

ARCHITECTURAL RECORD

Getting Down to the **Wire**

**LIGHTS, COMPUTERS, PHONE SYSTEMS—
THE WIRES THAT POWER OUR BUILDINGS
ARE MADE OF A TANGLE OF MATERIALS
THAT RAISE ENVIRONMENTAL AND
HEALTH QUESTIONS.**

By Alex Wilson

Even the greenest of architects seldom give much consideration to wiring in buildings. How significant can wiring be? It's just a small fraction of what's installed compared to other building materials—and don't fire codes more or less dictate what can be used? But some sleuthing about how wiring is made and used in buildings sheds light on a highly complex issue and points up a need to pay closer attention to today's practices, from environmental, health, and safety standpoints.

All modern buildings, of course, require wires and cables for power distribution and to carry voice and data signals. The term *wire* refers to an individual strand of material that conducts electrical current, whereas *cable* refers to two or more wires twisted together. Virtually all wire and cable used in buildings is wrapped in plastic insulation, and most of these components are made by bundling multiple insulated wires together, sheathing them in an additional outer jacket. Insulated wire and cable come in a large variety of types, and there are many performance standards and ratings that govern how and where they can be used. In the U.S., insulated wire and cable represents an annual \$20.5 billion market that is projected to grow by more than 5 percent per year through 2006, according to a 2002 report from the Freedonia Group. There are an estimated 11 million miles of data cabling in U.S. buildings today.

In general terms, power cables in commercial buildings must be either sheathed in metal armor (BX cable) or protected within metal conduit. In residential buildings, power cables can be jacketed in plastic; this type of cable is commonly referred to by a trade name, Romex (made by the Southwire Company). Data or communications cables can be installed in

most buildings without metal protection, but a specialized plenum rating is required for installation in ceiling and floor plenums.

Many materials coming together

Copper is the dominant conductor used in insulated building wire and cable. Though less common, aluminum wire is also used; it's lighter and less expensive than copper, but also less conductive, so more material is required for the same electrical capacity. Fiber-optic cable, which is made of glass, is increasingly used for data and communications applications commonly served by insulated wire and cable. Fiber optics transmit light signals instead of electricity to carry data—and they're lighter, less expensive, and more energy-efficient than copper for data transmission. Because they don't carry electric current, insulation requirements are not as great as for metal conductors.

Copper and aluminum wires and cables are typically insulated with a nonconductive material that allows wires to be in contact with one another without conducting electric current between them. The most common resins used for insulating wire are polyethylene (PE), polyvinyl chloride (PVC), and fluoropolymers. Nylon, various rubber compounds, silicone, and polyurethane are also used for insulation and jacketing, but less widely.

Polyethylene is the most common type of insulation and jacketing for high-voltage power-transmission cables, as well as for non-plenum-rated data cables, radio frequency wiring, and audio wiring. It has excellent dielectric properties (that is, it insulates well) but is inherently less flame resistant than other insulation materials. As a result, it's rarely used for power in buildings, and when used, other materials are often added to it to improve its flame resistance. It is widely used for data cable installations requiring no flame resistance, such as wire runs in conduit or behind fire-rated barriers.

Alex Wilson, the president of BuildingGreen and the executive editor of Environmental Building News, has written about energy-efficient and environmentally responsible design and construction for more than 20 years.

Polyvinyl chloride (PVC) is the most common insulation and jacketing material for wiring in buildings, owing largely to its good flame resistance and low cost. In Romex-type wiring, for example, PVC is typically used both as the insulation on individual conductors and as the jacketing that surrounds the bundle of individual wires. PVC has significantly greater flame resistance than polyethylene, but other additives are required to make it flexible and stable.

In the past 10 years, PVC has come under attack by several groups because of a variety of health and environmental concerns. The biggest concern is that under certain conditions, highly toxic dioxins can be released—especially from accidental fires or incineration at the end of its life. According to the National Institute of Environmental Health Sciences (NIEHS), dioxins are known to be toxic to laboratory animals, causing cancer and altering reproductive, developmental, and immune functions. There are also concerns about the need to add stabilizers and plasticizers to PVC, some of which have health impacts, and PVC also releases hydrogen chloride, a toxic, corrosive gas, when exposed to extreme heat—both before and after it ignites.

Various fluorine-containing polymers, especially fluorinated ethylene propylene (FEP), are increasingly common in data wiring insulation because of their exceptional dielectric properties, superb flame resistance, heat resistance, chemical inertness, durability, and flexibility. For plenum-rated data cable, FEP-insulated wire is often the only option allowed by code, due to fire-safety concerns. Such wire is often wrapped in a PVC jacket, though newer, more stringent “limited combustible” ratings require FEP jacketing. In addition to these performance benefits of FEP, the polymer can be recycled easily, according to DuPont.

While superb performance has spurred rapid growth of FEP wire insulation, some significant environmental and health concerns have arisen about the whole class of fluoropolymer materials (see sidebar at right). FEP does not burn easily, but it can emit toxic gases when it gets very hot, even without actual combustion. The primary gas emitted is hydrogen fluoride, which is more dangerous than the hydrogen chloride given off by PVC. Other toxic chemicals can be given off by FEP during fires; these poorly understood thermal degradation products have been referred to collectively as “the supertoxin.”

In addition to toxicity concerns, the chemicals emitted by FEP (and to a lesser extent by PVC) during a fire are highly corrosive. An article by Stephen Saunders, “Cabling: What You Don’t Know Can Kill You” (posted at www.wireville.com), suggests that it is the corrosivity of halogen-insulated wiring that may ultimately shift us away from halogen-based wire insulation and jacketing. Frank Bisbee, a data cable consultant and editor of www.wireville.com, suggests that how good or bad a particular type of cabling looks—relative to toxicity and potential for corrosive by-products to cause damage to electronic equipment—is highly dependent on how the tests are performed. If humidity during testing is very low, for example, there won’t be enough water vapor to convert hydrogen fluoride into hydrofluoric acid, or hydrogen chloride into hydrochloric acid, and acid corrosion will be less of a problem. Depending on the amount of oxygen present during a fire, the resultant emissions will vary tremendously, he says.

Making wires workable

To make insulated cables easy to manufacture and safe for buildings, three additives—plasticizers, stabilizers, and flame retardants—are typically added to insulation and jacket materials.

Plasticizers are usually added to PVC to make it flexible enough to be used to insulate wires. The most common plasticizers used in PVC are phthalate compounds, which have come under scrutiny because their chem-

The Fluorine Debate

Fluorine, chlorine, and bromine all belong to a family of elements known as halogens. Halogens form strong chemical bonds, which makes the resultant compounds durable and often inert—but their longevity also allows them to accumulate in biological systems. Many halogenated compounds have been demonstrated to be toxic in laboratory tests.

There is growing evidence that fluoropolymers, comprised almost entirely of carbon and fluorine, pose health and environmental dangers. According to some environmental and health advocates, they may be a worse threat than chlorinated polymers such as PVC.

Fluoropolymers go by many different names, but the family of chemicals is often referred to as perfluorochemicals (PFCs). They are synthetic chemicals that don’t occur naturally in the environment, and they exhibit properties that have made them useful for a wide range of applications, from nonstick surfaces to stain-shedding fabric treatments to wire insulation.

In April 2003, the U.S. Environmental Protection Agency (EPA) released a preliminary risk assessment for perfluorooctanoic acid (PFOA), one type of PFC, noting that “studies recently evaluated by the agency have raised a number of potential toxicity concerns.” The agency has solicited information about PFOA from the industry and the scientific community, and fluoropolymer manufacturers have voluntarily agreed to reduce emissions, to study their products to determine if they contribute to the widespread PFOA pollution, and to take steps to reduce worker exposure during manufacturing.

Several recent peer-reviewed papers in the journal *Environmental Health Perspectives* also detail the potential health impacts of PFCs. A September 2003 paper entitled “Neuroendocrine Effects of Perfluorooctane Sulfonate (PFOS) in Rats” presented evidence that PFOS can function as an endocrine inhibitor. In the December 2003 issue, another paper showed that out of 645 blood samples collected at random from six Red Cross blood banks around the country, all but one had measurable levels of PFOS.

Industry response to these concerns has been mixed. In the late 1990s, manufacturer 3M discovered that PFOA, used in producing its popular Scotchguard fabric treatment, was showing up in humans and wildlife worldwide, and in May 2000, the company announced it was voluntarily pulling it off the market. DuPont, which had purchased PFOA from 3M, has continued to produce the chemical to fuel its \$1.5 billion fluoropolymer business. DuPont downplays health and environmental concerns about PFOA, but also points out that its Teflon products, such as FEP, use PFOA in manufacturing but don’t contain the compound in the finished product. While DuPont claims that its fluoropolymer products are safe, the company also posts some consumer warnings on its Web site. A.W.

ical composition mimics natural hormones in humans and other animals, causing reproductive problems and birth defects. Unlike PVC, polyolefins used for wire insulation do not require the use of plasticizers.

Stabilizers are added to some plastics to increase resistance to heat, sunlight, moisture, and other stressors. The most common stabilizers used in insulation and jacketing are lead compounds, which can constitute 2 to 5 percent of the total weight of the material. PVC is the only widely used resin for which lead stabilizers are needed. Other stabilizers beginning to appear on the market include salt-metal blends, such as barium-zinc and calcium-zinc; organotin compounds; and metal-free organic compounds. Cable manufacturer Mohawk/CDT is one of the companies shifting to lead-free PVC; according to Michael Rubera, Mohawk's director of technical support, the company primarily uses polyolefin insulation and lead-free PVC jacketing on its non-plenum-rated data cables.

Flame retardants are added to plastics to slow the spread of a fire, reduce the amount of heat and smoke emitted during a fire, and cause a fire to self-extinguish. They operate by different means. Some retardants reduce the fuel content of the material, for example; others raise the decomposition temperature of the polymer by more tightly bonding the molecules; still others emit water at high temperatures.

PVC and fluoropolymer resins are inherently flame resistant due to their halogen content, but the plasticizers added to PVC are not, so additional flame retardants have to be added to PVC for use in some wiring applications. FEP is more flame resistant than PVC, but the hydrofluoric acid released when it's exposed to heat is more toxic than the hydrochloric acid released by PVC.

Three classes of flame retardants are commonly used in wire and cable insulation: halogenated compounds (based on bromine, fluorine, or chlorine), inorganic compounds (such as antimony), and phosphorous compounds. Among halogenated flame retardants, bromine-based compounds are more effective than chlorine-based compounds, because bromine forms a weaker bond to carbon and thus interferes more effectively with combustion. A number of brominated flame retardants are commonly added to polyolefin wire and cable insulation—either alone or mixed with an antimony compound.

Chlorine is sometimes added to polyethylene insulation, but its presence can negatively affect the performance of the polymer, and as with PVC, it may release hydrogen chloride or dioxin in the event of a fire.

The most common inorganic flame retardants are metal hydrates, antimony compounds, and zinc borate. Metal hydrates work by introducing water to the fire; when used, they can be either compounded with the resin, or packed in around the wires as the cable is manufactured. Aluminum hydroxide is widely used in plastics such as polyethylene. At temperatures above 480 degrees Fahrenheit, the compound degrades into water and alumina, slowing flame spread or extinguishing the fire. Magnesium hydroxide is similar but degrades at a higher temperature; it is more commonly used with polypropylene.

Antimony flame retardants are generally most effective when combined with halogens. Antimony trioxide is commonly added to PVC, for example. Halogen acid, released during a fire, reacts with the antimony compound and produces char, which acts as a physical barrier to flame spread. Antimony-halogen reactions in a fire also keep oxygen from easily combining with the fuel contributed by the polymer.

Zinc borate, alone or in combination with aluminum hydroxide, is used as a flame retardant in a variety of halogen-free polymers. Phosphorous-containing flame retardants are very versatile; many different compounds are used, although the most common are phosphate esters (used in flexible PVC) and chlorinated phosphates (used in polyurethanes).

Other components used to make insulation and jacketing, like

Greener Wiring: A Checklist for Action

General Guidelines

Design for easy access. Install wiring in readily accessible wiring chases to simplify future modifications.

Minimize wiring runs. Reduce material use by installing high-capacity runs to local hubs, rather than connecting each directly to a central hub. Local hubs can connect to workstations via wireless or short-wired connections.

Avoid wiring in exterior walls. Limit wiring runs and receptacle placement in exterior walls, particularly in residential buildings. Such installations interfere with insulation and can result in significant air leakage.

Avoid the need for plenum-rated and limited-combustion cable. Run data cable in metal conduit, sealed wiring chases, or cellular raceways in concrete decking to avoid the need for highly flame-resistant cable.

Don't overwire. Design for future wiring needs, but avoid installing wires unless there is an immediate need for them.

Design for future removal. Design installations so that wire can be easily removed when not in use.

Minimize EMF. Rely on "prudent avoidance" strategies to minimize exposure of building occupants to electromagnetic fields.

Go wireless. Use wireless data connections instead of hard-wired ones for maximum flexibility and minimum material use. Wireless connections may be usable in some local areas, even if they are not usable buildingwide.

Specifications

Plan for future needs. Install voice-data-video (VDV) cable that can serve upgraded networks so that cable will not become obsolete as quickly.

Eliminate use of lead stabilizers. Some PVC wire insulation and jacketing are composed of 5 to 10 percent lead by weight. Specify products that don't contain lead stabilizers.

Don't install lead-stabilized cable loose in plenums. To keep lead dust out of indoor air, cable that's stabilized with lead (which includes most plenum-rated cable) should be installed in metal conduit and not directly exposed to conditioned air circulating through ceiling or floor plenums.

Specify halogen-free products. Wherever possible, specify wire and cable insulation and jacketing that do not contain PVC, chlorinated polyethylene, FEP, or products containing brominated flame retardants.

Specify heavy-metal-free wire and cable. Cadmium, chromium, and other heavy metals are often used in pigments for wire insulation and jackets. Avoid using them whenever possible.

Use fiber-optic cable. Fiber optics, widely used to carry voice and data signals, require less insulation and jacketing than copper wiring. It may be possible to run fiber-optic trunk lines to smaller copper distribution lines, thus reducing total insulated cable use.

Removal

Remove old cable. As per 2002 revisions to the National Electrical Code, remove cable that is not being used or will not be usable in the future.

Follow safety precautions when removing old cable. Old cable contains high levels of lead dust. Ensure that workers wear proper respiratory protection, and seal removed cable in plastic bags.

Recycle old cable. Deliver old cable to facilities where it's properly recycled; never burn old cable to recover copper.

fillers, pigments, dyes, and lubricants, are generally of lesser environmental priority and concern than the ones mentioned above.

Searching for greener solutions

To date, there's been little attention paid to health and environmental concerns related to wiring, but one group that has studied the issue in some depth is the Massachusetts Toxics Use Reduction Institute (TURI). According to TURI deputy director Liz Harriman, there are significant international efforts to reduce lead use in insulation and jacketing. The European Union's directive on Waste Electrical and Electronic Equipment (WEEE) and the Restriction of Hazardous Substances Directive (RoHS) will ban lead from electrical equipment and electronics by 2006, and some manufacturers are removing lead from their products before this deadline. "TURI is working with the wire and cable industry and their suppliers in Massachusetts to keep them competitive in the global marketplace," Harriman says.

In terms of fire safety, U.S. codes rely exclusively on test standards for flammability and flame spread, ignoring the risks of toxic and corrosive gases released before and after ignition. This approach differs from some European codes, which assume that incapacitation from irritating gases can affect occupants' ability to escape from a building fire.

There is clearly interest in some circles in specifying halogen-free wiring. Clear alternatives to halogenated wire and cable are polyolefin products; to use these for insulation and jacketing, compounds are typically added for flame resistance, as described earlier. Borealis Compounds, the U.S. division of the Danish company Borealis A/S, offers such products in the U.S., but sales are limited. They're used primarily in subway systems and other locations where acid emissions from halogenated compounds are unacceptable. The manufacturing costs of flame-resistant polyolefin wiring are significantly higher than those of PVC, according to a Borealis engineer, and regulatory changes would probably be required to bring about a significant shift toward polyolefins from PVC.

Some manufacturers, including Mohawk/CDT, offer PVC-insulated wiring without lead or other heavy metals. Demanding lead-free or heavy-metal-free cable can hasten the transition away from these toxins.

Yet another approach is to specify polyolefin cable with lower flame resistance and place it in a fire-protected environment (e.g., metal conduit or cellular cores of concrete floor panels). Such a method will add to a project costs, however, and the trends are generally in the other direction: specifying plenum-rated, FEP-insulated cable that can be installed in plenums without additional protection.

For data and voice signals, fiber-optic cables and wireless technologies are increasingly viable options. One fiber-optic cable can replace many copper cables in high-capacity applications, and wireless data networks are quickly supplanting hardwired connections in settings such as classrooms and meeting rooms.

Leave no wire behind

A new requirement in the 2002 National Electrical Code (NEC), known as Article 800, specifies that abandoned cables must be removed from plenum spaces. The change was made because of a concern that leaving old cables in place when new ones are added leads to dangerous fuel loading in plenums. Though it's already being enforced in some jurisdictions, the requirement generally kicks in when a space is remodeled.

Removing old cable during renovations and retrofits raises the issue of lead exposure. Since 1984, most cable jackets have been made with lead-stabilized PVC. As the plasticizer leaches out over time, the jackets become brittle and the lead migrates to the surface, leaving behind dust with a high lead content. This dust, loose in ceiling or floor plenums, can easily reach building occupants or workers removing old cable.

Although there seems to be no concerted effort to study or address this potential health hazard, the new NEC requirement forces building owners and occupants to consider potential removal options when cables are

Some manufacturers are developing wire insulators that are free of halogens, which have come under fire for negative environmental and health effects.

first installed. Many owners are now requiring tenants to remove cables once they leave a space; this requirement should lead to more frugal use of cable, the installation of systems that facilitate eventual removal, and better labeling practices for cables in use.

Once old wire and cable is removed, what can be done with it? Copper is a valuable commodity, so old wiring is commonly recycled, but the various additives in wire insulation and jackets raise concerns about incineration, and most of these materials are difficult if not impossible to recycle. Of all the wire insulation and jacketing materials, FEP is the most recyclable, though recycling programs for this material are not known to exist and may not appear any time soon, since the labor involved in identifying and separating it out is substantial.

Wrapping up

Wiring remains a challenge for designers and builders involved in sustainable design. Acceptable alternatives are heavily controlled by codes that focus almost exclusively (in the U.S.) on flame spread and smoke development, with no regard for the toxicity of wire and cable products. Whether this will be considered in fire-safety testing of wire and cable remains uncertain, but it seems clear that the EPA and other agencies will continue researching the safety of halogen-containing insulators.

Perhaps the best news is that better solutions are on the way. "New, innovative materials that are halogen-free and flame retardant will hit the market," says TURI's Harriman. "There are significant drivers for their development, even if not from the building industry." ■