



## PROTECTING CRITICAL BUILDING CIRCUITS FROM FIRE – NEW STANDARDS AND DESIGN APPROACHES



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**Abstract** – Fire safety codes and standards date back to the nineteenth-century development of automatic sprinklers.<sup>1</sup> In 1895 a small group of sprinkler and insurance representatives created an association, now recognized as the National Fire Protection Association (NFPA), to classify and standardize a wide range of fire protection equipment such as sprinklers, hoses, hydrants, and extinguishers, as well as building materials such as doors, windows and woods. Soon thereafter in 1897, the NFPA published the world's first National Electrical Code (NEC) to also standardize electrical safety for wiring, alarms, and related equipment.<sup>2</sup> Since then, fire safety and electrical codes and standards have been adopted worldwide and continuously improved to help ensure best methods and practices for designing buildings.

**One area of primary importance in building design is the protection of critical electrical circuits such as alarms, emergency lighting, electrical fire pump feeds, emergency generators and air handlers as well as electrical feeds for emergency elevators.**

Architects and engineers have a multitude of ways to design and construct such critical circuits. With over 100 years of history, codes and standards have been put to the test many times. **As building designs, materials and construction methods have evolved, so too have the codes and standards.**

**This paper focuses on several very important recent fire and electrical code changes as they apply to critical circuits.**

Alternative technologies are evaluated and compared. In particular, electrical cables specifically designed to withstand fires are compared and contrasted with historical and untested construction methods that create barriers and protection encasements for conventional cables.

**Index Terms** – NFPA, NEC, fire protection, fire rating, fire resistance, fire test, critical building circuits, mineral insulated cables, construction methods, concrete, gypsum.

## INTRODUCTION

This paper presents a new and unique approach for protecting critical electrical circuits in buildings. Recently updated NFPA standards such as NFPA 20, NFPA 70, NFPA 72, NFPA 101, NFPA 110 and others<sup>3-9</sup> provide general world-wide principles for protecting electrical apparatus and emergency systems. Specifications and recommended selection criteria for electrical wiring survivability during fires are common to all of these standards. Together with the required product and equipment safety approvals and certifications required by the local reviewing authorities, manufacturers can now provide written confirmation that their equipment has been tested for critical circuit applications. Building architects, engineers and designers likewise have several options for implementing

critical circuit designs throughout their building designs.

### A. Typical Building Critical Wiring Systems

Critical electrical circuits exist in a wide variety of buildings, tunnels, subways and other structures. Protection of emergency electrical conductors is required to ensure that electrical power is maintained for emergency equipment in the event of a fire. The operation of these systems is critical to the life safety of the occupants of the building as well as for firefighting purposes. Figure 1 depicts several typical critical systems in buildings. For example, fire alarm and emergency lighting systems, backup generators, pressurization fans for emergency exits and stairwells, smoke extraction fans, fire pumps, and firefighters' elevators all require electrical systems to operate during fires.

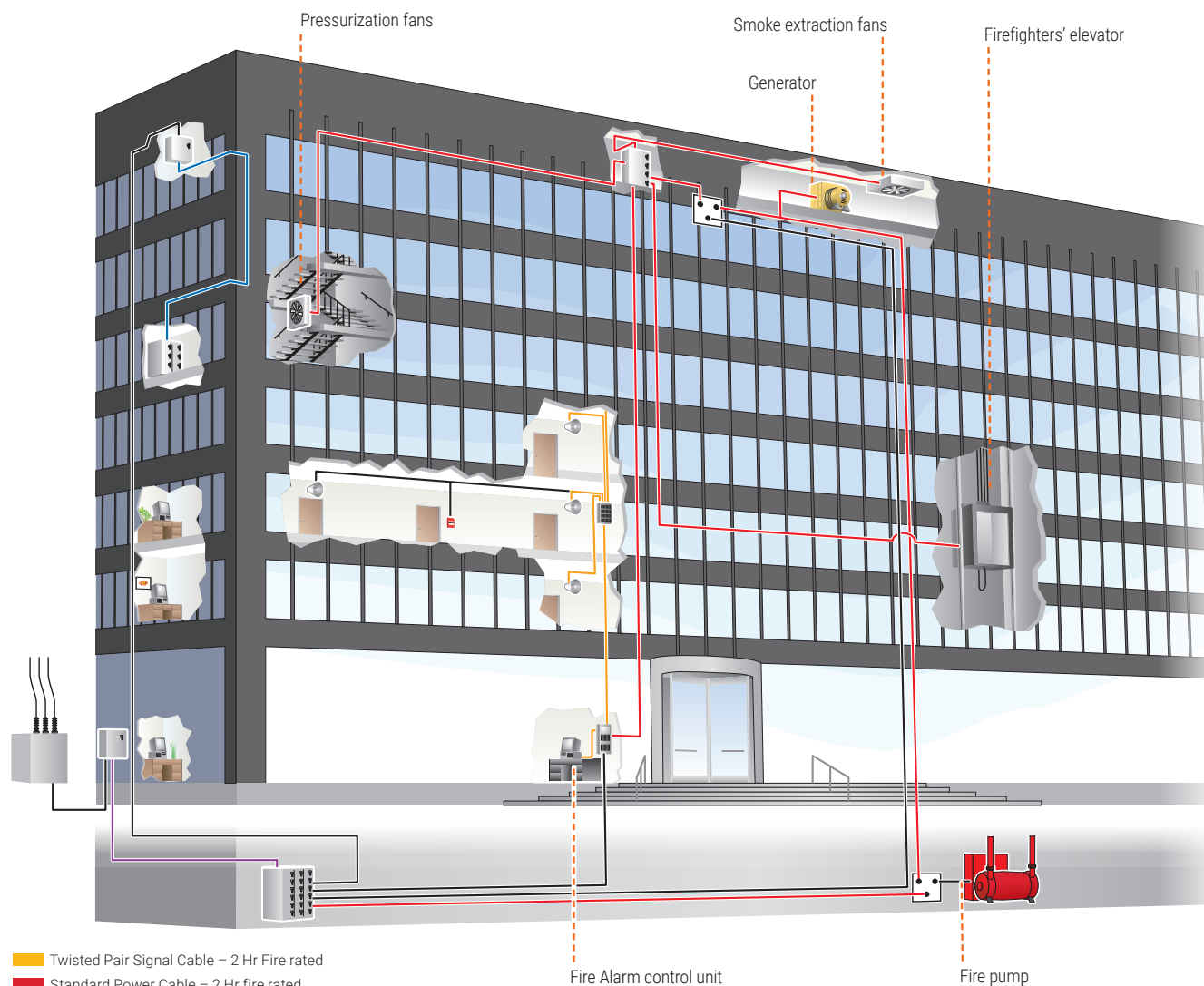


Figure 1. Typical Critical Wiring Systems in Buildings

THE COMMON  
ELEMENT IN  
ALL OF THESE  
STANDARDS  
IS THAT THE  
CABLE SYSTEMS  
HAVE MOVED  
FROM 1 HOUR  
TO 2 HOUR  
SURVIVABILITY.

This protection is necessary to extend evacuation time improve reliance on firefighting safety equipment, and to maintain alarm system operation and pressurization equipment.

Typically, a 2-hour fire-resistance rating is required depending on national and local codes, the type of circuit, and the environment. To ensure that these systems will be provided with electrical power for the required period, the conductors providing emergency power must also be operational during this time.

Unfortunately, numerous building, tunnel and subway fires around the world with resultant failures of emergency systems have prompted standards associations and certifying agencies to review and update fire standards and testing methods to better meet safety needs. In many cases, the system failures were attributed to the failure of electrical wiring which caused emergency equipment to lose power and endanger the lives of the occupants. As building designs have gotten larger and taller, tunnels longer and subway systems more densely populated, the demand for emergency system reliability has greatly increased.

#### B. Code Requirements

Code requirements for critical circuits are covered in the following 7 NFPA Codes:

- NFPA 20: "Stationary Pumps for Fire Protection"

- NFPA 70: "National Electrical Code"
- NFPA 72: "National Fire Alarm Code"
- NFPA 101: "Life Safety Code"
- NFPA 110: "Emergency and Standby Power System"
- NFPA 130: "Standard for Fixed Guideway Transit and Passenger Rail Systems"
- NFPA 502: "Road Tunnels, Bridges, and Limited Access Highways"

In Canada, the National Building Code has similar requirements.

The following systems and circuits are required to operate for a minimum of 2-hours during a fire:

- Emergency power supply generator to transfer switch circuit and transfer switch to emergency distribution switch board circuit.
- Firefighter's elevator circuits
- Fire pump circuits
- Pressurizing fans and smoke damper circuits
- Smoke venting fans
- Emergency power for lighting and exit signs must be available for safe egress and must also be sufficiently illuminated.
- Fire alarm survivability and notification circuits

Consistent with the latest NFPA requirements, the NEC has updated its survivability requirements as follows:

- Article 695 "Fire Pumps" requires 2 hour protection per 2008 NEC
- Article 700 "Emergency Systems" requires 2 hour Protection per 2011 NEC
- Article 708 "Critical Operating Power Systems" requires 2 hour Protection per 2011 NEC
- New Article 728 "Fire-Resistive Cable Systems" in 2014
- Article 760 "Fire Alarm Systems" requires 2 hour Protection per 2005 NEC
- NFPA 72 "Fire Alarms" requires 2 hour "Survivable Circuit" and cables must be installed per Article 760

The common element in all of these standards is that the cable systems have moved from 1 hour to 2 hour survivability.

### National Electrical Code® in Effect April 01, 2018

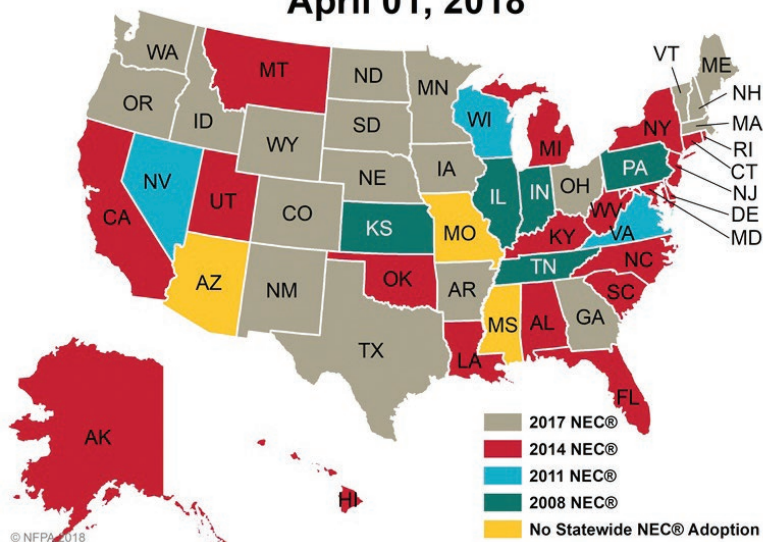


Figure 2. US NEC Adoption by State

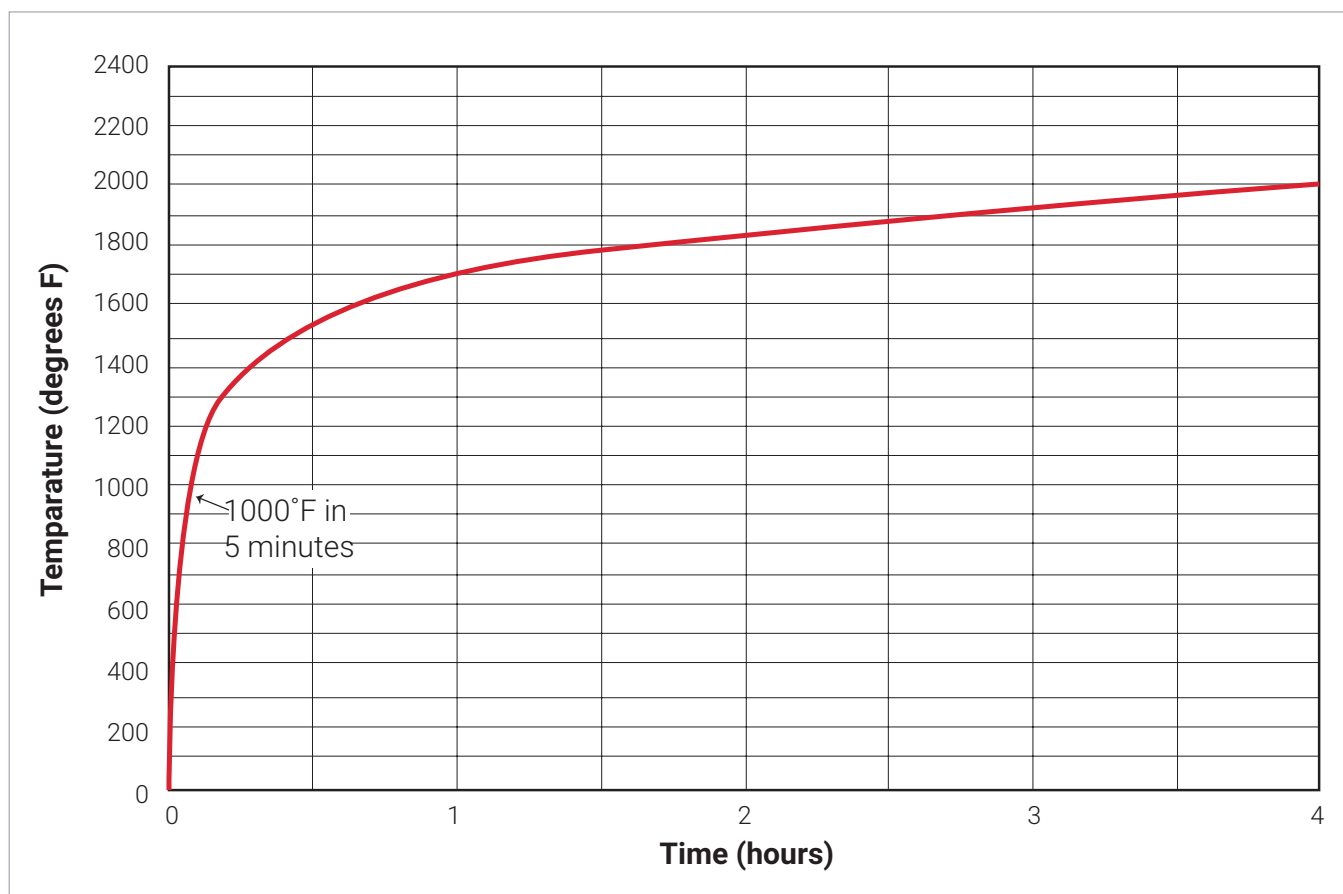


Figure 3. ASTM E119 Time/Temperature Curve

In the US, the NEC is updated every three years. However, adoption is up to individual states. Figure 2 indicates the level of adoption as of April, 2018.

As of April, 2018 only 19 states have adopted the latest 2017 requirements, but 42 states mandate a minimum 2-hour fire rating.

### 2-HOUR FIRE RATED SYSTEMS

To be recognized as a 2-hour system, circuits must operate and be protected for a minimum of two hours during a fire test as specified by ASTM E119. The ASTM E119 temperature profile is intended to represent a fully developed interior building fire.

The test temperatures ranges from 1000°F (537°C) at 5 minutes to 1850°F (1010°C) at 120 minutes rising as indicated in Figure 3.

To achieve these temperatures, specialized test furnaces are utilized for various types of materials and products. There are two ways to achieve 2-hour fire protected

circuits. The first is the use of fire-resistive cable systems that have been tested and certified by a testing agency according to a test standard such as UL 2196. The second way is to use construction methods to bury or enclose standard cables with building materials that are likewise tested and certified to meet a 2-hour fire test. It should be noted that cables protected using construction methods to achieve a 2-hour fire rating are not tested or approved as a system to verify cable integrity. Only the materials encasing the cables are tested. This can create some confusion and design concerns by architects and engineers.

### FIRE-RESISTIVE CABLE SAFETY AND COMPLIANCE

#### A. UL 2196 / ULC S-139 2-Hour Cable Test

The UL 2196 / ULC S-139 2-hour cable testing standard is quite rigorous and consists of a specific type of fire exposure followed by a water hose stream. Cables are energized



TO DATE,  
MINERAL  
INSULATED  
COPPER-CLAD  
CABLES (MI  
CABLE) ARE  
THE ONLY  
CABLES  
THAT MEET  
THE 2-HOUR  
VERTICAL AND  
HORIZONTAL  
UL FIRE TEST  
WITH NO  
LIMITATIONS.



Figure 4. UL 2196 Cable Test Wall



Figure 5. UL 2196 Test Furnace

during the fire test and after the hose stream to prove circuit integrity is maintained throughout.

The UL/ULC test standard uses the ASTM E119 curve during testing. A very important part of the UL/ULC test is to detect electrical failure of the cable.

Figures 4 and 5 are pictures of typical test walls and furnace used to conduct the cable testing.

Testing consists of mounting the cables and supports as specified by the manufacturer then powered at 600 V line to line / 347 V to ground. The 10 ft by 10 ft (3 m by 3 m) furnace produces the ASTM E119 fire temperature for 2-hours. Within 5 minutes of the fire test completion, power is disconnected and the wall is sprayed with the fire hose per UL requirements of 30 PSI and application duration of 0.9 seconds per square foot of exposed area. Once water testing is complete, power is re-applied to the electrical circuits. The test is considered passed when the test circuits re-engage the lights.

Both horizontal and vertical installations are individually tested across 10 ft (3 m) spans (including bends) and includes

splices if included as part of the listing per manufacturers installation guide.

Upon satisfactory testing, the cable system listing identifies:

- Installation requirements
- Manufacturers latest updates / changes
- Conductor sizes and configurations tested
- Splices if tested, and types of splices
- Support materials (steel, masonry or concrete) and method
- Horizontal distance between supports
- Vertical distance between supports

In some cases, cable listings are limited to specific orientations, sizes, and mounting methods.

The above noted code changes were implemented as a result of testing and research findings noted back in 2012<sup>10</sup>.

To date, mineral insulated copper-clad cables (MI cable) are the only cables that meet the 2-hour vertical and horizontal UL fire test with no limitations. Due to the wide variety and types of fire-rated cables, all cables and cable accessories must be carefully selected according to the agency listing and manufacturers' installation instructions and limitations.

## CONSTRUCTION METHODS OF ELECTRICAL PROTECTION

As noted earlier, cables can also be protected by encasing them in concrete, burying the cables surrounding the cables with drywall / gypsum board, or running the cables through concrete blocks. Each of these methods requires specialized techniques for design and installation to ensure the desired level of fire rating.

### A. Raceways Embedded in Concrete

This method of protection involves the installation of a raceway or conduit for the emergency conductors within the concrete such as in the floor or shear wall. (Figure 6)

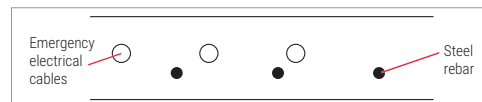


Figure 6. Section Through Reinforced Concrete Slab

APPROXIMATELY  
2.5 TO 3.5  
INCHES OF  
CONCRETE ARE  
REQUIRED FOR  
ONE HOUR FIRE  
RESISTANCE  
AND FOUR TO  
FIVE INCHES  
ARE REQUIRED  
FOR TWO HOURS

Factors which affect the fire-resistance rating of this protection method are:

- type of concrete used
- thickness of concrete cover achieved in the field

One of the advantages of concrete over other building materials is its inherent fire-resistive properties.<sup>11</sup> However, a rise in temperature will cause a decrease in steel reinforced concrete strength and modulus of elasticity. Fires will also cause structural components to expand resulting in increased stresses and strains. Building codes for structures are often focused on concrete strength requirements separately from fire resistance requirements. Thus concrete thicknesses for strength requirements are often less than those needed for fire resistance.

Reinforcing steel is significantly more sensitive to high temperatures than concrete. Hot-rolled steel reinforcing bars retain much of their yield strength up to about 800° F (427°C) whereas cold-drawn steel rods lose strength at only 500°F (260°C). Depending on the type of concrete and coarse aggregate used, concrete strength and insulating effects can dramatically change. For example, concrete containing siliceous aggregate will lose approximately 55% of its strength at 1200°F (650°C) whereas concrete with lightweight and carbonate aggregates retain most of their strength to 1200°F (650°C).

Fire Resistance Rating					
Concrete Type	1 Hour	1.5 Hour	2 Hour	3 Hour	4 Hour
Siliceous aggregate	3.5	4.3	5.0	6.2	7.0
Carbonate aggregate	3.2	4.0	4.6	5.7	6.6
Sand-lightweight	2.7	3.3	3.8	4.6	5.4
Lightweight	2.5	3.1	3.6	4.4	5.1

Table 1. Minimum Thickness (inches) for Cast in Place Floor and Roof Slabs <sup>12</sup>

Two inches of concrete has historically been considered adequate for 1-hour fire resistance. But as indicated in Table 1, concrete type and thickness can dramatically affect fire resistance.

Note that approximately 2.5 to 3.5 inches are required for one hour fire resistance and that four to five inches are required for two

hours. These thicknesses should be taken into account If concrete is being used to protect electrical cables either by embedding conduit/cables within floors or walls or by using concrete blocks or building concrete vaults or shafts.

It should be repeated that the fire ratings for concrete are based on structural strength testing and are not specifically meant as an indicator of electrical cable protection. Electrical cables all have temperature ratings based on their jacket insulation. Polymeric cables, for example, will typically have temperature ratings between 170°F (75°C) to 400°F (200°C). Figure 7 shows the temperature gradient in a 6 inch (152mm) concrete slab after a 2-hour fire exposure.

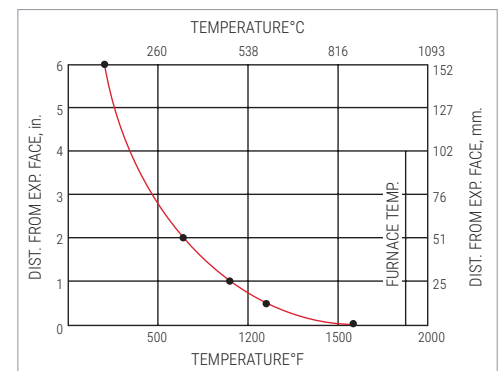


Figure 7. Concrete Slab Temperature Gradient After 2-Hour Fire Exposure. 2008 NFPA Handbook 19.2.2

Note that after 2-hours, the concrete surface 2 inches (50mm) below the concrete surface is 675°F (357°C) which is far greater than the rating of polymeric cables. That is why 2 inches (50mm) of concrete is considered 1-hour protection and 4 inches (100mm) is recommended for 2-hour protection.<sup>11</sup>

Encasing conduits in concrete requires proper coverage throughout the entire circuit. Note that 2 inch or 4 inch protection must be provided on all sides of the conduit. Encasing a 2 inch conduit in a slab floor implies a 6 inch building floor (2-inch concrete times two, plus 2-inch conduit). This only provides a 1-hour fire rating. To achieve a 2-hour rating requires at least a 10 inch concrete floor (4 inch concrete times two, plus 2 inch conduit) which is considered large. Moreover, this method, as with other construction methods, is not a listed system for cable fire protection. Encasing conduit in concrete is also very difficult after the fact when retrofit work has to be done.<sup>12</sup>



## B. Gypsum Board Enclosures

Gypsum has outstanding fire-resistant properties. When exposed to high temperatures, chemically combined water in the gypsum is gradually released, providing protection until all of its water is completely

driven off. The fire resistance and relative low cost of gypsum panels made gypsum board enclosures a popular choice for fire protection of life safety electrical circuits.<sup>14</sup>

Gypsum boards of different core formulation are fire-rated from one to four hours. By adding layers of gypsum panels to each side of the studs, the fire resistance of virtually any wall can be increased.

Several significant issues arise when using gypsum board enclosures to protect cables. One is the complexity of designing and constructing fire-resistant walls and shafts that are effective in producing 2-hour fire rating along the entire length of the cable system. Wall and floor penetrations, for example and cable entries and exits from the gypsum enclosures, can be particularly complex to design to prevent fire penetrations.

Secondly, gypsum enclosures have been tested for their resistance to fire, but have never been tested or listed for their protection of electrical conductors.

Thirdly, there are many construction/inspection issues of gypsum enclosures. Different gypsum panel types vary in fire resistance. Gypsum enclosures must be evaluated as an assembled system. In addition, it is essential that the assembly built in the field is representative of the one tested. Given these concerns, many industry experts consider fire-resistant assembly design and construction to be among the most complicated issues facing today's architects and specifiers.

## C. Concrete Shafts with Gypsum Separators

Gypsum boards are often used within concrete vertical shafts to separate standard electrical distribution wiring from life safety wiring (Figure 8).

Since wall and shaft way systems involve a number of products and materials. To meet fire safety requirements, assembly details must be taken into account, including: type and thickness of concrete or concrete block, size of framing members; number of fasteners; type of joint compound and finish; and fire-stopping materials to address penetrations that breach the panel wall.

This common practice is not listed, difficult to build, craft sensitive, subject to deterioration, consumes valuable space and is not as cost effective as using 2-hour fire rated cable for the life safety wiring. (Figure 9)

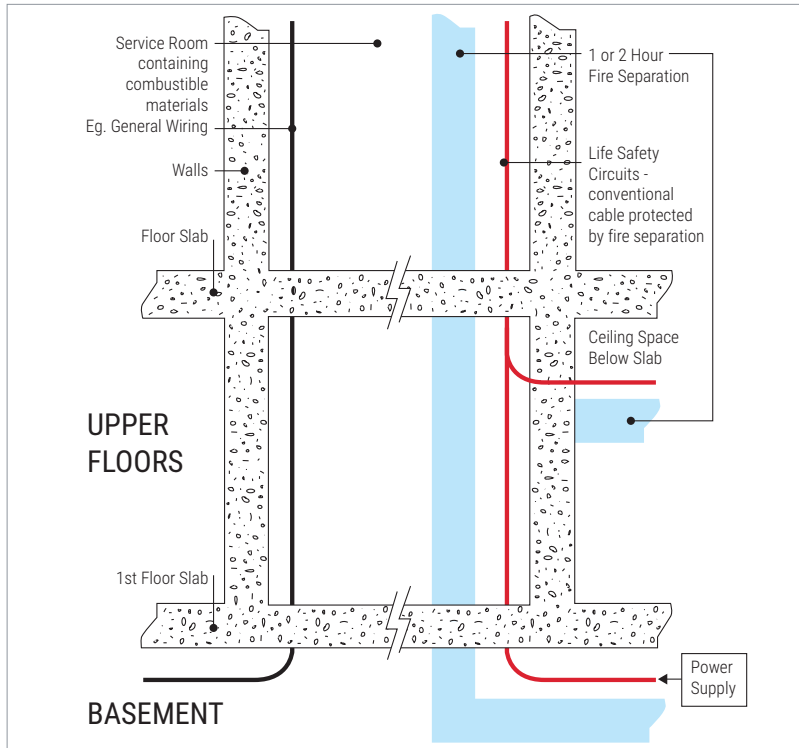


Figure 8. Distribution and Life Safety Wiring Separated by Gypsum Board in Concrete Shafts

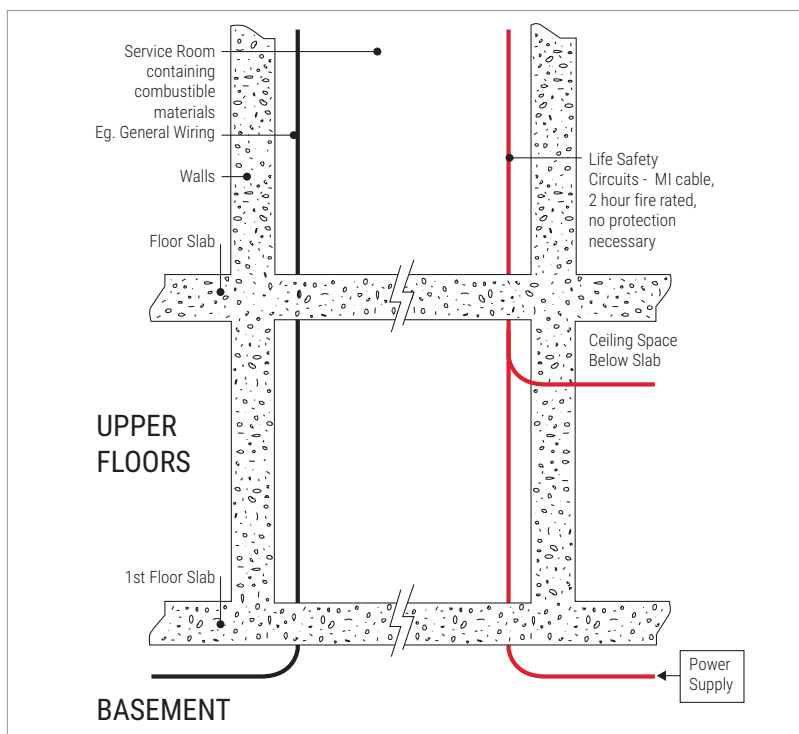


Figure 9. Vertical Shaft with Distribution and 2-Hour Rated Life Safety Wiring

DESIGNS  
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Designs using such construction methods to provide 2-hour cable ratings are not tested or approved in their final installed state and often lead to misapplied or inadequate protection. Two example field deficiencies are illustrated in Figures 10 and 11.



Figure 10. Inadequate Cable Penetration of Fire Protection Enclosure



Figure 11. Improper Gypsum Board Enclosure Installation

#### D. Performance Issues

Concrete walls, floors and ceilings and gypsum board assemblies are tested as a building material, not as a protection of electrical conductors. The test only stipulates a maximum temperature at the back (or inside) of the enclosure wall, which, it turns out, will exceed most standard cable capabilities.

According to the UL/ULC wall and partition system test criteria surface temperatures are measured at a minimum of nine locations on the unexposed side of the gypsum test specimen. During the test, the average temperature is not permitted to increase more than 250°F (121°C) above ambient nor is any individual thermocouple permitted to rise more than 325°F (163°C) above ambient. Assuming an ambient temperature of 70°F (21°C), the average temperature of the unexposed surface would be 325°F (163°C) with a maximum temperature of 395°F (202°C). Most conventional wiring is rated 194°F (90°C) which is well below

the allowable gypsum/concrete test temperatures. In some cases a temperature as low as 248°F (120°C) can cause PVC failure. Very few, if any, polymeric cables are capable of withstanding the temperatures permitted by concrete or gypsum board testing.

As pointed out earlier, gypsum shaft assemblies are highly complex and difficult to make properly. They are not listed for electrical cable protection. They are very trade sensitive and are subject to subsequent damage. Use of concrete to protect electrical cables is sensitive to the specific types of concrete, aggregate, reinforcing steel and thickness. In some cases the concrete thickness needed for structural integrity can be dramatically inadequate for fire protection, particularly of standard electrical cables.

One of the many lessons learned in the tragic 1991 high-rise fire in Philadelphia, which resulted from major failures in nearly all fire protection systems, was the importance of having truly independent emergency electrical systems. Primary and secondary electrical risers had been installed in a common enclosure, which led to their almost simultaneous failure when fire penetrated wall voids above the ceiling of an electrical closet. The then-current 1990 National Electrical Code recognized separate feeders as a means of supplying emergency power, but those services needed only to be “widely separated electrically and physically.” Since then, the NEC has required dedicated enclosures for life safety circuits.

It is this requirement for separation between normal and emergency feeders that encourages the use of concrete or gypsum enclosures; yet the same effective separation can be more easily and cost effectively achieved by using a 2-hour fire-rated MI cable, while avoiding all the issues surrounding drywall enclosures.

#### E. Economics

Despite the challenges of specifying and constructing concrete or gypsum board enclosures and their questionable performance in protecting standard cables, economics are often cited for choosing construction methods over fire-rated cables.

Studies<sup>14</sup> have shown that the cost of using concrete or gypsum panel enclosures for 1-hour fire protection compared to using



fire-rated cables is comparable. When designing for a 2-hour rating which is now the norm, the cost of using 2-hour rated wiring for life safety circuits is less expensive.

These comparisons depend on many factors including the size and type of conductors, accessories, enclosures and labor rates. However, architects and engineers are advised and will find it worthwhile to do their own economic evaluation for their specific cases by considering the use of fire rated cables. Costs, however, are not the only issue in specifying fire-rated life safety circuits. With the trends towards increased survivability of critical circuits and the widespread availability of fire-rated cables, considering their use is a wise decision. Furthermore, the growing vigilance regarding fire protection code compliance on the part of authorities and the growing trend towards using only 2-hour rated life safety systems makes using fire-rated cables a great way to reduce any concerns about construction method deficiencies.

## CONCLUSIONS

For over 100 years, fire safety codes and standards have been instrumental in saving lives and property by recommending best methods and practices for designing buildings, including building materials and electrical systems. Driven by incidents of high-rise fires and failures of critical life safety circuits, agencies have continuously improved their fire safety standards. Building materials, electrical systems, and fire safety systems have also continuously improved. For example, fire alarm systems, sprinklers, smoke management technologies, fire separations, flame spread of construction materials, and electrical cable technology have improved hand in hand with codes and standards evolution.

Whether designed for commercial buildings, health facilities or airports, the systems specified by architects and engineers are increasingly complex when it comes to fire protection. It is a serious responsibility on the part of professionals to make sure that all building life safety systems are designed and synchronized to function when needed. In particular, today's modern buildings utilize a wide variety of monitoring sensors, communication devices, sophisticated emergency lighting, annunciation, air and

water handling equipment that depend on reliable wiring for uninterrupted powering and communication during the first few hours of an emergency. With the availability of new fire-rated products, particularly 2-hour fire rated wiring, plus a discriminating understanding of fire-rated construction methods, building professionals are equipped to specify the safest systems.

## REFERENCES

1. History of the NFPA Codes and Standards – Making System, NFPA Journal, 1995
2. NEC – History and Purpose, Mike Holt, 1999
3. NFPA 20: "Stationary Pumps for Fire Protection"
4. NFPA 70: "National Electrical Code"
5. NFPA 72: "National Fire Alarm Code"
6. NFPA 101: "Life Safety Code"
7. NFPA 110: "Emergency and Standby Power System"
8. NFPA 130 : "Standard for Fixed Guideway Transit and Passenger Rail Systems"
9. NFPA 502: "Road Tunnels, Bridges, and Limited Access Highways"
10. Where Are We Now? Two-Hour Fire-Rate Cable, Thomas P Hammerberg, 2015
11. Construction Fire Protection Methods, Pentair 2013
12. Fire and Concrete Structures, David N. Bilow, Mahmoud E. Kamara, ASCE Structures Congress 2008
13. Fire Resistance of Reinforced Concrete Buildings, CRSI Technical Note, 2016
14. Achieving Fire Protection of Electrical Life Safety Circuits, Barry O'Connell, 2009

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