The Future of Building Science Education with the U.S. Department of Energy Solar Decathlon

Preprint

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Background

Residential and commercial buildings accounted for 39% of energy consumption in the United States in 2021 [1]. This places buildings ahead of industry and transportation as the largest energy-consuming sector in the country. Energy codes and standards have been developed and widely adopted to improve building energy efficiency and reduce the environmental impacts associated with energy consumption. Although new and renovated buildings subject to prevailing energy codes are more energy efficient than their predecessors, energy consumption in the buildings sector has not decreased in recent decades, with overall building energy consumption remaining relatively flat since 2000 [1]. This is primarily because new buildings are being built (i.e., adding new energy loads) faster than the sector is saving energy (i.e., improving energy efficiency). In order to reverse this trend and decrease total building energy consumption, all new buildings must extremely energy efficient—ideally meeting the requirements for zero energy [2].

As new buildings are constructed and existing buildings are renovated, the industry workforce needs to be equipped with the proper skills to take on this challenge. This requires students in architecture, engineering, construction, and other disciplines to be educated on the fundamentals of building science and to understand how to apply those principles to building design. This educational approach is facilitated in part by collegiate competitions, including the U.S. Department of Energy (DOE) Solar Decathlon®.

Founded in 2002, the original Solar Decathlon aimed to inform the public about energy efficiency and renewable energy in buildings, and to create market demand for these technologies. The challenge of the first Solar Decathlon was to show the public that it was possible to build an energy-efficient home that could be powered by rooftop solar panels. Fourteen collegiate teams met this challenge, with innovative houses displayed on the National Mall in Washington, D.C. for more than 100,000 visitors [3].

In the years since that inaugural event, the market demand for zero energy has increased significantly. As of 2021, 60% of Fortune 500 companies had set at least one sustainability goal [4], and more than 300 educational institutions were rated in the Association for the Advancement of Sustainability in Higher Education's (AASHE) Sustainability Tracking, Assessment and Rating

System (STARS) [5]. The public is demanding action on sustainability, and students are challenging their educational institutions to provide programs that will prepare them to solve the energy challenges they will face in their careers.

In alignment with this shift, the Solar Decathlon has evolved to push the boundaries of innovative technologies and construction practices, to demonstrate the market readiness and affordability of zero energy buildings, and to execute proven design and construction approaches. Colleges and universities have begun to leverage the Solar Decathlon to expand their design-build programs and enable a shift to hands-on learning.

Overview

Today, the Solar Decathlon prepares the next generation of building professionals to design and build high-performance, low-carbon buildings powered by renewable energy. Through this collegiate competition, teams engage in the challenge of the built environment to successfully develop unique and innovative solutions. Teams compete in one of two Challenges: the Design Challenge, a one- to two-semester, design-only competition, or the Build Challenge, a two-year design-build competition [6]. These Challenges represent the application of skills learned in the classroom through a hands-on project that enables deeper educational impact.

Celebrating its 20th anniversary in 2022, the Solar Decathlon has challenged more than 25,000 students to create efficient, affordable buildings powered by renewables, while promoting student innovation, STEM education, and workforce development opportunities in the buildings industry.

As with an Olympic decathlon, students compete in 10 categories, or Contests. Teams must excel in all 10 Contests to win the competition. The current program Contests are:

- Architecture
- Engineering
- Market Analysis
- Durability and Resilience
- Embodied Environmental Impact
- Integrated Performance
- Occupant Experience
- Comfort and Environmental Quality
- Energy Performance, and
- Presentation [7].

The Solar Decathlon has been called "the most prestigious international university competition on sustainable habitat… Universities from all over the world participate in this competition in collaboration with institutions and companies with the aim of designing, building on a real scale and monitoring a prototype of a housing cell with the highest level of self-sufficiency and use of renewable energies"[8].

One of the DOE's most successful outreach efforts, the Solar Decathlon aims to:

- Improve building science curriculum at universities and institutions
- Provide participating students with unique training that prepares them for the clean energy workforce, and
- Educate students and the public about the latest technologies and materials in zero energy design and technologies, smart home solutions, and high-performance buildings.

Impact

Over 20 years of competition, more than 790 collegiate teams in 40 countries have participated in the design of zero energy buildings for the Solar Decathlon. These teams have included 25,000 collegiate participants who go on to advance the buildings industry through thought leadership in new technologies and methods. One faculty member said, "I keep coming back to the Solar Decathlon because it's the most powerful learning experience that I've seen in over 20 years of teaching undergraduate and graduate students."

The Solar Decathlon has also expanded to include international competitions in Europe, China, Latin America, Africa, India, and the Middle East, establishing "a worldwide reputation as a successful educational program and workforce development opportunity for tens of thousands of students" [6]. Worldwide, there are now more than 40,000 Solar Decathlon alumni from both the U.S. and international versions.

The competition is also improving representation in the workforce, helping grow the future female STEM workforce in particular. In 2021, 52% of Build Challenge students and 49% of Design Challenge students noted "female" as the gender with which they most identify. In 2019, only 27% of STEM workers in the United States were women [9]. Through a focus on recruitment of talented individuals from a variety of demographics and backgrounds during a formative time in career development, the Solar Decathlon aims to shift the building industry to be more representative of the country as a whole.

From a technical perspective, the Solar Decathlon focuses on broadly sharing building science knowledge. Some of the most significant building science learning experiences students and faculty have mentioned include:

- thinking about building systems as a whole, instead of individual systems
- different design strategies that can be used to create a net zero building
- education on building science and construction, and
- real world operations and how to apply theoretical knowledge.

Participating in a team-oriented project also allows students to build their soft skills. Our students and faculty say they have grown in the follow ways, among others, through the Solar Decathlon:

- selling a narrative
- learning how to enable architecture and engineering students to work together
- increasing their ability for proactive planning and research
- growing their own agency and confidence, and
- finding external partners and understanding how homes are actually built.

In response to how the Solar Decathlon helps students learn more than typical classwork alone, one faculty member said, "Yes, especially in the hard-to-measure area of soft skills."

Build Challenge

In the Solar Decathlon Build Challenge, teams compete over a period of two academic years to design and fully build or renovate a residential project in their local community. The Solar Decathlon initially only included the Build Challenge, but has since expanded to include the Design Challenge, outlined in the following section.

The biennial Build Challenge is composed of two phases, the Design Phase and the Build Phase. During the Design Phase, teams begin with a conceptual design and work to develop detailed construction plans, which are presented to a jury of industry experts for Approval to Proceed to the Build Phase of the competition. Teams that receive this approval are also awarded prize funding from DOE in recognition of the work completed up to that point and to support the construction activities to follow. During the Build Phase, teams complete construction/renovation, operate the house for measured evaluation of its performance, and exhibit the finished and fully functional house to their local community. Final points are awarded after jury presentations at the Solar Decathlon Competition Event where the winner is determined.

Six of the 10 Build Challenge Contests are evaluated by expert juries, while 4 are evaluated by measuring the performance of the completed house. The Contests are scored individually, and the team that receives the most overall points is crowned as the winner. Winning teams are those that best blend architecture and engineering with sound building science, indoor environmental quality and comfort, and energy efficiency that enables zero energy performance.

While there is only one winning team at the end of the competition, there is a lasting and tangible effect on each of the communities associated with Build Challenge houses. Permanent construction of zero energy buildings allows for engagement with local industry, community members, municipal governments, and others. Through local exhibitions, teams are empowered to communicate the importance of their innovations and solutions to a broad public audience [10]. And the students who participate in the Build Challenge take valuable skills learned through these design-build projects and enter the workforce ready to take on the challenges facing the buildings industry.

While the Build Challenge requires a significant commitment of time and resources, its influence on students, faculty, and the collegiate programs they represent is widely recognized. According to a Build Challenge faculty member, the experience is transformative:

> "For faculty, this is very likely to be the most profound experience of your teaching career … It completely changed the way I see what my students and I are capable of together, and it enlivened my sense for how much room for creativity and exploration there is in the built environment. It will also help you gain experience in the breadth of our charge, which is represented well by the 10 Contests."

To illustrate this impact another way, over the course of 10 editions of the Build Challenge, at least 20 institutions have returned to participate in subsequent years. These colleges and universities have witnessed the educational effects of the Solar Decathlon firsthand, and many are using the competition to bolster their university curriculums.

Design Challenge

To make the educational successes of the Solar Decathlon more accessible to a wider set of students and educational institutions and programs, the Solar Decathlon Design Challenge was introduced in 2018. As an annual design-only competition that maintains the core structure of the Solar Decathlon, student teams work for one to two academic semesters on either a residential or commercial building design project that meets zero energy requirements. In the 2022 edition, teams designed new construction or retrofits in one of six Divisions: single-family housing, attached housing, multifamily buildings, education buildings, or office buildings. Through completion of energy modeling, life-cycle analysis, interior and exterior architectural design, structural engineering, and design of mechanical and plumbing systems, teams learn about all building systems required to complete zero energy design. Students submit preliminary documentation and present initial designs to a jury of experts to compete for a finalist spot.

The annual program concludes at the Solar Decathlon Competition Event, where "student teams present their designs to a panel of industry experts, discuss design strategies with peers, learn from thought leaders, and connect with industry partners through unique networking opportunities" [11]. Winners are selected in each Division; the first-place team of each Division then gives a short presentation to a grand jury, and one team from the Commercial Divisions and one team from the Residential Divisions are awarded the titles of Grand Winner.

To demonstrate how the Design Challenge is "equipping the next generation building workforce with the skills and passion to create future-ready buildings," consider the following details about the 57 finalist teams that competed in 2021:

- 97% of team designs were all-electric.
- 96% of projects had on-site renewable energy systems.
- 48% of projects supported disadvantaged communities.

- Nine projects mentioned using prefabricated parts or off-site construction.
- Teams cultivated 95 industry partnerships to bring real-life experience to their design.

Universities often return to the competition after their first experience with the Design Challenge, with 58% of institutions returning from the 2020 to 2021 competition cycle. Between 2019 and 2022, more than 40 institutions participated at least twice in the Design Challenge. Not only does the Design Challenge prepare students to enter the workforce, but it also prepares collegiate teams to move on to the next level of project development and commitment in the Solar Decathlon—the Build Challenge. As an example, 12 institutions that participated in the 2021 Design Challenge are currently participating in the 2023 Build Challenge.

Building Science Education

To complement the practical project-based learning of the Build Challenge and Design Challenge, students participating in the Solar Decathlon are required to learn fundamental building science principles, either through their collegiate coursework or through educational resources provided by the competition organizers. The goal of this requirement is to ensure that all students begin the competition with a strong foundational knowledge of the scientific principles behind how and why buildings use energy. Many years of observing student presentations and their answers to jurors' questions during Solar Decathlon events led the competition organizers to identify the need for an updated, purpose-made Building Science Education course, made available in 2021.

The Solar Decathlon Building Science Education series is a peer-reviewed, academically robust educational resource that consists of eight modules and optional content that covers building science fundamentals; it is designed for students and working professionals from both technical and non-technical backgrounds [12]. In 2021, 73% of faculty who participated in the Solar Decathlon said their collegiate programs do not require any training on high-performance buildings, sustainable design, or construction of buildings; the Building Science Education series helps fill that gap. Nearly all (95%) faculty members said this competition helped their students learn more than coursework alone. Students and faculty have said, "I loved the online course…There is so much information!" and "The Building Science course is indispensable."

Dr. Paul Torcellini, the lead author of the Building Science Education series at the National Renewable Energy Laboratory (NREL), delivers instruction by carefully layering information to build from basic principles of physics to complex building science principles and applications. This allows learners to enter the course with no prior education in this field and finish with the ability to speak confidently about how and why buildings use energy. Additionally, the course masterfully weaves together real-life examples from NREL's plug load reduction strategy [13], interviews with industry leaders [14], and subject matter experts from other national laboratories, such as Pacific Northwest National Laboratory [15]. Comprehension quizzes after the episodes cement the knowledge gained from the short 5- to 15-minute videos. The bite-sized chunks allow learners to choose topics they might need to learn from scratch, such as Fourier's Law [16]. The

material can also serve as a refresher on topics such as the difference between source and site energy [17]. The 8 modules, which include more than 10 hours of content, include the following topics and are updated yearly to maintain relevance and technical accuracy:

- Module 1: Buildings and Energy
- Module 2: Zero Energy Buildings
- Module 3: Building Envelopes
- Module 4: Heating, Ventilation, and Air Conditioning
- Module 5: Lighting
- Module 6: Plug Loads
- Module 8: Renewable Energy and Zero Energy Buildings.

The popularity and effectiveness of the Solar Decathlon Building Science Education course was illustrated by student feedback gathered after the 2021 competition. In a post-course feedback form, 87% of students rated their satisfaction with the course 8 or higher on a 1–10 scale. A review of this feedback categorized written commentary from students to assess their satisfaction; this showed that students had a net positive response to the course format, the depth of material presented, the course content, and the level of engagement. Continued analysis of student and faculty feedback on the course will provide the Solar Decathlon organizers with critical information that can be used to improve the effectiveness of the course.

The training videos are freely available to all Solar Decathlon Build Challenge and Design Challenge participants, with quizzes to ensure comprehension. To increase the accessibility of this content to students, professionals, and other interested individuals outside of the Solar Decathlon competition, the video episodes are also available on the Solar Decathlon YouTube channel, where they have been viewed more than 8,500 times and have generated more than 99,000 impressions [18]. This ensures that any learner, at any age, has the opportunity to master the content and become a successful contributor to the building science workforce.

Conclusion

Over the past 20 years, the Solar Decathlon has successfully educated the public and driven market demand for high-performance, energy-efficient buildings; with that success, the competition has shifted to primarily focus on developing the next generation of building professionals through superior educational opportunities. The platform has expanded to make high-performance, low-carbon design and construction more accessible to more people. International Solar Decathlon events have increased the Solar Decathlon experience for tens of thousands of students around the world. The addition of the Design Challenge to the U.S. Solar Decathlon platform reduces the time and resource commitment for collegiate institutions to bring building science and zero energy design education to students. The “Local Build” format of the Solar Decathlon Build Challenge enables a transition to community-focused design solutions and engagement with local stakeholders through permanent construction and renovation projects in each team’s local region.

The future looks bright as the competition begins its third decade and continues to serve as a catalyst for zero energy design training and practice in theory and in real life. One faculty member summed up the program by saying "The Solar Decathlon Competition is the best way for our students to challenge themselves and compete against the best sustainably minded students in the world…This event is a catalyst for change in our culture as well as an experience that generates employment opportunities for our students."

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