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U.S. DEPARTMENT OF ENERGY SOLAR DECATHLON: CHALLENGING STUDENTS TO BUILD ENERGY EFFICIENT, COST-EFFECTIVE, AND ATTRACTIVE SOLAR-POWERED HOUSES

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ABSTRACT

The U.S. Department of Energy Solar Decathlon challenges collegiate teams to design, build, and operate solar-powered houses that are cost-effective, energy-efficient, and attractive. The winner of the competition is the team that best blends affordability, consumer appeal, and design excellence with optimal energy production and maximum efficiency. The paper discusses the solutions developed for the event including architectural trends, transformations to the built environment, new use of materials, and integration of unique design elements.

We believe that the solutions implemented for Solar Decathlon 2011 represent current trends and that by analyzing, critiquing, and exposing the solutions pursued, the industry can become better suited to address existing challenges. Constructing a solar community using high-efficiency design and unique materials while remaining code compliant, safe, and effective results in solutions that are market relevant, important, and interesting to the industry as a whole.

1. INTRODUCTION

The U.S. Department of Energy Solar Decathlon challenges collegiate teams to design, build, and operate solar-powered houses that are cost-effective, energy-efficient, and attractive. The winner of the competition is the team that best blends affordability, consumer appeal, and design excellence with optimal energy production and maximum efficiency.

The first Solar Decathlon was held in 2002; the competition has since occurred biennially in 2005, 2007, 2009, and 2011. The next event will take place in fall 2013 at the Orange County Great Park in Irvine, California. Open to the public free of charge, the Solar Decathlon gives visitors the opportunity to tour the houses, gather ideas to use in their own homes, and learn how energy-saving features can help them save money today.

The Solar Decathlon serves multiple purposes: (1) educates student participants and the public about the many cost-saving opportunities presented by clean-energy products, (2) demonstrates to the public the opportunities presented by cost-effective houses that combine energy-efficient construction and appliances with renewable energy systems that are available today, (3) provides participating students with unique training that prepares them to enter our nation's clean-energy workforce.

Through 2011, the Solar Decathlon has involved 92 collegiate teams, each of which pursued multidisciplinary course curricula to study the requirements for designing and building energy-efficient, solar-powered houses. It has established a worldwide reputation as a successful educational

program and workforce development opportunity for thousands of students, and affected the lives of 15,000 collegiate participants.

In 2011, the Solar Decathlon provided more than 350,000 house visits to the public over 10 days and reached millions of readers and viewers in markets across the globe through various media.

This paper discusses the solutions developed by the university students. Various topics including unique architectural trends and transformations to the built environment, new use of materials, and integration of design elements are presented. The objective is to summarize the entries including numerous leading edge solutions and discuss their effect on efficiency, solar integration, and house performance.

Consisting of 19 unique houses designed for different climates and clients yet sited and tested in a single location, the Solar Decathlon houses provide a unique and interesting opportunity for comparison of design approaches. As part of the competition, each house is challenged to complete identical tasks and subjected to rigorous evaluation from both a design and performance perspective. We believe that the solutions implemented for Solar Decathlon 2011 represent current trends and that by analyzing, critiquing, and exposing the solutions pursued the building industry can become better suited to address existing challenges.

Constructing a solar community with 100% solar penetration using high efficiency design and unique materials within a condensed construction schedule and environment is difficult. Completing this work while remaining code compliant, safe, and effective results in solutions that are market relevant, important, and interesting to the industry as a whole.

2. THE COMPETITION

The National Renewable Energy Laboratory (NREL) collaborates with the Department of Energy to develop the Rules that guide the design and evaluation of each competition prototype house. To ensure an interesting yet challenging competition, NREL evaluates typical performance requirements for residential housing and develops a balance of tasks, juried evaluations, and continuous monitoring that together comprise the final score for each team. At the end of the competition, the team with the highest score wins.

The competition is divided into 10 contests, each worth 100 points. The ten contests, discussed individually below are: Architecture, Market Appeal, Engineering, Communications, Affordability, Comfort Zone, Hot Water, Appliances, Home Entertainment, and Energy Balance.

2.1 Architecture

The Architecture contest is a juried contest in which a team of professional architects evaluate each competition prototype house, construction drawings, construction specifications, and an audiovisual presentation. This jury assigns an overall score for the design's architectural merit and implementation, considering criteria such as the effective use of architectural elements, the holistic nature of the design, lighting implementation, and whether or not the overall project offers a sense of inspiration and delight to Solar Decathlon visitors.

2.2 Market Appeal

The Market Appeal contest, like the Architecture contest, is a juried contest in which a team of three professionals from the homebuilding industry assigns a score for the competition prototype house's market appeal. The jury consists of individuals with expertise in marketing, specialty residential construction, and interior design. Tasked with evaluating the responsiveness of the design to the characteristics and requirements of a team-defined target client, the jury evaluates each house from perspectives of livability, marketability, and buildability.

2.3 Engineering

Similarly, the Engineering contest is a juried contest in which engineers assign an overall score for the design's engineering merit and implementation. The jury considers the functionality, efficiency,

innovation, and reliability of all systems contained within each competition prototype house prior to determining a final score for each team. In addition to evaluating the actual house and the supporting design documentation, the jury also evaluates a detailed energy analysis created by each team that explains the design considerations, load forecasts, and other engineering features integral to house performance.

2.4 Communications

The goal of the Communications contest is to ensure that all communications materials and presentations educate consumers about the project and topics relevant to the project. Also a juried contest, three professional communicators including individuals with expertise in educational exhibits, digital communications and public presentations were engaged for the Solar Decathlon 2011. The jury evaluates each team's website, public exhibit materials, public exhibit presentation, and video walkthrough. The ability of a team to clearly communicate the unique and important features of their competition prototype house is integral to success in this contest.

2.5 Affordability

New to Solar Decathlon 2011, the Affordability contest is structured such that all available points are earned for achieving an estimated construction cost of $250,000 or less. Reduced points are earned for a construction cost between $250,000 and $600,000. To determine the estimated construction cost, NREL hired a professional cost estimator who reviewed the design documentation submitted by teams and evaluated the on-site competition prototype house to determine an accurate and verifiable estimate. The estimator worked with each team to appropriately evaluate each house including many unique components and construction techniques.

2.6 Comfort Zone

The comfort zone contest evaluates each house on its ability to maintain a consistent and reasonable temperature and humidity throughout the contest period. All available points for temperature are earned at the conclusion of each scored period by keeping the time-averaged interior dry-bulb temperature between 71.0°F (21.7°C) and 76.0°F (24.4°C) during the scored period. All available points for humidity are earned at the conclusion of each scored period by keeping the time-averaged interior relative humidity below 60.0% during the scored period.

2.7 Hot Water

The Hot Water contest simulates the daily hot water needs for a household by requiring teams to draw at least 15 gallons (56.8 L) of hot water in no more than 10 minutes. All available points are earned by delivering an average temperature of at least 110°F (43.3°C). An average temperature below 100°F (37.8°C) earns no points. For temperatures between 100°F (37.8°C) and 110°F (43.3°C), reduced points are earned. During the 9 day contest period, teams were required to complete 16 hot water draws where the maximum number of hot water draws for one day did not exceed three, but occasionally occurred consecutively.

2.8 Appliances

To further evaluate the competition prototype house's performance for a typical household, the competition includes contests and subcontests that evaluate typical residential appliances. Within the Appliances contest, teams earn points for operating the refrigerator, freezer, clothes washer, clothes dryer, and dishwasher successfully. The refrigerator and freezer are evaluated continuously for the duration of the event. Teams are required to successfully wash and dry 6 loads of laundry during the contest week to earn full points for the clothes washer and clothes dryer subcontests. Similarly, teams need to run the dishwasher multiple times during the contest period with water reaching a minimum temperature of 120°F (48.9°C) to earn full points.

2.9 Home Entertainment

Beyond the physical performance of appliances and the evaluation of the competition prototype house by juries, each house is expected to function for the house's target market. The Home Entertainment subcontests evaluate the house's ability to keep all

interior and exterior house lights on for specified periods, to vaporize water using a kitchen appliance, to host a dinner party, to operate a TV and computer for specified periods of time, and to host a movie night for competing teams. Each of these tasks is interdependent with other aspects of the competition. For example, the vaporization of water will place significant amounts of moisture into the air which affects team performance in the Comfort Zone contest. Similarly, the energy used to host a successful dinner party and movie night affects a team's performance in the Energy Balance contest.

2.10 Energy Balance

The overarching contest of the competition, performance in the Energy Balance contest is affected by performance in each of the other contests. In this contest, all available points are earned at the conclusion of the specified energy balance period for a net electrical energy balance of at least 0 kWh. A positive net electrical energy balance indicates net production; a negative net electrical energy balance indicates net consumption.

3. TEAM INNOVATIONS

Each of the 19 participating teams who presented a competition prototype on the National Mall in Washington D.C. in September of 2011 integrated countless innovations and integrated approaches that can be evaluated and considered to develop an understanding of the energy efficiency and integrated solar generation opportunities and trends available to the market today. Using commercially available components and cost-effective solutions, the student teams developed integrated approaches to ensure success. The following provides a brief overview of each team's approach and innovations.

3.1 New Zealand

Inspired by the traditional New Zealand holiday home, the New Zealand house (Image 1) integrates natural, low-maintenance materials and a drying cupboard that dries clothes by pumping solar-heated hot water through a heat exchanger. The design encourages flexible, effective and adaptive indoor-outdoor use.

Image 1: New Zealand Solar Decathlon House

3.2 Team Florida

The Flex House (Image 2), designed by Team Florida, is a sustainable one bedroom house that can be easily shipped and includes integrated shading, a liquid desiccant system, and renewable materials.

Image 2: Team Florida Solar Decathlon House

3.3 Tidewater Virginia

Tidewater Virginia's house (Image 3) demonstrates the integration of design that blends into a historical neighborhood with smart, innovative technologies and comprehensive space planning.

Image 3: Tidewater Virginia Solar Decathlon House

3.4 Team New Jersey

The ENJOY house (Image 4) is the first competition house to be constructed entirely of precast concrete. The team used cutting edge fabrication techniques to create a prefabricated concrete design that is functional and inviting.

Image 4: Team New Jersey Solar Decathlon House

3.5 Purdue

Purdue's INhome (Image 5), which placed 2nd in the competition, sought to demonstrate a design that combined technological innovation with functional, accepted, and cost-effective design. The home features a self-watering biowall with vertically arranged plants, an air-to-air heat pump, and a heat pump hot water heater. A straightforward design, the house performed well throughout the competition.

Image 5: Purdue Solar Decathlon House

3.6 Tennessee

Tennessee (Image 6) designed a house with an integrated shipping structure, a dynamic double façade system, and extensive home automation that maximizes potential energy savings.

Image 6: Tennessee Solar Decathlon House

3.7 Middlebury College

Self-Reliance (Image 7) demonstrates a traditional, familiar design that uses an extremely efficient envelope, windows, and design to minimize energy use while integrating cutting-edge technology.

Image 7: Middlebury College Solar Decathlon House

3.8 Parsons NS Stevens

The Empowerhouse (Image 8) is a certified Passive House that minimizes energy demand by optimizing the building envelope, using a highly efficient micro-mechanical system, and strategic daylighting.

Image 8: Parsons NS Stevens Solar Decathlon House

3.9 Appalachian State

Consisting of multiple easily transported modules, the Solar Homestead (Image 9) maximizes the functionality of outdoor space via a porch covered by bifacial solar panels and integrates technology such as a trombe wall seamlessly.

Image 9: Appalachian State Solar Decathlon House

3.10 Florida Int'l

Florida International's house (Image 10) responds to its environment, its inhabitants, and its use. The pavilion design links the interior with the exterior and the operable overhanging louvers serve multiple purposes including privacy, shading, and protection from hurricane force winds.

Image 10: Florida Int'l Solar Decathlon House

3.11 Canada

TRTL, Canada's entry to the competition, responds to the particular needs and culture of their target market. The house integrates rounded forms with sophisticated controls and native materials.

Image 11: Canada Solar Decathlon House

3.12 Team Belgium

Aiming for simplicity, the E-Cube (Image 12) is a house that is stripped of all nonessential components and finishes. The house is a modular, affordable, and flexible kit that can be assembled very efficiently.

Image 12: Team Belgium Solar Decathlon House

3.13 Team China

Team China's house (Image 13) combined six shipping containers into a house that is easy to transport, assemble and expand. It uses natural ventilation, vacuum insulation, and varied materials.

Image 13: Team China Solar Decathlon House

3.14 Maryland

The overall winner of the competition, the WaterShed house (Image 14) integrated energy efficient construction and unique flexible spaces with solutions to water shortages and reclamation. Incorporating a constructed wetland, green roof, and liquid desiccant waterfall, the home combines comfort with performance.

Image 14: Maryland Solar Decathlon House

3.15 Illinois

The Re_home (Image 15) is a rapid-response solution for a family affected by natural disaster. Combining efficient design with low-cost solutions, the house integrates unique ventilation and conditioning systems with efficient use of space.

Image 15: Illinois Solar Decathlon House

3.16 Team Massachusetts

The 4D Home (Image16) is a New England-inspired home that focused on reducing baseline energy consumption. It uses sustainable materials, hybrid solar thermal panels, and moveable functional walls.

Image 16: Team Massachusetts Solar Decathlon House

3.17 Sci-Arc/Caltech

The CHIP house (Image 17) demonstrates unique geometry that enables both a car park and a terraced interior. The home consistently demonstrates alternative approaches to typical residential design.

Image17: Sci-ARC/Caltech Solar Decathlon House

3.18 Team New York

The Solar Roofpod (Image 18) responds to the fact that urban rooftops are largely underutilized and is intended to be located on the roof of existing mid-rise buildings.

Image 18: Team New York Solar Decathlon House

3.19 Ohio State

The enCORE house (Image 19) creates a balance between function, environmental sensibilities, economics, and aesthetics through a holistic design approach. Utilizing passive design features and active technology and controls, the house responds to changing environmental and social needs.

Image 19: Ohio State Solar Decathlon House

4. TRENDS

Reviewing the designs presented at Solar Decathlon 2011 enables one to develop an understanding of current architectural, engineering, market, and environmental trends in the energy-efficient and integrated distributed generation fields.

Responding to the Affordability Contest, the teams demonstrated many cost-effective solutions. While the houses do not represent "cheap" houses, the strategies employed for the competition were evaluated from a cost-benefit perspective and higher cost solutions were integrated only if the benefits outweighed any additional costs.

With increasing efficiency of photovoltaic panels and significant availability of heat pump hot water systems, reliance on solar thermal has waned.

The importance of holistic, integrated design towards success continues to be recognized. By understanding the impact that the HVAC systems have on architectural design, for example, teams were able to develop designs that integrated various elements to maximize performance and savings.

Other trends identified for Solar Decathlon 2011 include advanced window systems and coatings, desiccant cooling at a residential scale, attention to water filtering and use, and the use of bio-based and high recycled-content materials. These elements, not specifically required by the competition criteria, were included by the students because of perceived importance to the overall design success.

5. CONCLUSIONS

The Solar Decathlon 2011 competition continued to demonstrate cutting-edge design for the residential market by effectively challenging thousands of university students to bring design to life and demonstrate a fully-functional, energy-efficient, solar-powered house to the public.

This paper summarizes the competition approach, the extent of innovation developed and presented by the Solar Decathlon and the current trends in energy-efficient, solar-integrated residential design. Innovation is expected to continue at a rapid pace, with many new technologies and solutions to be presented as part of Solar Decathlon 2013.

6. ACKNOWLEDGEMENT

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Additional information: www.solardecathlon.gov