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Fire event timeline for basement fire scenarios in single family dwellings

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Fire Event Timeline for Basement Fire Scenarios in Single Family Dwellings

Gary Lougheed, Joseph Su, Noureddine Bénichou, Alex Bwalya, Bruce Taber, Patrice Leroux
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Outline

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- Background
- Objectives
- Experimental Program
- Key Findings

Background

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- Advent of new materials and innovative products/systems used in construction of houses
- Need to better understand performance and impact on the life safety of occupants under fire conditions in single family dwellings
- Canadian codes and materials commissions requested NRC to undertake research
- Phase 1 – Unprotected floor assemblies
- Phase 2 – Structural wall assemblies

Timeline

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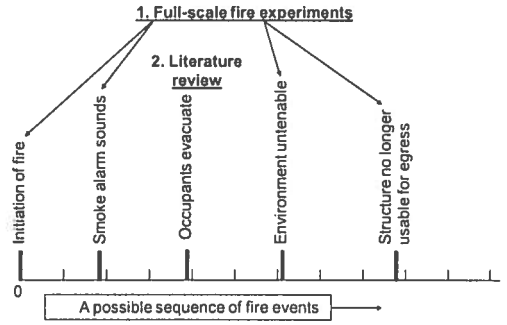

Test Facility

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- A full-scale test house simulating a two-storey detached single-family house with a basement

Basement

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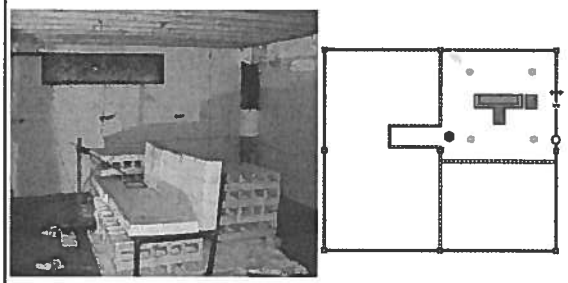
- Relatively severe, fast-growing fire to challenge the floor above



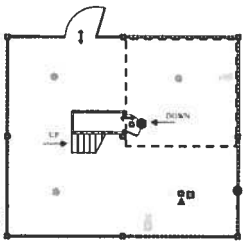
Basement Ceiling – Unprotected Assemblies

Solid wood joists | Wood I-joists (LVL flanges) | Wood I-joists (FJL flanges)

Steel C-joists | Metal-plate wood trusses | Metal-web wood trusses

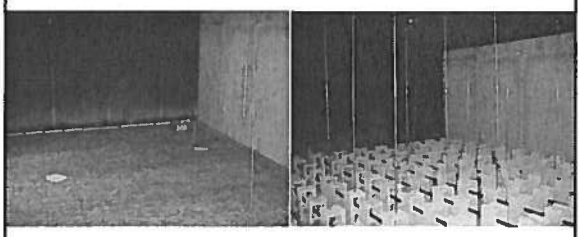
First Storey

- State of doorway to basement:
  - Open
  - Closed

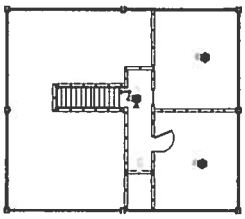


First Storey
Loading on Test Floor Assembly

- OSB Subfloor
- 0.95 kPa imposed load (20 psf, i.e. ½ NBC design load)
- Self-weight of test floor assembly

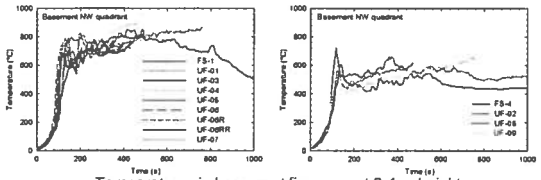


Second Storey



Fire Scenarios

open basement doorway | *closed basement doorway*



Temperatures in basement fire room at 2.4 m height

- Relatively severe, fast-growing fire in the basement
- Very reproducible fire exposure
- Challenge to the structural integrity of unprotected floor systems

Measurements and Analysis

- Smoke alarm responses
- Estimation of time to untenable conditions
- Structural response of floor assemblies

Smoke Alarm Responses

Smoke alarm location	Basement fire room		1st storey		2nd storey corridor		2nd storey bedroom (open)		2nd storey bedroom (closed)	
type	I	P 2	I 3	P 4	I 5	P 6	I 9	P 10	I 7	P 8
Tests with open basement doorway										
Test UF-01	-	40	75	85	125	135	140	150	200	205
Test UF-03	-	48	58	73	123	133	143	143	218	228
Test UF-04	-	30	65	85	115	130	160	225	230	250
Test UF-05	-	45	40	55	130	145	155	165	245	275
Test UF-06	-	45	75	85	115	125	130	200	230	255
Test UF-06R	-	38	58	78	113	123	138	163	198	223
Test UF-06RR	-	43	73	78	128	138	143	153	223	248
Test UF-07	-	50	40	55	110	130	130	145	190	210
Tests with closed basement doorway										
Test UF-02	-	42	72	97	172	182	212	n.a.	427	541
Test UF-08	-	50	85	95	205	205	220	210	515	515
Test UF-09	-	44	79	89	179	179	209	204	479	459

Smoke Alarm Responses

- Smoke alarms in the basement detected the fire in 30 – 50 s – Average 43 s.
- Activation time delayed for non-interconnected smoke alarms

Open Basement Door (average response time)
- 67 s main floor;
- 126 s second floor corridor;
- 198 s bedroom with open door;
- 264 s bedroom with closed door.

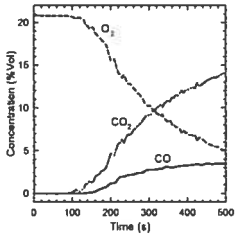
Closed Basement Door (average response time)
- 86 s main floor;
- 187 s the second floor corridor;
- 206 s bedroom with open door;
- 489 s bedroom with closed door.

Tenability Analysis

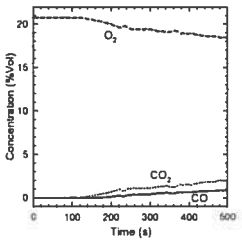
- Untenable conditions
  - Smoke obscuration (optical density measurements)
  - Toxic, asphyxiant gases ($CO/CO_2/O_2$ measurements)
  - Heat (temperature measurements)

Tenability Analysis – gas measurements

open basement doorway

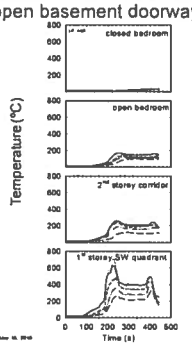


closed basement doorway

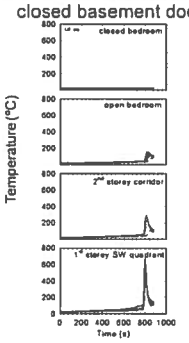


Tenability Analysis – temperature measurements

open basement doorway

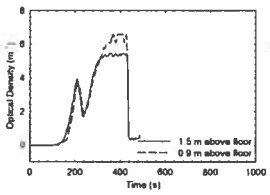


closed basement doorway

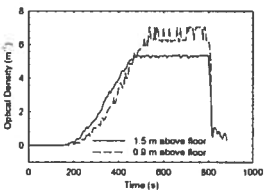


Tenability Analysis – optical density measurements

open basement doorway



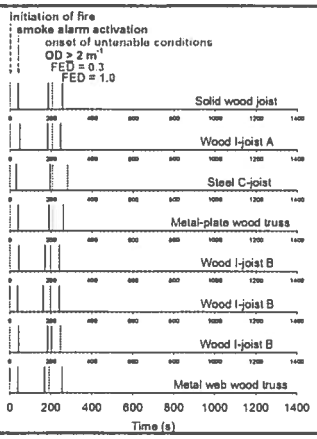
closed basement doorway



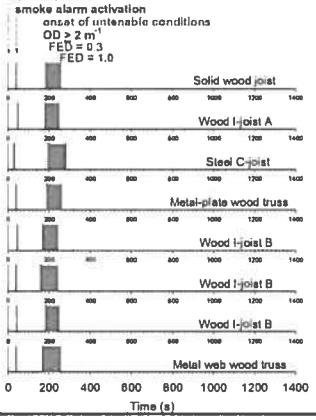
Tenability Analysis – estimation of time to untenable conditions

- Depending on many factors
  - Fire characteristics and house geometry
  - Endpoints for tenability analysis (incapacitation used)
  - Occupant characteristics, activities, susceptibility, thresholds/tenability limits
  - Each occupant likely to have a different time
- Tenability limit/threshold values used
  - Smoke obscuration: optical density (OD) = 2 m^{-1}
  - CO/CO_2 or heat exposure: fractional effective dose approach
    - FED = 1 for a healthy adult of average susceptibility
    - FED = 0.3 for a more susceptible person

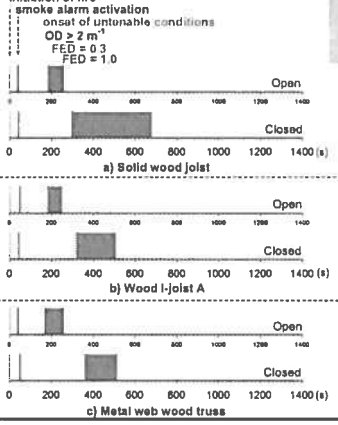
open basement doorway



open basement doorway

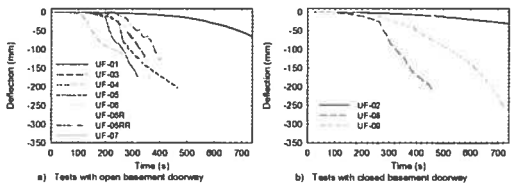


Comparison: open vs closed basement doorway



Structural Response of the Test Assemblies

- Temperatures
- Flame penetration
- Deflections

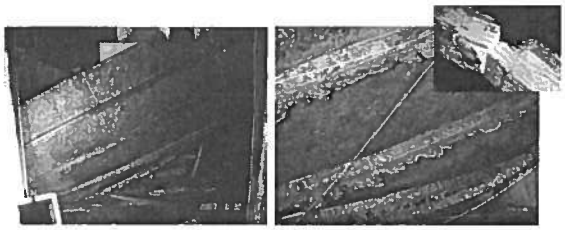


Primary Mode of Floor Failure

Solid wood joist assemblies: subfloor failure (burn through)

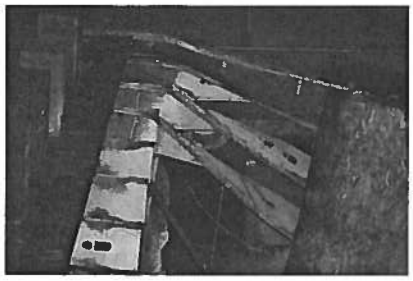
Primary Mode of Floor Failure

Wood I joists A and B: web materials burned through
Wood I-joist B: breakdown at finger joints of lumber flanges



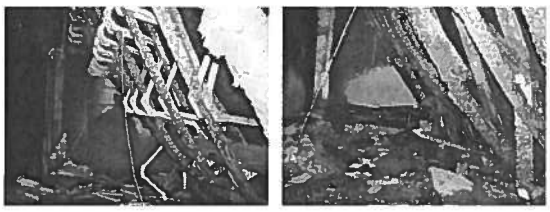
Primary Mode of Floor Failure

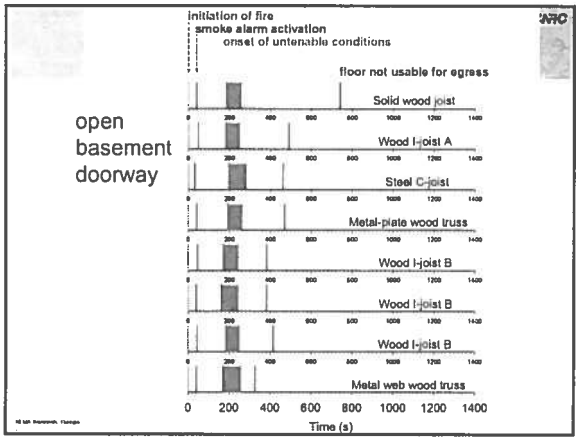
Steel C-joists: lost strength and deformed

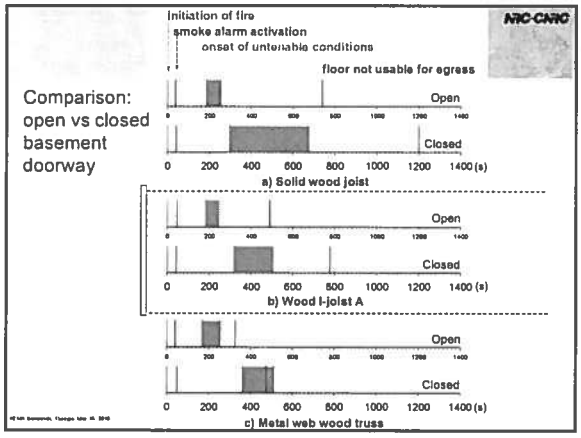


Primary Mode of Floor Failure

Metal-web & metal-plate wood trusses: metal-wood connections







Key Findings

- **Tests with an open stairwell to the basement**
  - Fire events followed a chronological sequence:
    - initiation of the fire
    - activation of smoke alarms
    - loss of tenable conditions in open areas on upper storeys
    - finally structural failure of the test floor assembly
  - Untenable conditions for occupants in open areas on upper storeys were reached at approximately the same time regardless of the type of the test floor assemblies
  - The untenable conditions were reached before failure of the test floor assemblies occurred

Key Findings (continued)

- **Limited tests with a closed door to the basement**

  3 assemblies: solid wood joist, wood I-joist, metal-web wood truss

  - Reduced fire size in the basement
  - Slowed the transport of combustion products from the basement to the upper storeys
  - Delayed the time to reach tenability limits for occupants on upper storeys
  - Delayed the times for the test floor assemblies to reach structural failure
  - Metal-web wood truss assembly failed before tenability limits were reached in open areas on upper storeys

Key Findings (continued)

- **All tests**
  - The time to reach failure for the engineered assemblies was shorter than for the solid wood joist assemblies
  - Untenable conditions were not reached, for the duration of the tests, in the second-storey bedroom where the door to the bedroom was kept closed
  - Results support the code requirement for working interconnected smoke alarms on each level of a house to alert occupants as early as possible in the event of a fire
  - Results reinforce the importance of continued public education on home fire safety, fire emergency preparedness and immediate evacuation upon a fire alert

Further Studies

- Consortium project (2008-2010) – protected floor assemblies in basement fire scenarios
  - engineered floor systems protected by gypsum board, sprinkler or other measures
  - Impact of the protection measures on fire performance and tenability conditions
- Fire Performance of Houses Phase 2 (starting 2011)
  - Innovative wall assemblies for single-family houses

Acknowledgments

- Project partners (Phase 1):
  - *Canada Mortgage and Housing Corporation*
  - *Canadian Automatic Sprinkler Association*
  - *Canadian Wood Council*
  - *Cement Association of Canada*
  - *City of Calgary*
  - *FPInnovations - Forintek Division*
  - *North American Insulation Manufacturers Association*
  - *Ontario Ministry of Community Safety and Correctional Services/Office of the Fire Marshal*
  - *Ontario Ministry of Municipal Affairs and Housing*
  - *Wood I-Joist Manufacturers Association*