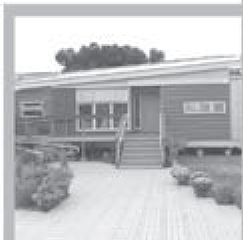
SOLAR DECATHLON

2005



SOLAR DECATHLON 2005: THE EVENT IN REVIEW

OCTOBER 7–16, 2005

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Cover Photos (counterclockwise from upper left): University of Colorado home, Cornell University home, and California Polytechnic State University home (photos by Chris Gunn). The Colorado team celebrates their first-place finish in the 2005 Solar Decathlon (photo by Stefano Paltera/Solar Decathlon).

2005

Solar Decathlon 2005: The Event in Review

October 7–16, 2005

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National Renewable Energy Laboratory

Message from the Competition Director

They say that to do something great in life, the accomplishment must have significance. The significance comes from making a difference, either in your life or the lives of others. The Solar Decathlon has both. The event turns students into leaders, and disbelievers into believers.

Two years before the contest, when most of the students joined their respective Solar Decathlon teams, little did they know how daunting the task would be. From the long hours designing and building a house from the ground up, to the demanding requirements necessary to build and occupy a house on the National Mall, competing in the Solar Decathlon is hard. For those with the right stuff, it built character and leadership—qualities that will change their lives for the better. That's significant.

To power a house day after day on sunlight is a technological accomplishment that many find hard to believe—especially in cloudy weather. What the teams proved is that solar energy really works and energy efficiency pays off. Considering the consequences of billions of people around the world burning finite fossil fuels at an ever-increasing rate, demonstrating technologies that can make a difference is significant.

To everyone who helped, thank you for making the 2005 Solar Decathlon the greatest competition ever held. To the 2005 faculty advisors, thank you for providing the motivation and leadership that were instrumental in inspiring your students to succeed. Your unwavering belief in their potential has made the difference in the stunning demonstration of talent and skill on the National Mall.

To all the students, the ***class*** of 2005, thank you for showing the nation and the world that the future is now. I applaud each one of you for demonstrating the positive power of ingenuity and productivity. As you move on and begin your careers, I expect you to continue to lead us to a brighter future!

To the new teams preparing for the 2007 Solar Decathlon, I hope this technical report provides insight and guidance. The report was written with you in mind. In architecture, as well as engineering, the iterative process of improving each successive design is the key to making progress. If we are to have cost-effective, appealing solar-powered houses in the near future, ***your*** designs based on what you have learned will help take us there.

Sincerely,

Richard King

Richard King

Solar Decathlon Competition Director Richard King (left) congratulates members of the University of Colorado team on winning the Communications contest. The Colorado team would go on to win the overall competition.

Acknowledgements

The 2005 Solar Decathlon was made possible under the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Program. DOE partnered with the National Renewable Energy Laboratory (NREL—a DOE laboratory), the American Institute of Architects, the National Association of Homebuilders, BP, DIY Network, and Sprint Nextel to sponsor the event. The dedication and hard work of the 18 college and university teams from the United States, Canada, and Spain made this second competition a great success. The authors appreciate the support and guidance of Richard King, Wendy Butler-Burt, Chris Powers, and John Horst of DOE; Greg Barker and Ed Hancock of Mountain Energy Partnership; and Sheila Hayter and Sara Farrar-Nagy of NREL for their contributions and reviews. The authors would also like to thank Janie Homan (NREL), who edited the document, and Jim Miller (NREL), who did the document layout.

Never have so few worked so hard to accomplish so much! After the Opening Ceremony on October 6, the 2005 Solar Decathlon teams paused for a group photo—likely their last moment of relative calm until the competition ended October 14.

Photo Credits: The authors would like to acknowledge the talent, patience, and professionalism of the two photographers—Stefano Paltera and Chris Gunn—who took the vast majority of photos in this report. Unless otherwise attributed, Stefano Paltera took the photos in the foreward matter and pages 1–19, and Chris Gunn is responsible for the photos in pages 20–48.

Executive Summary

In the fall of 2005, 18 teams from colleges and universities across the United States, including Puerto Rico, and from Canada and Spain, assembled in Washington, D.C., for the second Solar Decathlon. The Solar Decathlon is a collegiate competition that demonstrates energy-efficient and solar technologies that meet today's residential energy demands. The United States Department of Energy (DOE), its National Renewable Energy Laboratory (NREL), the National Association of Home Builders (NAHB), the American Institute of Architects (AIA), and private-sector partners BP, Sprint Nextel, and DIY Network sponsored the competition.

Teams were required to design and build small, energy-efficient, completely solar-powered houses and to compete side-by-side in 10 contests. The energy source for each house was limited to the solar energy incident on the house during the competition. The 2005 event took place from October 6–16, 2005, on the National Mall in Washington, D.C. The Mall was again selected for this event because it is a national stage, but it necessitated the transport of each solar home from its campus to and from Washington, D.C., at considerable expense. Regulations that were designed to protect the National Mall limited building size and height, mandated handicapped accessibility, prohibited excavation, and limited the entire event (arrival, assembly, competition, disassembly, and departure) to 21 days.

Solar Decathlon participants were selected through a proposal review in September 2003. Eight of the selected institutions also competed in the 2002 event. The 18 teams that participated in the 2005 competition follow:

- California Polytechnic State University, San Luis Obisbo
- Canadian Solar Decathlon (Concordia University and Université de Montréal)
- Cornell University
- Crowder College
- Florida International University
- New York Institute of Technology
- Pittsburgh Synergy (Carnegie Mellon, University of Pittsburgh, and The Art Institute of Pittsburgh)
- Rhode Island School of Design
- Universidad Politécnica de Madrid
- Universidad de Puerto Rico, Mayagüez
- University of Colorado, Denver and Boulder
- University of Maryland
- University of Massachusetts Dartmouth
- University of Michigan
- University of Missouri-Rolla and Rolla Technical Institute
- University of Texas at Austin
- Virginia Polytechnic Institute and State University
- Washington State University

The rules for the 10-contest competition were revised and improved from the 2002 inaugural event. They are described in detail in the section on Contests and Scoring (see p. 6). Each contest was worth a maximum of 100 points, except Architecture, which was worth 200 points. Underpinning all elements of the competition were the requirements that only solar energy could be used to power life and work; that dwelling livability, aesthetics of the structure, and integration of dwelling with energy systems were key elements; and that the projects would advance the state of the art. The competition houses were required to provide hot water for domestic needs and all the electricity for an electric car, lighting, heating and cooling, and household appliances—in short, residential life with all the modern conveniences. The Energy Balance contest required that the teams use only the amount of energy their systems could produce during the event. In a spirit of teaching and inspiring, all teams were required to open their homes to the public during tour hours, to help educate the public about their projects and the technologies they employed.

Some 120,000 people visited the 2005 Solar Decathlon event. The weather was inclement during much of the competition week, but this did nothing to dampen the enthusiasm of the visiting public. Many visitors toured the homes, often waiting in long lines to do so. Tours provided an opportunity to hear each team's explanation of the home's features and function, and to view each team's completed interior, including a kitchen, living room, bedroom, and bathroom. Homes were a minimum of 450 ft^2 (41.8 m^2) of conditioned space within a maximum building footprint of 800 ft^2 (74.3 m^2). As in the 2002 Solar Decathlon, homes employed not only sophisticated energy systems, they were also beautifully finished and furnished inside and out, with thoughtful integration of design aesthetics, functionality, and consumer appeal. To learn about each team house and individual team competition results, see Details by Team (p. 19). The event received extensive coverage by the national media, as well as coverage by each teams' local media. This media coverage resulted in upward of 800 million impressions (see Attendance, Media, Web site, p. 3).

The Solar Decathlon culminated on the National Mall, but it is also a two-year investment of vast quantities of time, money, physical labor, and creativity from each team and its student and faculty members. Teams were composed of architects, engineers, designers, communicators, fundraisers, and builders. Each of the 18 participating teams can be justifiably proud of their accomplishments, irrespective of their place in the competition overall. The organizers believe these early student collaborative efforts in architecture, engineering, and building science can become a model to foster improved interactions in the building industry, resulting in better building designs that integrate solar energy with energy efficiency.

The overall winner of the competition, the University of Colorado, used a strategy of resolutely performing nearly all the required competition tasks despite the adverse weather conditions. They wanted to demonstrate that solar works, even when it rains. The Colorado team performed well in many of the 10 contests, although they did not receive any points in the Energy Balance contest. Their 7-kW photovoltaic (PV) array was not the largest of the competition, but their energy storage capacity was quite robust and served to sustain the house and its efficient loads (see p. 16 graphs). The team understood how the energy flowed in their home, having performed a very comprehensive modeling of the home prior to the competition. Cornell University placed second, and California Polytechnic State University placed third overall in the competition. For more information about the awards received by each team, see Details by Team (p. 19).

As in the 2002 event, in 2005 most teams used crystalline silicon PV modules to provide electricity from the sun. Installed peak capacity ranged from 3 kW to nearly 11 kW. The only limitation on PV system size imposed by the regulations was the maximum footprint limitation of 800 ft^2 (74.3 m^2) on all solar and shading components. Two teams used thin-film PV, and one of those (Missouri Rolla) integrated the solar hot water system with the PV to absorb the sun's heat and collect waste heat from the PV modules for heating hot water. The other team employing thin films, Florida International University, used building-integrated PV transparent glass amorphous silicon PV panels in place of windows.

NREL staff and contractors instrumented each home and measured and recorded temperature, humidity, lighting levels, and other data during the event. The Solar Decathlon "solar village" on the Mall was connected via wireless networks for data acquisition and Internet connectivity, allowing the organizers, the teams, and the public to monitor the results of the competition in near real time, both on the Mall and via the Internet. Throughout the competition, all teams responded to the meteorological conditions, developing strategies and making trade-offs to improve their chances of winning despite the lack of sunshine.

The 2005 Solar Decathlon homes raised the bar in performance relative to the inaugural event. And the team homes have proven once again that there are multiple aesthetic and functional solutions to the challenge of creating homes powered entirely by the sun. The students and faculty who participated in the 2005 Solar Decathlon demonstrated a vision to everyone for a bright energy future that runs efficiently and dependably on renewable energy.

There will be future Solar Decathlons. The next Solar Decathlon will be held in 2007, and another in 2009. More information is available on the Solar Decathlon Web site (***www.solardecathlon.org***).

"It feels so good to see people enlightened by what we've done. And the kids! Children feel we should start doing these things."

— New York Institute of Technology Team Member Shana Lerner

Why hold a Solar Decathlon? The future of these children, and millions like them around the world, is a big part of the answer. Hundreds of children from area schools visited the Decathlon on October 11 for the School Day event.

Children who came for School Day learned a lot about solar energy and energy efficiency—but there was also time to enjoy a spirited musical interlude with the Solar Decathlon team from Puerto Rico.

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Event Overview

For 10 days in October 2005, a "solar village" on the National Mall in Washington, D.C., welcomed more than 120,000 visitors. Eighteen teams of students from colleges and universities from the United States (including Puerto Rico), Canada, and Spain had come to compete in 10 contests to determine which team designed, constructed, and operated the most attractive and energy-efficient home powered solely by the sun. The teams also had come to the nation's capital to share with the public what they had learned about the latest solar energy and energy efficiency technologies.

The 2005 Solar Decathlon was the second such competition, with the inaugural event occurring in fall 2002. Public and media interest was equally intense the second time around. The next Solar Decathlon will occur in fall of 2007, with future events to occur every two years after that.

Just like the well-known Olympic decathlon, the Solar Decathlon consists of 10 contests. But the Solar Decathlon centers on all the ways we use energy in our daily lives—at work, at home, and at play. To compete, the teams must design and build energy-efficient homes that are powered exclusively by the sun. These homes must maintain a comfortable temperature, provide attractive and adequate lighting, power household appliances for cooking and cleaning, power home electronics, power an electric vehicle, and provide hot water. The contests evaluate the aesthetics of the team projects as well. Although the homes are small—no greater than 800 ft^2 (74 m^2)—they must be attractive and easy to live in.

Like the athletic decathlon, the Solar Decathlon tests proficiency in a wide range of skills. Unlike its athletic counterpart, however, the Solar Decathlon is a team event, in which the diversity of abilities comes from the composition of the team rather than a single individual. Architecture and engineering students work with students from other disciplines, such as marketing, communications, graphic design, and computer science, to design, communicate, troubleshoot, and build this challenging project.

Web Site Resources
www.solardecathlon.org/2005/technical_report.html

2005 Solar Decathlon Rules and Regulations

Daily Journals

Daily Event Schedule

Juror and Judge Information

Solar Decathlon 2002: The Event in Review

The teams built their houses on or near their home campuses and transported them to the competition site on the National Mall. All the houses completed their land journey by truck, but the houses from Madrid and Puerto Rico also came great distances by ship. Some houses arrived in one completed piece, and others had to be assembled from multiple pieces. Assembly of the village in Washington, D.C., began at 12:01 a.m. on September 29, 2005. The teams and the competition organizers from the U.S. Department of Energy (DOE) and its National Renewable Energy Laboratory (NREL) worked around the clock for seven days to complete assembly of the village.

More than 120,000 visitors came to the National Mall in Washington, D.C., to experience the second Solar Decathlon.

Cécile Warner

On September 30, a Virginia Tech student worked on roof installation, a major milestone in building any house, but critically important in the Decathlon because the roof supports the PV system.

While the students assembled their houses, a team from the National Renewable Energy Laboratory installed monitoring systems to capture data essential to conducting several of the contests. The University of Michigan house is pictured.

NREL/PIX14605

Students from the Universidad de Puerto Rico painted the finishing touches on their house on October 5.

Opening the Solar Village

U.S. Secretary of Energy Samuel W. Bodman officially opened the Solar Decathlon village during a ceremony on Thursday, October 6, 2005. Representatives from Solar Decathlon sponsors—NREL, the American Institute of Architects (AIA), BP, DIY Network, and Sprint Nextel—shared the stage with the Secretary, who introduced the 18 teams.

"These homes are helping to bring the promise of solar power to reality," Secretary Bodman said. "It's inspiring to see these young people work together through the design and building stages of these next-generation homes. I want to congratulate all of the teams who are competing and note that the awards they win here won't compare to the prize of knowing, down the road, that their work helped strengthen our world's energy supply with more available use of solar power."

The Solar Decathlon teams came to the Mall to compete, but they also came to share information with visitors. Team houses were living demonstrations of the latest in energy efficiency and renewable energy designs and products, and the best in home design. The event was a valuable educational opportunity for consumers.

In addition to touring the team houses, visitors could attend a variety of free workshops. Most workshops, presented by DOE, NREL, and the Department of Housing and Urban Development, were about solar energy and energy efficiency in the home. The National Association of Homebuilders (NAHB), AIA, BP, and Sprint Nextel (all of whom are Solar Decathlon sponsors) presented workshops for specialty audiences (e.g., homebuilders). Also for consumers, the Solar Electric Power Association held an expo, where 60 solar-related companies exhibited their products and services.

With great fanfare, Secretary of Energy Bodman (center), representatives from the Solar Decathlon sponsors, and the student decathletes opened the 2005 Solar Decathlon on October 6.

The solar village also featured three educational exhibits: *Energy Today*, *Anatomy of a House*, and *Powered by Renewables*. Visitors could learn about energy sources and uses in the United States today and in the future, tips on saving energy in the home, grid-connected solar electric (also called photovoltaic or PV) systems, and the renewable energy power systems (PV, biodiesel generator, and wind turbine) powering the solar village.

Attendance, Media, Web Site

During the 11 days the Solar Decathlon was open to the public (October 6–16, 2005), the event received significant foot and Web traffic, as well as media coverage.

About 120,000 visitors came to the National Mall to tour the solar village, despite overcast skies and rain from the opening ceremony until the winner was announced on October 14. It rained more than seven inches on Friday and Saturday, October 7 and 8, alone! See the "What Made the 2005 Competition Unique?" section (p. 13) for more information about the effects of the weather on the competition. Fortunately, the village was still open to the public on Saturday and Sunday, October 15 and 16, so those who hadn't braved the weather earlier in the week still had a chance to tour the houses under fairly clear skies.

The official Solar Decathlon Web site, ***www.solardecathlon.org***, received about 73,000 unique visits between October 6 and October 16, 2005. The average time per visit was more than eight minutes.

Solar Decathlon stories appeared in print, online, and on television and radio (see summary in Table 1). Highlights included stories on or in the CBS Evening News, DIY Network, *New York Times*, *Los Angeles Times*, *Washington Post*,

"Every one of these houses is a marvel of engineering and design, and a model of creativity and innovation."

— U.S. Secretary of Energy Samuel W. Bodman

Popular Mechanics, and Sirius radio. The Solar Decathlon also was, or will be, featured on five cable shows on Discovery Canada, DIY Network, HGTV, This Old House, and the New York Times TV/Discovery Channel. The programs vary from short features to full-length documentaries.

Table 1. Media Hits, Airings, and Impressions for Solar Decathlon 2005

Media Type	Stories/Airings	Impressions (in millions)*
Print	178	80
Television	285	18
Cable Programming	7	480
Radio	11	109
Online	383	197
Grand Total	**864**	**884**

*For print media, impressions were calculated as circulation multiplied by 2.5 for newspapers and 3.3 for magazines. For television and cable programming, impressions equal the number of viewers; for radio, the number of listeners; and for online media, the average number of visitors per site on which a given story was posted. Numbers are rounded up or down to the nearest million.

Media interest in the 2005 Solar Decathlon was huge. The story filed by this TV reporter featured the University of Maryland.

Congressional, White House, and International Interest

The 2005 Solar Decathlon attracted members of Congress as well as committee staff to the solar village. Several teams first caught the attention of their Congressional delegations while their homes were under construction. Home district visits usually were followed up with a visit when teams finished their entries on the National Mall. In addition, DOE sponsored special Congressional tours of the solar village for members and staff of the House Science Committee and the Renewable Energy and Energy Efficiency Caucus.

Following visits to the Solar Decathlon, Congressional interest only grew. After the competition was over, the Energy Subcommittee of the House Committee on Science held a hearing to showcase winning teams and the energy technology highlights from the 2005 Solar Decathlon. The Subcommittee also examined the research and policy implications of the Decathlon, including the steps necessary to make solar power more viable in the mainstream market.

The White House was also interested in the Solar Decathlon. First Lady Laura Bush invited Colorado team leader Jeff Lyng to sit with her during the State of the Union address in January 2006. During the address, President Bush announced his Advanced Energy Initiative, which includes a proposal to increase funding for research and development of solar technologies.

The international community was also well represented at the Solar Decathlon. Dignitaries from Spain and Canada came to offer encouragement to the teams from their countries. Many visitors from Puerto Rico came to support their team, and tourists from other countries were much in evidence during the event.

Congressman Lamar Smith (R-Texas) stopped by with good luck wishes for the University of Texas team on October 7, the first day of active competition.

After the opening ceremony, Secretary Bodman (left) and Spanish Ambassador to the United States Carlos Westendorp shared a friendly conversation at the Universidad Politécnica de Madrid home.

Canadian Minister of Environment Stéphane Dion paid a visit to Team Canada's home on October 11. The home features a PV window complete with maple leaves.

> *"As you walk through these fabulous solar homes, you'll see technologies that were pioneered at DOE, NREL, and other national laboratories."*
>
> — NREL Director Dan Arvizu

Sponsors

The primary sponsor of the 2005 Solar Decathlon was the DOE Office of Energy Efficiency and Renewable Energy. The National Renewable Energy Laboratory, a DOE laboratory, was charged with managing and organizing the competition and event. AIA and NAHB spread the word about Solar Decathlon to their architect and builder members (respectively), provided workshops, and created networking opportunities for the students and celebrated their accomplishments. Private-sector sponsor BP offered "at-cost" PV systems to all the teams, as well as free technical assistance. Before the competition, the company issued a request for proposals to the teams to encourage innovative applications of building-integrated PV. The University of Texas won the bid and received a free PV system. BP also hosted a reception, sponsored the onsite "People's Choice" award, conducted media outreach, and bought advertising for the event throughout the Washington, D.C., area. DIY Network conducted significant media outreach and publicized the event to its subscribers via dedicated Web content. DIY sponsored an online "Voter's Choice" award and produced a documentary of the event, which aired December 2005. Sprint Nextel brought its "cell on wheels" or COW to the National Mall and set up a local area network for the whole village, providing Internet connectivity and telecommunications support to the teams and organizers. The company also provided organizers with cell phones to use during the event and helped to power the village with a fuel cell.

"Your passion, knowledge, and skills are obvious. You have created beautiful houses, but they will have very little impact if you can't communicate about them effectively."

— Solar Decathlon Director Richard King

Students As Solar Energy Ambassadors

As crowds of visitors lined up to tour the homes, the student decathletes assumed one of their most important roles: ambassadors for solar energy and energy efficiency. Home Tours were a component of the Communications contest, which challenged teams to communicate their experiences to a wide audience—including other students and professors, school children, tourists, homeowners, and energy and building professionals. Through Web sites and public tours of the houses on the National Mall, the teams shared their stories about the Solar Decathlon and the knowledge they had gained.

Washington State University team members showed off their evacuated-tube collectors for the solar hot water system.

In the University of Massachusetts Dartmouth living room, visitors listened closely to a student's description of various features of the house. Questions were encouraged, and the students were excellent teachers.

Long lines formed outside the Rhode Island School of Design home and all the other homes.

On the Crowder home tour, students showed visitors the flooring, trim, and cabinetry—all made from hardwood from the Pioneer Forest in the Ozarks.

At the California Polytechnic State University home, the learning began outside with signs describing a variety of features, including the energy-efficient aspects of the home.

A student tour guide from the Florida International team showed visitors around, pointing out custom track lighting that was designed to save energy.

Contests and Scoring

The 10 Solar Decathlon contests are based on three guiding principles:

- During competition, teams must supply the energy requirements necessary to live and work using only the sunlight shining on their entry—the global solar radiation incident on the house.
- Houses exemplify good design principles that will increase the public's awareness of the aesthetic and energy benefits of solar and energy efficiency design strategies and technologies, which in turn will increase the use of these design principles and technologies.
- The work of the teams, organizers, and sponsors will stimulate accelerated research and development of renewable energy, particularly in the area of building applications.

Some contests are scored by measuring performance, such as meeting certain lighting-level or temperature requirements. Others require the successful completion of tasks. Some contests are scored by judges who are experts in architecture, engineering, and other appropriate fields. The subjective judging evaluates things that measurements cannot evaluate, such as aesthetics and "livability." Some contests are scored by a combination of these methods.

The 10 Contests

The following describes the 10 contests of the 2005 Solar Decathlon. In 2007, there will be changes to some of the contests. See "What's New for the 2007 Competition" (p. 18).

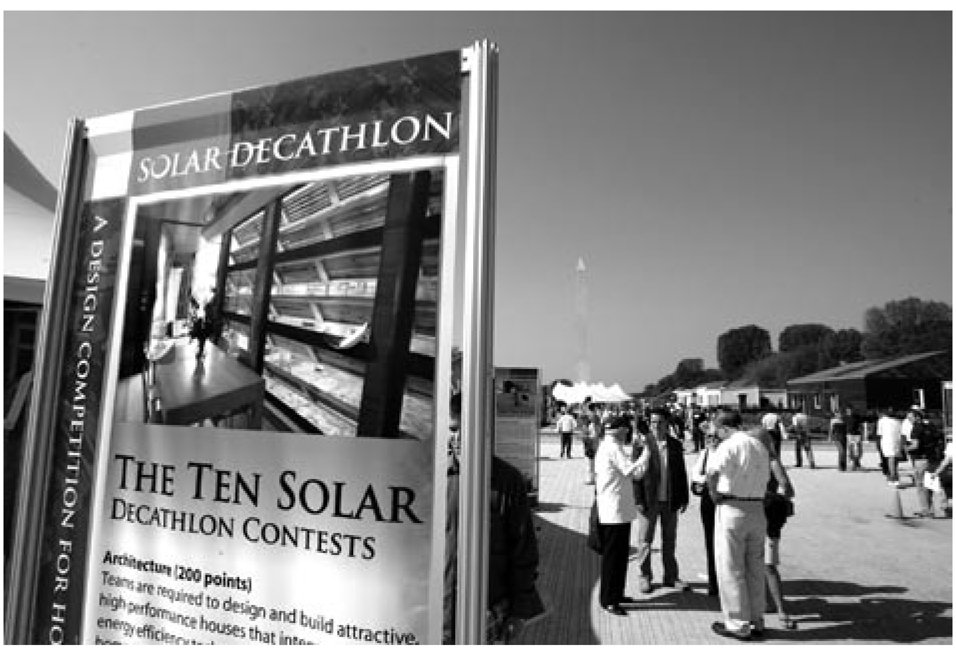
Architecture *(200 points)*
Teams were required to design and build attractive, high-performance houses that integrated solar and energy efficiency technologies seamlessly into home design. Scoring well in Architecture was crucial; teams could earn up to 200 points, twice the number of points available in the other contests. A jury of esteemed architects toured the team homes to judge the Architecture contest.

Dwelling *(100 points)*
Experts from the residential buildings industry awarded points for this contest based on their evaluations of the "livability" and "buildability" of the homes. They assessed whether the houses were designed well for everyday living, simple to maintain, and attractive to potential home buyers. They also evaluated flexibility of design and construction, the construction methods used, and marketability of the houses. The Dwelling judges toured the team houses to make their assessments.

Documentation *(100 points)*
The Documentation contest awarded points based on how well teams analyzed their designs for energy performance and how thoroughly they documented the design process. Teams were required to document all stages of the Solar Decathlon project. A panel of engineers evaluated the building energy analyses performed by the teams in the early stages of design. A panel of architects specializing in project management and documentation evaluated the teams' final "as-built" drawings.

Communications *(100 points)*
The Communications contest challenged teams to communicate their experiences to a wide audience through Web sites and public tours. Points were awarded based on success in delivering clear and consistent messages and images that represented the vision, process, and results of each team's project. To judge this contest, a panel of experts in Web site development evaluated the team Web sites remotely, while a panel of experts in public relations experienced student-led tours of each home during the competition.

Comfort Zone *(100 points)*
The Solar Decathlon teams designed their houses to remain a steady, uniform, comfortable temperature and humidity throughout. Full points for this contest were awarded for maintaining narrow temperature (72°F/22.2°C–76°F/24.4°C) and relative humidity (40%–55%) ranges inside the houses. A panel of engineers with expertise in building heating, cooling, and ventilation also toured the homes to make comprehensive assessments of thermal comfort and indoor air quality and to award points based on those assessments.



Signage in the solar village described the ten contests of the Solar Decathlon.

Appliances *(100 points)*

To earn points, student teams had to maintain certain temperature ranges in their refrigerators (34°F/1.11°C to 40°F/4.44°C) and freezers (–20°F/–28.9°C to 5°F/–1.5°C). During the competition, the list of tasks included using appliances to wash and dry 12 towels on each of 2 days; cooking and serving meals to contest officials on each of 4 days; cleaning dishes using a dishwasher on each of 4 days; and operating a TV/video player for up to 6 hours and a computer for up to 8 hours on 5 of the competition days. Points were awarded for this contest through measurements and task completion.

Hot Water *(100 points)*

Teams scored points in the Hot Water contest by successfully completing the "shower tests." They aimed to deliver 15 gallons/57 liters of hot water (110°F/43.3°C) in 10 minutes or less. A panel of engineering judges also toured each home to make a comprehensive assessment of the hot water systems and awarded points based on those assessments.

Panache was not required of the decathletes, but it was definitely encouraged. Here, New York Institute of Technology students get into the spirit of the cooking task.

One of two "laundry days" at the Decathlon featured this Pittsburgh Synergy student, who seems happy to be doing household chores.

Lighting *(100 points)*

To win this contest, teams had to meet specific lighting-level requirements in each room of the house. Contest officials measured lighting levels to ensure teams maintained typical lighting levels during the day and at night. Ideally, lighting design incorporated ambient and task lighting, electric lighting, and natural "daylighting" for energy efficiency and occupant comfort. A panel of lighting design experts toured the homes to subjectively evaluate overall lighting design—aesthetics, innovation, and annual performance.

Energy Balance *(100 points)*

The Energy Balance contest required teams to use only the energy generated by the PV systems on their houses during the competition to provide all of the electricity for the contests. Teams earned full points if the energy supplied to the batteries was at least as much as the energy removed from the batteries.

Getting Around *(100 points)*

In the Getting Around contest, teams used electricity generated by the solar electric systems on their houses to charge their street-legal, commercially available electric vehicles. Points were awarded based on how many miles each team completed on each day.

Competition Schedule

By the time the teams arrived on the National Mall, some contest activities had already been completed. The Documentation contest was complete, and the Web site judges had begun their evaluations on September 29. But the bulk of contest activities occurred while the village was open. To accommodate contest activities such as the judges' tours, some of the houses were closed some of the time during public hours. See Table 2 for the complete competition schedule.

Table 2. 2005 Solar Decathlon Schedule

September	Contests	Measurement, Task, or Event
Wednesday 28		Team orientation
Thursday 29–Friday 30		Assembly Monitoring equipment installation Rules and regulations inspections
October		
Saturday 1– Sunday 2		Assembly Monitoring equipment installation Rules and regulations, general building planning, structural, plumbing, mechanical, electrical, and Americans with Disabilities Act (ADA) inspections
Monday 3–Tuesday 4		Assembly Monitoring equipment installation Network connection Rules and regulations, general building planning, structural, plumbing, mechanical, electrical, and ADA inspections
Wednesday 5		Assembly Monitoring equipment installation Network connection Rules and regulations, general building planning, structural, plumbing, mechanical, electrical, and ADA inspections House commissioning Opening ceremony dress rehearsal BP opening reception
Thursday 6		House commissioning Opening ceremony and ribbon cutting AIA/NAHB student reception
Friday 7		Public tours
	Lighting	Electric lighting quantity measurements (spot measurements with a hand-held sensor)
Saturday 8		Public tours Beginning of "solar only" period
	Architecture Dwelling Communications	Architecture jury, Dwelling panel of judges, and House Tours panel of judges toured and evaluated team houses.
	Lighting	Electric lighting quantity measurements
Sunday 9		Public tours
	Architecture Dwelling Communications	Architecture jury, Dwelling panel of judges, and House Tours panel of judges toured and evaluated team houses.
	Lighting	Electric lighting quantity measurements
Monday 10		Public tours
	Comfort Zone	Temperature and humidity control measurements
	Appliances	Refrigerator and freezer temperature control measurements Computer and TV/video monitor operation, cooking, and dishwashing tasks required
	Hot Water	Shower tests required

October	Contests	Measurement, Task, or Event
Monday 10 (cont'd)	Lighting	Standard usage pattern and integration of electric and natural lighting measurements Exterior lighting compliance Lighting panel of judges toured and evaluated team houses.
	Energy Balance	Energy Balance measurements
	Getting Around	Teams drove electric cars for mileage credit.
	Architecture Dwelling	Architecture jury and Dwelling panel of judges announced results.
Tuesday 11		Public tours
	Comfort Zone	Temperature and humidity control measurements
	Appliances	Refrigerator and freezer temperature control measurements Computer and TV/video monitor operation, clothes washing and drying, cooking, and dishwashing tasks required
	Hot Water	Shower tests required
	Lighting	Standard usage pattern and integration of electric and natural lighting measurements Exterior lighting compliance Lighting panel of judges toured and evaluated team houses.
	Energy Balance	Energy Balance measurements
	Getting Around	Teams drove electric cars for mileage credit.
	Communications	Communications panel of judges announced results.
		Canadian Embassy student reception
Wednesday 12	Comfort Zone	Team houses were closed to the public for 24-hour measurements of temperature and humidity control.
	Appliances	Refrigerator and freezer temperature control measurements Computer and TV/video monitor operation, cooking, and dishwashing tasks required
	Hot Water	Shower tests required
	Lighting	Standard usage pattern and integration of electric and natural lighting measurements Exterior lighting compliance Lighting panel of judges announced results.
	Energy Balance	Energy Balance measurements
	Getting Around	Teams drove electric cars for mileage credit.
		ASHRAE student reception
Thursday 13		Public tours
	Comfort Zone	Temperature and humidity control measurements Engineering panel of judges toured and evaluated homes.
	Appliances	Refrigerator and freezer temperature control measurements Computer and TV/video monitor operation, clothes washing and drying, cooking, and dishwashing tasks required
	Hot Water	Shower tests required Engineering panel of judges toured and evaluated homes.
	Lighting	Standard usage pattern and integration of electric and natural lighting measurements Exterior lighting compliance
	Energy Balance	Energy Balance measurements
	Getting Around	Teams drove electric cars for mileage credit.
	Documentation	Results of Documentation contest announced.

October	Contests	Measurement, Task, or Event
Friday 14		Public tours Contest measurements and tasks ended at 11:00 a.m. Overall winner announced at 2:00 p.m.
	Comfort Zone	Temperature and humidity control measurements Engineering panel of judges toured and evaluated homes.
	Appliances	Refrigerator and freezer temperature control measurements Computer and TV/video monitor operation, clothes washing and drying, cooking, and dishwashing tasks required
	Hot Water	Shower tests required Engineering panel of judges toured and evaluated homes.
	Lighting	Integration of electric and natural lighting measurements Exterior lighting compliance
	Energy Balance	Energy Balance measurements
	Getting Around	Teams drove electric cars for mileage credit and drove a final lap around the village.
	Comfort Zone Hot Water	Engineering panel of judges announced results.
Saturday 15		Public Tours Victory Reception
Sunday 16		Public Tours Disassembly began after 6:00 p.m. or when house was clear of visiting public, whichever happened first. End of "solar only" period
Monday 17– Wednesday 18		Disassembly

Site design was featured prominently in the 2005 Solar Decathlon homes. The Cornell garden added serenity and a sense of place to the home.

Ruby Nahan

Cornell students gave away their edible garden one plant at a time as they prepared to disassemble their home on October 16.

Jury and Judging Panels

Architecture Jury

Steve Badanes
Jersey Devil design/build

Ed Mazria
Mazria Odems Dzurec

Sarah Susanka
Susanka Studios

Ken Wilson
Envision Design

Dwelling Panel of Judges

Dennis Askins
Karim Rashid Design

Robert Burt
Bozzuto Construction Company

Sam Grawe
Dwell Magazine

Katherine Salant
Author and nationally syndicated columnist

NREL/PIX14604

The Architecture jurors held lively debates about the merits of each entry, including the pictured New York Institute of Technology home. The jurors spent 30 minutes at each house—20 minutes interacting with the students and 10 minutes in conference.

The House Tours judges experienced and evaluated the student-led tours at the Missouri Rolla home and all other Decathlon homes.

Architectural Documentation Panel of Judges

Phil Bernstein
Autodesk, Inc.

Kathryn Prigmore
HDR Architecture & Engineering

Grant Simpson
RTKL Associates, Inc.

Energy Analysis Panel of Judges

Doug Balcomb and Mike Deru
National Renewable Energy Laboratory

Pete Jacobs
Architectural Energy Corporation

Russ Taylor
Steven Winter Associates

Norm Weaver
Interweaver Consulting

Web Site Panel of Judges

Ethan Goldman
BuildingGreen

Kim Master
What's Working

Alan Wickstrom
BuildingOnline, Inc.

House Tours Panel of Judges

Ben Finzel
Fleishman-Hillard, Inc.

Jaime Van Mourik
National Building Museum

Craig Savage
Building Media, Inc.

Engineering Panel of Judges

Steven Emmerich
National Institute of Standards and Technology

John Mitchell
Solar Energy Laboratory, University of Wisconsin

Terry Townsend
Townsend Engineering, Inc., President-elect of ASHRAE

Lighting Panel of Judges

Howard Brandston
Brandston Partnership, Inc.

Sandra Stashik
Grenald Waldron Associates

Gary Steffy
Gary Steffy Lighting Design, Inc.

Competition Organizers

Director

Richard King
U.S. Department of Energy

Project Manager

Cécile Warner
National Renewable Energy Laboratory

Rules and Regulations Committee

Michael Wassmer, Chair
Pamela Gray-Hann, Sheila Hayter, Linda Hill, Doug Manno, Ruby Nahan, Charles Newcomb, Byron Stafford, Robi Robichaud, and John Thornton
National Renewable Energy Laboratory

Dan Eberle
Formula Sun

Ed Hancock and Greg Barker
Mountain Energy Partnership

Susan Piedmont-Palladino
Washington Alexandria Architectural Consortium

Howard Brandston (center) announced the results of the Lighting contest just a few minutes after the panel's deliberations wrapped up on October 12. Listening in are (from left) contest official Sheila Hayter and Lighting contest judges Gary Steffy and Sandra Stashik.

"First, let me tell you how impressed I am with all of you. We saw a range of product and expense, but in the end, it didn't matter. It was a job superbly done. You should all celebrate, because you are all winners."

— Lighting Judge Howard Brandston

Competition Results and Perspectives

> *"We thank the students for their enthusiasm, innovation, hard work, and ability to tread water and slog through the mud. We couldn't be more proud of them. This Solar Decathlon built on the last one, with the houses even more innovative and efficient."*
>
> — David K. Garman, Under Secretary of Energy

On October 14, 2006, the University of Colorado placed first in the 2005 Solar Decathlon, with Cornell University, and California Polytechnic State University (Cal Poly) placing second and third, respectively. Table 3 on page 14 shows the final placement for all teams. To gain a sense of the day-to-day developments during the 2005 event, please read the Daily Journals written by Competition Director Richard King (see ***www.solardecathlon.org/2005/daily_journal.html***).

This section includes insights and analysis by the competition organizers as to why the top teams performed well. These comments are offered in the spirit of giving all Solar Decathlon teams an equal opportunity to learn from past experience and compete successfully in the future.

What Made the 2005 Competition Unique?

The 2005 Solar Decathlon teams, like their 2002 predecessors, were smart, talented, inspired, and incredibly hard working. But one thing they didn't share with the 2002 teams was the luck of good weather. It was hot in 2002, and the sun shone virtually every day of the event. In 2005, it was just the opposite. The sun shone during assembly, the clouds rolled in before the opening ceremony, the rain fell in torrents the first couple of days of the event, and the sun wasn't really seen again until after the winner had been determined. Solar champions without much sun: How did Colorado, Cornell, and Cal Poly do it?

On October 14, Under Secretary of Energy David Garman presented the 2005 Solar Decathlon trophy to the University of Colorado team.

Web Site Resources
www.solardecathlon.org/2005/technical_report.html

Daily Journals

Final Detailed Scores and Standings

2005 Solar Decathlon Rules and Regulations

Brief Contest Reports

Instrumentation and Monitoring for Solar Decathlon 2005

- Balance: They had well-rounded teams with "specialists" in areas that affected performance across all aspects of the project and all 10 contests.
- Organization: They built a strong team from the beginning of their projects. Throughout the two years leading up to the event and during the event, they made sure they knew and understood the rules and kept current on rules interpretations.
- Communication: An important aspect of team organization, all members of the teams were aware of progress on the whole project, not just their areas of expertise.
- Strategy: These teams adjusted their strategies to the inclement weather earlier than other teams did.
- Luck: All three teams were lucky that the weather didn't improve.

> *"All week, we had no direct sun, but the teams were still washing clothes, running the dishwasher. . . If solar energy can work this week, it can work anywhere in the world!"*
>
> — University of Colorado Student Project Leader Jeff Lyng

Table 3. Final Results for the 18 Teams of the 2005 Solar Decathlon

Final Standing	Team	Architecture (200)	Dwelling (100)	Documentation (100)	Communications (100)	Comfort Zone (100)
1	Colorado	162	85	92.3	98	69.137
2	Cornell	188	85	75.76	69.85	84.454
3	Cal Poly	192	95	82.09	75.55	75.44
4	Virginia Tech	200	99	84.69	85.2	62.167
5	NYIT	188	92	73.84	85.4	57.011
6	Texas	180	92	82.7	79.35	69.566
7	Missouri Rolla	172	75	77.47	74.25	61.963
8	Maryland	146	79	75.16	85.8	65.308
9	Madrid	154	75	89.04	69.65	55.845
10	Pittsburgh	180	89	74.56	78.25	53.946
11	Puerto Rico	128	69	66.95	87.3	56.792
12	Crowder	132	70	36.7	52.7	40.387
13	Florida Intl	146	76	71.14	72.55	37.441
14	Canada	116	51	72.68	79.55	68.193
15	Washington State	162	66	78.09	84.5	49.339
16	RISD	180	81	60.52	72.9	50.011
17	Michigan	154	56	83.55	68.3	47.086
18	UMass Dartmouth	100	52	44.55	38.05	24.497

Colorado, Cornell, and Cal Poly had similar strategies during contest week (October 10–14), when measurements were taken to evaluate house performance objectively. Consequently, all three teams benefited from the foul weather. Why did Colorado place first over Cornell and Cal Poly? They dominated three contests—Communications, Documentation, and Getting Around—that other teams tended to overlook in favor of other subjectively judged contests. Colorado's collective performance in those three contests was enough to overcome their solid, but not spectacular, performance in Dwelling and Architecture.

Visitors braved stormy weather to spend time at the Decathlon. The teams that answered the challenge of rain and overcast skies throughout the competition week were rewarded in the end.

The Virginia Polytechnic Institute and State University (Virginia Tech) team, which finished fourth overall, dominated the Architecture and Dwelling contests, so why didn't they win? Unlike Colorado, Cornell, and Cal Poly, they gambled that the weather would improve. Early in the contest week, they shut most of their systems down and essentially forfeited many points in the objectively evaluated contests (e.g., Comfort Zone, Appliances, and Hot Water). They bet on the sun shining toward the end of the week. If the sun had appeared, Virginia Tech would have resumed participation in the objective contests and received full points for the Energy Balance contest. Colorado, Cornell, and Cal Poly wouldn't have been able to receive full points for Energy Balance

Appliances (100)	Hot Water (100)	Lighting (100)	Energy Balance (100)	Getting Around (100) (miles/points)	Total Points (1100)
72.007	95.33	79.938	0	318.8/100.00	853.716
74.381	97	90.574	0	195.2/61.02	826.039
80.392	87.917	92.238	0	83.9/28.50	809.13
22.987	56.083	83.556	60.15	85.1/30.67	784.501
64.135	55.167	81.449	0	149.9/48.61	745.614
51.352	23.5	78.479	42.45	62/21.84	721.235
43.987	28.333	74.142	100	31.3/10.91	718.059
67.981	68.583	85.235	0	101.6/36.93	708.592
64.517	72.583	87.912	0	98.7/36.30	704.844
30.746	47.167	70.632	23.23	15.1/ 9.34	653.575
66.651	22.5	76.485	0	149.1/52.93	626.605
35.629	40.583	80.897	100	98.2/37.73	625.423
13.113	22.5	64.446	100	20.2/10.42	608.009
45.739	46.25	84.628	0	50.6/23.142	586.383
22.392	35.5	65.45	6.26	12.1/ 8.18	575.215
23.667	15.75	85.844	0	1/ 5.00	571.492
17.943	16.25	66.517	0	97.2/35.92	545.568
9.64	10	57.47	0	46.7/19.35	326.755

had the sun shone more, because their energy deficit was too great to overcome with only a day or two of additional sun. Virginia Tech would not necessarily have won the competition, but the top three finishers would likely have been different.

How Did 2005 Contests and Scoring Differ from 2002?

After a review of the inaugural 2002 competition, the organizers at DOE and NREL made several changes to the Solar Decathlon contests and scoring.

Changes to scoring the 2005 competition were significant:

- Scoring of the 2002 competition was based on team rankings. Teams were ranked first through fourteenth (14 teams), and scores were assigned based on rank. Team scores went up and down during the competition, because rankings in individual contests were dynamic. As rankings changed, so did scores. In the 2005 competition, the ranking system was discarded, and points were cumulatively awarded for achievement. Generally, team scores were always increasing from the beginning of the contests.

Virginia Tech was the early favorite after scoring impressive victories in both the Architecture and Dwelling contests. At the pictured Architecture award ceremony, juror Sarah Susanka commented, "Everything about this house is wonderful. It took my breath away."

- In 2002, penalties could have a significant impact on scores. For some contests, the number of penalty points accrued effectively determined rankings. Often, the team with the fewest penalty points was ranked first, and the team with the most penalty points was ranked last. Some penalties were assigned after a team had been ranked, thus changing their score. By awarding cumulative points for achievement, the "need" for penalties in 2005 was greatly reduced. Although rare in 2005, some penalties were assigned and did result in reduction of some scores.
- In 2002, 155 points were available in various contests for using less electrical energy to complete specific tasks. Several teams gained points in 2002 by turning off appliances, thereby using less electrical energy. By eliminating these points in 2005, the organizers removed the incentive to use such a strategy, which is inconsistent with an important goal of the Solar Decathlon—to demonstrate that solar power can provide the energy for a modern lifestyle. This change was insignificant to the overall competition, because energy efficiency was still critically important to success in most of the judged contest activities, and especially in the measured Energy Balance and Getting Around contests.
- In 2002, "partial credit" was not awarded. In 2005, partial credit was awarded for some contest activities.
- In 2002, performance in the Getting Around contest was based on total mileage credit accrued during the week. Teams could drive to designated locations to receive a designated number of mileage credits. In 2005, performance in this contest was based on a team's accrued daily mileage relative to other teams' accrued daily mileage credit. Mileage credit was based on actual miles driven, and driving routes were not specified.

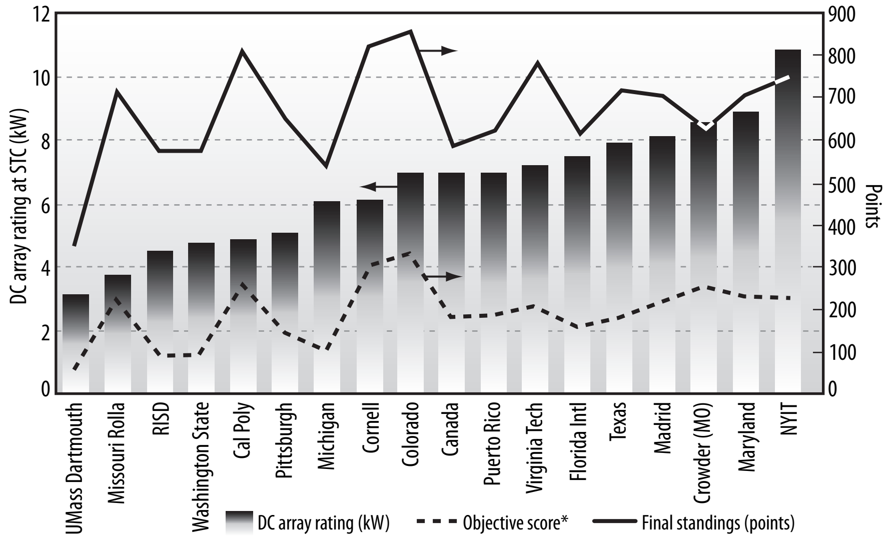
PV and Energy Storage: Sizing Up the Systems

Here's an idea: Show up at the Solar Decathlon with the biggest, most powerful PV array and you're sure to win. But, wait, that didn't work in 2005. How about bringing a super-sized energy storage system—wouldn't that be critical to success, especially during the overcast conditions experienced in 2005? Not necessarily.

Colorado, Cornell, and Cal Poly finished first, second, and third, respectively, in the 2005 Solar Decathlon. Yet, as shown in Figure 1, the size of their PV arrays ranked only tenth, eleventh, and fourteenth, respectively, in the competition. Figure 2 makes the same comparison for energy storage capacity. In this case, Colorado, Cornell, and Cal Poly ranked fifth, third, and eighth, respectively.

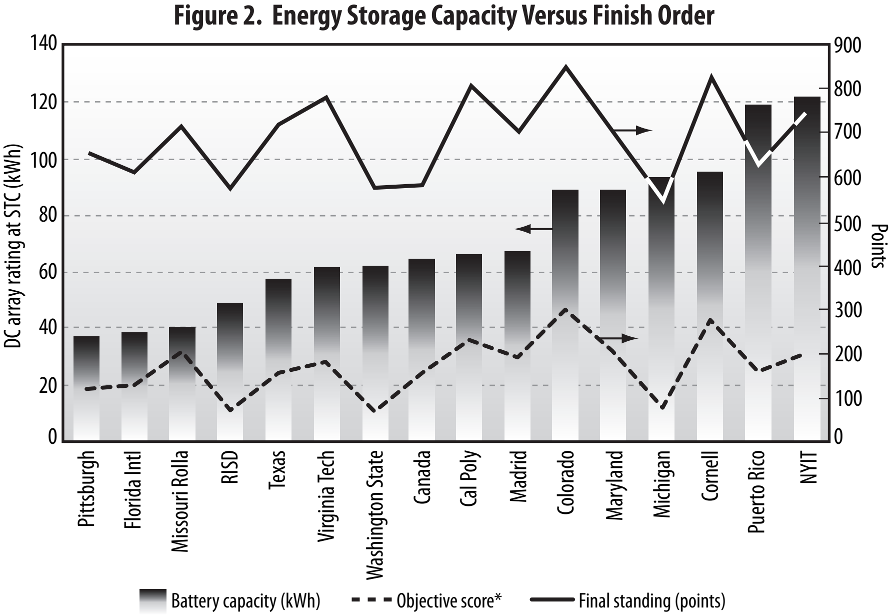
The top teams proved in 2005 that energy management was more important than power and energy storage capacities. Reacting quickly to changing conditions—being willing to change strategies based on which approach would garner the most points—was also a key to victory.

Figure 1. PV Array Size Versus Finish Order



* Total of points received for all objective (measured) contest activities (480 points available). 03826401

Figure 2. Energy Storage Capacity Versus Finish Order



* Total of points received for all objective (measured) contest activities (480 points available). 03826402

- In 2002, subjective juries and panels ranked 14 teams from 1 to 14. In 2005, subjective juries and panels were asked to follow a general set of scoring guidelines, but were free to award any number of points they wanted. Ties were allowed.

Several contests were changed in 2005:

- The 2002 Design and Livability contest became two contests: Architecture (the design aspect) and Dwelling (the livability aspect), worth 200 and 100 points, respectively. "Buildability," which had not been evaluated in the original contest, became a part of the Dwelling contest in 2005.
- All elements of the 2002 Design Presentation and Simulation contest were moved to the 2005 Documentation contest. The Final Project Summary and Pre-Event Deliverables contest activities were added in 2005.
- The 2002 Graphics and Communications contest was renamed Communications, and the newsletters contest activity was eliminated. In 2005, teams were evaluated only on Web sites, house tours, and branding effectiveness.
- For the Comfort Zone contest, required temperature and relative humidity set-point requirements were revised, and a 24-hour evaluation with tighter tolerances was eliminated. Subjective contest activities "Innovation of System" and "Consumer Appeal/Integration of System" were changed to "Comprehensive Assessment of Thermal Comfort" and "Comprehensive Assessment of Indoor Air Quality."
- The 2002 Refrigeration and Home Business contests were eliminated. Elements of these contests were moved to a new contest called Appliances. Required refrigerator set points were revised. TV/video operation and computer operation requirements were revised and moved to the Appliances contest. The "Office Space Comfort and Integration" contest activity in the 2002 Home Business contest was integrated into the 2005 Dwelling contest. The "Contest Diaries" contest activity within the 2002 Home Business contest was eliminated.
- The subjective components of the 2002 Hot Water contest, "Innovation of System" and "Consumer Appeal/Integration of System," were eliminated and replaced by the 2005 "Comprehensive Assessment of Hot Water System" contest activity.
- Laundry and dishwashing tasks were moved from the 2002 Hot Water contest to the 2005 Appliances contest, and the requirements were revised.
- The "Innovation of System/Integration of System" and "Consumer Appeal/ Lighting Environment" contest activities of the 2002 Lighting contest were replaced with the "Daylighting Quality" and "Electric Lighting Quality" contest activities in 2005. The "Kitchen Work Surface" continuous light-level measurement was eliminated. The "Office Work Surface" continuous light-level measurement was retained and renamed "Integration of Electric and Natural Lighting." The "Handheld Light Meter Evaluations" contest activity was renamed "Electric Lighting Quantity," but the general approach was the same. In 2005, the "Exterior Lighting" and "Standard Usage Patterns" contest activities were added to the Lighting contest. These new contest activities established more realistic lighting usage profiles in the village.
- The Getting Around contest was broken into six distinct activities in 2005. Each day of driving was a separate contest activity, and the final lap to mark the official end of the competition was another distinct contest activity.

Team Approaches in 2005 versus 2002

The 2005 teams clearly made architectural design a high priority, and the general level of architectural sophistication was greater than in 2002. Comments received by the competition organizers from visitors to the Mall and the Architecture jury support that observation. In addition, several trends were visible in the 2005 homes that indicate an evolution in design from the 2002 homes:

- Several homes in 2002 were modular, arriving on the Mall in multiple "pieces"—whereas 2005 teams moved toward single-piece homes.
- Site design, not a significant consideration in 2002, was a prominent feature of several overall designs in 2005.
- Although there were some green roofs in 2002, roofs were not intended as living spaces. In 2005, several teams featured habitable green roofs.
- In 2002, several teams intentionally exceeded height and footprint limits, whereas in 2005, the small number of teams that exceeded those limits did so unintentionally.
- In 2002, only a couple of teams emphasized general sustainable living practices (such as use of environmentally preferable materials, rainwater collection, and onsite agricultural production), but in 2005, many teams made this a focus.
- In 2002, tour routes through the homes for the visiting public were an afterthought for many teams. In 2005, public tour routes were carefully considered by most teams.
- In 2005, PV arrays were significantly larger than in 2002.
- In 2002, all teams had solar water heaters. In 2005, two teams did not use solar water heaters at all.

Several trends remained the same from 2002 to 2005:

- Structural integrated panels (SIPs) were the predominant building envelope strategy favored by the teams.
- Thin-film PV was not heavily featured.

Rhode Island School of Design students served candlelit dinners in their rooftop garden, with the Smithsonian Castle a picturesque backdrop. Several Solar Decathlon homes in 2005 featured habitable green roofs.

- The houses featured a mix of radiant and forced-air heating systems.
- Lead-acid batteries remained the battery system of choice.

What's New for the 2007 Competition?

An increase in funding for the teams, coupled with a long-term research and development goal, marks the biggest change for Solar Decathlon 2007. Beginning with the 2007 competition, teams are being challenged to meet a whole-house, levelized energy cost of $0.10/kWh by the year 2015, while complying with the criteria associated with the 10 contests. The 20 entries selected to compete in 2007 were chosen based on many criteria, including the presence of a research and development component that meets this critical cost outcome. In previous competitions, the teams received US$5,000 upon acceptance to compete. The rest of the funding for their projects they raised themselves. Upon successful completion of a series of deliverables, the teams chosen to compete in 2007 will receive funding of US$50,000 per year for two years. Even with these additional funds, the teams will still have to do considerable fundraising.

There are two significant contest changes for 2007. The Dwelling and Documentation contests of 2005 have been replaced by two new contests: Engineering and Market Viability. Although there are two new contests, all the components of the Dwelling and Documentation contests have been retained. The drawing submittal requirements for the Documentation contest in 2005 are now under the Architecture contest. The "Buildability" (ease of construction and replication of design) and "Livability" components of the 2005 Dwelling contest will be evaluated by a jury as part of the "Market Appeal" component of the Market Viability contest. The "Project Deliverables" component of the Documentation contest will also be evaluated within the Market Viability contest. A new "Economic Analysis" component to evaluate the teams' methods for reaching the $US0.10/kWh levelized-energy-cost goal is part of Market Viability. The energy analysis component of Documentation is part of the new Engineering contest. And two subjectively evaluated components of Comfort Zone and Hot Water have been moved to the new Engineering contest. The Lighting contest in 2007 is the only contest that has both subjective evaluation components and measured performance components.

In addition to these contest-related changes, a few other significant changes are worth noting, because they may affect the teams' project plans and public perception of the event. The "solar only" period, during which no generators are allowed without significant penalty, will begin five days into assembly, which is five days earlier than in previous events. This change will challenge the teams to get their PV systems functioning earlier, and it will demonstrate the viability of solar power more readily to public visitors. In past events, the presence and noise of fossil-fuel-powered generators has created a conflict with the stated overall goals of the event.

In previous competitions, teams had to contain their batteries within the footprint of the house, so most houses effectively had an "unusual" utility room that contained a good number of batteries. In 2007, teams will be allowed to contain batteries in a structure outside of the house footprint, thereby having the option to design houses that look more like solar-powered houses that are connected to the utility grid. This change is important to public perception and acceptance of solar power.

Details by Team

Teams are listed by order of finish.

University of Colorado, Denver and Boulder 20
Cornell University 22
California Polytechnic State University, San Luis Obisbo 24
Virginia Polytechnic Institute and State University 26
New York Institute of Technology 28
University of Texas at Austin 30
University of Missouri-Rolla and Rolla Technical Institute 32
University of Maryland 33
Universidad Politécnica de Madrid 35
Pittsburgh Synergy (Carnegie Mellon, University of Pittsburgh, and The Art Institute of Pittsburgh) 36
Universidad de Puerto Rico, Mayagüez 38
Crowder College 39
Florida International University 41
Canadian Solar Decathlon (Concordia University and Université de Montréal) 42
Washington State University 43
Rhode Island School of Design 45
University of Michigan 46
University of Massachusetts Dartmouth 48

On October 5, when this picture was taken, the 2005 Solar Decathlon opening ceremony was just a day away and the solar village hummed with activity. Pictured are members of the Cal Poly team installing safety wires on their ADA-compliant ramp.

Web Site Resources
www.solardecathlon.org/2005/technical_report.html

2005 Solar Decathlon Rules and Regulations
Equipment Summaries
Complete Drawing Sets for the 2005 Teams
Brief Contest Reports
Solar Decathlon 2002: The Event in Review

In the following pages are details of design approaches and philosophies, special features, and competition strategies related to each team home. Tables 4–8 include equipment summaries for teams that finished in the top five, which is important information for 2007 and other future decathletes. Similar information is included for all 2005 and 2002 teams in the online Web Site Resources.

This section also includes team-specific comments made by jurors and judges of the various contests. This, too, is vital information for future decathletes as a guidepost of what will (and will not) score points—and more importantly, why this is the case. Innovation is a key judging criteria, and the judges looked for it and rewarded it at every opportunity.

Finally, this section describes the special awards that Decathlon teams earned. Solar Decathlon sponsors and professional organizations see the event as a proving ground for the design and engineering trendsetters of the future. As such, the organizations are eager to recognize and reward the Decathlon team achievements.

University of Colorado, Denver and Boulder

Colorado's home features a movable roof constructed of custom steel struts that lowers for ease of travel and lifts for a feeling of openness and increased lighting when the house is stationary.

The University of Colorado's entry emphasizes natural materials throughout, as you might expect of a team from scenic Colorado. Although the university took top honors overall in the 2002 competition, the 2005 team didn't rest on its laurels. Instead, they worked hard to design, construct, and demonstrate an original, sustainable modular home concept.

When they got to the National Mall, the team worked even harder. Faculty Advisor Mike Brandemuehl said they were the first to arrive and the last to leave each day of the competition. The Colorado team drove their GEM (electric car) as if their lives depended on it, because one never knew when an extra point or two would be needed.

What's Different?

- For the walls, the team combined two off-the-shelf "green" building components into one newly patented SIP. Colorado's "BIOSIP" is like a giant ice cream sandwich made of two panels of Sonoboard—a strong but lightweight board made of recycled materials by Sonoco Company—that are filled with BioBase 501, a lightweight foam insulation made from soybean oil by BioBased Systems.
- Most of the home's furnishings, and even the tableware, are made of natural materials such as corn, wheat, soy, and even coffee. Building on this, the team used food-related metaphors in their communications pieces as "branding" elements.
- The team transported the home to and from Washington, D.C., primarily using a biofuel—B100 (pure) biodiesel.

Architecture, Interior Comfort

- A radiant-heat floor and well-insulated walls (R-30 to R-35) provide uniform levels of interior warmth and comfort.
- A "solar hearth" that contains the home's mechanical systems adds to its interior attractiveness.
- The home is designed to be highly accessible to the public, including people with disabilities.
- A movable roof constructed of custom steel struts lowers for ease of travel and lifts for a feeling of openness and increased lighting when the house is stationary.

Heating and Cooling Systems

- A ductless, nonintrusive heating, ventilation, and air-conditioning (HVAC) system provides cooling for the home.

PV and Solar Thermal

- The evacuated tube solar thermal water heating system is designed to provide heat both for domestic hot water and for the integrated radiant floor system.
- The rooftop PV system comprises 32 SunPower 200-watt (W) solar panels that are 16% efficient. OutBack Power Systems donated the balance of the PV system.
- The home demonstrates building-integrated PV via the PV awnings that provide electricity for the home as well as shade for its windows.

The 2005 Colorado team matched its 2002 counterpart by winning the Communications contest. Both the Web site panelists and the House Tour panelists unanimously chose Colorado as the winner. The team used creative and accessible ways of communicating on their Web site and within their house. The judges found the Web design to be clean and fresh, while their writing style on the Web was snappy, fun, and clear, covering a lot of content. The House Tour judges echoed the praise: "This team's entire focus seemed to be interacting with the public. Food was a very effective branding mechanism. The tour connected with the technologies… this is the team who figured out who the audience is."

It was evident that the Colorado team communicated well not only with the outside world, but also with each other. The members of this team were clear on their roles and committed to each other and to the goals of the competition.

Colorado also set the standard for Documentation by winning that contest, which evaluates the quality of documents submitted for the schematic design, design development, construction, and "as-built" phases of the Solar Decathlon project.

Colorado's kitchen is visible from the living room. Clerestory windows at the roofline allow in natural daylight.

During the summer prior to the competition, Scott Horowitz, Colorado's calm and patient driver, and Burkholder drove hundreds of miles to determine the best charging per mileage scheme. They found that driving a slow and steady 15 mph/ 24 km/h gained the most miles/kilometers per charge. Each day during the competition, Colorado set the bar for points awarded in the Getting Around contest, and ended up winning that contest handily.

The team also did a lot of other things right. They scored well in many of the judged contest activities. They planned for a battery bank that could get them through a week of cloudy weather. Their energy storage allowed them to score well in Getting Around in addition to the Appliances and Hot Water contests.

Along with the overall Solar Decathlon victory, the Colorado team received two special awards. BP, a Solar Decathlon sponsor, presented the team with its Brand Value Award for being "green" and demonstrating environmental leadership. And DIY Network, also a Decathlon sponsor, bestowed the Best Built Home Award on the Colorado house.

The team performed well in all four components of this contest, a proven key to overall success. In particular, the energy analysis report was, in the words of the judges, "a tour-de-force." One judge said, "This is how it should be done!"

Key to this team's overall success, and their eventual victory, was their use of strategy and the ability to function in spite of the rainy weather. On Tuesday, October 11, at 8:00 a.m. they decided to "live in the house," which meant operating the system the way a homeowner would normally do in a rainy situation and draw from the batteries. But they had also planned well. "We focused on designing for a 40-year model worst case weather scenario. That's why we're doing okay now," said Colorado team member Kristin Field, when presenting to the Engineering panel of judges.

They looked at the scoring spreadsheet, considered the weather, calculated the number of points they could gain in which contests, and developed a strategy to win. Like all good competitors, they gamed it well.

First, they took a long hard look at the scoring spreadsheet to determine which achievements would give them the most points. They sacrificed the Energy Balance contest to focus on contests that required energy usage. To ensure success in their strategy, they took a gamble on the weather. But they also looked at about five different weather reports each day, just in case they needed to change strategies.

They knew how best to drive the car, and the best time to charge it. Student team member Frank Burkholder was their GEM specialist. He made it his job to know how to get the best mileage out of the car.

Table 4. University of Colorado Home Details

Item	Specifics
PV kW (STC rating)	6.98
PV Modules	Primary: 34 Sunpower SPR-200-BLK Secondary: 3 SBM Solar Module-60
Charge controllers	3 Outback MX-60; 1 Morningstar Prostar PS15M-48V
Inverters	2 Outback VFX3648
Battery bank/type	370 AH, 48 V/40 Deka Solar 8L16 flooded lead acid
Space heating	Primary: Thermomax Mazdon collectors; solar thermal space heating/ water heating hybrid
Space cooling	Mitsubishi mini-split heat pump (HP) with 2 indoor units
Ventilation	Energy recovery ventilator (ERV)
Water heating	4 Thermomax MAZ20 evacuated tubes
Primary building envelope/Insulation	SIP/Rigid foam (partial soy content)

After the competition, the team transported the house to the Colorado campus, where it will be displayed for about a year as a tool for education and outreach. Then the house will be delivered to its purchaser—Prospect New Town in Longmont, Colorado—a New Urbanist community featuring sustainable, green-built residences.

The Colorado team won the Getting Around contest handily by implementing a plan to get the most miles possible from each charge of their electric vehicle.

Cornell University

The Architecture jury praised the Cornell University house, commenting that the crisp building set in a lush edible landscape made a great initial impression.

The Solar Decathlon house from Cornell University is designed for production as highly affordable factory manufactured housing. Its custom HVAC system combining a heat pump and a desiccant energy recovery ventilator, which the team felt was ideal for the humidity in Washington, D.C., gives the house flexibility in different climates. The house design can be tailored to fit the homebuyer's functional needs, aesthetic preferences, and financial capabilities.

What's Different?

- The house is designed for production as a modular housing system, with a target cost between $50,000 and $100,000.
- The Cornell team was entirely student-run and led, with faculty serving as advisors.
- The key feature of the heating and cooling system is an energy recovery ventilator that houses a silica gel wheel, which transfers heat and humidity between intake and exhaust airstreams.
- Dinner menus were planned around produce from the house's "edible landscape," designed to feed two people for six months and featuring 30 varieties of food plants.

Architecture, Interior Comfort

- A folding, rather than sliding, glass wall (called the "NanaWall") between the living room and patio connects the interior and exterior living spaces, but also provides an excellent thermal seal.
- The house uses SIPs for the walls instead of traditional stud-framed construction.

• A student-designed modular cabinetry unit spans the north wall and contains all the storage for the house.

Heating and Cooling Systems

• The custom energy recovery ventilator is coupled with an electric heat pump and air-handler.

• The house features a fully automatic computerized control system for the energy recovery ventilator and the rest of the heating and cooling system; a touch-screen control allows for manual override.

PV and Solar Thermal

• A 6.2-kW crystalline silicon PV system powers the house; all panels were donated by General Electric.

• An evacuated-tube solar thermal system, donated by Sun Spot Solar, provides all the domestic hot water and radiant floor heating.

As the first-place team in both the Comfort Zone and Hot Water contests, Cornell demonstrated how good engineering design integrated with the building architecture will successfully result in good indoor environmental quality and meet all the household's hot water needs.

For the Comfort Zone contest, the team incorporated advanced technologies to ensure the competition temperature and humidity set points were maintained throughout the week. Their desiccant system allowed them to control the indoor humidity levels during most of the competition, a feat that only this team accomplished during the especially wet competition week. A mechanical ventilation system controlled by a CO_2 sensor ensured that good indoor air quality could be maintained at all times. Cornell demonstrated a comprehensive understanding of the engineering required to ensure a comfortable and safe indoor environment, and they were able to execute their design ideas into a system that worked.

This view of the Cornell living room shows the "NanaWall," a folding glass wall that eases the transition from indoor to outdoor space.

The Engineering contest judges reported Cornell's hot water system was a solid design that worked quite well. Most notably, however, Cornell was the only team to successfully complete all nine of the shower tests conducted during the competition.

The Architecture jury, which ranked the Cornell house high (tied for third with New York Institute of Technology), was impressed from the very beginning by several things, commenting that the crisp building set in the lush edible landscape made a great initial impression. "The entry sequence, the layout of the spaces, and the excellent cabinet work contributed to an interior that lived up to the promise of the exterior. While not technically an architectural issue, the business plan to make the technologies more acceptable to the public by 'easing into solar' showed maturity and foresight."

It was clear from the beginning that this team meant business, which served them well on their journey to a second-place overall finish. They included MBA candidates on their team to assist with fund-raising and management. This was truly

Table 5. Cornell University Home Details

Item	Specifics
PV kW (STC rating)	6.16
PV Modules	56 General Electric GEPV-110-M
Charge controllers	3 Outback MX-60
Inverters	2 Xantrex SW5548
Battery bank/type	1985 AH, 48 V/24 C&D Technologies msEndur AT-35 AGM lead acid
Space heating	Primary: Seido 5-16 collectors; solar thermal space heating/ water heating hybrid
Space cooling	Trane split-system HP w/ RotorSource desiccant wheel
Ventilation	Desiccant-wheel ERV, exhaust fans
Water heating	2 SUNDA Seido 5-16 evacuated tubes
Primary building envelope/Insulation	SIP/Expanded polystyrene

a multidisciplinary team of engineers, architects, graphic designers, various liberal arts students, and landscape architecture students, who developed the beautiful edible landscape and the comfortable grass sofa and lounging chair around the house. Their landscape architect also did the team's lighting design.

"Our strength was bringing different points of view—this was most critical," said team member Emile Chin-Dickey. "At times, initially, it was hard to communicate. But we learned how an engineer or architect would think. Eventually, sometimes even I (a liberal arts student) would make a suggestion, and the architects would say 'Yeah! That's good.' "

The Cornell team's ingenuity shows with their use of under-the-deck space for battery storage, which obviates the need for a separate space inside the house. A rule change for the 2007 Solar Decathlon allows battery storage outside the footprint of the house.

Chin-Dickey said that Cornell used the same strategy as Colorado in not participating—in Energy Balance—because, "We knew our strengths and chose to take advantage of our house performance."

California Polytechnic State University

Architecture jurors lauded Cal Poly's choice of exterior materials as innovative, well composed, and well executed—giving the house a memorable look.

The team from California Polytechnic State University (Cal Poly) dedicated themselves to simplicity, employing a design strategy that incorporates as many mechanical and as few automated systems as possible. This approach encourages inhabitants to interact with the home and also helped the team fit the house and its systems on just one truck for the coast-to-coast drive from California to Washington, D.C.

What's Different?

- At 2,826 miles/4,548 kilometers, the Cal Poly house traveled the furthest distance over land to arrive at the competition.
- Partly to make a statement on the environmental impact of cars, the team decided to rank the Getting Around contest last in their order of energy priorities during the competition.

Architecture, Interior Comfort

- The team employed a passive architectural design strategy, incorporating as many mechanical and as few automated controls as possible. This so-called "switch rich" strategy is meant to help adapt the building to seasonal variations and different climates.
- A 13-ft/4-m retractable wall on the south side of the house opens to a deck system surrounded by a rain screen.

• The house is made from local and reclaimed materials and includes three distinctive sets of materials for each major section of the house (mechanical, living, and cooking).

PV and Solar Thermal

• The PV array consists of 28 BP Solar panels capable of generating as much as 4.9 kW. Mounted on the house's flat roof, the system is equipped with two maximum power point trackers, allowing the PV array to operate efficiently at all times of the day.

• The conventional solar heating system consists of two flat-plate collectors that provide hot water for domestic use.

Electrical Load

• The "switch rich" house incorporates user interactivity with operable windows and shades as the predominant strategy for controlling temperature.

Good planning helped Cal Poly win the Appliances contest. They successfully completed more of the Appliances tasks than any other team, while maintaining near-perfect refrigerator and freezer temperatures during the entire competition. This team operated their TV/video and computer, prepared meals, ran their dishwasher, and washed their clothes using hot water (this in itself was a notable accomplishment considering the week's weather), while at the same time making sure their refrigerator and freezer temperatures consistently stayed within the allowed temperature range. During the difficult conditions the weather presented, only good planning and careful use of all energy consumption could have led Cal Poly to this level of success in the Appliances contest.

Cal Poly won the Lighting contest because their architecturally integrated lighting design not only met the competition requirements, but also contributed significantly to the comfortable visual environment of the home's interior. They received a near-perfect score in the quantitative portion of this contest. In the subjective areas, the Lighting judges said the daylighting was bright and all encompassing, and that Cal Poly had succeeded in completing an extremely elegant design. The judges found the electric lighting system to be equally impressive, noting that Cal Poly's use of up and down lighting was "wonderful."

Cal Poly scored high in design—taking second in both the Architecture and Dwelling contests. This house is "elegantly made, simple… so much more crafted than many of the others, even those with a similar idea," said an Architecture juror.

The Architecture jury commended the Cal Poly design for several specific things. The choice of exterior materials is innovative, well composed, well executed, and gives the house a memorable look. The machine-made aesthetic is tempered with a sure handling of color, material contrasts, and scale. The house is a model of economy and simplicity and very much in the modernist tradition of a "machine for living." The jury was impressed with the decision to make a "real kitchen" where one could make a "real meal" and then open it up completely to the living space. The attention to craft is impressive, and the consistency of material and of language for details gives coherence and character to the house.

The Cal Poly interior has an open and airy feel throughout. Work areas in the generously sized kitchen all have a view through a window.

Table 6. California Polytechnic State University Home Details

Item	Specifics
PV kW (STC rating)	4.9
PV Modules	28 BP 4175
Charge controllers	2 Outback MX-60
Inverters	2 Xantrex SW5548
Battery bank/type	230 AH, 48 V/24 Trojan 8D AGM lead acid
Space heating/cooling	Carrier 2-speed split system HP
Ventilation	ERV
Water heating	2 Heliodyne Gobi 410 flat-plate collectors
Primary building envelope/Insulation	SIP/Expanded polystyrene

“This house is just really impressive. The team did a really professional job in its design and construction,” said a Dwelling contest judge. “The interior wall panels are durable, easy to care for, and look really good. If this house were factory-built, these panels could be installed precisely, and the clean look demonstrated here could be replicated.” The design is so clean. It doesn’t feel small, even though the conditioned space is one of the smallest in the Solar Decathlon.

High scores in the subjective contests and solid performance in the objective contests led Cal Poly to a third-place overall finish in the Solar Decathlon.

Cal Poly’s building-integrated PV awning does double duty as a power source and an attractive design element.

Virginia Polytechnic Institute and State University

The Virginia Tech home is all about light, from its floating roof, which gestures toward the sun, down through its three translucent walls.

Virginia Tech’s Solar Decathlon home is designed to be a celebration of solar energy. From its floating roof, which gestures toward the sun, down through its three translucent walls, this home is all about light. It’s a modular home that can be fine-tuned to be enjoyed in nearly any climate.

What’s Different?

- Although the primary structure is wood frame, the east, west, and south walls are made of two panels of 35-mm/1.4-in. polycarbonate material filled with aerogel insulation. These translucent walls serve to connect the people inside to their immediate surroundings; motorized MechoShades provide privacy and shade, as needed, and can also deflect summer heat.
- The ceiling is made of a strong fabric material stretched over a curved structure.
- The home was built on a chassis so it could be moved to and from Washington, D.C., in one piece. When it arrived at its destination, the structure’s supporting trusses were unfolded and lowered to provide support for the exterior deck.

Architecture, Interior Comfort

- The roof is designed to “float” above a clerestory atop the walls, giving the home a light, airy feel.
- The 3-ft/0.9-m Thermal-Steel north wall houses most of the electrical and mechanical systems, so visitors and occupants alike can easily move through the home.
- The three polycarbonate walls and the roof are part of a “tunable” enclosure that can be adjusted for many different climates.

Heating and Cooling Systems

- The translucent walls allow solar energy to help warm the home in cool weather.
- A water-to-water heat pump is used for hot water and space heating (by means of a radiant floor).

Lighting (including daylighting)

- Clerestory windows at the tops of the walls provide daylight for the home.
- During the day, the ceiling reflects daylight from the clerestories down into the home, and at night it reflects the light from fixtures at the top of the walls into the home.
- Light-emitting diode (LED) lights at the bases of walls provide a colorful display at night.

PV and Solar Thermal

- The rooftop PV system is pitched and can be adjusted to capture an adequate amount of sunlight, no matter what the season.
- The team chose to use a ground-source heat pump rather than a solar thermal system to heat water and the interior space; on the National Mall, the "ground" was a 300-gallon/1136-liter water storage tank below the home.

Bryan Atwood, a student team member and one of the designers of the Virginia Tech house, put it simply. "Our idea was that when the public walks into our house, we want them to say 'it's better than the one I live in.' " Succeed they did, taking first place in both the Architecture and Dwelling contests.

The Architecture jurors were unanimous in their assessment of the Virginia Tech house as "absolutely exquisite." They had the sense that nothing had been overlooked. And most importantly, they sensed that the team had worked particularly well as a team. There were no obvious seams between the conventional divisions of architecture, engineering, and interior design. The jury agreed that it was an extraordinary achievement on every level. They especially appreciated the early commitment to solve the transportation problem as a design problem itself. Remarkable also was the design of the technological spaces and interfaces, reinforcing the jury's opinion that every decision was considered a design decision.

"As a professional, I'd be proud to have done this myself. It's not just a good project for students, it's just good," said one Architecture juror.

The Dwelling contest judges noted several impressive features in the Virginia Tech design. They reported that "everything about the design is clever," from the method developed to transport the light-construction structure to the user-friendly interactions with the sophisticated systems within the house. They also noted the "good flow" in the house. The judges said they could envision people living comfortably in the house, and that the house is buildable and marketable. "It pushes the limits of the market's tastes while at the same time whetting the market's appetite for something exciting and different. The innovation in achieving the desired outcome far surpasses expectations and demonstrates an exemplary level of ingenuity."

According to the Lighting contest judges, Virginia Tech's lighting design was clean, integrated, and "beyond excellent." This team successfully integrated their lighting design with the architectural design of the

This view of the kitchen displays the clean elegance of the interior space found throughout the Virginia Tech house.

Table 7. Virginia Polytechnic Institute and State University Home Details

Item	Specifics
PV kW (STC rating)	7.2
PV Modules	36 Sunpower SPR-200-BLK
Charge controllers	2 Sunny Island 4500
Inverters	3 SMA Sunny Boy 2500 (grid-tie); 1 SMA Sunny Boy 1800 (grid-tie); 2 SMA Sunny Island 4248
Battery bank/type	258 AH, 48 V/20 Concorde SunXtender PVX-2580L lead acid
Space heating	FHP Manufacturing water-to-water HP
Space cooling	Geothermal water-to-air HP
Ventilation	Heat recovery ventilator, exhaust fans
Water heating	None (FHP Manufacturing WH018 electric water-to-water heat pump)
Primary building envelope/Insulation	Wood frame/Aerogel; SIP/Expanded polystyrene

house. The lighting in this house contributes to making it very livable. The use of residential fixtures gives an otherwise modern space a homey feel. Virginia Tech tied for first place in the electric lighting component of the Lighting contest. "They got it!" said a judge in reference to the controls and dimming. One concern, however, was the very high connected lighting load.

Greg Mella, representing the American Institute of Architects (AIA), a Decathlon sponsor, presented an AIA Presidential Citation to Virginia Tech. Chip Clark, a student architect and member of the Virginia Tech team, appreciated the accolade. "We worked really hard at refining our design. To have people at the top of our field say they appreciate it is amazing."

Translucent walls and a curved ceiling, which the Architecture jury appreciated, are clearly visible in the Virginia Tech living room.

New York Institute of Technology

The NYIT house design consists of two main structures joined by an enclosed sunspace. An Architecture juror pronounced the house "incredibly charming and clever."

The team from the New York Institute of Technology (NYIT) dubbed their house "Green Machine/Blue Space." The design consists of two main structures joined by an enclosed "sunspace" (like a breezeway). The Green Machine structure contains most of the home's mechanical systems, as well as the kitchen, bathroom, and a roof garden for growing food and collecting rainwater. The Blue Space houses areas for sleeping, relaxing, or working.

What's Different?

- There's a hydrogen fuel cell on the premises.
- A used shipping container forms the section of the house that contains the mechanical systems, kitchen, bathroom, and roof garden.
- Furniture designed by students creates "micro-environments." Each piece provides temperature/comfort control and lighting control within its own area. This minimizes the use of large-scale mechanical heating/cooling and can direct light where it is needed.
- Decathlon visitors were offered a hand held computer (PDA), which provided a multimedia animation presentation explaining the function of many of the home's key features.

Architecture, Interior Comfort

- The Green Machine (shipping container) provides power and is the beating heart of house. The Blue Space contains culturally specific spaces for life and is built with materials indigenous to the locale. High R-value building panels used in this area are made of compressed wheat straw.
- "Micro-environments" of comfort are located inside the house to create daylighting and protection from south light.

PV and Solar Thermal

- Electricity from a roof-mounted PV system is used to separate hydrogen from water through electrolysis; the hydrogen is stored and later used to power a fuel cell that produces electricity and heat on demand.
- A solar-powered evacuated tube system is used for domestic hot water.

Electrical Load

- Highly efficient appliances minimize the energy demand.
- An efficient heat pump is used for HVAC.
- A dynamic energy balance model simulates every electrical load in the house.

"We have something very special here," said NYIT student team member David Schieren. "Hydrogen is the fuel of the future. And it's just as safe as any fuel out there. Visitors embrace it. That's why we're here on the Mall." The public's interest was clearly remarkable, as evidenced by people standing outside in the rain to learn about the hydrogen system.

NYIT shared (with Cornell) a third-place tie in the Architecture contest. The NYIT house provoked the most discussion among the Architecture jurors. Several fundamental decisions impressed them: the initial diagram splitting the serving and the served spaces; the concept of micro-environments, which yielded an unexpected marriage of furniture and mechanical systems; the loft space; and the bold step of using hydrogen fuel cell technology. The jury felt that each of these decisions impacted all aspects of the design in a consistent manner that emphasized imagination, innovation, and even humor at every scale. "There's a totally different aesthetic here, and it's incredibly charming and clever," said one juror.

In the Dwelling contest, NYIT again tied for third, this time with the University of Texas. The Dwelling judges found the NYIT design one of the most flexible demonstrated in the Solar Decathlon. They were sold on the idea of including all the expensive components of a house (the kitchen, bath, and laundry) in a central core section and then attaching the living space to this core. "The market potential for this core concept is exciting. You could easily produce the core and market it to builders across the country. A builder could purchase the core and then customize the house attached to it. By purchasing the core, the builder avoids the complications of having to construct the most expensive components of the house."

The loft bedroom of the NYIT house is above the living room. The living, dining, and home-office furniture were designed and built by NYIT students to be multifunctional.

Table 8. New York Institute of Technology Home Details

Item	Specifics
PV kW (STC rating)	10.8
PV Modules	54 Sanyo HIP-200BA3
Charge controllers	n/a
Fuel cell	Plug Power GenCore 5T48
Hydrogen generator	Proton Energy Systems HOGEN RE
Primary energy storage	Low-pressure hydrogen; high-pressure hydrogen
Backup battery bank/type	33 AH, 48 V/4 AGM lead acid
Space heating/cooling	Mitsubishi mini-split HP w/ 3 indoor units
Ventilation	Exhaust fans
Water heating	Thermomax MAZ30 evacuated tube
Primary building envelope/Insulation	SIP/Pressed agricultural products

The NYIT team showed that even if you have a complex technology, you are still able to convey your ideas to the public. The Communications contest judges scored NYIT well. "Their house tour was told in clear, friendly terms. They made the technology more approachable. We were very impressed by the 'hydrogen guys' outside. They were so enthusiastic."

Visitors stood in line in the rain to view the hydrogen fuel cell system, here being described by two NYIT student team members.

University of Texas at Austin

The Texas house consists of prefabricated modules that snap together. The Architecture jury was impressed with the team's grasp of getting the passive elements right first, before adding high-tech elements.

The University of Texas at Austin team used their Solar Decathlon experience to educate their local community—including children—about sustainable design, solar power, and energy efficiency. Their house design embodies these concepts, with an aesthetically pleasing blend of local natural materials and cutting-edge technology. The SNAP house (for Super Nifty Action Package) consists of prefabricated modules that snap together for ease of transportation and assembly on the National Mall.

What's Different?

- The team incorporated a broader vision of homeowners participating in the energy economy by producing, as well as consuming, energy.
- A green roof is planted with native Texas grasses.
- "SNAPcomm"—a touch-screen LCD panel with custom programming (done by students)—is integrated with a computer to control all systems in the house and obtain information (such as weather data) from the Internet.
- The emphasis is on sustainable materials that are recyclable or have recycled content, have low-energy life cycles, or are reclaimed.

Architecture, Interior Comfort

- Prefabricated modules snap together for ease of transportation and construction.
- Sliding doors and operable windows open up the livable spaces to each other and to the outdoors.
- Built-in furniture has flexible uses, such as office/entertainment cabinetry.

Heating and Cooling Systems

- Most windows are operable, allowing for cross breezes and reducing the need for active cooling.
- The PV array is elevated above the roof structure to ventilate waste heat.

- Southern glazing is recessed under the PV panels and behind sliding louvered panels, which block unwanted sunlight.
- Consolidated space for heating and cooling systems forms a "spine" for the house.

PV and Solar Thermal

- The PV array comprises 42 BP 4175 modules with enhanced silicon nitride monocrystalline cells.
- The evacuated tube array for hot water is placed vertically along the edge of the south deck to define an outdoor space.
- The house incorporates four PV panels manufactured by Romag in partnership with BP that are laminated between glass to create a solar shade that also transmits light.

The SNAP house features northern clerestory windows and a southern window wall to maximize daylighting and minimize solar heat gain and glare. LEDs are used for artificial lighting because of their size, energy efficiency, and negligible heat gain. A rich pallet of materials, including mesquite flooring, impresses visitors.

The Architecture jury commented that the SNAP house was successful on many levels. It was memorable, clever, well done, and original… super nifty in fact. The jury consistently looked for an understanding of passive principles, and the SNAP house demonstrated a grasp of the importance of getting the passive elements right first, before adding the high tech. The theme of connections was carried through literally, in the highlighting of the joints between modules, and experientially in the relationship of inside and outside, and from room to room.

"What a great impression this house made on us!" commented a Dwelling contest judge, noting an easy and natural flow pattern through the house. The judges liked seeing where the sections of the house are connected and said the team did a nice job with the transition between the sections. "The innovation in achieving the desired outcome far surpasses expectations and demonstrates an exemplary level of ingenuity."

The Engineering contest judges recognized the team for doing many right things with their engineered systems. The size of the solar collectors and storage tank were well matched. Ceiling fans helped mix the air in the space. The team provided the right amount of separation between their air supply intake and system exhaust. They did a nice job limiting the possible sources of volatile organic compounds and other contaminants, and they included dehumidification in their system design.

The University of Texas design includes plenty of natural light and mesquite (abundant in Texas) wood flooring.

Prior to the competition on the National Mall, BP Solar held a separate competition open to all Decathlon teams, with a free PV system as the awarded prize. Texas won, and they were awarded a set of BP 4175 PV panels (valued at about $40,000), which they used on their house. BP representatives felt that among all the entrants, Texas had most successfully integrated the PV panels into the home's design. After the competition ended, BP presented Texas with a BP Brand Value Award for Performance, which signifies setting global standards.

University of Missouri-Rolla and Rolla Technical Institute

The Missouri-Rolla house design is traditional in its reflection of the work of Frank Lloyd Wright. But it's forward-looking as the only house in the competition that uses thin-film PV panels as the primary power source.

The team from University of Missouri-Rolla and Rolla Technical Institute chose a traditional design that pays tribute to Frank Lloyd Wright.

What's Different?

- Uncommon for a solar house of this size, the northern roof has the same pitch as the southern roof. The team felt it was more important for the house to blend into traditional designs than to have the ideal pitch for solar. The students ran computer simulations to be sure their desired pitch would meet the energy needs of the house.
- Everything in the house is subtly designed around a mathematical sequence known as the Fibonacci Sequence, or the Golden Ratio. This shape can be found in most shapes in nature, from pinecones to seashells.
- Frank Lloyd Wright, who also incorporated the Golden Ratio into his designs, influenced the house's relationship to nature and many aspects of the design, such as the shape and color of the trim.
- This is the only house in the competition that uses thin-film PV panels as the primary power source.

Architecture, Interior Comfort

- The house contains 28 windows and trim and built-ins in shapes and colors reminiscent of Frank Lloyd Wright's shapes and colors.
- The house is made from SIPs and has a standing seam cooper roof.

PV and Solar Thermal

- The team placed importance on sizing the PV array efficiently.
- The solar thermal/electric system is combined into one hybrid system, producing both hot water and electricity.
- The house is equipped with radiant floor heating.

The Architecture jury was surprised and impressed by the quality of the home's interior. It was clear to the jury members who had seen the 2002 entry that the team had made an effort to address past weaknesses. That said, "Really good design requires a real team effort, and including architecture students on the team might have made the difference between a nice house and a great house." The extensive glass and careful placement of windows, the cabinetry (especially the featured kitchen island), and the oak trim were elements the jury singled out as particularly commendable.

To the Dwelling contest judges, the house seemed so much bigger than only 500 ft^2/ 47 m^2 of conditioned space. One judge noted that he saw more of a home quality

The kitchen, with its central island, was very popular with visitors to the Missouri-Rolla house. DIY Network presented the team with the "Best Kitchen Design Award."

than a "weekend" quality. "The workmanship in this house is quite good, and the mass market appeal would be very high for this design." The kitchen island was very well done. Finally, the judges felt that although this design was very marketable and livable, the innovative ideas that would contribute to the state of the art were limited.

For the House Tours portion of the Communications contest, the judges liked what they saw: "Having an energetic person out front was fantastic. Clearly as a team, they want to make the house tours matter. They are passionate. They set us up well, and they explained the craft side. The answer tent (an outdoor staging area for visitors) is a great idea for when they have elbow-to-elbow people."

Missouri Rolla was one of three winners of the Energy Balance contest, by ending the competition with as much or more energy stored in their battery systems as when they began the competition.

DIY Network, a Decathlon sponsor, echoed the Dwelling judges about the quality of the Missouri Rolla kitchen. DIY presented the team with the "Best Kitchen Design Award."

University of Maryland

The Maryland house was the "People's Choice Award" winner of the 2005 Solar Decathlon. The Dwelling contest judges commented that the house feels big and comfortable, with a kitchen layout that is very usable.

In the words of its architect, the University of Maryland's elevated house is "anchored to the Earth, yet touches it lightly." To achieve this vision, the students focused on teamwork and student leadership. Material choices were also very important to this team, as was finding an appropriate permanent location for the house.

What's Different?

- The house has an exposed structure with an unusual curved roof, integrating the solar panels into the form of the structure.
- Elevating the house reduced its footprint, which allows for more surface permeability. Site placement and land-use issues are important components of residential sustainability.

Architecture, Interior Comfort

- Clean, simple lines and a spacious floor plan emphasize a simple and sleek space.
- All walls are stick frame construction with an innovative environmentally sensitive blow-fill insulation.
- Southern-facing windows allow the concrete floor to absorb heat from the sun.
- Two porches, which are accessed from the kitchen and bedroom, contribute to the open feel to the house.

Heating and Cooling Systems

- The team selected polypropylene pipes for plumbing to avoid using PVC (polyvinyl chloride) piping.
- A radiant flooring system covers the entire home.

PV and Solar Thermal

- Charcoal-gray BP Solar panels are integrated into the design, forming part of the overall architectural character of the house.
- The PV power conversion system is from OutBack Power Systems.
- An evacuated tube system with twin-glass solar tubes is used for hot water.

Early on in their planning process, the Maryland team developed and ratified a team constitution, placing particular emphasis on student leadership and integration among disciplines. The team's first private donation was from a recent University of Maryland graduate and former 2002 Solar Decathlon team member.

The house is elevated with the mechanical elements underneath and a floating floor. This design approach allowed for 770 ft^2/72 m^2 of livable space inside of a maximum-allowable footprint of 800 ft^2/74 m^2.

A primary student goal was to make sure the house had a permanent home after the competition. They found a worthy recipient and donated the house to a 13-acre (5.3-hectare) community farm for use as a staff residence (through the Maryland-National Capital Park and Planning Commission). Red Wiggler Farm employs mentally challenged adults and provides opportunities for local youth to participate in small-scale farming.

The Dwelling contest judges commented that the house feels big and comfortable, with a kitchen layout that is very usable. "Really good workmanship went into constructing this house. A builder would be able to easily construct this house either on site or in a factory." The judges added that although this design is very marketable and livable, the innovative ideas that would contribute to the state-of-the-art were limited.

The Lighting contest judges appreciated the nice warm feel the team created in their house with both their electric lighting and daylighting designs. "The lighting levels were enough that a person could easily function in the house when it was daylit. The team picked the perfect color for the walls. The color is reminiscent of the sun, yet it also reflects somewhat."

The Communications contest judges praised the team for really planning how people would circulate through the house, for their elegant presentation, and for having a great brochure for visitors. "There will be a lot of families coming down to the competition, and this is one of the few teams that made a tangible effort to reach out to children."

The BP group thought well of the house, presenting Maryland with its Brand Value Award for innovation and delivering breakthrough solutions. And the Maryland house proved the popular favorite at the 2005 Solar Decathlon by winning the "People's Choice Award," sponsored by BP. The many thousands of visiting public, who were offered ballots and the opportunity to vote their personal preference, determined the winner of this award.

A welcoming living area greets visitors on entering team Maryland's home. Clerestory windows above the space provide lighting during the day.

Universidad Polytécnica de Madrid

Students from the Universidad Politécnica de Madrid brought their "Magic Box" home across the ocean—to the delight of visitors on the National Mall. Documentation contest judges felt that Madrid's design drawings set a new standard for the competition.

The house from Universidad Politécnica de Madrid is designed to be an attractive and comfortable Mediterranean style home that anyone could enjoy living in, apart from its energy efficiency and solar generation features. The house includes "greenhouse windows" and movable walls—allowing for an interior patio—that provide a great interior/exterior connection. The hydraulic wall in the living area that opens to accommodate a larger space gives the house its name: the Magic Box.

What's Different?

- Nearly 40 students participated in the Madrid team, and most of them came to Washington, D.C., for the Decathlon.
- The house has sliding interior walls allowing it to be one large space or three or five spaces. The living room is also movable and creates an interior courtyard.
- Greenhouses on the south wall and a green roof provide a strong interior/exterior connection.

Architecture, Interior Comfort

- The house is designed to emphasize comfort and attractiveness, as well as energy management.
- Extensive use of clay tile on walls as well as roofs and floors provides effective insulation while adding to the Mediterranean feel.

Heating and Cooling Systems

- The key feature of the heating and cooling system is use of commercially available gel phase-change material under the floor for preheating or precooling intake air.
- Highly effective insulation, including clay tiles in the outer walls, is a key part of the house's heating and cooling.
- The house features fully automatic controls for the lighting system and heating and cooling system, both of which can be operated manually.

PV and Solar Thermal

- The house uses fives different types of panels. All are frameless laminated crystalline silicon panels chosen to

Team Madrid's living room features windows with solar-electric cells. A wall of the room can move to reveal an interior patio.

- show how well they can be incorporated into the house design and perform architectural functions.
- The PV system includes a monitoring system for supervision purposes, as well as an energy management system for an efficient use of solar energy.
- An evacuated-tube solar thermal system provides the domestic hot water. Heat from the draining shower and dishwasher is captured for preheating incoming hot water.

The Madrid team finished second in the Documentation contest, which evaluates the quality of documents submitted for the schematic design, design development, construction, and "as-built" phases of the project. Up to 100 points were available based on the evaluation from a panel of judges who scored each team's submittals. The Madrid drawings set a new standard for the competition. One judge commented that the entire Madrid submittal serves as an effective case study, and that it "goes beyond just being an effective set of drawings. It is a wonderful exercise in effective communication."

The Lighting contest judges thought the students gave a lot of thought to their design and were able to give good rationalization for most of their design decisions. The judges, however, would have preferred to see more integration between the lighting and architecture. "This design feels like there should be a lot of light, yet it didn't feel as bright as one might expect."

The Communications contest judges said the model houses (in an outdoor staging area) were great, and that the team's brochure did an excellent job of telling the Madrid story. One bit of advice from the judges involved the team's concept: "The Magic Box is an incredibly cool concept that should have been much more integrated into the house tour."

Pittsburgh Synergy (Carnegie Mellon, University of Pittsburgh, The Art Institute of Pittsburgh)

The back, south-facing porch of the Pittsburgh house makes an inviting seating area. The Dwelling contest judges commented on the "edgy" look and "radical student architecture" of the house.

The Pittsburgh Synergy Solar Decathlon team includes students from Carnegie Mellon, University of Pittsburgh, and The Art Institute of Pittsburgh. The Pittsburgh house is intended to be a bridge to housing of the future. It features north and south walls tilted toward the sun and a translucent polycarbonate north wall.

What's Different?

- To better use solar resources, the north and south walls of the home tilt 12º to the south.
- The north wall of the home, enclosing all the "service" areas including the bedroom, is made of translucent cellular polycarbonate glazing.
- The translucent wall can be used for video projection of campus information at the house's planned permanent location on the Carnegie-Mellon campus.
- For this team, the KISS Principle stood for Keep It Simple, Students.

Architecture, Interior Comfort

- The living area of the home, referred to as a great room, features a total-glass south wall and cement floor for thermal mass to aid heating and cooling. Shades for the south wall are manually controlled—the team believing that the occupants are the best operators.
- Environmentally sustainable building materials are used for most of the house.
- The home is intended to be simple, geometric, and elegant.

Heating and Cooling Systems

- A variable-speed, mini-split system heat pump is used for heating and cooling.
- A 150-ft^2/14-m^2 evacuated glass tube solar thermal slab heating system will be activated when the house returns to Pittsburgh.

- Upon return to Pittsburgh, a geothermal heat pump (helpful for Pittsburgh winters and not possible on the Mall in D.C.,) will be added.

PV and Solar Thermal

- The 5.1-kW solar array features 30 BP Solar modules.
- The house's 12º tilt to the south makes it easier to accommodate the PV system.
- A solar water heating system (which is allocated relatively more of the rooftop solar resource than the PV system) provides hot water for radiant, in-floor heating and domestic hot water.

This was the first house the Architecture jury visited, so they had little sense of relative success or expectations. The jurors' memories of the quality of this house, however, were so strong that they decided to revisit it during deliberations. Seeing it full of visitors did nothing to diminish the first impression of a "spacious feeling" and a "beautiful job of identifying the different spaces" in a small footprint. The articulation of different areas was remarkable. The jury commended, in particular, the recognition that an airlock at the entry is an important part of a coherent thermal strategy. The house demonstrated architectural innovation, a rich material palette, and a memorable form, all of which answered the challenge admirably.

The Dwelling contest judges commented on the "edgy" look and "radical student architecture" of the Pittsburgh house (such as the 12º tilt and the wall slats running on an angle). Although such houses are starting to have appeal to the general consumer, the judges felt that this house would not necessarily appeal to the mass market yet. Another comment was that, "The open bathroom is a neat concept, but it appears that everything could get wet with this particular layout."

The Dwelling panel of judges singled out Pittsburgh's ingenious furniture design, saying it went beyond the competition expectations. Also, the judges noted that the concrete flooring got a true test during the Dwelling panel's visit because weather was rainy the entire week of competition. "It held up well to the foot traffic during the rainstorms, which proves that it is a low-maintenance floor. This is a nice livability feature."

The dining, home-office, and living spaces of the Pittsburgh house commune with the outdoor seating area through large, south-facing windows.

After results were announced for each contest, the decathletes would hustle over to the scoreboard to see their teams' standing. The scoreboard was updated every 15 minutes.

Universidad de Puerto Rico

The Puerto Rico house has large south-facing windows to maximize the daylight and minimize use of electric lights. Fixed louvers over the windows block radiation, but let in sunlight.

The Solar Decathlon team from Puerto Rico brought the warmth of island life to the National Mall. Hospitality and social interaction are fundamental to Puerto Rican culture. The house design encourages these values by creating a direct visual and physical relationship between interior and exterior spaces.

What's Different?

- Along with the Madrid team, this team had to be ahead of the curve—they shipped their house to the competition across the ocean and needed to complete it sooner than the other teams.
- Students modified the clothes dryer to use solar hot water heat instead of electricity, which was designed to save significant amounts of electricity.
- The roof angle was designed with a 20º pitch. Although not optimal for a PV system in Washington, D.C., the team felt this was important because it's the norm in Puerto Rico.
- Undergraduate students did all the design and construction.

Architecture, Interior Comfort

- The house has an expandable, modular design.
- By situating the terrace by the living room, the living space seems bigger and more open.
- Exterior beams and columns reflect the horizontal aesthetics of Puerto Rican design and attach to the exterior of the house.
- The house features many off-the-shelf, consumer-available materials.
- Variations in interior elevations separate common spaces.

Heating and Cooling Systems

- Team members modified a conventional air-conditioning system, which controls both the house's temperature and relative humidity.

PV and Solar Thermal

- Using the solar hot water system for clothes drying required more solar collectors, a larger storage tank, and higher-temperature water, but it saved electricity.
- The PV system comprises 40 BP Solar modules (BP-4175) with 44 MK-8A8D batteries. The inverters, charge controllers, and the rest of the PV system are from Xantrex.

No matter the weather, the students from Puerto Rico remained exuberant throughout the competition. "Mi casa es su casa" (My house is your house), they said when welcoming visitors into their home. House tours were a major focus for this team,

The living room of the Puerto Rico house opens up to an outdoor deck, a design that encourages the hospitality and social interaction so important to Puerto Rican culture.

with the twin goals of sharing the Puerto Rican lifestyle and making all visitors, both English- and Spanish-speaking, feel especially welcome.

The house has large south-facing windows to maximize the daylight and minimize use of electric lights. Fixed louvers over the windows block radiation, but let in sunlight.

Puerto Rico earned second place in the Communications contest. They got points for easy navigation, solid and consumer-friendly content, and creative graphics on their Web site. The team scored big points in the House Tours element of the Communications contest. According to the judges, "They use their culture—everything from live music and artwork on the walls to emphasizing the importance of community in their culture—as an effective and appealing way of branding themselves, their mission, and their messages."

Puerto Rico won the DIY Network "Voter's Choice Award." DIY, a Solar Decathlon sponsor, invited its Web site visitors to vote on their favorite houses based on online photos of all competition houses.

Crowder College

The Crowder team used the American Arts & Crafts style native to their region to inspire this modified bungalow design.

The Solar Decathlon team from Crowder College in Neosho, Missouri, adapted an architectural style integral to the history of the area—the American Arts & Crafts house.

The style incorporates many of the same principles that are known today as *sustainable design*: beauty and functionality; harmony with the surrounding landscape; an open, inviting floor plan; built-in details such as benches and bookcases; and windows for ample light and appealing views.

What's Different?

- The courtyard on the north side of the building is accessible from the home's interior.
- The home features an improved PV-thermal design that was originally showcased in the 2002 Decathlon competition. In addition to generating electricity, the integrated modules are also designed to supplement the solar domestic water heating, space heating, and space cooling systems.
- Hardwood flooring, trim, and cabinetry are from the Pioneer Forest, the only forest in Missouri certified as renewable by the Forest Stewardship Council.
- The team used electricity from the trailer-mounted, portable solar-electric system designed for the 2002 Decathlon competition to power tools during construction.

Architecture, Interior Comfort

- Steel/foam panelized wall and roof construction were chosen to facilitate quick assembly after transport.
- Steel studs are used for the structure, which can stand up to a tornado.
- Flexible spaces allow for dual use, such as a bedroom with a wall bed that can be put away during the day.
- The team applied a common unit of measure (approximately the length of the solar panel) to determine dimensions for recesses, doorways, window placement, and private spaces.

Heating and Cooling Systems

- The team modified and improved the water-heating system designed for the 2002 competition.
- Waste heat from the PV modules heats water through a system of copper tubes attached to the back of the modules and an extra layer of glazing added above the modules.

• Some components of the system are used to chill water at night to help with air-conditioning.

PV and Solar Thermal

• The hybrid PV/thermal modularized solar system uses high-efficiency, heat-tolerant Sanyo HIT 190 modules that can maintain higher voltages at higher temperatures.

• Roof design is based on the dimensions of the panel itself.

It took three trucks to get the Crowder house to Washington, D.C. The first one broke an axle. The second one lost a wheel. But, the third truck was the charm and delivered the team's house to the Mall. Rather than dwell on the negative and sit idle while waiting for their house to arrive, the Crowder students pitched in to help another team. In the true spirit of camaraderie, they went to work on the Cornell house, whose team was light on "people power" the first day. The Cornell students reciprocated by helping Crowder catch up once their house arrived.

The Crowder team chose wood from the Pioneer Forest in the Ozarks for much of the cabinetry, trim, and flooring in their home.

Crowder was one of three winners of the Energy Balance contest, by ending the competition with as much or more energy stored in their battery systems as when they began the competition.

The Lighting contest judges ranked the team well, saying they did an incredible job considering the resources immediately available to them. "Even though the students did not have the tools and expertise to guide them like some other teams had, they had good intuition and made some nice decisions."

Sometimes the decathletes just had to grab a quick nap. In this case, a Pittsburgh Synergy student took a moment to recharge her batteries.

Florida International University

Reflecting Florida's architectural roots, the northern facade of the Florida Intl house is virtually all windows, which are protected by operable louvered blinds to control daylighting.

The Solar Decathlon team from Florida International University named their U-shaped house *Engawa*, which is a Japanese architectural term that describes space both inside and out. The house is centered around a courtyard, and by adapting the interior walls, the U shape can be transformed into a square and four rooms can become one.

What's Different?

- Using the steep roof, the house's rear gutter can be used to incorporate a rainwater catchment system.
- The team drew on diversity, with representatives from many cultural backgrounds and many disciplines—including creative writing, journalism, architecture, and engineering.
- The ductless HVAC system uses refrigerant and a variable speed compressor for maximum efficiency; the system's programmable controls adjust the temperature if someone leaves the room.

Architecture, Interior Comfort

- The design emphasizes historical ways of heating and cooling, with operable windows and blinds.
- The design can easily be expanded to work with any square footage.
- The structure is made of a unique prefabricated steel frame with insulated foam panels.
- All building materials are hurricane compliant.
- The interior walls can be changed in any way; there are no load-bearing walls in the interior.
- The interior incorporates bamboo flooring and non-toxic natural paints.

PV and Solar Thermal

- Thin-film PV-integrated windows can be used as a projection surface for film, video, or visual presentations.

With contest rules stipulating a maximum-allowable footprint of only 800 ft^2/74 m^2, the teams were looking to double up on functionality wherever possible. Florida Intl answered this call with two Murphy beds, one in the living room and one in the bedroom.

There is playful track lighting on high ceilings weaving throughout the space. A "smart" system controls lighting, shades,

The bedroom footprint of the Florida Intl house is a mirror image of the living room footprint, but furnished differently.

and HVAC. The house incorporates LED lighting, occupancy sensors, skylights, and light shelves. A light shelf is a passive architectural device that permits daylight to enter deep into a building. Light shelves enhance daylight quality, conserve energy by allowing perimeter light to be dimmed or turned off, and increase occupant comfort. Reflecting Florida's architectural roots, the house's northern facade is virtually all windows, which are protected by operable louvered blinds to control daylighting.

Florida Intl was one of three winners of the Energy Balance contest, by ending the competition with as much or more energy stored in their battery systems as when they began the competition. This was a bit like making lemonade if you have lemons. According to team member Eugenia Demarco, "Our biggest problem was that when the competition started, our batteries weren't fully charged. This really hurt us during this rainy week. We have efficient lights, efficient air-conditioning."

The Communications contest judges thought that Florida Intl had a great theme with the *Engawa* concept by giving the public something to take away. The students explained the technology in user-friendly language and talked about features in terms of how you would live in the house.

Florida Intl won the DIY Network Award, which was based on votes from DIY's network and DIYnetwork.com staff.

Canadian Solar Decathlon (Concordia University and Université de Montréal)

Team Canada's home was designed for a harsh northern climate. The DOE Energy Efficiency and Renewable Energy Office and NAHB awarded the team a first-place plaque for building the most energy-efficient house at the Decathlon.

The Canadian Solar Decathlon team included tight walls, lots of thermal storage, and plenty of foam insulation in its home designed for a harsh northern climate. Yet about 50% of the house is (triple glazed) window area. The home's high-tech features—such as a home automation system that links temperature to window blinds and roof-integrated PV panels—are meant to invisibly control the energy in the home.

What's Different?

- The team designed a home automation system that monitors the home's temperature and links to controls throughout the house.
- Phase-change materials and a wall of water placed adjacent to a window serve as thermal storage.

Architecture, Interior Comfort

- The home includes tight walls, lots of thermal storage, and plenty of foam insulation.
- Rather than using plastic siding, the team chose environmentally friendly wood siding.

PV and Solar Thermal

- The PV panel is integrated into the roofing materials.
- A solar thermal system using evacuated tube collectors provides domestic hot water and assists with space heating.

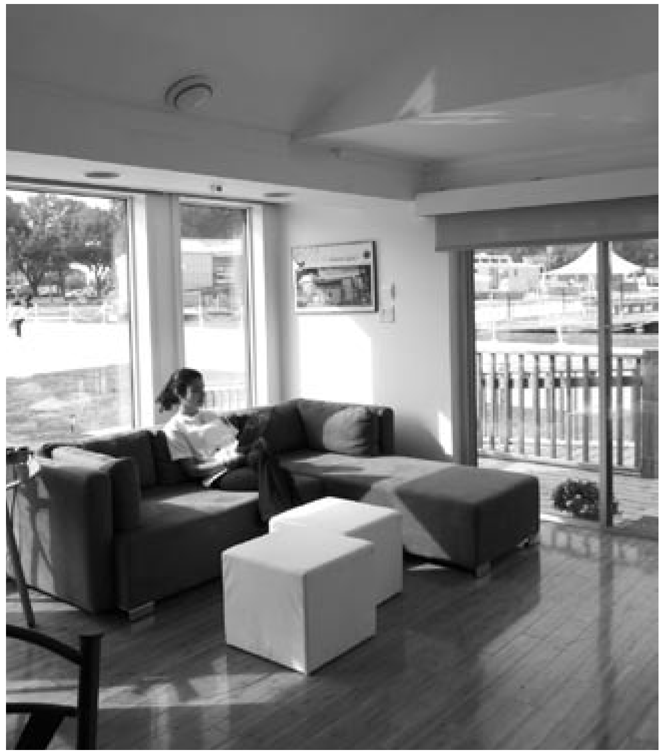
This home features occupancy sensors and digitally controlled lighting. Motorized blinds prevent heat from the sun from entering the south-facing windows during summer. Warm air from the solar panels, which would normally simply dissipate, finds a use in the clothes dryer.

The Lighting contest judges commented that this team went all out with their lighting control system, which was the strength of the overall design. But the judges felt the team missed some opportunities to choose fixtures that would have celebrated the space.

The Communications contest judges liked the team's use of a maple leaf motif and thought the Web site reflected an excellent job in identifying the audience, adding that the content was original and the writing solid.

The DOE Energy Efficiency and Renewable Energy Office and the National Association of Homebuilders recognized the team with a first-place plaque for building the most energy-efficient house. The prize also included sending two students to the International Builders' Show in Orlando, Florida, in January 2006.

Decathlon sponsor BP presented the Canadian team with a BP Brand Value Award for Progressiveness, which signifies always looking for a new and better approach.



Team Canada's living room features an abundance of natural daylighting. Motorized blinds prevent heat from the sun from entering the south-facing windows during summer.

Washington State University

The shipping container in which the Washington State house traveled formed the core of the house on site at the National Mall. The Architecture jury admired the team's exuberance of ideas and the risks taken in their execution.

As the only team in the competition from the northwestern United States, the Washington State University team saw the Solar Decathlon as an opportunity to showcase many products and technologies from their region. The team designed their house to be affordable, but also to have wide appeal and exemplify sustainability along with architectural beauty. As a result, the students emphasized space planning, used function to create beauty, and selected their building materials carefully.

What's Different?

- The student team built the refrigerator, furniture, structural connections, and the cabinetry.
- The shipping container in which the house traveled formed the core of the house on site at the National Mall.
- The team used a new type of SIP that was designed by a Spokane architect. It is the inverse of a traditional SIP in that the interior is a corrugated steel frame and the polystyrene is on the exterior. Electrical and plumbing can run through the SIP without compromising its structural integrity.
- The team modified a hot water tank by replacing the alternating current (AC) heating elements inside the tank with direct current (DC) elements that draw directly on the PV panels, allowing full use of the PV system.

Architecture, Interior Comfort

- The skin of the building, decking, and siding are made of wood-plastic composite products donated by Washington State's Wood Materials and Engineering Laboratory and produced by the students.
- Composite decking and siding give a Northwest "feel," but are more cost efficient and sustainable than products made solely of wood.

Heating and Cooling Systems

- The fully integrated heating and cooling system is based on a system from Glacier Bay, which makes highly efficient refrigerators for the marine industry. The refrigerator is so efficient that the compressor has to run only 4% of the day. The rest of the time, the compressor is available for space cooling.
- The system draws on waste heat from the refrigerator's compressor to preheat domestic hot water.

PV and Solar Thermal

- The PV system comprises 16 RWE Schott Solar PV panels and an OutBack inverter.

Washington State students built the house's refrigerator, furniture, structural connections, and cabinetry.

- Hot water is produced by an evacuated tube system.

The Architecture jury admired the team's exuberance of ideas and the risks taken in their execution, commenting that, "This house combines imagination with pragmatism, offering a realizable vision of solar living. It's fun and clever in a unique way… almost funky, with an ad hoc feeling of using found materials."

At the Solar Decathlon victory reception, the Washington State students were recognized for creative fund-raising. They had the lowest cash budget of any team and completed their project almost entirely with in-kind donations. They came up with clever vehicles for fund-raising, including holding a series of telethons. They showed no fear in "cold calling" potential sponsors and were often rewarded for their efforts. The team commented that they had received overwhelming support from sponsors and the local community.

Solar Decathlon Project Manager Cécile Warner stands ready to distribute towels for the laundry activity of the Appliances contest. A whole lot of towel washing went on during the competition, but not much drying. The dearth of sunshine during competition week had teams factoring energy expenditures on a points-per-kWh basis—and many deemed drying towels expendable.

Rhode Island School of Design

The RISD house is designed for an urban setting and to allow use as a row house. Heliotropic vertical louvers track the sun to keep out unwanted heat.

The house from the Rhode Island School of Design (RISD) is fresh and innovative both in look and feel and in energy management. The house is designed as a home office for an urban setting and to allow use as a row house. From the heliotropic metallic louvers on the exterior to phase-change energy storage at its core, the house is designed to maximize energy efficiency and minimize the need for solar panels.

What's Different?

- A sliding glass wall between the living room and the balcony deck allow the living area to open up to a sidewalk-café-style indoor/outdoor space.
- The house features an elegant rooftop garden to keep it cool and in touch with nature in the midst of city life.
- Phase-change materials are used for both heating and cooling.

Architecture, Interior Comfort

- The house is designed for an urban setting. The north and south sides are very open, but the east and west sides have only "sliver" windows that could be eliminated if common walls were needed for row house use.
- The bedroom converts to a home office with one wall having a Murphy bed and another having office fixtures that also fold away.

The south wall of the RISD house opens up completely so that its inhabitants can extend their living area, weather permitting.

Heating and Cooling Systems

- A passive strategy is used for heating and cooling (no furnace or air-conditioning chiller); electricity is used only for pumps and fans.
- Both heating and cooling are radiant from water pumped through pipes.
- Heliotropic vertical louvers track the sun to keep out unwanted heat.

PV and Solar Thermal

- The house has only 24 PV panels and 2 solar hot water panels, with the latter also used to heat the phase-change material for the heating system.
- A central goal of the house design was to minimize the need for energy.

Because of the stream of visitors at the Decathlon, the house was designed with a clear circulation promenade through it. All utilities are in one place and visible from outside the house through a removable panel. An entire school class at RISD submitted proposals for the lighting system, which features two custom-designed task lamps. Radiant-heated floors were fairly common on the National Mall, but RISD had the only home with a radiant-heated ceiling. This allowed custom tube lights (with magnetic bases) to be positioned anywhere on the ceiling or used as task lights.

Part of the heating and cooling system was the use of 144 "bricks" of an advanced phase-change material positioned under the floor. RISD students told visitors to think of the bricks as a battery to store heat and cold. With each brick able to store 4,000 Btu, the homeowner could collect heat during sunny periods and bank it for cloudy periods.

RISD was one of two winners of the Electric Lighting component of the Lighting contest. The judges commended the students for using real creativity in their electric lighting design: "The coloration works really well, nice and warm. The wall sconces are marvelous. This lighting design is very appropriate for a residential application."

The Architecture jury praised the house, singling out the artwork and furnishings, cork floor and cabinetry, phase-change subfloor, and heliotropic louvers as exemplifying a consistent exploration of the world of materials, whether for performance or experience. "In this way, the contribution of students of art and design were equal to those of engineering and architecture in making the house a singular vision of the house of the future."

University of Michigan

The Michigan house is based on monocoque designs from the aircraft and automobile industries, in which the external skins of an object support some or most of the load of the structure.

At the 2005 Solar Decathlon, MiSo* wasn't a type of soup… it was short for Michigan Solar House Project. The house design is a prototype for a housing system that can be mass-produced, an approach and process that creates less material waste and encourages longer usable life. Modular construction allows consumers to add more space or customize the house in other ways.

What's Different?

- The house is based on monocoque designs from the aircraft and automobile industries, in which the external skins of an object support some or most of the load of the structure. The design resists wind loads of at least 90 mph/145 km/h.
- Although not a traditional material in "green" architecture, aluminum was chosen for the shell of the house. The material quality of aluminum is not downgraded extensively when recycled and its light weight is ideal for the portability of the modules.
- The house features a solar chimney, in which the sun heats air in glass spaces at the base of the south wall. The hot air then rises along the curve of the roof and is either released into the house in the winter or outside in the summer. A specialized ceramic paint coating inside an 8-in./203-mm cavity provides insulation value in addition to the air itself.

Architecture, Interior Comfort

- A curved roof allows for natural passive ventilation in the interior and superior airflow control through dampers at the base and at the top. DC-powered fans add assistance at critical temperature extremes.
- Three materials make up the interior pallet of finishes: ash wood, stainless steel, and sunflower board.
- Each module of the house is constructed from four major structural components: solar chimney, north roof, north wall, and floor. The infrastructure of the modules

makes it possible for HVAC, plumbing, and electrical systems to be seamlessly connected, regardless of order or configuration.

- A single circulation path and open floor plan maximize the use of space and optimize future reconfiguration of spaces through the addition or substitution of modules.

This arching window follows the roofline of the Michigan house and provides natural daylighting into the home's work and living spaces.

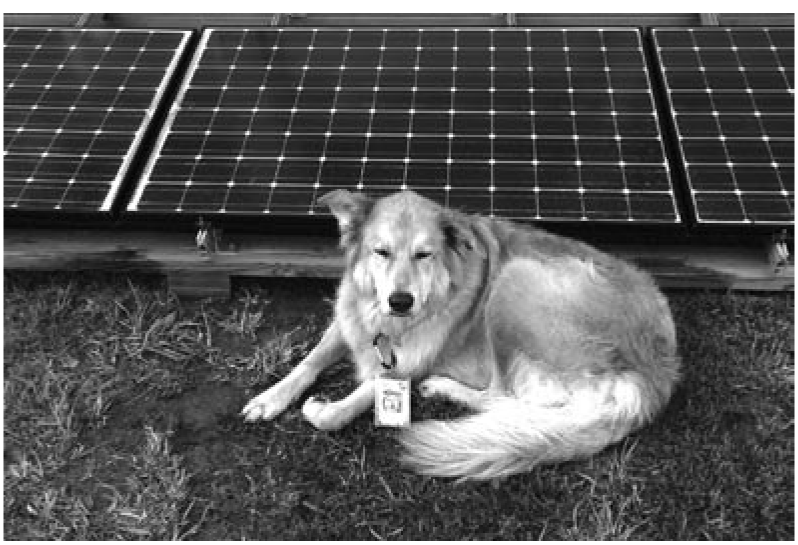
Heating and Cooling Systems

- The solar thermal panels on the roof are supplemented by a small electric heater. The water storage tank in the center of the house serves as the hub for hot water control to heat the radiant floor.
- The solar chimney is, in effect, one of the heating and cooling systems in the house. The cavity of air keeps hot air out of the house for cooling conditions and, with the opening and closing of specially placed louvers, can also be used to heat the interior of the house.

PV and Solar Thermal

- A 6-kW system of 32 Sanyo HIT 190-watt PV modules is arranged in 6 rows along the curved roof; the inverter is from Out-Back Power Systems.
- A closed solar thermal system by Viess-man can heat 50 to 60 gallons/189 to 227 liters of water per day to about 140ºF/60ºC through the use of an evac-uated tube system. The storage tank was specifically designed to minimize the losses of heat when occupants are not using hot water by providing insulation as well as some minimal electric backup heating.

Many Solar Decathlon teams adopted the architectural style, functional consider-ations, and spatial configurations native to their regions. In a similar vein, the Michigan team adapted the manufactur-ing knowledge and sense of craftsman-ship identified with the Great Lakes area and synthesized them into a new system meant for dwelling.



All decathletes were required to wear Solar Decathlon identification at all times on the National Mall. NYIT students made sure that Zero, the team dog, was in full compliance.

University of Massachusetts Dartmouth

The UMass Dartmouth Solar Decathlon home now resides in Berkeley Springs, West Virginia, where it is being used as a solar technology research center for the community.

The house from the University of Massachusetts Dartmouth was designed with the Solar Decathlon in mind, but it also adheres to guidelines that would make it suitable for Habitat for Humanity. To learn about the requirements for such a home, the UMass Dartmouth team helped an Oak Ridge National Laboratory group build a Habitat home in Tennessee.

What's Different?

- The house was built in three pieces for shipping. Only two were actually part of the Decathlon entry—the third provided a second bedroom for the permanent home.

Architecture, Interior Comfort

- The house is designed to deemphasize technology, use off-the-shelf components, and look like a "normal" home.

Heating and Cooling Systems

- The house is very tightly constructed. A blower-door test was conducted by ENERGY STAR home raters.
- The house is heated with radiant flooring.

PV and Solar Thermal

- One roof-mounted evacuated-tube solar thermal system is used for the radiant floor system.
- The PV system is rated at 3.1 kW and uses a dual inverter.

This engineering-dominated team received considerable support from its Southeastern Massachusetts community, including architectural design, construction by a private firm, and help from a large number of UMass Dartmouth alumni. The budget for the entire project was less than $75,000. Two of the appliances were donated by Whirlpool, a regular Habitat for Humanity sponsor.

UMass Dartmouth was one of three teams (with Crowder and RISD) that suffered major transportation-related mishaps en route to the competition. An accident during transport left half of the house in Massachusetts. The team later went back, loaded it on a flatbed, and brought the rest of their house to the National Mall, but it was too late to assemble it properly. This misfortune actually provided a unique opportunity for the public to see how a modular home comes together.

The UMass Dartmouth Solar Decathlon home now resides in Berkeley Springs, West Virginia, some 80 miles/129 kilometers from the National Mall. Mountain View Builders, LLC, a "green" building company, transported the house from the Mall to the permanent site, where it is being used as a solar technology research center for the community.

Each Solar Decathlon home was required to provide a well-lit work area. The UMass Dartmouth team placed theirs next to a south-facing window for plenty of natural light.

Abbreviations and Acronyms

AC	alternating current
ADA	Americans with Disabilities Act
AIA	American Institute of Architects
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
C	Celsius
Cal Poly	California Polytechnic State University
COW	cell on wheels
DC	direct current
DOE	Department of Energy
ERV	energy recovery ventilator
F	Fahrenheit
Florida Intl	Florida International University
GEM	Global Electric Motorcar
in.	inch
HP	heat pump
HVAC	heating, ventilation, and air-conditioning
km/h	kilometers per hour
kW	kilowatt
LED	light-emitting diode
m	meter
MiSo	Michigan Solar House Project
mm	millimeter
mph	miles per hour
NAHB	National Association of Homebuilders
NREL	National Renewable Energy Laboratory
NYIT	New York Institute of Technology
PDA	personal digital assistant
PV	photovoltaics
PVC	polyvinyl chloride
RISD	Rhode Island School of Design
SIP	structural insulated panel
SNAP	Super Nifty Action Package
STC	standard test condition
UMass	University of Massachusetts Dartmouth
Virginia Tech	Virginia Polytechnic Institute and State University
W	watt

Web Site Resources

www.solardecathlon.org/2005/technical_report.html

2005 Solar Decathlon Rules and Regulations

The official rules and regulations for the 2005 Solar Decathlon.

Daily Journals

During the competition, daily updates written by Competition Director Richard King were posted on the Web site. These journals give a sense of day-to-day life during the competition.

Daily Event Schedule

This schedule contains all activities the teams needed to know about, 24 hours a day, from the time of their arrival in Washington, D.C., through assembly, the competition, disassembly, and departure.

Juror and Judge Information

Brief biographical information about each juror and judge.

Solar Decathlon 2002: The Event in Review

Report about the 2002 event.

Final Detailed Scores and Standings

The complete scoring spreadsheet, including very detailed information for each team and contest.

Brief Contest Reports

Teams had the option of submitting a brief report for the subjectively judged contest activities listed below. Before the event began, these reports were given to members of the jury or panel of judges associated with each of the contest activities. The jurors and judges used the reports to preview what they would be evaluating at the event. The contest reports provided by the teams ranked in the top three for each activity are included. All contest reports from the Colorado team are also included.

- Architecture Jury Evaluations
- Dwelling Panel Evaluations
- Communications Panels Evaluations
  - Web Site
  - House Tours
- Lighting Panel Evaluations
  - Electric Lighting Quality
  - Daylighting Quality
- Engineering Panel Evaluations (Comfort Zone and Hot Water)
  - Comprehensive Assessment of Thermal Comfort
  - Comprehensive Assessment of Indoor Air Quality
  - Comprehensive Assessment of Hot Water.

Instrumentation and Monitoring for Solar Decathlon 2005

Description of the monitoring equipment used in the competition.

Equipment Summaries

Information about the following equipment used in each 2005 and 2002 competition house:

- Space heating, cooling, and ventilation
- PV systems
- Electrical storage and conversion
- Water heating systems
- Building envelope materials.

Complete "As-Built" Drawings and Submittals from the 2005 Teams

Drawings and other required information such as equipment and specifications as submitted by the teams for the 2005 competition. These files are in variety of file formats, which may or may not be readable by any given user.

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