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## It's not lightweight construction. It's what happens when lightweight construction meets fire.

## Two recent studies detail the relationship between fire and engineered wood construction assemblies—notably, that they burn quicker and fail faster than their dimensional lumber counterparts. What do the findings mean for the fire service, builders, consumers, and NFPA codes?

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*By Alan R. Earls*

Early in the afternoon of August 13, 2006, the fire department in Green Bay, Wisconsin, responded to a suspected residential basement fire. An engine company focused on the flames while a ladder company worked on ventilation. The department also had a report that someone was in the building and prepared to make an entry.

Firefighters Arnie Wolff and Jo Brinkley-Chaudoir arrived on the scene four minutes after the fire was reported. Approximately seven minutes later, at the request of the incident commander, they began a search of the home's first floor. They took the precaution of crawling in and sounding the floor to ensure it could support them. The floor, made of concrete for a radiant heating system, seemed solid. Satisfied it would hold, the firefighters inched their way into the structure on their hands and knees as the fire roared beneath them in the basement.

Within moments, they heard a loud cracking sound. The floor gave way, plunging them into the fiery basement. Despite a fractured hip and ribs and first-degree burns on her back and upper arms, Brinkley-Chaudoir managed to escape by crawling through a basement window. Wolff fell into another part of the basement, separated from Brinkley-Chaudoir by a partial wall and blocked by floor debris. Wolff, a 17-year veteran of the department, perished in the fire, and his body was recovered the next day. Medical examiners determined that he had died of smoke inhalation and burns.

An after-report of the incident by the National Institute for Occupational Safety and Health found that the concrete first floor had concealed the severity of the fire in the basement. The report highlighted the extreme speed with which lightweight wood I-joists, such as those used in the house that burned, can reach their failure point when exposed to fire.

The findings have become all too familiar for firefighters. In January 2007, Hamilton County, Tennessee, lost a "firefighter of the year" in another sudden structural collapse blamed on lightweight construction that failed in a fire. In April of that year, the failure of lightweight construction in a fire contributed to the death of a rookie firefighter in Prince William County, Maryland.

Such incidents have fueled a growing concern for the fire service and pose a significant challenge to the code community. In recent decades, an expanding range of construction methods and building products, particularly wooden truss roofing systems and wood I-joists that together are often termed "lightweight construction," have been widely embraced by residential builders for their ability to deliver economy and functionality. Lightweight residential structures began to appear widely about 25 years ago, according to APA–The Engineered Wood Products Association (formerly the American Plywood Association), and have become increasingly popular ever since. From an engineering perspective, lightweight materials and construction techniques often outperform traditional dimensional lumber and assembly methods. Many recently built communities across the country are composed entirely of lightweight structures.

In separate studies by Underwriters Laboratories (UL) and the National Research Council of Canada (NRC), however, findings confirmed what firefighters have long suspected about what happens to lightweight construction when it is exposed to fire. In repeated tests by both groups, under carefully controlled conditions, lightweight structures were found to burn faster and lose their structural integrity quicker—in some cases much quicker—than those built with dimensional lumber, with obvious ramifications for the fire service and for anyone who lives in a residence constructed with lightweight materials.

For the fire service, the issues around fire and lightweight residential construction are immediate and often visceral. In Green Bay, Assistant Fire Chief Robert Goplin says the increased potential for sudden and catastrophic structural failure presented by lightweight construction is forcing his department to rethink many of its fire and rescue practices. "We are trying to drive home to the troops that this stuff is out there and it won't go away," says Goplin. "We have looked at those situations more closely and recognized that with floors failing faster, the occupant may not, in fact, be able to exit…We have reevaluated when we will make an entry and when we won't."

In response to this dilemma, new programs such as UL's "Structural Stability of Engineered Lumber in Fire Conditions" online course offer fire departments better understanding of the challenges posed by lightweight construction. The interactive program offers an overview of some of the lightweight construction techniques, the advantages of such materials, and the potential risks associated with these materials during fires.

Issues around lightweight construction and fire raise code questions, too. Robert Solomon, a department manager for Building and Life Safety at NFPA, says there is no prohibition on the use of lightweight construction in any existing NFPA codes. In addition, NFPA codes, along with the International Residential Code® developed by the International Code Council (ICC), already include provisions, such as sprinklers, for protecting residences built with lightweight engineered materials. Even so, Solomon says, fire safety in this area needs to be reconsidered.

Solomon says he's been aware of concerns around lightweight construction since the mid-1980s. In the past, he says, model building and residential code developers have not seen the need to specify structural fire resistance ratings or performance criteria in one- and two-family dwellings. "Although the warning flags have been raised on these construction types, there is always a reluctance to make changes to the codes until something more than anecdotal experience and subjective fixes are available," explains Solomon. Fire safety advocates hope the UL study, which was championed by the Chicago Fire Department, has removed any remaining subjective elements from the lightweight construction discussion.

For Gary Keith, NFPA's vice-president of Field Operations and Education and chair of the Home Fire Sprinkler Coalition Board of Directors, the most critical step for dealing with lightweight fire issues is pushing ahead with NFPA's Fire Sprinkler Initiative, which encourages communities to adopt ordinances requiring sprinklers in all new one- and two-family homes.

"What is most disturbing to us now is the movement by states, influenced by the builder community, to actually prohibit counties and municipalities from adopting a sprinkler requirement," says Keith. He says NFPA originally hoped to wage an offensive campaign that would rapidly push wider adoption of sprinklers. Instead, resistance from sprinkler opponents has the initiative, to some extent, on the defensive. Now, though, with the information provided by the UL report, Keith says he expects to see a return to a more aggressive approach by sprinkler advocates to get local ordinances adopted. "We now have a number of states actively considering the adoption of codes that retain the sprinkler language," he says.

**From anecdote to science: The UL report**

The fire service and sprinkler advocates are quick to say the same thing: The problem isn't lightweight construction. The problem is what happens when lightweight construction is exposed to fire.

Lightweight construction uses "engineered lumber," a term generally used to describe a wood structural member that is fabricated through use of bonded fibers and materials and that is usually put together as a composite joist or beam. Engineered lumber offers a great structural platform for the support of floor and roof assemblies, says NFPA's Solomon. Such composite beams and joists allow builders to implement the long spans and open rooms that are prevalent in modern-era home construction.

Borjen Yeh, director of the Technical Services Division for APA–The Engineered Wood Association, touts what he considers some of the key attributes of the products. "Engineered products are very efficient and green because they often can be manufactured from smaller logs and in shapes and designs that are tailored to their application," he says. "That makes them more economical and a better use of resources."

The performance of those engineered products under unmitigated fire conditions, however, is at the crux of the concern over lightweight construction. Sawn lumber, a staple in the home-building business for many years, has structural limitations that the engineered materials can surpass, but it

has traditionally demonstrated better performance under fire conditions. Even relatively simple solutions, such as attaching a 5/8-inch-thick Type X gypsum wall board to lightweight assemblies, can improve the fire performance characteristics of the engineered materials, says Solomon.

The UL study, Report on Structural Stability of Engineered Lumber in Fire Conditions, was funded by the Department of Homeland Security, with technical assistance provided by the Chicago Fire Department, the International Association of Fire Chiefs (IAFF), and Michigan State University. The study, released last December, was developed in response to a Federal Emergency Management Agency Fire Prevention and Safety Grant and focused on the use of wooden I-joists and truss systems as replacements for traditional 2- by 10-inch (5- by 25-centimeter) floor joists and 2- by 6-inch (5- by 15-centimeter) roof joists.

Robert Backstrom, senior staff engineer with UL Research, notes that the study was especially timely since it was initiated just as the U.S. Fire Administration put a special focus on the dangers of engineered construction systems. "The tests conducted in this research effort were done in a systematic manner using standard protocols, and the results were largely in accord with what the fire service knew or suspected about lightweight," says Backstrom. "The difference is that now, with this research, hard data exists to understand the magnitude of the problem."

The tests conducted by UL involved exposure of components to fire in a large-scale horizontal furnace using the time-temperature curve of the American Society for Testing and Materials (ASTM) E119 test. The study included nine fire tests, two of which focused on roof and ceiling systems while the rest looked at floor joists. Methodologically, the study aimed to provide "apples to apples" comparisons among assemblies and to show how different construction materials, including traditional lumber, fared in different types of fires. In floor tests, two 300-pound (136-kilogram) mannequins simulated a pair of firefighters, in addition to a 40 psi deadload along the perimeter of two edges of the floor.

The experiments documented striking differences between traditional and engineered systems. For example, a traditionally constructed floor system, without a drywall ceiling to protect its underside, withstood the test fire for 18 minutes. By comparison, a similar system using engineered wooden I-beams survived for about six minutes.

The report specifically noted the concern often expressed by firefighters regarding rapid structural collapse and added that "reviewing data from Test Nos. 1 and 2 support this observation." UL also partnered with Michigan State University to develop data on the burning rates of dimensional wood and composite wood, such as oriented strand board, and found comparable burning rates.

Another part of the project extrapolated from the experimental data and known properties of engineered products using "finite element analysis" in an effort to model and predict more generally the behavior of engineered wood products in fires. However, while the authors made some progress toward this goal, they discovered that their models rarely matched the results in the actual experiments, which they attributed to the complexity of the relationship between the original fire, the combustion of the engineered wood, and the mechanical degradation of the wood products. The researchers' stated expectation is that further efforts and standardized testing will gradually help to fill in the gaps, providing a more comprehensive understanding how exactly failures occur.

The NRC study, Fire Performance of Houses: Phase I Study of Unprotected Floor Assemblies in Basement Fire Scenarios, was also released last December and sought to establish the "typical sequence of events such as the smoke alarm activation, onset of untenable conditions, and structural failure of test assemblies" in a simulated two-story, single-family house with a basement. "With the relatively severe fire scenarios used in the experiments, the times to reach structural failure for the wood I-joist, steel C-joist, metal plate, and metal web wood truss assemblies were 35 to 60 percent shorter than that for the [traditional] solid wood joist assembly," the study reported. In every instance, the floors failed, "characterized by a sharp increase in floor deflection and usually accompanied by heavy flame penetration through the test assemblies, as well as by a sharp increase in compartment temperature above the test floor assemblies."

UL's Backstrom says that, with such quantifiable information, the firefighting and code communities can now work from a shared reference point as they figure out how to proceed. While a variety of construction assemblies have been certified for one to two hours of fire resistance, it appears the

fire service is asking for performance compatible with that of legacy construction, says Backstrom. "They are simply asking for a quantity of time that they have traditionally had, that they've based their tactics on for more than 100 years, and that they're familiar with—appoximately 30 minutes," he says.

**The importance of codes**

Reaching that 30-minute mark with lightweight construction would most likely mean some combination of expanded passive protection for wood components and active measures such as sprinklers, Backstrom says. So far, sprinklering has received the most attention through changes in relevant NFPA codes, such as NFPA 1, Fire Code™; NFPA 101®, Life Safety Code®; and NFPA 5000®, Building Construction and Safety Code®, that date back to 2006, as well as through more recent changes accepted by the ICC. In September 2008, the ICC passed its own residential sprinkler mandate for its International Residential Code®,which requires the installation of home fire sprinkler systems in all new one- and two-family dwellings effective January 1, 2011. "There is also a need for passive fire resistance by means of gypsum board, drop ceilings, or some of the spray- or brush-applied materials that have already demonstrated performance under an appropriate test fire resistance protocol—ASTM E119 or UL 263—used with steel building materials," Backstrom adds.

In fact, a 1992 NFPA report was an important step in assessing the impact of fire on lightweight construction and helped point the way to improvements such as better fastening for gusset plates used in truss systems. The National Engineered Lightweight Construction Fire Research Project–Technical Report: Literature Search & Technical Analysis,sponsored by the Fire Protection Research Foundation, offered a look at studies published over the previous 20 years relevant to fire safety analysis of lightweight wood construction. The report gathered and analyzed scores of existing studies and documents but found a paucity of useful information regarding the failure characteristics of lightweight components. The report suggested that "standardized test procedures and performance acceptance criteria must be developed, primarily to assist with determining modes of failure and warning signal prior to failure, and to support firefighting tactics."

Similar improvements are likely in the near future, says Solomon. "I believe you will see some form of protection measures, such as attachment of Type X gypsum wall board, residential sprinklers, or both, becoming a caveat for use of lightweight residential construction," he says.

Such steps tend to be unpopular with builders, however, because of what they describe as the cost and complexity of implementing them. Yeh, of APA–The Engineered Wood Association, also believes that the increased fire vulnerability of engineered products needs to be weighed fairly with all the risks faced by the fire service. "Any loss of a firefighter is unacceptable," Yeh says, "but in fact lightweight construction is only a small contributor to the dangers faced by crews."

NFPA codes include other construction-related requirements, and more could be added. NFPA 1, for example, discusses a Fire Fighter Safety Building Marking System that can be used by the jurisdiction to provide basic information about any structure. An information sign mounted at the front of the building captures basic data for firefighters, such as the nature and distribution of the building contents, as well as the type of building construction used. This concept is designed to let the incident commander make informed decisions about where and whether to deploy personnel.

The venues for debating any additional protection measures will take place in NFPA 5000®, Building Construction and Safety Code®, as well as in the Internal Residential Code and the International Building Code. Each of these codes has specific chapters and sections that focus on wood construction, so a change to mandate greater fire protection could potentially happen there, says Solomon.

Another initiative is reportedly in the works to raise the issue of passive protection of engineered components in a future ICC code-development cycle. According to Sean DeCrane, a battalion chief for the City of Cleveland and an IAFF representative to the ICC, a proposal has been filed for consideration at the ICC's October code hearings that would require light frame construction, as defined in the IRC, to be protected by 5/8-inch gypsum board. The exceptions would be crawl spaces less than three feet (1 meter) high, "or if residential sprinklers are installed," explains DeCrane.

The proposal would also include an open-ended alternative allowing the use of any other covering that would provide a 30-minute fire rating. "We provided that option as an encouragement for the marketplace," DeCrane adds.

**Sprinklers: A key to the solution**

NFPA's recently launched sprinkler advocacy effort, "Fire Sprinkler Initiative: Bringing Safety Home" (www.firesprinklerinitiative.org ), would also help limit the threat fire poses to lightweight residential construction. The initiative calls for requiring sprinklers in every new one- and two-family home in the United States, a goal supporters say can be achieved through codes, local mandates, and individual action.

Sprinkler advocates—with the fire service leading the charge—argue that the cost of including sprinklers in new construction is minimal, with an enormous safety benefit. "The cost of sprinkler systems to the home builder, in dollars per sprinklered square foot, averages only $1.61," says Lorraine Carli, NFPA's vice-president for Communication. This figure includes all costs to the builder associated with the system, including design, installation, and other costs such as permits, additional equipment, and water meter fees.

Even so, there is market resistance. "People will consider spending a lot of money on a kitchen upgrade or other amenity enhancements," says Solomon, "but they get really hung up on sprinklers."

About 400 communities across the country, including Scottsdale, Arizona, currently have some kind of sprinkler ordinance, and major home insurers offer up to a 20 percent discount on policies for homes that are sprinklered. Jim Ford, assistant fire chief and fire marshal with the fire department in Scottsdale, is in an ideal position to judge the potential role sprinklers can play in minimizing the fire hazard of lightweight construction. "Here it's pretty simple. We haven't had any room-and-contents fires that extended into the attic, and no collapses, over the past 20 years," he says.

That's thanks to a pioneering sprinkler ordinance in Scottsdale that went into effect in the mid-1980s and has since protected a total of some 45,000 structures in the city. At the same time, says Ford, his department has encountered fires that began outside a home and, after entering attics and crawl spaces in lightweight structures—that is, bypassing the sprinkler system—quickly precipitated a collapse. "In two of the last three fires of that type, we were seeing collapses as we arrived," he says.

Sprinkler advocates say that the increased presence of home fire sprinklers in NFPA codes and in other codes such as the Internal Residential Code, the code most states rely on for guidance in the residential construction, indicates that home fire sprinkler protection is becoming the national model. At the same time, though, they caution that widespread adoption will take time. Solomon says the code committees "know what people in the fire service are looking for." At the same time, he says, patience is necessary. "With so much construction like this having taken place over the last 25 years," he says, "there are no easy fixes."

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SIDEBAR

## Danger for Firefighters

According to NFPA Fire Analysis and Research Department statistics, 250 firefighters died of injuries suffered at structure fires from 1997 to 2006. Of those, 44 were killed inside buildings as a result of structural collapses, and another nine were outside and struck when walls collapsed. Of the 44 killed inside, 24 were killed in roof collapses in 14 fires, 17 in floor collapses in 13 fires, two in a wall collapse in a fire, and one in a ceiling collapse.

Full details on construction are not available for many of the collapse incidents, but trusses were involved in the collapse in seven incidents. These seven incidents claimed 12 lives. Five firefighters died in two roof collapses where wood trusses, described as pre-engineered wood and lightweight wood, were involved. Three firefighters were killed in two collapses involving lightweight wood floor trusses. And another was killed in a floor collapse involving open manufactured wood I-beams.

The National Institute of Occupational Safety and Health (NIOSH) points out that carpet, ceramic tile, lightweight concrete, and similar floor coverings may increase the danger to firefighters because they add weight to the floor system and because the insulation these materials provide may cause the floor to not feel warm, despite the fire beneath it.

NIOSH also stresses that engineered wood I-joists represent a rising technology in the building sector, since it offers certain advantages over traditional construction methods. Changes in the building construction industry, driven by technological advancements and societal needs, suggest that the use of engineered wood products will continue to grow, according to NIOSH.

SIDEBAR

### Here, there, everywhere

## The rapid rise of engineered wood products.

The use of engineered wood products has grown significantly in recent decades. According to APA–The Engineered Wood Products Association, engineered wood components saw their first commercialization in the 1960s but didn't enjoy widespread use until the 1980s. Since then, production has increased more than ten-fold, with the U.S. and Canada combining for 1.28 billion linear feet of engineered components in 2004, at the peak of the housing boom.

APA estimates that engineered I-joists (below) comprised 4 to 6 percent of the market in the 1980s. By 2002, surveys showed that I-joists had achieved 44 percent of single-family floors. APA estimates that 58 percent of I-joists are used in new residential floors, 24 percent are used in nonresidential building construction, and 18 percent are used in repair and remodeling projects.

Surveys conducted by the National Association of Home Builders Research Center indicate that, not counting concrete floors, I-joists were used to build 48 percent of the single-family floor area and 40 percent of the multifamily "raised" floor area in 2007. The remaining floors were built with lumber joists, lumber trusses, or steel joists.

**PHOTOS**

Anatomy of structural failure: The UL tests included two 300-lb mannequins to simulate a pair of firefighters in protective gear. In this photo, the basement fire below is causing the supporting joists to weaken; note the bowing of the floor.

A mannequin crashes through the floor as the supporting joists fail.

The view from below after a test, with the center of an engineered I-joist almost completely burned away by fire. (Photos: Underwriters Laboratories)

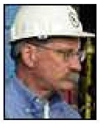
**UL TEST HIGHLIGHTS**

While most of the 100-plus page UL report on the testing of lightweight building components focused on engineering calculations, several key points emerged to clarify the fire performance of engineered wood components, including:

- Deflection times
  Although a computer model predicted that the test floor assembly using engineered I-joists would retain its strength longer during a fire than the traditional wood platform, the opposite was the case. Furthermore, the engineered wood supports began to fail and deflect almost from the start of the test and proceeded to degrade in stages, leading to floor vibration, noise, collapse, and burn-through.
- Charring
  The rate at which engineered wood and traditional wood chars is similar. However, because of the very thin cross section of the I-beams, the report found that this charring rate poses immediate dangers to the mechanical integrity of the structure.
- Heat sensitivity
  Oriented strand board beam sections exhibited initial charring at a much lower temperature than traditional wood, making it impossible to further test some properties of the material.
- Heat conduction
  Due to compressed plies and binding material, the engineered samples conducted heat faster than other wood samples.
- Brittleness

Engineered wood product samples exhibited increased brittleness and loss of mechanical strength compared with traditional wood components when heated in an oven, even without being exposed to fire. Researchers suggested this was due to separation of the constituent compressed fibers under mechanical and heat stress.

**AUDIO**



Bob Backstrom senior staff engineer with Underwriters Laboratories on the UL flamability test of lightweight contruction products.

- The origins of the UL test?
- The results of the test
- Surprises in the test results?
- Mitigating factors in the inherent fire issues?
- More audio clips

**RELATED INFORMATION**

- For the complete UL report on the burn tests conducted on lightweight engineered wood assemblies, and for more information on lightweight construction and fire, email Bob Backstrom at UL at Robert.G.Backstrom@us.ul.com.
- National Research Council of Canada fire report.
- "Structural Stability of Engineered Lumber in Fire Conditions" an online fire service training course based on the UL report.