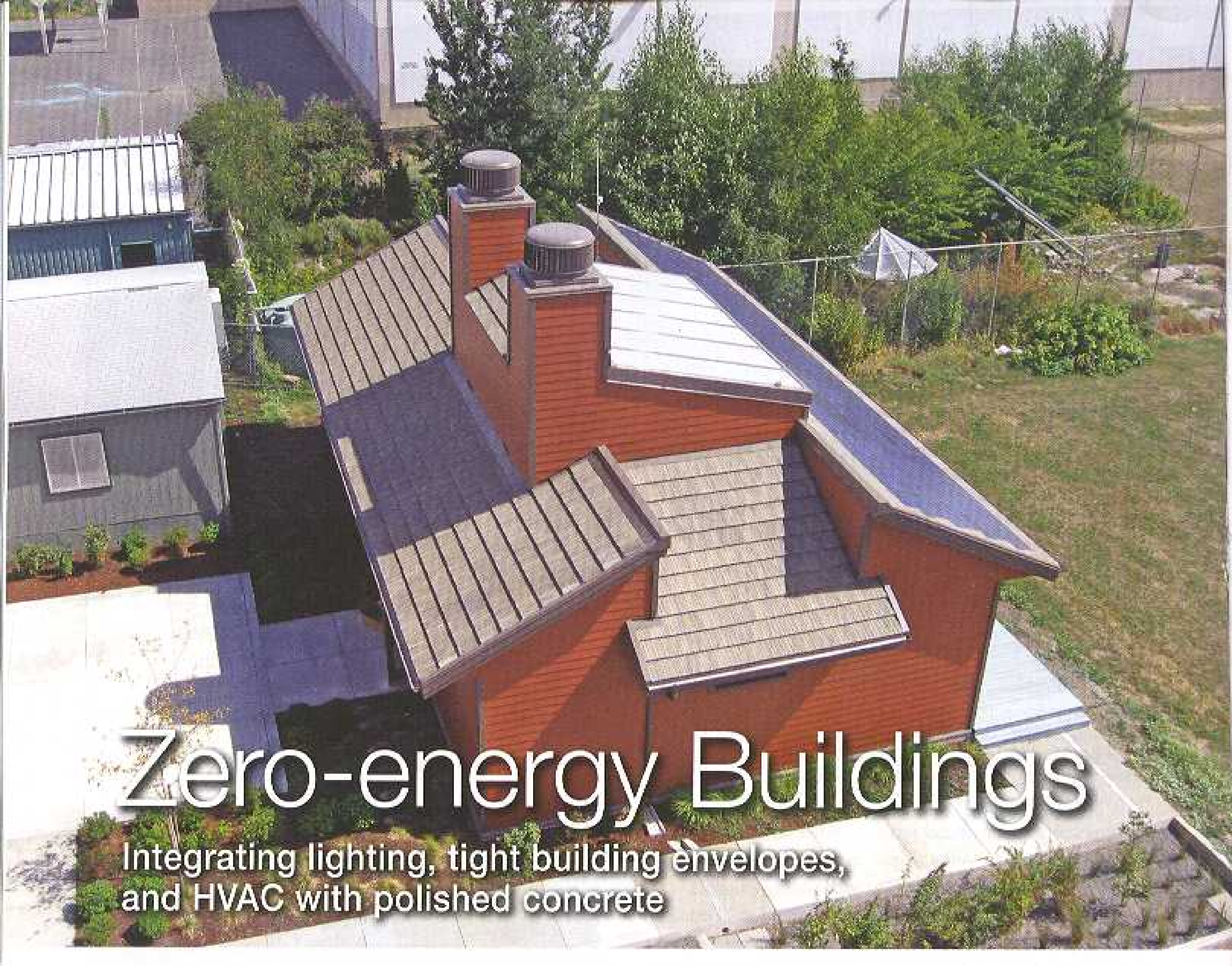


Zero-energy Buildings

Integrating lighting, tight building envelopes, and HVAC with polished concrete

by Greg Schwietz, CSI, CDT, and Paul Nutcher, CSI, CDT

Photo courtesy SRG Partnership Inc.

STRATEGIES FOR DAYLIGHTING AND ACHIEVING HIGH R-VALUE BUILDING ENVELOPES CAN BE ENHANCED BY INTERIOR CONCRETE ELEMENTS, INCLUDING POLISHED CONCRETE FLOOR SYSTEMS AND CONCRETE MASONRY UNIT (CMU) WALLS.

In fact, integrating daylighting, tight building envelopes, and exposed concrete surfaces fosters the elements needed for a passive heating and cooling system in most northern climates.

Further, building-integrated photovoltaics (BIPVs) can reduce the grid power needed for lighting and plug loads; in northern climates, it is even possible to eliminate the HVAC unit. By adding mechanical dehumidification and possibly having air-conditioning run on power from additional PVs, school classrooms in southern climates can also get off the grid. While these all provide environmental benefits to facilities, this article focuses on the use of polished concrete.

Real world examples

Schools and other building types can be adapted to a passive heating and cooling design approach, especially if they have higher occupancy rates during the workday and vacancies overnight.

The combination of a bare polished foundation slab's thermal mass, daylighting with diffusing light technology, and high R-value wall and roofing systems were all found to be common design approaches leading recent buildings to achieve near zero-energy status. Lesser, but integral, components in their success included such elements as acoustical ceiling tiles with high light-reflectance values and addressing occupant behavior.

An example is the Evans-Harvard High-performance Classroom at Portland, Oregon's Da Vinci School. It eliminated its HVAC system and, instead, installed polished concrete floors. By integrating these aforementioned elements into a classroom project, the school building's project team was able to gain Platinum certification under the Leadership in Energy and Environmental Design (LEED) program for a 232-m² (2500-sf) freestanding classroom.

Polished concrete floors can provide energy-conserving thermal mass, recycled content, and enhanced indoor environmental quality for projects pursuing LEED or CHPS.

Photo courtesy L&M Construction Chemicals

Thermal mass

Thermal mass applies to concrete, stone, or masonry building materials that can absorb the sun's heat (in non-geothermal applications) and then slowly release it. Having a passive heating and cooling system may eliminate the need for HVAC units to run for some parts of the year, depending on climate and location.

At the Da Vinci School, the project team installed a polished concrete floor with an exposed aggregate finish that absorbs radiant heat from the sun. Through convection, the colder night air from high-efficiency heat recover ventilators cools the foundation slab to level the heating and cooling loads. Two ceiling fans help direct the air toward the slab during night, maximizing the benefits of the thermal mass.

A damper below the skylight can be opened overnight for passive cooling of the concrete slab and walls during the summer. A turbine ventilator

Students at the Da Vinci School play their instruments with the benefit of a daylighting system maximized by the reflective polished concrete floor, ceiling panels, and skylight diffuser.

Images courtesy SRG Partnership Inc.

helps draw out the hot air during the day, eliminating the need for mechanical cooling equipment.

The passive heating and cooling system for the school building—designed by Portland's SRG Partnership under the supervision of project architect Tim Grenstead—was made possible with the technical assistance on the light diffuser from Charlie Brown, with the University of Oregon's Energy Studies in Buildings Lab program.

During winter months, heat from occupants and from the sun entering a large overhead skylight combines to be absorbed by thermal mass materials including a polished concrete floor system within the interior. Electric resistance heaters supplement the space when needed.

Net-zero and LEED

LEED and the Collaborative for High-performance Schools (CHPS) rating systems reward project teams with credit for Indoor Environmental Quality (EQ) and the resulting thermal comfort levels achieved through fresh air ventilation. LEED is part of a continuum of Silver, Gold, and Platinum certification levels with zero-energy buildings and restorative architecture as the ultimate goal.

The leveling of heating and cooling loads with interior concrete elements assists project teams within the Energy and Atmosphere (EA) credit category of LEED v.3.0 (*i.e.* LEED 2009). In fact, the most points in the rating system assigned to any of the categories are in the EA category, with a possible 21 points for EA Credit 1, *Optimizing Energy Performance*. Additional points are achievable for incrementally larger percentages of energy conservation in:

- EA Credit 1;
- Innovation and Design (ID) Credit 1, *Innovation in Design*; and
- EA Credit 2, *On-site Renewable Energy*.

The project team also gained points toward LEED certification through meeting the requirements of EA Credit 3, *Enhanced Commissioning*, and EA Credit 5, *Measurement and Verification*.

The amount gained in the EA category is significant because it takes 40 points for a minimum certification level. A perfect score in this category would bring the project team about half of the points needed to gain certification.

LEED point totals typically shoot very high on the scorecard when project teams use the foundational slab's thermal mass in a passive heating and cooling system to eliminate the usual HVAC unit and strive for net-zero-energy buildings. Many project teams have gained high-level LEED certification for designing net-zero-energy buildings, as demonstrated by the Da Vinci project.

However, before even considering going for LEED, there are prerequisites in all but the ID, Water Efficiency (WE), and Regional Environmental Priorities (REP) categories. Most important for energy efficiency is the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) 90.1-2007, *Energy Standard for Buildings Except Low-rise Residential Buildings*, benchmark. A LEED v.3.0-registered project has to meet this in order to attempt application for certification. Additionally, the energy systems must be commissioned by a third party to verify the heating and cooling system performance and that no chlorofluorocarbons (CFCs) are present in the system.

Modeling thermal mass

When constructing a net-zero-energy building, many design aspects must be considered. The climate, materials, and building layout, use, and orientation are all factors that come into play. Generally, good design practices incorporate energy modeling of the building and the details associated with it, according to Florida-based E3 Building Sciences' Ben Millar.

One of the best resources for understanding the energy efficiency of polished concrete floors combined with exposed CMU walls is the research paper, "Modeling Energy Performance of Concrete Buildings for LEED-NC Version 2.2 Energy and Atmosphere Credit 1," by engineers Medgar L. Marceau and Martha G. VanGeem. It is sponsored by the Portland Cement Association (PCA).[1]

Software modeling is needed to convert the thermal mass benefits of exposed concrete interior to documentation required to record LEED points. Specifically, the authors stated the software must model yearly energy use on an hourly basis.[2] The study examined several building types in different climate zones and concluded:

the effect of thermal mass is to lower both energy use and cost relative to the baseline framed exterior insulation finishing system (EIFS) buildings.

Medgar and VanGeem also conducted a sensitivity analysis to determine how energy use and cost vary with concrete floor thickness. The analysis considered different floor thicknesses, as well as different building types and surrounding climates. The study says:

The results show that regardless of building type or location, increasing floor thickness in increments of 38 mm (1.5 in.)—from 191 to 305 mm (7.5 to 12 in.)—increases the energy cost savings by a small amount.

The study also found energy modeling software would credit interior partition walls by helping provide further energy conservation while some furniture types could dampen the positive effects of polished concrete floors if they consumed a large floor portion. It is important to note VisualDOE software defaults the amount of thermal mass negated by a typical office layout as covering 85 percent of the floor.

The structures in the study are very common office buildings, unlike the Da Vinci classroom, which intentionally went further toward zero-energy performance. For example, the walls in the building were R-39 and the roof R-60. Again, zero-energy buildings typically go beyond LEED's current requirements and the U.S. Green Building Council (USGBC) intends to move the certification requirements further ahead during future updates to the rating system to match innovations in energy-efficient building design.

For the Da Vinci project, some might find the interior partition and the inner side of the exterior walls austere. One cost-effective treatment for exposed concrete or masonry on the interior, especially under an acoustically sensitive design criteria, could be the addition of draperies. Curtains can be drawn or opened for the effect occupants desire—addressing acoustics or thermal comfort. Open curtains allow the walls to absorb more heat from the sun while closed curtains would be more desirable during hot weather to enhance night cooling of the room. Occupants and facility managers would have to be educated as to the costs and benefits of using the curtains during various times of the year.

Net-zero costs

An experienced energy modeling team can be crucial when trying to design and build a net-zero building because they would be best qualified to handle the complexity of the building systems and their energy use, explained Millar.

He also noted it is important to maximize the energy savings per dollar spent on building materials and systems. Doing this is sometimes difficult because factors (*i.e.* climate and materials) are sometimes dependent on each other. For example, the amount of insulation a wall needs may be different in Florida than in Minnesota. This makes sense because one may have a 49-C (88-F) difference from inside to outside (–29 to 20 C [–20 to 68 F]) in Minnesota and only an 8-C (14-F) difference (25 to 32 C [78 to 90 F]) in Florida.

Therefore, spending extra money on going from R-13 to R-30 will not produce the energy savings per dollar in Florida that it would in Minnesota. The materials used also affect each other. For example, increasing the building shell's efficiency—with higher R-vales and tighter construction—will also reduce how much an increase in HVAC efficiency has on the energy savings per dollars spent. This is because raising the shell's efficiency decreases the loads on the mechanical system. In other words, there will be less for the HVAC system to do; therefore, making it more efficient affects a lower percentage of the overall building use.

Daylighting

Most classroom space is occupied primarily during the day, providing ideal environmental conditions for a daylighting strategy. After reviewing data from Illuminating Engineers Society of North America (IESNA) and CHPS, the project team was recommended a minimum target illumination of 20 footcandles. This is below the 30 to 100 recommended by the IESNA, but is still within the 19 to 100 range of international standards.[3]

The polished concrete floor at the Da Vinci School's LEED Platinum freestanding classroom project provides thermal mass for a passive heating and cooling system. This resulted in the elimination of an HVAC system.

Light-reflective floors

Light-reflective floors—including several concrete surface treatment methods—can improve illumination inside buildings by reflecting light from both the sun and ambient lights, according to PCA.[4]

Instead of adding more costly lighting units or increasing the intensity of artificial lighting, the project team can create a polished concrete floor using white cement, or by using shake-on bright colors before a slab treatment. Either method can increase light-reflectance. Polished concrete can require high levels of expertise to achieve proper surface quality so mock-ups are often suggested.

The specifier has several options for the slab—full-depth, two-course toppings, and shake-ons—to create a permanent reflective surface that will not wear off as paints and coatings can over time. In some cases, slag cements can be used to save on the cost or scarcity of white sand or brightly colored crushed rocks; slag and portland cement can significantly brighten concrete though other pozzolans may darken concrete.

Fine white sands or crushed white stone aggregate within the mix can help achieve uniform concrete color if white concrete is not cost-prohibitive. Before polishing a 28-day-cure slab, shake-on pigments can be applied to achieve the same reflectancy as white concrete. Such a floor surface is a passive means for improving illumination and can add to the potential for near-zero-energy construction.

Lighting systems

Lighting systems in schools can be the highest of the electrical demands during teaching days. Extensive daylighting is needed to reduce the building's peak energy consumption during the most likely hours of occupation. New advances in light diffusers are enhancing the possibility of building getting off the electric grid.

In the case of Da Vinci, advanced daylighting systems channel the sun's rays through a skylight with special louvers set between two polycarbonate panes to control light permitted within the space. The louvers can be angled to direct the sunlight toward the diffuser. The light then meets the diffuser, which is suspended below the skylight and slightly below the ceiling so its angled sides are parallel to the sloped ceilings. The fabric reflector bounces some light downward, but most of it is directed to the classroom's ceiling and outer edges, including the vaulted ceiling. The louvers can be automated or manually operated, and their stepper motors are mounted within the ceiling for quiet operation.

Using a light diffuser over a large centralized skylight can help eliminate a glaring bright spot on the floor under the skylight. When the sunlight is reflected at right angles onto reflective ceiling tiles, the natural light is spread evenly throughout the room. Additional sunlight can enter through a set of clerestory windows facing south and shaded by eaves. Depending on locations and climates, windows may be operable to promote natural ventilation.

"The most sustainable material you can use is no material at all," said SRG's Tim Grenstead, of the daylighting and passive heating and cooling systems.

During times of decreased sunlight at Da Vinci, the lights mounted into the diffuser are amplified and dispersed, only using 0.4 W/sf. The supplemental lighting fixtures include four sets of two T5 fluorescent bulbs mounted atop the reflector's diagonals.

During cooler months, the sun's light energy can be used to heat classrooms. The diffuser can be adjusted to spread light from the sun toward the concrete walls and the polished concrete floor where it can be stored in the heat sink for passive heating. During the summer months, the only weak spot in the school building's design are the vertical windows.

The minimal amount of electric power needed for the freestanding classroom was generated by BIPV concrete roofing tiles. An array of 153 tiles was integrated within the roofing system on the south-facing area. The goal for the project team was to generate 100 percent of the electric power needed over the duration of one year with the PV shingles. These were expected to generate 5600 kw/hr annually (compared to the average energy use in an American home of 10,000 kw/hr). Net metering was also installed, as well as an energy-monitoring kiosk to assist occupants in monitoring their energy consumption behavior as well as provide motivation to achieve net-zero-energy occupant behavior.

Additionally, several conservation measures were used, including lighting sensors and very low plug loads to calculate the building's overall anticipated zero-energy performance.

Natural ventilation

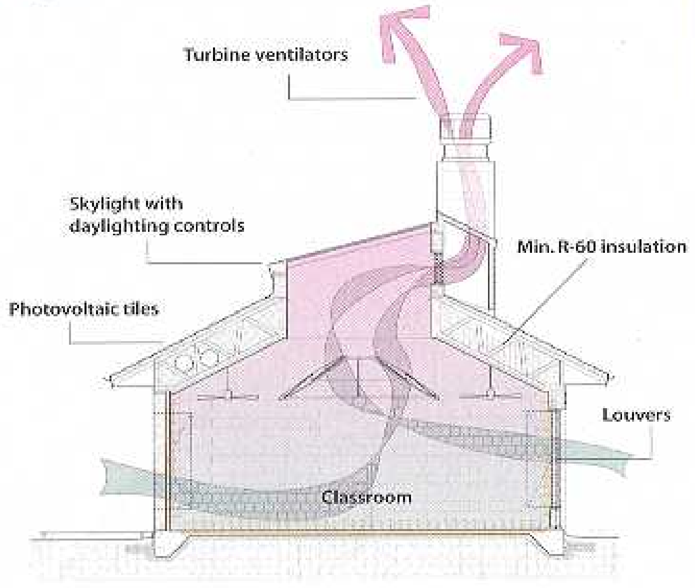
On the Da Vinci School project, there are fewer windows, and the draperies along the walls can assist in cooling at night when they are open, instead of blocking the natural ventilation system's ability to blow cold air on the block wall.

Designers also need to be aware of modifications to the newly proposed changes to ASHRAE 62.1, *Ventilation for Acceptable Indoor Air Quality*, which requires a mechanical ventilation system to supplement natural design approaches. Compliance with this standard is required for obtaining LEED's EQ Credit 1, *Outdoor Air Delivery Monitoring*, and EQ Credit 2, *Increased Ventilation*.

The new ASHRAE requirement will give occupants more control over their environment as operable windows can be located near undesirable outside places, including those near human activity which generate noise and poor air quality.

Other issues beyond solar heat gain and noise/air pollution also confront natural ventilation strategies.[3] These include:

- dewpoint;
- internal heat loads;
- opening sizes and locations;



Some of the building features of the Evans-Harvard High-performance Classroom at Da Vinci Arts Middle School.

- high afternoon temperatures;
- diurnal temperature range; and
- climate.

Added sustainable benefits

The project team's strategy of incorporating passive systems into school design has many benefits, including eliminating periodic replacement of floor coverings by using polished concrete floors.

A net-zero-energy building is designed to be virtually airtight, leaving little room for off-gassing of materials, furnishings, and finishes during passive heating days. In addition to energy conservation and daylighting, the polished concrete floor contributes to regional and recycled content, and provides a laboratory-tested low-volatile organic compound (VOC) flooring solution for assisting both LEED and CHPS project teams. According to a *Concrete Construction* report on an American Terrazzo Association lifecycle cost analysis, polished concrete floors also offer more than a 60 percent reduction in ongoing maintenance costs compared to floor coverings and vinyl tile products.

Concrete can be separated during demolition and crushed for recycling or reuse, while substituting fly ash can add recycled content to the concrete mix. While fly ash darkens the slab, proper finishing can correct this. Further, the high gloss of a polished concrete floor can provides some reflectivity in addition to a brightly colored slab. Decorative concrete finishes on floors and walls eliminate needing applied flooring finishes, which require replacement and may end up in the landfill at the end of their useful life. Architectural concrete can be patterned, scored, stamped, rolled, or inlaid into the concrete structure. To address acoustics and avoid echoes, the designers deliberately created walls that are not parallel.

ADDITIONAL **INFORMATION**

Authors

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Abstract

Strategies for daylighting and achieving high R-value building envelopes can be enhanced by concrete interior elements including polished concrete floor systems and concrete masonry unit (CMU) walls. Integrating these factors creates many elements needed for a passive heating and cooling system. By adding mechanical dehumidification and air-conditioning run on power from additional photovoltaics (PVs), school classrooms in southern climates can also get off the grid.

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Division 09
Acid resistance
American Architectural Manufacturers Association
Anodic film
Environmental Protection Agency
Organic seal

Occupant behavior

Although the project team designed, installed, and constructed the classroom, the students and staff wanted to achieve net-zero as well, according to Randy Bachelor with the Bonneville Environmental Foundation.

"I think integrated student knowledge will help the project stay on track," he explained. "There are net-zero occupant behaviors that have to be learned in order for the building to use less energy than it makes from the photovoltaic panels."

Bonneville donated the PV roof tiles and wall-mounted devices for monitoring energy consumption and energy generation. The monitoring device helps occupants see in real time per year, month, week, or day how much energy they are consuming. This affects the occupants as they try to reduce energy as much as possible, and it serves as a teaching tool for students wanting to better understand how solar power generation works.

Maintenance and opening and closing the draperies and windows are among the new behaviors occupants had to learn to achieve zero-energy construction. Operable windows and ventilation louvers must be opened and closed to maximize the amount of natural heating and cooling of the occupied space. Teaching them when to open and how much was the challenge, according to the project team.

Maintaining zero-energy buildings can require minimal effort. Normal maintenance for polished concrete includes regular sweeping, damp mopping about once a month, and some reapplication of the hardener as suggested by the manufacturer.

Conclusion

The Evans-Harvard High-performance Classroom at Arts Middle School gained Platinum certification and was expected to achieve nearly zero-energy status, according to Glen Phillips of Portland-based Green Building Services (GBS), provider of the project calculations needed for the LEED project team.

The success of net-zero-energy design depends greatly on the relationship between the building materials and their effect on consumption. Concrete construction is a very passive means of providing thermal mass and new innovations in daylighting. Advancements in building-integrated photovoltaics are increasing the possibility of being integrated into concrete construction for powering any lighting or space heating needed for occupant comfort.

Most of the contractors and material suppliers donated their services and materials to bring light to both today's building designers and tomorrow's students of music at Da Vinci. Perhaps the students' exposure to this form of architecture will encourage them to pursue in construction. Their motivation could only be enhanced by experiencing the positive wavelengths from both the sun and the sounds in the classroom. **CS**

Notes

[1] For more information, see "Concrete's Mass Appeal for Energy Performance" by Medgar L. Marceau and Martha G. VanGeem in the November 2008 issue of *The Construction Specifier*.

[2] For more information on the 2002 study, see "Modeling Energy Performance of Concrete Buildings for LEED-NC Version 2.2: Energy and Atmosphere Credit 1," by Medgar L. Marceau and Martha G. VanGeem, sponsored by the Portland Cement Association (PCA).

[3] For more, see "Designing the High-performance Classroom," by G.Z. Brown, Dylan Chavez, and Terry Blomquist, in the September/October 2008 issue of *Solar Today*.

[4] For more information, see "Light Reflective Floors," by the Portland Cement Association in *Decorative Concrete*, Tech Brief.

[5] See Chris Dixon's "Naturally Ventilated Commercial Buildings" in the January 2010 issue of *Walls & Ceilings* magazine.