Environmental Building News™
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Passive Solar Heating

Using the sun for most of a building's heating needs is in the DNA of green building. But in an age of superinsulation, does it still make sense?

by Alex Wilson

I WAS FORTUNATE TO HAVE BEEN involved in the glory days of the passive solar energy movement. In the late 1970s I worked in Santa Fe for the New Mexico Solar Energy Association, which was at the epicenter of the burgeoning movement to create buildings that relied on south-facing glass, integrated thermal mass, and carefully designed building geometries to deliver heat in the winter and maintain natural cooling in the summer. We thought we had the answers to the world's energy woes. It was a heady time.

In some ways, passive solar was a low-tech response to the first wave of solar energy systems that emerged following the 1973 energy crisis. Those early *active-solar* systems were complex and prone to failure, and many of them were only marginally successful when they operated as designed. Passive solar systems were far simpler, with no moving parts. The buildings became the solar heating system, with solar collection, heat storage, and distribution handled passively and by virtue of the geometry, materials, and design.

While passive solar remains in the DNA of green building, we're now more likely to hear about high-performing buildings with R-5 windows and R-40 walls, with rooftop solar-electric systems and high-tech energy recovery gadgetry. Is passive solar still relevant? I decided to find out.

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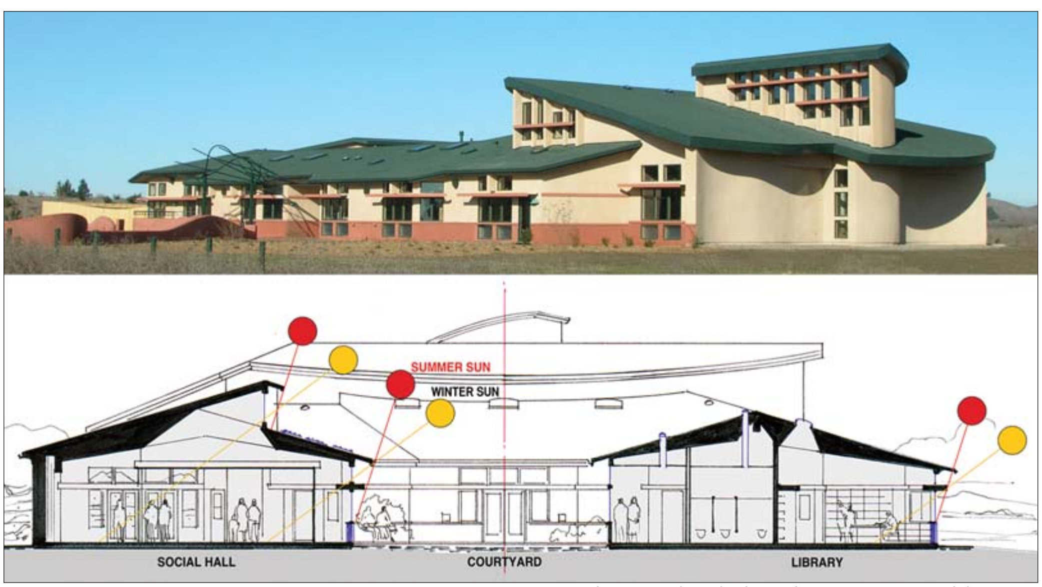

Above: David Bainbridge, Below: San Luis Sustainability Group

The 20,000 ft² Congregation Beth David Synagogue in San Luis Obispo, California, was completed in 2006 at a cost of $161/ft². Measured energy consumption shows 82% savings compared with a standard Title-24 building in California—and a 90% reduction in CO_2 emissions. A combination of direct gain and water walls, with effective shading, provides passive solar heating, daylighting, natural cooling, and natural ventilation.

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"If we had more partners in this effort, there would be a lot more leverage."

– Anne Less of consulting firm Mary Davidge Associates, on supporting Google's healthy materials program

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What's Happening

A Peek Inside Google's Healthy Materials Program

Since November 2010, Google's facilities teams have been methodically adhering to stringent building product selection criteria for all of the company's North American projects. To date, these have all been tenant fit-outs, but Google is moving into its first whole-building new construction project under the program and expanding it to other offices internationally in July 2012, beginning with pilot tenant improvement projects in Dublin, São Paulo, and Bangalore. Google had about 32,500 employees at the end of 2011, according to its financial report.

As of May 2012, the program had covered about half of Google's portfolio in North America, with the largest concentrations of space at the company's headquarters in Mountain View, California, and New York City.

Program Goals

"Maintaining a healthy workplace is a strong priority for Google," says Anne Less of Mary Davidge Associates, a consulting firm that supports Google's sustainable facilities programs. This mandate comes right from the top, with strong support from cofounder and CEO Larry Page, who has been known to walk around the offices with a particle counter. Among other benefits, Google's focus on occupant health is helpful when the company competes for talent around the world.

Google's healthy materials program seeks to avoid substances on the Living Building Challenge (LBC) Red List and the U.S. Environmetal Protection Agency's Chemicals of Concern list. Extending beyond the LBC requirements, the program includes furniture and furnishings. The company is also pushing for transparency by requiring full participation in the Healthy Building Network's Pharos product ingredient and hazard screening tool for any product in a category that Pharos covers, according to Less. (Disclosure: BuildingGreen collaborates with the Healthy Building Network on development and distribution of Pharos.)

Google also aims to achieve at least LEED Gold certification on all its projects. The LEED credits include mandates for recycled content and regional materials—making it even harder, because products that contribute to those credits must also meet Google's avoidance criteria.

This case study is excerpted from a BuildingGreen special report forthcoming in July 2012, "Avoiding Toxic Chemicals in Commercial Building Projects: A Handbook of Common Hazards and How to Keep Them Out."

Challenges

Google's staff and consultants, and the design teams working on its projects, have encountered a number of persistent challenges.

Certification domination: Manufacturers have been so well trained to think in terms of certification that some don't realize that just having their product in Pharos is not enough. "Suppliers will constantly tell me: 'I got the Pharos stamp of approval,'" notes Less, who then has to explain to them that Pharos is not a product certification and that manufacturers have to fully disclose in Pharos *and* meet Google's health criteria before their products can be specified.

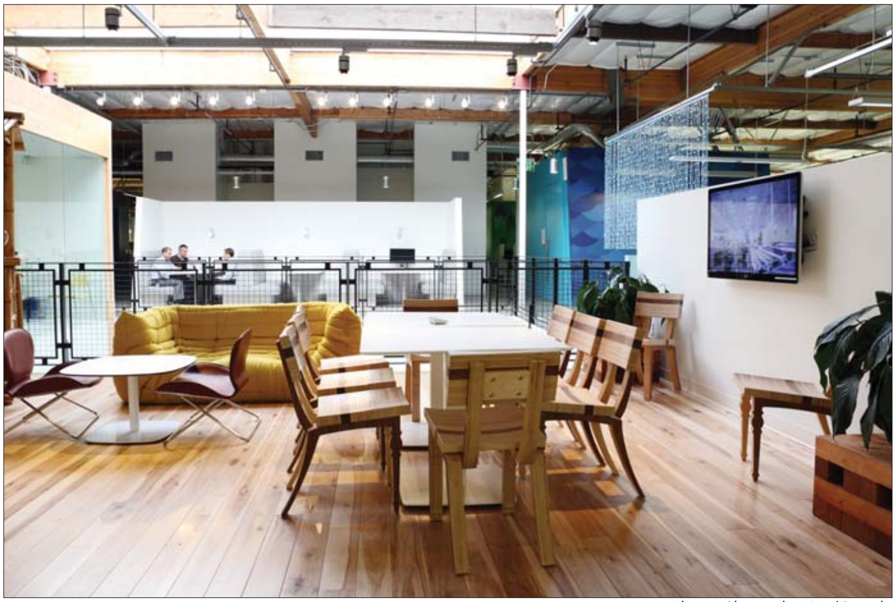

Photo: Christophe Wu/Google

Indoor spaces with sustainably harvested wood floors, soy-based furniture, and ample daylighting help provide a healthy work environment for Google employees.

Being a lonely voice: "If we had more partners in this effort, there would be a lot more leverage," Less notes. Design firms say that they are excited about this focus, but they don't encounter clients other than Google who will back them up.

Transparency: Manufacturers don't always know about everything that goes into their products, and when they do, they often consider that information proprietary. Some prefer to provide the information privately to Google rather than disclose their ingredients publicly. To be fair, Google has many trade secrets of its own, something that Less hears about a lot from suppliers.

Avoiding formaldehyde: The industry has been trained by LEED to focus on added urea-formaldehyde (UF), but the LBC red list calls out all formaldehyde. That affects medium-density fiberboard (MDF), laminates, doors, and many other components. "There are alternatives, but they are much more expensive," notes Anthony Ravitz, green team lead for Google's Real Estate and Workplace Services group. That means Google can use them for specialty items like countertops but not for more ubiquitous work surfaces and doors.

Furniture is a challenging category, mostly because there are so many components. Again, manufacturers may not know all the ingredients in their products, and even if they do, they may not have viable alternatives. PVC and bisphenol-A are common on parts and pieces of desks and chairs. Formaldehyde is common in work surfaces—in the laminates, adhesives, and substrates. And upholstered furniture has flame retardants, which California requires for fire safety (although Governor Jerry Brown is reviewing the regulations).

Duct liner: "We were surprised to discover a lot of chemicals of concern," says Less, "which is troubling because the air we breathe goes through that material." Formaldehyde, flame retardants, and heavy metals are among the substances that turned up in their review of product formulations.

Fabric window shades: Almost all have flame retardants, but fabrics on workstations can be specified without flame retardants or stain-resistant coatings as long as the manufacturer applies those coatings after weaving the fabric rather than before.

Successes

Market transformation is happening. Google and its project teams are building awareness and educating the market to push for greater transparency and cooperation. In the carpet sector, companies that started out being very uncomfortable with transparency have now become advocates for it. Manufacturers in that industry and many others have demonstrated further leadership by helping pilot the Health Product Declaration, the industry's first common reporting standard for transparency around the health impacts of building materials.

Lessons learned

Relationships with salespeople are key. They have advocated within their own companies for these issues. They are on the front lines.

Even without transparency, rigorous screening can make a difference. "When we visited their factories, we discovered that furniture manufacturers that have been working with the Cradle-to-Cradle program have made a lot of progress," says Ravitz. Now that they have cleaner products, it would seem that more disclosure would only benefit them, Ravitz suggests.

Results

Google has yet to implement a systematic air-quality testing program, but the team is working on that. Ravitz notes, however, that many of the toxic substances they're trying to avoid are not volatile and wouldn't show up in air quality testing. That's one of the reasons they are also focused on minimizing airborne particles, which often carry contaminants into people's lungs, with high-efficiency filtration. In the meantime, they visit job sites periodically with a photo ionisation detector (PID), which helps catch any unexpected VOC emissions.

–Nadav Malin

LEED 2012 Postponed to 2013, Renamed LEED v4

The U.S. Green Building Council (USGBC) has postponed plans to ballot the next version of LEED until June 2013. With this announcement, USGBC promises to keep LEED 2009 available for a full three years from now.

The move came in response to a growing outcry from architects and other building industry professionals, who had three related concerns:

- The proposed changes in the rating system were too much, too fast, especially in a weak real estate market.
- Some of the changes needed more refinement, especially in the Materials & Resources category, where whole new approaches to material selection had been introduced with each public comment draft.
- Tools and resources needed to achieve the credits would not be widely available by the time the new system was slated to launch in November 2012.

No longer tied to a particular year, USGBC is also reverting to a version naming system for the rating system, so the new version will be called "LEED v4" instead of "LEED 2012."

The new plan gives time for a beta test to proceed while allowing for its results to inform a fifth public comment period, which is scheduled to run from October 2 to December 10, 2012. USGBC asserts that language in LEED supporting the highest standards of forest certification and pushing for transparency and avoidance of chemicals of concern will not be watered down during this extended process.

–Nadav Malin

For more information:

U.S. Green Building Council
www.usgbc.org

Participation Grows in AIA's 2030 Commitment

At its annual convention in Washington, D.C., the American Institute of Architects (AIA) released its second annual report documenting progress toward AIA's 2030 Commitment. Developed to support Architecture 2030's 2030 Challenge, the program promotes greening of firm operations and documenting of predicted energy performance of projects in design, with the goal of helping the industry monitor progress toward the 2030 Challenge goals—currently pegged at 60% fossil fuel reduction compared with average buildings.

The good news from the new report documenting 2011 activities is that the number of firms that have signed onto the commitment continues to grow. At 212, it still represents only a tiny fraction of AIA members, but it is up significantly from 2011. Of those who were eligible, 53% submitted reports as required by the program, including 656 million square feet of projects. That's up from 48% in 2010 but shows that there are still a significant number of firms, especially the very small ones, that signed onto the Commitment but didn't manage to report.

The reported results changed little from 2010 to 2011:

- Average reduction in predicted energy use intensity went from 35% to 34.6%.
- A respectable 12.8% of projects (by floor area) are on track to hit the 2030 Challenge 60% reduction target, up slightly from 12.1% in 2010.
- Energy modeling was done for 57% of the whole-building projects, down from 58% in 2010.
- Firms intend to collect actual energy use data after the project is occupied on 45% of projects (up from 37% in 2010).

Greg Mella, AIA, vice president at SmithGroupJJR, has been instrumental in supporting this program. He feels that it's too early to expect trends in relation to achievement of the 2030 Challenge goals. "The transformations required to shift the momentum of our practice will take several years," he said, adding, "But for firms, an awareness of energy performance across a practice is the first step."

–Nadav Malin

For more information:

The American Institute of Architects' 2030 Commitment
www.aia.org

Photo: SmithGroupJJR

The Oakland University Human Health Building, designed by SmithGroupJJR in 2011, has a predicted energy use intensity reduction of 68.3%.

Newsbriefs

Prepare for Killer Heat, Says NRDC—Resilience efforts could save thousands of lives, according to the Natural Resources Defense Council (NRDC), which has published a review of data predicting dramatic increases in heat-related deaths in the largest U.S. cities by the end of the century. "Killer Summer Heat: Projected Death Toll from Rising Temperatures in America Due to Climate Change" analyzes a study published in the Journal of the American Meteorological Society. Based on a "business-as-usual" scenario of continued reliance on fossil fuels with no significant policy interventions, the study predicts a cumulative toll of more than 150,000 heat-related deaths by century's end—but NRDC points out that those numbers may be conservative as they do not take into account population growth or aging baby boomers swelling the ranks of the heat-susceptible elderly. Most states experienced record summer temperatures in 2011, but the effects can be most dramatic in cities due to the urban heat-island effect. Most cities are expected to see dramatic increases in excessively hot days and related mortality, but cities already experienced in heat management could see better outcomes. For more information, see www.nrdc.org.

Photo: Wiley Brewer

According to NRDC, many U.S. cities will see large increases in heat-related deaths in the coming decades; Louisville, Kentucky, could see a nearly tenfold increase by the end of the century.

Sunny Skies, Net-Zero Cloud—While centralized, off-site information storage may reduce the impact of some activities, "the cloud" is powered by massive data centers: according to Greenpeace, the cloud's electricity use is larger than that of most nations. In an effort to address that, Hewlett-Packard has published design guidelines for data centers that can be run on direct current (DC) microgrids (see "A Surge of Popularity for Efficient DC Power," *EBN* May 2011) and grid-tied renewable resources for net-zero power use. The new guidelines, being tested by the company's research arm, HP Labs, use workload planning to match supply with demand for a total reduction in power use of 30% and an 80% reduction in grid dependence. At a center with a photovoltaic array, this demand management approach allows noncritical workloads to be scheduled during daylight hours, when solar energy is readily available. For more information, see www.hpl.hp.com.

Envelope Commissioning How-To from NIBS—Building envelope commissioning (BECx) is gaining momentum as a way for project teams to achieve and verify performance. A new publication from the National Institute of Building Sciences (NIBS)—NIBS Guideline 3-2012—outlines the process of incorporating BECx from project inception through operations and maintenance to ensure that a building's materials and systems meet expectations regarding air flow, moisture control, durability, and a number of other factors. A revision of a 2005 NIBS guideline, Guideline 3-2012 is intended for use with ASHRAE Guideline 0-2005, which details the commissioning process, and aligns with ASTM E2813, *Standard Practice for Building Enclosure Commissioning*. BECx is one of many topics causing a stir in the public comment period for LEED v4: originally part of the commissioning prerequisite, it was removed in a revision due to concerns about cost and now applies only to the commissioning credit. For more information, see www.nibs.org.

No More Secrets: "Facebook" for Buildings Tells All—In the latest stop on its "Honest Buildings Across America" tour, Honest Buildings has partnered with the Seattle 2030 District to release comprehensive data on 32,000 of the city's commercial and mixed-use buildings. The Honest Buildings

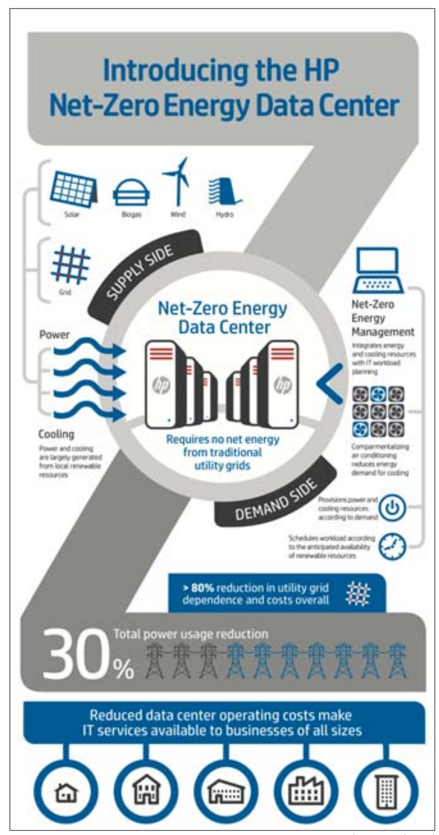

Image: Hewlett-Packard

This infographic illustrates HP's Net-Zero Energy Management guidelines for data centers.

online platform is intended to help connect building owners, architects, and service providers and to provide transparency and encourage competition for energy-efficient buildings. The data, collected from users and public and proprietary sources, includes ownership and management information, a record of renovations and projects, and whether a building is LEED-certified or Energy Star-rated. Says Pat Sapinsley, AIA, advisor to Honest Buildings, "Information that has historically been disaggregated…can now be associated with that building with one click." Since its launch earlier this year, Honest Buildings has released data on 475,000 buildings across the U.S. In addition to 95,000 buildings in Texas, 30,000 in San Francisco, and 15,000 in the D.C. metro area, the site profiles 250,000 New York City structures, including those subject to the City's annual benchmarking requirements for City-owned buildings (see "NYC Benchmarks Buildings, Finds Room for Improvement," *EBN* Feb. 2012). The platform is open to anyone to compare buildings based on various criteria as well as to submit buildings or review them using the site's seven-star "Honesty Rating" system. For more information, see www.honestbuildings.com.

AIA Guide: IgCC a Sign the Game Has Changed—The American Institute of Architects (AIA) has produced a guide to help architects implement the International Green Construction Code (IgCC), which was introduced in March 2012 by the International Code Council, and to advocate for adoption of the code in their own jurisdictions. "The AIA Guide to the IgCC" points out that architects familiar with the code will be sought for their expertise as the code is more widely adopted. The guide gives chapter-by-chapter summaries and commentary on the implications of IgCC provisions for design and practice, saying, "The IgCC…is not itself a game changer but further evidence that the game has changed." Encouraging advocacy for code adoption, the guide recalls the initial uncertainty and confusion surrounding the Americans with Disabilities Act (ADA), whose accessibility accommodations have since become second nature. To avoid this confusion regarding the IgCC, says the guide, architects "have to articulate what the IgCC actually requires" and remind officials that "the issue is not more regulation; it is consistent regulation." For more information, see www.aia.org/igcc.

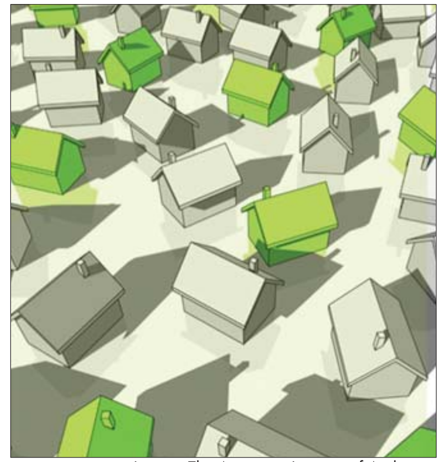

Image: The American Institute of Architects

The AIA has published a detailed guide to help architects navigate the International Green Construction Code—and to effectively advocate for its adoption.

Obama Administration Targets Asthma in Low-Income Communities—U.S. federal agencies have announced a plan to reduce disparities in childhood asthma, which disproportionately affects low-income and minority families. Nearly 26 million Americans suffer from asthma, and the annual economic cost is estimated to be $56 billion. Says Secretary of Housing and Urban Development Shaun Donovan, "We must do everything we can to ensure all children have a healthy place to call home." The plan will coordinate efforts among agencies involved in health and environmental quality to target services to communities most at risk; to increase understanding of its causes; and to test preventive measures. For example, the plan recommends that federally assisted housing include policies to reduce exposure to secondhand smoke, pests, mold, and other asthma triggers, encouraging state and local governments to do the same. It also recommends coordination between health and housing programs to identify opportunities for asthma management, reduce environmental exposure, and encourage referrals to health services; programs involved could include weatherization and lead remediation efforts. For more information, see www.epa.gov/childrenstaskforce.

Product News & Reviews

CarbonCure: Capturing Carbon in Concrete Blocks

Could injecting carbon dioxide (CO_2) directly into concrete masonry units (CMUs) during production be a tool for lowering carbon emissions from construction? The makers of the CarbonCure Block System say that their system both lowers the environmental impact of CMUs and improves their overall strength.

The production of portland cement, a key ingredient in concrete, results in approximately 5% of the world's anthropogenic CO_2 emissions. Reducing the amount of this CO_2 in concrete products has long been an industry goal, but CarbonCure is the first company to bring to market a viable, mass-produced product that "sequesters" significantly more CO_2 from the atmosphere than standard concrete without requiring a radical change in technology.

How carbon is injected

CarbonCure CMUs are produced using a specially designed mold that is attached via a hose to a tank of CO_2 supplied from local industrial sources—usually high emitters such as refineries or fertilizer plants. The CO_2 is injected at a carefully controlled rate as the concrete mix is pressed in the mold. Robert Niven, CEO and founder of CarbonCure, says one of the advantages of CarbonCure is that it does not fundamentally change how the CMUs are produced. Because the system can basically be bolted onto existing CMU production facilities, "We can commission a plant in half a day at very low cost."

Speeding up a natural process

More than half the CO_2 created during the production of portland cement is generated by the chemical reaction called *calcination*, during which calcium carbonate (limestone) is converted to calcium oxide under high heat, producing CO_2 as a byproduct. When the cement is later mixed with water, aggregate, and admixtures to form concrete, some CO_2 is absorbed back into the concrete during curing in a process called *carbonation*. According to Niven, while standard concrete continues to undergo carbonation over time, the process gradually becomes less effective as the CO_2 hardens the surface and the concrete becomes less permeable. "Simple carbonation is limited by depth; at most you get about 2 mm of carbonation," claims Niven. "It would take about 1,000 years to get the same amount of carbonation as you would get from our process in around six seconds."

CMUs are an ideal fit for CarbonCure technology because blocks use a relatively dry, porous cement mix, which allows the CO_2 to penetrate deep into the block. Depending on size, weight, and density, a CarbonCure block will convert from 1.75 ounces (50 g) to 3.50 ounces (100 g) of CO_2, according to data from the company's pilot work. Nevin says that the total CO_2 kept out of the atmosphere is actually higher and is closer to 7 ounces (200 g) per block because the CMUs are 10%–48% stronger than standard products. The added strength allows block manufacturers to use 10% less portland cement, and they require less time (about 38% less) in the steam-curing kiln. A stronger block also leads to 20% fewer defective blocks. It's the combination of carbon reductions and early strength gains that make the product especially attractive.

Photo: CarbonCure Technologies, Inc.

CarbonCure injects CO_2 taken from industrial sources, such as refineries, directly into concrete masonry units as they are being formed; the special molds and CO_2 injection system can be installed in as little as half a day without affecting the rest of the production equipment.

Taken together, the company estimates that for every 50,000 CarbonCure CMUs produced, CO_2 emissions are reduced by 13 tons (about 12 metric tons) and product waste by 11 tons (about 10 metric tons). To put that in perspective, in 2010, 119 U.S. block manufacturers produced an average of 6.1 million CMUs each, according to concrete block trade groups. If all those CMUs were made using CarbonCure, it would sequester 160,000 tons (145,000 metric tons) of CO_2 from the atmosphere. While that is less than half a percent of the 46,000,000 tons (42 million metric tons) released by cement production in 2008 (the last year data was available through the U.S. Energy Information Administration), it could be part of an overall carbon reduction strategy.

Full production runs

Three major CMU producers, Shaw Brick, Atlas Block, and Basalite, have incorporated CarbonCure technology, but none are currently making regular, full production runs of the blocks. Shaw and Basalite have, however, already sold CarbonCure blocks for projects. Brady Hawley, operations and sales manager at Shaw Group, oversaw three years of CarbonCure CMU testing. "We have now accomplished full-scale runs and have made a lot of strides towards making this a full-scale operation, including a run of 5,000 blocks that are going to be used in a local school." Hawley said the latest round of CarbonCure blocks looked and performed as well as standard blocks, and he claims the technology is "potentially revolutionary."

Niven says CarbonCure and the companies using the technology are being cautious rolling out these CMUs, citing market demand and capacity, and are currently supplying block on a project-by-project basis. But he sees a big opportunity for the CMU industry because the technology provides a clear, marketable green CMU that is cost-competitive with standard blocks and doesn't require a radical technology change. Though CarbonCure is currently being used for CMUs, in time Niven expects the technology to be adapted to other precast concretes as well.

– Brent Ehrlich

For more information:

CarbonCure Technologies, Inc.
www.carboncure.com

Vacuum Insulation Panels Push the Envelope to R-30 Per Inch

Walls can only be so thick, so an R-1-per-inch difference between insulation types has a significant impact on overall performance in energy-efficient buildings. With R-values an order of magnitude above that of many conventional insulation types, Dow Corning's new vacuum insulation panels (VIPs) could change many previous assumptions. Formerly reserved for such markets as transportation and appliances (especially refrigerators and freezers), VIPs are being designed for the construction market and are currently being installed in pilot projects.

Dow Corning's VIPs are composed of a fumed silica cake, with silicon carbide and polyester fibers for structural support, encased in an inner layer of polyethylene and an outer layer of polyethylene, polyester, and aluminum. The panels are vacuum-sealed, and the edges are heat-sealed.

Because of the construction, the panels have thermal bridging at the edges—much like windows—and as a result, the whole-panel R-value is lower than that of the center. The center-of-panel insulation value for Dow Corning's VIP is R-39 per inch, but a standard 2' x 4' panel provides approximately R-30 per inch overall. R-value does increase linearly with increased thickness, according to Charlie Zimmer, global program manager for high-performance insulation at Dow Corning. So a 1" panel will have roughly double the R-value of a ½" panel, he explained, but as panel size increases, thermal bridging along the edge of the panel is reduced relative to the size of the panel, meaning total R-value (and thus cost-effectiveness) increases with panel area. Although there is no air movement through the panels, they must be sealed at the seams (with tape, for example) to prevent leakage there.

Photo: Dow Corning Corporation

Seen here encased in mineral wool, this vacuum insulation panel will eventually become part of a ventilated rainscreen façade.

Another vacuum insulation product was released by Owens Corning (no relation to Dow Corning) under the brand name Aura in the early 1990s, but the new product has some major differences. According to Zimmer, the Aura panels had to hold more of a vacuum to reach high insulation values and as a result required more metal for structural support. While the fiberglass core reached a center-of-panel R-value significantly higher than that of Dow Corning's VIP, increased thermal bridging at the edge of the panel compromised the overall performance.

Dow Corning's VIPs aren't yet widely available. The company is bidding on specific projects across North America, Europe, and Asia, testing the panels in various applications, and collecting performance data. Because vacuum insulation hasn't been widely used in building applications, Dow Corning intends to have real-world references for product performance and installation details before rushing into a market that isn't ready. One problem the company faces is that existing energy modeling programs don't include VIP technologies, preventing accurate energy modeling.

One of the projects piloting the panels is a retrofit of the historic Fraunhofer Center for Sustainable Energy Systems (CSE) in Cambridge, Massachusetts. Martin Sachs, marketing specialist at the Fraunhofer CSE, explained that the panels "fit well with the ethos of the building," explaining that the Fraunhofer CSE is a "living laboratory," a building used specifically to test innovative building products.

Other targeted applications for the VIPs include external insulation finishing systems (EIFS) and insulating underneath rainscreens, in curtainwall spandrels, and in interior partitions. In one published case study, eight 2' x 3' VIPs were encapsulated between two aluminum skins to create one 6' x 8' composite panel used as insulation in a curtainwall spandrel. Dow Corning is currently targeting commercial markets, but residential markets and roofing, flooring, and precast concrete applications are being considered.

Proper installation and protection of the panels is important. A puncture or edge-seal failure would cause a loss of the vacuum, and the insulating value of a standard 2' x 4' panel would drop from R-30 per inch to R-8 per inch (still a very high R-value, which Dow Corning attributes to the microporous structure of the fumed silica cake). The company is currently testing various methods of protection, such as surrounding them with metal composites in curtainwall applications or with extruded polystyrene (XPS) in a masonry wall. Depending on the materials, the insulating value of the wall could drop due to conductive heat loss.

Assuming the panels suffer no punctures or accidental damage, Dow Corning expects the VIPs to maintain more than 80% of their thermal performance after 25 years and is working with a third party to verify the predicted life of the panels.

At \$10–\$12 per square foot for standard 2' x 4' panels, the VIPs cost significantly more than conventional insulation types for comparable R-values (rigid polystyrene, for example, could run somewhere around \$6.90 per ft^2 for R-30 at the high end). Both initial and long-term cost savings could be realized, though, through reduced wall thickness and achievement of greater insulation value than would otherwise be possible. According to cost analysis and market research done by the Fraunhofer CSE, vacuum insulation products "are continually dropping in price." Dr. Jan Kosny, leader of Fraunhofer CSE's building enclosures team, estimates that the cost of panels will eventually reach \$3–\$4 per square foot. Especially in EIFS applications, VIPs are expected to become more cost-effective.

– Martin Solomon

For more information:

Dow Corning Corporation
www.dowcorning.com

Passive Solar Heating *(from page 1)*

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Passive Solar Design: Three Approaches

In passive solar buildings, solar energy collection, storage, and distribution are integrated into the building design. There are three classic approaches to passive solar: direct gain, indirect gain, and isolated gain.

Direct gain: South-facing windows

South-facing windows (or north-facing for our readers in the Southern Hemisphere)—including clerestory windows that bring light deeper into a building—capture sunlight, while thermal mass that is distributed around the building interior absorbs and stores some of that solar energy, releasing it to the interior over an extended period. Direct-gain designs are the simplest and most practical passive solar systems, and they are by far the most common.

Indirect gain: Thermal storage walls

Rather than having sunlight shine directly into the occupied space, indirect-gain passive solar systems have thermal mass positioned between the glazing and the living space. With Trombe walls (named after the French inventor Felix Trombe), that thermal mass is provided by masonry or concrete. Water walls use containers of water in place of masonry. The glazing is positioned a few inches to a foot or more away from the south-facing wall. Sunlight is absorbed by the dark surface, and that absorbed heat slowly moves through the wall to the interior surface, where it radiates warmth to the living space. Indirect-gain systems are usually installed today as supplements to direct-gain designs.

Isolated gain: Sunspaces

In a third flavor of passive solar system, isolated-gain systems capture solar energy outside the insulated building envelope, usually in a "sunspace," and allow it to flow into the building by convection through windows, doors, or vents through the wall. There is typically thermal storage in the space to moderate nighttime temperatures, but the useful heat is delivered primarily during the daytime. Some sunspaces provide both isolated gain and indirect gain—if the back wall of the sunspace (the south wall of the building to which it is attached) is

Photo: Maclay Architects

Designed by architect Bill Maclay, the River House is a net-zero-energy home in Vermont's Mad River Valley with deep overhangs that shade the extensive area of south-facing, low-e glass. Removal of most trees to the south was necessary to provide good solar exposure on this wooded site.

uninsulated masonry and can serve to store and transmit heat.

Passive solar vs. suntempering

A distinction is often made between passive solar design and *suntempering*. With direct-gain passive solar designs, one often saw the rule of thumb that up to 12% of the floor area could be in south-facing glass, while suntempered spaces could have no more than about 7% of the floor area in south-facing glass. Suntempered buildings are essentially standard buildings with appropriate orientation and somewhat more of the glass placed on the south walls than on other façades.

True passive solar designs involve higher percentages of south-facing glass relative to floor area and depend on thermal storage to prevent spaces from being too hot during the day and too cold at night. Suntempered spaces rely only on the inherent thermal mass in standard light-frame construction systems and furnishings.

Why Passive Solar Is Important

There has been a strong trend within the green building movement in recent years to create buildings that go well beyond compliance with energy codes. For some, the goal is net-zero energy, for others carbon neutrality or fossil-fuel avoidance. With any of these approaches, creating a highly energy-efficient building envelope is the first priority, and it's a requirement of Passive House certification (see "Passive House Arrives in North America," *EBN* Apr. 2010).

But along with the energy performance of the building envelope, solar gain is also important with any of these performance targets—especially Passive House. Even a well-insulated box will eventually reach the ambient average outdoor temperature if there are no energy inputs to it. If the goal is to avoid fossil fuels or carbon emissions in operating that building, solar energy is the best option we have for achieving net-zero-energy performance.

One can begin to understand the importance of passive solar gain in a Passive House by examining Passive House Planning Package (PHPP) energy modeling program outputs. David White, a Passive House consultant and the owner of Right Environments in Brooklyn, New York, says that for a typical Passive House in the Northeast that relies on its heating system to provide 15 kWh/m^2·yr (the maximum for Passive House certification), solar gain is supplying about 15 kWh/m^2·yr and internal loads another 10 kWh/m^2·yr. In other words, even though energy conservation still does the heavy lifting, the supplemental heating load would double if it weren't for passive solar gain.

Not As Relevant As It Used to Be

When J. Douglas Balcomb, Ph.D., and his research associates at Los Alamos National Laboratory were refining definitions of solar savings and coming up with rules of thumb for south-facing glass and thermal mass, almost no windows exceeded R-2; walls and ceilings rarely surpassed R-15 and R-35, respectively. It's a different world today, with triple glazing, low-e coatings, and gas fills pushing center-of-glass window R-values above R-8 and insulation levels commonly reaching R-40 for walls and R-60 for ceilings—at least within the green building community.

In these ultra-low-energy buildings, heating simply isn't as big an issue today as it was thirty years ago, argues Marc Rosenbaum, P.E., of South Mountain Company. "The Los Alamos folks never thought about buildings with as little heat loss as what we're creating today," he told *EBN*. When you're at the Passive House level of performance, it's not unusual to have heating account for as little as 20% of the total energy use of a home, according to Rosenbaum. Water heating is often a greater demand. In Passive House monitoring, Efficiency Vermont found 1,700–1,800 kWh per year for heat and about 3,000 kWh per year for water heating.

Rosenbaum is a leading proponent of renewable energy, but his interest in passive solar has waned over the years. "To be honest, I'm not doing it," he admitted. "If I have to spend extra money to put extra mass in a house, it's not going to come up very far in my list of priorities. I can spend that money better elsewhere."

Other experts *EBN* contacted about passive solar design were more positive about its place today. Ken Haggard, founder of the San Luis Sustainability Group and coauthor with David Bainbridge of *Passive Solar Architecture* (Chelsea Green Publishing, 2011), has been

Photo: Don Wong

This 2,600 ft^2 home in St. Peter, Minnesota, designed by Sarah Nettleton Architects, features passive solar design with concrete floors for thermal storage. Sliding shade screens can be seen on the south-facing fenestration. The house achieved LEED Gold, missing Platinum by just a few points.

incorporating passive solar design features into nearly all of his projects for thirty-plus years, and he remains a firm proponent. But he argues that it's not just about passive solar *heating*. "It's important not to define passive design strictly on the basis of heating," he told *EBN*. He considers passive design to include cooling, ventilation, and daylighting as well.

Photo: Don Wong

Inside the home of Jack and Mary Spear in St. Peter, Minnesota, thermal mass is provided by the poured-concrete floor.

Mike Nicklas, FAIA, of Innovative Design in Raleigh, North Carolina, has been a proponent of passive solar design and daylighting since the 1970s and has served several times as chairman of the American Solar Energy Society. While most of his work is with larger buildings where passive solar heating isn't as relevant (due to internal loads), he always works passive solar into homes and into smaller, skin-dominated commercial buildings. He cringes at what he sees as a new trend with net-zero-energy buildings of forgetting about passive solar and relying on a larger PV system. "People just do what they want to do and throw on a bunch of PV at the end," he complained.

Elements of Passive Solar Design

Incorporating passive solar into our buildings can mean a lot of different things. While some strategies have fallen out of favor, others aren't likely to ever go out of style. Here are key elements of passive solar design, including heating as well as cooling-load avoidance and daylighting.

Applicability of passive solar

Passive solar heating is best suited to residential and smaller, skin-dominated commercial buildings. This means that the San Luis Sustainability Group pursues skin-dominated buildings even for its larger projects. "We feel that skin-dominated buildings are better ecologically and socially as well as being more balanced in regard to heating, cooling, and daylighting—as well as more aesthetically acceptable," says Haggard. "Load-dominated buildings are easier to heat but more difficult to passively cool and ventilate due to their bulk."

Orientation and geometry

Passive solar buildings should have the long axis oriented east to west, maximizing the south exposure (or north exposure, in the Southern Hemisphere). Except near the equator, south-facing glass transmits maximum sunlight in the winter, when the sun is low in the sky, and transmits proportionately less sunlight in the summer months because the sun is higher—with sunlight striking the glass at a more acute angle. With south-facing windows, very simple fixed overhangs or awnings can effectively shade the glass in summer.

Carefully balancing that shading is important for swing conditions. In the fall, outside temperatures are still fairly warm, so the fact that the sun stays lower in the sky (allowing more of it to reach south-facing windows protected by overhangs) can be problematic. In the spring, that sunlight is very beneficial because outside temperatures are still quite cool. Thus, a fixed overhang may provide more shading than desired in the spring but not enough shading in the fall. Adjustable awnings are one solution to that concern—although, with the help of simple computer modeling, fixed overhangs can be configured to provide a reasonable compromise. In larger buildings, a narrow footprint helps maximize solar access.

Bringing solar energy into a building

Glazing is the foundation of passive solar design. It has also proven to be one of the most challenging elements—particularly during the 1990s and early 2000s, when most U.S. window manufacturers offered only heat-rejecting windows with low-solar-heat-gain-coefficient (SHGC) glass. To function well for passive solar, glazing should transmit as much sunlight as possible. In the early days of passive solar design, clear, double-glazed insulating glass units (IGUs) were most commonly used. With the advent of low-e glazings, heat loss was greatly reduced—but so was solar gain.

Nicklas, who has battled against the nearly universal shift to low-e glazings, still specifies clear, double-glazed glass on the south—at least for higher glass used for daylighting (in commercial buildings, for comfort reasons, he may specify low-e for glass below seven feet). On the east and west façades, he usually specifies tinted low-e glass, and on the north untinted low-e.

On residential projects and in more

northern climates, it is common to have only two window specifications: one for the south and another for all other façades. Marc Rosenbaum is now regularly specifying triple glazing with center-of-glass U-factors as low as 0.11 (R-9) and SHGC values as high as 0.62. With this glass, he's getting about 80% of the solar gain that double-glazed clear IGUs used to provide—but with significantly less heat loss. To put that into a Btu framework, assuming a clear day and a 40°F temperature differential, these new top-performing windows provide about 300 Btu/ft^2·day less solar gain than the older, clear-glass options, but the R-6 windows would lose just 160 Btu/ft^2·day, compared with 480 Btu/ft^2·day for those older windows (a difference of 320 Btu/ft^2·day). Rather than using poorly performing windows and compensating with thermal mass, Rosenbaum argues, it makes better financial sense to use better windows and a smaller heating system.

Several designers *EBN* spoke with commonly specify different window dimensions for different orientations to avoid mix-ups on the jobsite. The problem of mix-up is so significant that building scientist Terry Brennan, when he was more involved in design and construction, gave up on tuning windows by orientation. "It's hard to get the right windows installed in the right places," he told *EBN*. "I go for the R-value over solar heat gain."

In cold regions, snow cover can improve performance in the winter months—just when that additional solar gain is most beneficial. The typical increase in solar gain from snow-covered ground is about 5%, according to the manufacturer of the Solar Pathfinder, a site-assessment tool.

Absorption of solar energy

There's a common (mistaken) assumption that surfaces need to be dark to absorb sunlight. It is true that darker surfaces absorb solar energy more effectively than light-colored surfaces, but dark surfaces in the building interior also prevent visible light from bouncing around, requiring additional electric lighting to be provided.

"One passive function must not conflict with another," said Haggard. "From a lighting standpoint, dark interiors are inefficient and glare-producing." Haggard feels that natural lighting is the prime function of passive solar building because it so strongly affects occupant health and also reduces the need for electricity. "Our overriding rule is that buildings should be as light as possible on the inside and as dark as possible on the outside; dark buildings tend to recede into their landscape setting in almost all natural environments." With thermal masonry and water walls, it's a different matter. These should have absorptivity as high as possible to maximize heat collection.

Storage of solar energy

Thermal storage is a critical component of passive solar heating—nearly as important as glazing. Without enough thermal mass in a building, air temperatures will rise too much during sunny days, and there will be inadequate carryover into the evening hours. Thermal mass also increases construction cost—so there is motivation to skimp. "The critical failure of direct gain [in the 1970s and '80s] was not enough thermal mass," says Rosenbaum. He feels it is still not adequately addressed in a lot of Passive House designs. "I'm concerned about overheating," he told *EBN*. In PHPP modeling, "there's only one input cell in the whole thing for thermal mass," he said. German buildings typically have more mass, according to Rosenbaum, which he thinks may explain why thermal mass is not a significant focus of the Passive House program.

To work well as thermal mass, materials need adequate heat capacity; that's why heavy materials work well. But thermal storage materials also have to be reasonably conductive so that heat can move into and out of them easily—though not too conductive. Copper has great heat capacity, but heat moves out of it too quickly for it to provide effective thermal mass in buildings. Wood has a reasonable heat capacity, but

Photo: San Luis Sustainability Group

Plastered straw-bale walls provide distributed thermal mass in the Congregation Beth David Synagogue, and the light wall colors effectively bounce daylight throughout the space.

the conductivity is too low for it to work really well; it's hard to push enough heat into the wood. Water has very high thermal capacity but also relatively high effective thermal conductivity (due to convection of the water). This property can make water walls or roof ponds great cooling systems in hot climates, but they have to be engineered carefully to ensure that they will also work well for heating.

Thermal mass can be distributed or concentrated. Ken Haggard likes a combination of the two. The distributed mass his firm provides is generally at least two inches of stucco on frame walls or exposed concrete-block interior walls along with an exposed slab floor. "We have finally trained the local contractors to do interior, two-inch-thick stucco walls without complaining about the curing requirements," he noted. He generally aims for dedicating the entire floor, plus about half of the interior wall area, to thermal mass. "If at the end we find we need a little more mass, usually determined by the performance modeling, we add a double layer of ⅝" drywall to the ceiling."

In addition to that distributed mass, Haggard usually provides indirect gain by placing glazed 9"-thick (240 mm) water tanks under the south-facing windows. Most of Haggard's buildings end up with some water walls. "We have local welders who do the tanks inexpensively and have never in 30 years had a leak," he reports.

Phase change materials (PCMs) offer an exciting thermal storage opportunity for passive solar buildings. "Advances in micro-encapsulated phase-change materials could be a game changer for increasing thermal capacitance in lightweight construction," says Michael Holtz, FAIA, principal at LightLouver. Innovative Design has been incorporating PCMs into passive solar designs for decades—using numerous products that have come and gone.

Photo: David Bainbridge

Architect Ken Haggard used a combination of direct gain and water walls in the Congregation Beth David Synagogue; the water walls can be seen beneath the south-facing windows.

Nicklas estimates that his firm has used PCMs on at least 50 projects over the years, but he mostly relies on more traditional materials: veneers of masonry and stone, plaster walls, tile floors, and brick. In spaces that are used a lot, he often aims for 4"–6" (100–150 mm) of thermal mass in the floor and a 4" (150 mm) veneer on the walls. "It's hard to beat a brick," he added, noting that bricks are both inexpensive and attractive.

Whatever the thermal mass, there is usually a cost associated with it. "We've found in our practice that thermal mass is the only passive component that adds expense to the construction of a passive building," said Haggard. "This is why we're so interested in the new nanotech phase-change materials that can be added to drywall or masonry."

Distribution of passive solar heat

Passive solar buildings by definition do not rely on fans or pumps to distribute heat captured from the sun. With direct gain, the distributed thermal storage materials release heat based on temperature differences between that mass and the room. When the indoor air temperature is lower than the surface temperature of the mass, there is a net release of heat to the space. With adequate solar gain and properly sized mass, enough heat will be stored during the day to keep the space comfortable into the evening hours.

With indirect gain, the heat delivery is also primarily by radiant flow from the warm inner surface, but the flow is mostly in one direction—through the thermal storage material.

With both direct- and indirect-gain systems, convection also plays an important role in heat distribution. Air in contact with the surface of the thermal mass warms up and rises through its natural buoyancy, establishing convective loops in the living space. Convection also helps distribute warm air throughout the occupied space—delivering solar heat to spaces that may not be directly heated by the sun. This is why open floor plans are beneficial with passive solar buildings.

Features to Enhance Passive Solar

Complementary strategies and components are what make passive solar designs really shine.

Exterior shading

While the winter sun is low in the sky and reaches windows beneath fixed overhangs that easily block the summer sun, the need for shading differs significantly in spring and fall. Fixed overhangs may not be as satisfactory as adjustable awnings, exterior roll-down shade screens, or exterior roller blinds at these times. These window attachments can provide a high level of controllability, and some systems can even be automated based on indoor and outdoor conditions. For more on window attachments, see "Making Windows Work Better" (*EBN* June 2011) and WindowAttachments.org, which BuildingGreen manages for the U.S. Department of Energy.

Moveable insulation on windows

For optimal passive solar performance, south-facing glass should be as clear as possible (with a high SHGC). Some passive solar experts, including Mike Nicklas, argue against the overuse of low-e coatings for this reason. To achieve the desired solar gain without causing excessive heat loss, moveable insulation can be used on clear-glass windows. "The best solutions are still double-clear glass with an insulating shade or panel behind it," says Paul Torcellini, Ph.D., P.E., of the National Renewable Energy Laboratory.

While insulating cellular blinds and other types of moveable insulation have the drawback of requiring occupant actions to achieve effectiveness (and studies have shown that occupants may not regularly take those actions—see "Occupant Engagement—Where Design Meets Performance," *EBN* Nov. 2011), this is a viable strategy for the right client. Automated interior shading devices are becoming more common as well.

Landscaping

While shading systems incorporated into the building provide the greatest flexibility, a lot can be accomplished with carefully planned landscape plantings. Deciduous trees provide excellent shade during the summer months and into the fall, then lose their leaves in late fall, admitting more solar gain. Be aware, though, that the branch structure of a typical deciduous tree will block about half of the direct sunlight. Placement of landscaping close enough to a building to provide effective shade can also cause interference with air circulation and rainwater drainage systems.

Tall annual plants and vines can also be very effective natural shading systems for passive solar buildings. They can even work well shading east and west façades that are difficult to shade with fixed overhangs and awnings.

Integrated ventilation of thermal mass

Passive solar expert David Bainbridge is a proponent of nighttime convective cooling. In places with reasonably high diurnal temperature cycling, directing ventilation air across thermal mass can cool the mass during nighttime hours, allowing it to absorb heat during the day and keep the house cooler. This strategy doesn't work in climates that are too humid for night-flushing or that do not cool down adequately at night. The same approach can function on a building's roof using a roof pond, though the complexity and the liability risk of having water sitting on a roof keep this approach far out of the mainstream—even though this was the most effective of the classic passive solar systems for both heating and cooling, according to Haggard.

Options for Back-Up Heat

As Norbert Lechner, FAIA, so clearly articulates in the textbook *Heating, Cooling, Lighting: Sustainable Design Methods for Architects* (John Wiley, 3rd edition, 2008), whenever possible we should rely on passive systems for heating, cooling, and lighting before we look to electrical and mechanical options. But in the vast majority of buildings, passive systems will not satisfy 100% of energy needs. With passive solar heating, what are the best options for back-up heat?

It may make more sense to focus on what systems *aren't* appropriate. In general, when there is significant solar gain, one should avoid heating systems with a significant flywheel effect, such as masonry heaters or concrete slabs with radiant-floor heating. With these systems, heat may still be delivered to the living space many hours after the en-

Software to Aid in Passive Solar Design

Tool	Developer & Website	About the Software
EnergyPlus	U.S. Department of Energy www.energyplus.gov	EnergyPlus is the successor to DOE-2. It was built on DOE-2.1E and BLAST (from the U.S. Army Corps of Engineers), and it effectively addresses radiative, conductive, and convective heat transfer. The current version (7.1) runs on Windows, Mac, and Linux platforms. EnergyPlus itself is not user-friendly, but graphical interfaces are available, including OpenStudio for Google SketchUp.
eQUEST	James J. Hirsch & Associates www.doe2.com/equest/	eQUEST is a sophisticated energy modeling tool that was built on the DOE-2 platform using funding from the State of California. Mike Nicklas uses eQUEST on everything, both commercial and residential. He claims that this tool does a good job with solar gain, daylighting, and thermal mass.
Passive House Planning Package (PHPP)	Passivhaus Institut www.passiv.de/en/04_phpp/04_phpp.htm	PHPP is used for determining compliance with the Passive House certification system. It is a spreadsheet-based tool that does a good job modeling passive solar gain but is limited in how it treats thermal mass.
REM/Design	Architectural Energy Corporation www.archenergy.com/products/remdesign	REM/Design is a residential energy modeling tool developed by Architectural Energy Corporation, now a part of United Technologies Corporation. The companion program REM/Rate is the most widely used home energy rating software in the U.S. REM/Design addresses passive solar fairly well.
SUNREL	National Renewable Energy Laboratory, U.S. DOE http://www.nrel.gov/buildings/sunrel/	Developed (as SUNCODE) back in the early 1980s, this tool (or at least the original) remains a favorite of some designers. "Everything under the hood was visible," said Rosenbaum, referring to SUNCODE, "but there were no defaults, so you had to be a good modeler or you could get garbage results." SUNREL is available from NREL but is in need of an upgrade.

Rules of thumb for direct-gain passive solar systems

	Very Cold	Cold	Moderate	Temperate	Mild	Tropical Dry	Tropical Wet
Thermal Load	Heating only	Heating only	Heating and some cooling	Balanced heating and cooling	Cooling and some heating	Cooling with minimal heating	Cooling only
Aperture Area as Percent of Floor Area	10–20%	10–25%	14–20%	9–15%	8–13%	6–11%	0%
Square Feet of Mass per ft^2 of Solar Aperture	5–10 ft^2	6–11 ft^2	8–12 ft^2	9–14 ft^2	9–14 ft^2	9–14 ft^2	9–14 ft^2

Source: *Passive Solar Architecture* by David Bainbridge and Ken Haggard, Chelsea Green Publishing, 2011

ergy inputs into those systems have ceased, resulting in overheating.

Better complements to passive solar design are small, responsive heating systems, such as forced-air or hydronic central heating systems, or space heaters, such as through-the-wall-vented gas heaters, pellet stoves, or mini-split air-source heat pumps—the latter becoming a favorite of many leading-edge designers today. Reflecting on 30-plus years of low-energy building design, Andy Shapiro of Energy Balance in Montpelier, Vermont, noted that he started off with solar pioneer Norman Saunders "doing these incredibly complicated systems. It keeps getting simpler and simpler." He now gets heating loads so low that small point-source heating systems are perfectly adequate; and they obviate the need for expensive distribution systems.

Rules of Thumb and the Passive Solar Design Process

To provide guidance on how much solar glazing and thermal mass to provide, researchers in the '70s and '80s came up with detailed rules of thumb. Doug Balcolm and his team at Los Alamos National Laboratory published these rules in the much-cited *Passive Solar Design Handbook, Volume 2.*

How relevant are these rules of thumb today? Have they been replaced with newer values that account for better-performing glazings and building enclosures?

Surprisingly, most of the experts contacted for this article still rely on the old principles from around 1980. "The rules of thumb have not changed considerably over the past few decades," suggests Michael Holtz, though he notes that products have changed—including insulation materials, glazings, and HVAC options—so the design guidelines have to respond to that.

A common design practice is to start off with simple rules of thumb and plug those into energy modeling software (see the sidebar for information on the most common energy modeling tools for that process) to test the outcome. NREL's Torcellini calls the rules of thumb "a good starting point."

Bainbridge and Haggard published simple rules of thumb in their 2011 book *Passive Solar Architecture* (see table). In a cold climate with only heating demand, for example, the south glass can range from 10% to 25% of the building floor area, with 6–11 ft^2 of distributed thermal mass needed per square foot of south glass.

Suntempering Is Increasingly the Right Solution

The goal of using solar energy to heat our buildings is every bit as relevant today as it was in the 1970s and '80s. But as our insulation levels, window energy performance, and airtightness have improved, the risk of passive solar gain overheating these spaces has increased.

The safer approach today is to aim for suntempering, with smaller areas of south-facing glass (or lower-SHGC glass if larger glazing areas are desired for aesthetic reasons). Advanced low-e coatings mean that less heat will be lost back out through the glass at night, so more modest glazing areas will result in smaller temperature swings and fewer periods of overheating.

If true passive solar heating—with south glass areas exceeding about 8% of the floor area—are called for, very careful attention must be paid to thermal mass to keep temperature swings within reason. Newer phase-change materials may help provide enough thermal mass, but whatever the thermal storage provided, expect a cost to be associated with it.

Although it's still prudent to reduce energy needs as much as possible as a first step, PV has an increasingly important role in low-energy buildings. In highly insulated buildings, some of the leading energy designers are coupling a suntempering strategy with supplemental electric heating using mini-split air-source heat pumps that are powered by rooftop PV modules. In such a system, the baseline heating can still be provided by direct-gain solar and the people in the space, while carefully controlled peak heating requirements can be met with electricity generated on the building site. Solar energy—indeed, *passive* solar if one defines passive as not requiring fans or pumps—will provide all of the needed heat, and comfort can be maintained within tight tolerances.

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BackPage Primer

Dry-Bulb? Wet-Bulb? What's the Difference?

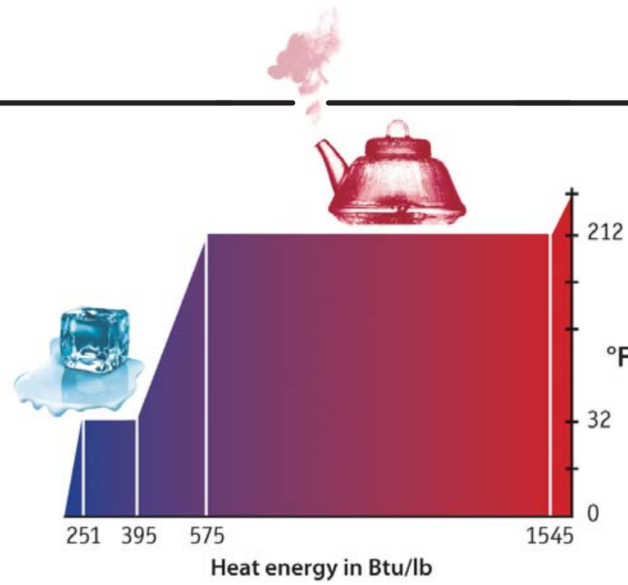

Illustration: Peter Harris

Although the acts of melting ice and boiling water are mundane occurrences, the underlying physics are not so simple. The illustration shows what happens to the temperature of water as heat is added (Btu per pound on the horizontal axis). The graph shows plateaus at 32°F and 212°F. Why does the temperature hold steady, even as heat is being added, right at water's melting and boiling points?

The temperature holds steady because it takes so much energy to accomplish the phase changes. Only when the *last* molecule of water has changed phase does the temperature of the material rise. All the energy it takes to accomplish phase changes is hidden.

We call the energy expressed in the sloped sections of the graph *sensible heat* because a thermometer can "sense" this heat. We call the energy expressed in the plateaus *latent heat* because it is hidden from the thermometer. Look at how much energy is hidden as the latent heat of vaporization of water at 212°F: 970 Btu in just one pound of water—the difference between the heat energy in water at its boiling point (575 Btu/lb) and the amount needed to produce steam (1,545 Btu/lb).

This is how perspiration and other types of evaporative cooling work: because the phase change from liquid to vapor requires so much energy, the molecules must absorb that energy from the nearest heat source (when you're exercising, that heat comes from you; in an evaporative swamp cooler, it's from warm ambient air).

Measuring sensible and latent heat requires two different types of thermometer—*dry-bulb* and *wet-bulb*. Unlike a typical (dry-bulb) thermometer, which measures sensible air temperature, the wet-bulb thermometer is wrapped in a cotton wick; when the wick is completely wet, you can swing the thermometer around, and the water evaporating off the wick pulls the wet-bulb thermometer's temperature down in direct proportion to the water content of the air around it. The drier the air, the more water evaporates off the wick and the lower the wet-bulb temperature goes; the more humid the air, the less water evaporates and the more similar the dry-bulb and wet-bulb temperatures are.

The wet-bulb thermometer measures the latent heat content of the moisture-laden air. But even more important is the difference between the two temperatures: that tells us the *relative humidity*—the moisture content of the air compared with how much moisture it can hold. Identical dry- and wet-bulb temperatures mean that the air is holding as much moisture as it possibly can—100% relative humidity.

The device that holds both thermometers is called a *sling psychrometer*; its measurements (and other elements of the science known as *psychrometrics*) can be expressed in the psychrometric chart—the topic of an upcoming BackPage Primer.