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U.S. Department of Energy Solar Decathlon*

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ABSTRACT

The U.S. Department of Energy (DOE) Solar Decathlon® Design Challenge is a collegiate competition that challenges student teams to design high-performance buildings that push the boundaries of the industry. In the 2020 Design Challenge, DOE piloted the Design Partners Program, a low-risk opportunity for builders and building owners to harness student innovation and explore zero energy design for current or upcoming projects. Design Partners provide a student team of architects and engineers with project requirements. By the end of the Design Challenge, Design Partners receive a zero-energy design alternative and cost estimate for their project. The collaboration allows Design Partners to incorporate innovative concepts such as grid-interactivity, resilience, and low embodied carbon in a low-risk environment. It also provides the future generation of engineers and architects with invaluable experience designing a building for a client under real-world circumstances. This article summarizes the current policy, technology, health, and economic trends that make zero energy buildings desirable and feasible, and presents the value of the Solar Decathlon to industry. We highlight innovative solutions 2020 Design Partner pilot projects are bringing to the building industry.

INTRODUCTION

In 2018, the buildings sector—including both residential and commercial structures—accounted for 20% of global delivered energy consumption [1]. Offering significant opportunities for energy savings, the

*Based on a paper presented at the 2020 Virtual AEE World Energy Conference.

building sector is slowly evolving to address energy efficiency through high-performance design strategies. High-performance buildings extend beyond energy efficiency and energy security to include comprehensive building science, optimized mechanical systems, healthy indoor air quality, enhanced occupant experience, and resilience. With current socio-economic and climate issues, there is an increasing demand for high-performance buildings to prioritize affordability, comfort, health, durability, and safety.

Some educational programs around the globe lack consistent training curricula that provide the architecture, engineering, and construction management skills needed to effectively integrate high-performance building measures. Emerging crises related to affordability, human health, disaster risks, and water shortages are increasing the value of these skills. To address the shortage of necessary design skills and assist academic institutions to effectively integrate them into their degree programs, DOE inaugurated a high-performance building design competition in 2014 known as the Race to Zero Student Design Competition. As of 2019, this competition is now known as the U.S. Department of Energy Solar Decathlon® Design Challenge and focuses on two critical goals: to integrate high performance with design in degree programs, and to inspire students to enter sustainable building careers.

Competition results during the past 6 years demonstrate substantial success toward these goals, including:

- More than 250% growth in the number of teams participating, from 28 teams in 2014 [2] to 103 teams in 2021 Design Challenge [3]
- Feedback from Faculty Advisors suggesting more than 500% growth in the number of participating programs that have integrated the Design Challenge into their curricula [4]
- Deep engagement with participating students reinforcing how life-changing the competition experience is, solidifying their commitment to sustainable building careers [4].

Through industry engagement and the Design Partners Program, the Solar Decathlon Design Challenge is bringing real-world solutions to current real-world issues in the building industry. Simultaneously, the competition trains the next generation of the building workforce with the skills and passion to create future-ready buildings.

COMPETITION BACKGROUND

The Solar Decathlon Design Challenge is a collegiate competition comprising 10 contests that challenges student teams to design highly efficient and innovative buildings powered by renewable energy [4].

There are 7 total divisions, including residential and commercial building types. The Residential Divisions include Suburban Single-Family Housing, Urban Single-Family Housing, and Attached Housing. The Commercial Divisions include Elementary School, Mixed-Use Multifamily Building, Office Building, and Retail Building.

The fundamental focus of the Solar Decathlon Design Challenge is building science. Each participating student completes a building science training curriculum provided by DOE to develop a strong foundational understanding of building science and zero energy building design principles. Designs are evaluated on the understanding of environmental challenges and the effective application of building science strategies to address them. In tandem with building science considerations, submitted designs are evaluated in 10 contests: architecture, engineering, market analysis, durability and resilience, embodied environmental impact, integrated performance, occupant experience, comfort and environmental quality, energy performance, and presentation. The criteria entailed within each contest challenge student teams to address all aspects of high-performance building design. Successful designs integrate each design consideration into a cohesive design. Each contest is outlined briefly next and references the Solar Decathlon 2021 Design Challenge Rules [4].

Architecture

Elegant, yet functional architecture positions a building for successful market acceptance. The Architecture contest evaluates student submissions in their ability to employ architecture to marry aesthetics with effective building science, energy efficiency, occupant experience, comfort, natural ventilation, energy production, and resilience.

Engineering

Efficient building design is achieved through integration of thoughtful engineering. The Engineering contest considers the informed selection and design of all building envelope components and building

systems, including lighting, plumbing, heating, ventilation, and cooling. Designs are evaluated with a holistic approach to building system design that optimizes resource efficiency with system performance to successfully address climate, code, and occupant experience considerations.

Market Analysis

Providing effective zero energy alternatives that are financially feasible is essential to successful adoption. The Market Analysis contest evaluates an understanding of the target market with considerations toward affordability, likelihood of adoption by intended occupants, and cost-effectiveness of the design. This includes detailed financial analysis of construction materials, with attention to life-cycle costs. Successful designs also exhibit flexibility and adaptability to changing needs of occupants to ensure the building meets the demands of the target market.

Durability and Resilience

To address increasing demand for resiliency and energy security in the building sector, the Durability and Resilience contest challenges designs to incorporate materials and strategies that enhance the longevity and resiliency of the building. In addition to strategic material selection and building envelope design, the contest evaluates designs on the ability for the building to react to natural or manmade disruptions.

Embodied Environmental Impact

Many building materials harbor hidden environmental impacts along their production line or upon end-of-life. The Embodied Environmental Impact contest challenges teams to look beyond the final product and examine environmental impact from material extraction, manufacturing, transportation, construction, and lifetime. Evaluation criteria consider the circular economy and the full life cycle of a building, from cradle to grave. This includes considerations of reclamation, refurbishment, repair, reuse, and recycling of materials throughout the building's life cycle.

Integrated Performance

To emphasize the importance of an integrated design approach,

the Integrated Performance contest evaluates how effectively the whole-building performance is optimized through passive and active strategies that cross multiple building disciplines. A successful integrated design employs architectural and engineering elements that complement each other for optimal performance. For example, a building that is properly oriented will more effectively capture passive heating, cooling, ventilation, and lighting. Without one design element (e.g., building orientation), additional energy-consuming systems are required to provide the dependent design element for interior conditions (e.g., mechanical HVAC).

Occupant Experience

Human-centric design is essential to successful adoption and utilization of a high-performance buildings. The Occupant Experience contest places the human experience at the center of the design strategy, evaluating how the building optimizes occupants' quality of life while meeting the energy performance goals. This includes strategies for efficiency, comfort, health, and safety that address operational expectations of consumers and thoughtful selection of technologies and appliances that are integrated into the overall design.

Comfort and Environmental Quality

Well-designed buildings provide both a comfortable and healthy indoor environment. The Comfort and Environmental Quality contest evaluates the building's capability to deliver intended comfort and indoor environmental quality. To provide a healthy indoor environment, the design must include a comprehensive approach to indoor air quality that incorporates ventilation, filtration, dilution, and material selection strategies. For occupants to be comfortable, the building must be able to control temperature and relative humidity levels, as well as reduce exterior noise infiltration.

Energy Performance

Effective whole-building energy analysis and decision-making is the foundation for energy performance. The Energy Performance contest evaluates reduction of whole-building energy consumption, ability to generate clean energy that is needed onsite, and interaction with local grid operations. As a central component of the competition criteria,

energy performance considerations challenge student teams to develop innovative strategies for incorporating energy efficiency measures into their designs.

Presentation

Innovative design is insufficient on its own; presentation quality can dramatically affect consumer perception and the likelihood of innovation being adopted. The Presentation contest evaluates the student teams on their ability to effectively communicate their design strategies, both verbally and visually. This contest challenges the students develop essential communication skills to convey value to a diverse audience and inspire future professionals, incumbent industry leaders, and the public to pursue energy efficiency and renewable energy opportunities.

INDUSTRY IMPACT

A significant component of the Solar Decathlon Design Challenge is industry engagement. Student teams partner with industry experts to inform specific aspects of design and gain real-world knowledge of the building design process. This provides students with the unique opportunity to learn current strategies for efficient, integrated system design and addresses building science considerations from leaders in the building industry. Industry engagement serves as a positive feedback loop, with the fresh perspective of students inspiring industry experts and industry leaders inspiring young professionals entering the industry.

The impact of the Solar Decathlon Design Challenge is not simply an educational experience for students entering the workforce; the competition provides a low-risk testbed for innovative technologies and for organizations to explore zero energy alternatives for current or future projects.

DESIGN PARTNERS PROGRAM

To lower the bar of entry and increase adoption of high-performance buildings, the Solar Decathlon Design Partners Program provides a unique, low-risk opportunity for organizations considering a

zero-energy ready design for a planned or existing building project. The program partners builders and building owners with participating student teams in a client relationship, with the student teams working with the Design Partner to design a zero-energy design alternative that meets project requirements.

The Design Partner Program allows builders and building owners to explore zero energy design alternatives for current or future projects and visualize potential cost and energy savings, removing a large barrier to zero energy adoption—fear of the unknown. Furthermore, it provides an opportunity to incorporate innovative concepts such as grid-interactivity, resilience, and low embodied carbon in a low-risk environment.

All teams participating in the Solar Decathlon Design Challenge are strongly encouraged to work with a Design Partner as a client. Building owners and builders submit project opportunities to the Solar Decathlon, which are then made available to student teams through public posting on the Solar Decathlon website. Student teams engage Design Partners through posted project opportunities or proactive engagement of an interested building owner in their immediate communities. Once a partnership is established, participating Design Partners provide student teams with project requirements and design constraints. Design Partners meet with student teams for no more than 30 hours over the course of the competition (January through April) to attend design charrettes and review design decisions throughout the process. The final competition deliverable is a complete design package that is provided to the Design Partner, with design documents, energy performance metrics, and financial and life cycle analysis.

Design Partners is a win-win for both parties involved: student teams gain real-world experience working with a client and the Design Partner receives a real-world zero energy alternative to a project in their portfolio. During the pilot of this program in the 2020 Design Challenge, five successful Design Partnerships were formed. Three of these Design Partnerships are highlighted next as case studies of the success of Solar Decathlon Design Challenge in bringing high-performance building solutions to the building sector.

Figure 1. Interior Rendering from Purdue University of the Zero Energy James Cole Elementary School Designed for Tippecanoe School Corporation. [Image Credit: Purdue University Solar Decathlon team]

James Cole Elementary School, Stockwell, Indiana

Purdue University's student team partnered with Tippecanoe School Corporation to design a zero-energy elementary school as a response to increasing energy expenditures. The existing school structure was constructed in 1988 with "energy efficiency at its core, integrating an innovative earth berm design, daylighting, and geothermal heating/cooling" [5]. The Purdue University team proposed a retrofit strategy to improve existing energy efficiency strategies and transform the school to a zero-energy facility (Figure 1). The design recommissioned existing mechanical systems and incorporates smart lighting controls to reduce energy use. Beyond energy efficiency, the Purdue University team incorporated their novel "Biowall" technology that utilizes plant material to filter incoming air, providing a case study for using the Solar Decathlon Design Challenge as a successful testing ground for novel technology solutions.

The result of the partnership was a zero-energy school that could be used as a model for other schools. The Purdue University team was rewarded for their successful design with second place in the Elementary School Division for the 2020 Design Challenge.

The SOlar URban CEnter (SOURCE),
City of Alexandria, Virginia

The Washington-Alexandria Architecture Center (WAAC) at Virginia Tech partnered with the City of Alexandria, Virginia to restore an existing historic structure into an urban office center. In support of the City of Alexandria's carbon and greenhouse emission reduction goals, the WAAC Solar Decathlon team designed a zero-energy retrofit for an iconic building downtown. The budget of the project was $40 million, and construction is planned for 2023–2025.

Through this partnership, the City of Alexandria was presented with a model for renovating historic structures that incorporates resiliency through a microgrid design and reduces environmental impact through rainwater collection, shown in Figure 2. This successful partnership illustrates the ability for Solar Decathlon student teams to bring direct positive impact to their immediate communities through innovative high-performance building design grounded in real-world solutions.

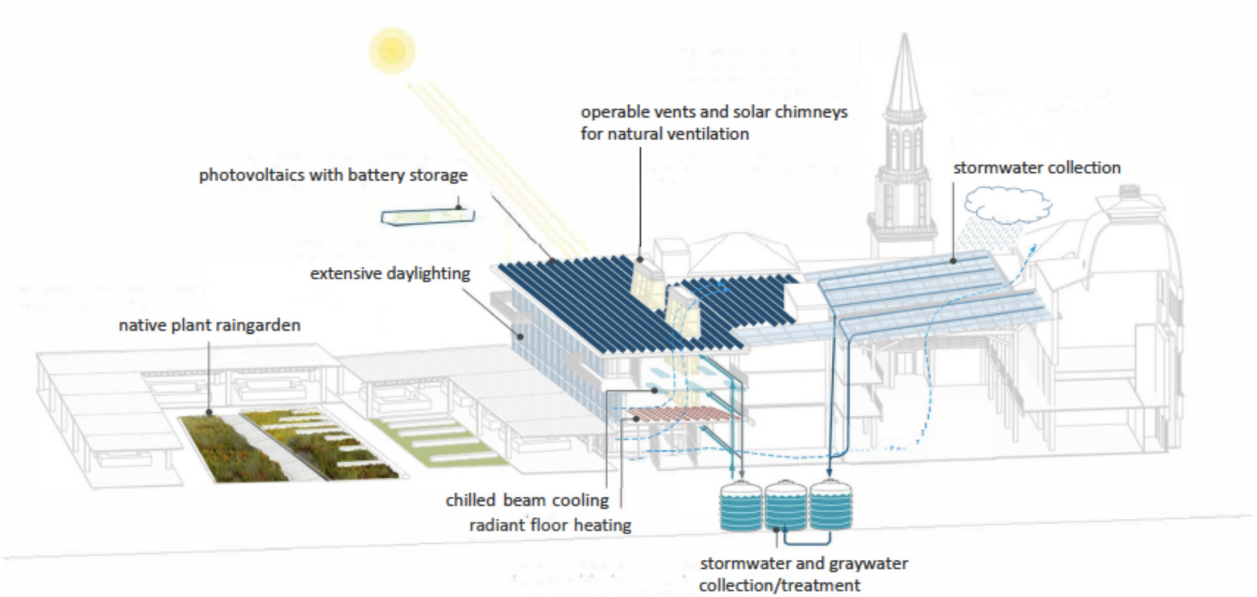

Figure 2. Schematic Diagram of the SOURCE, the Solar Urban Center, Washington Alexandria Architecture Center's Restoration of a Historic Building in Downtown Alexandria. [Image Credit: WAAC Solar Decathlon team]

Henry Smothers Elementary School Modernization

The University of District of Columbia (UDC) Solar Decathlon team partnered with District of Columbia Public Schools to modernize the local Henry Smothers Elementary School. The design proposes an addition to the existing structure, originally constructed in 1923, to realign the school with the District of Columbia Public School educational specifications. UDC's approach, a "Handshake with History," embraces and preserves the existing historical structure while expanding classroom spaces and incorporating aspects of modern education, including discovery common spaces and outdoor learning spaces.

The design effectively transforms the historic school into a microgrid that serves as a resilient community relief center for unforeseen events like power outages. The incorporation of strategic energy reduction measures, including optimized daylighting using circadian rhythm lighting design and reduction of plug loads, led to a modeled energy use intensity of 10 kBtu/ft^2-yr (Figure 3). With an anticipated cost of \$210/ft^2, the design fits the budget constraints initially proposed of \$38 million. Construction is anticipated in 2021.

CONCLUSION

The U.S. Department of Energy Solar Decathlon is a collegiate building design competition that provides the future generation of building and clean energy professionals with the real-world experience and multidisciplinary skills needed to accelerate adoption of high-performance buildings. The Design Challenge contests drive student teams to consider all aspects of building design, from architecture to market analysis to occupant experience. Through these evaluation criteria, the Solar Decathlon Design Challenge develops a solid groundwork of fundamental, physics-based building science and integrated high-performance, energy-efficient design principles. The competition is also a platform for young professionals to engage with industry experts and develop career connections. Beyond an educational experience, the Solar Decathlon Design Challenge harnesses student creativity to bring innovative solutions directly to the real

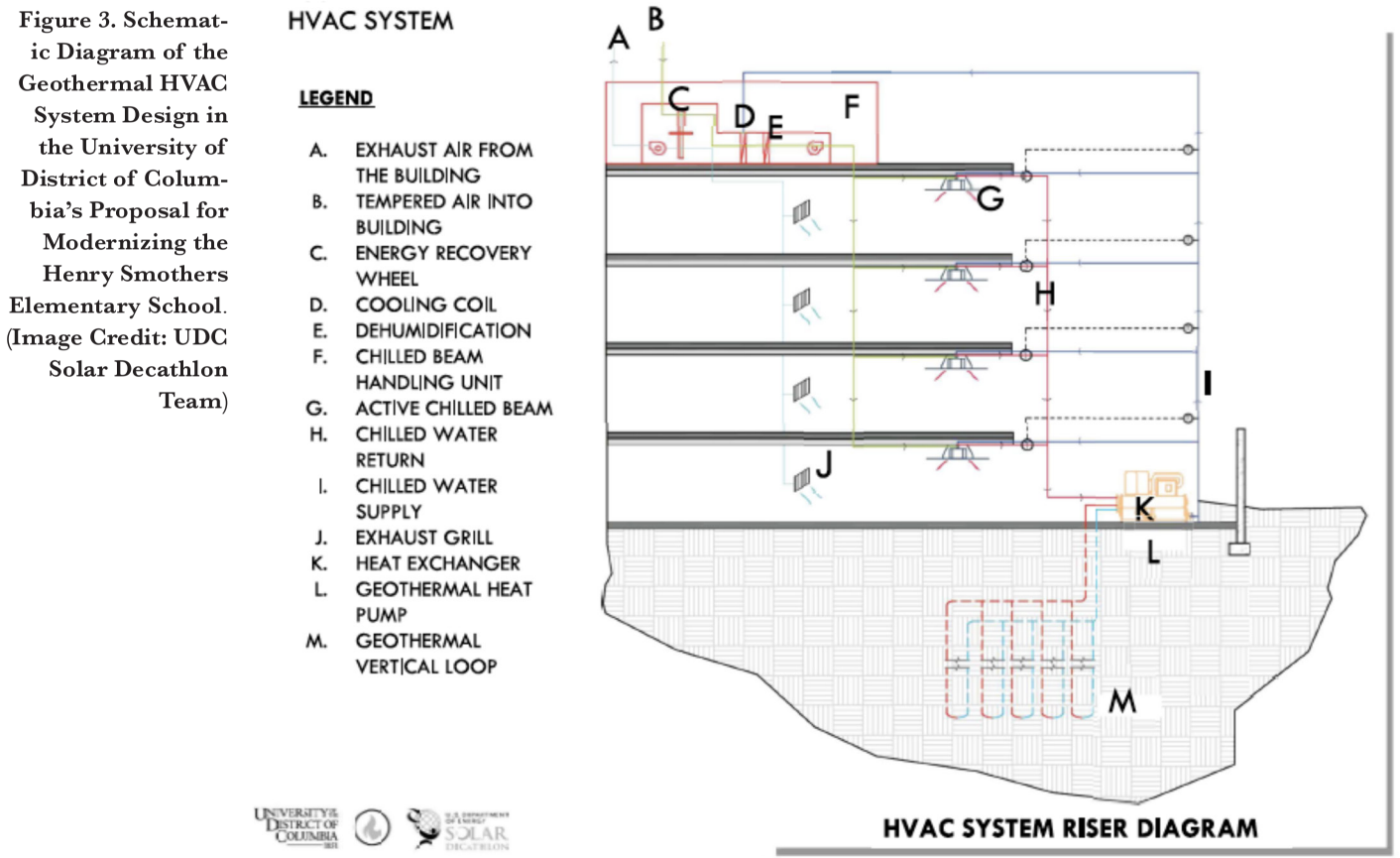

Figure 3. Schematic Diagram of the Geothermal HVAC System Design in the University of District of Columbia's Proposal for Modernizing the Henry Smothers Elementary School. (Image Credit: UDC Solar Decathlon Team)

world, directly impacting the current building industry.

Specifically, the Design Partners Program provides organizations with the opportunity to partner with a student team and explore a zero-energy alternative to a current or future project in a low-risk environment. In doing so, the Solar Decathlon Design Challenge works to ensure an energy secure future through educating the next generation of building professionals and providing builders and building owners with a low-risk opportunity to incorporate innovative high-performance building technologies and design practices into current, real-world projects.

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