NATIONAL ENGINEERED LIGHTWEIGHT CONSTRUCTION FIRE RESEARCH PROJECT

TECHNICAL REPORT:

LITERATURE SEARCH
&
TECHNICAL ANALYSIS

by

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Foreword

This literature search and technical analysis was conducted for the Technical Advisory Committee to the National Engineered Lightweight Construction Fire Research Project to identify areas of concern, and to identify current gaps in documentation. As a basis for developing a fire test program it is, together with its extensive companion bibliography, a first step.

The National Engineered Lightweight Construction Fire Research Project was initiated in September, 1990 with the goal of documenting the fire performance of engineered lightweight construction and the performance of fire sprinklers in these assemblies. Phase I tasks include the identification of gaps in knowledge, and test planning.

For some years, there has been widespread concern among fire service, manufacturing, fire sprinkler and insurance communities regarding the fire performance of construction that relies more on strength of the engineering design than on mass. The concern is for misapplication, firefighter and occupant safety, roof or floor collapse, and fire suppression system adequacy. The concern is that there is inadequate documentation for many current practices, and misapplication of codes, resulting in inadequate safety factors.

The Research Foundation expresses gratitude to the author, Kirk Grundahl, P.E. The Foundation and the author thank the project's Technical Advisory Committee listed on the following page for their contributions in all respects: technical expertise, review, as well as the financial resources to conduct Phase I. Of course, the interpretation and opinions expressed are the author's and those of the authors of the literature cited, and project participation does not necessarily constitute a participant's endorsement of every statement in the report.

NATIONAL ENGINEERED LIGHTWEIGHT CONSTRUCTION PROJECT

Technical Advisory Committee

American Hotel & Motel Association
Boise Cascade Corp.
Building Officials and Code Administrators
Canadian Wood Council
Downey Fire Department
Factory Mutual Research Corp.
Fairfield Department of Public Safety
International Conference of Building Officials
Industrial Risk Insurers
L.A. County Fire Department
MacMillan Bloedel Ltd.
National Fire Sprinkler Association
National Forest Products Association
PFS Corporation
Qualtim Technologies
J. Gordon Routley, P.E.
Trus Joist MacMillan Co.
Underwriters Laboratories Inc.
Virginia Beach Fire Department
Willamette Industries
Wood Truss Council of America

Executive Summary

The overall objective of the National Fire Protection Research Foundation (NFPRF) National Engineered Lightweight Construction Fire Research Project is to define the actual fire performance characteristics of engineered components. The components examined in this study include: metal plate connected (MPC) wood trusses, MPC metal-web wood trusses, pin-end connected steel-web wood trusses, wooden I-joists, solid-sawn (e.g., 2 x 10) wood joists, composite wood joists, steel bar joists, and steel C-joists.

Heavy timber trusses, bowstring timber trusses, heavy timber, and glue-laminated beams are discussed for additional information. They are not considered to be lightweight construction.

Phase I of this project involved performing a literature search to determine what relevant literature was available on this topic. A complete listing of the documents found in this search (approximately 2000 citations) may be obtained upon request from NFPRF.

During Phase II, literature pertinent to the topic was gathered and a technical analysis was prepared based on the readily available source documents. This analysis contains the following information:

- A discussion of the history of this topic, as well as the NFPRF project.
- A list of significant journal articles written about the fire performance of lightweight components and other related topics on fire performance. These articles are summarized and discussed by topic (e.g., trusses, steel, I-joists, glulam beams, timber trusses, heavy timber, connections, testing, fire ground tactics, etc.). The intent of this review is to accurately convey the concerns about fire performance, and to distill this information for further evaluation and discussion.
- A discussion of the statistics on losses due to fire. Covered are one- and two-family dwellings, apartments, non-residential fires, sprinkler performance, and civilian and firefighter injuries and fatalities. The intent of the statistics is to put the fire performance problem into perspective. The data can serve as a tool to help focus efforts that may be undertaken to enhance our ability to resolve performance concerns.
- A discussion of testing procedures and tests that have been used to assess the fire performance of the components under study. The testing is broken down as follows:
    - Unsheathed Assemblies.
    - Single Membrane Protected Assemblies.
    - Connections.
    - "Operation Breakthrough" Assemblies.
    - Coated Assemblies.

  In each of these areas, available tests are described, including title, author, sponsor, date, basic test description, test methods, data collected, and conclusions. Additional commentary is given after each test description to provide additional insight on the test method or other factors surrounding the test. A table summarizing all tests is included within each category listed above.

- A description of the sprinkler testing that has been performed primarily on engineered wood components. A detailed outline of the test specifics is provided, along with commentary on the tests performed.
- A discussion of requirements of the major U.S. model building codes: Uniform Building Code, National Building Code, and the Standard Building Code. The current local and model code development environment is also discussed.
- The information presented in each of the above topic areas is thoroughly discussed and evaluated. This includes a discussion of the literature that evaluates concepts presented in professional fire service journal articles, provides discussion of statistics, looks at failure modes of the various tested assemblies, and summarizes tests that have been performed. A series of test data summary tables identify where test data exists and where test data is not available.
- Conclusions based on the preceding information are developed. The major conclusions reached from this analysis are:
  - Lightweight building components are used extensively as structural members today, and the trend is for greater utilization in the future. Learning as much as possible about their structural and fire performance will only enhance firefighting safety .
  - Standardized test procedures and performance acceptance criteria must be developed, primarily to assist with determining modes of failure and warning signals prior to failure, and to support firefighting tactics, for the following areas:
    - ♦ Fire endurance performance of unsheathed lightweight building component assemblies.
    - ♦ Fire endurance performance of lightweight building component assemblies when a concealed space is created by their application.
    - ♦ Fire endurance performance of lightweight building component assemblies when sprinkler systems are incorporated.
  - There is a need for education and training in the following areas:
    - ♦ Engineering principles that apply to lightweight building components.
    - ♦ Explanation of the fire performance of lightweight building components.
    - ♦ Explanation of fire endurance testing procedures, and tables that help explain what the results from the testing performed mean.
    - ♦ Explanation of the use of mathematical fire endurance models as they are developed for lightweight building components.
    - ♦ The importance of code-conforming construction, and how violations of fire- and draftstopping influence the fire performance of lightweight building components.

- Strategy and tactics that are developed for fighting fires in buildings that employ lightweight building components. This includes developments based on current knowledge, as well as new knowledge gained through testing and experience.
- Develop the database technology that would aid pre-fire planning. This could then be expanded to provide detailed information on the performance of lightweight building components when fires have occurred in buildings that use them.

Appendix A gives a brief biographical sketch of the major authors cited in **Chapter 2**.

Appendix B is a glossary of related terms.

Appendix C reviews the comparative risk statistics.

Appendix D contains information pertaining to the bibliography of articles generated by the literature search.

Acknowledgments

This report is the culmination of discussion and guidance from the National Fire Protection Research Foundation Technical Advisory Committee. It represents the first time that the issues and test data surrounding the fire performance of lightweight components has been compiled into one document and evaluated. The purpose of this is to lay a factual foundation for this evaluation and provide the ability to set future direction on the issues surrounding lightweight component fire endurance performance. This project has been extremely difficult, due to the breadth of the issues surrounding this performance. The encouragement, feedback, guidance and commentary of the entire TAC is responsible for the finished product. In particular, we would like to thank those who took the time to make detailed comments on all the drafts prior to this completed document. They include:

Glenn Corbett	San Antonio Fire Department
Bob Glowinski	National Forest Products Association
Dennis Lockard	California Fire Chiefs
Alan Lambuth	Boise Cascade Corporation
Bob Berhinig	Underwriters Laboratories Inc.
Joe Piscione	Trus Joist MacMillan
Gordon Routley	Tridata
Tom Frost	Building Officials and Code Administrators International
Dick Davis	Factory Mutual Research Service Bureau
Dennis McCreary	International Conference of Building Officials

A special word of thanks must go to Glenn Corbett, Dennis Lockard, and Gordon Routley, for doing such a good job of providing their perspective and detailing the information that needed to be included in the document for relevance, accuracy, and clarity. We are particularly appreciative of Glenn and Dennis, who provided valuable insights, support, and encouragement.

The author also appreciates the inspiration and support provided by the Foundation and the administrators of this project, Rick Mulhaupt and Rich Bielen, through the travails that were encountered.

It is our fervent hope that this document will serve the general public's long-term interest in providing for the safe fire performance of lightweight component construction.

Kirk Grundahl
Jay T. Edgar

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Chapter 1: Concern Over Fire Performance of Lightweight Building Component Construction

1.1 Introduction

Over the last several years, articles written in professional fire service journals have been warning of poor fire performance in buildings that are constructed with lightweight construction components. This, in turn, has lead to a public debate on what the actual performance of these components is under fire exposure conditions. Given the disparate views on the fire performance of these structural elements, a reconciliation of the varying opinions on this issue is needed. Therefore, the National Fire Protection Research Foundation (NFPRF) undertook a project, called the **National Engineered Lightweight Construction Fire Research Project**. For this project, a Technical Advisory Committee (TAC) was created from organizations and individuals interested in the fire performance of lightweight building construction. This committee is chaired by J. Gordon Routley, P.E., a fire protection engineer and private fire service consultant. The organizations and individuals that make it up are listed below:

Participants

American Hotel & Motel Association
Boise Cascade
Building Officials and Code Administrators, International
California/Western Fire Chiefs Association
Canadian Wood Council
Downey, CA, Fire Department
Factory Mutual Research Corporation
Fairfield, CA, Department of Public Safety
Gordon Routley
Industrial Risk Insurers
International Conference of Building Officials
Los Angeles County Fire Department
National Fire Protection Association - Western Office
National Fire Sprinkler Association
National Forest Products Association
PFS Corporation
Qualtim Technologies International
Reedy Creek Improvement District
Schirmer Engineering Corporation
Trus Joist MacMillan
Underwriters Laboratories Inc.
Virginia Beach, VA Fire Department
Willamette Industries
Wood Truss Council of America

The first phase of the project gathered readily available, relevant literature on this topic to determine the documented understanding of the fire performance of these construction elements. A copy of this comprehensive search is available from the NFPRF. The second phase of the project is a review and analysis of the current understanding defined by this literature. This review and analysis forms the basis of this report.

1.2 History

A heightened professional concern over the performance of lightweight component construction was precipitated by the publication of Dr. Erwin L. Schaffer's article, "How Well Do Trusses Really Perform During a Fire?", in the March/April, 1988 edition of **Fire Journal** and a letter by Mr. Roger Montgomery, of Montgomery Builders Supply, Inc., to **Firehouse Magazine** in June, 1989. In summary, Montgomery expressed concern over the emotional nature of the fire service articles appearing in the press. He also noted that the Hackensack, New Jersey fire (where five firefighters lost their lives) did not involve metal plate connected (MPC) truss construction and should not be categorized by the fire service as performing in a fire the same as the heavy timber bowstring trusses in the automobile dealership. Schaffer's analysis claimed that comparative large-scale ASTM E119 fire testing and engineering analysis suggested that the fire performance of trusses *may* be equivalent to that of joist/rafter assemblies. He also stated that testing indicates truss assemblies give warning by deflecting substantially, and there is often flame-through of the sheathing near failure. These conditions should provide firefighters with sufficient warning of impending collapse.

This elicited a significant and varied response from the fire safety community, including the following published articles:

- "Are Wood Trusses Good for Your Health? The Safety Issue of Lightweight Wood Truss Floor Assemblies Provides Controversy," Francis L. Brannigan, **Fire Engineering**, June 1988.
- "Lightweight Wood Truss Floor Construction: A Fire Lesson," Glenn Corbett, **Fire Engineering**, July 1988.
- "How Wood Trusses Perform During a Real Fire," J. Gordon Routley, **Fire Journal**, January/February 1989.
- "A Primer on Truss Roofs. Why Truss Roofs are Hazardous for Firefighters," Francis L. Brannigan, **Firehouse**, March 1989.
- "Response to a Truss Manufacturer: The Dangers of Truss Construction Pointed Out, Again" (Due to Mr. Montgomery's letter), Francis L. Brannigan, **Firehouse**, June 1989.

While this debate provided an opportunity for public expression of the varying viewpoints, identification of specific concerns and possible solutions was not fully developed. As a result, in the spring of 1990, Qualtim Technologies International took the initiative to contact several prominent fire service members, engineered wood products manufacturers, and building regulators to determine their interest in developing an ad hoc group to discuss these issues. This led to the formation of an ad hoc committee, and a survey was sent out to gain a sense for current thought on this issue. Some pertinent comments from this survey on what was needed include:

Tom Brennan, **Fire Engineering Magazine**, answering, "What information do firefighters need from the engineered products group to better do their job?":

> *Just as you [the ad hoc committee] have started DIALOGUE AND CONCERN AND COOPERATION!!!*

Professor Bruce E. Cutter, University of Missouri, also Captain of Boone County Fire Protection District, answering, "What information do firefighters need from the engineered products group to better do their job?":

> *A pro-active approach to the problem is needed from both sides. We need to become advocates and supporters of early fire detection and suppression devices in both commercial and residential construction. We both need to participate in well-planned and documented studies that will examine some of the concerns the fire service has, and then make the results and recommendations known in both circles—fire service and truss manufacturers. Above all, we need to work together because neither the fire service nor the truss industry are going to go away.*

Robert Glowinski, National Forest Products Association, answering, "What are the short-term efforts that we need to undertake immediately to foster better fire safety?":

> *Establish ongoing dialogue between the fire service and engineered wood products industry.*

John Mittendorf, Los Angeles Fire Department, answering, "What are the short-term efforts that we need to undertake immediately to foster better fire safety?":

> *Continuing efforts of 'round table discussion.' Live meetings with an advance agenda.*

J. Gordon Routley, P.E., then of the Shreveport Fire Department, answering, "What should the long-term focus and goals for this particular group be?":

> *We need to develop educational material on all information for the fire service and designers.*

On June 27, 1990, at the Forest Products Research Society's 44th Annual Meeting, a special session was held on the Fire Performance of Light Frame Wood Structures. Speakers presented diverse papers on the following topics:

"Hazards of Fire Fighting in Light Frame Wood Structures," Francis L. Brannigan, Author/Lecturer, Port Republic, Maryland.

"Truss Industry Response to Concerns of Building Industry Regarding Fire Performance of Light Frame Wood Construction," Kirk Grundahl, P.E., Founder, Qualtim Technologies International, Madison, Wisconsin, representing the Wood Truss Council of America.

"Tests to Improve Fire Safety of Structures Built Using Wood I-Beams," Joseph R. Piscione, P.E., Manager, Product Acceptance, Trus Joist Corporation, Boise, Idaho.

"Design and Use of Fire Sprinkler Systems to Suppress Flame Spread and Enhance Performance of Wood Frame Structures," Russell P. Fleming, P.E., Vice President, Engineering, National Fire Sprinkler Association, Patterson, New York.

"Model Building Codes and Fire Protection for Light Frame Wood Construction," J. Robert Nelson, P.E., Senior Vice President, PFS Corporation, Los Angeles, California.

Subsequent to this meeting, the NFPRF became interested in providing a forum for discussion of this issue. This led to a planning meeting on September 18, 1990, at the National Fire Protection Association's (NFPA) Western Regional Office in Ontario, California. At this meeting it was concluded that a research project for lightweight component construction was needed. A project proposal was developed and sponsorship sought to undertake a literature review and technical analysis.

The rest of this report is a culmination of discussions and direction provided by the NFPRF TAC listed above. The document will cover concerns found in the firefighting literature, statistics on fire performance, fire endurance testing performed on lightweight building components, a general overview of code requirements for these components, and will end with a discussion, conclusions, and recommendations section.

Chapter 2: Literature Review

2.1 Firefighting Articles

The literature search discussed in **Chapter 1** yielded a variety of articles related to lightweight component construction. The following articles were written by the fire safety community and are pertinent to the issue of fire performance of lightweight building construction. A chronological listing of these articles provides an indication of when the problem was first recognized, and when broad-based concern became apparent.

2.1.1 Before 1970

11/1/58, "Firemen Fear Floor Collapse," **Fire Engineering**.

2.1.2 1970 - 1979

7/1/70, "Building Weaknesses—Do You Know Them?", Brannigan, F.L., **Fire Command**.

4/1/71, "Collapse Danger of Roofs with Light Weight Wood Trusses," Brannigan, F.L., **Fire Engineering**.

11/1/71, "Three Firemen Hurt as Canopy Collapses," Varner, B., **Fire Engineering**.

3/1/73, "Built to Collapse," Brannigan, F.L., **Fire Chief**.

1/1/74, "A Field Study of Non Fire-Resistive Multiple Dwelling Fires," Brannigan, F.L., National Bureau of Standards.

2/1/75, "Recognizing the Probability of Building Collapse," Cruthers, F., **Fire Engineering**.

11/1/76, "Fire Feeds on Design Weakness," Nailen, R.L., **Fire Engineering**.

5/1/77, "Dangers of Steel Bar Joists and Noncombustible Buildings," Sylvia, D., **Fire Engineering**.

10/1/78, "Design for Disaster," Brannigan, F.L., **Fire Command**.

3/1/79, "Non-Combustible Buildings—Death Traps for Fire Fighters," Sylvia, D., **Fire Engineering**.

2.1.3 1980 - 1985 (6 years)

2/1/81, "Firefighter Dies in Fall Through Roof," Dektar, C., **Fire Engineering**.

3/1/81, "Educate Architects," Brannigan, F.L., **Fire Engineering**.

3/1/81, "Enforce Fire Stopping Rules," Brannigan, F.L., **Fire Engineering**.

9/1/81, "Predicting Building Collapse," Dunn, V., **Firehouse**.

1/1/82, "Appendix A: The Hotel Vendome Fire. In Building Construction for the Fire Service, 2nd Ed.," Brannigan, F.L., National Fire Protection Association.

1/1/82, "Lightweight Construction Tests Open Fire Service Eyes to Special Hazards," Mittendorf, J., **Western Fire Journal**.

9/1/82, "Two Firefighters Killed Trying to Ventilate Roof," Ludford, L., **Fire Engineering**.

12/1/83, "Collapse Dangers of Timber Truss Roofs," Dunn, V., **Firehouse**.

1/1/84, "Take the Surprise Out of Building Collapse," Brennan, T., **Fire Engineering**.

1/1/84, "We Have a Roof Cave In," Fekete, **Fire Command**.

1/1/84, "Lightweight Building Construction Helps Prevent a Major Disaster," Jones, J.L., **Fire Engineering**.

1/1/84, "Truss Fire and Collapse," **WNYF**.

2/1/84, "How Many Disasters Do We Need?", Brennan, T., **Fire Engineering**.

5/1/84, "Don't Hit the Steel—A Myth," Brannigan, F.L., **Fire Engineering**.

9/1/84, "Void Spaces (Training Notebook)," Brannigan, F.L., **Fire Engineering**.

10/1/84, "Floor Collapse in Residential Structures," Dunn, V., **Firehouse**.

11/1/84, "Chesterfield VA Church had Lightweight Roof Trusses," **Fire Command**.

2/1/85, "Operating on Steel Open-Web Bar-Joist Roofs," Dunn, V., **Firehouse**.

4/1/85, "Building Construction: Firefighting Problems and Structural Hazards," Dunn, V., **Firehouse**.

6/1/85, "Firefighting on Sloped Peaked Roofs," Dunn, V., **Firehouse**.

8/1/85, "Beware the Truss," Brannigan, F.L., **Fire Engineering**.

8/1/85, "Collapse Analysis and Safety Precautions," Dunn, V., **Firehouse**.

11/1/85, "Trusses I," Brannigan, F.L., **ISFSI Instructograms**.

12/1/85, "Trusses II," Brannigan, F.L., **ISFSI Instructograms**.

12/1/85, "Firefighting in Wood-Frame Buildings," Dunn, V., **Firehouse**.

2.1.4 1986 - 1989 (4 years)

2/1/86, "Built Like a Brick Outhouse—Or is it?", Brannigan, F.L., **Fire Engineering**.

6/1/86, "The Mything Link in Fire Protection," Brannigan, F.L., **Fire Engineering**.

9/1/86, "Know Your Roof," Brannigan, F.L., **Fire Engineering**.

9/1/86, "Truss Collapse: Final Report (Lessons learned from the fatal Waldbaum's fire)," Dunn, V., **Firehouse**.

12/1/86, "Hazards of Lightweight Wood Truss Construction," Dunn, V., **Firehouse**.

3/1/87, "Ceilings and Suspended Loads," Brannigan, F.L., **Fire Engineering**.

4/1/87, "Wooden Structures High in the Sky," Brannigan, F.L., **Fire Engineering**.

9/10/87, "Trusses Suspect in Collapse," **Engineering News Record**.

1/1/88, "The Quick Collapse of a 'Slow Burner'," Comer, W.J., **Fire Engineering**.

3/1/88, "The Metal Deck Roof Debate," Brannigan, F.L., Mittendorf, J., **Fire Engineering**.

6/1/88, "Are Wood Trusses Good for Your Health?", Brannigan, F.L., **Fire Engineering**.

7/1/88, "Lightweight Wood Truss Floor Construction: A Fire Lesson," Corbett, G.P., **Fire Engineering**.

7/1/88, "Joist-Rafter versus Lightweight Wood Truss," Mittendorf, J., **Fire Engineering**.

8/1/88, "Truss Construction Claims More Lives," Brennan, T., **Fire Engineering**.

9/1/88, Letter to the editor, Brannigan, F.L., **Fire Journal**.

9/1/88, "More Dangerous Myths," Brannigan, F.L., **Fire Engineering**.

9/1/88, "New Jersey's Darkest Hour," **Firehouse**.

9/1/88, "Trusses Can Kill," **Firehouse**.

10/1/88, "Five Fall in Hackensack," Corbett, G.P., **Fire Engineering**.

1/1/89, "How Wood Trusses Perform During a Real Fire," Routley, J.G., **Fire Journal.**

3/1/89, "Are Wood Trusses Good for Your Health?", Brannigan, F.L., **The Voice.**

3/1/89, "More Dangerous Myths," Brannigan, F.L., **Fire Engineering.**

3/1/89, "A Primer on Truss Roofs," Brannigan, F.L., **Firehouse.**

3/1/89, "Light Weight Truss Construction Gives Up More Lessons," Kurzeja, W., **Fire Engineering.**

4/1/89, "Dangers of Operating Above a Fire," Dunn, V., **Fire Engineering.**

5/1/89, "Fire Loss Management Series. Part 2: Why Can't We Convince Them?", Brannigan, F.L., **Fire Engineering.**

5/1/89, "Tragedy Knows No Boundary," **Firehouse.**

6/1/89, "Ties That Bind," Brannigan, F.L., **Fire Engineering.**

6/1/89, "Response to a Truss Manufacturer. The Dangers of Truss Construction Pointed out, Again," Brannigan, F.L., **Firehouse.**

7/1/89, "Orange County Fatal Fire: Investigation and Analysis," Orange County Fire and Rescue Division Investigation, **Fire Engineering.**

8/1/89, "Hazards of Truss Floors, part 1," Brannigan, F.L., **Firehouse.**

8/1/89, "Truss Roof Collapse" (video), Dunn, V.

2.1.5 1990 - Present

3/1/90, "The Peaked Roof," Dunn, V., **Fire Engineering.**

5/1/91, "Lightweight Wood Trusses: More to Consider," Manny, W.F., **Fire Engineering.**

5/1/91, "The Timber Truss: Two Points of View," Mittendorf, J.W., Brannigan, F.L., **Fire Engineering.**

12/15/91, "Structural Collapse: Pinpointing the Dangers," Dunn, V., **Firehouse.**

The foregoing list is evidence that the professional concern over this issue came to the fore in 1984, and has progressed from there. The movement appears to have been led by Mr. Francis L. Brannigan, a fire protection educator and author from Maryland, and

Mr. Vincent Dunn, Deputy Chief of the New York City Fire Department. A brief biography of each of these, as well as several other authors, is found in **Appendix B**.

The literature search revealed that the concern with lightweight component construction fire performance is, for the most part, concentrated in the fire service as expressed through their various professional publications.

2.2 Concerns with Lightweight Construction

2.2.1 Firefighting Concerns

Since this project resulted from concerns expressed by the fire safety community over the performance of lightweight structural elements, a review of the specific literature that documents these concerns is helpful in order to focus on the issues.

All of the information that follows is taken directly from the referenced articles, which show the respective authors' perspectives on this topic. The intent of each article was left as is, in order to accurately show the author's point of view. Any information contained in articles known to be incorrect or misunderstood was left as originally written. Comments were paraphrased or quoted to accurately capture the author's meaning. (Note: articles in the following section are noted with a number in parentheses—e.g., '(19)', and are referenced by number at the end of this chapter. Commentary provided by the author of this report is printed in small capitals, as in, "THIS IS AN EXAMPLE OF COMMENTARY.")

2.2.2 General Concerns

Brannigan (19) clearly states that the chief interest of the fire service is the damaging force of fire, since fire destroys wooden structural members, distorts steel members, and causes connections to fail. Brannigan (30) further states that the "building [is the] firefighter's enemy."

> THESE GENERAL TENETS ARE SEEN THROUGHOUT THE FIREFIGHTING LITERATURE. IT IS CLEAR FROM THE LITERATURE THAT NOT ONLY IS THE BUILDING CONSIDERED THE ADVERSARY OF THE FIREFIGHTER, BUT SO ARE THE STRUCTURAL ELEMENTS. BY DEFINING THE BUILDING AND ITS STRUCTURAL FRAMEWORK AS AN ADVERSARY, A FIREFIGHTER CAN COME TO BELIEVE THAT THE BUILDING *IS* HARMFUL AND DEADLY—ONLY AN ANTAGONISTIC OPPONENT. THIS CONCEPT IS SEEN IN MUCH OF THE FIREFIGHTING LITERATURE ON LIGHTWEIGHT BUILDING CONSTRUCTION SYSTEMS. THE EMOTION COMES FROM THE INTENTION BY THE FIREFIGHTING LITERATURE TO ENSURE THAT FIREFIGHTERS ARE AWARE OF THE POTENTIAL DANGER, AND THAT THEY SHOULD NOT BE COMPLACENT IN LEARNING ABOUT HAZARDS IN THEIR WORKPLACE. THIS INTENT IS LAUDABLE AND NECESSARY, BUT THE MESSAGE SHOULD BE USED WITH DISCRETION, SINCE IT CAN EASILY LEAD TO MISINTERPRETATION. UNDERSTANDING ALL THE TECHNICAL

ASPECTS OF THIS ISSUE IS CRUCIAL TO MAKING DECISIONS ON THE FIRE PERFORMANCE OF ENGINEERED COMPONENTS.

2.2.3 Trusses

OFTEN, THE FIRE PERFORMANCE OF TRUSSES IS CATEGORIZED GENERICALLY, THEN BROKEN DOWN FURTHER INTO THE PERFORMANCE OF WOOD, COMPOSITE WOOD AND STEEL, HEAVY TIMBER, AND STEEL TRUSSES. AT TIMES, I-JOISTS ARE DEFINED AS TRUSS CONSTRUCTION AND INCLUDED IN DISCUSSION OF TRUSS PERFORMANCE. THOUGHTS REFLECTED IN FIRE SERVICE JOURNALS ON TRUSSES FOLLOW.

2.2.3.1 General Truss Performance

Many of Brannigan's[1] (19, 23, 28) views of the fire performance of trusses can be summarized through his published statements, including:

> *A truss is a truss is a truss. Light wood, heavy timber, steel, or wood and steel combinations are equally hazardous. There are many kinds of trusses. From a construction perspective they all share the same basic advantages, which are disastrous disadvantages for firefighters...*
>
> *A truss is a minimum reserve economical structure, designed to provide a long span, that uses the least amount of material...*
>
> *A truss has no redundancy. The failure of any element of a truss entitles the entire truss to fail...*
>
> *The failure of one truss is likely to cause the failure of adjacent trusses...*
>
> *Trusses provide vast inter-connected hidden voids in which the fire can be concealed and detonated, or deflagrating carbon dioxide can accumulate...*
>
> *The collapse of trusses is sudden and catastrophic...*
>
> *Trusses collapse without warning, injuring or killing firefighters. A failure of any member can cause the failure of the truss. There is no redundancy...*
>
> *Long spans are characteristic of trusses. Failure can be catastrophic. Multiple connections characterize the truss, and all connections are vital. The failure of any connection may be fatal...*
>
> *All trusses are designed to be the lightest they can possibly be and still support the design load under normal conditions...*

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[1] For a bibliographical sketch on this author, see **Appendix B.**

> *Even if the trusses do not fail, the wide span of roof boards between them can fail...*
>
> *Steel bolts conduct heat into the wood, destroying the wood by pyrolytic decomposition...*
>
> *Multiple truss failures are the rule, not the exception, and the failure of one truss can cause serious problems to other parts of the structure, even parts away from the initial failure point...*

Mittendorf[2] (18), Dunn[2] (12), and Routley[2] (27) reinforce or expand upon some of the concepts highlighted by Brannigan above. Dunn, in particular, points out that a large area of roof deck can collapse all at once due to timber truss (A TYPE OF GIRDER TRUSS) construction.

Mittendorf (18) and Cutter[2] (36,37) recognize the fact that if a fire burns long enough and hot enough, these hazards can apply to any roof made of any structural material. These articles tend to soften the tone of the other articles by recognizing that the fire severity and duration are the real hazard to firefighters during *any* structure fire.

Finally, Brannigan (23) states that the argument is often offered that the structural elements of a truss are "protected by [a sheet of] fire-rated" gypsum. In his opinion, "this is simply not true." He reasons that the ASTM E119 test is not an accurate predictor of performance of these assemblies in a real fire. He goes on to list what he believes to be a variety of deficiencies in ASTM E119 testing, which will be detailed later in this chapter.

2.2.3.2 Wood Truss Performance

In a video entitled, "Truss Roof Collapse," Dunn (40) states:

> *There is a saying in the fire service: 'Don't trust a truss.' Why? Because a burning wood truss is the most dangerous structure you'll ever encounter when fighting a fire...*
>
> *The truss has finally been identified as the killer it is. We found out what causes burning trusses to collapse and kill firefighters, and we're passing on this information so that you can increase your chances of survival.*

He explains the concept of trusses by saying:

> *The members are joined in a succession of triangles because triangles have the required stability and strength...Unfortunately, the same triangular design makes a truss uniquely vulnerable to collapse. If one member fails, the whole truss fails, and can cause the entire roof to fail.*

The video discusses 21 firefighters who died in six truss fires. It then explains that:

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[2] For a bibliographical sketch on this author, see **Appendix B.**

> *[As can be seen], a collapsing truss roof can kill or maim by plunging firefighters on top of the roof into the fire, by burying those below the roof, or by blocking their escape from the burning building. The collapsing truss can also cause walls to collapse.*
>
> *The primary reason [truss roofs are more dangerous than solid beam construction] is the fact that a truss burns much more rapidly than a solid beam of the same dimensions, because of its high surface-to-mass ratio.*

Another reason he cites for the danger surrounding trusses is that most of the combustible material is in the truss itself:

> *It's like having a lumberyard over your head.*
>
> *[A further reason] that trusses cause catastrophe is that, unlike solid wood beams, the members are all inter-connected. Connections are always the weakest link in a building and the first parts to collapse. Trusses are full of them. The strength of the truss depends on the strength of each individual member in that section. When one chord or web fails, the entire section, even the entire roof, can fail. A truss is only as strong as its weakest member.*
>
> *[The open design of truss roofs] actually promote the spread of fire. When a blaze hits this kind of roof, flames can race through trusses unchecked. This is especially true of lightweight wood trusses because the members are so small and flimsy.*

He also comments on metal plate connectors (MPCs) used to fabricate MPC trusses:

> *Those sheet metal surface fasteners are likely to loosen—fast—whether or not the fire is hot enough to char the wood. It can cause the fastener to curl up and pull away from the truss. These* ***killer connectors*** *help make the lightweight wood truss the most dangerous of all truss roofs.*

Brannigan (17, 23, 29, 31), Peterson (1), and Routley (27) also explain that wood trusses have a much greater surface-to-mass ratio than an equivalent piece of solid wood material, saying a wood section with a greater surface-to-mass ratio will ignite sooner and burn faster than one with less. Therefore, the lightweight wood truss is a fast burner when compared to a solid wood joist or rafter. Dunn (39) further states, "...The largest combination of combustible material within the structure is found to be within the ceiling space." The wood trusses in the ceiling form a maze of 2 x 4 inch framework below the plywood roof deck. "It becomes obvious, therefore, that if a fire occurs and the building is to be saved, the fire must not be allowed to enter the roof space."

Dunn (8) and Brannigan (23, 31) both detail concerns over the open concealed space between floors. They note that there is a hazard of the void being a reservoir for explosive carbon monoxide gas, and the rapid spread of fire throughout the concealed space in all directions.

Dunn (8,39), Corbett (26), Routley (27), and Mittendorf (25) all say that there is rapid failure in wood truss assemblies. Dunn states that, according to engineering calculations and practical firefighting experience, wood trusses can be expected to collapse within approximately ten minutes in a fully developed fire. Corbett notes that witnesses at an actual fire scene estimated that the third floor collapsed only ten to fifteen minutes after the alarm was received. Routley states, "The opinion within the fire service is that wood truss assemblies increase the danger to firefighters due to structural collapse of burning structures."

Brannigan (30) points out that wood trusses are hazardous when they are extended to support balconies in apartments or commercial structures. These balconies are often an exit for occupants and access for the fire department. Fire in the truss void can impact the structural integrity of the balcony and cause the collapse of the only exit for occupants. Therefore, firefighters should not rely on the balcony or stairway as a place of refuge.

Mittendorf (25) makes a comparison between rafter assemblies and lightweight wood truss assemblies in a collapse situation. He states that the rafters and roof may collapse during a fire in the attic, but the ceiling joists will protect the firefighters below. However, this is not the case with wood trusses, since a truss assembly is the sum of its inter-connected members; therefore, if a fire is in the attic, one must expect the entire truss to collapse as a unit into the structure.

> *This was graphically demonstrated in an attic fire in California when a lightweight metal plate connected truss roof suddenly collapsed without warning into the structure, severely injuring nine firefighters.*

Dunn (8) and Brannigan (24) note that lightweight wood trusses may have defects that result in additional problems. These defects include improper storage and rough handling which cause metal connectors to pull away from the wood surface, inadequate lumber dimensions at joints with high forces, knots located in the metal connector plate contact area, gusset plates not centered on joints, gusset lugs not embedded into the lumber, defective lumber, repair of split lumber with plates, lack of fit at truss joints, inadequate connector sizes, reduced lumber sections at joints due to improper finishing, moisture in roof spaces causing rusting, and fire retardant chemicals causing corrosion of fasteners.

Brannigan (19) states that wood girder trusses often have a bottom chord consisting of four 2 x 10s side by side. The length of the chord requires splicing of the chord with gusset plates, and that results in all the splices being located at the same point. Fire at the splice point can cause the bottom chord to fail. Since the bottom chord is under tension, this failure could cause the entire girder truss to fail, dropping all the trusses attached to it.

Finally, from a different point of view, Brannigan (17) states that all the comments that are made about truss plates are not to condemn the gusset-plate truss out of hand. He notes, "Any device that conserves natural resources and reduces the cost of building certainly has intrinsic merit." From an overall fire protection point of view, the early failure of such a truss may well be beneficial in that it may open the roof and, thus, ventilate the fire. He further states that "the building will not collapse; the collapse will be a local collapse, not a general one."

2.2.4 Timber Truss Roofs

> "TIMBER" TRUSS ROOFS ARE OFTEN CATEGORIZED WITH OTHER TRUSSES IN FIREFIGHTING LITERATURE. HOWEVER, THESE TRUSSES ARE USUALLY MADE OF BIGGER PIECES OF WOOD OR TIMBERS WHICH PROVIDE LONGER SPANS. THOUGHTS REFLECTED IN THE FIREFIGHTING LITERATURE ON TIMBER TRUSSES FOLLOW.

Dunn (9, 13) states that the timber-truss roof is one of the most dangerous structures that exists from a firefighting point of view. It is difficult to justify a long-duration, defensive firefighting operation inside a structure with a timber truss roof. Firefighters should anticipate early collapse of the roof and subsequent failure of one of the masonry walls. However, if the timber trusses are protected by fire-retarding materials, the collapse of the roof will occur more slowly, and the timber trusses are more likely to fail one at a time. Finally, the failure of a single timber truss can cause a large section of roof to collapse due to wide on-center spacing placement.

In contrast to this, Mittendorf (18) states that his experience with timber truss roofs has led him to an opinion that does not "totally coincide with popular perception of trusses in general." The principal hazards related to truss-type roofs are said to be: weak roof, early failure rate and collapse without warning. He cites the definition of 'early' in Webster's Dictionary as being "near the beginning of a process." He then relates failure times of actual fires:

- Waldbaum's Supermarket roof collapsed 32 minutes after initial units arrived.
- the Hackensack Ford dealership roof collapsed 35 minutes after initial units arrived.
- a bow string timber truss roof that sustained a significant fire for more than 45 minutes without collapsing, while the wood-joist, flat roof in an adjacent building had collapsed.

He then notes that while timber trusses can be a very hazardous type of construction, they can also provide the strength and time needed to conduct a successful aggressive attack on fire. The key for personnel is to have a working knowledge of the hazards of timber trusses and adhere to the appropriate on-site fire size-up criteria.

2.2.5 Connections

2.2.5.1 Truss Plate Connectors

Brannigan (17), Dunn (8), Routley (27), and Peterson (1) all point out that the "sheet metal surface fastener" is a major concern of the fire service. This is due to the feeling that the fastener collects heat and transmits it through the prongs, destroying wood fibers along these prongs by pyrolytic decomposition. Once this decomposition takes place, the entire wood truss fails.

Dunn (8,12,40) states further that these surface fasteners are "a deficient structural connection from a fire protection point of view"—and—"a dangerous structural connection." He also states, "...The heat from a fire can warp the thin sheet metal surface fastener, causing it to curl up and pull away from the wood truss." Therefore, from a fire protection point of view, "The sheet metal surface fastener is an inferior, dangerous type of connector, because the connection points are the first to fail." Finally, he calls these fasteners "killer connectors."

Manny (20) and Brannigan (24) also suggest that the argument that metal plate connectors act as heat reflectors has not been studied thoroughly enough to demonstrate that this has any bearing on the performance of a connector in a real fire condition.

Brannigan (23), Mittendorf (21), and Dunn (12, 39) all note that metal gusset plates, sheet metal surface fasteners or gang nails may be a problem in a fire. These fasteners may be effective truss connectors when tested in a laboratory, but from a fire protection point of view, they are deficient. They state that as the gusset plate heats up, it conducts heat to the prongs, or v-shaped points, which will cause the wood to expand. The wood is then destroyed by pyrolysis, which causes the gusset plate to fall out. Since the prongs are only 3/8 in. to 1/2 in. long [DEPENDING ON THE AUTHOR OF THE ARTICLE], the metal connector will not last very long under fire conditions. (SEE RELATED DISCUSSION ON PAGE 35 UNDER **Industry Literature**.)

2.2.5.2 General Connections

Manny (20) suggests that over time, connectors have a tendency to work their way out of structural members, and need reseating. This is due to drying and shrinking of wood, the settling of buildings, and vibrations from people, machinery, nearby traffic, etc. Therefore, the fire service should expect less stability and an earlier failure potential of lightweight wood truss assemblies as structures age.

Finally, Dunn (8) and Brannigan (23) note that fire vulnerability of connections due to fire is often overlooked. In any structural element, the point of connection may be the critical area subject to a failure during a fire. When one connection fails, it allows the entire system to fail. (SEE RELATED DISCUSSION ON PAGE 35 UNDER **Industry Literature**.)

2.2.6 Wooden I-Joists

> I-JOISTS ARE A RELATIVELY NEW KIND OF LIGHTWEIGHT ENGINEERED BUILDING COMPONENT. THOUGHTS REFLECTED IN FIRE SAFETY LITERATURE ON I-JOISTS FOLLOW.

Whitfield (4), Brannigan (12) and Clark (32) all state that the flames in a fire will quickly penetrate the thin web members of I-joists. Brannigan (12, 34) and Clark (32) further state that the surplus wood that makes it possible for firefighters to stand and operate on a burning structure is no longer available in wooden I-joists. This is because the web is thin and has holes cut into it to accommodate utilities. Once the fire reaches the I-joist, the plywood burns at a high rate of heat release, and fire extends through the holes, so that both sides of the joist burn rapidly. As soon as the plywood starts to burn, the I-joist loses strength. There is no reserve—there is no margin for safety. Again, expect early collapse.

Clark (32) notes that bonding adhesives have a flammable base. Ignition can be expected at relatively low temperatures, accelerating system failure. Fire causes the I-joist system to revert to its individual components due to adhesive bond degradation. This usually leads to sudden structural collapse. Therefore, Clark (32) states that members may lose strength in five minutes or less without providing warning.

2.2.7 Wood Joist Performance

> WOOD JOIST CONSTRUCTION IS OFTEN VIEWED AS THE BASELINE OF COMPARISON WHEN EVALUATING THE FIRE PERFORMANCE OF STRUCTURAL ASSEMBLIES. THOUGHTS REFLECTED IN FIREFIGHTING LITERATURE ON WOOD JOIST CONSTRUCTION FOLLOW.

Brannigan (28) states that the fire service should not put total emphasis on truss hazards, as this may lead to the erroneous conclusion that sawn joist or rafter roofs are completely safe. They simply have different defects.

Routley (27) and Dunn (7) note that a protected joist assembly seldom fails catastrophically. This is due to joists providing a built-in fire stop, avoiding rapid involvement of the entire void space.

Routley (27) and Schaffer (35) note that solid-sawn lumber components are said to provide warning of imminent collapse by gradually sagging under the fire load. Routley goes on to say that failure of one joist is seldom catastrophic because the remaining joists have more resistance to load transfer than trusses do. This is because of the increased chance that adjacent trusses are approaching their own point of failure when the initial truss burns through, which is not the case with joist construction.

Routley (27) states that while the fire endurance rating for unprotected joist assemblies is similar to that for unprotected truss assemblies, they do not have the same reputation for sudden collapse. Routley also notes that trusses often span wider spaces than joist systems, and joists are often supported by a partition wall system below. This makes joist systems safer for firefighters.

Dunn (7) notes that wood joist systems collapse in three different ways when attacked by fire: 1) the wood deck may burn through and collapse; 2) several floor joists may fail, causing a localized failure of the floor; and 3) a large section or entire floor level fails, sometimes causing failure of adjacent walls or floors below.

In the same article, Dunn notes that the collapse of wooden joist support systems does not occur as readily in residential buildings. The reasons for this are: 1) floors in residences are usually not as heavily loaded as floors in commercial buildings, 2) floors in residential buildings are subject to fewer structural alterations than those in commercial buildings, and 3) the underside of a floor in a residence is often protected from fire by a ceiling. Dunn also states that one should be most concerned about the bathroom floor in a residence, as it collapses more often than the other floors, due to the plumbing penetrations in a bathroom floor and the potential for rotting due to moisture.

Finally, Brannigan (17) notes that the "surplus wood of a sawn wooden beam makes it safer for firefighters to stand and operate on the burning structure." As long as only the fat is burning, the firefighter is relatively safe.

2.2.8 Steel Performance

FIREFIGHTING LITERATURE ALSO STATES THAT EVEN THOUGH STEEL IS NON-COMBUSTIBLE, IT HAS ATTRIBUTES THAT CAUSE PROBLEMS IN FIRES. THOUGHTS REFLECTED IN FIREFIGHTING LITERATURE ON STEEL FOLLOW.

2.2.8.1 General Steel Performance

Dunn (11) and Brannigan (16) relate that the failure temperature of steel is near 1000° F. At this temperature, the steel will lose 40% of its load-carrying capacity, and exert its greatest thrust due to expansion. Brannigan (16, 17, 34) notes that the coefficient of expansion of steel is such that substantial elongation can take place at ordinary fire temperatures. Elongating steel has been known to push down walls that are far from the location of the fire. Personnel on the roof a good distance from the fire area have been caught in the collapse.

Brannigan (17), Sylvia (38) and Dunn (11) note that steel is non-combustible, and leads to unwarranted confidence in its fire proof capabilities and suitability for all applications where fire is a problem. Unprotected steel has no fire resistance, and, consequently, a steel building can be destroyed by fire. The building itself will not burn, but it is likely to collapse during an interior fire due to burning contents. When a working fire occurs in a non-combustible building, firefighters must expect sections of the building to collapse.

Brannigan (33) states that steel girders are being used with increasing frequency as main structural elements. Building officials apparently believe the gypsum sheathing from the floor/ceiling assembly also protects the steel. "This is unevaluated." Should the steel be exposed to the fire in the concealed space, the steel will elongate, and, if restrained, will rotate on its axis and overturn, dumping all the trusses on it. This would cause a sudden collapse of a large section of the building.

Finally, Dunn (11) states that heated steel will bend, sag, warp, and twist unless it is covered, encased, or enclosed with some type of insulating material.

2.2.8.2 Steel Bar Joists

Brannigan (16, 34) and Dunn (10, 11, 12) state that steel bar joists may collapse after five to ten minutes of exposure to fire. Brannigan further states that when bar joists were tested using the ASTM E119 standard test for fire resistance, "they failed within seven minutes.

This failure rate can be compared with two-in. thick wooden beams,[3] which lasted only ten minutes."

Brannigan (16) relates that in tests done at Underwriters Laboratories, bar joists 30 ft. above a light-combustibles fire reached 1540° F in a little over five minutes. At this temperature, the steel bar joists would begin to rapidly lose their strength.

Dunn (11) and Brannigan (16) express concern about the spacing of steel bar joists. A wide on-center spacing (e.g., six feet on center) is not unusual for steel bar joists in a roof. Firefighters cutting a vent opening may find themselves standing on the cantilevered end of a corrugated steel sheet for only a very short period time, because the steel roofing will not support their weight.

Brannigan (16) and Dunn (12) state that unprotected steel bar joist trusses are particularly dangerous in a fire. This is due to steel being such a strong material that pieces with a very small cross-section can be assembled into trusses to provide long clear spans. Trusses are also inherently unstable, and therefore need to be tied together to resist overturning. These ties or braces transmit undesigned torsional loads from one truss to another, resulting in multiple truss failures during a fire.

Finally, Brannigan (30) notes a particular fire situation where unprotected bar joists formed the basement floor in a commercial building in Rockville, Maryland. There, a basement fire caused a joist to fail and the floor to open before employees on the first floor could get out of the building.

2.3 Other Related Products

2.3.1 Glue-Laminated Beams

GLUE-LAMINATED BEAMS ARE CLASSIFIED AS HEAVY TIMBER CONSTRUCTION WITHIN THE BUILDING CODE. THOUGHTS REFLECTED IN FIREFIGHTING LITERATURE ON GLULAM BEAMS FOLLOW.

Clark (32) states that glue-laminated wood beams can be as dangerous as any truss and should be treated accordingly. His reasoning is that under fire conditions, the strength of a glue-laminated beam deteriorates rapidly as it reverts back to its individual components. This belief is centered on the fact that the bonding adhesives used to manufacture glue-laminated beams have a flammable base. Ignition of these adhesives can be expected at relatively low temperatures, accelerating system failure. Finally, he states that in structures with laminated beams, one must expect early collapse.

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[3] These are assumed to be the same as '2 x' wood joists.

2.3.2 Heavy Timber Construction

THIS CONSTRUCTION TYPE HAS A SEPARATE CLASSIFICATION IN THE MODEL BUILDING CODES, AND IS KNOWN FOR ITS FIRE RESISTIVE PROPERTIES. THOUGHTS REFLECTED IN FIREFIGHTING LITERATURE ON HEAVY TIMBER CONSTRUCTION FOLLOW.

Dunn (10) states that heavy timber construction does not collapse during the early stages of a fire. Masonry walls, large timber girders and columns characteristic of this construction are very stable during the growth period of a fire. The problem with heavy timber construction is the radiating heat which will not allow firefighters to get close to the building, and which spreads to adjacent buildings. Once timbers become engulfed in fire, control of the structure fire is impossible. After several hours, the floors will collapse and free-standing walls will fall into the street.

2.4 Other Related Concerns

2.4.1 Concealed Spaces

Brannigan (30) notes the temptation to use sizable concealed spaces in attics for storage, maintenance shops, etc., and that a fire entering this truss void can be very dangerous. He recommends that sprinklers be required throughout concealed spaces. Dunn (39) adds that since the model building codes require fire stopping after only 3,000 ft.^{2} of area is built, many structures will not have firestopping divisions. If fire enters the concealed area, it will spread and involve the entire cockloft. A roof space containing a truss system will allow fire to spread more quickly than one containing solid wood joists. Fire spreads between the trusses and open web members more rapidly.

2.4.2 Testing For Fire Performance

Building codes generally permit the use of structural assemblies based upon performance in standardized fire tests such as ASTM E119. This testing has also been the subject of comment.

Brannigan (24), Dunn (10) and Routley (27) all note that firefighters cannot use this fire resistive test to estimate the structural stability of a burning building. They point out that the question firefighters have is not the test results, but the actual performance of all components under *real* fire conditions. ASTM E119 provides a theoretical basis for comparison, but it does not reproduce conditions encountered in real building fires.

Dunn (10) and Brannigan (24) both relate that the floor may collapse even though it has a 1-hour fire resistance rating, because:

- The actual fire may be more intense than the test fire.

- A small-scale sample of a floor cannot be used to predict the way a full-scale floor will act in a fire.
- The bearing walls, columns, or girders supporting the floor may collapse.
- The fire may burn undetected for longer than the 1-hour test period.
- The workmanship and materials of the actual building may be inferior to those of the test.
- The test does not simulate fire entering the truss void laterally.
- The test does not provide for any penetrations of the gypsum sheathing.
- The test does not provide for additional air being added to the assembly through deficient fire stopping.
- The test does not provide for a moving live load with some impact component, representing firefighters making a primary search for victims.

Routley (27), Brannigan (24, 30) and Cutter (36) note the concern that actual construction is seldom built like the tested assembly. The test assemblies are often built by the organization sponsoring the test so, as a consequence, the construction is perfect in every detail. They point out that buildings are rarely built perfectly, and that building inspectors cannot ensure that the exact assembly specifications are met in the field.

Finally, Brannigan (24) notes that the ASTM E119 time/temperature curve does not reflect real fire conditions. The National Bureau of Standards (NBS) performed a study and recommended a curve that more accurately reflects actual time/temperature conditions during a fire. He recommends that this time/temperature curve should be used.

(SEE RELATED DISCUSSION ON PAGE 35 UNDER **Industry Literature**.)

2.4.3 Building Code Concerns

THE LITERATURE CONTAINS COMMENTS EXPRESSED IN FIREFIGHTING LITERATURE ON THE ADEQUACY OF BUILDING CODES, WHICH ARE SUMMARIZED AS FOLLOWS:

Brannigan (34), Peterson (1) and Ryan (3) voice concern that firefighter safety has never really been addressed in building code regulations. The responsibility of firefighter safety is left to the fire department.

Brannigan (34) and Ryan (3) both acknowledge that building code requirements are not self-enforcing, and therefore regulations regarding draftstopping, firestopping, and compartmentation can be violated.

Brannigan (16) notes that most buildings have no protection from fire attack, since these buildings are legally classified as non-fire-resistant. It is acceptable—even expected—that a building will collapse in a fire. In a building code, as long as the structure carries its normal load, it is irrelevant that one type of building will collapse faster in a fire than another. Even buildings classified as non-combustible are subject to early failure in a fire.

Finally, Brannigan (34) states that in a combustible structure[4] involved in a fire, no code provision—however well-written, however well-meaning—provides personal safety for the firefighter. "The building is the enemy, and we must know the enemy."

2.4.4 Collapse Experience

> THE PRIMARY REASON FOR THIS STUDY IS COLLAPSE OF LIGHTWEIGHT BUILDING COMPONENTS WHICH HAVE CAUSED FATALITIES. SOME KEY INCIDENTS THAT HAVE HIGHLIGHTED CONCERN FOLLOW.

Brannigan (17) notes that six firefighters were killed in New York when a bow-string truss collapsed during a supermarket fire. Time from initial alarm to initial collapse was 37 minutes. The entire roof collapsed 25 minutes later. A Tempe, Arizona, firefighter was killed and several others narrowly escaped death when a wood truss roof[5] on a one-story restaurant collapsed 14 minutes after arrival. A fire in Ottawa, Kansas, for which a pre-fire plan existed, showed that the roof was supported with open, unprotected metal trusses, and that the firefighters should anticipate rapid roof collapse. The rear half of the roof collapsed 11 minutes after arrival of the fire department, and the remainder collapsed 10 minutes later.

Mittendorf (21) states that several structure fires in Southern California have graphically illustrated the partial or total structural failure of lightweight construction in a short time. In December of 1979, the Orange County Fire Department responded to a structure fire in a single-family dwelling with fire showing from the garage. Approximately 10 minutes after arrival the entire roof collapsed, injuring nine firefighters. During August 1981, the Los Angeles Fire Department responded to another common structure fire. First-in companies observed a one-story, multi-occupancy commercial building with a small amount of fire showing from the roof over the involved occupancy. Approximately 2 to 3 minutes after the arrival of the initial companies, the entire roof over the involved occupancy collapsed. The roof was of open-web construction.[6]

Dunn (7) notes that on October 17, 1966, 12 firefighters were killed when the joist floor[7] of a Wonder Drug Store in New York City collapsed. The first floor collapsed suddenly into the cellar without any warning signs, hurling 10 firefighters, company officers, and chiefs into the burning cellar. On June 17, 1972, in Boston, nine firefighters were crushed to death when the solid-sawn joist floors of the Vendome Hotel suddenly collapsed. Before these structural failures, there were no warning signs. Firefighters had no time to act and withdraw to safety, and no satisfactory explanation of the incidents followed.

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[4] All buildings are combustible to some degree.

[5] The specific type of truss was not stated in the article.

[6] The specific type of open web construction was not stated.

[7] It was assumed to be solid sawn wood joist.

However, a later report by the NFPA (41) on the Vendome fire provides a satisfactory explanation of the incident. The report states that:

> *...The collapse began when the seven-inch cast iron column lost its support. This was caused by a failure of the masonry bearing wall under the column. Failure of the column caused failure of the masonry wall supporting...the third, fourth and fifth stories and the roof, and as this wall dropped, floor joists were pulled from wall pockets...*
>
> *The renovations had caused excessive stresses on the bearing wall under the cast iron column. Only a small additional stress increase was required to cause failure...*

Dunn (40) headlines the following cities where fatal truss collapses have occurred:

- Orange County, Florida: two firefighters die when a lightweight wood truss roof caves in during a store fire.
- Hackensack, New Jersey: a bowstring timber truss roof collapses in garage fire—five firefighters are dead.
- Irving, Texas: A firefighter dies when the lightweight wood truss roof of a condominium collapses.
- Brooklyn, New York: a bowstring timber truss roof collapses in supermarket blaze—six firefighters are killed.
- Cliffside Park, New Jersey: five firefighters are killed in fiery collapse of bowstring timber truss roof.

In the Orange County, Florida, fire reported by Dunn above, a fire report by Edwin J. Spahn (43) states the following about the performance of wood truss assemblies:

> *The wood truss assemblies performed, generally speaking, as expected. There is evidence that the fire condition had proceeded through the initial development, 180 seconds to 300 seconds and into free burn, prior to discovery of the fire. There is evidence and statement to lend credence to the proposition that the fire entered into its initial development stages shortly before 1530 hours. Using these estimates, it is probable that more than one truss assembly and attendant top chord stabilizing roof sheath[8] had been subjected to continuing fire damage for approximately 25 to 30 minutes before collapse.*
>
> *The ultimate collapse of the truss and roof assemblies were accelerated because of several factors not provided for in current codes and standards.*

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[8] Plywood sheathing is assumed.

Routley (42) reports that four firefighters died on December 20, 1991, in Brackenridge, Pennsylvania, when a lightweight concrete floor supported by unprotected lightweight steel joists collapsed into the basement of a two-story building. The construction was of 1920 vintage.

Peterson (1) describes a single-family dwelling that used floor trusses throughout the floor system. When firefighters arrived at the scene, there was a total loss of the upper floor hallway between the bedrooms and the living room. There was also a definite loss of integrity of the support structure for the upper-level floor and the interior walls. It became apparent from the analysis of this fire that a dangerous fire safety problem existed with this type of construction, and a solution to the problem had to be found.

2.4.5 Warning Signals

> AS EXPRESSED IN THE FOREGOING COMMENTS, THE CONCERNS WITH CONSTRUCTION FOCUS ON UNEXPECTED COLLAPSE OR COLLAPSE WITHOUT WARNING BY THE STRUCTURAL ELEMENTS. ADDITIONAL GENERALIZED CONCERNS REGARDING THIS ISSUE ARE SUMMARIZED AS FOLLOWS:

Brannigan (30, 34) notes that firefighters cannot rely on outdated concepts, such as: floors will sag, floors and roofs soften, water will flow through bricks, smoke will push out of mortar joints, and strange noises will take place before collapse occurs. If firefighters rely solely on these warning signs for indication of collapse in today's lighter buildings, disaster will be the certain result.

Dunn (7) suggests that the floor deck of rooms with no ceilings below them will fail before the floor joists are weakened. Any time the floor deck appears spongy or weakened during a fire, the floor below must be examined for fire.

Routley (27) states that Schaffer's analysis (35) assumes that the warning signs will occur as predicted, and will be observed by someone who is in the right place to recognize the danger soon enough to warn everyone else. Routley and Brannigan (28) go on to state that the warning signs may be present and not recognized, or not present at all, and thus, do not allow enough time to escape.

Finally, Corbett (26) notes that in a San Antonio fire, firefighters operating on the third floor noted that prior to collapse, there was no flame-through of the flooring above the truss, and no sagging of the floor. The only indication of a problem with the floor was its feel of "sponginess". The potential for immediate collapse was indicated by the fact that the fire was burning through the exterior veneer at the location of the floor trusses, which meant the truss' concealed space was fully involved. A company officer decided to evacuate the area, and approximately 35 to 40 seconds after sponginess was indicated, the third floor collapsed. It was estimated that the third floor collapsed 10 to 15 minutes after receipt of the alarm at the fire alarm office. It appears that the fire was reported soon after ignition took place.

2.4.6 Tactical Issues

> THE FIRE SAFETY COMMUNITY RECOGNIZES THAT FIREFIGHTING TACTICS ARE CONSTANTLY REVISED WITH THE ADVENT OF NEW CONSTRUCTION PROCESSES. THOUGHTS REFLECTED IN FIREFIGHTING LITERATURE ON FIREFIGHTING TACTICS FOLLOW:

Brannigan (17, 23, 31) and Dunn (11) note that it is extremely dangerous to apply tactical operations based on experience with sawn beams[9] to other structural members such as trusses, wooden I-beams, and steel bar joists. It is no longer wise to employ tactics which have the assumption that firefighters are working on wood joists.

Dunn (8), Cutter (37), Brannigan (17, 19, 34), Mittendorf (21), Routley (27), and **Engineering News Record** (5) all suggest that there is no substitute for the fire department developing a system of accumulating and organizing information for pre-fire planning, and then performing follow-up inspections at the building site to further refine this plan. This information should be used in the development of suppression tactics for the building and standard operating procedures based on the collapse potential of that building.[10]

Cutter (36), Brannigan (28) and Dunn (11) all express concern over the ventilation procedures used by fire departments. Where ventilation is necessary, consideration should be given to horizontal ventilation, working from a roof ladder, or working from a ladder truck to accomplish the ventilation. Having steel bar joists, wood trusses, or wood I-joists in a roof system creates a hazard to the firefighter on that roof, if the firefighter is expecting solid-sawn joist construction and uses typical venting procedures.

Brannigan (17, 34) suggests that all firefighters should be aware of whether the fire is a structure fire or a contents fire. Once the fire becomes a structure fire, firefighters do not belong on the roof, or on or beneath the floors. It should be announced immediately that it is a structure fire and all personnel should evacuate the building immediately.[11]

Brannigan (34) and Sylvia (38) note that a safe rule for steel trusses is that a fully involved, non-combustible building is about to collapse. A lightweight steel truss building has almost no inherent fire resistance. If there is enough fire to justify a second alarm, it is almost a certainty that the building is unsafe to enter.

Dunn (6) suggests the following tactics to help firefighters prevent injury or death:

- When operating at a private home with a sloping roof, it is probably more effective to vent the top floor windows than to cut a roof vent.

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[9] E.g., solid-sawn lumber joists and rafters, like 2 x 10s.

[10] This is the single-most mentioned activity that could reduce the risk to firefighters in fighting structure fires.

[11] It is assumed Brannigan implies a fire with the structural elements involved.

- The pre-fire plan should include the type of roof construction.
- The fire department should develop standard procedures for operating on sloped roofs. This should be based on life safety, fire containment, and property protection—in this order of importance.
- Sloping roofs are generally designed to support less live load than a flat roof. Therefore, sloping roofs will support fewer firefighters.
- Firefighters should understand that when they walk on the roof of a burning building, they risk the possibility of falling through and not being able to get out alive.

Dunn (7) further suggests that to avoid plunging through a burning floor deck, encroaching firefighters should keep one leg outstretched in front of them as they move forward. Another technique that can be used is to drop an axe or a halligan tool onto the floor in front of the firefighter before advancing. These techniques will not protect a firefighter from a floor joist collapse, but they will indicate a weakened floor deck above the floor joist.

Finally, the Illinois Fire Service Institute (22) suggests these tactics:

- Pre-plan all new construction and any remodeling that use lightweight components.
- Modify fire department tactics to open concealed spaces quickly.
- Maintain records of all buildings that uses lightweight components.
- Be aware of the time factor—always ask, "How long has the fire been burning?"
- Remember, some floor systems give no warning prior to collapse.

2.4.7 Fire Safety

Peterson (1) states that fire safety relates to the following areas of concern: life safety, property protection, and continuity of operations. He notes that the degree of risk that will be accepted by occupants is a difficult decision, at best. In a residential home, he suggests that the level of protection equivalent to the standard 2 x 10 floor joist construction would be desired for any fire safe design using a wood truss floor or other lightweight construction material. The solution he suggests for lightweight construction is to use a drywall ceiling in all unprotected areas. This would allow adequate escape time for occupants and firefighters, and sufficient protection for firefighters from unexpected collapse.

2.5 Concluding Remarks Found in the Literature

MANY OF THE ARTICLES FOUND IN THE LITERATURE DREW CONCLUSIONS WITH RESPECT TO FIRE PERFORMANCE, AND AT TIMES RECOMMENDED ACTION FOR ADDRESSING THE PERFORMANCE CONCERNS. THESE CONCLUDING REMARKS ARE SUMMARIZED HERE.

GENERALLY, MUCH OF THE FIREFIGHTING LITERATURE RECOGNIZES THE NEED FOR CONSTANTLY UPDATED, DETAILED PRE-FIRE PLANNING, AS WELL AS THE NEED FOR EARLY DETECTION AND SUPPRESSION (E.G., SPRINKLER) SYSTEMS, EXPANDED FIRE

PREVENTION EDUCATIONAL EFFORTS, AND THE MOST INFORMED FIREFIGHTING TACTICS.

Brannigan (24) and Peterson (1) note that in reference to trusses, any device that conserves natural resources or reduces the cost of buildings has intrinsic merit.

Mittendorf (18) reminds readers that by focusing on roof truss hazards, one may be distracted from remembering and recognizing that all roofs can pose serious dangers. Any roof can be fatal if the proper ratios of fire, time, and construction type are correctly combined. The amount of time before failure cannot be predicted for a roof of any type. However, any roof can be dangerous and collapse unpredictably during the early stages of a fire.

Summers (4), Manny (20), Cutter (36), and Grundahl (2) all suggest that a pro-active, cooperative approach involving both sides is needed to learn more about the actual performance of these components in fires. This is information and feedback that firefighters need to better predict field performance. Straesesky and Weber (22) state that there has been considerable speculation concerning what floor systems might do under fire conditions, but that there has been very little information published on this subject. Schaffer (35) and Mittendorf (21) suggest that the focus should be on the time required for failure, the speed or rate of failure, and warning signals.

Brannigan (24) cautions against accepting the claims of the lightweight component industry, based on obsolete test procedures.

Cutter (37) and Routley (27) recognize that the economics of wood truss construction[12] are a reality, and that wood construction is here to stay. Routley (27) goes on to state:

> *The fire service must recognize the dangers presented by these construction methods and concentrate on pre-fire planning and fire ground safety to reduce the risks.*

Finally, Manny (20) and Cutter (36) suggest that manufacturers and fire service personnel need to work together to define appropriate actions to protect lives, since neither the fire service nor the lightweight building component industry are going to go away.

2.6 Industry Literature

2.6.1 Truss Plate Connectors

INFORMATION ON THE PERFORMANCE OF TRUSS PLATE CONNECTORS WAS PROVIDED TO THIS PROJECT IN THE FORM OF PHOTOGRAPHS AND VIDEOTAPES. DETAILS FOLLOW.

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[12] And more broadly, lightweight building components

In a series of photographs taken by Haan (14), the performance of connector plates is shown after trusses have been involved in a fire in a residence (See Figures 1a-c). These photographs show that the truss plates do protect the wood beneath the truss plate from the heat of fire by reflecting the radiant energy. This was also said to be the case in an article by Schaffer (35).

The photographs also show that the truss plates appear to have pulled away somewhat from the wood after involvement in the fire. There is no clear reason for the gaps to be present in the plated joints. The cause of the plates pulling away from the wood at the joints as they have in these photographs is unknown; one possibility is some combination of expansion of the steel and shrinkage of the wood.

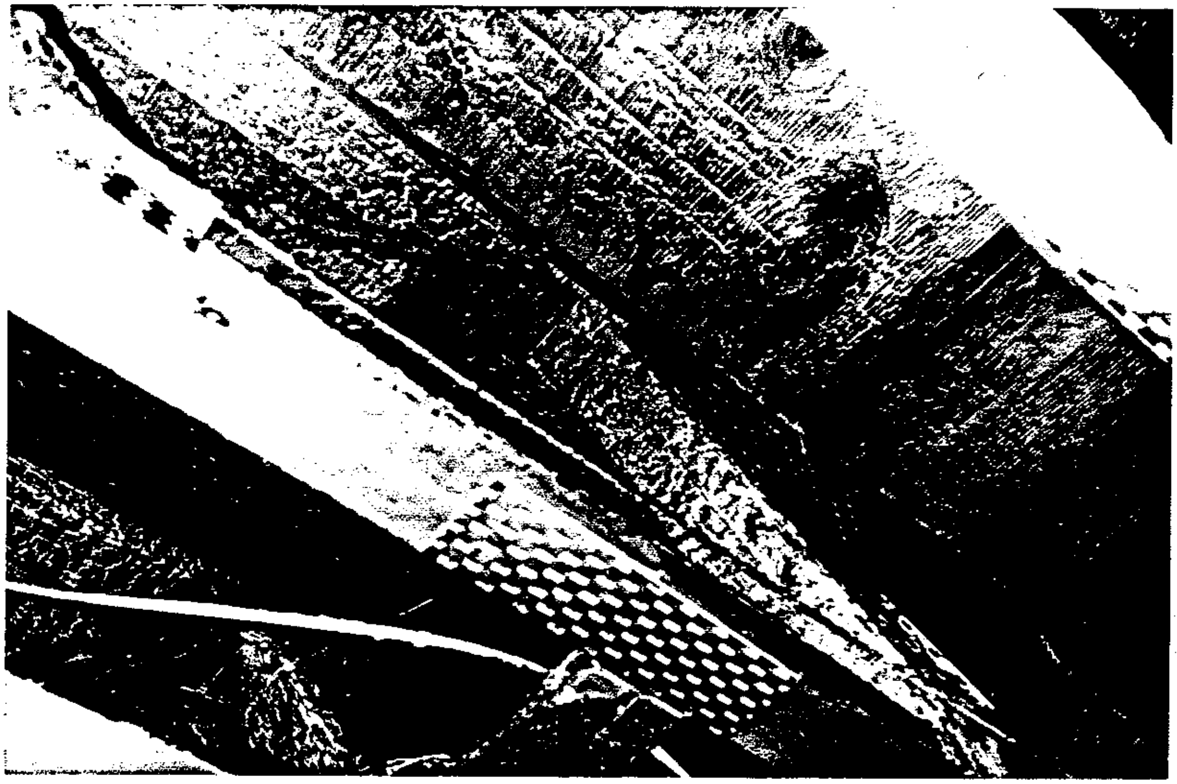

Figure 1a. Photograph of a bottom chord splice plate (14).

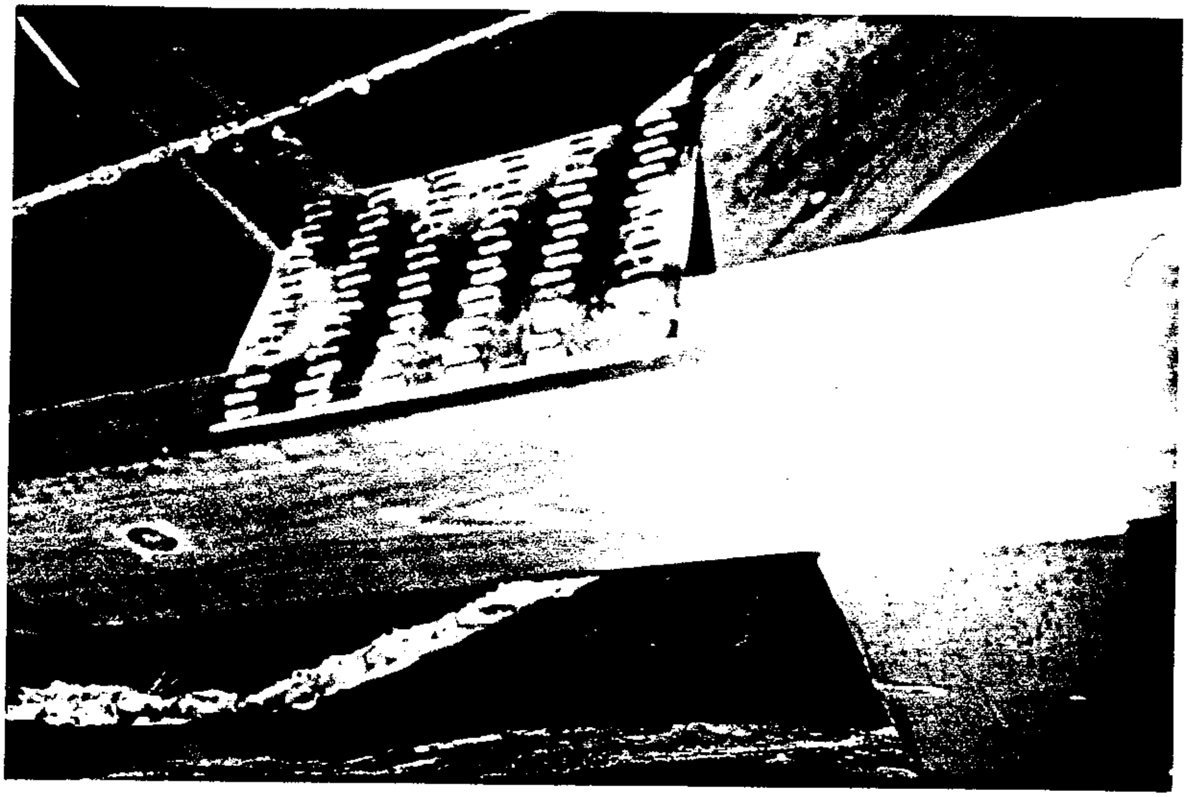

Figure 1b. Photograph of a bottom chord joint connection (14).

Figure 1c. Photograph of a peak joint connection (14).

A Weyerhaeuser Fire Technology Laboratory videotape (15) of a test on a truss plate splice joint under ASTM E119 fire exposure conditions shows a specimen as it goes through the various stages of fire endurance performance. This includes a reflectivity phase, where the wood is being protected by the truss plate; a conduction phase, where the wood underneath the truss plate becomes charred; and a failure phase due to the charring of the wood below the plate. The failure of the plate is due to the applied load on the truss, not by the truss plate's curling up or warping away from the wood due to fire exposure.

Schaffer (35) states that in the United Kingdom and Australia, lumber spliced with connector plates have been fire tested. Under conditions of full tensile design load and full fire severity, the times to failure were 4 minutes in the Australian test and 6.5 minutes in the British test.

2.6.2 General Connections

Schaffer (35) notes that testing has been done on continuous lengths of 2 x 4 lumber under full design load and fire exposure. Average times to failure for the solid 2 x 4 were 9.5 minutes for Coast Douglas Fir, 11.7 minutes for Southern Pine and 12 minutes for Messmate. The Messmate was tested with a finger joint, and its average time to failure was 9 minutes, 75% of the time to failure for the continuous lumber.

2.6.3 Testing for Fire Performance

THE ASTM E119 TEST HAS COME UNDER SCRUTINY AS A SUITABLE TEST METHOD. COMMENTS ON ASTM E119 IN THE GENERAL LITERATURE FOLLOW.

Ryan (3) notes that the ASTM E119 scope statement, which is found in most fire test standards, contains the following caveat:

> *This standard should be used to measure and describe the properties of materials, products, or assemblies in response to heat and flame under controlled laboratory conditions and should not be used to describe or appraise the fire hazard or fire risk of materials, products, or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire risk assessment that takes into account all pertinent factors of the fire hazard of a particular end use.*
>
> *The results of these tests are one factor in assessing fire performance of building construction and assemblies. These methods prescribe a standard fire exposure for comparing the performance of building construction assemblies. Application of these test results to predict the performance of actual building construction requires careful evaluation of test conditions.*[13]

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[13] ASTM E119-83 **Standard Methods of Fire Tests of Building Construction and Materials.**

Ryan (3) states that an ASTM E119 1-hour rated assembly is expected to collapse just after the 60 minute period of exposure. This should be recognized by everyone dealing with ASTM testing and dealt with accordingly.

Finally, Ryan (3) points out that research has shown that the ASTM E119 time/temperature curve does not follow curves developed in other fire scenarios. Some fires exceed 1700° F in early stages. Other scenarios show that the temperature never exceeds 1200° F for long periods of time. He queries, "Which is more hazardous: the fast-growing fire that drops off, or the steady, slow-burning, temperature-increasing, long-duration fire?" Further, he says that it is impossible to test assemblies under all possible conditions. The E119 time/temperature curve has been judged by knowledgeable experts to best represent a relatively severe-intensity fire for use in a comparative assessment of the adequacy of assemblies for protecting building occupants, and the spread of fire in compartments.

2.7 Summary of Concerns with Lightweight Construction

2.7.1 Firefighting Concerns

A SUMMARY OF THE ISSUES THAT WERE EXPRESSED IN THE FIREFIGHTING LITERATURE FOLLOWS. CONTENT HAS BEEN LEFT AS STATED IN THE ARTICLES. DISCUSSION OF THIS CONTENT CAN BE FOUND IN **CHAPTER 7: DISCUSSION.**

2.7.1.1 Trusses

The first major concern regarding a truss is that if one element of a truss fails, the entire truss fails. This suggests that there is no redundancy within a truss, and that it resembles a series of pin-end connected members. This concern is taken one step further in that the failure of a single truss will also cause failures of adjacent trusses. Trusses are said to collapse without warning, injuring or killing firefighters. Multiple truss failures are said to be the rule rather than the exception, and the failure of one truss causes serious problems to other parts of the building.

Trusses are also designed to span very long distances using the smallest amount of material possible. The triangular configuration of trusses creates a concealed space that is open to the passage of flames and hot gasses throughout the floor/roof cavity. This allows for the potential rapid extension of the fire to other areas of the building.

Finally, trusses are said to consist of multiple connections that are all vital to performance. The failure of any connection may have fatal consequences.

2.7.1.1.1 Wood Trusses

Wood trusses have all of the performance characteristics of trusses as defined above. Their performance is also characterized more specifically. It is noted that wood trusses have a greater surface-to-mass ratio than joist construction, so that they will ignite sooner and burn faster. It is also believed that a great amount of combustible material lies within the concealed space of a wood truss assembly. Wood trusses are expected to collapse within approximately 10 minutes in a fully developed fire.

It is pointed out that trusses are often extended to support balconies in apartments and commercial structures. Fires in trusses using this construction style can cause the collapse of the only exit for occupants and firefighters. Therefore, firefighters should not rely on the balcony or stairway as a place of refuge.

It is also noted that wood trusses may have defects that cause structural problems. These defects normally occur during the manufacturing process, and may contribute to the early collapse of a truss during a fire. Finally, literature and educational videos identify the wood truss as a killer, and state that it is the most dangerous structure that exists from a firefighting perspective.

2.7.1.1.2 Truss Plate Connectors

In the literature and educational videos, connections are viewed as a deficient structural connection from a fire protection point of view, and are referred to as "killer connectors." They are dangerous because the heat from a fire can warp the thin sheet metal surface fastener, causing it to curl up and pull away from the wood truss. The metal surface fastener also conducts heat, causing wood fibers adjacent to the teeth to be destroyed by pyrolytic decomposition. Once the wood is destroyed at the connection, the entire truss fails. These fasteners may be effective truss connectors when tested in a laboratory for structural strength; but when they are subject to fire, they are deficient.

Finally, there is a concern in firefighting that vibration from normal building activities may cause the truss plates to loosen over time. This could contribute to the early failure of truss plate connections in a fire. The point of connection is the critical area subject to failure during a fire. When a connection fails, it allows the entire system to fail.

2.7.1.1.3 Timber Truss Roofs

Timber truss roofs are claimed to be one of the most dangerous structures because of early collapse of the roof and potential failure of the masonry walls. Also, timber truss roofs are often built with wide on-center spacings, causing large sections of the roof to collapse if the truss collapses.

Conversely, there is the view that timber truss roofs, although hazardous, can provide the strength and time needed to conduct a successful aggressive attack of the fire. The key to fighting these fires is to adhere to appropriate on-site fire size-up criteria, and to possess a knowledge of timber truss roofs.

2.7.1.2 Wooden I-Joists

A concern surrounding wooden I-joists is that the adhesive used for bonding may deteriorate during a fire, causing the I-joist to fall apart. Another concern is that the web material is very thin and often has holes cut into it. This allows the fire to extend through the holes, and burn both sides of the joist rapidly. It also allows for the extension of the fire.

2.7.1.3 Wood Joist Construction

It is stated that one should be aware that sawn joists and rafter roofs are not completely safe—they simply have different characteristics. It is noted that joist assemblies seldom fail catastrophically. Should one joist fail, the others will support the existing load. A concern in joist construction is the bathroom area in the residence. Floors in the bathroom collapse more often than those in other areas due to plumbing penetrations and rotting due to moisture. Finally, it is stated that joists are safer for supporting the weight of firefighters in a burning structure. As long as the "fat" of the joist is burning, the firefighter is relatively safe standing on the floor or roof.

2.7.1.4 Steel Member Performance

Steel is known to expand dramatically and lose approximately one-half of its load-carrying capacity when temperatures near 1000° F. Expanding steel often causes problems with other structural elements in a fire. Steel is non-combustible, which often leads to unwarranted confidence in its fire-resistive properties. Unprotected steel has no fire resistance, and a steel building *can* be destroyed by a fire.

2.7.1.4.1 Steel Bar Joists

Steel bar joists were noted to fail under ASTM E119 standard test conditions at approximately 7 minutes. It was noted that this should be compared with wood joists, which lasted 10 minutes. Another concern regarded bar joist construction with wide on-center spacing that is typically found in a roof system. Firefighters who cut a hole for ventilation may find themselves standing on only a thin piece of corrugated steel, which could bend or twist, causing a fall. Bar joists are also noted to be an extremely strong structural member, using very small steel sections. The long spans and high strengths require the use of ties to resist overturning. However, in a fire, these ties may cause multiple truss failures.

2.7.1.5 Other Building Components Not Considered to Be Lightweight

There is a separate model code classification for heavy timber construction, including solid wood or glued-laminated members, typically 6 inches or greater in width and 10 inches or greater in depth. Actual sizes allowed are prescribed by the code, and may be slightly less in some cases and greater in others. Heavy timber is also often referred to as "mill" construction. During a fire, heavy timber construction resists failure longer than a conventional wood frame structure because the structural members are larger, have a smaller surface-to-mass ratio, and take longer to burn. As a wood member burns, a layer of char develops which acts like insulation, slowing the rate of burning. These wood members continue to carry structural loads by virtue of the mass of the unburned wood. This concept applies to all wood members, with heavy timber being the most durable, due to its having a greater mass of wood.

2.7.1.5.1 Heavy Timber Construction

This type of construction is very durable in the early stages of a fire. The only problem with this construction type is that radiating heat from total involvement of a large building may prevent firefighters from getting close enough to the building to fight the fire, and allow the fire to spread to adjacent buildings. After hours of burning, the building will eventually collapse.[14]

2.7.1.5.2 Glue-Laminated Beams

It is stated that glue-laminated beams will collapse early, due to the adhesive bond deteriorating under fire. The adhesives can be expected to burn at a relatively low temperature, accelerating system failure. With laminated beams, one must also expect early collapse.

2.7.1.6 Concealed Spaces

The concern with concealed spaces is the rapid spread of fire throughout the truss void. There is also concern that a concealed space will be used for storage and other uses, which may increase the load on the trusses, causing earlier collapse.

2.7.1.7 Testing of Fire Assemblies

Testing done on fire-rated assemblies is of concern because it does not represent the actual performance of components under realistic fire conditions. The reasons behind earlier-than-expected collapse of tested assemblies are:

- The actual fire may be more intense than a test fire.
- The test specimen may not allow for prediction of the performance of an actual floor.
- The fire may have burned undetected for longer than the test period.
- The actual building may not be constructed as well as the test specimen.
- Testing does not take into account penetrations of the gypsum.
- Testing does not provide for additional air being available through poor fire- and draftstopping.
- Impact loading due to a firefighter's weight is not taken into account.

Finally, it is noted that tests are also sponsored by organizations with a vested interest in the result; therefore, the construction is perfect. This level of construction quality is probably not performed in the field. There may be other time/temperature curves that more accurately reflect real fire conditions. Their use should be considered in the future.

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[14] After hours of burning most, if not all, buildings will collapse.

2.7.1.8 Building Codes

Firefighter safety has never been addressed in building code regulations. The responsibility is left to the fire department. Building Codes are not self-enforcing; therefore, fire-safe measures can be violated, or disregarded. Many buildings within the model building code regulations are allowed to be built unprotected from the attack of fire. In these cases, both combustible and non-combustible buildings are expected to collapse in a fire, and may be subject to early failure as well. Finally, it is noted that no building code provision provides for the personal safety of the firefighter.

2.7.1.9 Warning Signals

With new lightweight components, firefighters cannot rely on outdated warning concepts such as:

- The floors will sag.
- The floors or roofs will soften.
- Water will flow through bricks.
- Smoke will puff out of mortar joints.
- Strange noises will take place.

It was noted, however, that often floors or roofs will begin to feel spongy—an indication of a problem. However, warning signals may not always be observed as predicted, and recognized soon enough to warn everyone. This is cause for concern.

2.7.1.10 Tactical Considerations

It is unwise to assume what is not known when making tactical firefighting decisions. It is equally unwise to assume all construction behaves like wood joists. Therefore, there is no substitute for pre-fire plans and follow-up inspections. This information can be used in suppression tactics and factored into fire ground operation procedures based on the collapse potential of the building. Then tactics can reflect the conditions, construction and materials encountered.

New ventilation procedures must be given consideration. Using safe working practices on the roof or venting walls and windows may be more appropriate. A safe rule is that a fully involved building is about to collapse. If the fire begins to burn the structural components, firefighters do not belong on the roof, or on or beneath the floors. Key tactical information required includes knowing when the fire begins to burn structural components and how long the fire has been burning.

2.7.1.11 General Fire Safety

The degree of risk that will be accepted for building occupants is a difficult decision, at best. Given this, fire safety can be broken into three primary areas of concern: life safety, property protection, and continuity of operations—in that order of importance.

2.7.2 Industry Literature

A SUMMARY OF THE ISSUES EXPRESSED IN LITERATURE FOUND OUTSIDE OF THE FIRE SAFETY COMMUNITY ON THESE TOPICS FOLLOWS:

2.7.2.1 Truss Plate Connectors

It has been suggested that these connectors reflect heat during the fire, and actually protect the wood below the connector themselves. There are photographs and a videotape of a connector plate under fire conditions that show a period of time where the truss plate *does* protect the wood below due to the reflection of radiant energy. The plate eventually does conduct heat in the wood below it, causing pyrolysis to take place. This reduces the strength of the connection until it fails.

There is also a concern that truss plates loosen during a fire. Photographs indicate this may occur to some degree, but the reason behind this occurrence is unknown.

2.7.2.2 Other Connections

Testing has shown that finger joints in lumber retain 75% of their strength in a fire, as compared to identical pieces of solid lumber.

2.7.2.3 Testing for Fire Performance

It was noted that ASTM E119 should be used only as a measure of comparative performance of various test assemblies under standardized test conditions. To use these test results to predict the performance of actual building construction requires careful evaluation of the test conditions.

A 1-hour rated assembly is expected to perform for only the one hour time period—nothing more, nothing less. However, this rating does not mean the assembly will last for one hour during a "real" fire exposure.

Finally, the ASTM E119 test method has been judged by knowledgeable experts to represent a relatively severe fire for use in assessing the adequacy of the tested assembly in providing life safety protection. It would be impossible to test every specific assembly type under all possible fire conditions. A representative sampling is the best approach.

2.8 Summary

THE FOREGOING PROVIDES A COMPENDIUM OF THE POINTS OF VIEW AS EXPRESSED IN THE LITERATURE. ANALYSIS OF THESE COMMENTS IS FOUND IN **CHAPTER 7: DISCUSSION.**

2.9 References to Articles

(1) Peterson, W., Fire Marshal, Bowlingbrook Fire Department, Bowlingbrook Illinois. "Fire Safe Building Design with the Use of Engineered Wood Floor Trusses in Single Family Dwellings."

(2) Grundahl, K. "Radical Perspective on the Wood Truss Fire Issue," Woodwords, September/October 1989.

(3) Ryan, John E., Letter to Kirk Grundahl, regarding September/October 1989 Woodwords article.

(4) Joe Kannapell meeting with Virginia State Fire Marshals Office, September 21, 1988. Meeting with Mr. Howard H. Summers, Jr., Chief Fire Marshal, State of Virginia, and Mr. John Whitfield, Fire Protection Engineer, State Fire Marshals Office.

(5) "Fire Suppression Can Save Lives," **Engineering News Record**, July 28, 1988.

(6) Dunn, V., "Fire Fighting On Sloping Peaked Roofs," **Firehouse**, June 1985.

(7) Dunn, V., "Floor Collapse In Residential Structures," **Firehouse**, October 1984.

(8) Dunn, V., "Hazards of Lightweight Wood Truss Construction," **Firehouse**, December 1986.

(9) Dunn, V., "Collapse Dangers of Timber Truss Roofs," **Firehouse**, December 1983.

(10) Dunn, V. "Building Construction: Firefighting Problems In Structural Hazards." **Firehouse**, April 1985.

(11) Dunn, V. "Operation on Steel Open-Web Bar-Joist Roofs" **Firehouse**/February 1985.

(12) Dunn, V. "Constructive Terms of Building Design" **Firehouse**/April 1986.

(13) Dunn, V. "Truss Collapse: Final Report," **Firehouse**, September 1986.

(14) Haan, T.K., Robin, Photos Of Trusses Involved In A Fire. Received upon request of author.

(15) Grundahl, K. "Proprietary Videotape of A Truss Joint Under Fire Conditions."

(16) Brannigan, F.L., "Know Your Roof," **Fire Engineering**, September 1986.

(17) Brannigan, F.L. "Building Construction For The Fire Service, 2nd Edition," National Fire Protection Association.

(18) Mittendorf, J.W., "The Timber Truss: Two Points of View," **Fire Engineering**, May 1991.

(19) Brannigan, F.L., "The Timber Truss: Two Points of View," **Fire Engineering**, May 1991.

(20) Manny, W. F. "Lightweight Wood Trusses: More to Consider," **Fire Engineering**, May 1991.

(21) Mittendorf, J., "Lightweight Construction Tests Open Fire Service Eyes To Special Hazards," **Western Fire Journal**, January 1982.

(22) Straesesky, J and Weber, C., "Testing Floor Systems, **Fire Command**," June 1988.

(23) Brannigan, F.L. "As Frank Brannigan Says, Beware of the Truss," **Fire Engineering**, August 1985.

(24) Brannigan, F.L. "Are Wood Trusses Good For Your Health? The Safety Issue of Lightweight Wood Truss Floor Assemblies Provokes Controversy," **Fire Engineering**, June 1988.

(25) Mittendorf, J., "Joist Rafter Versus Lightweight Wood Truss. Strength of These Assemblies Comparable - Until Fire Strikes," **Fire Engineering**, July 1988.

(26) Corbett, G.P., "Lightweight Wood Truss Floor Construction: A Fire Lesson. A Recent San Antonio Fire Provides Some Hard Hitting Lessons About The Safety Of This Common Type Of Construction." **Fire Engineering**, July 1988.

(27) Routley, J.G., "How Wood Trusses Perform During A Real Fire" **Fire Journal**, January/February 1989.

(28) Brannigan, F.L., "A Primer On Truss Roofs: Why Truss Roofs Are Hazardous For Firefighters," **Firehouse**, March 1989.

(29) Brannigan, F.L., "Response To A Truss Manufacturer; The Dangers Of Truss Construction Pointed Out, Again," **Firehouse**, June 1989.

(30) Brannigan, F.L., "Hazards Of Truss Floors - Part II," **Firehouse**, October 1989.

(31) Brannigan, F.L., "Construction Hazards: Truss Hazards Part 4 of 6," American **Fire Journal**, May 10, 1988.

(32) Clark, A., "The Bare Facts On Hidden Dangers," **Fire Command**, July 1984.

(33) Brannigan, F.L., "Are Wood Trusses Good For Your Health?" **Fire Engineering**, June 1988.

(34) Brannigan, F.L., "Beware The Truss," **Fire Engineering**, August 1985.

(35) Schaffer, E.L., "How Well Do Wood Trusses Really Perform During A Fire?", **Fire Journal**, May/April 1988.

(36) Cutter, B.E., "The Fire and Wood Truss Debate: Solution. Working Together," **Woodwords** May 1990.

(37) Cutter, B.E., "Working Together To Solve The Wood Truss Problem," **Fire Journal**, January/February 1990.

(38) Sylvia, D., "Non-Combustible Buildings - Death Traps For Firefighters," **Fire Engineering**, March 1979.

(39) Dunn, V., "Lightweight Wood Parallel Chord Truss Construction," **WNYF**, 1st Issue, 1982.

(40) Dunn, V., "Truss Roof Collapse, with Additional Comments by Frank Brannigan," Part III of Collapse of Burning Buildings Videotape Training Program, **Fire Engineering**, Firefighter Survival Training Series, Copyright 1989.

(41) FEMA/National Fire Academy, "Building Construction for Fire Suppression Forces, Principles: Wood and Ordinary Construction," B58-B67, date unknown.

(42) Routley, J.G., Investigative report for the U.S. Fire Administration.

(43) Spahn, J.E., "Sunrise Investigation," Orange County, Florida, April 24, 1989.

Chapter 3: Fire Loss Statistics

To assess the concerns expressed in firefighting literature, it is important to review known information. This includes available data and statistics on the fire performance of lightweight component construction, as well as results of physical testing of the construction type in question. A review of the relevant statistical information is included in this chapter. A review of physical testing data appears in **Chapter 4**.

In order to have a base from which to perform a risk assessment in the future, and to provide a guide with which to focus efforts on areas that are critical from a fire endurance perspective, it is helpful to review the statistics surrounding this issue. This information can provide a view of the magnitude of various aspects of fire loss, as well as clarify issues that require further review.

3.1 One- and Two-Family Dwelling Fires

A view of the fire problem in the United States can be obtained by defining where that fire problem exists. Seventy-five percent of the fire-related fatalities in 1988 occurred in residential properties. Five percent were in non-residential properties. Sixty-seven percent of fire-related injuries in 1988 occurred in residential properties with 13% in non-residential properties. These data are shown in the two Figures below, and are virtually the same as data for 1983.

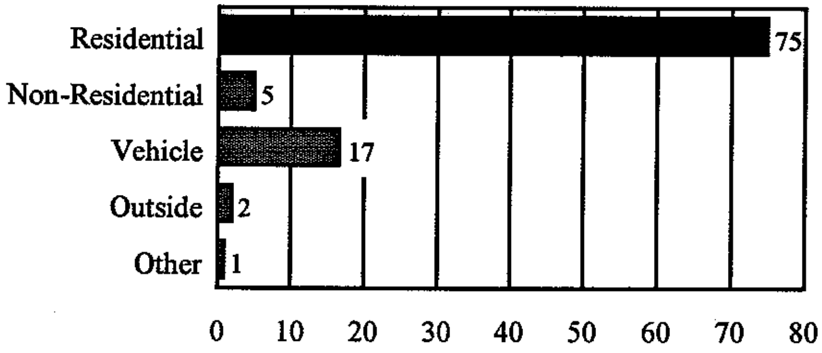

Figure 2. Percent Fatalities[1]

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[1] Federal Emergency Management Agency (FEMA), **Fire in the United States**, 7th ed., August 1990.

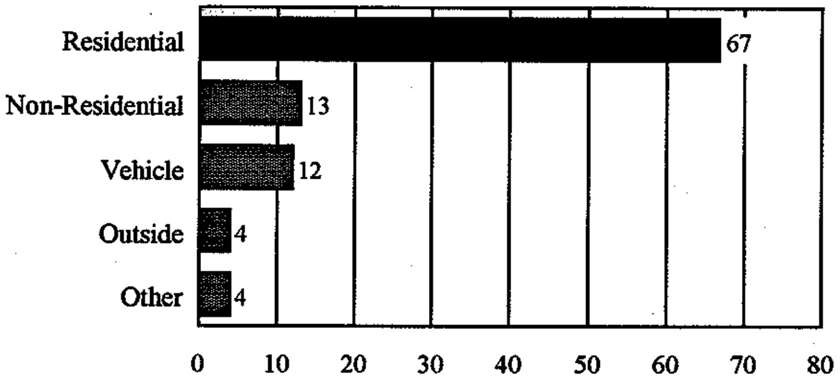
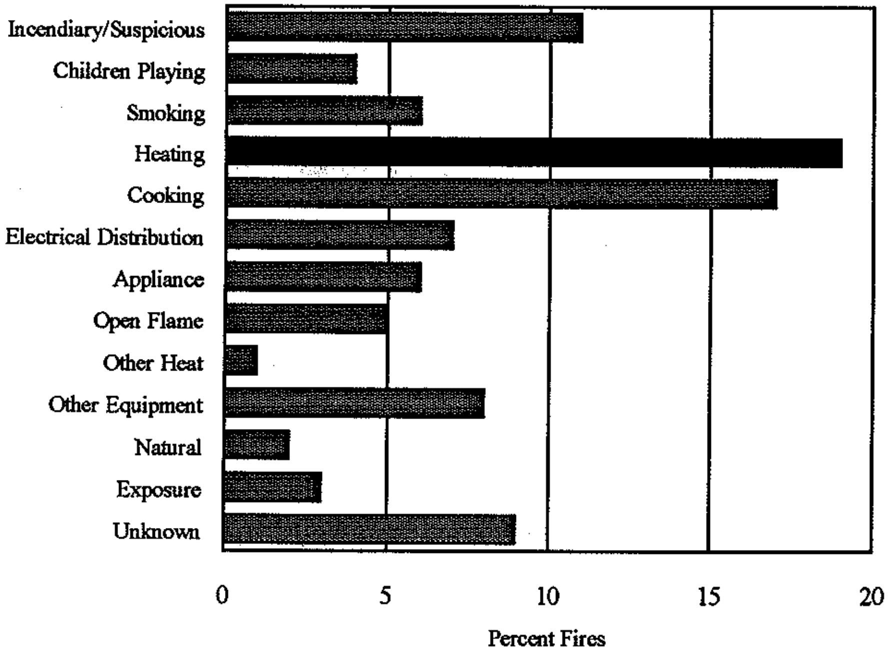


Figure 3. Percent Injuries[2]

Figure 4 below details the leading causes of residential fires in 1988.[3] A similar trend is seen in the 1983 data.[4]



Raw%	Adjusted%
11	12
4	5
6	7
19	22
17	19
7	8
6	6
5	6
1	1
8	9
2	2
3	3
9	

Figure 4. Cause of Residential fires[5]

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[2] Ibid.

[3] FEMA, **Fire in the United States,** 6th ed., July 1987.

[4] FEMA, **Fire in the United States,** 7th ed., August 1990.

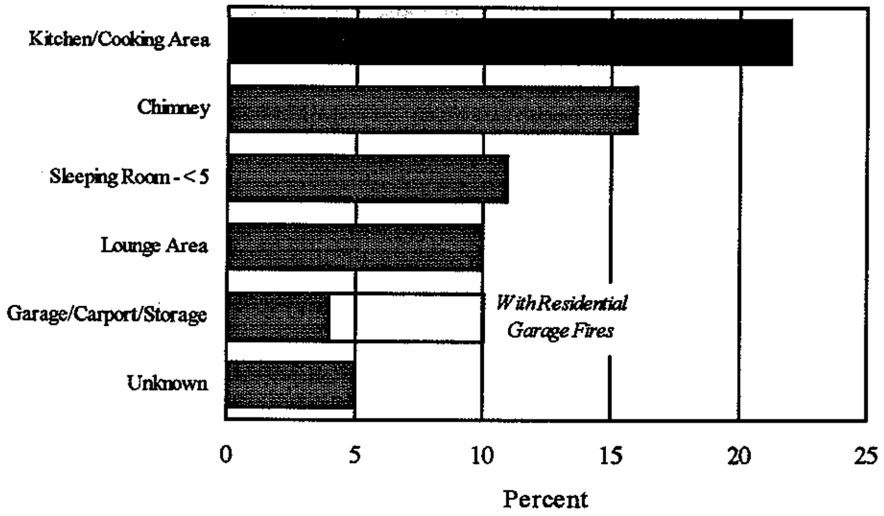
[5] Source: National Fire Incident Reporting System (NFIRS)

Heating fires are those where the equipment involved in ignition includes: central heaters, fireplaces, portable space heaters, fixed-room heaters, wood stoves, and water heating. The central- and water-heating portions of the problem have remained relatively unchanged over the years, while fires due to portable space heaters, wood burning stoves and chimneys rose very sharply from the late 1970s to the early 1980s, then subsided somewhat.[6]

Cooking—the second leading cause of residential fires—was the leading cause of fires in the 1980s, but was passed by heating with the surge in use of alternative space heaters and wood heating in the late 1970s. Cooking is by far the leading cause of fire injuries. Most cooking fires come from unattended cooking, rather than equipment failures.[7]

It is assumed most often that arson (incendiary/suspicious fires) is a crime against businesses; in fact, the statistics indicate that there is a very large arson problem in the home. The causes range from vandalism fires set by youths and revenge fires set to end quarrels, to fraud against landlords or insurance companies. Residential arson fires are set most often in bedrooms.

Additional insight into residential fires is gained by looking at the leading rooms of origin for fires in one- and two-family dwellings (see Figure 5). This is virtually the same as data from 1983.



Raw%	Adjusted %
22	28
16	17
11	12
10	11
4	4
5	

Note: The white bar for garage fires indicates approximately how large they would be if the residential garage portion of storage fires was added here. All of the other bars would decrease and would have to be re-computed because the added garage fires would increase the total number of fires by 6 percent.

Figure 5. Leading Rooms of Fire Origin for Residential Structures [8]

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[6] Ibid.

[7] Ibid.

[8] Ibid.

Fires - 544,000 **Civilian Fatalities - 3,900** **Civilian Injuries - 14,100**

	Percentages		
Area of Origin (901 Code)	**Civilian Fatalities (For Ranking)**	**Fires**	**Civilian Injuries**
Living room, den, lounge (4)	40.2	11.6	21.9
Bedroom (21-22)	24.1	11.6	20.9
Kitchen (24)	14.0	20.6	27.5
Structural Area (70-79)	**5.8**	**15.5**	**7.4**
[Crawl space (71)]	(1.5)	(3.2)	(2.9)
[Unspecified (79)]	(1.0)	(1.0)	(0.7)
[Balcony, porch (72)]	(0.9)	(1.1)	(0.9)
[Ceiling/Floor Assembly (73)]	(0.7)	(0.8)	(0.5)
[Ceiling/Roof Assembly (74)]	(0.6)	(2.3)	(0.7)
[Wall Assembly (75)]	(0.6)	(2.0)	(0.8)
Dining room (23)	2.3	1.1	1.6
Heating equipment room (62)	1.9	3.7	3.6
Bathroom (25)	1.2	1.7	1.9
Hallway, corridor (01)	1.2	0.9	1.1
Garage* (47)	1.1	3.4	3.7
Interior stairway (03)	1.0	0.4	0.4
Closet (42)	0.9	1.2	1.3
Other known single area	**4.2**	**26.6**	**7.5**
[Chimney (51)]	(0.4)	(18.9)	(0.7)
Multiple areas (97)	0.8	0.7	0.6
Unclassified, not applicable (98-99)	1.3	1.0	0.6
Total	**100.0**	**100.0**	**100.0**

* Does not include dwelling garages coded as property type, which is a larger number.

Table 1. Annual Averages of Fatalities and Injuries in One- and Two-Family Dwellings and Mobile Homes, 1980-1984 [9]

Table 1 (above) provides even greater detail, and shows that fires originating in structural areas made up 15.5% of fires during the study period. Of all fires, 0.8% started in a floor/ceiling assembly area and 2.3% started in a roof ceiling assembly area. Fires that began in a concealed floor or roof space or crawl space caused 2.8% of the civilian fatalities and 4.1% of civilian injuries. 81.8% of the civilian fatalities and 73.8% of civilian injuries occur in fires that start in main living areas of residential structures.

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[9] NFPA Standard 13D, 1989 Ed.

The leading areas of fire origin, taken from a more recent study, are shown in Table 2. Here, fires began in structural areas less than two percent of the time. Forty-nine percent of the time fires began in a living area that typically would be compartmentalized.[10]

Area of Home	Heating	Cooking	Incendiary	Electrical Distribution	Smoking	Children Playing	Total
Lounge	5,442 13.1%		2,116 13.5%	1,529 12.4%	1,919 25.8%	698 10.6%	11,704 11.0%
Sleeping Under 5	1,160 2.8%	85 0.4%	2,778 17.7%	2,333 18.9%	2,957 39.8%	3,122 47.6%	12,435 11.7%
Kitchen/Cooking	1,037 2.8%	22,416 95.0%	1,218 7.7%	1,400 11.3%	569 7.7%	448 6.8%	27,088 25.4%
Lavatory					282 3.8%		282 0.3%
Closet						355 5.4%	355 0.3%
Garage/Carport/ Vehicle Storage		97 0.4%		631 5.1%	199 2.7%	314 4.8%	1,241 1.2%
Chimney	21,524 52.1%						21,524 20.2%
Heating Equipment Area	3,843 9.3%						3,843 3.6%
Exterior Balcony/Open Porch		169 0.7%					169 0.2%
Ceiling/Roof				980 7.9%			980 0.9%
Exterior Wall			932 5.9%				932 0.9%
Court/Terrace/Porch		85 0.4%					85 0.1%
Multilocation/Use			1,048 6.7%				1,048 1.0%
Unknown							25,254 23.7%
Total Fires	**41,286**	**23,322**	**15,706**	**12,342**	**7,435**	**6,559**	**106,650**

Note: For each cause, the five most common rooms or areas of origin reported are shown. Data here are NFIRS raw counts, NOT national estimates. Percentages shown are column percentages (e.g., percentages of heating or cooking fires, not percentages of lounge fires).

Table 2. Leading Rooms of Origin by Cause for One- and Two-Family Dwelling Fires[11]

Finally, a 1986 national survey by the National Association of Home Builders on residential fire fatalities found that newer homes were much safer than older homes: 43 lives were lost in homes less than five years old. In sharp contrast, approximately 4,100 lives, or 89% of all

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[10] FEMA, **Fire in the United States**, 7th ed., August 1990.

[11] Ibid.

residential fire fatalities during the study period, occurred in homes that were 20 years old or older.[12]

3.1.1 Observations on One- and Two-Family Dwelling Fires

The significance of the high number of fire-related fatalities in residential properties indicates that the greatest impact can be achieved by solving problems associated with compartments. The issues here include penetrations of protective membranes and concealed spaces, assuring that compartments comply with code-conforming construction techniques, installing the proper rated assembly, residential sprinkler protection, etc. Figure 4 shows that sprinklers placed in the living space could effectively contain many of these fires and reduce losses to civilian lives, property and, consequently, the potential loss of firefighter lives.

Based on statistics, residential fires are the nation's most serious fire problem. Three-quarters of all fire-related fatalities and two-thirds of all fire-related injuries occur in residential properties. Fire and code officials have focused attention on the need for smoke detectors. Getting people out of a burning structure early is the best way to save lives. Also, residential sprinklers could drastically reduce the dollar loss attached to these fires. The application of sprinklers may go a long way toward reducing civilian fatalities and injuries even further.

The foregoing data suggest that the majority of fires begin in areas where there is compartmentation. Fires began within a structural space 3.1% of the time and caused 2.8% of civilian fatalities and 4.1% of civilian injuries. This suggests that most fires originate within compartmentalized rooms where a protective membrane separates the structural system from the fire. In these instances, the performance of the protective membrane will be vital to the performance of the overall structural system in a residential fire.

The key to compartment effectiveness is having the compartment remain intact prior to and during a fire. Any penetration will cause the fire to spread rapidly to other areas of the structure. With proper compartmentation, one can expect a given period of satisfactory performance for structural elements in the majority of fires that occur in residential properties. In many cases, the performance of a compartment can be approximated through calculation methods.

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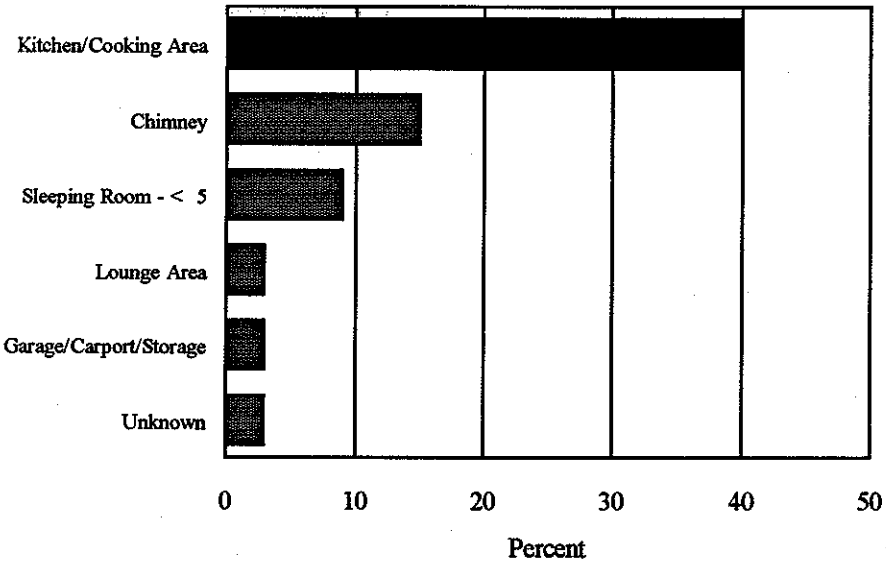
[12] **Nation's Building News**, October, 1991

3.2 Apartment Fires

A trend similar to that of single-family residential fires is seen for the leading room of origin in apartments (see Figure 6). The exception is that apartments do not have as many chimney fires.



Raw %	Adjusted %
40	41
15	16
9	10
3	3
3	3
3	

Figure 6. Leading Rooms of Origin in Apartment Fires, 1987[13]

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[13] FEMA, **Fire in the United States**, 7th ed., August 1990.

In a study shown in Table 3, fires that originated in a structural areas made up 8.1% of all fires.[14] Of these, 0.7% began in a structural assembly area.

Fires - 123,000 **Civilian Fatalities - 930** **Civilian Injuries - 5,4700**

	Percentages		
Area of Origin (901 Code)	**Civilian Fatalities (For Ranking)**	**Fires**	**Civilian Injuries**
Living room den, lounge	38.50	11.30	23.20
Bedroom	28.70	17.40	27.10
Kitchen	9.80	35.30	27.20
Hallway corridor	4.30	3.20	3.40
Interior stairway	3.20	1.00	1.10
Structural area	**3.10**	**8.10**	**3.50**
Balcony	(1.20)	(1.30)	(0.70)
Unspecified	(1.00)	(0.50)	(0.20)
Ceiling/Roof Assembly	(0.30)	(0.70)	(0.30)
Lobby	1.30	0.60	0.70
Dining room	1.20	0.80	1.00
Closet	1.20	1.90	1.90
Balcony, porch	1.20	1.30	0.70
Other known single area	**4.10**	**17.80**	**8.80**
Bathroom	(0.60)	(2.10)	(1.30)
Multiple Areas	1.60	0.70	0.90
Unclassified, not applicable	1.80	0.60	0.50
Total	**100.00**	**100.00**	**100.00**

Table 3. Annual Averages of Fatalities and Injuries in Apartments, 1980-1984 [15]

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[14] NFPA 13 R, **Installation of Sprinkler Systems in Residential Occupancies up to Four Stories in Height,** 1989 Edition.

[15] Ibid.

A more recent study details the leading rooms of origin in apartment fires (see Table 4).[16]

	Leading Causes						
Area of Home	**Cooking**	**Arson**	**Smoking**	**Heating**	**Children Playing**	**Open Flame**	**Total**
Interior Stairway		308 4.5%					308 0.9%
Hallway		755 10.9%	140 2.6%				895 2.7%
Lounge Area		739 10.7%	1,427 26.7%	379 14.6%	293 11.5%	295 13.2%	3,133 9.4%
Sleeping Under 5	66 0.5%	1,137 16.5%	2,049 38.3%	251 9.7%	1,331 52.2%	460 20.5%	5,294 15.8%
Dining	32 0.2%						32 0.1%
Kitchen/Cooking	13,333 96.4%	444 6.4%	355 6.6%	221 8.5%	193 7.6%	269 12.0%	14,815 44.3%
Lavatory					59 2.3%	195 8.7%	254 0.8%
Closet					194 7.6%		194 0.6%
Trash Area/Container			322 6.0%				322 1.0%
Chimney				281 10.8%			281 0.8%
Heating Equipment Area				660 25.4%			660 2.0%
Exterior Balcony	121 0.9%					88 3.9%	209 0.6%
Court/Terrace/Patio	38 0.3%						38 0.1%
Unknown	241 1.7%	3,520 51.0%	1,061 19.8%	808 31.1%	481 18.9%	932 41.6%	7,043 21.0%
Total	**13,831**	**6,903**	**5,354**	**2,600**	**2,551**	**2,239**	**33,478**

Note: For each cause, the five most common rooms or areas of origin reported are shown. Data here are NFIRS raw counts, NOT national estimates. Percentages shown are column percentages (e.g., percentages of heating or cooking fires, not percentages of lounge fires).

Table 4. Leading Rooms of Origin by Cause for Apartment Fires, 1987[17]

In this study, no fires were recorded as beginning in structural member areas. The fires began in areas that were compartmentalized 70.7% of the time.

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[16] Ibid.

[17] Ibid.

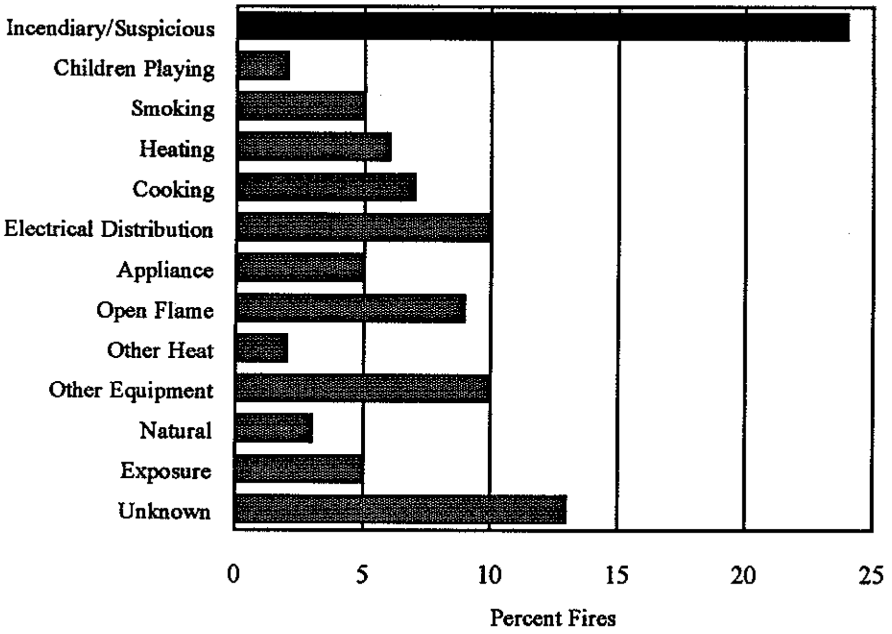
3.2.1 Observations on Apartment Fires

Fires beginning within compartments make up the majority of fires in apartments, as is the case with one- and two-family dwellings. Therefore, the same comments apply to apartments as were made about one- and two-family dwelling fires above.

3.3 Non-Residential Fires

In general, the non-residential share of the fire problem is getting smaller, while the residential share is growing. There has also been a dramatic improvement in life safety over the last few years in non-residential structures.[18]

Stores, offices, manufacturing facilities, and storage facilities have the greatest number of fires and dollar loss.[19] The leading causes of non-residential structure fires are shown in Figure 7 below:



Raw %	Adjusted %
24	27
2	3
5	6
6	7
7	8
10	11
5	6
9	11
2	2
10	12
3	4
5	5
13	

Figure 7. Causes of Non-Residential Structure Fires, 1987[20]

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[18] FEMA, **Fire in the United States**, 7th ed., August 1990.

[19] Ibid.

[20] Ibid.

3.3.1 Observations on Non-Residential Fires

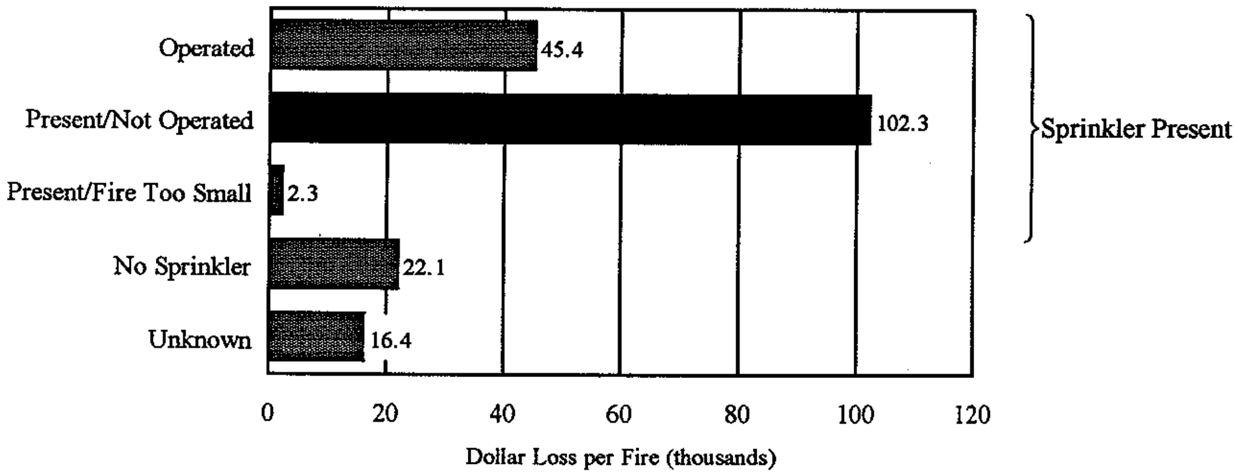
By far, the leading cause of non-residential fires is incendiary[21], which has been the case since the National Fire Incident Reporting System (NFIRS) was started.[22] It is difficult to define which fires are incendiary, since they are set in areas that have easy access, and with the intent to damage or destroy the structure. If these fires are disregarded, the majority of fires are accidental and start in locations that may either be protected by sprinklers or compartmentalized, as can be deduced from the causes listed in Figure 7.

Since the majority of fires in non-residential structures are incendiary, they are probably set outside of normal business hours. This is a benefit, considering there is less likelihood of civilian fatality and injury; but it is worse for firefighters, since these fires would often be set during time periods, and in ways that are less desirable from a firefighting standpoint. For example, the arsonist often uses accelerants and other highly flammable materials to speed the burning process.

When considering life-safety of occupants, given that only 5 to 10% of all fires and 5 to 7% of fire-related fatalities occur in non-residential occupancies, the focus should be on residential construction.

3.4 Sprinkler Performance

Figure 8 relates the performance of sprinklers in terms of dollar loss in non-residential fires.



Note: Sprinklers are most often present in buildings with contents of high value. Therefore, dollar loss statistics can be misleading. Also, small losses may not be reported, which would skew the statistics.

Figure 8. Sprinkler Performance in Non-Residential Structures: Dollar Loss per fire, 1987[23]

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[21] Often referred to as "arson".

[22] FEMA, **Fire in the United States**, 7th ed., August 1990.

[23] Ibid.

It is clear from Figure 8 that when sprinklers operate properly, damage (as reflected by dollar loss) is reduced by more than 50%. One must be concerned, however, by the magnitude of loss when sprinklers are present and operate. The mitigating factor behind this high amount of loss is that sprinklers are most often present in properties of high value, and with contents of higher value. Historically, sprinklers are not provided in structures which are small in area or relatively low in value (e.g., single-family dwellings).

Statistics provide evidence that automatic sprinklers reduce fire loss in industrial properties. This evidence is shown in Table 5, which shows statistics on the impact of sprinkler systems from 1980 to 1983.

Property Class	No Sprinklers	Sprinklers Present	Percent Reduction
All manufacturing, industry, utility, defense	20,700	8,800	57
Plastic product manufacturing	59,900	36,400	39
Sawmills, planing mills, wood product mills	22,600	12,600	44
Metal product manufacturing	15,100	5,300	65
Motor vehicle manufacturing, assembly	19,000	5,600	70
Paper, pulp, paperboard manufacturing	16,800	4,800	71
Machinery manufacturing	17,700	3,300	81
Furniture, fixture, bedding manufacturing	34,600	4,900	86
Total	**206,400**	**81,700**	**60**

Loss figures are expressed to the nearest hundred. Estimates are based on the annual NFPA survey and the Federal Emergency Management Agency's (FEMA's) National Fire Incident Reporting System, using statistical methods developed by analysts of NFPA, FEMA, and the US Consumer Product Safety Commission. Complete and partial sprinkler systems are not distinguishable. The property uses included in manufacturing, industry, utility, and defense are codes 600-799 in NFPA 901, **Uniform Coding for Fire Protection.**

Table 5. Average Loss Per Fire in Dollars, 1980-1983 [24]

As shown in this table, the average loss per fire for industrial properties is cut by more than half when sprinklers are present. The table also shows results for those specific industrial property classes that have enough fires to give meaningful data. Also note that properties showing the lowest percentage reductions in dollar loss per fire tended to have more severe fires. The actual dollar savings per fire was at least $9,800 in all categories.[25]

When viewing Table 5, one should be cautious about the following points:

- Loss figures are very sensitive to the influence of a few large-loss fires, even when a multiple-year average is used.

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[24] NFiPA Fire Analysis Division, "Automatic Sprinkler Systems Do Have an Impact in Industry," **Fire Journal**, January, 1987.

[25] Ibid.

- The databases supporting these calculations cannot distinguish complete from partial systems, which may cause an underestimation of the impact of sprinkler systems.
- Evidence shows that sprinklered properties tend to be larger than comparable non-sprinklered occupancies, so the implied savings may be even greater than these figures indicate.[26]
- Sprinklered properties may also be better built and maintained from a fire safety standpoint. This may mean that the statistics shown are crediting sprinklers with loss reductions that were actually caused by many factors. This effect tends to overstate the specific impact of sprinklers.[27]

The statistics in Table 5 include only fires reported to fire departments and, as such, may omit some of the most dramatic sprinkler successes. This has also been a problem with sprinkler statistics in the past. Success stories in small- and even medium-size fires were not reported. Where sprinklers were not successful, human error was often the problem: water was shut off, primarily by closed valves; maintenance was inadequate; or water distribution was obstructed in other cases. These reasons were the cause of unsuccessful sprinkler performance in 47% of the cases from 1925 to 1969.[28]

Operation Life Safety, a program of the International Association of Fire Chiefs, monitors sprinkler activations. Information pertaining to sprinkler performance in the United States for the period of 1983 to 1991 is found in Figures 9 and 10, and Tables 6 and 7.

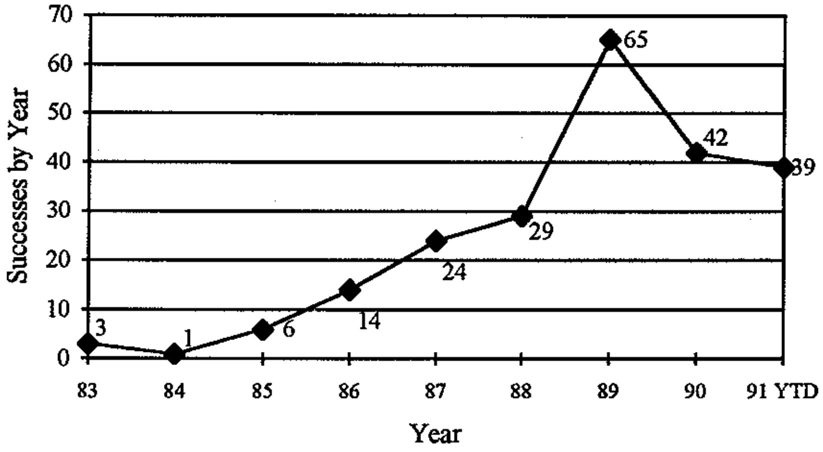

Figure 9. Reported Activations by Year [29]

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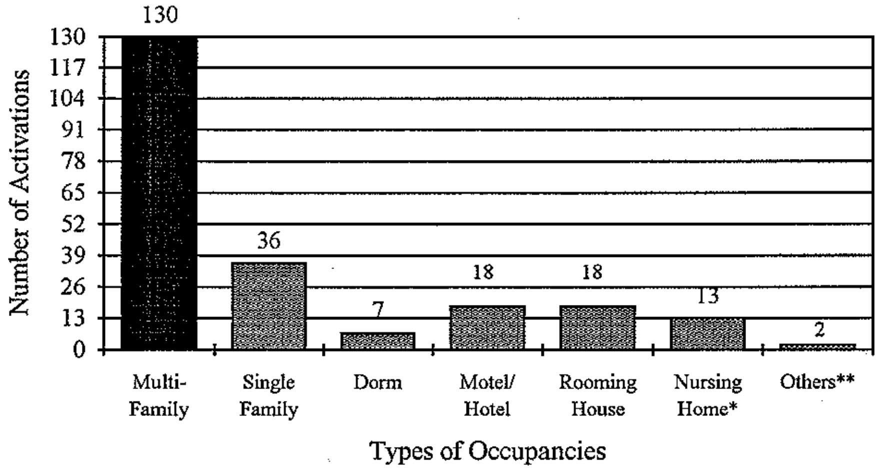
[26] F.E. Rogers, "Fire Losses and the Effect of Sprinkler Protection of Buildings in a Variety of Industries and Trades," Building Research Establishment current paper 9/77, Borehamwood, United Kingdom, February, 1977.

[27] NFIPA Fire Analysis Division, "Automatic Sprinkler Systems Do Have an Impact in Industry," **Fire Journal**, January, 1987.

[28] Ibid.

[29] **Operation Life Safety Newsletter**, 6(12), December, 1991.



* Includes home care, convalescent and retirement home facilities
** Includes high-rise and child-care facilities

Figure 10. Reported Activations by Type of Occupancy, 1983-1991 [30]

Description	# Activations
One-head activations	165
Two-head activations	15
More than two-head activations	2
Not Reported	41

Table 6. Sprinkler Activations Per Fire, 1983-1991 [31]

Room of Origin	# Activations	Percent
Kitchen	86	38.6
Bedroom	33	14.8
Living room	20	8.9
Closet	10	4.4
Laundry room	8	3.5
Storeroom	6	2.7
Bathroom	6	2.7
Garage	3	1.3
Basement	3	1.3
Dining room	2	0.9
Chimney	1	0.4
Others	17	7.6
Not Reported	28	12.5
Total	**223**	

Table 7. Room of Origin, 1983-1991 [32]

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[30] Ibid.

[31] Ibid.

Residential sprinklers are also becoming more prevalent, and have been shown to be an effective way to reduce fatalities in home fires.[33] Cobb County, Georgia, a suburb of Atlanta, alone has recorded more than 18 residential fires that were successfully controlled by sprinklers. It is estimated that these fires could have produced at least 17 fatalities had the sprinklers not been present. Another incident involved a fire that occurred in a group home for the developmentally disabled. One of the residents left a lighted cigarette in a closet. At approximately 2 a.m., a sprinkler head in the closet activated and set off an alarm. The fire burned out the closet door, but was successfully extinguished by the sprinkler. This scenario is a prime example of a potential multi-victim incident averted by sprinklers.

Obviously, firefighter safety is enhanced by the presence of sprinklers. Since most fires are controlled by the activation of one sprinkler head, the fire never gets to a size that is dangerous. This contributes to fire ground safety.

Almost $4 billion in residential property was lost in fires in 1989. A 1982 study of sprinklered and unsprinklered dwellings by the City of Scottsdale, Arizona and the U.S. Fire Administration showed property savings of 85% when automatic sprinklers were present and operated in the residence.

3.4.1 Observations on Sprinkler Performance

It is interesting to note that of all the sprinkler activations shown in the above figures and tables, one head usually controlled the fire. Also, the room of origin for these fires was consistent with those shown in the statistics in the previous section. Generally, the room of origin is in an area that is compartmentalized and a primary living area, such as the kitchen, bedroom or living room. This further suggests that the focus ought to be on protected lightweight building components and the various fire performance aspects of this construction method, including concealed spaces.

There is no question that sprinklers can be important in diminishing the impact of fires in any type of construction. It is proven that sprinklers reduce property loss and life loss. There is also a strong possibility that sprinklers could reduce firefighter fatalities, since they contain, and even extinguish, fires prior to arrival of the fire department. Sprinklers are currently the most pro-active fire safety approach in building construction.

3.5 Civilian Fire Casualty Statistics

As shown in Figures 11-14 below, the trends for civilian fire fatalities and injuries have been consistent during the period of 1983 through 1988. Fatalities per million population in the United States averaged 24.8 per year and injuries per million averaged 120.7 per year for this period. The fatalities and injuries are slightly less for 1990 at 20.7 fatalities per million and

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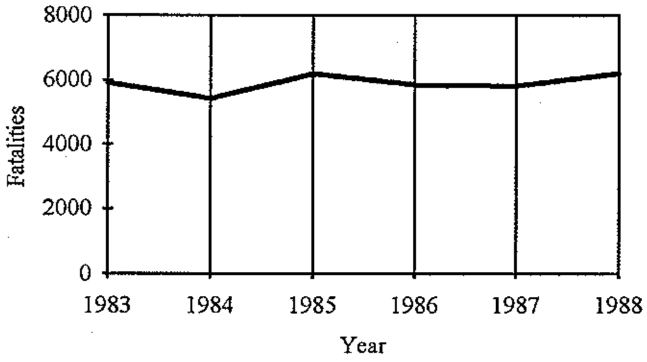
[32] Ibid.

[33] M.J. Dittmar, "Residential Automatic Sprinklers: Grassroots Initiatives," **Fire Engineering**, June, 1991.

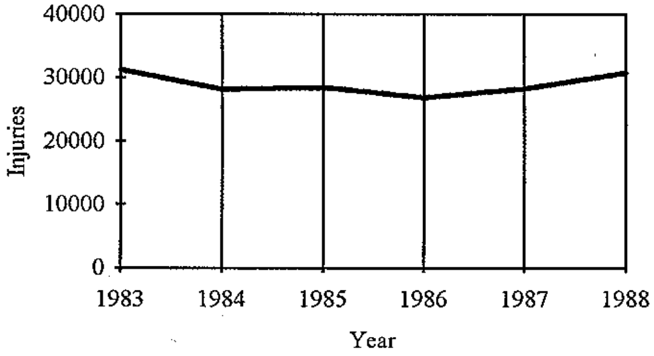
114 injuries per million. The trend for civilian fatalities is clearly decreasing when data from 1974 to 1983 are considered.

To put this in a comparative context, the yearly average for fatalities and injuries per million population in automobile accidents are 188 and 21,307, respectively, for the same period.



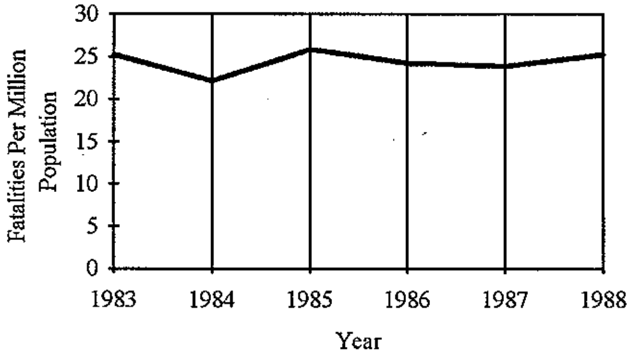
1983	1984	1985	1986	1987	1988	6-Year Change
5,920	5,420	6,185	5,850	5,810	6,215	+ 5.0 %
Average = 5,870						

Figure 11. Civilian Fire Fatality Trend[34]



1983	1984	1985	1986	1987	1988	6-Year Change
31,275	28,125	28,425	26,825	28,215	30,800	- 15 %
Average = 28,944						

Figure 12. Civilian Fire Injury Trend[35]



1983	1984	1985	1986	1987	1988	6-Year Change
25.3	22.2	25.9	24.3	23.9	25.3	0
Average = 24.8						

Figure 13. Civilian Fatalities Per Million Population[36]

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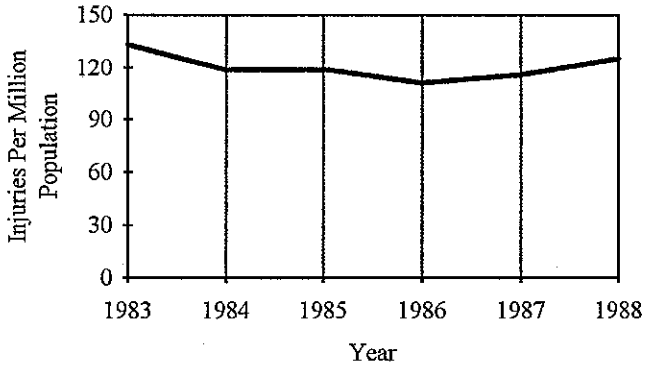
[34] FEMA, **Fire in the United States**, 7th ed., August 1990.

[35] Ibid.



1983	1984	1985	1986	1987	1988	6-Year Change
133.5	118.9	119.1	111.3	115.9	125.3	- 6.1 %
Average = 120.7						

Figure 14. Civilian Injuries Per Million Population [37]

3.5.1 Observations on Civilian Statistics

Fortunately, the trend in fire fatalities and injuries is decreasing. It is surmised that smoke detectors and fire safety education measures are beginning to work. There is also the possibility that construction is safer in a fire due to better electrical distribution systems, construction materials, codes, etc.

3.6 Firefighter Casualty Statistics

It is very important that the influence lightweight components have on firefighter fatalities and injuries be considered, since this is the primary concern that instigated this study. This will also be important when assessing the cost of solutions in relation to overall risks, and in performing a risk assessment.

3.6.1 Firefighter Injury Statistics

The statistics pertaining to firefighters reveal that fires in residential occupancies account for 67% of all firefighter injuries (See Figure 13 below).

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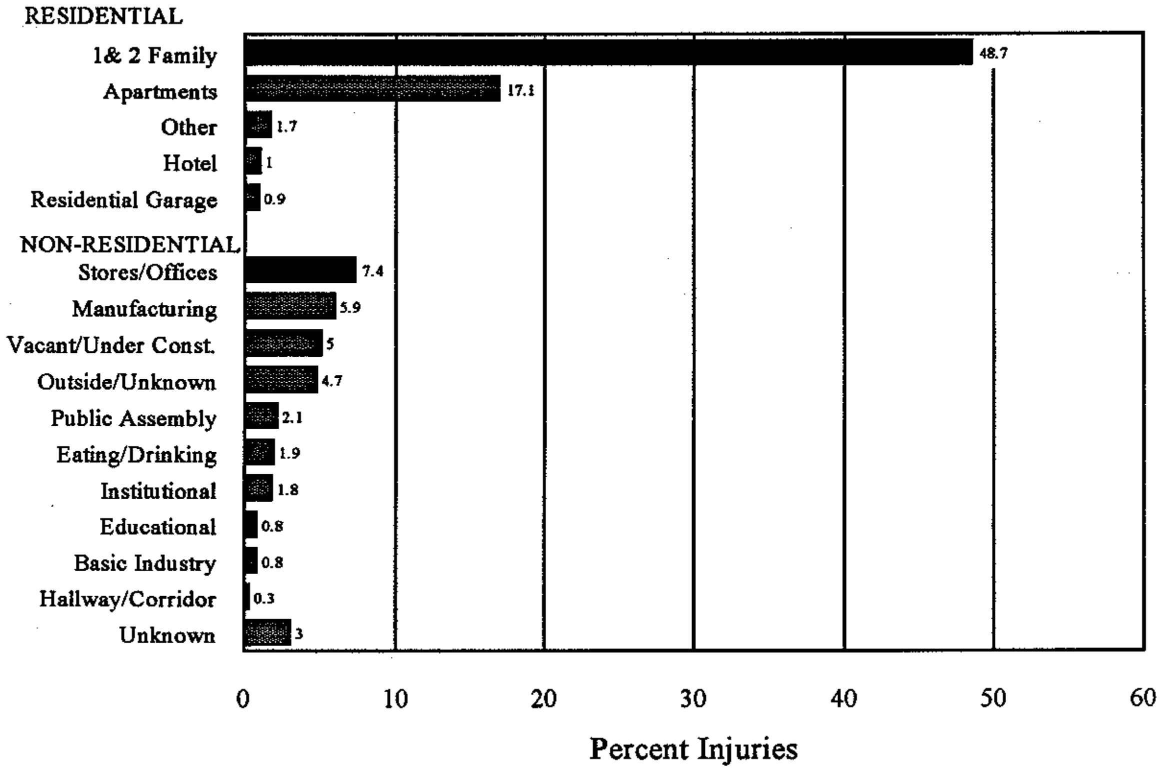
[36] Ibid.

[37] Ibid.



Note: "Public Assembly" here excludes Eating/Drinking, which is shown separately. "Storage" here excludes residential garages, which is shown separately. "Outside/Unknown" here excludes "Vacant/Under Const.," which is shown separately.

Figure 13. Firefighter Injuries Detailed by Property Type, 1987 (Structure Fires Only)[38]

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[38] Ibid.

However, when firefighter injuries per 1,000 fires are detailed, non-residential construction is shown to be more dangerous to firefighters than residential construction (See Figure 13).

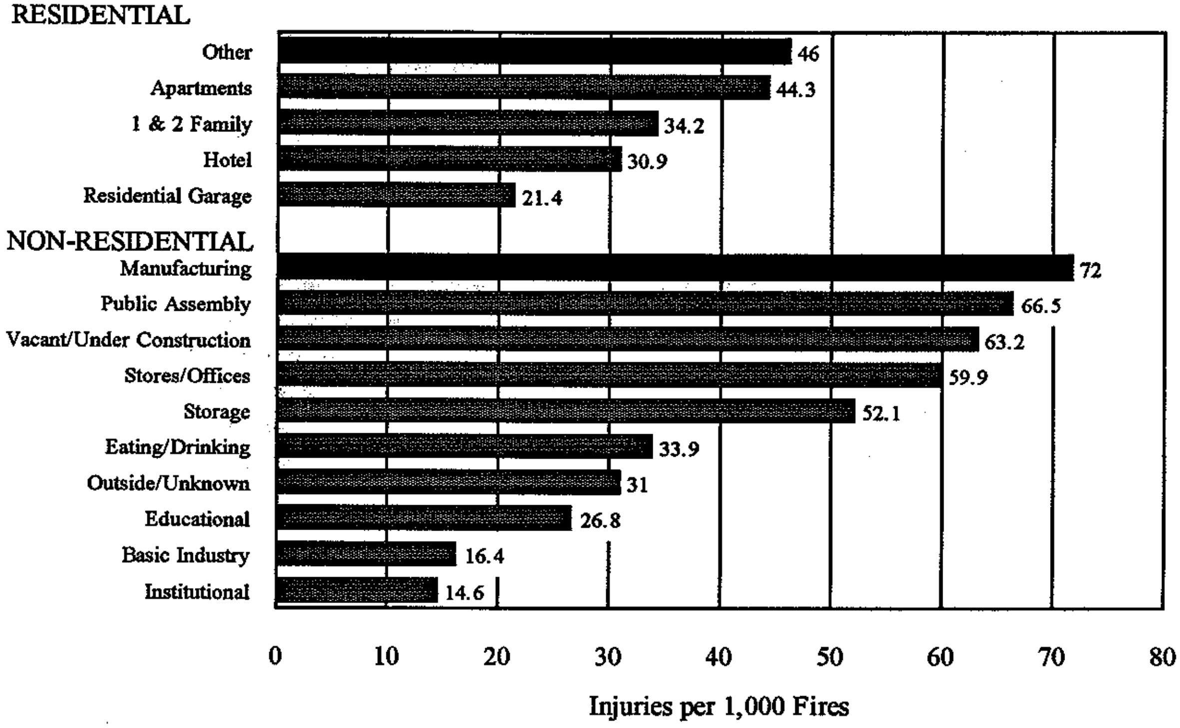

Figure 14. Firefighter Injuries per 1,000 fires by Type of Property, 1987 [39]

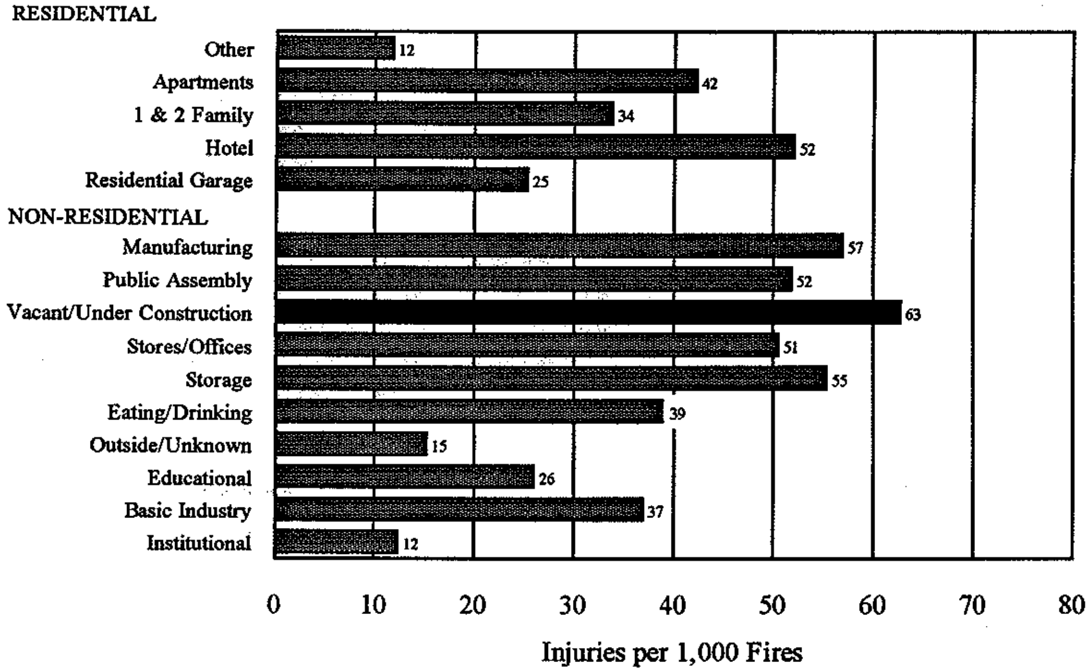

Figure 15. Firefighter Injuries per 1,000 fires by Type of Property, 1988 [40]

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[39] Ibid.

3.6.2 Firefighter Fatality Statistics

Figure 16 shows the number of firefighter fatalities for each year from 1977 through 1990.

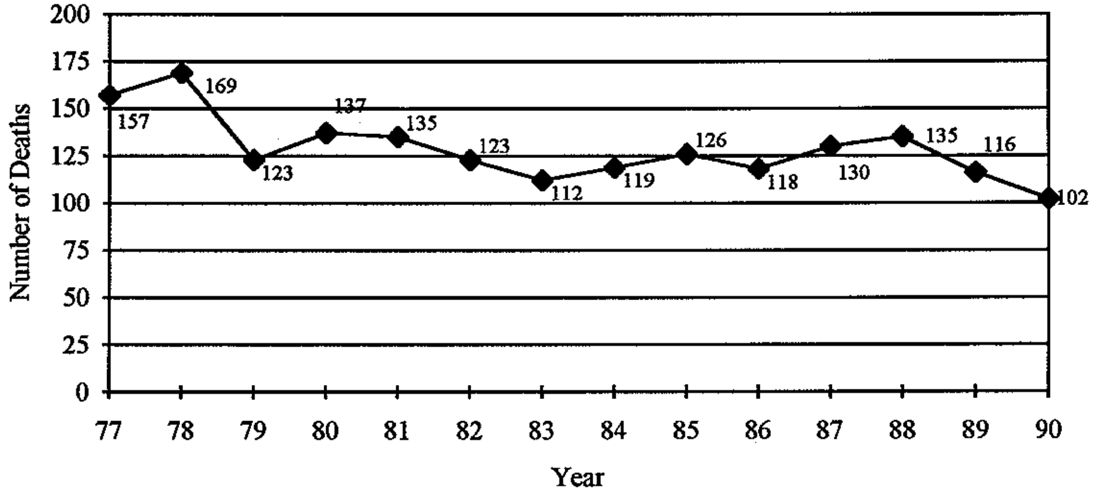

Figure 16. Firefighter Fatalities 1977-1990 [41]

As can be seen, there is a downward trend in firefighter fatalities. Why this is so is not immediately apparent from the literature. One could surmise that firefighters are staying more physically fit, are taking more safety precautions, are better educated on fire ground techniques, etc. This may also be due to the fact that building codes are continuously being upgraded to add new life safety measures, and construction materials and methods are improving, which may result in greater firefighter safety on the fire ground.

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[40] Ibid.

[41] Washburn, AE, LeBlanc, PR, and Fahy, RF, "Report on Fire Fighter Fatalities," **NFPA Journal**, July/August 1991, p. 47.

Figure 17 details firefighter fatalities by type of duty in 1990. Of all on-duty firefighter fatalities, 43.1% were on the fire scene where the structure could have contributed to the loss of life.

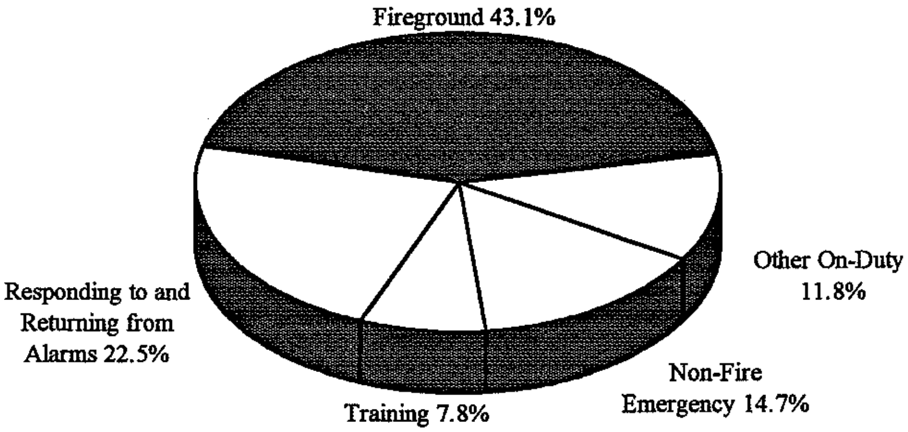

Figure 17. Firefighter Fatalities by Type of Duty, 1990 [42]

To gain a better sense of firefighter fatalities and their causes, data were reviewed from **Fire Command Magazine** Fire Incident Reports from 1980 through 1989. Each of the fatalities detailed were reviewed for cause. The statistical breakdown is detailed in Table 8 and Figures 18 and 19.

	Cause						
Year	**Fatalities**	**Heart Attack**	**Fell or Struck by Object**	**Structural Collapse**	**Exposure to Fire Products**	**Electrocution**	**Other Conditions**
1989	110	59	9	7	6	3	26
1988	129	51	5	17	2	2	52
1987	124	62	6	3	4	0	49
1986	113	58	13	2	8	1	31
1985	119	48	12	7	5	1	46
1984	116	38	15	3	7	2	51
1983	106	52	10	3	6	1	34
1982	117	54	8	12	8	2	33
1981	123	64	7	2	5	0	45
1980	134	60	11	6	7	1	49
TOTAL	**1191**	**546**	**96**	**62**	**58**	**13**	**416**
PERCENT	**100%**	**45.84%**	**8.06%**	**5.21%**	**4.87%**	**1.09%**	**34.93%**

Table 8. Firefighter Fatalities Taken From Fire Command Magazine, 1980-1989 [43]

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[42] Ibid.

[43] Fire Command statistics compiled by the NFPA Fire Analysis and Research Division. Prepared by authors

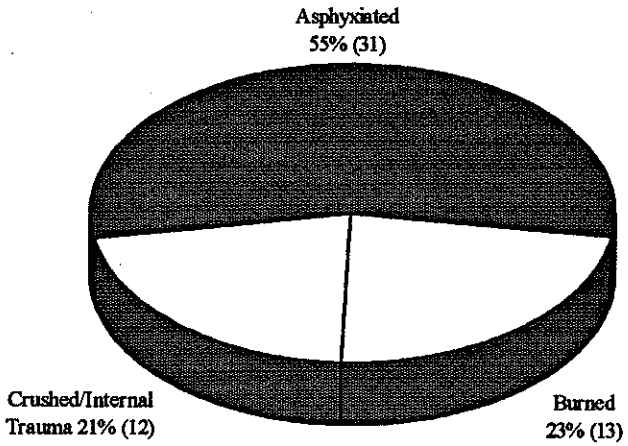

Figure 18. Firefighter Fatalities by Nature of Injury, 1983[44]

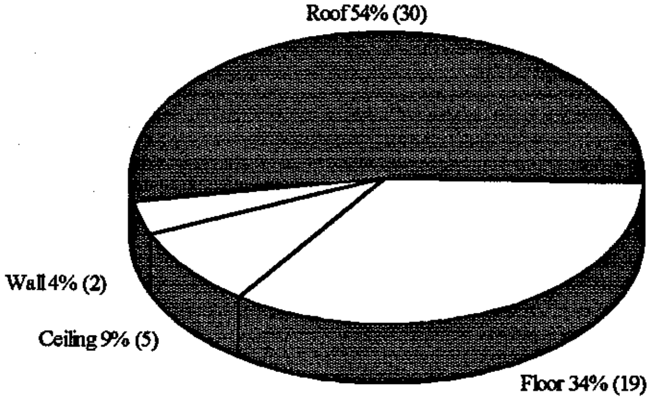

Figure 19. Firefighter Fatalities by Nature of Injury, 1990[45]

The structural collapse cause of fatality data shown in Table 8 was further broken out when the incident report stated specifically that the cause of fatality was due to structural collapse. This includes any conditions that would allow even an inference that the cause of fatality was by structural collapse. For example, a ceiling collapse was included in the structural collapse category, yet it was unknown whether it was the structural supporting member that collapsed, or simply the ceiling material. Therefore, when there was enough detail in "Fell or Struck By Object" (again from Table 8) to place it into the structural collapse category, this was done. This is believed to provide a more realistic picture of structural collapse-related fatalities. This detailed breakdown is shown in Table 9.

---

[44] Source: NFIRS

[45] FEMA, **Fire in the United States,** 7th ed., August 1990.

Year	Total Fatalities	Non-Comb. Wall	Wood Frame Products	Ordinary Roof/Floor[q]	Non-Combust. Roof/Floor	Light Frame Wood Trusses[a]	Timber Trusses	Comb. Wall
1980	134	1.0	3.0	1.0		1.0[f]		
1981	123	1.0		1.0				
1982	117	5.0	1.0	4.0	2.0[o]			
1983	106	1.5[h*]			1.5[hn*]			
1984	116			2.0		1.0[e]		
1985	119	1.0[l*]	2.0	4.0[l*]				
1986	113		0.5[k*]			1.0[d]		0.5[k*]
1987	124	1.5[g**]	1.5[gj*]					
1988	129	3.5[c*]	6.0[i]		2.0[m]	0.5[c*]	5.0[p]	
1989	110	2.0	2.0		1.0	2.0[b]		
TOTAL	**1191**	**16.5**	**16.0**	**12.0**	**6.5**	**5.5**	**5.0**	**0.5**
PERCENT	**100.0%**	**1.39%**	**1.34%**	**1.01%**	**0.55%**	**0.46%**	**0.42%**	**0.04%**

* In five cases (c,g,h,k,l) more than one failure mode is referenced in the event description.

a Unless otherwise noted, all fatalities are in light commercial structures. Truss type is not defined in the description.

b Assumed metal plate connected trusses in Orange County Gift Shop (Mercantile Occupancy). Description does not say.

c Trusses collapsed causing concrete block wall to fall on a firefighter (Mercantile Occupancy).

d A Johnsonville, South Carolina Church (Assembly Occupancy) Truss roof collapsed. Truss type unspecified.

e An apartment building (Group R-2 occupancy) under construction caught due to a fire placed in an unfinished chimney. Roof truss collapsed. Truss type unspecified.

f A delicatessen/restaurant (Mercantile Occupancy) fire roof truss collapse. Truss type unspecified.

g Wood frame roof collapsed causing concrete block chimney to fall.

h 15,000 ft.^{2} manufacturing plant assumed to use steel bar joists. Caused brick wall to collapse.

i Assumed wood frame in a single-family residence ceiling collapse.

j 100-year-old wood frame church

k Wood frame structure collapsed causing facade to collapse.

l Wall collapse due to roof collapse. Roof type not designated.

m Collapse of concrete floor on steel beams, 1 Fatality. Steel Beam the other.

n Steel bar joist collapse.

o 4 in. concrete floor poured over original joist floor.

p Hackensack, New Jersey Fire. Bolted Timber Bowstring Girder Trusses.

q Description only says the building was of ordinary (type 3) construction.

Table 9. Cause of Fatality by Collapse/Structural Failure[46]

Table 9 was generated by reading each summary in **Fire Command Magazine**, from 1980 through 1989, and ascertaining the specific structural collapse cause of fatality. Unfortunately, the detail of the incident report is often not specific enough to identify the specific structural product. These were categorized in the wood frame products or ordinary category due to the use of 'wood frame' or 'ordinary' in the incident description.

The total fatalities that appear to be attributable to structural framing of the floor or roof system over the period of 1980 through 1989 are 45, 3.8% of the total firefighter fatalities for this period.

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[46] Firefighter fatalities taken from NFiPA **Fire Command Magazine.** Statistics compiled by the NFiPA Fire Analysis and Research Division. Summary prepared by Kirk Grundahl.

A similar study done by the Fire Analysis and Research Division of NFPA for the Federal Emergency Management Agency (FEMA) in August, 1989, provides specific information on firefighter fatalities in structural collapses. For the purpose of this study, structural collapse was defined as: "The failure of structural members resulting in the collapse of a structure or portion of a structure." Two categories of structural collapse were used: the first when firefighters were caught or trapped by a collapsing roof, wall, floor or ceiling; the second when firefighters were struck by a collapsing roof, wall, ceiling or piece of wall.[47]

The study reported that from 1979 through 1988, 93 firefighters were killed in structure fires as a result of structural collapse. Of these 93 victims, 56 were caught or trapped, and 37 were struck by a collapsing roof, wall, etc. Figure 20 shows the number of firefighter fatalities according to these two categories:

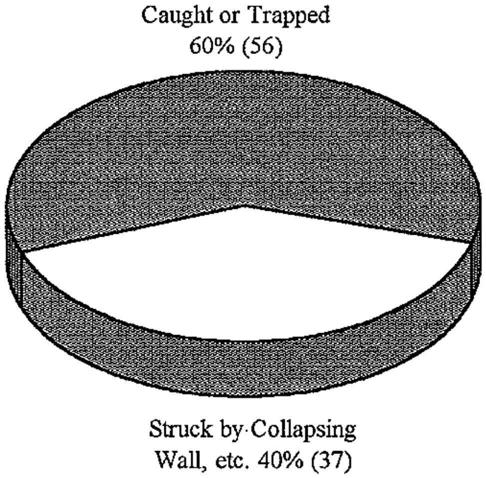

Figure 20. Firefighter Fatality by Category [48]

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[47] "Analysis Report on Firefighter Fatalities," Prepared by Fire Analysis and Research Division, NFPA for the Federal Emergency Management Agency, August 1989.

[48] Ibid.

Of the 56 who were caught or trapped by structural collapse, 31 were asphyxiated, 13 died of burns, and 12 died as a result of crushing injuries or internal trauma. These data can be seen in Figure 21.

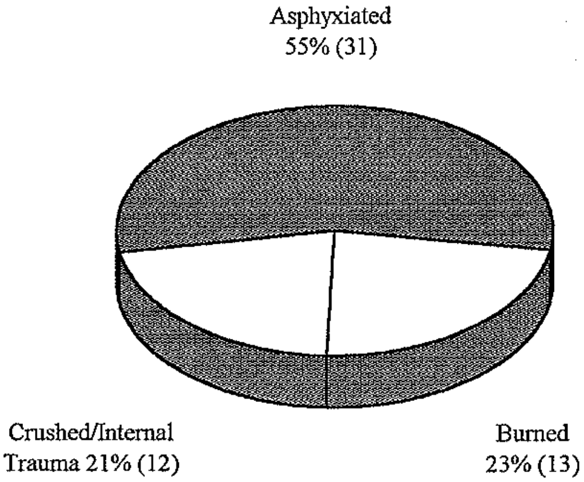

Figure 21. Firefigther Fatalities Resulting From Being Caught or Trapped by a Structural Collapse (56 fatalities) [49]

The building components involved in the collapses were the roof (30 fatalities), floor (19 fatalities), ceiling (5 fatalities), and walls (2 fatalities). These data can be seen in Figure 22.

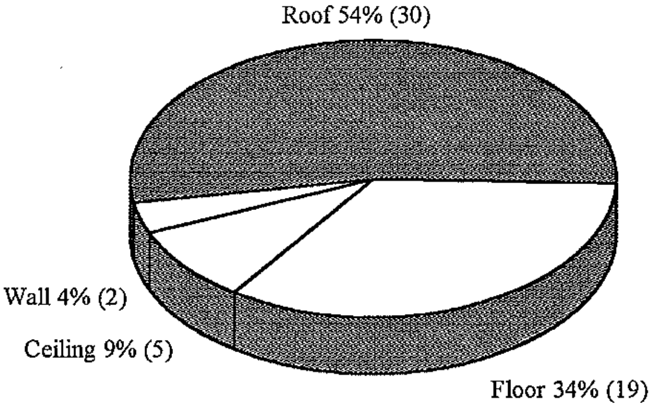

Figure 22. Building Components Involved in Firefighter Fatality [50]

The 30 fatalities in roof collapses occurred as follows: 10 of the victims were on the roof performing ventilation, 17 were inside performing fire suppression activities, 2 were inside pulling ceilings, and 1 was involved in a search for occupants. These data are shown in Figure 23:

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[49] Ibid.

[50] Ibid.

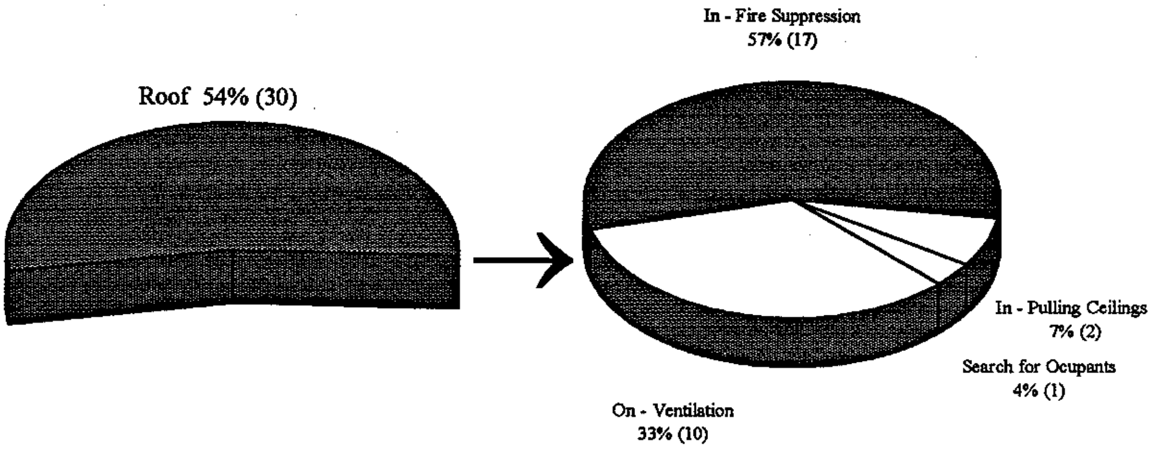

Figure 23. Firefighter Activity During Fatality-Causing Roof Collapse [51]

Figure 24 summarizes the type of occupancy where firefighters were caught or trapped in a structural collapse.

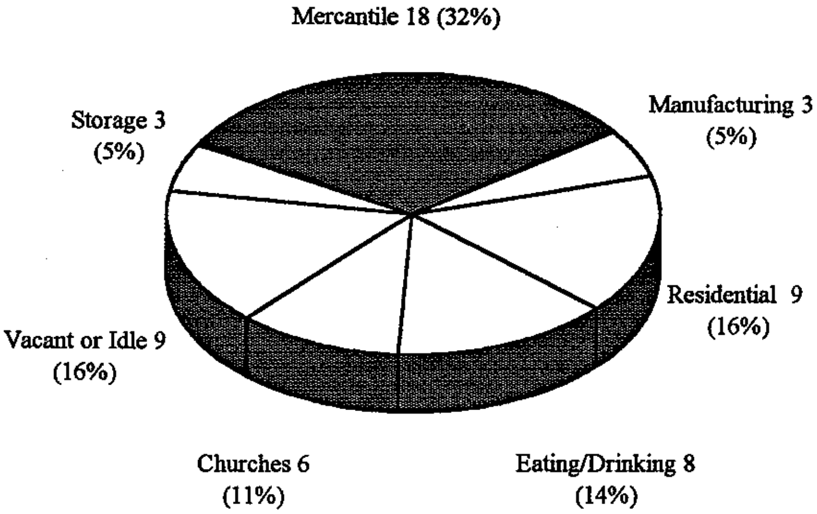

Figure 24. Firefighters Caught or Trapped in Structural Collapses, 1979-1988

Of the 93 fatalities reported in the study, 37 occurred by being struck by a collapsing wall or piece of wall while outside the structure. Of these 37 victims, 30 were operating hand lines (one from an elevated platform) or performing other suppression activities, 3 were killed while escaping from the building, 2 were attempting to move vehicles (in separate incidents), 1 died when a natural gas explosion caused a wall collapse as he and others were attempting to rescue an elderly woman from a fire escape, and 1 was attempting to open a door with a ceiling hook when the wall collapsed on him. These data are shown in Figure 25:

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[51] Ibid.

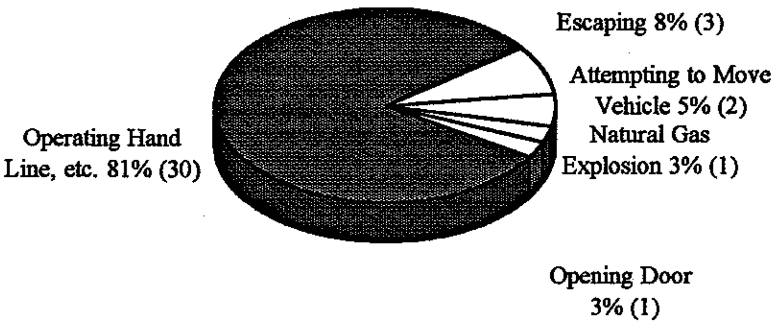

Figure 25. Firefighter Fatalities Caused by Wall Collapse, by Activity (37 fatalities) [52]

In 12 of the wall collapse fatalities described above, the roof was also reported to have collapsed; and in another, the floors collapsed, causing the walls to collapse by being pushed out. The failure of firefighters to maintain an adequate distance between themselves and the building appears to have been a factor in almost all wall collapse fatalities.[53]

Figure 26 summarizes the NFPA study on firefighter fatalities for the period 1979 through 1988:

- 93 firefighters killed
  - 56 caught / trapped
    - 31 asphyxiated
    - 13 burned
    - 12 crushed / internal trauma
  - 37 struck by a wall
    - 30 operating hand line, etc.
    - 3 escaping
    - 2 attempting to move vehicle
    - 1 natural gas explosion
    - 1 opening door

Figure 26. Summary of Firefighter Fatalities 1979 through 1988. [54]

3.6.2.1 Fatalities Due to Truss Roof Collapse

The NFPA study also identifies collapses involving truss roofs. Seven of these collapses were reported to involve truss roofs. Eleven firefighters died when they were caught or trapped in six of the collapses. The seventh collapse resulted in a firefighter being struck by a collapsing wall after the roof collapsed. The most severe incident occurred in Hackensack, New Jersey, in 1988, when five firefighters were killed when a wood bowstring truss roof

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[52] Ibid.

[53] Ibid.

[54] Ibid.

collapsed.[55] This seems to confirm the numbers developed from Fire Command Magazine as shown in Table 9 above.

3.7 Summary of Fire-Related Statistics

The major fire problem in the United States appears to be in residential structures. Most fires start in areas that are compartmentalized, giving occupants and firefighters a longer period of time to work, and to safely exit the structure than would be the case if the fires started in an unprotected area or a concealed space.

The non-residential fire problem is decreasing and great improvement in life-safety has been shown. When compared to residential fires, non-residential fires cause more injuries to firefighters—probably due to the greater number of hazards encountered in these fires.

It is interesting to note that in most of the sprinkler activations detailed, one head usually controlled the fire. It is also interesting that the room of origin for these fires was consistent with those shown in the statistics for residences and apartments. Generally, the room of origin is in an area that is compartmentalized and a primary living area, such as the kitchen, bedroom or living room. This further suggests that the focus ought to be on protected lightweight building components.

Sprinklers will be important in the future for diminishing the impact of fires in any type of construction. It is proven that sprinklers reduce property loss and life loss. There is also a strong possibility that sprinklers could reduce firefighter fatalities, since they contain, and even extinguish, fires prior to arrival of the fire department. Sprinklers are currently the most pro-active fire safety approach in building construction.

Regarding firefighter fatalities, **Fire Command** data indicate that 3.8% (45 total) of all firefighter fatalities for the ten-year period from 1980-1989 were due to some type of floor or roof structural collapse. NFPA Fire Analysis and Research Division data for the period from 1979-1988 indicate that 54 fatalities were caused by the roof, floor or ceiling collapse. This represents 4.2% of all firefighter fatalities for this period. These figures include all structural materials types, such as solid-sawn joists, heavy timber trusses, wood trusses, steel trusses, etc.

The **Fire Command** study separated out the categories of non-combustible roof/floor systems, light frame trusses and timber trusses, and found the fatalities to be 0.55%, 0.46%, and 0.42% of total fatalities, respectively. The NFPA study found that 12 firefighters died in buildings using truss construction, or 0.9% of all fatalities for the time period under study, corroborating the **Fire Command** data.

These data indicate that the number of the lightweight component construction-related firefighter fatalities due to structural collapse is very small. It implies that lightweight

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[55] Ibid.

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[55] Ibid.

component construction has not increased the hazard for firefighters over and above the hazard that has always existed on the fire ground. Performing a risk assessment would be helpful in analyzing this data further. Yet, one firefighter fatality due to structural member failure is one too many. The statistics don't provide insight into how many heart attack fatalities were triggered by the shock of collapse conditions. The statistics are also not detailed enough to provide more information about the contribution lightweight building construction makes to fire-related problems and fatalities.

Chapter 4: Fire Performance-Related Testing of Structural Assemblies

As noted in previous chapters, a large amount of information is available on the fire performance of lightweight component assemblies, including opinions, experience, and standard and non-standard tests. While there has been criticism of the adequacy of a number of tests to assess fire performance (see **Chapter 2: Literature Review**), only standardized fire testing permits an accurate evaluation of comparative performance.

4.1 Types of Tests Performed

ASTM E119, "Standard Methods of Fire Tests for Building Construction and Materials," is the primary standard used to measure the fire performance of floor/ceiling, roof/ceiling, and wall assemblies and columns, and is the test recognized and accepted by most building codes. The key elements of the ASTM E119 test are[1]:

- Each test follows the ASTM E119 standard time/temperature curve.
- The assembly to be tested is fully instrumented with at least 9 thermocouples, which in the case of roofs, floors and walls are located on the unexposed surface of the specimen. The instrumented locations are specified to provide measurement of thermal transmission through the assembly. This is one of three criteria used to determine the assembly's fire resistance rating.
- The test specimen is intended to represent the construction for which classification is desired. Each specimen is conditioned prior to testing so that its temperature and moisture content is representative of the assembly in its actual environment.
- The area of the assembly exposed to fire is defined. The area for walls and partitions shall not be less than 100 ft.^{2}, and the area for floors and roofs shall not be less than 180 ft.^{2}.
- The load applied to the test specimen shall be a constant superimposed load that, unless specified by the sponsor, applies the maximum allowable design stresses pursuant to recognized structural design criteria.
- The conditions of acceptance for a particular assembly classification are:
    - The specimen shall sustain the applied design load for the duration of the test.
    - At no time during the test duration shall cotton waste be ignited while placed over the unexposed surface.
    - The average temperature rise on the unexposed surface shall not increase more than 250° F (139° C) above its ambient temperature.

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[1] **ASTM Fire Test Standards**, sponsored by ASTM Committee E 5 on Fire Standards, 2nd Edition, 1988, pp. 43-69

  - The temperature at any single thermocouple shall not rise more than 325° F (181° C) above the initial temperature.
  - For steel structural members, the temperature of the steel shall not exceed 1300° F at any location during the classification period.
  - The average temperature on the steel specimens shall at no time exceed 1100° F.
  - In concrete specimens with tension steel, the temperature shall not exceed 800° F for cold-drawn pre-stressing steel, or 1100° F for reinforcing steel.
  - In wall assemblies, the test specimen is also subject to a hose stream test. For 1-hour assemblies, the water is applied at 30 psi for one minute to simulate specimen stability under suppression activities.

- The rating periods are typically expressed in terms of time, i.e. 45 min., 1-hour, 2-hour, etc.

Small-scale tests are often performed using the ASTM E119 time/temperature curve to evaluate the performance of a combination of materials prior to testing in the large-scale furnace. In some cases, the small-scale test facilities have the capability of applying load. In others, it is mainly a means of evaluating the temperature profiles developed in the small-scale furnace, to predict their performance in large-scale tests.

The ASTM E119 test was developed under the consensus standards development procedures of ASTM, and can be used to satisfactorily *compare* performance of materials under standardized test conditions. Several other tests have been performed on assemblies under what would be termed 'ad hoc' conditions.[2] When a test is conducted using this type of procedure, it is very difficult to compare the performance of one assembly to another.

In other cases, 'ad hoc' testing is done using parts of the ASTM E119 standard. Often, the time/temperature curve is used while the load and assembly size are varied. These tests are usually performed primarily for gathering information, not for model code acceptance.

There is also a standard guide for room fire experiments, ASTM E603. This guide covers full-scale compartment fire experiments that are designed to evaluate the fire characteristics of materials, products or systems under actual fire conditions. This set of procedures is only a guide for room test procedures, experiment design, and result interpretation.[3] At this time there is no accepted ASTM standard test procedure for room fire tests that can be used to evaluate the performance characteristics of roof, floor or wall structural elements.

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[2] Instances when testing was done using non-standardized procedures will be denoted in the summary of the reports.

[3] Taken from the scope statement of ASTM E603.

A variety of international test standards follow ASTM E119 test procedures quite closely, if not exactly. These will also be briefly discussed in this chapter.

4.2 Key Testing Characteristics

The following characteristics are typically measured during testing to allow for analysis and comparison of test results:

4.2.1 Load

Applied load is extremely important in the performance of a structural assembly. In order to make accurate comparisons between assemblies, the impact of the superimposed loads must be equivalent. Generally, this is achieved by applying a load that reaches the maximum allowable design stress on the assembly. Also, an attempt is usually made to maximize the stress on what is considered to be the most critical component of the assembly. The test design attempts to maximize other stresses on the assembly to as near allowable design stress as is feasible from an engineering perspective. If this is not done, the reduced loading must be given special consideration when comparing the performance of assembly types.

4.2.2 Fire Exposures

There has been considerable discussion and debate on the best fire exposure to use for assessment of structural members in a fire. Most standardized tests employ a fire of increasing temperature over time, referred to as time/temperature curves. The current ASTM E119 time/temperature curve is shown in Figure 27. For example, the time/temperature curves in Australian Standard 1530 and British Standard BS 476 closely resemble this curve.

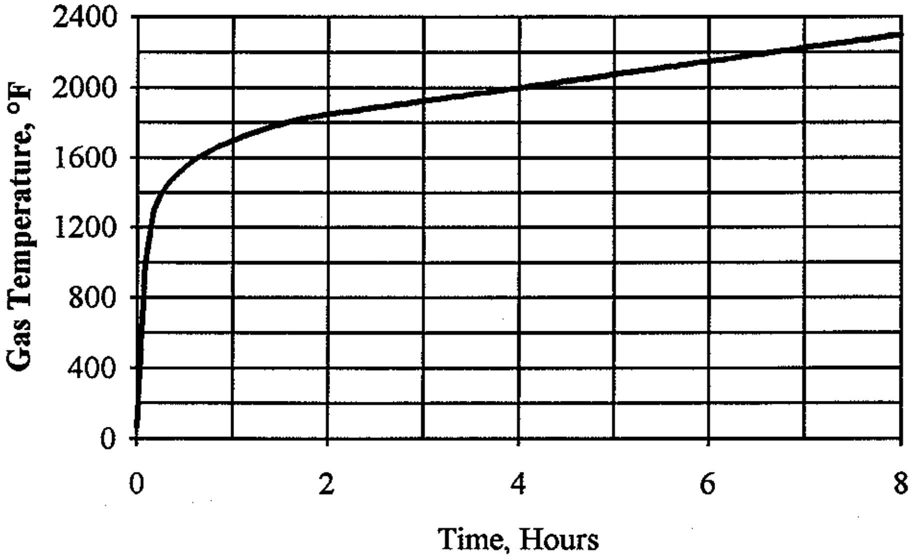

Figure 27. ASTM E119 Time/Temperature Curve

A figure that shows the severity of the ASTM E119 time/temperature in terms of material properties has been prepared and is shown in Figure 28.

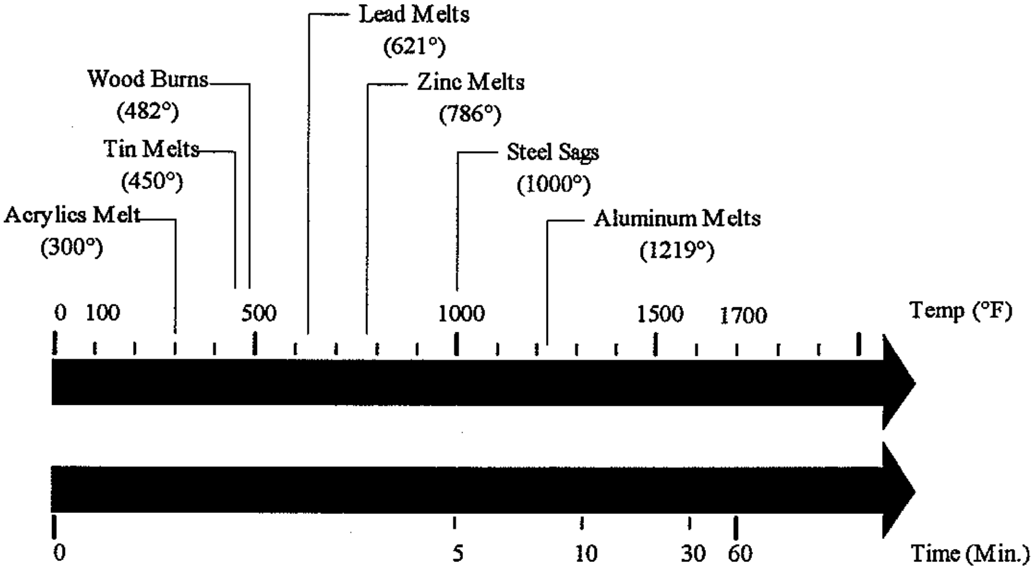

Figure 28. ASTM E119 Standard Fire Exposure [4]

Use of other fire exposures has been suggested. Frank Brannigan and others have been proponents of the NBS-developed time/temperature curve (Figure 29) as more accurately reflecting a contents fire for a residential structure.

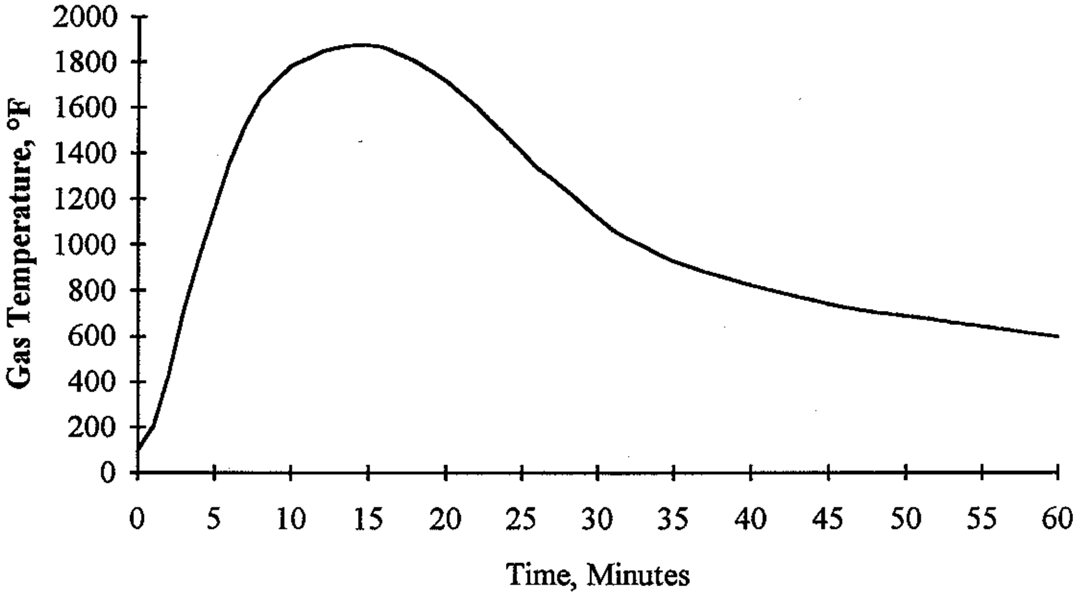

Figure 29. NBS Room Fire Test 9 Time/Temperature Curve[5]

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[4] Truswal Systems Corporation, "What About Wood Trusses and Fire?" Copyright 1984.

Australian researchers use a time temperature curve developed by Rodack and Ingberg (Figure 30) for typical fires in a residential building.

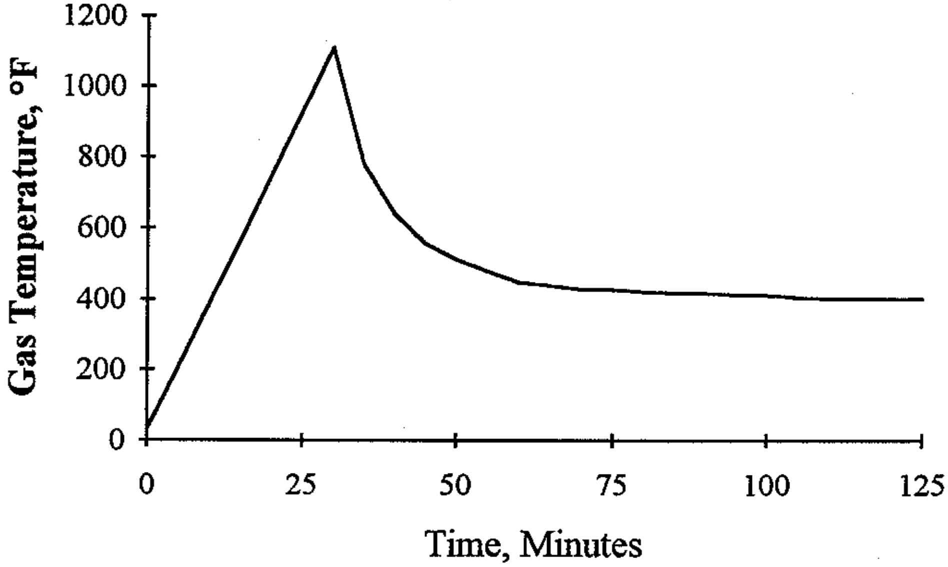

Figure 30. Rodack and Ingberg Time/Temperature curve for Residential Buildings[6]

In ad hoc testing, Captain John Mittendorf of the Los Angeles Fire Department used four gallons of paint thinner and sawn pallets as a representative fire exposure.[7] Similarly, the Illinois Fire Service Institute used four gallons of diesel fuel and one gallon of gasoline in five gallons of water as a fire exposure.[8]

Fire tests conducted to evaluate sprinklers and full-scale rooms often use a combustible crib, a specified combustible commodity (e.g., paper or furnishings), or a propane-burner substitute as the fire source. These fire sources are standardized as much as possible.

In order to make realistic comparisons between assemblies, the fire source must be repeatable. The time/temperature curve used most often is from ASTM E119. Therefore, this method provides most of the available test data. Other time/temperature curves have been used primarily for experimental purposes.

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[5] Brannigan, F.L., "Are Wood Trusses Good for Your Health?" **Fire Engineering**, June 1988.

[6] Leicester, T.H., Seath, C.A., and Phau L., "The Fire Resistance of Metal Connectors," Proceedings of the 19th Forest Products Research Conference. Melbourne, Australia, November 12-16, 1977.

[7] Mittendorf, J., "Lightweight Constructions Tests Opens Fire Service Eyes to Special Hazards," **Western Fire Journal**, January, 1982.

[8] Straseske, J. and Weber, C., "Testing Floor Systems," **Fire Command**, June, 1988.

4.2.3 Furnace Pressure

Adjustment of furnace gas pressures is sometimes used to simulate the pressures occurring in actual and large-scale fires. Because of the significant effect on pressure from items such as openings and their location, there is little consensus as to the establishment of specific pressure levels for fire tests. The ASTM E119 standard does not provide guidance for pressures to be applied in an assembly test. The more positive the pressure on a test assembly, the quicker the fire may penetrate protective membranes or sheathing materials. Generally in the United States, floor/ceiling assemblies are tested with a mild amount of positive pressure due to the natural buoyancy occurring in the test furnace. In Europe, assemblies are tested under a specified amount of positive pressure.

4.2.4 Fuel Load

In ASTM E119 testing, natural gas is the fuel typically used. Generally, the flow of fuel to the burners is monitored to ensure uniform heat throughout the furnace.

When a solid fuel is used to evaluate the fire performance of a system, it is far more difficult to develop fires of consistent quality. The only way to accurately evaluate assemblies comparatively is to use identical fuel loads and types of fuel.

4.2.5 Restraint

Restraint addresses the ability or inability of a structural member to expand under fire conditions. An assembly is restrained if the effects of fire are resisted by forces external to the element. An assembly is unrestrained if the structural element is free to expand and rotate at its supports. In general, steel and concrete systems are tested as restrained members due to the expansion characteristics of steel, and steel reinforcement. Because of its thermal stability, wood is tested as an unrestrained system. Determining if elements are tested under restrained or unrestrained conditions is an area where engineering judgment must be used, since it is not specified in ASTM E119.

4.2.6 Ventilation

ASTM E119 has no direct provision for ventilation. The air required for combustion of components in a fire test assembly is controlled by the need to provide a standard fire exposure. The National Bureau of Standards (NBS) ran several tests using high and low amounts of excess air. These results are reported in later sections of this study. These tests must be distinguished from standard tests where oxygen for combustion must be controlled to maintain the standard time/temperature exposure.

4.2.7 Deflection

Deflection measurements are typically made in assembly testing, but are not required by the ASTM E119 standard. This information is useful in determining deterioration of strength and imminent collapse. It is also useful in comparing deflection performance between assemblies. Deflection and rate of deflection are measures of a system's plasticity under fire conditions and the potential a system has for collapsing without much warning.

4.2.8 Size

In most test standards, the size of the assembly is specified. Size is important—specifically with regard to the applied load. The smaller the specimen size, the higher the applied load will need to be to provide the maximum allowable stress on the member. Size also influences stresses that are critical from a design perspective. In short roof or floor assembly specimens, shear becomes critical; in longer specimens, bending moment, the moment of inertia, and modulus of elasticity (MOE—the stiffness, or ability to resist deflection) become critical.

4.2.9 Test Duration

The duration of the test is usually determined based on some end-point criterion. The end point could be a specific temperature level, load carrying capacity, deflection performance, time period, etc.

4.2.10 Element Tested

Tests are generally performed on either single elements or a combination of elements in an assembly. Single element tests usually produce times of the shortest duration. As an explanation, Dr. Tibor Harmathy has established a number of rules for fire endurance calculations.[9] He states that elements tested as part of an assembly will always perform better than elements tested singly. Therefore, if one has test results for a variety of structural elements, elements can be substituted for one another if the element being substituted has a better fire endurance performance under standardized conditions.

4.3 Test Results

In addition to statistics (as discussed in **Chapter 3**), the base of knowledge on the performance of lightweight building components exists in the form of test data. To aid in providing background, report summaries obtained from the literature search of pertinent tests have been prepared covering the following areas:

- unsheathed assemblies
- single membrane protected assemblies
- connections

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[9] Harmathy, T.Z., "Ten Rules of Fire Endurance Ratings," **Fire Technology**, 1(2), pp. 93-102, May, 1985.

- "Operation Breakthrough" assemblies
- assemblies protected with coatings
- sprinklered assemblies

All available data from these tests have been summarized. Comments regarding the individual tests are given at the end of each summary. Analysis of the testing and test data can be found in **Chapter 7: Discussion**. Conclusions are found at the end of each section, as well as in **Chapter 8: Conclusions and Recommendations**.

It should be noted that with respect to concerns expressed about lightweight component construction, the mode of assembly failure is critical. Non-structural assembly failure (i.e., temperature rise or flamethrough of the sheathing), while very important, does not raise the same concerns with respect to this study, and is not the subject of this report.

Chapter 4-1: Fire Endurance Performance of Unsheathed Assemblies

4-1.1 Report: Lightweight Construction Tests Open Fire Service Eyes to Special Hazards

Author: J. Mittendorf

Sponsor: Los Angeles City Fire Department

Date: May, 1981

Basic Test Description: Metal plate connected (MPC) trusses, wood I-beams (also known as wooden I-joists), open pin-end connected steel web (PECSW) construction, and panelized construction were subjected to fire conditions. The general concept of the test was to utilize typical construction, and observe and record behavioral characteristics.

Test Methods Used: The test specimens were constructed to represent actual field conditions. Trusses used the correct on center spacing; 1/2 in., 3/8 in. or 3/4 in. CDX plywood decking; and were hung or supported as they would be in normal installations. The span of the construction was limited to the size of the donated products. Each test fire was generated from four gallons of paint thinner and sawn pallets. The fire exposure for each test was believed to be approximately equal. No live load was imposed on any of the structures. The test time began at ignition of the thinner and pallets. A time limit of 6 min. per test was used.

Report Observations:

Structural Member	Span (ft.)	Spacing (in. o.c.)	Sheathing Material	Failure Time (min:sec)
Wood I-beams	12	32	1/2" CDX ply.	1:20
PECSW construction	20	24	1/2" CDX ply.	3:20
MPC Truss floor system*	30	16	3/4" CDX ply.	5:00
MPC Truss roof system*	Unknown	32	1/2" & 5/8" CDX ply.	6:00
8 x 8' panel. sys., 2x4 joists	8	24	1/2" CDX ply. & 1 x 6" sheath.	did not fail

* Penetration depth of gusset plate teeth = 3/8 in.

Table 10. Non-Standardized Test Results.

Report Summary: Testing revealed the following:

I-Joists: Once the 3/8 in. web burned and weakened, the entire structure weakened and failed.

PECSW Construction: The weak point of this construction was the junction of the 2 x 4 chord, steel tube webbing and pins. After collapse of the test sample, it was evident that each junction point that had significant char failed.

Metal Gusset Plate Trusses: The early collapse of this test sample was caused by two factors: 1) It was found that once the 2 x 4s charred to a depth of 0.25 in., the gusset plates pulled out; 2) Because the 2 x 4 ends were butted together and held by gusset plates, there was no structural integrity once the gusset plate was pulled free. This allowed the 2 x 4s to separate, causing failure. When metal gusset plates were exposed to fire, the following factors contributed to failure:

- The amount of load or stress imposed on a joint.
- The ability of the plate to conduct heat to the prongs, which causes the wood to expand, and lose its grip on the gusset plate prongs.
- The depth and penetration of the prongs.

When 3/8-in. prongs are used, once the wood is charred 1/4 in., there is only 1/8 in. of wood left creating a friction bond.

Metal Plate Connected Roof Trusses: This truss used a continuous 2 x 4 bottom chord, which was instrumental in the truss' ability to resist failure. Upon close inspection, it was evident that this construction was about to fail when the test was stopped at six minutes.

Panelized: This test was used to compare the difference between roof decking used today and that used 20 years ago. It is obvious that there is no comparison. After extinguishing the fire, it was still possible to walk on the 1 x 6 sheathing, whereas the plywood sheathing of previous tests had been destroyed.

Report Conclusions: The need for each firefighter to become familiar with new developments that will effect job performance and job safety, and pre-fire planning cannot be emphasized enough. For the firefighter, this means a reduction in time to work on buildings which were built with lightweight construction. Although most of the test samples were smaller than what would be found in practical applications, each test resulted in early failure of the construction. Each test was relatively basic; however, each produced similar results when compared with recent fires that have involved this type of construction. Consider what today's firefighter will encounter when faced with normal spans, air conditioning or heating equipment, and several truckmen on the roof.

Comments: THIS WAS THE INITIAL TESTING DONE IN AN ATTEMPT TO DETERMINE THE RELATIVE PERFORMANCE OF LIGHTWEIGHT COMPONENT SYSTEMS. WITHOUT STANDARDIZATION (I.E., USING IDENTICAL SPAN, SPACING CONDITIONS AND SHEATHING MATERIALS), IT IS DIFFICULT TO MAKE COMPARISONS BETWEEN THE CONSTRUCTION TYPES TESTED. THIS IS DUE PRIMARILY TO THE FACT THAT THERE ARE NOT EQUIVALENT STRESSES BEING PLACED ON THE MEMBERS TESTED. SPECIFIC DETAILS ON THE STRUCTURAL MEMBERS SUCH AS FLANGE SIZE AND DEPTH OF I-JOISTS WOULD BE EXTREMELY

VALUABLE IN EVALUATING THESE TESTS AS WELL. THIS INFORMATION WAS NOT AVAILABLE IN THE REPORT.

THE REPORT ALSO STATES THAT THE FAILURE WAS EARLY, BUT DOES NOT DEFINE "EARLY". THE RELATIVE MEANING BEHIND THIS NEEDS TO BE CLEARER.

4-1.2 **Report:** Testing Floor Systems

Authors: J. Straseske and C. Weber

Sponsor: Illinois Fire Service Institute at the University of Illinois

Date: Fall, 1986

Test Methods Used: The floor systems used for demonstrations were:

1) Conventional 2 x 10 joists on 16 in. centers.
2) Wood I-beams on 24 in. centers.
3) Open-web trusses with wood members and gusset plates on 24 in. centers.
4) Open-web trusses with a stamped out steel webs on 24 in. centers.
5) Open-webbed trusses with a wooden top and bottom chord and pipe web members on 24 in. centers.

All decks were identical in size, manner of loading and ignition source. The decks were built 8 x 9 ft., and were set up on 8 in. concrete blocks, three layers high. Block foundations enclosed each system on three sides. Each deck was placed on a 2 x 6 sill plate mounted on top of the blocks. The 2 x 10 system used a 2 x 10 box sill. The open-webbed truss systems were enclosed on the outside perimeter of the deck by 3/4 in. plywood to enclose the box sill. All deck systems were sheathed with 3/4 in. tongue-and-groove waferboard that was nailed down with 8 penny, coated nails. A live load of 31 psf, consisting of concrete blocks, was distributed across each deck. The fuel for the fire was contained in cut-off 55 gal. barrels approximately 12 in. high. The ignition fuel source was 4 gal. of diesel fuel, 1 gal. of gasoline, and 5 gal. of water.

Report Observations: The 2 x 10 platform began to sag at 8 min., and burned through the sheathing at 9 min. No further significant damage occurred, and the fire was extinguished at 13 min. The 2 x 10 system continued to carry its load after the 13 min. burn. The system gave ample warning that a structural problem was developing: it sagged, but the system did not fail entirely.

At 4 min., 40 sec., the wooden I-beam platform failed completely. There was no sagging or warning noises to indicate a structural problem. The system carried the load until failure. The failure of the wood I-beam system to sag prevents firefighters from determining if the building is in structural trouble.

The metal plate connected wood truss system began sagging at approximately 8 min., and burned through the sheathing at 9 min. The sagging of the floor was very evident, but the system continued to carry the load until the fire was extinguished at 15 min., 45 sec. By sagging, this system gave a definite indication of structural problems.

The metal web wood truss began sagging at 6 min. Most notable was that the metal web failed to carry the load. As the web failed, the top and bottom chords came together. The fire was extinguished at 7 min., 30 sec., when the fire burned through the sheathing.

Burn through of the sheathing of the pin-end steel webbed wood trusses occurred at 6 min., 50 sec. At burn through there was no noticeable sag. At approximately 8 min., parts of the bottom chord were hanging down into the fire. At 9 min., 45 sec., the system failed without any warning or sagging.

A summary of these tests results is shown in Table 11.

Structural Member	Spacing	Assemb. Rating (min:sec)	Structural Failure (min:sec)	Loading (psf)
2 x 10	16 in. o.c.	9:00[1]	> 13:00	31.0
I-joist	24 in. o.c.	4:40[1]	4:40	31.0
MPCT[2]	24 in. o.c.	9:00[1]	15:45	31.0
MPSWT[2]	24 in. o.c.	7:30[1]	N/A	31.0
TJL	24 in. o.c.	6:50[1]	9:45	31.0

[1] Assembly rating is due to deck burn through.

[2] MPCT = Metal Plate Connected Truss; MPSWT = Metal Plate Steel Web Truss; TJL = Trus Joist L-Series Truss; TPSB = Truss Plate Spliced Beam; F_b = fiber bending stress.

Table 11. Non-Standardized Test Results.

Report Summary: These test results tend to show that some of the truss systems have inherent strength. They also show that open web trusses allow for rapid lateral spread of the fire, and that some systems give no warning prior to collapse. The following thoughts can be drawn from this testing:

- Pre-plan all new construction and any remodeling using lightweight components.
- Modify fire department tactics to open up concealed spaces very quickly.
- Push for modification for building codes to control the amount of square footage that can be built with these lightweight components, without firestops.
- Maintain records of all buildings using lightweight components.
- Be aware of the time factor—always ask, "How long has the fire been burning?"
- Remember—some floor systems give no warning prior to collapse.

The times stated in this article from ignition to collapse are those found in these test fires. They should not be taken as a guarantee that various floor systems will last as long in every fire. The time should serve only as information when making decisions about fire suppression operations.

> **Comments:** MAKING VALID COMPARISONS BETWEEN THESE TESTS IS VERY DIFFICULT. THESE ARE MORE STANDARDIZED THAN THE TESTS DESCRIBED ABOVE IN THAT ALL SPANS ARE EQUIVALENT AND THE LOAD IS CONSISTENT. THE KEY TO MAKING A VALID COMPARISON, HOWEVER, IS IN HAVING AN EQUIVALENT STRESS BASIS, WHICH IS NOT THE CASE HERE. WHEN COMPARING THESE TESTS TO THE **Section 4-1.1** TESTS, IT IS CLEAR THE SPAN INFLUENCED THE TIME TO FAILURE. AS WITH THE **Section 4-1.1** TESTS, MORE DETAIL IS NEEDED IN THE TEST REPORT ON THE SPECIFICS OF THE STRUCTURAL MEMBERS USED IN THIS TESTING. WITHOUT THIS DETAIL, DEEPER ANALYSIS OF THESE TESTS IS NOT POSSIBLE. IT IS INTERESTING TO NOTE THAT THE METAL PLATE CONNECTED TRUSS PERFORMANCE IS EQUIVALENT TO THE SOLID-SAWN JOIST PERFORMANCE IN THESE TESTS. ALSO, THE PERFORMANCE TIMES INCREASED WHEN COMPARED TO THE **Section 4-1.1** TESTS. THIS POINTS OUT THE IMPORTANCE OF MAKING COMPARISONS BETWEEN TESTS THAT HAVE STANDARDIZED TEST PROCEDURE. WITHOUT THIS, VALID COMPARISONS CAN NOT BE MADE.

4-1.3 **Report:** Comparative Fire Endurance Tests of Unprotected Engineered Wood Component Assemblies.

Authors: Proprietary

Sponsor: Proprietary

Date: April, 1988

Basic Test Description: The members tested were: 9.5 in.) TJI 25 series joists (a Truss Joist Corporation product, 10 in. metal plate connected trusses, 10.75 in. space joist- or metal web-trusses, and 2 x 10 dimensional lumber. The members were tested as unsheathed, with single units subjected to a 500 lb. load at center span for the test duration. Modifications were made to the various members so that the critical components were stressed to approximately 30% of the allowable design load under the given load and span conditions. In addition, holes were cut in the I-joist web conforming to building code approval. Holes and notches were removed from the solid-sawn joists in conformance with model building codes. Each test specimen was 8 ft., 1 in. long.

Test Methods Used: The fire tests were performed using ASTM E119-83 as a guide. The I-joists were stressed to approximately 30% of their allowable moment- and shear capacity. The solid-sawn joists were stressed to approximately 40% of their allowable moment capacity, and 30% of their allowable shear capacity. The truss plates were sized to achieve a truss design that would be stressed to approximately 30% of the allowable load capacity for both the metal plate connected- and space-joist trusses. Each member type was modified in order to approach a worst-case scenario under test conditions. A hole representing 40% of the allowable hole size was removed from the web at center span of each I-joist. In addition, all pre-cut knock-out holes were removed. Notches and holes were cut into the solid-sawn joists in accordance with building code criteria. The maximum allowable holes and notches were used. The trusses were designed with compression- and tension chord splices located at one of the quarter points of the chase opening. Maximum chase openings were used in both trusses.

Report Observations: The two wood I-joist specimens were tested first, and the time/temperature readings were used as a guide for the remaining specimen tests in an effort to produce repeatable results. Ignition of each specimen was targeted for between 2 and 3 min. after furnace ignition. Similar temperatures at corresponding thermocouple and time periods indicated the furnace conditions were fairly consistent for each test. Deflection and time to failure was measured for each test.

Report Summary: The test data indicate that wood I-joists, metal plate connected trusses, and space-joist trusses exhibit similar performance characteristics. The deflection for each was small, until the member temperature reached 1000° F. Deflection increased dramatically after that point. The deflection was slightly greater for the wood I-joist than for the two types of trusses tested. This would suggest that trusses undergo a more gradual relaxation in load carrying capability as they burn, when compared to I-joists. Failure typically began near the 3 min. mark, and was completed by 5 min. in these members.

Six minutes after furnace ignition, the solid-sawn joists exhibited less than 10% of the mid-span deflection observed with other member types. After ten minutes, the joists had deflected only one inch. The joists did not begin to deflect appreciably until the member temperature reached 1000° F. Once this temperature was attained, mid-span deflection increased at an ever-increasing rate. Exactly when failure would have occurred for the solid-sawn joist is unknown.

Based on the results of this study, the following conclusions can be made:

- The wood I-joists, metal plate-connected trusses, and metal web trusses appear to have similar fire endurance capabilities. The fire endurance performance of these products were dependent on their critical components, which are the web for the I-joists and the tension splice for the trusses.
- The 2 x 10 solid-sawn joist performed better than the engineered wood components in these tests.

The results and conclusions of this study must be maintained in the proper context. Due to the limitations of the test facility, it was difficult to control as many of the variables as would have been preferred in order to accurately assess comparative fire endurance performance. Given proper control of these variables, it is felt that more accurate comparisons between member types can be made.

Comments: THIS IS THE FIRST SERIES OF TESTS THAT HAVE ATTEMPTED TO PERFORM COMPARISONS ON A STANDARDIZED, EQUAL-STRESS BASIS. THESE hole representing 40% of the allowable hole size was removed from the web at center span of each I-joist. In addition, all pre-cut knock-out holes were removed. Notches and holes were cut into the solid-sawn joists in accordance with building code criteria. The maximum allowable holes and notches were used. The trusses were designed with compression- and tension chord splices located at one of the quarter points of the chase opening. Maximum chase openings were used in both trusses.

Report Observations: The two wood I-joist specimens were tested first, and the time/temperature readings were used as a guide for the remaining specimen tests in an effort to produce repeatable results. Ignition of each specimen was targeted for between 2 and 3 min. after furnace ignition. Similar temperatures at corresponding thermocouple and time periods indicated the furnace conditions were fairly consistent for each test. Deflection and time to failure was measured for each test.

Report Summary: The test data indicate that wood I-joists, metal plate connected trusses, and space-joist trusses exhibit similar performance characteristics. The deflection for each was small, until the member temperature reached 1000° F. Deflection increased dramatically after that point. The deflection was slightly greater for the wood I-joist than for the two types of trusses tested. This would suggest that trusses undergo a more gradual relaxation in load carrying capability as they burn, when compared to I-joists. Failure typically began near the 3 min. mark, and was completed by 5 min. in these members.

Six minutes after furnace ignition, the solid-sawn joists exhibited less than 10% of the mid-span deflection observed with other member types. After ten minutes, the joists had deflected only one inch. The joists did not begin to deflect appreciably until the member temperature reached 1000° F. Once this temperature was attained, mid-span deflection increased at an ever-increasing rate. Exactly when failure would have occurred for the solid-sawn joist is unknown.

Based on the results of this study, the following conclusions can be made:

- The wood I-joists, metal plate-connected trusses, and metal web trusses appear to have similar fire endurance capabilities. The fire endurance performance of these products were dependent on their critical components, which are the web for the I-joists and the tension splice for the trusses.
- The 2 x 10 solid-sawn joist performed better than the engineered wood components in these tests.

The results and conclusions of this study must be maintained in the proper context. Due to the limitations of the test facility, it was difficult to control as many of the variables as would have been preferred in order to accurately assess comparative fire endurance performance. Given proper control of these variables, it is felt that more accurate comparisons between member types can be made.

Comments: THIS IS THE FIRST SERIES OF TESTS THAT HAVE ATTEMPTED TO PERFORM COMPARISONS ON A STANDARDIZED, EQUAL-STRESS BASIS. THESE

WERE PERFORMED ON SHORT-SPAN, SINGLE ELEMENTS AND NOT ON AN ASSEMBLY. THE SMALL-SCALE NATURE OF THE TEST FACILITY MADE IT DIFFICULT TO ACHIEVE EQUIVALENT LOADS ON CRITICAL MEMBERS. IN THIS CASE, DUE TO THE SHORT SPAN, SHEAR STRESSES PREDOMINATED. IDEALLY IN THIS TESTING, BENDING MOMENTS OR EXTREME FIBER TENSION STRESSES CAUSING FAILURE OF THE ELEMENT WOULD BE PREFERRED. NEVERTHELESS, THIS TESTING SHOWED THAT SOLID-SAWN JOISTS PERFORM BETTER THAN THE LIGHTWEIGHT COMPONENTS TESTED. THESE TESTS PROVIDE ONLY A VERY ROUGH VIEW OF RELATIVE PERFORMANCE DUE TO THE FACT THAT MANY VARIABLES COULD NOT BE CONTROLLED IN THE SMALL-SCALE TEST FURNACE.

4-1.4 **Report:** ASTM E119-73: Fire Endurance Test on a Floor Assembly (Design FC-209) Consisting of 2 x 10 Wood Joists with a 23/32 in. Plywood Deck and Vinyl Tile Flooring.

Authors: Factory Mutual Research

Sponsor: National Forest Products Association

Date: June 20, 1974

Basic Test Description: The construction contained nominal 2 x 10 wood joists spaced 24 in. on center. The floor consisted of a single layer of 23/32 in. thick plywood underlayment, with a vinyl-asbestos tile flooring. No ceiling membrane was installed. The joists were nominal 2 x 10 Southern Pine #2, S-Dry 1250 fiber bending. The joists—each 13 ft., 6.75 in. long—were fastened to a 2 x 10 header on a 2 x 6 wood plate.

Test Method Used: The test was conducted in accordance with the standard fire test of building construction materials, ASTM E119-73. Before the assembly was subjected to fire exposure, a superimposed live load of 57.4 psf was applied to the floor. The total live and dead load of 62.1 psf was based on the repetitive member fiber stress of 1450 psi in bending and a joist depth of 9.25 in. The clear spans of the joists were 12 ft., 10.75 in. The exposed underside of the floor assembly was subjected to the fire exposure. The temperature in the furnace followed the standard time/temperature curve as measured by 16 thermocouples placed 12 in. below the lower edge of the joist.

Report Observations: Deflection measurements, structural failure of the system, and a number of other visual observations were recorded during the tests.

Report Summary: The floor assembly withstood fire exposure for 13 min., 34 sec. before structural failure occurred. Analysis of the unexposed surface temperature chart indicates that the average temperature at 13 min. of fire exposure was 150° F, while the allowable average temperature was 320° F. The average deflection at failure was 2.83 in.

> **Comments:** THIS TEST IS ONE OF THE FIRST UNSHEATHED TESTS WHERE THE JOISTS ARE STRESSED TO THEIR MAXIMUM ALLOWABLE DESIGN LOAD CAPACITIES. THEREFORE, THIS ASSEMBLY CAN BE COMPARED TO OTHER UNSHEATHED ASSEMBLIES THAT FOLLOW THE ASTM E119 PROCEDURES IN TOTAL.

4-1.5 Report: ASTM E119 Fire Endurance Test of a Floor Assembly (Design FC-212) Consisting of 2 x 10 Wood Joists with a 23/32 in. Plywood Deck and Nylon Carpet Flooring.

Authors: Factory Mutual Research

Sponsor: National Forest Products Association

Date: July 17, 1974

Basic Test Description: The construction contained nominal 2 x 10 wood joists grade marked Southern Pine Inspection Bureau #2 kiln-dried, 1250 fiber bending stress. The joists were cut to a length of 13 ft., 6.5 in., secured to a 2 x 10 wood header, and fastened to a 2 x 6 wood bearing plate. The joists were spaced 24 in. on center. The floor consisted of a single layer of 23/32 in. thick plywood underlayment with a nylon carpet flooring. No ceiling membrane was installed.

Prior to the assembly being subjected to fire exposure, a superimposed live load of 57.3 psf was applied and maintained throughout the test. The combined live and dead load of 62.4 psf was based on a clear span of 12 ft., 10.5 in. The loading was calculated to stress the joist to a maximum repetitive member design stress of 1450 psi in bending. The underside of the assembly was subjected to fire exposure. The temperature in the furnace followed the standard time/temperature curve as measured by 16 thermocouples which were placed 12 in. below the joists.

Report Observations: Deflection measurements, time to failure, and other visual observations of the tests assembly were recorded for this test.

Report Summary: The floor assembly withstood fire exposure for 12 min., 6 sec. before structural failure occurred. Analysis of unexposed surface temperatures indicate that the maximum individual temperature recorded during the test was 103° F, while the allowable individual limiting temperature was 398° F. The average deflection at failure was 3.58 in.

> **Comments:** WHEN COMPARED WITH THE TESTS IN **Section 4-1.4**, THIS TEST IDENTIFIED THE EFFECT OF FLOOR COVERINGS, CARPET AND VINYL ON FIRE PERFORMANCE. THIS ASPECT APPEARS TO HAVE LITTLE BEARING ON TEST RESULTS. THE TEST PERFORMANCE RANGE FOR THE SIMILAR UNSHEATHED

2 X 10 JOIST TESTS IS 12 TO 14 MINUTES. ADDITIONAL TESTING COULD TO BE DONE TO DETERMINE HOW WIDE THIS RANGE ACTUALLY IS.

4-1.6 Report: Fire Endurance Test of Unprotected Wood Floor Constructions For Single-Family Residences, NBS 421346.

Author: B.C. Son

Sponsor: United States Department of Housing and Urban Development

Date: May 10, 1971

Basic Test Description: Part of a series of fire tests. In two tests, numbers 2 and 4, the 2 x 10 joists were Douglas fir, which was assumed to have a stress level of 1050 psi in bending. The joists were spaced 16 in. on center, with a span of 13.5 ft. A load of 63.7 psf was calculated to produce an extreme fiber bending stress of 1050 psi in the joists, and was applied to the floor through four hydraulic jacks. One half of the specimen consisted of two layers of 1/2 in. plywood with no covering, while the other half consisted of two layers of 1/2 in. plywood with nylon 501 carpet over a hair pad underlayment.

Tests 9 and 10 consisted of 2 x 8 Douglas fir joists spaced 16 in. on center. The applied live load was reduced to 20 psf, which resulted in a 21 psf total load. This represented approximately 40% of the working stress of the joists. Two flooring systems were also applied to this test. One consisted of a layer of 1/2 in. thick plywood with a square-edged joint. The plywood was placed leaving a 1/16 in. joint spacing. The joint was protected by nominal 2 x 3 in. blocking. The other area consisted of a 5/8 in. thick tongue-and-groove plywood on all four edges.

Test Methods Used: The load was applied 8 min. before the test started, and was distributed to approximate a uniform load. The average temperature inside the furnace was measured by 12 protected thermocouples, and followed the ASTM E119-69 time/temperature curve by automatic control of the gas flow to the burners.

Report Observations: Smoke development measurements, deflection measurements, time to failure, and other visual observations were recorded. In the 2 x 10 test, load failure occurred at 11 min., 38 sec. On the plywood side only, the flamethrough time was 13 min., 30 sec., and the unexposed side temperature failure time was greater than 15 min. On the side with the double-layer plywood and carpet, neither the flamethrough time, nor the unexposed side temperature failure time was reached. The deflection at failure was 2.7 in. for the side without carpet, and 3.3 in. for the side with carpet.

The 2 x 8 test structurally failed at 13 min. The 5/8 in. tongue-and-groove plywood had flamethrough at 11 min., 50 sec., and unexposed side temperature failure at 10 min. The 1/2 in. spaced plywood with 2 x 3 in. end blocking had flamethrough at 11 min., and unexposed side temperature failure at 9 min. The deflection of the 1/2 in. plywood side was 7 in., and the 5/8 in. plywood side was 12 in., at failure.

Report Summary: Bare wood floor constructions conforming to FHA minimum property standards are able to marginally meet a fire endurance time requirement of 10 min. The addition of a separate finish floor should increase the fire endurance time, depending on its additional thermal resistance. This is estimated to be approximately 30 sec. for 1/8 in. vinyl asbestos tile to approximately 10 min. for carpeting over a hair pad.

> **Comments:** THIS APPEARS TO BE THE FIRST TEST DONE ON UNSHEATHED ASSEMBLIES TO DETERMINE WHETHER A TYPICAL FLOOR SYSTEM (OF THAT TIME) COULD MEET THE HUD 10-MINUTE EXPOSED FLOOR FIRE ENDURANCE REQUIREMENTS. THE JOISTS SELECTED WERE DOUGLAS FIR, WHICH WERE ASSUMED TO HAVE A STRESS LEVEL OF 1050 LB./IN^2. A MAXIMUM DESIGN LOAD WAS APPLIED TO THE ASSEMBLY BASED ON THIS ASSUMPTION. THERE IS THE POSSIBILITY THAT THE JOISTS USED WERE NOT AT THEIR FULL DESIGN ALLOWABLE FIBER BENDING STRESS. THESE TESTS ADD TO THE KNOWLEDGE OF THE PERFORMANCE OF 2 X 10 JOISTS AND THE IMPORTANCE OF SHEATHING TO PROTECT AGAINST FLAMETHROUGH. THE FAILURE OF 11 MIN., 38 SEC. INCREASES THE DATA NEEDED TO DEFINE THE PERFORMANCE RANGE OF 2 x 10's.

4-1.7 **Report:** Replicate Fire Endurance Tests on Unprotected Wood Joist Floor Assembly

Authors: R.H. White, E.L. Schaffer, and F.E. Woeste

Sponsor: Forest Products Laboratory

Date: March, 1983

Basic Test Description: Nominal 2 x 10 Douglas fir dimension lumber, 14 ft. long, was used in the tests. The testing consisted of eleven 14 x 18 ft. unsheathed joist floors. Five floors supported a maximum floor load of 79.2 psf (100% of maximum design load based on fiber bending stress, per the test report). Six other floors supported a 11.35 psf (14.3% of maximum design load based on fiber bending stress, per the test report) live load floor that is more typical of the actual loading encountered in residences. Plywood, 23/32 in. thick, was used as sheathing. Fourteen joists attached to headers were used to construct the 14 x 18 ft. frame. The joists spanned 13 ft., 10.5 in., and were spaced 16 in. on center.

Test Methods Used: The standard ASTM E119 time/temperature curve was followed for each floor. Gas burners within the furnace provided the standard fire exposure to the test specimen.

Report Observations: Thermocouples recording the temperature within the furnace and on the test specimens, the atmospheric pressure within the furnace, deflection of the floor, and other visual observations were recorded.

Report Summary: For the six floors loaded to 11.35 psf, the mean time for initial joist failure was 17 min., 54 sec., with a coefficient of variation of 3.7%. The mean time to second joist failure was 18 min., 6 sec., and the mean time to third joist failure was 18 min., 24 sec. For the five floors loaded to 79.2 psf, the mean time for initial joist failure was 6 min., 30 sec. with a coefficient of variation of 11.6%. The mean time for second joist failure occurred at 6 min., 42 sec. and third joist failure occurred at 7 min., 6 sec.

The average deflection of joists loaded to 79.2 psf was roughly 4.05 in. at failure. The average deflection of joists loaded to 11.35 psf was roughly 1.7 in. at failure.

> **Comments:** IT IS OBVIOUS FROM THIS TESTING THAT THE DEFLECTION OF AN ASSEMBLY AT FAILURE IS DEPENDENT ON THE LOADING ON THE FLOOR—THE GREATER THE LOADING, THE MORE LIKELY DEFLECTION WILL BE OBSERVABLE UNDER FIRE ENDURANCE PERFORMANCE CONDITIONS. IN THIS TESTING, LOADING THE FLOORS TO THE MAXIMUM ALLOWABLE DESIGN LOAD OF 79.2 PSF RESULTED IN AN INITIAL JOIST FAILURE AT 6 MIN., 30 SEC. THREE JOISTS FAILED WITHIN 7 MIN. THIS SHOWS THE LOAD SHARING EFFECTS OF FLOOR SYSTEMS THAT HAVE MEMBER SPACING LESS THAN 24 IN. ON CENTER. IF IT IS ASSUMED THAT FAILURE TIME FOR THE ASSEMBLY IS THE TIME FOR THE FIRST JOIST TO FAIL, THEN AT THE MAXIMUM LOAD OF 79.2 PSF, THE AVERAGE (MEAN) FAILURE TIME WAS 6 MIN., 30 SEC. HOWEVER, THIS WOULD BE MISLEADING BECAUSE OF THE REDUNDANCY PROVIDED BY THE SYSTEM. AS A RESULT, THE ENTIRE ASSEMBLY WILL FAIL SOMEWHAT LATER THAN THE 6 MIN., 30 SEC. AT A LITTLE OVER 7 MIN., HOWEVER, THREE JOISTS HAD FAILED. UNDER THE LIGHTER LOAD OF 11.35 PSF, WHICH IS SIMILAR TO THE AVERAGE LIVE LOAD FOUND IN DOMESTIC DWELLINGS FROM THREE SURVEYS[1], THE JOIST FAILURE TIME INCREASED TO APPROXIMATELY 18 MIN. IT IS ALSO INTERESTING TO NOTE THAT THE DEFLECTION DECREASED DRAMATICALLY FOR JOISTS TESTED UNDER THE 11.35 PSF LIVE LOAD, WHEN COMPARED TO FULL LOAD. THIS STUDY ALSO MADE AN ESTIMATE OF THE TIME TO FAILURE FOR A JOIST SYSTEM UNDER A 40 PSF LOAD. THIS TIME TO FAILURE WAS INTERPOLATED TO BE APPROXIMATELY 13 MIN. THESE DATA CLEARLY SHOW THE EFFECT LOAD HAS ON FIRE ENDURANCE AND THE TIME IT TAKES FOR VISIBLE DEFORMATION OF THE ASSEMBLY TO OCCUR DURING A FIRE. WE ALSO LEARN THAT THE RANGE OF 2 X 10 PERFORMANCE EXPANDS TO 6 TO 7 MIN. UNDER MAXIMUM ALLOWABLE DESIGN LOADS.
>
> THERE IS A QUESTION WITH RESPECT TO THE APPLICATION OF THE DESIGN LOAD AND THE ADEQUACY OF THE TEST APPARATUS THAT WAS USED FOR THIS TEST.

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[1] Carmen, 1969; Corotis and Doshi, 1977; and Issen, 1980

THE 79.2 PSF APPLIED LOAD MAY ACTUALLY BE IN EXCESS OF THE MAXIMUM ALLOWABLE DESIGN LOAD, DUE TO THESE FACTORS. GIVEN THIS, THE 2 X 10 FIRE PERFORMANCE RANGE WOULD NOT EXPAND DOWN TO THE 6 TO 7 MINUTE RANGE, BUT WOULD BE HIGHER THAN THIS. THIS DATA SHOULD NOT BE VIEWED AS RELIABLE, BUT RATHER FOR GENERAL INFORMATION PURPOSES ONLY. THE LOWER RANGE OF THE FIRE ENDURANCE PERFORMANCE OF 2 X 10S CANNOT BE PREDICTED USING THIS DATA.

4-1.8 **Report:** A Floor-Ceiling Assembly Consisting of Wood Trusses with a Plywood Floor. (Design FC-250)

Author: Factory Mutual Research

Sponsor: Truss Plate Institute

Date: May 10, 1977

Basic Test Description: The floor assembly consisted of 12 in. deep floor trusses, made with nominal 2 x 4 wood chords and webs, spaced 24 in. on center. The floor was sheathed with a single layer of 3/4 in. thick plywood. The trusses were exposed from below. The assembly was subjected to a uniformly distributed live load of 55.1 psf, which resulted in a combined live and dead load of 60 psf.

Test Methods Used: The test was conducted in accordance with ASTM E119-76. The temperature of the furnace chamber was measured using sixteen thermocouples 12 in. below the level of the lower chords.

Report Observations: The furnace and surface temperatures, deflections, and other visual observations were recorded during the testing.

Report Summary: The furnace temperatures in this test exceeded the standard time/temperature curve from 5 min. into the test until failure. (No attempt was made to correct the test results due to excessive furnace temperatures, as is allowed by E119 test procedures.) The floor allowed flames to penetrate the unexposed surface at a plywood end joint at 7 min., 30 sec. At 10 min., 12 sec., one of the chains used to move the loading tanks was tight due to the deflection of the floor, resulting in the floor no longer being able to support the applied load. The test was terminated at 14 min., 36 sec. The average deflection at 12 min. was 11.5 in.

Comments: IT IS OBVIOUS FROM THIS REPORT THAT THERE WAS A SUBSTANTIAL AMOUNT OF DEFLECTION IN THIS TRUSS TEST AT FAILURE. THIS WOULD IMPLY THAT TRUSS CONSTRUCTION CAN PROVIDE A WARNING OF IMMINENT COLLAPSE DUE TO THIS DEFORMATION—PARTICULARLY WHEN ONE COMPARES THIS TO THE DEFLECTION PERFORMANCE OF 2 X 10 JOISTS IN **Sections 4-1.4** AND **4-1.5**, WHERE DEFLECTION WAS 3.58 AND 2.83 IN., RESPECTIVELY. IN THIS CASE, THE TRUSSES WERE LOADED TO THEIR FULL

DESIGN LOAD, AND PERFORMED STRUCTURALLY FOR APPROXIMATELY 10 MIN. THIS IS VERY SIMILAR TO THE 2 X 10 JOIST PERFORMANCE REPORTED PREVIOUSLY. THE ASSEMBLY RATING WAS 7 MIN., 30 SEC. IN THIS TEST DUE TO FLAMETHROUGH AT A PLYWOOD JOINT. THIS COULD BE ELIMINATED BY USING A DOUBLE WOOD FLOOR OR BY ATTACHING A TYPICAL SHEATHING COVERING, SUCH AS CARPETING, TO THE TEST ASSEMBLY.

NOTE, HOWEVER, THAT THESE TRUSSES WERE MANUFACTURED WITHOUT A SPLICE PLATE IN THE BOTTOM CHORD, WHICH WOULD INFLUENCE THE FIRE ENDURANCE PERFORMANCE OF THE TRUSS. MANY FLOOR TRUSSES (TYPICALLY THOSE LESS THAN 20 FT. LONG) ARE MANUFACTURED WITHOUT SPLICE PLATES IN THE BOTTOM CHORD AND THEREFORE COULD BE EXPECTED TO PROVIDE FIRE ENDURANCE SIMILAR TO THAT OF JOIST CONSTRUCTION.

4-1.9 Report: Floor Assembly Consisting of 7.25 in. Deep Steel Joists with 23/32 in Plywood Deck and Vinyl Tile Flooring. (Design FC-208)

Authors: Factory Mutual Research

Sponsor: National Forest Products Association

Date: June 19, 1974

Basic Test Description: Part of a series of tests. This test construction consisted of 7.25 in. deep channel-shaped steel joists made of 16 gauge steel spaced 24 in. on center. The joists were 13 ft., 6.5 in. long, and secured to a nominal 2 x 8 wood header. A single layer of 23/32 in. thick underlayment grade plywood was used as sheathing, and a 1/16 in. thick vinyl tile floor covering was applied. A live load of 65.7 psf was applied to the floor. A total live and dead load of 69.8 psf resulted in a maximum joist bending moment of 34,900 in.-lb. on a clear span of 12 ft., 11 in.

Test Method Used: The tests followed the ASTM E119 standard time/temperature curve as measured by 16 thermocouples, placed 12 in. below the lower flange of the joists.

Report Observations: Temperature of the furnace, temperatures of the unexposed surface of the floor, deflection, and visual observations were recorded for this test.

Report Summary: The floor assembly withstood the fire exposure for 7 min., 24 sec. before flames penetrated the unexposed surface. At 7 min. 30 sec., the floor failed to support the superimposed load. The average deflection at 7 min. was 7 in.

Comments: THIS TESTING PROVIDES DATA FOR COMPARING THE 2 X 10, 12 IN. METAL PLATE CONNECTED TRUSS, AND STEEL CHANNEL-SHAPED JOISTS UNDER ASTM E119 TEST CONDITIONS (SEE FURTHER TESTS BELOW). IN EACH CASE, A SUPERIMPOSED LOAD WAS APPLIED THAT RESULTED IN MAXIMUM

BENDING STRESS ON THE STRUCTURAL MEMBERS. THEREFORE, RELATIVE PERFORMANCE COMPARISONS CAN BE MADE BETWEEN THESE SPECIFIC ASSEMBLIES. NOTE, HOWEVER, THAT THESE REFERENCED TESTS WERE DONE BY DIFFERENT SPONSORS AT DIFFERENT TIMES FOR DIFFERENT REASONS, SO ABSOLUTE COMPARISON MAY NOT BE POSSIBLE.

4-1.10 **Report:** ASTM E119 Test of a Floor Assembly Consisting of 7.25 in. Deep Steel Joists With 23/32 in. Plywood Deck and Nylon Carpet Flooring (Design FC-211)

Author: Factory Mutual Research

Sponsor: National Forest Products Association

Date: July 16, 1974

Basic Test Description: The assembly consisted of 7.25 in. deep, 16 gauge channel-shaped steel joists, spaced 24 in. on center. These joists were 13 ft., 6.5 in. long and secured to a nominal 2 x 8 wood perimeter joists. A single layer of 23/32 in. thick underlayment was used as a flooring. The plywood deck was covered with sponge rubber waffle pad and a nylon carpet. A superimposed live load of 65.4 psf was applied to the 12 ft., 11 in. clear span joists. The combined live and dead load was 69.8 psf. This resulted in the channel-shaped steel joists being stressed to their maximum design stress of 34,900 in-lb. in bending.

Test Method Used: The assembly was subjected to the conditions of ASTM E119-73.

Report Observations: Furnace temperature, temperature on the unexposed surface, deflection, time to failure, and visual observations were recorded for this test.

Report Summary: At 5 min., 12 sec., the floor assembly failed to support the superimposed load, and the test was terminated. The average deflection of the assembly was 10 in.

Comments: THE ONLY CHANGE TO THIS ASSEMBLY FROM **Section 4-1.9** WAS THE USE OF A PAD AND CARPET COVERING. THE COMMENTS STATED ABOVE APPLY HERE AS WELL. THE RANGE OF STEEL JOIST PERFORMANCE IN THESE TESTS IS 5 TO 7 MIN. ADDITIONAL TESTING IS NEEDED TO FURTHER DEFINE THE FULL BREADTH OF STEEL PERFORMANCE.

4-1.11 **Report:** Comparative Fire Tests in Wood and Steel Joists

Author: Southwest Research Institute, San Antonio, Texas

Sponsor: National Forest Products Association

Date: 1961

Basic Test Description: The criteria used to develop this test procedure were as follows:

- The test structure should be sufficiently large so that the wood and steel members to be evaluated could be of a size and span representing full-scale roof framing.
- The test enclosure should be such that both roof framing systems could be exposed simultaneously to equivalent fire conditions, and arranged so that each system could react independently.
- A roof load calculated to develop the design capacity of each wood and steel member should be applied.
- The fire exposure should follow the temperatures set forth in the standard ASTM E119 time/temperature curve.

The clear span for both joist systems was 28 ft., and the spacing was 3 ft., 7 in. on center. Clearance beneath the joists was 9 ft., 5 in. The left panel was supported by two 4 x 14 in. solid-sawn wood joists which were designed in accordance with the National Design Specification® for stress grade lumber. The right panel was supported by two 14 in. open web (14S4) steel joists, which were designed in accordance with the manufacturer's recommendations. The roof was designed for a total load of 30 psf. Heat was supplied by six equally spaced, industrial-type gas burners, which were positioned on each side of the structure and directed through ports in the walls.

Test Methods Used: During the test, the flow of gas was regulated to provide uniform test chamber temperatures in accordance with ASTM E119.

Report Observations: Furnace temperature and deflection measurements were recorded during the tests.

Report Summary: The wood and steel joists deflected at the following rates:

Time (min.)	Temperature (°F)	Steel Joist Defl. (in.)	Wood Joist Defl. (in.)
4	900°	1	approx. .16
7	1120°	approx. 3	approx. .33
12	1300°	18*	.5

*This was the limit of the measuring device

Table 12. Wood and Steel Joist Deflection Rates.

At 13 min., the gas was cut off, and the deformation continued to increase until the panel with the steel joists collapsed into the furnace.

The panel with the wood joists supported the full design load during the entire test, and the maximum deflection recorded was 1/2 in. After 13 min. of fire exposure, there remained 80% of the original wood section—undamaged and available to carry load.

The steel joists did not burn, but they failed to support the load under E119 conditions. The wood joists were charred, but continued to support the full design load without appreciable deformation.

> **Comments:** THESE TESTS SHOW THE DIFFERENCE IN PERFORMANCE OF UNPROTECTED STEEL AND UNPROTECTED WOOD. THE UNPROTECTED WOOD IS PROTECTED BY THE CHARRING PROCESS, WHEREAS EXPOSED STEEL RAPIDLY LOSES ITS YIELD STRENGTH AS TEMPERATURES EXCEED 1000° F. THIS IS A GOOD COMPARATIVE TEST, SINCE CONDITIONS BETWEEN STRUCTURAL MEMBERS WAS AS EQUIVALENT AS POSSIBLE, DUE TO THE SPECIALIZED NATURE OF THIS ASSEMBLY. IT IS DIFFICULT TO EXTEND MEANING TO THIS BEYOND THIS SPECIFIC COMPARISON.

4-1.12 **Report:** Comparative Fire Test of Timber and Steel Beams

Authors: Southwest Research Institute, San Antonio, Texas

Sponsor: National Forest Products Association

Date: Assumed to be 1961.

Basic Test Description: Two beams were evaluated in the same furnace. The left panel was supported by a 16 in. rolled steel beam (designated 16 WF 40), designed for the applied roof load in accordance with American Institute of Steel Construction. The right panel was supported by a 7 x 21 in. glue-laminated timber beam designed in accordance with the National Design Specification® for stress-grade lumber, and the design standards of the American Institute of Timber Construction. Both beams had a clear span of 43 ft., 3 in., and were supplied with 2 in. of camber to offset initial deflection. The roof construction consisted of bulb-tee sections spaced at 32-5/8 in. on center, and attached to the top edges of the beams and exterior walls. gypsum form board, 1/2 in. wide, was placed on the bulb-tees to receive the lightweight concrete deck, which was poured to a depth of 2.5 in. The two sections of the roof deck were entirely separated by a longitudinal joint 2 in. wide, which was covered by a flexible insulating blanket. This allowed each panel to move independently for a vertical distance of 36 in. without loss of heat in the structure. The total design load on the roof consisted of an applied live load equivalent to 30 psf on the roof surface, plus the dead load weight of the deck construction and the test beams. This resulted in a total load of 12,346 lb. for the wood beam, and 12,432 lb. for the steel beam. The difference in total load is due to the lesser weight of the wood beam. The 7 x 21 in. wood beam was selected because it met the requirements of the design. The induced stress was 1552 psi, and the calculated deflection was 2.32 in., or L/224. The 16WF40 steel beam was selected because it met the requirements of the design and is a stock item. The calculated deflection was 1.51 in., or L/344. The induced stress was 12,524 psi.

Test Methods Used: The furnace supplied heat by gas burners that were controlled to conform to the ASTM E119 time/temperature curve.

Report Observations: Temperatures and deflection were measured inside the furnace.

Report Summary: The wood and steel deflection data are summarized in the following table. Time listed is time after burners were lit.

Time (min.)	Temperature Near the Beam (°F)	Steel Beam Deflection (in.)	Wood Beam Deflection (in.)
6	894	2.0	approx. .25
14	1194	8.5	approx. 1.0
20	1279	11.75	approx. 1.5
29	1422	35.5	2.25

Table 13. Wood and Steel Deflection Data.

At 30 min. of exposure, the steel no longer supported the roof panel.

The wood beams supported the full design load throughout the test, with a maximum deflection of 2.25 in. at 30 min. After 30 min. of fire exposure, 75% of the original wood section remained undamaged and the beam continued to support the full design load.

> **Comments:** THIS TEST MAKES A DIRECT COMPARISON BETWEEN THE PERFORMANCE OF TWO STRUCTURAL MEMBERS. THE BEAMS WERE DESIGNED TO CARRY THE FULL DESIGN LOAD OF 30 PSF. THEREFORE, THIS TEST COMPARES EQUIVALENT STRESS PERFORMANCE BETWEEN THESE TWO STRUCTURAL MEMBERS. THIS TESTING INDICATES THAT ONCE STEEL REACHES APPROXIMATELY 1000° F, ITS ABILITY TO RESIST DEFLECTION DECREASES RAPIDLY. IT IS DIFFICULT TO EXTEND A CONCLUSION BEYOND THIS SPECIFIC COMPARISON, HOWEVER, DUE TO THE SPECIALIZED NATURE OF THIS TEST ASSEMBLY.

4-1.13 Report: Fire Performance of Selected Residential Floor Constructions Under Room Burnout Conditions, NBSIR 80-2134

Author: J.B. Fang

Sponsor: United States Department of Housing and Urban Development

Date: December, 1980

Basic Test Description: All the fire resistance tests were performed in a burn room having a 10.7 x 10.7 ft. floor with a 7.4 ft. ceiling height. A doorway opening measuring

30 in. wide and 80 in. tall was situated in the middle of one of the room walls to serve as the single source of room ventilation. The internal walls of the test room were lined with 5/32 in. thick prefinished and printed, three-ply lauan plywood panels. The wall framing consisted of nominal 1 x 3 furring strips spaced 16 in. on center and secured to concrete block walls. The plywood panels were applied with long edges parallel to the wood furring strips. The household furniture used for each test was that commonly found in a recreation room, and included a sofa, upholstered chair, ottoman, end table, bookcase, and coffee table. The fire load density used for this series of fire tests was 4.7 psf of floor area, which was average for recreation rooms in the basements of single-family homes in the Washington, D.C. metropolitan area. In addition to the furnishings, old record files were added in sufficient quantities to reach the required total fire load density. 10 lb. of paper was also placed atop the coffee table, 4 lb. each on the tops of the ottoman and the end table, and the rest—approximately 170 lb.—on the shelves of the bookcase. An Olefin carpet with foam rubber backing was placed on top of a protective layer of 5/8 in. thick Type X gypsum wallboard covering the concrete floor. The total fire load ranged from 7.3 to 7.8 psf, with an average of 7.6 psf of floor area.

For each test, a selected floor-ceiling assembly, 12 x 12 ft., was built over the top of concrete block walls in the burn room, carried uniformly distributed loads, and was subjected to these fire conditions. A portion of the assembly exposed to the room fire below was 10.5 x 10.5 ft. Seven floor-ceiling assemblies were tested. Tests 1 - 4 were unsheathed, and 5 - 7 were protected. The protected tests (5 - 7) are described in **Chapter 4-2: Fire Endurance Performance of Single Membrane Protected Assemblies.**

Test 1: Test 1 was conducted on 2 x 8 wood joists placed parallel to the wall containing the doorway opening, and spaced 16 in. on center. Each joist was kiln-dried, construction grade #2, Eastern Spruce. The joists were cut to 11.7 ft. in length, and secured to 2 x 8 wood rim joists. The rim joists were toe-nailed to nominal 2 x 8 sill plates resting on the concrete blocks. A single layer of 5/8 in. thick plywood subfloor was laid perpendicular to the joists. An olefin carpet with foam rubber backing was fixed to the plywood deck. The load applied was 40 psf, which represented 69% of the maximum allowable stress.

Test 2: Test 2 was conducted on C-shaped, galvanized steel joists, 7.25 in. deep, with a 1.75 in. flange, a 9/16 in. lip, and 18 gauge thickness. The joists were spaced 24 in. on center, beginning with one joist positioned along the centerline of the room width. Each joist was cut 11.7 ft. long and secured to a 2 x 8 wood rim joist. A galvanized steel strap was installed at mid-span, in accordance with the structural design for the steel joists. The rim joists were secured to a 2 x 8 wood sill plate. A 5/8 in. thick plywood floor was attached. An Olefin carpet with foam rubber backing was applied over the plywood. The load applied to this assembly was 72 psf, which represented 100% of the maximum allowable stress.

Test 3: Test 3 was a C-shaped galvanized steel joist, 7.25 in. deep, with a 1.75 in. flange, and an 18 gauge thickness. The joists were spaced 32 in. on center, and were fastened to a 2 x 8 rim joist. The rim joists were secured to a 2 x 8 sill plate. A single layer of 3/4 in. thick tongue-and-groove plywood was installed perpendicular to the joists. A piece of Olefin carpet with foam rubber backing was installed over the plywood deck. A load of 40 psf was applied to the joists, which represented 74% of the maximum allowable stress.

Test 4: Test 4 was constructed in a manner similar to that for Test 1, except that the wood joists were spaced 24 in. on center starting with a floor joist positioned along the horizontal centerline of the room width. A 23/32 in. thick underlayment grade plywood was placed on the joists. Southern Pine #2 bridging was installed along the mid span. The wood joists used were Southern Pine, Construction Grade #2--Medium Grain. A 40 psf load was applied to the joists, which represented 100% of the maximum allowable stress.

Test Methods Used: For each test, the assembly was loaded with 5-1/2 x 6 x 8 in. steel blocks, weighing 50 lbs., to the prescribed load. The uniform load was normally applied a few days prior to the fire test. The ignition source used for all experiments was a section of newspaper weighing 0.9 lb., and placed along the central backrest on seat cushions of the sofa supported by a steel frame holder to ensure reproducible ignition conditions between tests. The paper was conditioned to equilibrium in a room controlled at a dry bulb temperature of 23 ± 3°C, and a relative humidity of 50 ± 5% prior to the test. The fire test was started by remotely igniting the newspaper using an electric heating element and a book of paper matches.

Photographic and videotape records and visual observations were made of the progress of the room fires, including the burning characteristics of the assembly, flamethrough and collapse of the structural elements. The fire was allowed to burn until structural failure occurred in the test assembly.

The room air temperatures were monitored at eight locations, including seven within the test room and one in the doorway opening. A total of 25 thermocouples were arranged at various heights in vertical thermocouple trees at the seven locations inside the room.

The surface temperatures of the plywood paneling and the concrete block walls were determined at 16 locations attached to the exposed and unexposed surfaces at selected locations. One location was at the front wall, eight were distributed over the back wall in the vicinity of the ignition source, and three were situated at the left and right plywood paneling walls.

The temperatures on the exposed side of the test assembly were measured using nine thermocouples. Eight thermocouples were installed on both top and bottom flanges of each selected floor joist. One thermocouple was placed on the fire exposed face of the ceiling at the center of the room for test assemblies with a gypsum board ceiling. Finally, on the unexposed surface, three additional thermocouples beneath pads were used to measure temperatures at the points which appeared to be the hottest during the test.

Deflection measurements were made during the test at the mid point and quarter points of each joist. A total of six points for each test structure were measured.

Levels of static pressure which developed within the room were continuously measured. Two locations were used for these pressure measurements: one was 0.7 ft. from the front block wall at 0.2, 0.6, 1.3, 2.7, 3.7, and 5.1 ft. below the ceiling; the other was at the mid-width of the paneling wall at 0.2 ft. from the ceiling.

Total heat fluxes were measured at selected locations using five Gordon foil type, water-cooled heat flux gauges.

Horizontal velocities of the air entering and leaving the fire room through the doorway opening were monitored with six bi-directional flow probes in conjunction with variable reluctance, differential pressure transducers and carrier demodulators. The optical density of smoke was measured at various locations by determining the attenuation of a collimated light beam passing through effluent gas and impinging on a photodetector.

Combustion gas venting from the fire room was sampled at four locations for measuring concentrations of selected gas types.

A total of 136 sensors were automatically read and recorded at a rate of 8 sec. per scan during the entire duration of the test.

Report Summary:

Test 1: Flame penetration occurred near the joint between two sheets of plywood subfloor in the southwest corner, located above the right arm of the sofa, and was observed at 10 min., 17 sec. There was a load failure with steel blocks falling onto the floor, resulting from structural collapse of the centrally located wood joist at 10 min., 43 sec. The average surface temperature of the carpet finish floor increased rapidly to 206°C at 11 min., 7 sec., and the individual temperature readings at two locations exceeded 240°C at 10 min., 59 sec.

Test 2: Failure of the assembly took place at 3 min., 47 sec., by the passage of flames to the unexposed surface near the center of the assembly. The deflection of the test floor measured at the center point showed a rapid increase after 3 min., 31 sec., and the central joist collapsed at the same time as flamethrough. The temperature rise on the unexposed surface in the vicinity of burn through reached 163°C at 3 min., 41 sec.

Test 3: Flame penetration near the west quarter point along the center joist on the west side of the tongue-and-groove joint between two sheets of plywood underlayment located above the right seat cushion of the sofa was observed at 3 min., 58 sec. Based on results of deflection measurements, structural collapse of the center joist occurred at 3 min., 59 sec. One thermocouple positioned on the carpet in the neighborhood of the flamethrough region indicated a steep temperature rise to 239°C at 4 min., 7 sec. The average temperature rise of the surface thermocouples was less than 45°C at the end of the test.

Test 4: Deflection measurements at the center of the assembly showed a rapid increase at 11 min., 52 sec., and the centrally located joist fractured, causing the steel blocks to fall into the fire room at 12 min. Passage of flames and hot gases through the assembly to the unexposed surface occurred at 12 min., 2 sec. in an area near the center of the assembly on the southwest side, somewhat away from thermocouple locations. The average surface temperature on the carpet flooring increased rapidly to 462°C at 12 min., 8 sec., and the individual temperature rise of greater than 196°C occurred almost at the same instant as flame penetration.

Report Conclusions: Based on the experimental results, the following observations can be made regarding the unsheathed assemblies: The unsheathed, light gauge, steel framed assemblies allowed passage of flames, and suffered structural collapse in 4 min., compared to approximately 10 min. for the exposed wood frame floors. Under fire exposure, wood frame floors deflected at a slower rate as compared to steel framed floors; their ultimate collapse is due to the gradual reduction in cross-sectional area of floor joists caused by the charring and burning of wood. Failure due to passage of flames to the unexposed surface of the floor structure resulted from the increased deflection of floor joists with elevated temperatures, which promoted joint separation and developed openings in the plywood subfloor.

The results are summarized in the following tables:

	Structural Elements					Time to		Time to Unexp. Temp. Rise		Maximum Deflection	
Test No.	Floor Joists*	Plyw. Subf. thick. (in)**	Joist Spacing (in.)	Applied Load (psf)	Max. Allow. Stress (%)	Flame-Through (m:s)	Struct. Failure (m:s)	Avg. Temp 139°C (m:s)	1-Point Temp. 181°C (m:s)	Time (m:s)	Center Point (in.)
1	Wood	5/8	16	40	69	10:17	10:43	11:02	10:56	10:43	14.36
2	Steel	5/8	24	72	100	3:47	3:47	3:50	3:41	3:47	14.25
3	Steel	3/4	32	40	74	3:58	3:59	N.R.	4:04	4:07	13.0
4	Wood	23/32	24	40	100	12:02	12:00	12:08	12:02	12:00	6.9

* Wood Joists, nominal 2 x 8 Steel Joists, 1.75 X 7.25 in. X 18 gauge, Super-C. Span of all joists was 10.67 ft.; all assemblies were unsheathed.

** An olefin carpet with foam rubber backing was installed over the plywood subfloor.

N.R. = not reached

Table 14. Test Results for NBSIR 80-2134.

Test No.	Initial Room Temp (°C)	Ambient Relative Humidity (%)	Time to Flame Appearance on Newspaper (min.)	Time from Flame Appearance to					
				Room Flashover			Flames Emerging from Doorway (min.)	Ignition of Carpet (min.)	Termination of Test (min.)
				Ignition of		20 kW/m^2 on Floor (min.)			
				Newspaper (min.)	Filter Paper (min.)				
1	28	50	0.75	1.50	1.53	1.35	1.28	1.58	11.22
2	27	60	0.22	2.30	2.33	2.18	1.82	2.37	4.95
3	27	52	0.15	2.32	2.35	2.37	2.02	2.50	4.38
4	26	54	0.13	2.47	2.52	2.34	1.89	2.52	12.13

Table 15. Continuation of Test Results for NBSIR 80-2134

Comments: THE FOREGOING TESTS ARE THE ONLY SERIES OF TESTS REVIEWED THAT HAVE BEEN CONDUCTED WHICH SIMULATE ACTUAL FIRE CONDITIONS. THE TIMES TO FAILURE ARE VERY SIMILAR TO THOSE OBSERVED IN THE ASTM E119 TESTS. DEFLECTION PERFORMANCE OF THE ASSEMBLIES IS SIMILAR AS WELL. THE APPLIED LOAD INFLUENCES THE FIRE ENDURANCE TEST RESULTS. RESULTS OF THE STEEL JOIST TESTS SHOW GREATER DEFLECTION UNDER HEAVIER APPLIED LOAD. WOOD JOIST PERFORMANCE SHOWS GREATER DEFLECTION UNDER 69% OF THE DESIGN LOAD. THE SOUTHERN PINE JOIST SYSTEM WAS AT 100% OF THE MAXIMUM ALLOWABLE STRESS, YET THE FAILURE TIMES ROSE AND THE DEFLECTION DECREASED, WHICH IS CONTRARY TO LOGICAL EXPECTATIONS. THIS POINTS OUT THE FACT THAT BASING DECISIONS ON SINGLE TESTS CAN LEAD TO RESULTS THAT ARE NOT EXPECTED. CHANGING ANY VARIABLE IN A TEST PROGRAM (E.G., SPECIES OF LUMBER, MOISTURE CONTENT, ETC.) CAN CHANGE THE TEST RESULTS FOR UNSHEATHED ASSEMBLIES. IT FURTHER SUGGESTS THAT ANY COMPARATIVE UNSHEATHED TESTING SHOULD BE PERFORMED UNDER IDENTICAL CONDITIONS (I.E., CONDITIONING, STRESS LEVELS., ETC.) IN ORDER TO GAIN INSIGHT ON COMPARATIVE PERFORMANCE.

4-1.14 Report: Fire Endurance Tests of Selected Residential Floor Constructions, NBSIR 82-2488

Author: J.B. Fang

Sponsor: United States Department of Housing and Urban Development

Date: April, 1982

Basic Test Description: This series of tests was conducted with a pilot furnace which had internal dimensions of 8 x 9.6 ft., and a height of 9.35 ft. The furnace was fired with natural gas. Eight nozzle-mixing gas burners were distributed evenly over the floor area into two rows of four burners each, and mounted to the furnace in the upright position.

Each floor/ceiling assembly measured 8 x 10 ft., and was laid atop the specimen support frame. For Tests 1 and 2, which were protected tests, the applied load was calculated to stress the floor joists to a maximum total deflection and bending moment permitted by the design specifications. This was done in order to compare the fire performance results of the floor assemblies evaluated in the test furnace with those obtained in the room tests. The structural loading for Tests 3 - 5 and 8 - 10 were selected to develop the same magnitude of bending stresses in the floor joist as those produced in Tests 3, 4, and 7 (at 40 psf) in the series. A live load of 54 psf—which corresponds to approximately 93% of the respective maximum load based on the maximum allowable bending stresses for wood joists—was applied to each assembly. Tests 3 - 7 and 9 were all conducted on unsheathed 2 x 8 wood joists. Assembly 10 was a 7.25 in. deep, 18 gauge steel C-joist test. Tests 3 - 5, 9 and 10 used the new time/temperature curve developed from the room tests. Tests 6 and 7 used the ASTM E119 time/temperature curve. For specific test information, see the summary table. Tests 1, 2, and 8 were protected by Type X gypsum wallboard, and will be described in **Chapter 4-2: Fire Endurance Performance of Single Membrane Protected Assemblies.**

Test Methods Used: Each test assembly was built and installed in a test frame of the furnace. Several days prior to fire exposure, the assembly was loaded uniformly with steel blocks to the prescribed load. Unprotected, fast response thermocouples were used to provide the mean gas temperature, which followed the time/temperature curves through manual control of the gas flow to the burners.

Report Observations: Photographic and videotaped records were made of the burning characteristics of each test assembly, including floor deflection, time to burn through, and time to structural failure. Temperatures in the furnace were monitored by using nine commercial metallic sheathed mineral-insulated fast response thermocouples, and nine ASTM E119 standard protected furnace thermocouples. Deflection of the test assembly during the test was measured at the midpoints and selected quarter points of the three centrally located floor joists. Static pressure at various locations inside the test furnace were continuously monitored through four steel pipes extending through the east and west walls of the furnace, with their open ends flush with the wall surfaces. Total heat flux occurring at selected locations were measured with three Gordon-foil-type, water-cooled heat gauges. Continuous gas samples were drawn from the flue gas stream with steel tubing. Outflow gases were analyzed for oxygen, carbon dioxide, and carbon monoxide. The output signals from the thermocouples and various transducers were recorded every eight seconds, and visual observations were recorded.

Report Summary:

Test 3: Penetration of the plywood subfloor/carpet flooring was observed at 6 min., 4 sec. Floor deflection showed a significant increase at 5 min., 10 sec. At test end, the total deflection was 2.24 in. The entire test structure collapsed and fell into the furnace at 6 min., 53 sec. Individual temperature rise on the unexposed surface near the center of the test floor exceeded 181°C at 6 min., 34 sec. Average temperature rise was less than 49°C at the time of test termination. The fire exposure for this test was the new time/temperature curve based on room tests. A high level of excess air was used.

Test 4: Passage of flames and hot gasses through the assembly to the unexposed side occurred at 6 min., 7 sec. Additional penetration of flames to the unexposed surface was observed at 6 min., 40 sec. at several locations near the center of the test floor. Structural collapse of the center joist—based on floor deflection measurements—occurred at 7 min., 52 sec. Maximum deflection was 10.8 in. at 7 min., 52 sec. One thermocouple in the vicinity of the center of the assembly indicated a steep temperature rise to 247°C at 6 min., 56 sec. The average surface temperature rise of the unexposed face exceeded 139°C at 7 min., 13 sec. The fire exposure for this test was the newly developed time/temperature curve. A high level of excess air was used.

Test 5: Flame penetration of the carpeted plywood subfloor occurred at 7 min., 0 sec. The rate of deflection measured at the center of the test floor showed an increase at 8 min., 48 sec. Maximum deflection was 10.7 in. at 10 min., 48 sec. One surface thermocouple located on the carpet surface near the location of burn through registered 223°C at 10 min., 8 sec., and the maximum average temperature rise of the unexposed surface was 177°C at the end of the test. The fire exposure for this test was the new time/temperature curve. A high level of excess air was used.

Test 6: Penetration of flames through the unexposed surface was observed at 16 min., 8 sec. Floor deflection measured at the center of the test assembly increased rapidly at 14 min., 50 sec., and the total deflection was 6.9 in. when the test was terminated at 16 min., 50 sec. A single thermocouple on the carpet floor near the center of the assembly indicated 204°C at 16 min. The average value read by the surface thermocouples on the unexposed side at test termination was 202°C above its initial value. The ASTM E119 time/temperature curve was used. A low level of excess air was used.

Test 7: Flames penetrated the carpeted plywood deck near the center joist at 17 min., 35 sec. Deflection was 11.9 in. at 17 min., 40 sec. The maximum individual thermocouple temperature on the unexposed face was 103°C at 17 min., 10 sec. Average surface temperature rise was 217°C over ambient after 18 min. of test duration. Assembly 7 was tested using the ASTM E119 time/temperature curve. A low level of excess air was used.

Test 9: Failure of the test assembly due to flames passing through the unexposed surface was observed at 9 min., 9 sec. Floor deflection measured at the center of the test assembly increased dramatically at 8 min., 30 sec. The maximum deflection was 3.7 in. at 10 min. The maximum temperature rise measured by one thermocouple on the unexposed surface near the center of the test floor was 181°C at 9 min., 38 sec. Average temperature rise of the unexposed surface was 74°C at the time of test termination. The fire exposure for this test was the new time/temperature curve. A low level of excess air was used.

Test 10: The fire burned through to the unexposed surface, causing system failure at 4 min., 38 sec. Deflection measurements indicated a rapid increase at 2 min., 45 sec. The maximum deflection was 9.1 in. at 5 min., 50 sec. A single thermocouple near the center of the test structure exceeded 181°C above ambient temperature at 4 min., 24 sec. The average temperature rise of the unexposed surface was 131°C at 5 min., 48 sec. The fire exposure for this test was the new time/temperature curve. The steel joists were stressed to 68% of their maximum allowable stress for this test. A low level of excess air was used.

A summary of these tests follows:

							Time to		Time to Unexp. Temp. Rise		Maximum Deflection	
Test No.	Floor Joists*	Joist Spacing (in.)	Applied Load (psf)	Max. Allow. Stress (%)	Fire Expos. **	Level of Excess Air	Flame-Through (m:s)	Struct. Failure (m:s)	Avg. Temp 139° F (m:s)	1-Point Temp. 181° F (m:s)	Time (m:s)	Center Point (in.)
3	Wood	24	54	94	N.D.	High	6:04	6:53	N.R.	6:39	7:00	2.2
4	Wood	24	54	93	ASTM	High	6:07	7:52	7:13	6:53	8:00	10.8
5	Wood	24	54	93	N.D.	High	6:53	7:36	10:39	10:06	10:48	10.7
6	Wood	24	54	93	ASTM	Low	16:08	14:42	16:46	16:00	16:50	6.9
7	Wood	24	54	93	ASTM	Low	17:35	13:10	N.R.	17:08	18:10	12.2
9	Wood	24	54	93	N.D.	Low	9:09	8:48	N.R.	9:38	10:00	3.7
10	Steel	32	55	68	N.D.	Low	4:38	2:48	5:48	4:24	5:50	9.1

* Wood joists: Southern Pine, nominal 2 x 8; Steel Joists: Super-C, 1.75 in. x 7.25 in. x 18 gauge;
All assemblies have plywood subfloor thickness of 23/32 in., with no gypsum board ceiling
** N.D. = Newly Developed; ASTM = ASTM E119

Table 16. Test Results for NBSIR 82-2488

Report Observations: The new time/temperature curve—which represents a high intensity, short duration fire exposure—is regarded as a more realistic representation of the severity of room fires found in residential occupancies.

The purpose of this testing was to compare the newly developed time/temperature curve with the ASTM E119 curve. Tests were also run with low and high percentages of excess air in order to determine the effect of oxygen concentration in the furnace on the failure time of combustible construction. The following observations were made of the unexposed assemblies from these tests:

- Wood joist floors exposed to the newly developed fire conditions had a shorter time to failure compared with residential room fire tests of the same floor construction. This was due primarily to increased burning rates of combustible materials in the test structure with excess air present in the test furnace.

- Individual test assemblies tested under the newly developed time/temperature curve resisted flame penetration for approximately 40% less time than those using the ASTM E119 curve.
- Under the new fire exposure condition, unsheathed wood frame floors allowed passage of flames at 9 min., compared with 4.5 min. for the exposed light gauge steel frame floor. The seams of the floor opened due to the sag of the steel joists.
- The fast response thermocouple has a shorter lag time and provides a better indication of the true furnace temperature when compared to the ASTM E119 thermocouple—especially during the early stages of the test.

Comments: THIS TESTING WAS PERFORMED TO COMPARE A TIME/TEMPERATURE CURVE DEVELOPED FROM ROOM FIRE TESTS WITH THE ASTM E119 TIME/TEMPERATURE CURVE. THE ONLY TESTS THAT MAKE AN EXACT COMPARISON ARE TESTS 6, 7, AND 9. THE AVERAGE TIME TO STRUCTURAL FAILURE FOR THE ASTM E119 TESTS WAS 13 MIN., 56 SEC. STRUCTURAL FAILURE FOR THE NEW TIME/TEMPERATURE CURVE UNDER SIMILAR TEST CONDITIONS WAS 8 MIN., 48 SEC. THUS, USE OF THE NEW CURVE RESULTS IN MORE RAPID FAILURE OF ASSEMBLIES. THIS APPLIES TO TIME OF FLAMETHROUGH OF THE SHEATHING AS WELL. STRUCTURAL FAILURE TIME DUE TO THE NEW TIME/TEMPERATURE CURVE OCCURRED APPROXIMATELY 40% EARLIER THAN WHEN THE ASTM E119 CURVE WAS USED. THIS TEST SERIES ALSO INVESTIGATES THE AMOUNT OF AIR SUPPLIED IN A TEST. THE GREATER THE AMOUNT OF AIR AVAILABLE TO THE FURNACE IN TESTING, THE MORE QUICKLY AN ASSEMBLY WILL FAIL. THEREFORE, WHEN A FIRE IS WELL VENTILATED, SUPPLYING A GREATER AMOUNT OF AIR TO THE FIRE SOURCE, AN ASSEMBLY WILL FAIL MORE RAPIDLY.

4-1.15 **Report:** Fire Endurance Tests of Plywood on Steel Joist Floor Assemblies, With and Without Ceiling, NBSIR 73-14-1

Authors: H. Shoub and B.C. Son

Sponsor: National Bureau of Standards

Date: March, 1973

Basic Test Description: The area and size of the floor assembly was 11 ft. x 9 in. x 17 ft., 11 in., and consisted of 3/4 in. tongue-and-groove underlayment-grade plywood over 6 x 1.75 in. cold-rolled steel "C"-joists, spaced 24 in. on center. Half of the plywood surface—8 ft., 11.5 in.—was covered with 3/8 in. nylon pile carpeting with jute backing, laid over 1/4 in. rubberized hair padding. The other half was not covered. A load equivalent to 51.4 psf was applied to the floor specimen.

Test Methods Used: Testing was generally performed in accordance with the requirements of ASTM E119 for floors and roofs.

Test Results: Failure occurred at 3 min., 15 sec. when flamethrough occurred at the unexposed surface, followed by collapse of the entire assembly at 3 min., 45 sec.

> **Comments:** THE DETAIL AVAILABLE FOR THIS TEST IS LIMITED; THEREFORE, IT IS NOT KNOWN IF THE LOAD APPLIED TO THE FLOOR WAS THE MAXIMUM DESIGN LOAD FOR THE JOIST WAS APPLIED. IF IT WAS, IT CAN THEN BE COMPARED TO THE OTHER ASTM E119 TESTS ABOVE. THIS MAY, THEREFORE, EXTEND THE RANGE FOR CHANNEL-SHAPED STEEL JOISTS DOWN TO 3 MIN. 45 SEC.

4-1.16 Report: Fire Endurance Test of a Steel Sandwich Panel Floor Construction, NBSIR 73-164

Author: B.C. Son

Sponsor: National Bureau of Standards

Date: April, 1973

Basic Test Description: The structural frame of the floor assembly consisted of 6 x 3 in., 14 gauge steel "C"-joists as stringer beams, the joists being 48 in. on center. The overall size of the assembly was 10 ft., 7.25 in. x 17 ft., 11 in. The sandwich panels that were applied to the top of the joists were 3 in. thick, having a paper honeycomb core, with a top surface of 3/8 in. C-D plugged interior grade plywood, and a bottom surface of 26 gauge, galvanized sheet steel. Carpeting was bonded to the plywood. A 40 psf load was applied to the floor assembly during the test.

Test Method Used: The test procedures followed ASTM E119.

Test Results: Failure by flamethrough occurred at a joint between two sandwich panels at 8 min., 45 sec., followed by structural failure at 9 min.

> **Comments:** THIS ASSEMBLY WAS TESTED UNDER A TYPICAL FLOOR LIVE LOAD. THEREFORE, IT CANNOT BE COMPARED TO OTHER TESTING WHERE THE FULL DESIGN LOAD WAS APPLIED.

4-1.17 Report: Fire Testing of Nail Plate-Connected Wood Beams

Authors: B. Roald and E. Aasheim

Sponsor: Norwegian Institute of Wood Technology

Date: 1988

Basic Test Description: The testing consisted of truss plate-joined joists that were combined into beams. Four beams were tested, each 4.6 m long. The beams consisted of:

- Beam 1: four joists, 2.87 in. x 7.79 in. with 1.53 in. laminated veneer lumber (LVL) attached to the bottom.
- Beam 2: four joists, 2.87 in. x 7.79 in. with 1.53 in. LVL attached to the top and bottom.
- Beam 3: two joists, 1.88 in. x 7.75 in. unprotected.
- Beam 4: three joists, 1.82 in. x 7.75 in. with 1.53 in. LVL at the top and bottom.

Each single joist consisted of two parts connected in the center with truss plates. The truss plates were gang nail GN-T150, 6.9 in. x 13.8 in. x 0.6 in. Loads were applied to the four beams to produce a bending moment at the joint location. Due to the load application, beams were exposed to bending tension on the upper side and bending compression on the lower side. The load capacity was not limited by the wood, but by the truss plates.

Test Method Used: The fire test was conducted for 60 min. following the standard time/temperature curve of ISO 834.

Report Observations: Thermocouples were located on each truss plate, and placed directly under the truss plate and at the end of the teeth, so that there were 12 thermocouples on each truss plate.

Report Summary: The results are summarized in the following table:

Beam	Bending Moment (ft.-lbs.)	Failure (min.)
1	7,374	55
2	7,674	*
3	2,957	20
4	4,435	50

* Failure did not occur during the test period of 60 min. After 60 min., the load was increased, and the beam failed at a bending moment of 10,620 ft.-lbs.

Table 17. Test Results for Norwegian Institute of Wood Technology Test.

By placing two or more nail plate-connected beams together, it is possible to achieve improved fire resistance compared to a single nail plate-connected beam.

> **Comments:** THIS REPORT OBSERVES THAT MULTIPLE MEMBERS PERFORM BETTER THAN A SINGLE PLY MEMBERS. THIS MAY BE DUE TO THE FACT THAT THE INTERIOR TRUSS PLATES ARE PROTECTED BY THE WOOD SURROUNDING THEM. THIS STUDY ALSO BUILDS ON THE COMMON EUROPEAN USE OF SACRIFICIAL WOOD TO PROTECT CONNECTIONS. IT IS PROBABLE THIS HAS APPLICATION FOR MULTI-PLY GIRDER TRUSSES (AT LEAST THREE OR MORE CONNECTED TRUSSES) USED BY THE MPC WOOD TRUSS INDUSTRY. IT IS CONCEIVABLE THAT THESE TRUSSES PERFORM BETTER UNDER FIRE CONDITIONS THAN SINGLE TRUSSES SPACED WIDELY (GREATER THAN 4 FT. ON CENTER). HOWEVER, IT IS NOTED THAT ISO 834 INCORPORATES POSITIVE PRESSURE AND UTILIZED BARE THERMOCOUPLES, BOTH OF WHICH MAY EFFECT THE RESULTS OF THIS TEST. CARE MUST BE TAKEN WHEN COMPARING THESE RESULTS WITH RESULTS FROM OTHER TESTS WHICH USE DIFFERENT TEST STANDARDS.

4-1.18 Report: Fireball Tests of Open Webbed Steel Joists

Author: T.E. Waterman, IIT Research Institute

Sponsor: General Services Administration

Date: May 15, 1977

Basic Test Description: Testing resulted from the General Services Administration's concern about storage of records and the potential for fire. The use of high-temperature sprinkler heads permitted areas above the fire to experience temperatures of approximately 1600° F for up to ten minutes. Anticipating that this exposure may cause joist failure, GSA sought to experimentally determine temperatures reached by joists typical of those found in GSA's record centers. Exposing fire temperatures were chosen to approximate the maximum temperatures that were measured by Factory Mutual Research Corporation (FMRC) Test F. Failure was deemed to occur when a joist member temperature exceeded 1100° F. Joists were fabricated for this test to be representative of open webbed steel joists found in the record centers. Each joist was made with a 7 ft. upper chord and a 6 ft. lower chord, and was 12 in. deep.

Test Methods Used: Five instrumented, representative joists were held against the ceiling of a 10 x 15 ft. room. The joists were supported at each end by protected steel frames. Fire in the test room was provided by propane diffusion burners placed near the floors. A recorder measured the temperature at six ceiling locations.

Report Observations: Temperatures on the various components—upper chord, web, and lower chord—of each unsheathed joist were measured. Unsheathed joists generally reached temperatures between 1400 and 1600° F when exposed to the FMRC Test F time/temperature curve. The connections between the chords and the webs remained cooler than the other portions of either chord or web. The flanges of the upper chords in contact with the ceiling remained cooler than the top chords that were exposed to the fire at the ceiling corrugations.

Report Summary: Based on this test, no joist tested would have met the temperature limitation of 1100° F.

> **Comments:** THIS IS AD-HOC TESTING PERFORMED FOR A SPECIFIC PURPOSE. A DIFFERENT TIME/TEMPERATURE CURVE AND FAILURE CRITERIA IS INTRODUCED. BECAUSE OF THIS, IT IS VERY DIFFICULT TO RELATE THIS TYPE OF TEST TO ANY OF THE OTHER UNSHEATHED TESTS PERFORMED.

4-1.19 Report: BMS 92 Fire Resistance Classifications of Building Constructions

Authors: Subcommittee on Fire Resistance Classifications of the Central Housing Committee on Research, Design, and Construction

Sponsor: United States Department of Commerce and the National Bureau of Standards

Date: October 7, 1942

Basic Test Description: Testing was performed on joists of 2 x 10 Southern Pine or Douglas fir #1 Common or Better Grade, using a subfloor of 3/4 in. wood sheathing, diaphragm of asbestos paper, and finish tongue-and-groove wood flooring. The ratings apply for loadings developing not more than 1000 psi maximum fiber bending stress in the joists. All constructions were rated as combustible because of wood supports and floorboards. Spacing is assumed to be 16 in. on center.

Test Methods Used: The fire tests were conducted in accordance with the standard Specifications for Fire Tests of Building Construction and Materials, American Standards Association (ASA) No. A2-1934. The results of fire tests conducted at the National Bureau of Standards were used as a basis for the ratings. The ratings, in general, were taken directly from test results, and represent the lower average of results.

Report Observations: The ultimate fire resistance time period for exposed wood joists was 15 min.

> **Comments:** THESE TESTS APPEAR TO BE SOME OF THE EARLIEST TESTS PERFORMED ON FLOOR SYSTEMS. THE KEY TO THESE TESTS WAS THE CRITERIA LIMITING STRUCTURAL MEMBERS TO 1000 PSI MAXIMUM FIBER BENDING STRESS. THIS RESTRICTION ON FIBER BENDING STRESS IS PROBABLY THE REASON FOR THE FIRE RESISTANCE OF WOOD JOISTS BEING 15 MIN. A 2 X 10 DOUGLAS FIR OR SOUTHERN PINE #1 OR BETTER GRADE OF LUMBER HAS A FIBER BENDING STRESS EXCEEDING 1000 PSI USING CURRENT DESIGN VALUES.

Test	Structural Member	Spacing	Assemb. Rating (min:sec)	Structural Failure (min:sec)	Avg. Defl. at Floor (in.)	Loading (psf) - % Design Stress	Comments
FM FC 209	2 x 10; 23/32"ply. w/vnl[5]	24 in. o.c.	N/A	13:34	2.83	62.1 (100%)	ASTM E119
FM FC 212	2 x 10 ;23/32"ply. w/cpt[5]	24 in. o.c.	N/A	12:06	3.58	62.4 (100%)	ASTM E119
NBS 421346 (2)	2 x 10; 2-½" ply.	16 in. o.c.	N/A	11:38	2.7	63.7 (100%)	ASTM E119
NBS 421346 (4)	2 x 10; 2-½" ply. w/cpt.[5]	16 in. o.c.	N/A	11:38	3.3	63.7 (100%)	ASTM E119
NBS 421346 (9)	2 x 8; ½ in. ply. w/blk[5]	16 in. o.c.	10:00	13:00	7.0	21.0[1] (40%)	ASTM E119
NBS 421346 (10)	2 x 8; 5/8 in. ply. T&G[5]	16 in. o.c.	9:00	13:00	12.0	21.0[1] (40%)	ASTM E119
FPL	2 x 10	16 in. o.c.	N/A	6:30	4.0	79.2[6] (100%)	ASTM E119
FPL	2 x 10	16 in. o.c.	N/A	13:06	N/A	40.0[1]	ASTM E119
FPL	2 x 10	16 in. o.c.	N/A	17:54	1.7	11.35[1]	ASTM E119
FM FC 250	12 in. MPCT[7]	24 in. o.c.	7:30	10:12	11.5	60.0 (100%)	ASTM E119
NFPA Tech Report 1	4 x 14 Wood Beam	3 ft. 7 in. o.c.	N/A	> 13:00[2]	0.5	30.0[1]	ASTM E119
NFPA Tech Report 1	14 in. Steel bar joist	3 ft. 7 in. o.c.	N/A	13:00[2]	18.0	30.0[1]	ASTM E119
FM FC 208	7¼ in. Steel C-joist	24 in. o.c.	7:24	7:30	7.0	69.8 (100%)	ASTM E119
FM FC 211	7¼ in. Steel C-joist	24 in. o.c.	5:12	5:12	10.0	69.8 (100%)	ASTM E119
NBSIR 73-141	6 x 1¾ in. C-joist	24 in. o.c.	3:15	3:45	N/A	51.4[1]	ASTM E119
NBSIR 73-164	6 x 3 in. 14 ga C-joist	48 in. o.c.	8:45	9:00	N/A	40.0[1]	ASTM E119
NFPA Tech Report 3	7 x 21 Wood Beam	Sngl. Elmt.	N/A	> 30:00[3]	2.25	30.0[1]	ASTM E119
NFPA Tech Report 3	16 WF 40 Steel Beam	Sngl. Elmt.	N/A	30:00[3]	35.5	30.0[1]	ASTM E119
NIWT (1)	11.5 X 9.3 in. Beam	5 PC. Beam	N/A	55:00	N/A	7,374 ft.-lbs.	ISO 834 TPSB[7]
NIWT (2)	11.5 x 10.8 in. Beam	6 PC. Beam	N/A	> 60:00	N/A	7,674 ft.-lbs.	ISO 834 TPSB[7]
NIWT (3)	3.77 x 7.79 in. Beam	2 PC. Beam	N/A	20:00	N/A	2,957 ft.-lbs.	ISO 834 TPSB[7]
NIWT (4)	5.66 x 9.3 in. Beam	3 PC. Beam	N/A	50:00	N/A	4,435 ft.-lbs.	ISO 834 TPSB[7]
BMS 92	2 x 10	16 in. o.c.	15:00	N/A	N/A	N/A	1000 psi mx.F_b ASA A2-1934[7]
IITRI J6397	12 in. Steel Bar Joist	Sngl. Elmt.	N/A	10:06	N/A	dead ld	FMRC Test F;1100°=Fail.[4]

[1] Assumed to be a limited load test. Loading not 100% of design load.

[2] 1/2 in. deflection of wood; 18 in. deflection for steel; 80% of wood undamaged.

[3] 2.25 in. deflection for wood beam at 30 min.; collapse of steel at 30 min.; 76% of wood undamaged.

[4] Time bottom chord reached 1000° F is assumed to be failure.

[5] vnl = vinyl covering; cpt = carpet covering; blk = 1 x 3 end blocking; T&G = tongue-and-groove.

[6] Whether or not this test was at full design load or greater than full design load has been questioned. The structural failure time listed may not be correct.

[7] MPCT = Metal Plate Connected Truss; F_b = fiber bending stress; TPSB = Truss Plate Spliced Beam.

Table 19. Standardized Unsheathed Assembly Tests.

Test	Structural Member	Spacing	Assemb. Rating (min:sec)	Structural Failure (min:sec)	Loading (psf)	Failure Analysis
IFSI	2 x 10	16 in. o.c.	9:00[1]	> 13:00	31.0	System sagged/gave warning
IFSI	I-joist	24 in. o.c.	4:40[1]	4:40	31.0	No sag/warning
IFSI	MPCT[2]	24 in. o.c.	9:00[1]	15:45	31.0	System sagged/gave warning
IFSI	MPSWT[2]	24 in. o.c.	7:30[1]	N/A	31.0	System sagged/gave warning
IFSI	TJL	24 in. o.c.	6:50[1]	9:45	31.0	No sag/warning
J. Mittendorf	I-joist	32 in. o.c.	N/A	3:20	dead ld	"Early Failure"
J. Mittendorf	TJL	24 in. o.c.	N/A	5:20	dead ld	"Early Failure"
J. Mittendorf	MPCT[2]	16 in. o.c.	N/A	1:20	dead ld	"Early Failure"
J. Mittendorf	MPCT[2]	32 in. o.c.	N/A	> 6:00	dead ld	"Early Failure"

[1] Assembly rating is due to deck burn through.

[2] MPCT = Metal Plate Connected Truss; MPSWT = Metal Plate Steel Web Truss; TJL = Trus Joist L-Series Truss.

Table 18. Non-Standardized Ad-Hoc Unsheathed Assembly Tests.

Structural Member	Structural Failure (min:sec)	Avg. Defl. of Floor (in.)	Loading - % Design Stress
9.5 in. I-joist	~ 5:00	3.1	30% of capacity
10 in. MPCT[1]	~ 5:00	2.7	30% of capacity
10 in. MPSWT[1]	~ 5:00	2.75	30% of capacity
2 x 10	> 10:00	1.1	30/40% of capacity

All tests were proprietary; spacing was single element.

[1] MPCT = Metal Plate Connected Truss; MPSWT = Metal Plate Steel Web Truss.

Table 18a. Standardized Ad-Hoc Unsheathed Assembly Tests.

Test	Structural Member	Spacing	Assemb. Rating (min:sec)	Structural Failure (min:sec)	Loading (psf) - % Design Stress	Loading (psf)
NBSIR 88-2134 (1)	2 x 8 5/8" ply.	16" o.c.	10:17	10:43	11.3	40 (69%)
NBSIR 88-2134 (2)	7¼"steel C 5/8" ply.	24" o.c.	3:47	3:47	14.25	72 (100%)
NBSIR 88-2134 (3)	7¼"steel C 3/4" ply.	32" o.c.	3:58	3:59	13.00	40 (74%)
NBSIR 88-2134 (4)	2 x 8 23/32" ply.	24" o.c.	12:00	12:00	6.90	40 (100%)

Table 20. Standardized Room Burn Tests.

Test	Structural Member	Assemb. Rating (min:sec)	Structural Failure (min:sec)	Avg. Defl. of Floor (in.)	Comments
NBSIR 88-2488 (3)	2 x 8 23/32" ply.	6:89	6:53	2.24	New T/T curve; high air
NBSIR 88-2488 (4)	2 x 8 23/32" ply.	6:07	7:52	10.8	ASTM E119; high air
NBSIR 88-2488 (5)	2 x 8 23/32" ply.	6:53	7:36	10.7	New T/T curve; high air
NBSIR 88-2488 (6)	2 x 8 23/32" ply.	14:42	14:42	6.9	ASTM E119; low air
NBSIR 88-2488 (7)	2 x 8 23/32" ply.	13:10	13:10	12.2	ASTM E119; low air
NBSIR 88-2488 (9)	2 x 8 23/32" ply.	8:48	8:48	3.7	New T/T curve; low air
NBSIR 88-2488 (10)	7¼"steel C 23/32"ply.	2:48	2:48	9.1	New T/T curve; low air

All assemblies were loaded to 54 psf, which was 93% of their capacity; all spacings were 24 in. on center.

Table 21. New Time/Temperature Curve Evaluation Tests.

Test	Structural Member	Spacing	Assemb. Rating (min:sec)	Structural Failure (min:sec)	Avg. Defl. at Floor (in.)	Loading (psf) - % Design Stress
FM FC 209	2 x 10; 23/32"ply. w/vnl	24 in. o.c.	N/A	13:34	2.83	62.1 (100%)
FM FC 212	2 x 10 ;23/32"ply. w/CPT	24 in. o.c.	N/A	12:06	3.58	62.4 (100%)
NBS 421346 (2)	2 x 10	16 in. o.c.	N/A	11:38	2.7	63.7 (100%)
NBS 421346 (4)	2 x 10; 2-½" ply.	16 in. o.c.	N/A	11:38	3.3	63.7 (100%)
FPL	2 x 10	16 in. o.c.	N/A	6:30	4.0	79.2[2](100%)
FM FC 250	12 in. MPCT[1]	24 in. o.c.	7:30	10:12	11.5	60.0 (100%)
FM FC 208	7¼ in. Steel C-joist	24 in. o.c.	7:24	7:30	7.0	69.8 (100%)
FM FC 211	7¼ in. Steel C-joist	24 in. o.c.	5:12	5:12	10.0	69.8 (100%)

[1] MPCT = Metal Plate Connected Truss; MPSWT = Metal Plate Steel Web Truss; TJL = Truss Joist L-Series Truss; TPSB = Truss Plate Spliced Beam; F_b = fiber bending stress.

[2] Whether or not this test was at full design load or greater than full design load has been questioned. The structural failure time listed may not be correct.

Table 22. ASTM E119 Unsheathed Assembly Tests at Full Design Load.

4-1.20 Evaluation of Unsheathed Assemblies Testing Performance

Test data available allowing direct comparison between assemblies are represented by eight tests (see Table 22 above). These tests indicate that in unsheathed assemblies, wood joists have greater fire endurance than steel C-joists. The data also indicate that metal plate connected (MPC) trusses have fire endurance times that fall within the range of performance for 2 x 10 joists, if the FPL failure time of 6 min., 30 sec. is accurate. If this test is removed because of unreliable data, then MPC trusses have fire endurance times that fall just below the range of performance for 2 x 10 joists. The MPC truss assembly tested, however, did not have a splice plate located in the bottom chord of the truss. It is expected that this may reduce the time to failure, although by an unknown amount.

Information on testing of unsheathed assemblies suggests that wood charring protects the wood member and aids in the structural performance under fire conditions. This is in contrast to steel, where once the steel member reaches a temperature greater than 1000° F, its strength rapidly decreases.

The National Bureau of Standards (Now called the National Institute of Standards and Technology, or NIST) report NBSIR 82-2488 provided data comparing ASTM E119 to a typical burning room, and a new time/temperature curve based on room burn tests. This report indicates that ASTM E119 overstates fire endurance performance as compared to room burn time/temperature curve performance. However, this should be contrasted with full-scale room fire tests showing 2 x 8 joist fire endurance to be 10 to 12 min., in the range of what would be expected for 2 x 8's exposed to ASTM E119 testing. This indicates that the room burn time/temperature curve may not have been calibrated to replicate room burn performance from which it was derived. These NBS tests can provide baseline data, should there be a desire to develop fire test standards that more accurately replicate actual field conditions. To claim that one time/temperature curve is better than another based on this testing would be premature.

Non-standard test data on unsheathed assemblies provided in this chapter cannot be used to compare performance due to the lack of standardized testing procedures.

ASTM E119 can, however, be used to make comparisons between assembly types when maximum design loads are applied to the test assembly. Currently, model building codes require ASTM E119 tests to be performed on protected assemblies only. Therefore, unsheathed tests that have been performed have no utility from a model code perspective, but do provide additional data for study.

Based on the literature review, there are currently no fire endurance performance criteria for unsheathed assemblies. The Federal Housing Administration (FHA) previously had a 10 min. requirement. It was abandoned in November of 1984 as a result of Office of Management and Budget Circular A119, which stated that all federal agencies must use prevailing voluntary codes and standards where they exist. Therefore, the local or model code requirements would determine unsheathed assembly application and required fire endurance, if any. It is likely this lack of performance criteria is the reason for the small amount of standardized data available on unsheathed assemblies under fire conditions.

Chapter 4-2: Fire Endurance Performance of Single Membrane Protected Assemblies

The following protected assembly tests provide fire performance data on the use of a single layer of gypsum wallboard attached to horizontal structural elements. The most important of these are single layer systems with wallboard attached directly to structural elements. These tests generally result in assembly fire endurance performance between 45 and 60 min.

4-2.1 **Report:** Underwriters Laboratory Design Number L506

Author: Underwriters Laboratory

Sponsor: Gypsum Association

Date: 1950

Basic Test Description: The test assembly used 1/2 in. thick sheets of fire rated wallboard. This wallboard was applied directly to 2 x 10 wood joists which were spaced 16 in. on center and firestopped. The subfloor applied to the joists was 1 x 6 tongue-and-groove, fastened diagonally or 1/2 in. plywood. The finish flooring was 1 x 4 tongue-and-groove boards or 5/8 in. plywood.

Test Method Used: The test followed ASTM E119 procedures.

Report Observations: The only data provided are in the UL directory. This assembly provides a 3/4-hr. unrestrained rating with finish ratings that range from 15 min. to 20 min., depending on the type of gypsum. The gypsum finish ratings are summarized in the following table:

Company	Finish Rating Time (min.)
Canadian Gypsum Company, Ltd. Type SCX, SHX, WRX	15
Celotex Corporation Type A	18
Celotex Corporation Type B	20
Celotex Corporation Type C	15
Domtar Gypsum Type C	20
Gold Bond Building Products Type FSW-1 or FSW-G	20
James Hardy Gypsum Type 3	20
Republic Gypsum Company, Type RG-1	15
Republic Gypsum Company, Type RG-3	20
United States Gypsum Company Types SCX, SHX, WRX	15

Table 23. Gypsum Finish Rating Times.

> **Comments:** UNFORTUNATELY, MORE DETAILED DATA ON THESE TESTS ARE NOT AVAILABLE. IF TIME TO FAILURE FOR THESE ASSEMBLIES WERE KNOWN, BETTER COMPARISONS COULD BE MADE BETWEEN OTHER ASSEMBLY TYPES LISTED IN THIS CHAPTER. THESE DATA CAN BE USED TO COMPARE FINISH RATINGS WITH OTHER ASSEMBLIES, AND PROVIDE SOME ESTIMATE OF THE FIRE ENDURANCE PERFORMANCE OF THE STRUCTURAL FRAMING AFTER THE FINISH RATING TEMPERATURE HAS OCCURRED.

4-2.2 **Report:** Underwriters Laboratories Design Number L520

Authors: Underwriters Laboratories, Inc.

Sponsor: Perlite Institute

Date: August 1968.

Basic Test Description: Fire rated, 5/8 in. thick gypsum produced by Canadian Gypsum Company, Ltd. (Type C); Celotex Corporation; Domtar Gypsum (Type 5); Georgia Pacific Corporation, Gypsum Division (Type GPFS-C); Pabco Gypsum Company (Type C or PG-C); and United States Gypsum Company (Type C or IP-X2) was applied to resilient channels 1/2 in. deep, and spaced 24 in. on center. The resilient channels were attached perpendicular to the 2 x 10 wood joists, which were spaced 16 in. on center and firestopped. A 5/8 in. thick plywood subfloor was attached to the wood joists with a 1-5/8 in. thick Perlite sand concrete finished floor over the subfloor. Glass fiber bat insulation, 3 in. thick, was applied directly over the top of the furring channels.

Test Method Used: ASTM E119.

Report Observations: The only data provided in the UL directory were the unrestrained assembly rating of 45 min. and a finish rating of 21 min.

> **Comments:** THESE DATA ARE INCLUDED TO PROVIDE AN INDICATION OF THE EFFECTS OF ADDING RESILIENT CHANNELS AND GLASS FIBER INSULATION, AND USING A TYPE C VERSUS TYPE X GYPSUM BOARD.

4-2.3 **Report:** Building Research Laboratory 5036

Authors: R.W. Bletzacker, J.G. Birle, and D.A. Lucht

Sponsor: Trus Joist Corporation

Date: July, 1971

Basic Test Description: The test consisted of 9-13/16 in. deep I-joists with 3/8 in. plywood webs and 1-7/16 x 2-9/16 in. flanges having a length of 13 ft., 9 in. The I-joists