Building Green with Nanotechnology

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ABSTRACT

Nanotechnology, the manipulation of matter at the molecular scale, is opening new possibilities in green building through products like solar energy collecting paints, high-insulating translucent panels, and heat-absorbing windows. Even more dramatic breakthroughs are now in development such as spray-on solar collecting paint, windows that shift from transparent to opaque with the flip of a switch, and environmentally friendly biocides for preserving wood. These breakthrough materials are opening new frontiers in green building, offering unprecedented performance in energy efficiency, durability, economy and sustainability. This paper provides an overview of nanotechnology applications for green building, with an emphasis on the energy conservation capabilities of architectural nanomaterials in green building.

Keywords: green building, green technology, clean technology, nanotechnology, architecture

1 THE GREEN BUILDING IMPERATIVE

Green building is one of the most urgent environmental issues of our time. Buildings are responsible for 40 percent of the emissions responsible for global climate change and 42 percent of the electricity consumed in the U.S. Waste from building construction accounts for 40 percent of all landfill material, and sick building syndrome costs an estimated $60 billion annually. Clearly, buildings play a large part in our current environmental dilemma.

But they also offer an opportunity to improve environmental quality and occupant health. Green building is a catch-all phrase encompassing efforts to reduce waste, toxicity, and energy and resource consumption in buildings. The green building movement has grown to the point that major cities like Chicago and Seattle now require new buildings to comply with strict environmental standards. As public and private clients alike call for more sustainable buildings, and architects become increasingly adept at designing them, a dramatic shift is emerging, from buildings that harm the environment to ones that heal it.

Architects, owners and builders committed to green building, however, are often frustrated by limited material choices. Buildings need light, for example, but current windows are extremely poor insulators, leading to increased energy consumption. Similarly, alternatives to polyvinyl chloride (PVC) pipe for plumbing are healthier than this known carcinogen but can be costly. Now, however, a new frontier is opening in building materials as new products and possibilities are introduced by nanotechnology.

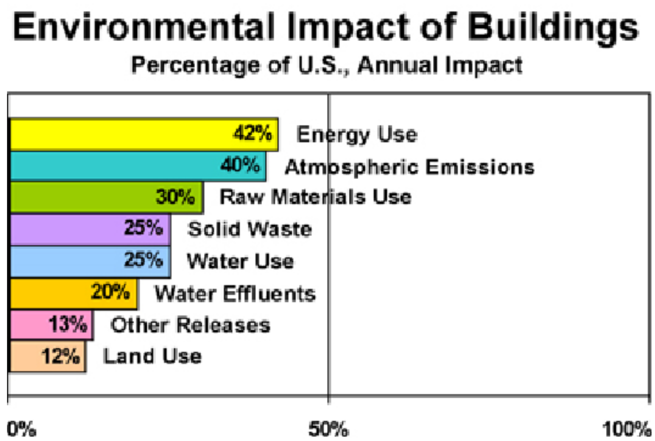


Figure 1: Environmental impacts of buildings (Levin, 1997).

2 NANOTECHNOLOGY FOR GREEN BUILDING

Nanotechnology, the control of matter at dimensions of roughly one to one hundred billionths of a meter, is bringing dramatic changes to the building industry. Products incorporating nanotechnology were valued at $13 billion last year, with sales expected to top $1 trillion by 2015. Already, nanotechnology has brought us self-cleaning windows, smog-eating concrete, and wi-fi blocking paint. And in the world's nanotech labs work is underway on illuminating walls that change color with the flip of a switch, nanocomposites as thin as glass yet capable of supporting entire buildings, and photosynthetic building facades.

Many nanotechnology-enabled products and processes now on the market can help create more sustainable buildings. Those in development today that can be brought to market offer even more promise for dramatically improving the environmental performance of buildings. Nanotechnology-enabled advances for green building include new materials such as carbon nanotubes and insulating nanocoatings, as well as new processes including photocatalysis and nanoporous filtration. Nanomaterials can contribute to green building by improving the strength, durability, and versatility of structural and non-structural materials, reducing their toxicity, and improving insulation.

2.1 Improved Material Strength

Material strength is critical in a building, defining its structure, longevity, and resistance to gravity, wind, earthquake, and other loads. A load-bearing structural material's strength/weight ratio is particularly important because stronger, lighter materials can carry greater loads per unit of material. Greater strength/weight ratio therefore means fewer materials, which in turn means fewer resources and energy consumed in production.

Nanotechnology promises significant improvements in structural materials both through nano-reinforcement of existing materials like concrete and steel, and through the introduction of altogether new materials like carbon nanotubes. Reinforcement of concrete is a particularly rich field, with experimentation taking place in dozens of labs around the world. Concrete is the most common human-made material by volume, and its key ingredient, portland cement, is by itself responsible for almost ten percent of the emissions responsible for global climate change.

"Development of nano-binders can lead to more than 50 percent reduction of the cement consumption, capable to offset the demands for future development and, at the same time, combat global warming," report Sobolev and Ferrada-Gutiérrez [1]. Nanofiber reinforcement has been shown to improve the strength of concrete significantly. Even simply grinding portland cement into nanoparticles has been shown to increase compressive strength four-fold [2].

Steel's high strength/weight ratio and combination of compressive and tensile strength make it the material of choice for tall buildings. But it can be weakened by corrosion and is extremely heavy. Corrosion can be inhibited, however, using a proprietary steel manufacturing technology by MMFX which creates a laminated atomic-scale structure similar to plywood. [3].

Sandvik now offers Nanoflex, a high-modulus steel of extreme strength to create thinner and even lighter components than those made from aluminium and titanium. Sandvik Nanoflex is currently being used in medical equipment, such as surgical needles and dental tools. [4].

In addition to reinforcing existing materials, nanomaterials like nanotubes and buckypaper may lead to new building materials. Carbon nanotubes, sheets of graphite one atom thick formed into a cylinder, can be more than 50 times stronger than high-carbon steel [5]. Nanotubes offer the promise of structures many times lighter yet stronger than steel. Also known as buckytubes, a reference to Buckminsterfullerenes (carbon molecules twice as hard as a diamond,) they may form the building blocks of tomorrow's architecture, along with buckypaper, a planar material composed of buckytubes.

Buckypaper may have non-structural applications as well. Researchers at the University of Texas at Dallas have produced transparent carbon nanotube sheets stronger than steel and so thin that a square kilometer would weigh only 30 kilograms. The nanotube sheets combine high transparency with high electrical conductivity and could be used as electrodes for bright organic light emitting diodes in energy-efficient displays and solar cells [6].

2.2 Improved Building Insulation

Nanotechnology may also play a role in conserving energy through improved building insulation. Because of their high surface/volume ratio, nanofibers can trap large amounts of air, increasing a product's insulating ability. This is the principle behind one of the most popular nanomaterials for building now on the market—Nanogel. Nanogel insulation is a form of aerogel, the lightest weight solid in the world. It has a content of 5 percent solid and 95 percent air. The high air content means that a 3.5-inch thick Nanogel panel can offer an insulating value of R-28 in a 75 percent translucent panel [7].

Because it traps air at the molecular level, an insulating nanocoating even a few thousands of an inch can have a dramatic effect. Nansulate HomeProtect ClearCoat employs Hydro-NM-Oxide, which the manufacturers say is by far the world's best thermal insulation medium—R-10 to R-13 per inch, as compared to polyurethane foam (R-6.64 per inch) and fiberglass batts (R-3.2 per inch) [8].

Other products integrate insulating nanoparticles with conventional materials. Masa Shade Curtains are coated with metal nanofilm to block ultraviolet rays and improve insulation. The stainless steel film absorbs infrared rays, blocking out sunlight and lowering room temperatures by 2-3° C more than conventional products [9].

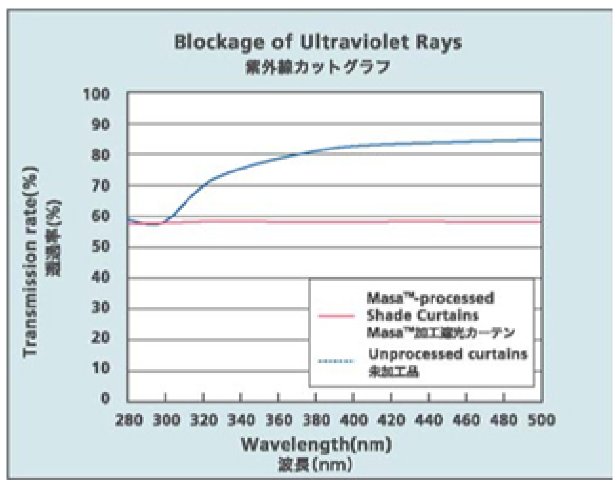


Figure 2: Ultraviolet ray transmission (Suzutora, 2007).

2.3 Nanocoatings

Some nanocoatings are used to insulate materials, while others protect wood, metal and masonry. Scratch-resistant nano-coatings are becoming a viable alternative to polyurethane coatings that can produce harmful volatile organic compounds (VOCs). Nano-engineered ultraviolet curable coatings by Ecology Coatings, for example, not only contain no toxic solvents, they contain no water, eliminating the need for heat curing, cutting manufacturing energy consumption by 75 percent [10].

DuPont is also working on nanoparticle paint for autos. The paint, licensed from Ecology Coatings, is cured using ultraviolet (UV) light at room temperature, rather than in the 400° F ovens required for conventional auto paint.

"We are in the early stages of a profound industry change," said Bob Matheson, technical manager for strategic technology production at DuPont. Ecology Coatings is also working on coatings that would make a wide range of reprocessed organic and waste materials durable enough to be used as building materials.

Nanocoatings can break down dirt as well, and PPG and Pilkington offer self-cleaning window glass. The Jubilee Church in Rome by Richard Meier & Partners Architects features self-cleaning concrete panels. Photocatalytic titanium dioxide nanoparticles are built into the precast panels, making them shed dirt. Depolluting nanocoatings that trap airborne pollutants in a nanoparticle matrix and decompose them can be applied to almost any surface cleansing surrounding air.

"Among other things, we want to construct concrete walls that break down vehicle exhausts in road tunnels," said Karin Pettersson, a spokeswoman for Swedish construction giant Skanska. "It is also possible to make pavings that clean the air in cities."

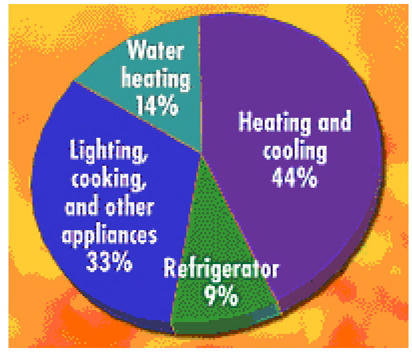
2.4 Air Filtration

The EPA rates indoor air quality among the top five threats to human health, and estimates medical expenses due to poor indoor air quality at $60 billion per year. Nanotechnology can improve indoor air quality through detection and filtration of unwanted airborne particles, and by reducing or eliminating offgassing and VOCs in finishes and cleansers. A new nano device, capable of detecting fungus that attacks wood, for instance, has been developed by a team of Polish scientists. Aspergillus versicolor is very a common mold fungus known to produce carcinogenic toxins. The fungus is detected using nanofibers whose properties change in the presence of the fungus and spark an electrical signal [11].

The high surface/volume ratio of many nanofibers makes them excellent materials for filters. Their small size enables them to trap fine unwanted particles while still providing sufficient airflow. Samsung Electronics' Nano e-HEPA (High Efficiency Particulate Arrest) is one of several nano-enabled air filtration systems now on the market. A metal dust filter coated with silver nanoparticles eliminates 99.7 precent of influenza viruses, and another nano-filter eliminates all noxious VOC fumes from paint, varnishes and adhesives [12].

2.5 Energy Conservation and Conversion

Buildings consume nearly 50 percent of all energy used in the U.S., and lighting and other appliances use one third of the energy used in buildings. The amount of energy used by lighting could be reduced greatly by nanotechnology.



How We Use Energy In Our Homes

Figure 3: Residential energy consumption (US Dept of Energy, 2004).

"This will completely change the way we use lighting," said Professor Ravi Silva of The Advanced Technology Institute at the University of Surrey, developers of one such project. "Ultra Low Energy High Brightness Light (ULEHB) will produce the same quality light as the best 100 watt light bulb, but using only a fraction of the energy and last many times longer."

These new ultra low energy lighting devices will be fabricated using carbon nanotube-organic composites. ULEHB lighting may offer a cost efficient and clean replacement solution for mercury based fluorescent lamps and many other low efficiency heat-producing light sources. The technology can also be used for low cost solar cell production [13].

Similar hybrid organic-inorganic materials, organic light-emitting devices (OLEDs), are highly efficient and long-lived natural light sources in which ultra-thin layers of organic molecules are deposited on glass or transparent plastic. Since OLEDs are transparent when turned off, they could be installed as windows to mimic the feel of natural light after dark. Almost any surface in a home, whether flat or curved, could become a light source, including walls, curtains, ceilings, cabinets and tables.

The sun offers us a continuous source of clean, free energy. Solar represents less than .5 percent of today's energy market, but is growing 30 percent annually. Solar collection devices currently rely on silicon technology, but new solar nanotechnologies based on thin film materials, nanocrystalline materials, and conducting polymeric films offer the prospects of cheaper materials, higher efficiency, and flexible features.

Nanosolar produces thin-film solar cells that can be seamlessly integrated into building facades. The company is purchasing sites to build the world's largest factory for making solar power cells, which will ultimately produce enough cells to power 325,000 homes, tripling the U.S. production of solar cells [14].

Konarka has developed light-activated “power plastic” that is flexible, lightweight, lower in cost and more versatile in application than traditional silicon-based solar cells. It is made from conducting polymers and nano-engineered materials that can be coated or printed onto a surface, making it possible to incorporate a range of colors and patterns. Power plastic is bringing power-generating capabilities to building components including awnings, roofs, windows, and window coverings [15].

Work is even underway to create spray-on polymer-based solar collecting paint. "You just paint it on," said Wake Forest University Professor David Carroll of the nano-phase material with an efficiency of 6 percent, double that of similar cells, but still well shy of silicon’s 12 per cent efficiency. "I strongly believe we can get there within the next year," Carroll said of the 12 percent efficiency goal [16].

2.6 Environmental Sensing

In just five years, the global market for nanosensors is expected to top $17 billion. Within a decade, nanosensors will be collecting and transmitting vast amounts of information about our environment and its users. Sensors smaller than a penny are already available that detect airborne toxins like carbon monoxide in and around a building. These nanosensors will conserve energy and resources by collecting and transmitting data on changes in temperature, humidity, and other indoor air quality factors.

Buildings will incorporate a rich network of interacting, intelligent objects, from light-sensitive photochromic windows to user-aware appliances. Tomorrow’s green buildings will be constantly changing, as their components continuously interact with their users, their environment, and each other. These dynamic environments will be almost organic in their ability to learn and respond to changes, and architects will need to learn to design for change.

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