in Full-Scale Insulated Gypsum Board-Protected Wall Assemblies with Resilient Channels, IRC Internal Report No. 676, National Research Council of Canada, 1994.
25. Kodur, V.K.R., et al, Fire Resistance Tests on Loadbearing Steel Stud Walls, Proceedings of Third International Conference on Fire Research and Engineering, Society of Fire Protection Engineers, Bethesda, MD, 1999.
26. Ahrens, Martin; Risky Behaviour, NFPA Journal, Natural Fire Protection Association, Quincy, MA, January / February Edition, 1999.
27. Fire Safety Design in Buildings, Canadian Wood Council, Ottawa, 1996.

Canadian Wood Council
Conseil canadien du bois

Canadian Wood Council

Conseil canadien du bois
1400 Blair Place, Suite 210
Ottawa, ON K1J 9B8
Tel: 1-800-463-5091
e-mail: info@cwc.ca

Our Websites:

Canadian Wood Council:
www.cwc.ca

Wood Design & Building Magazine:
www.wood.ca

WoodWorks Software for wood design:
www.woodworks-software.co

Wood*WORKS*! Project:
www.wood-works.org