INNOVATION

U.S. DEPARTMENT OF ENERGY SOLAR DECATHLON

Our H_2Ouse. Our Water Use.

UC DAVIS

Innovation Jury Narrative

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Our Story

With its second entry into the Department of Energy Solar Decathlon, the University of California at Davis (UC Davis) is proud to continue its history of appealing design and student-driven engineering, with its new team name: the Blue Mustangs. Since its inaugural entry in Solar Decathlon 2015, UC Davis has capitalized on the project as an opportunity for students to explore designs that can address a need. For the agriculturally-focused UC Davis, the lack of suitable housing for migrant farmworkers was a social and environmental problem that felt close to home. To address this problem, the 2015 entry “Aggie Sol” presented below market-rate zero net energy (ZNE) housing, featuring night-time radiant cooling via rooftop sprinklers and a purpose-built floorplan catered to low-income agricultural workers. For the 2017 home, defining the problem scope and determining how the Blue Mustangs could address the problem was the starting point. Amid a severe drought in California in 2015, the problem seemed obvious, but refining the problem scope and how to tackle the problem was an extensive and iterative process. Eventually "Our H_2Ouse" (pronounced “Our House”) arose. Similar to the UC Davis 2015 entry, we continue the philosophy of addressing environmental and social needs. Our H_2Ouse balances innovative and experimental systems with a simple and adaptable implementation designed around our three pillars: to be drought-resilient, educational, and inclusive.

Our State

California has the largest population in the United States as well as the largest agricultural output[1,2]. This plethora of people, animals, plants and machines can require anywhere from 50-100 million acre-feet of water annually[3]. To sustain such high levels of organic and inorganic activity, California produces the second largest carbon footprint in the U.S.. However, California’s per-capita emissions are the third lowest in the nation. Although the environmental burden of California is high, its low per-capita emissions is a testament to the cognizant and progressive nature of Californian residents. California continues to lead standards and innovations in terms of environmental and technological platforms, but to maintain Californian lifestyle, the status quo in California must evolve to meet the challenges of the future.

The Governor of California, Jerry Brown, announced the "end of the drought" in April of this year; however, California’s struggle is far from over. With the cyclical nature of the drought events in California, combined with the continued growth and development of the state's population and cities, the need for sustainable and renewable water and energy management will only grow more pressing. In the past 5 years, numerous state government initiatives have responded to these looming issues, largely by setting long-term goals for water and energy reduction and incentives for renewable energy and water production and use. Many of these initiatives involve increases in resource efficiency use within the residential sector, which while exerting some of the smallest consumption rates, has great potential for effective conservation strategies[4,5]. Although technological advances can increase efficiency, California demonstrated the importance of user behavior during its most recent drought. With state-wide mandatory conservation in 2016, Californians successfully reduced their urban water consumption by 25%, and Jerry Brown called on California's population to "make water conservation a way of life", rather than a temporary practice. California needs to evolve so all residents have the knowledge and ability to conserve their water and energy use, and the means to implement crucial lifestyle changes. Our H_2Ouse embodies this goal through dedication to occupant engagement and education, by providing an affordable residence, and by providing a means to a water and energy conservation lifestyle.

Our Research & Development

Establishing a Doctrine

When innovation stands alone, it can be interesting. When innovation can present a viable solution to a plaguing problem, it can inspire change and spark a movement. With this mindset of innovating with a purpose, the Blue Mustangs believe that building a ZNE home or even building a cutting-edge ZNE home is inadequate unless it fulfills a need and addresses a persistent problem. This is because the difficulty in innovation and engineering does not strictly lie within the boundaries of a technical solution. For the innovative solutions of today, the challenges often arise in the space between the problem and the technical solution, as the solution must not only be feasible but also cost-effective, widely-applicable and purposeful.

Independent Prototyping

The process began with one class: ECI 126, or Green Building. This class was taught by the faculty advisor for the Solar Decathlon, and featured guest lecturers in architecture, sustainable practices, and current innovative technology. The class focused on informing students about the status quo in building, and the problems associated with traditional building practices. It provided a framework and tools that future decathletes would later use for the Solar Decathlon effort. Students began building a working knowledge for building materials and passive solar techniques, as well as practice with energy modeling, scale modeling, and 3D modeling in Revit. Eventually, the class was divided into three groups, and each group designed their version of a successful decathlon home. These designs were modeled, prototyped, and competed against each other. This mini competition gave rise to the Ed House, focused on educational feedback. In the midst of mandatory conservation measures on our very own small town, a growing desire to address our drought-stricken region gave rise to an expanded focus which blended education with water conservation; thus, Our H_2Ouse was born.

Refining the Problem Scope

Since its inaugural entry in Solar Decathlon 2015, UC Davis has capitalized on the project as an opportunity for students to engage and experiment with innovative engineering and design solutions. The most important step was defining a problem scope which innovative solutions could address. For the agriculturally-focused UC Davis, the lack of suitable housing for migrant farmworkers was a social and environmental problem that felt close to home. To address this problem, the 2015 home, Aggie Sol, presented below market-rate ZNE housing, featuring innovative night-time radiant cooling via rooftop sprinklers, and a purpose-built floorplan catered to low-income agricultural workers. For the 2017 home, defining the problem scope and how the Blue Mustangs could play a role in addressing the problem would be the starting point. Amid a severe drought in California in 2015, the problem seemed obvious, but refining the problem scope and how to tackle such a problem was an extensive and iterative process. Ultimately, the Blue Mustangs continued with the goal of addressing the social and environmental plight by creating Our H_2Ouse, an inclusive and drought-resilient home, teeming with integrated feedback systems which create a personalized living experience and inspire a conservation lifestyle.

Collaboration

With a working design, students were split into teams, such as building design, landscape design, water, structures, and energy modeling. The innovation process began with students familiarizing themselves with the current range of innovations that existed. This involved extensive online research, usually conducted by reading research papers, or reports, such as "California's Water" shown in Figure 1 on the right. As research was performed, all findings were assembled and organized on a cloud-based file sharing system so that they would remain accessible to all current and future team members. Perhaps even more beneficial was the communication with relevant on-campus research groups which included the Center for Lighting Technology, the Center for Water-Energy Efficiency, the Western Cooling Efficiency Center, the Center for Visualization, and the Center for Watershed Sciences. Professional architects, designers, and marketing professionals were consulted throughout the process for constructive criticism and professional guidance. In addition to these exchanges, students witnessed innovative technologies in action at various on-campus buildings, including the Honda House, Jess S. Jackson Sustainable Winery Building, and the 2015 Aggie Sol. These exchanges and building tours gave inspiration to students, sparking investigation of a different avenue of research and helping to form the basis for innovative features in Our H_2Ouse.

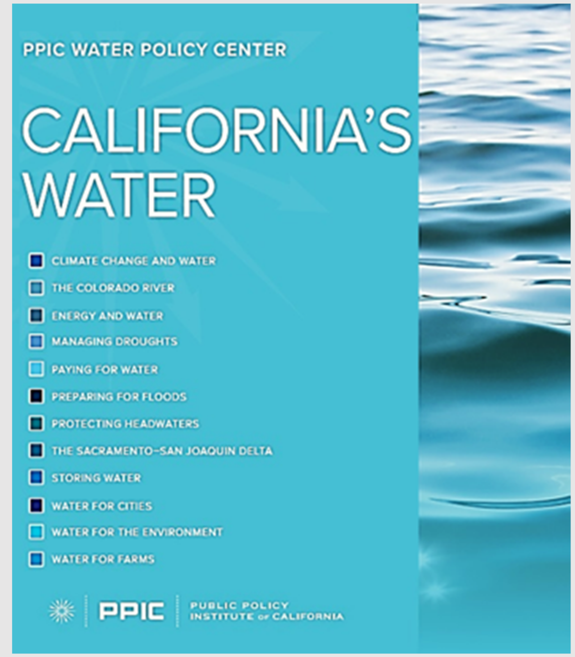

Figure 1: California's Water Policy - published by the Public Policy Institute of California

Developing an Innovative Design

The 2016-2017 academic year also consisted of structured academic classes (ECI 189E-Structural Engineering, and ECI 128-Green Construction), but now with curriculum in direct relation to evolving the house and getting ready for the competition. Once preliminary research ceased students moved to developing their own novel solutions. Students met weekly with staff, faculty, and classmates to present their ideas and receive input and constructive criticism. Once this step was complete, the range of ideas was narrowed down into a cohesive assemblage of innovations that were to be developed into features of Our H_2Ouse. These potential features were all vetted to ensure they addressed at least one of the three pillars of design for Our H_2Ouse: drought resilient, educational, and inclusive. Further development of potential features involved collaboration between workgroups, on-campus organizations, and industry mentors. Many times students could predict the potential success of a design choice by industry data, survey data, and real-life statistics of a similar building; however, extensive modeling, researching, and testing were needed for student-developed systems in which no data was available. For many of the engineering dilemmas, software and excel models allowed students to construct theoretical models of their proposed designs to draw conclusions, and to either support or refute the efficacy and feasibility of their system. In other cases, students were able to purchase certain components of their system and test them in a simulated performance. For example, while determining the necessary coding and physical/virtual connections needed for water monitoring, the electrical team installed several of their water meters on the kitchen sink of the Solar

Decathlon jobsite office. Instead of halting the systems development phase once construction began, teams continued to modify their innovations as the house was being assembled. This allowed them to gain a better gauge for the performance of their systems before they were implemented in their final intended format.

To select the most appropriate innovations to pursue, workgroups constructed weighted decision metrics under the guidance of faculty and industry mentors. These decision metrics consisted of spreadsheets in which each design option received a score in weighted relevant categories. The option with the cumulative highest score was selected for use in Our H_2Ouse. Common heavily-weighted categories included cost, estimated life performance and maintainable efficiency, as well as perceived market appeal. Any product that was selected via this metric was finally presented to the rest of the team to ensure it did not interfere with the intentions of any other workgroup. Through this process, every component and system of Our H_2Ouse was ultimately chosen through a collaborative and interdisciplinary approach.

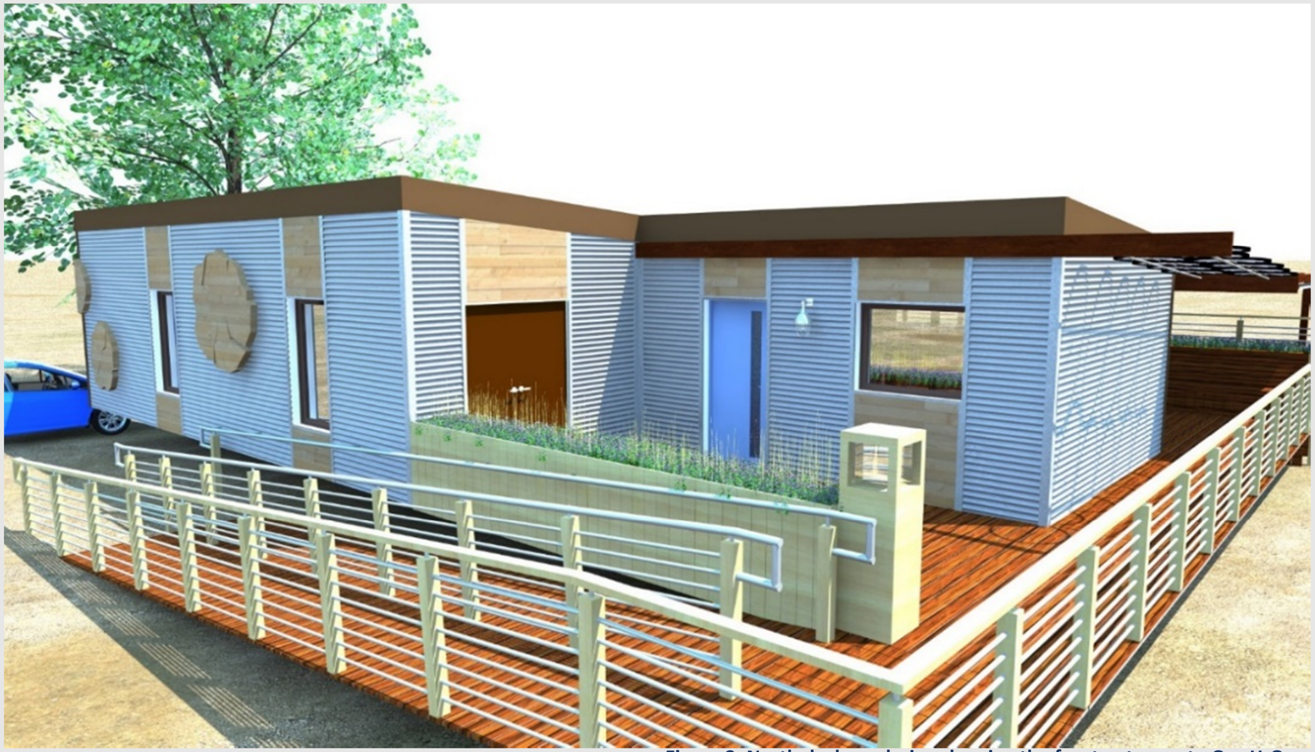

Figure 2: North deck rendering showing the front entrance to Our H_2Ouse

Our Vision

Recognizing the water and energy problems plaguing California, the Blue Mustangs developed Our H_2Ouse to create feasible and desirable homes using California-specific strategies. This house is an inclusive, drought resilient home, and provides salient information feedback for its residents. While Our H_2Ouse displays new and innovative technology, it also works hand-in-hand with current technologies.

Our H_2Ouse addresses the most pervasive and unpredictable factor in energy and water savings: user behavior. The virtually untapped resource of user behavior modification can exploit the efficacy of "smart" technologies by modifying the user inputs associated with such technologies, thus bridging the gap between the potential water/energy savings and the realized water/energy savings. Addressing energy savings for one home through user behavior requires motivation through education and salient reminders that facilitate long-term lifestyle changes. To truly impact energy reduction — reduction that reaches beyond one home and begins to address a growing problem — statewide collective action is required. The Blue Mustangs are confident that behavioral changes and a cultural shift towards a new water conservation status quo can be inspired by collective action much like the success of the exercise technology, Fitbit®- just replace steps with drops. Because Our H_2Ouse has been designed to support a wide-range of housing applications, it is the hope of UC Davis students and faculty that Our H_2Ouse can continue to promote inclusive, drought-conscious, and innovative residential development while decreasing the environmental impact of the residential sector.

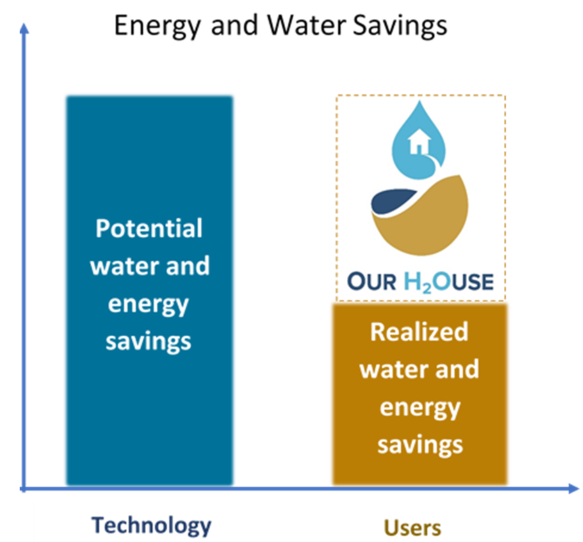

Figure 3: Our H_2Ouse bridges the gap between potential and realized water/energy savings by addressing the user in addition to just the technology

Our H_2Ouse responds to California drought events with water efficient technology, drought-tolerant landscaping, and water-conscious interior design.

Our H_2Ouse educates occupants through feedback mechanisms salient systems, and intentional design.

Our H_2Ouse is feasible for a wide range of residents, with full ADA accessibility, low-cost solutions, and reconfigurable features.

Our Innovations

Our H_2Ouse becomes not only a beautiful place to live but also a tool to decrease urban water consumption in California. Historically, most innovations meant to address this issue centered around replacing current technology with more advanced technology, which inherently use less water. Undoubtedly, these products have helped people reduce their water use, but typically, the savings fall short of their potential. For example, a sink may have a low-flow rate, but if the user leaves it running as they walk away, the lower-flow fixture will save some water, but nothing compared to a technology that convinces the user not to walk away. Our H_2Ouse achieves this by marrying smart technologies with easy behavior-changing information to influence water and energy consumption in new and influential ways, at both the occupant and the community level.

Water and Energy Monitoring and Information Feedback

Household appliances and devices tend to be used with little regard for their energy and water demand, which leads to unnecessary resource waste. Research papers[6,7,8,9,10,11,12,13,14] and collegiate interviews regarding user habits corroborate that occupants consume more than intended due to a basic lack of awareness. This lack of awareness is fed by the status quo of societal norms. For example, showers are characterized by units of time, rather than gallons of water, thereby distancing the behavioral use from the resource consumption. If showers were characterized by gallons of water, the user is inherently reminded of the impact, simply through accurate and quantitative feedback. Typically, occupants are provided feedback only on a high-level basis by sources like energy and water bills. This feedback is nonspecific in both time and space, meaning the user cannot pinpoint when the most influential behavior occurs or what appliances cause the most impact with regards to water and energy use. The Blue Mustangs electrical team, comprised of computer science and electrical engineering students, addressed this void with a water and energy monitoring system. This system embodies our Our H_2Ouse design pillars of the home by promotion of water and energy efficiency through cost-effective data collection, and comprehensive displays of informative data feedback.

The research phase for the controls and monitoring team concluded with an innovative water monitoring plan, involving a single main-line sensor and an algorithm to disaggregate different water flows. However, developing such a system is highly-involved and purchasing accurate sensors for every hot and cold-water line proved prohibitively expensive and therefore noncompliant with all of our design pillars. As is common when designing within a budget, we found a great alternative. We decided that every hot and cold water line would have less expensive, but acceptable sensors cross-checked by a robust and highly accurate mainline sensor. This small adjustment allows the cost-effective system to be considerably accurate through the added benefit of discerning which water line is drawing from the mainline at any moment.

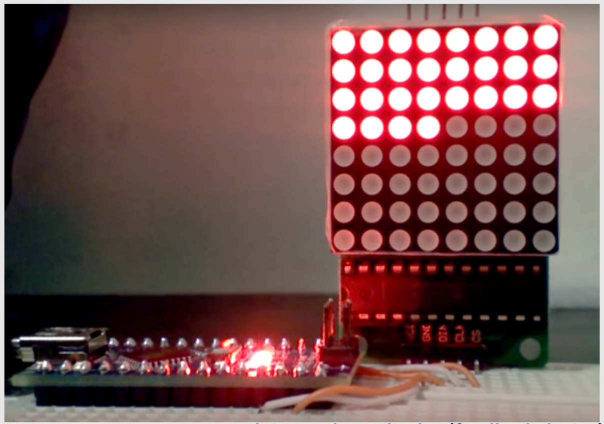

Figure 4: An Arduino and LED display (feedback device)[19]

The challenge for the UC Davis team was how to create innovative ways to increase the functionality of the collected data by displaying it in some of the same influential formats that would be used for the information feedback about water. To overcome user indifference and establish a salient reference point for appropriate and adequate water use, Our H_2Ouse features unique occupant-level and community-level devices which show real time water consumption. Sequential illumination of individual LEDs, which correspond to incremental units of water, allow for visible water meter feedback near the kitchen, bathroom sink, and shower. These devices transform unconscious waste into thought-provoking conservation, resulting in individual behavioral changes — changes that the Blue Mustangs are confident will permeate beyond the walls of Our H_2Ouse to influence conservation on a much grander scale.

To further expand upon the influence of Our H_2Ouse, a community-level feedback device was created to educate, inspire, and facilitate awareness of water resource responsibility. Aggregated occupant water use, in relation to gallons saved when comparing to the average occupant water use, is shown via an unconventional and dynamic water feature. This feature, placed prominently at the front of the house, directly relates to the home's total water consumption compared to an average household's total water consumption. The ambient, eco-feedback display mimics ecological processes, such as the filling and draining of reservoirs with a limited water supply, providing homeowners a more physical and relatable depiction of water conservation. The occupants are rewarded by this feature as they increasingly save more water than is used on average. Rewarding such positive behavioral changes and motivates occupants and can be a catalyst for a friendly neighborhood challenge, turning household occupants into a conservation team and increasing both neighborhood and inter-household accountability. This system could be upscaled, with water features for individual houses as well as a hub for a neighborhood-level water feature which aggregates all water-saving data, allowing neighborhoods to team up and challenge other neighborhoods to this "conservation game".

The interior of Our H_2Ouse features a single device similar to the tablet-based HUDs that many teams utilize for control purposes; however, the user interface (UI) of Our H_2Ouse's system is unique in that it emphasizes clear and customizable information feedback formats. As such, the device features usage breakdowns, prospective economic costs that the occupants can expect based off their current water and energy usage, as well as a comparison to usage goals. The flexibility of this UI allows the occupant to set goals for water use, change the format of the data display, and utilize other settings (such as adjusting the number of people living in the home).

Another unique feature of the device, and in our humble opinion one of the most exciting differentiators of Our H20use, is how we have assimilated the device into the architecture of the building. The tablet itself is integrated into the home by placing it behind different pieces of two-way mirrored glass throughout the home. In this format, occupants can be greeted by information summaries while looking at themselves in the bathroom vanity mirror as they brush their teeth, shave, etc., or in a more public format located in the home's main living room. The tablet is easily removable and can be carried to and placed in alternate areas of the home according to occupant preference. These adjustability features address the uncertainty that surrounds feedback devices, in terms of the most effective modes of information delivery and the best locations for maximum, sustained impact. This flexibility is a key innovation of the UI, as the development of effective feedback is still very much in flux. By allowing occupants the ability to alter the device location and the format of the display, we hope they customize the platform in the way they find most helpful and beneficial. To enhance this process, the device tracks its own effectiveness by allowing homeowners to log when placement and formatting changes were made in relation to changes experienced in water and energy use.

Achieving occupant "water and energy consciousness" was not an ambition unique to the electrical team. This aim permeated through all teams including architecture, interior design, landscape, and electrical/controls. Architecture students worked closely with water and mechanical students to design mechanical rooms that can serve as natural reminders of the home's water and energy supply. Instead of tucking away water and energy distribution equipment in a basement or garage, the mechanical room entrances have prominent placement in the floorplan, which separates water and energy equipment, thereby increasing ease of access as well as occupant safety. Interior design students implemented water-themed finishes and artwork that has a low "embodied water" use in production and conveys the inherent beauty of water. Landscape design students worked with the electrical team to create a dynamic exterior water feature which displays the gallons the household saves compared to an average household, educating both the occupants and the surrounding community. Additionally, the landscape team opted for a clay pot irrigation format over traditional drip irrigation for the vegetable garden planters. This allows for high water efficiency, and adds an interactive element which brings the user back to engagement with outdoor water use, steering away from drip irrigation, which promotes distance between the user and their water use.

Innovations in Building

While the main innovation of Our H2Ouse is the way in which it engages occupants in the conservation experience, it also features an array of innovative building products, processes and materials which provide the home and its occupants with long term sustainability features and related benefits. Sourcing green building and carpentry textbooks[15,16], students were well aware of ZNE home design and building strategies. An obvious emphasis was placed upon improving the efficiency of the home's active and passive maintenance of indoor air temperature, mainly through added upfront investment in sensing and control technologies (active) as well as insulation material and shading strategies (passive). Other main concepts included site-specific material selection and sourcing, as well as integrated design processes that would result in cohesive home aesthetic and operation. Along with the home's three design pillars, catering to these goals and methods resulted in enduring and innovative home form and function.

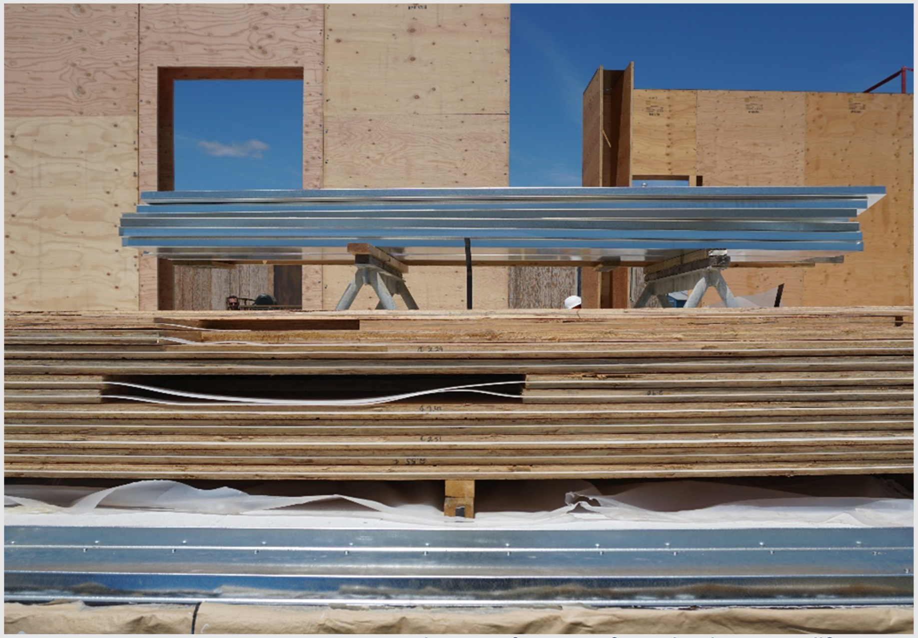

Figure 5: Close-up of BamCore® panelized Prime Wall® System

The basis of a home's passive temperature control is the insulative properties (R-value) of its building envelope. Our H_2Ouse maximizes its R-value through the significant reduction of thermal bridging, expansion of envelope thicknesses, and thorough sealing of the entire building envelope assembly. The crux of innovation for the building envelope of Our H_2Ouse resides in the use of the Bamcore® Prime Wall® system. This prefabricated, panelized wall system features 5" wide interior and 12" wide exterior walls that have a miniscule 2.5% framing factor (% of wall cavity occupied by wood studs) compared to 20+% of traditionally framed walls. As such, the wall can be entirely filled with blown-in insulation, allowing impressively elevated levels of thermal and acoustic buffering. Additionally, the mineral wool of the wall cavity reduces the home's inherent fire hazard, and as there are no studs to drill through for electrical and plumbing lines, easing installation of the respective systems for subcontractors. Because the ¾" width (interior) and the 1 ¼" width (exterior) wall panels feature bamboo cores and a 1/8" traditional plywood veneer, the entire wall panel is structurally stable whilst providing a flat mounting surface for cabinets, mirrors and other finish items, eliminating the need for drywall. The near stud-less Prime Wall® system uses minimal Douglas Fir framing lumber and primarily bamboo core material in its production. This allows for a completely carbon neutral wall system, as substantially high levels of sustainable carbon sequestration can be achieved with bamboo's rapid life-cycle, minimal fertilizers and pesticides, and intensively dense production. Simply, Bamcore® not only saves carbon emissions during the use phase of its life cycle by significantly reducing a home's heating and cooling load, but it also reduces carbon loading during its production phase, as it sequesters significant atmospheric CO_2.

The thermally insulative properties inherent within the building material choices of Our H_2Ouse are augmented with the use of the latest in aerosol-based sealing technologies. Aeroseal, invented by UC Davis's very own Mark Modera (Director of the Western Cooling Efficiency Center) is used in Our H_2Ouse to plug holes not just in HVAC ducting, but throughout the entire home. A significant component of a building's energy demand can be attributed to air leakage through small cracks and gaps in places such as junctions between walls, window frames, door frames, and outlet boxes[17]. When used solely to seal HVAC ductwork, Aeroseal is a proven sealing technology with exciting potential to significantly reduce whole-house uncontrolled air intrusion. Preliminary tests showed Aeroseal is able to seal 30% of envelope leaks, and with use of greater blower-door pressures, it can be expected to achieve up to 50% sealing efficacy[18]. Once refined in the residential market, this cutting-edge technology may then be applied to the commercial sector where its impact upon the state's energy grid could be far greater in scale.

The standard solution for south side shading of passive houses often consists of static roof or window overhangs. These design features are undoubtedly effective at blocking sunlight infiltration, yet they require a concession in relation to shading adjustability and control. Our H_2Ouse employs two dynamic strategies to overcome the stagnant nature of this shading strategy. The first and most noticeable feature is the modular south deck shade structure, which features a series of shade cloth screens that are easily adjustable. Less noticeable, but far more innovative, is the solar-intuitive, thermochromic window coating which is installed on the inner glazing of all the home's south facing windows. This coating requires no electricity, internet connection or any other special materials or equipment to switch between its tinted and un-tinted modes, and can determine whether to allow or block solar heat gain simply based off temperature differentials. The combination of these two features allows Our H_2Ouse to employ an innovative and responsive shading scheme, without compromising adaptability, which we believe is an essential feature to satisfying the needs and preferences of diverse occupants as well as the varying seasons throughout the year.

Our Impact

Although ZNE homes are known to have higher upfront costs of construction, research is beginning to show that homeowners will experience a quick return on investment due to benefits such as greater independence from grid-supplied water and energy, higher resale value, and government incentives. However, these benefits can only be experienced if the home's sustainable features are appropriately durable and can continuously perform their functions for the expected life cycle. In all cases, our building innovations are expected to provide occupants with their respective benefits from 30 years (RavenWindow) to a maximum of 70 years (Bamcore). However, the most exciting and long-lasting impact is the potential influence of the home's feedback mechanisms. As the occupants grow to incorporate the information feedback displays into their conscious actions, there is the likelihood of developing ingrained water and energy conservative habits — habits that can easily become the societal norm for this generation or the next. Additionally, this self-expansive conservation can permeate the surrounding community through the community-level feedback device which serves as a daily reminder and representation to the passersby of the tangible nature of our limited water resources. The Blue Mustangs are confident that behavioral changes and a cultural shift towards a new water conservation status quo can be inspired through such collective action solutions. As previously mentioned, we believe this is a proven tactic as Californians have demonstrated their capability to conserve when mandated; therefore, with the capability demonstrated, only the motivation remains. We believe this motivation is best cultivated through a collective action-based game, similar to the successful model of Fitbit®, wherein a cultural shift will force a change in status quo and Californians can then look to a brighter future, reclaiming its water one drop at a time.

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11. Appendices

11.1. The “average” home

Figure 31 below shows the “average” home from the Oregon DEQ study. It is a 2,262 square foot, 2x6 load-bearing insulated framing, 2 level home, representing the average market size and building practices of the 2008 Oregon residential building code.

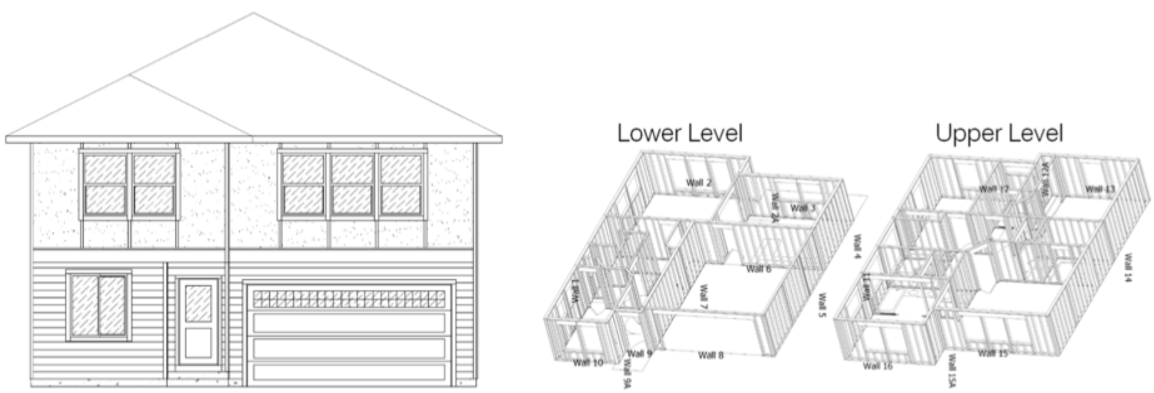

Figure 31: The “average” home from the Oregon DEQ study (Quantis 2010)

Table 7 below shows some key characteristics of the “average” home. More information can be found directly in the Oregon DEQ report:

http://www.deq.state.or.us/lq/pubs/docs/sw/ResidentialBldgLCA.pdf

Characteristic	Description
Location	Portland, Oregon USA
Interior Size	2,262 square feet
Exterior Dimensions	33 ft x 35 ft
Stories	2
Garage	Yes, attached
Foundation	Vented crawl space
Conditioned Building Volume:	20358 ft^3
Bedrooms	3
Bathrooms	2
Framed Floor Insulation	R30 fiberglass
Walls Insulation	R21 fiberglass, framing factor 26%
Ceiling Insulation	R38 fiberglass
Windows	Double-glazed, low-e, vinyl frame, U-0.35; 374 ft^2 of windows, minimal solar gain orientation
Doors	2¼-in solid wood, R2.8
Heating	90% efficient gas furnace
Water Heating	58% efficient gas storage tank
Building Standards	Oregon building code minimum
Air Conditioning	None
Flooring	2,000 ft^2 carpet, 200 ft^2linoleum
Roofing	Asphalt shingles
Roof Truss	Standard truss
Duct Leakage	RESNET/HERS default, all leakage outside of thermal envelope
Building Air Leakage	6.5 ACH@50 Pascals
Siding	2124 $ft^2$of wood siding
Lifespan of House	70 years
Walls	92-5/8-in studs; 8'1" height; single sole/double top plates, headers on all
Floor Framing Style	Post and beam
Floors	4" x 8" beams[14],, 32" on-center,[15] plywood subfloors

Table 7: Characteristics of the "average" home

11.2. Structural insulated panels (SIPs) home

The SIPs home was also a 2,262 square foot, two level home, made with prefabricated wall panels. These panels consist of expanded polystyrene (EPS) sandwiched between oriented strand board (OSB) for an overall thickness of 6.5" and an overall insulation of R23. For more detailed information see the Oregon DEQ report which can be found here:

http://www.deq.state.or.us/lq/pubs/docs/sw/ResidentialBldgLCA.pdf

11.3. LCA Results

LCA results, weighted average climate zone, incineration w/ energy recovery. Shown at the level of one home (MT CO_2e)	**Traditional**	**SIPs**	**BamCore**	**Carbon savings of replacing wood stud walls with BamCore walls**	**Carbon savings of replacing SIP walls with BamCore walls**
Carbon sequestered in building	-10	-12	-21	-11	-8
Materials	7	8	26	19	18
Transport to job site	1	1	1	0	0
Energy (70 years)	516	412	380	-136	-32
EoL	7	9	9	2	0
Total	521	418	396	**-125**	**-22**

Table 8: LCA results in MT CO_2e

11.4. Carbon benefits of scale

The table below estimates the carbon savings of replacing traditional stud framing walls with BamCore walls. Results are shown per 100,000 homes, over 10, 20 and 50 years.

	Traditional	SIPs	BamCore	Carbon savings of replacing wood stud walls with BamCore walls
Showing results per	100000	homes	10	years
Direct Land Use Change			-9,112,491	-9,112,491
Carbon sequestered in building	-9,587,614	-12,380,542	-20,619,916	-11,032,303
Materials	7,064,054	8,305,933	26,384,832	19,320,778

Transport to job site	822,956	1,471,730	1,257,553	434,597
Energy (70 years)	516,095,194	412,317,061	380,389,520	-135,705,674
EoL	6,525,123	8,627,888	8,703,703	2,178,581
Total	520,919,712	418,342,069	387,003,202	**-133,916,511**

Showing results per	100000	homes	20	years
Direct Land Use Change			-9,112,491	-9,112,491
Carbon sequestered in building	-19,175,227	-24,761,084	-41,239,833	-22,064,606
Materials	14,128,107	16,611,866	52,769,664	38,641,557
Transport to job site	1,645,912	2,943,459	2,515,107	869,195
Energy (70 years)	1,032,190,387	824,634,122	760,779,040	-271,411,348
EoL	13,050,245	17,255,775	17,407,407	4,357,162
Total	1,041,839,425	836,684,139	783,118,894	**-258,720,531**

Showing results per	100000	homes	50	years
Direct Land Use Change			-9,112,491	-9,112,491
Carbon sequestered in building	-47,938,068	-61,902,710	-103,099,582	-55,161,514
Materials	35,320,268	41,529,665	131,924,160	96,603,892
Transport to job site	4,114,779	7,358,648	6,287,766	2,172,987
Energy (70 years)	2,580,475,968	2,061,585,304	1,901,947,599	-678,528,369
EoL	32,625,613	43,139,439	43,518,517	10,892,904
Total	2,604,598,561	2,091,710,347	1,971,465,970	**-633,132,591**

Table 9: Carbon savings of scaling, 100,000 new homes over 10, 20 and 50 years. Results are in MT CO_2e