Developing the Next Generation of Net Zero Professionals through the Race to Zero

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ABSTRACT

The U.S. Department of Energy (DOE) Race to Zero Student Design Competition (Race to Zero) inspires collegiate students to become the next generation of building science professionals through an annual zero energy ready building design challenge. As the industry looks to close the gap to achieve more net zero energy construction, Race to Zero teams are tasked with exploring how to apply net zero principles across climate regions nationally and internationally. The Race to Zero is moving the building industry towards net zero energy by teaching professionals entering the workforce about strategies to reach net zero and helping them understand the economics. For the past four annual competition events, teams developed comprehensive, integrated residential designs with industry partners that were both market-ready and innovative. To develop competitive designs, teams employed various innovative technologies and strategies, including building modeling with various software packages, designing for unique siting constraints, and integration into the community and greenscapes. Through an interdisciplinary, collaborative design approach, Race to Zero teams gained an understanding of the concepts needed to achieve zero energy buildings. This paper provides case studies of winning concepts, demonstrating the solutions and tools used to reach zero energy ready homes. The paper also reviews trends across the net zero designs.

Background of Race to Zero

DOE Race to Zero inspires college students to become the next generation of building science professionals through an annual zero energy ready building design challenge. The Race to Zero is formulated to advance building science curriculum in universities through creative student collaboration. The competition incentivizes designs that carefully consider building science and innovation. During the course of one to two semesters, teams of students design and develop complete construction plans for homes such that the total amount of energy used by the building on an annual basis is roughly equal to the amount of on-site or off-site renewable energy generation.

During the past four years, the contest categories have evolved to respond to the needs of industry. As shown in Figure 1, the 2014 competition started with two contest categories, and three were included in 2015. The 2016 and 2017 competitions included four categories.

2014	2015	2016	2017
• Single-Family Detached Residential House Design • Single-Family Attached Residential House Design	• Single-Family Detached • Single-Family Attached • Multifamily Buildings	• Suburban Single-Family • Urban Single-Family • Attached Housing • Small Multifamily	• Suburban Single-Family • Urban Single-Family • Attached Housing • Small Multifamily

Figure 1: Expanding contests in the Race to Zero Student Design Competition[1]

[1] (Home Innovations Research Labs 2013), (DOE 2015), (DOE 2016), (DOE 2017)

Table 1 defines the contest categories of the 2016 and 2017 competitions.

Table 1: Race to Zero Contest Category Definitions

Contest	Building Size (ft^2)	Lot Size Maximum (ft^2)
Suburban Single-Family	1,000–3,000	4,000
Urban Single-Family	600–2,500	5,000
Attached Housing (two to six unites)	500–2,500	3,000 ft^2 per dwelling unit
Small Multifamily (three or fewer stories above grade)	350–2,000	No minimum or maximum

According to internal records during the first four competitions, the program successfully engaged approximately 1,400 students and professors from 131 teams across the United States, Canada, and other international locations.

Race to Zero is based on the DOE Zero Energy Ready Home program, which builds on the comprehensive building science requirements of ENERGY STAR® for Homes, Version 3, along with proven DOE Building America innovations and best practices. Additionally, the program employs the U.S. Environmental Protection Agency (EPA) Indoor airPLUS and the International Energy Conservation Code (PNNL 2015) insulation values. DOE Zero Energy Ready Homes are verified by a qualified third-party and are at least 40%–50% more energy efficient than a typical new home (DOE 2018). The program uses the Home Energy Rating System (HERS) Index score developed by the Residential Energy Services Network (RESNET) to estimate the energy use of the home (DOE 2018).

Teams are encouraged to be multidisciplinary, and some teams collaborate with another collegiate institution. Additionally, teams are required to develop industry partnerships to provide a market-ready perspective for proposed design solutions and to help select and integrate building systems. In the competition, the term *market-ready* is understood to mean a building design that can be constructed in today's market by typical trade contractors and at reasonable cost of ownership in the neighborhood proposed for its location.

To prepare for the competition, students are required to take an on-demand building science training course that covers topics such as building enclosure fundamentals, moisture control, and windows. Students can receive a waiver from the team's faculty lead if equivalent training is provided as part of the student's curriculum. This training ensures that students are knowledgeable in the basics of building science.

Jurors score teams according to 10 equally weighted evaluation parameters: architectural design; interior design, lighting, plug loads, and appliances; energy analysis; constructability; financial analysis; envelope performance and durability; indoor air quality and ventilation; mechanical, electrical, and plumbing systems design; innovation; presentation and documentation quality (DOE 2017). The jurors select first- and second-place teams, then the first-place teams in each contest compete to be the Grand Winner of the competition.

The teams in Race to Zero may develop projects based on updates of designs from builders or develop original work. Teams may also choose to retrofit or modernize an existing building. Each team selects and defines a specific location with building lot or site and neighborhood characteristics as context for the building design and its relationship to surrounding structures and the community. By establishing industry relationships, teams are highly invested in the outcome of the project and might even work with their industry partners to build the project and realize their designs.

Variability in Designs

Race to Zero teams come from diverse locations. Design differences come from variances in surrounding environmental conditions. Competition entries span every International Energy Conservation Code climate region in the United States and several zones overseas (PNNL 2015). As expected, envelope design varies from one climate zone to another, as does mechanical system design. Race to Zero teams choose a variety of architectural styles: some choose to closely match that of surrounding buildings, and others choose to implement new or modern styles. Most Race to Zero teams choose to design all-new construction; however, in the first four years 10% attempted retrofits of existing buildings.

Teams must also consider the cost of living and median income in the area they select. Teams must carefully balance a desire for low utility costs throughout the life of the home with the need to keep construction costs low.

Trends of the Race to Zero Student Designs

Trends in the Race to Zero student designs were evaluated across the initial four years of the competition. In total, 131 team entries were analyzed in detail (28, 33, 31, and 39 in 2014, 2015, 2016, and 2017, respectively), including construction plans for each whole building, end uses of energy, and on-site renewable generation. All entries were analyzed for the central competition goal of reaching net zero energy consumption.

Space-Conditioning Design Selection

Race to Zero design teams are required to fully plan mechanical systems for their entries. Energy-efficient and climate-appropriate space conditioning is vital to achieving net zero construction. According to the United States Energy Information Administration (EIA), for the most recent year available, 2009, space heating accounted for 41.5% of energy use for U.S. residential buildings, and air conditioning accounted for 6.2% of energy use (EIA 2013). Race to Zero student designs incorporate modern building science design principles to reduce energy use from these systems. Seventy-seven percent of home designs use a form of electric heat pumps for space conditioning. These heat pumps are an energy-efficient alternative to traditional combustion-based heating equipment. Homes that use heat pumps instead of natural gas boilers or furnaces eliminate site pollution and instead use electricity produced from either the grid or on-site renewable energy installations to condition the home. U.S. Census data for characteristics of new single-family home construction from the most recently available year of 2016 show that only 41% of constructed single-family homes contained heat pumps. The same data show that 56% of newly constructed single-family homes contain traditional forced-air furnace systems. And the U.S. Census data for multi-family units show that 51% of completed units use heat pumps (U.S. Census Bureau 2017). Twelve percent of entrants chose to use high-efficiency combustion gas heaters or furnaces because of their relatively low cost to install and operate. The decision by student design teams to use efficient electric equipment instead of combustion equipment outpaced industry trends. This decision was based on lower life-cycle costs instead of the high upfront cost, which often prohibits builders from using these technologies.. This demonstrates the value of Race to Zero in providing experience to future industry professionals well before they would learn about these techniques in the industry.

Indoor Air Quality Design Selection

Teams must follow the EPA Indoor airPLUS guidelines for a high standard of indoor air quality. Indoor airPLUS specifically mandates the installation of equipment in warm-humid climates with “sufficient latent capacity to maintain indoor relative humidity (RH) at or below 60% ” (EPA 2018). Designs must meet this requirement as well as all applicable building codes for ventilation while still designing for net zero energy use. Homes designed for drier climates do not need to meet this requirement. Traditional mechanical ventilation systems expend energy by exhausting air directly into the outdoor environment. Energy recovery ventilator systems take outgoing indoor air and reuse the heat and moisture to condition incoming air. Similar to energy recovery, ventilators are lower cost heat recovery ventilation systems. Heat recovery ventilators reuse the heat from outgoing ventilation air to condition incoming air, but they do not exchange moisture like more costly energy recovery ventilators do. Among four competition years, 62% of the teams (81 teams) used either energy or heat recovery ventilators. Energy recovery ventilators were planned for use by 52% of teams, and heat recovery ventilators were planned by 10% of teams. The application of advanced ventilation systems builds future professional knowledge of these technologies as a viable alternative to traditional exhaust ventilation systems.

Envelope Design Selection

Race to Zero teams are required to detail the building envelope design of their contest entries. Traditional enclosures use basic wood framing techniques to construct the walls of a structure. These techniques use a standard spacing of 16 inches between joists, studs, and rafters mounted to wood frame members, which does not allow for additional insulation beyond code levels (American Wood Council 2001). Structural insulated panels (SIPs) are prefabricated off-site before assembly of the building on-site and include slots for windows and other penetrations; this process reduces the risk of installation errors. SIPs are a composite structural panel with a rigid foam core, and they reduce thermal bridging. They can be used for the entire envelope of a building, including the roof, walls, and floor. SIPs also provide more comfort and long-term durability because they are up to 15 times more airtight that traditional construction (EPS Buildings 2018).

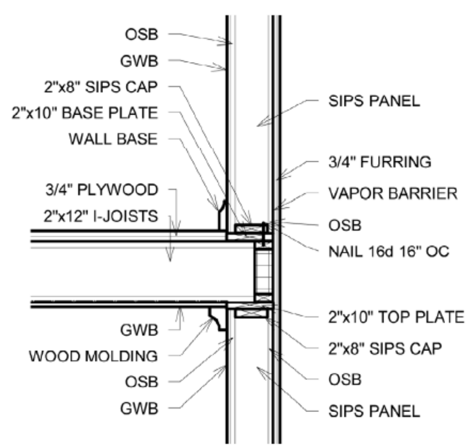

Figure 2: Envelope detail from Philadelphia University’s 2016 first place entry for New Affordable Zero Homes

As shown in Figure 2, SIPs are integrated into the wall system of a building. Teams chose to use SIPs in 44% of the projects over the past 4 competitions. In addition, 27% of design teams chose to use some form of advanced framing, which uses wider stud spacing of 2x6 inches rather than 2x4 inches. Student design teams implementing SIP envelope and advanced framing techniques early in their professional career gain a familiarity with their costs, restrictions, and benefits.

Roof design also varied across climate zones. Designs included metal roofs, asphalt shingles, and green roofs incorporating vegetation. Ninety percent of teams designed roofs to be optimally ready for solar photovoltaics (PV) in terms of maximum solar exposure.

Foundation design also varied across climate zones. Sixty-five percent of teams chose to use slab-on-grade foundations, which could be based on market or local code.

Window choices made by teams reflect budget consciousness and space-conditioning loads. Seventy percent of teams indicated they used double- or triple-pane windows (early competition teams did not specify window type). Triple-pane windows were selected by 24% of teams. Other teams discussed their choice to implement windows with higher solar heat gain coefficients to maximize passive house design.

Lighting, Appliance, Domestic Hot Water, and Plug Load Selection

An increasing share of home energy use comes from electricity use from plug loads and appliances. In 1993, non-weather-related appliance, electronics, water heating, and lighting energy use accounted for 42% of home energy usage; by 2009, this grew to 52% of home energy usage (EIA 2013). All Zero Energy Ready Homes are required to comply with ENERGY STAR program standards, which certifies several categories of appliances for meeting standards of energy efficiency (EPA 2018). Thus, student teams planning appliances for contest entries become comfortable and familiar with selecting energy-efficient choices. Teams selected a variety of water heating options. Eighty-two percent of teams selected heat pump water heaters that were either air source or geothermal types.

Lighting design in Race to Zero entries showed a strong use of daylighting techniques and practically universal use of light-emitting diode lightbulbs compared to conventional incandescent or compact fluorescent lightbulbs. Sixty-two percent of teams implemented daylighting techniques into their design process. These teams carefully chose the orientation of their buildings and used elements such as skylights and light shelves to promote natural lighting, which has been shown to reduce seasonal depression and promote alertness (Society of Light and Lighting 2015).

Energy Analyses

All Race to Zero teams are required to perform home energy analyses to estimate the energy use of their designs. The HERS rating is meant to provide a quantitative measure to compare new or planned construction to the energy efficiency of existing homes and also account for on-site renewable energy generation. Existing homes score approximately 130 on the scale, with typical new homes scoring 61. A net zero energy home achieves a score of 0 on the scale, and homes that generate more energy on-site than they consume score 0 or below. Teams learn to use the REM/Rate software to score their designs, and they achieved HERS scores much lower than those of typical new construction homes.

In addition, teams used optimization tools such as BEopt™, DesignBuilder, EQuest, and RETScreen to improve decision-making. WFI was also a popular choice, with two to seven teams using the software each year. In all, 42% of teams used two to four tools modeling tools to inform their design decisions.

Student teams in the Race to Zero competition successfully implemented strategies of energy analysis as part of an integrated design process to achieve a Zero Energy Ready Home. This use of energy analysis early in the design process ensured the design of efficient homes.

Financial Analyses

Estimated construction costs varied widely among design entries. For the Suburban Single-Family category, average construction cost for entries including renewable energy were estimated at $123.05/ft^2$. Many of the entries in this category were designed for a custom-built home market, raising the average price. For the Urban Single-Family category, average construction cost with renewables was estimated at $113.33/ft^2$. Teams that chose to enter this category often chose to partner with local nonprofit organizations such as Habitat for Humanity to create net zero energy homes designed specifically for low-income community residents in need of housing. In the Attached Housing category, the average construction cost with renewables was estimated at $139.28/ft^2$. For the Small Multi-family category, average estimated cost per unit was slightly more, at an estimated $162.18/ft^2$.

Figure 3 shows the 43 teams that clearly discussed their costs per square foot compared to the HERS score of their design. The average cost at $167.13/ft^2$ (Taylor 2015) and a HERS score of 61 (Elam 2017) are shown to give an indication of where the industry is currently constructing residential homes. This shows that overall the net zero designs are coming in at industry costs with energy consumption less than the industry average.

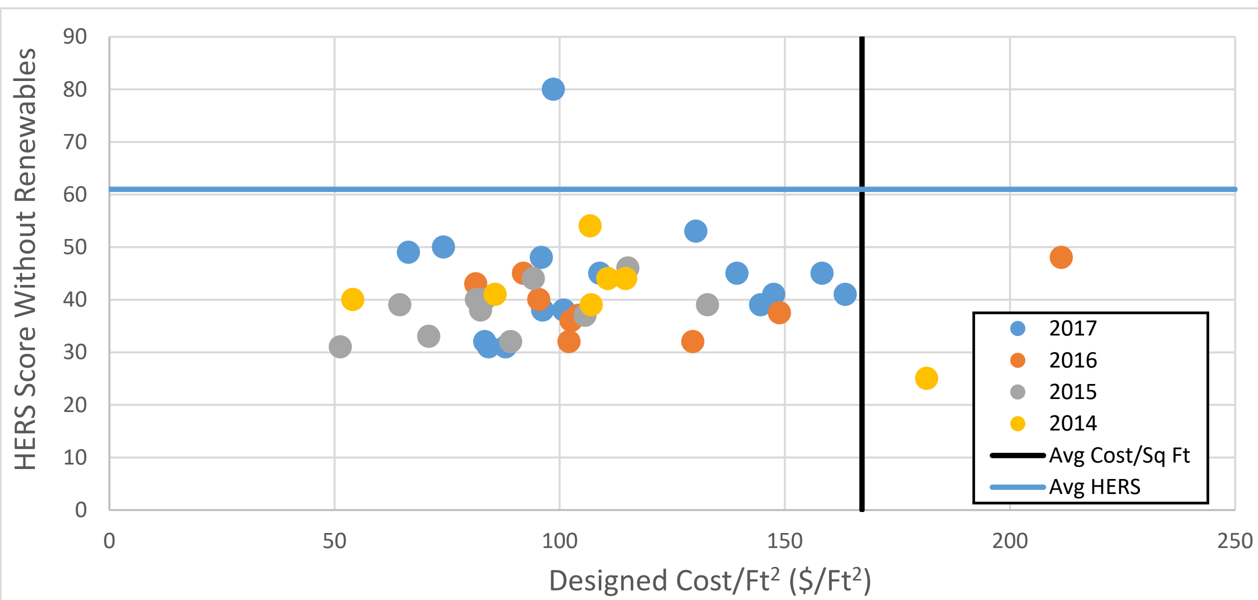

Figure 3: Historical entry comparison of cost per square foot without renewable energy and HERS score

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[2] It is best to compare construction costs in separate categories. The entries for 2014 and 2015 were placed in the 2016 categories according to their characteristics.

Students on Race to Zero design teams learn to appropriately design their projects to realistic buyer expectations. Affordability for Race to Zero entries is measured using a debt-to-income ratio. A debt-to-income ratio compares the amount of debt required to finance a newly constructed or retrofit net zero energy home to the income of a potential buyer in the target market providing a fair way to compare homes designed for different target markets in areas with disparate median incomes. Teams were encouraged to aim for a debt-to-income ratio of 38% or less. Of the 54 teams that clearly stated their achieved ratio, 74% achieved a debt-to-income ratio of 38% or less.

Whole-Building Analyses

Retrofit entries use existing buildings and replace outdated or dilapidated systems with modern, energy-efficient components. Approximately 10% of Race to Zero entries from 2014–2017 worked with a retrofit design. Although achieving high energy efficiency of retrofit designs is certainly possible, teams had more difficulty reaching the energy-efficiency thresholds of the new construction entries.

Table 2 shows the team HERS scores for both retrofit and new construction with and without renewables (among the 105 teams that clearly stated their score) for teams that provided the values in the project submission.

Table 2: HERS Scores for Race to Zero Designs

HERS Scores	Retrofit	New Construction
With renewables	10	-4
Without renewables	43	42

For homes, the most realistic form of on-site renewable energy generation is solar PV panels. Many design teams implemented solar PV and included costing options with and without this generation. Student teams planned their solar PV systems to account for local and federal governmental subsidies for residential systems when appropriate and available.

In addition, among 131 entries, 77% of teams created entirely electric entries. These homes designed without combustion equipment give future building science professionals the freedom to pursue net zero source energy use when combined with on-site renewable electricity generation.

Case Studies of Winning Zero Energy Ready Home Designs

Two project designs from the most recent Grand Winners in the Race to Zero are shared to show the solutions selected to meet net zero and competition requirements. The following case studies are drawn from the teams' documentation submitted to and reviewed by the jurors at the competition; selected juror comments are also provided to share industry feedback.

2017 Grand Winner: Ryerson University and University of Toronto, LaneZero Project

Major cities such as Toronto are struggling to simultaneously densify while maintaining a sense of community. The sustainable future of our cities depends on finding new ways to inhabit existing infrastructure. The LaneZero project, developed by the Future Cities Collective team with members from Ryerson University and the University of Toronto, was the Grand Winner of the 2017 Race to Zero, seamlessly integrating into currently thriving neighborhoods.

In downtown Toronto, low-density, detached residential neighborhoods contain more than 155 mi (250 km) of publicly owned alleys or laneways. This underused space on valuable land provides a unique opportunity for unobtrusive densification. The Future Cities Collective project exemplifies possible laneway housing opportunities in Toronto, promoting the efficient use of public and private property in the city. LaneZero, as shown in Figure 4, uses laneways, or alleys, to artfully fit into its neighborhood.

For LaneZero to achieve net zero site energy, the design strategy employed a three-tiered approach: (1) minimize conditioning needs through envelope, geometry, mass, and orientation; (2) increase passive conditioning strategies through natural ventilation, solar heat gains, and daylighting; and (3) supplement active conditioning through an efficient conditioning system. In addition, the team incorporated PV on the pitched roof, which makes the project a net energy producer (Ryerson University, University of Toronto 2017).

The team used the DesignBuilder tool for energy analysis, which led to the decisions of providing heating and cooling capacity by thermal zone met by radiant floor (heating) and hydronic fan coils (cooling). The heat pump has an efficiency of SEER 13 (cooling) and Heating Seasonal Performance Factor (**HSPF**) 11 (heating), and the system is controlled using an Ecobee smart thermostat. The home scored a HERS value of 51 without PV and 11 with PV. Figure 4 shows the home was designed to maximize natural ventilation on both floors.

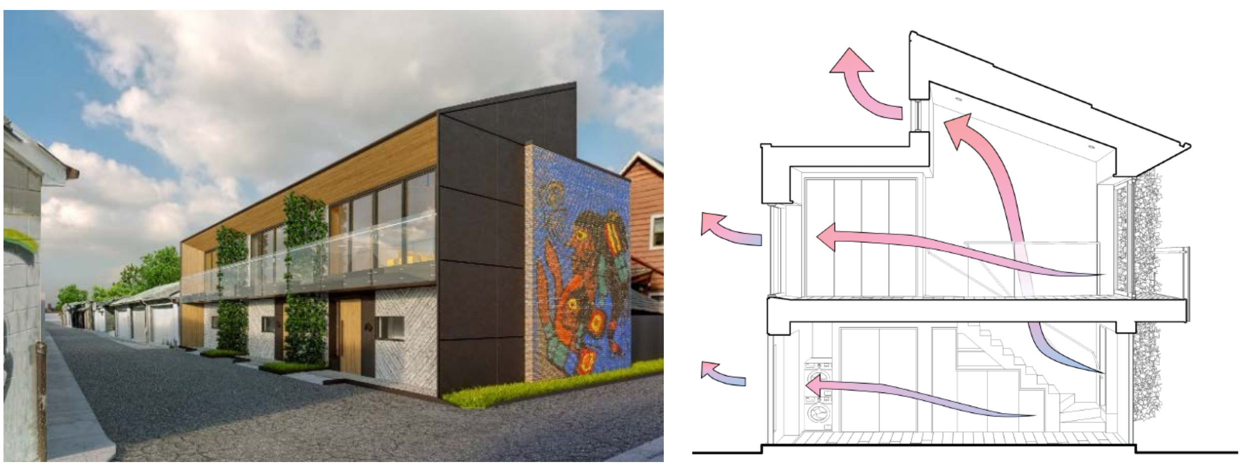

Figure 4. (a) LaneZero and (b) diagram of the LaneZero natural ventilation (Ryerson University, University of Toronto 2017)

Selection of the envelope components accounted for long-term structural integrity, preventing moisture issues, and providing optimal thermal performance for the lifetime of the building. WUFI hygrothermal analysis software was employed to show the absence of thermal bridging within the envelope selection and acceptable moisture levels within the home.

Given a 25-year mortgage (the maximum available in Canada), a 20% down payment, and an interest rate of 2.5%, the monthly mortgage was found to be $832.50, resulting in a debt-to-income ratio of 35%. The team found that the units could be rented at a monthly rate of $1,800, yielding an excellent return on investment for the owner of the lot.

Juror comments on the winning design stated that the team "nailed the purpose of the competition," had outstanding architectural design, and developed a great concept to refill laneways and alleys. Overall, LaneZero brings life to laneways through comfortable, efficient housing, and is intended to make laneway homes a desirable and sustainable way to live.

2016 Grand Winner: Prairie View A&M University—Double Barrel Project

Resilience is a global concern and for the students at Prairie View A&M University, the highest priority in their project was to bring resilience to their Double Barrel project. The team's concept focused designing an affordable and sustainable that could withstand home hot and humid climates and natural disruptions (floods, hurricanes, etc.).

The Independence Heights neighborhood outside of Houston, TX holds historic significance yet has high vacancy rates and is prone to frequent flooding. The home was designed to provide an affordable, high-performance, small-footprint home for low-income families in an area that needs it most. Prior to design, the team visited the infill site to understand the design constraints and context. On the narrow and deep lot, Team Green Future sought to achieve Passive House standards and meet the Zero Energy Ready Home requirements within the context of the neighborhood.

The team modeled the design in the BEopt optimization tool. Adjustments were made to the base design based on the team's experience with the climate. Then the design was modeled in REM/Rate. The base design achieved a HERS score of 36 prior to the addition of a 6.3-kW PV system, as modeled in PVWatts, to achieve a HERS Score of -9 .

Figure 5. Double Barrel project rendering and interior design (Prairie View A&M University 2016)

The 1,567 ft^2 home features a three-bedroom, two-bath dwelling with wood siding using advanced framing and continuous insulation. The home, as shown in Figure 5, stands on raised supports and has an open floorplan to allow for natural light. A mini-split system was found to have the extra capacity to handle all dehumidification in the humid Houston climate because the smallest units available will have extra capacity relative to the small footprint of the home.

Jurors stated that the simple design enabled affordability and that the team tied the design vision to revitalization of the community. Additionally, the jurors approved of the team employing both high-performance and readily available products in construction. The team took on the challenges of meeting Zero Energy Ready Home requirements, the requirements of low-income residents, and resilience in one design.

Conclusion

In the past four years, approximately 1,400 students received benefits from the Race to Zero Student Design Competition, and there is growing interest in this topic. Students participating in the competition gain collaborative experience working with industry partners to create complete designs for functional net zero energy homes. Additionally, because of partnerships created at Race to Zero with sponsors and jurors, students often move into careers in building science, with jobs ranging from working with jurors at urban planning firms to building information specialists at a developer to estimators at production builders.

The Race to Zero provides early career exposure to excellent building science principles, using a variety of analysis tools, applying local building codes, and using industry programs to push their designs toward net zero. This develops a group of industry professionals that are entering the workforce with the real-life knowledge to implement techniques that can successfully achieve net zero residential building construction.

The overall goal of the Race to Zero is to educate future design professionals on net zero energy techniques. Students learn about energy-efficient design and construction techniques before graduation and bring their knowledge with them to fill a skill gap present in industry. The Race to Zero moves the industry toward net zero design and construction by developing the knowledge and skill set of the professionals entering the workforce who believe in net zero and understand the economics. Additionally, Race to Zero teams are capable of not only meeting a local need but also developing a net zero design.

Race to Zero provides a unique opportunity to educate the next generation of building professionals about innovations that can drive industry change through robust building science and engineering.

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