

A haptic, high-performance house: The GRoW Home

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Abstract

This paper discusses the design, construction, and operation of a high-performance passive / active solar residential project which fundamentally engages ecology through daily and annual thermo-climatic patterns of sun and climate. Designed for the 2015 Solar Decathlon competition, the GRoW home endeavors to give solar energy tactile and haptic form, expanding upon the intangible electrical energy generated on the rooftop with photovoltaic panels. This house aims to bring residential occupants into an experiential and ritualized engagement with the biotic and abiotic elements of the solar-based ecology in which they participate. The house's architecture gives the user agency in the stewardship of these energetic flows to simultaneously create a dynamic and captivating set of spaces and a less fossil fuel-intense means of living. This paper reviews the core design concepts which influenced decisions of passive heating and natural ventilation, envelope construction, HVAC system selection and configuration, interior layout and detailing, and performative furniture design. It provides an overview of the analysis processes of lighting and energy simulation throughout design to provide quantitative feedback to the design in the development of performance. Last, it reviews the measured performance of the house during its competition period in Irvine, CA.

Introduction

Nearly every two years since 2002 the US Department of Energy (DOE) has issued a challenge for the design, construction and operation of exceptionally high-performance single-family housing. This call culminates in an exhibition of projects which show not only the latest in energy technology, but also a set of forward-thinking formal, spatial, and material ideas. The DOE's Solar Decathlon is on its surface an intercollegiate competition, but is with each subsequent iteration an increasingly sophisticated design exposition.

As a competition, the Solar Decathlon is exceptionally detailed and complex. As its name suggests, teams compete with one another in ten events. Of these, five (Comfort Zone, Appliances, Home Life, Commuting, and Energy Balance) are objective and evaluated with monitoring or through simple task completion (DOE, 2015). These contests ensure that the house is run as a typical occupied house would be, and energy loads from such things as space conditioning, dishwashing, laundry, cooking, refrigeration, home electronics use and electric car use are all applied to the

house's energy systems. The other five (Architecture, Engineering, Market Appeal, Communications, and Affordability) are assessed with juries of professionals and academics who review the projects against specifically articulated criteria.

As an exhibition, the Solar Decathlon presents an opportunity to showcase architectural design innovation. The projects regularly take on formal, spatial or conceptual constructs which shape their eventual morphology as much as the need to capture solar energy or the need to operate at high efficiency. To cite a few examples, the DALE project in 2013, by Southern California Institute of Architecture and California Institute of Technology used two movable, prefabricated modules to differentially create an internal outdoor space living space, which tripled inhabitable square footage (Sci-Arc/Caltech, 2013). The DesertSol project, also exhibited in 2013, by the University of Nevada Las Vegas, is designed for the Nevada desert, addresses water concerns as well as solar needs, by capturing the occasional rainwater and using it for cooling through a cool tower (UNLV, 2013). The WaterShed project in 2011 by the University of Maryland, was inspired by the Chesapeake Bay ecosystem, and addresses not only energy but also water issues through onsite design strategies such as green roof and constructed wetland (U Md, 2011).

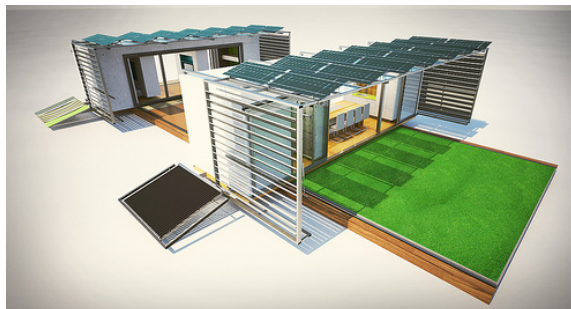


Figure 1: Sci-Arc/Caltech's Dale, competitor in the 2013 Solar Decathlon



Figure 2: UNLV's DesertSol, 2nd place finisher in the 2013 Solar Decathlon



Figure 3: U of MD's WaterShed house, 1st place finisher in the 2011 Solar Decathlon

The GRoW home, discussed in this paper, was positioned to address both the tight energy constraints of the competition as well as the broad design opportunities presented by this challenge. The project was undertaken with a hybrid structure of both curricular and co-curricular activities. The initial ideas were generated in a seminar course, and then developed through summer internships, and six subsequent semester-length design studios and three auxiliary seminar courses.

Theoretical design basis

The GRoW design team has drawn from the thinking of several architects and theoreticians. Reyner Banham recognized in *The Architecture of the Well-Tempered Environment* that advanced space conditioning systems led to a decoupling of architecture from the responsiveness to climate (Banham, 1969). The GRoW Home reasserts the duty of the architect to inflect spatial design based on the climate resources available in a particular place. From Phillippe Rahm's conceptual work, such as



Figure 4: Lacaton & Vassal's Latapie House, which features an elegantly detailed polycarbonate enclosure outside the main conditioned volume.

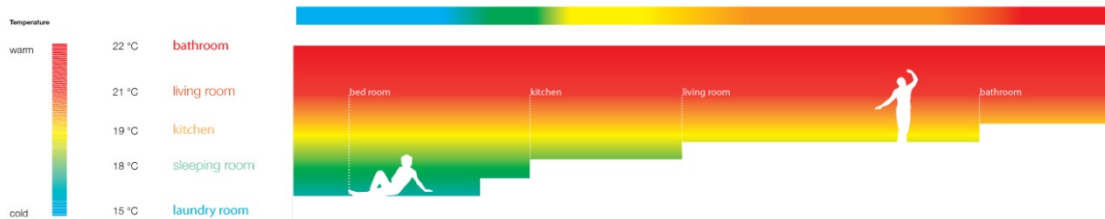


Figure 5: Section from Phillippe Rahm's "Convective Apartments" showing functions related to specific thermal conditions.

"Convective Apartments" and "School, Neuveville, Switzerland" we draw the ideas that spaces can be programmed based on their thermal characteristics, so that diversity, rather than homogeneity is to be celebrated (Rahm, 2010 and Rahm, 2007). From the current work of Lacaton & Vassal, such as the Latapie House, we observe that flexible, indeterminately

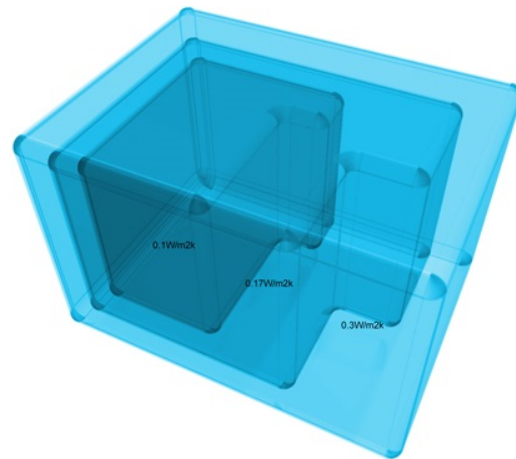


Figure 6: Diagram showing thermally nested spaces in Phillippe Rahm's "School, Neuveville, Switzerland" programed spaces can be beautiful and inspiring, yet made from the most straightforward of materials (Lacaton & Vassal, 1993). Last, the shape of such vernacular forms as production greenhouses can yield interesting possibilities for residential work.



Figure 7: Typical production greenhouse from the western NY / Southern Ontario region. Photo courtesy of Ontario Greenhouse Vegetable Growers.

Core Design Concepts

Four key concepts have informed the GRoW Home design decisions from overall organization to system selection to material detailing. These four are the DNA of the project; the implementation of each will be discussed further in subsequent pages.

1. **Recognize energy hierarchy:** Consider passive design first, conserve energy next, and contribute power last.
2. **Live with nature:** Evoke the qualities of the outdoors with plants, light, air, material, color, and connections.
3. **Think functional flexibility:** Design for a longer life with a looser fit.
4. **Nurture active stewardship:** Empower the occupant to steward resources by engaging with energy and material use.

1. Recognize energy hierarchy: *Consider first, conserve next, and contribute last.*
Consider: To design a truly ultra-efficient home, it is critical first to reduce the energy loads the homeowner (or society) incurs. For the GRoW Home, this means a small conditioned area (770sf) enclosed with a superinsulated, tight envelope of structurally insulated panels (SIPs) with twice the code-required R-value. Windows are triple paned, argon-gas filled, and low-e coated, and located to distribute reflected sunlight off adjacent walls. Ample daylight is always provided from at least two sides in each room, and this design was verified with daylight simulation, as discussed later in this paper. Dedicated ventilators sized for the cooling load on a Buffalo summer day are located high on the lee-ward sides of the house to exhaust by cross and stack ventilation air brought in through the GRoWlarium. The separation of window and ventilator allows the wall to optimize light, view, and air flow. Passive solar gain through south-facing folding glass doors is retained in the dark tile floors, which are protected from summer sun by rolling shades on the GRoWlarium walls and roof. The house itself is sheltered with shades integrated into the overhead canopy, further reducing cooling loads.

The embodied energy of materials is reduced by using locally manufactured SIPs, regionally harvested wood finishes, and locally fabricated metals. Energy from fossil-fuel-intensive food systems is reduced by growing nearly all of the produce required for the two house occupants in the home and surrounding landscape.

Conserve: Some energy is required to run a home, but the GRoW Home has carefully selected equipment and appliances to minimize this use. LED lighting is used throughout, selected for a high color rendering index and low color temperature to be pleasant and complement incoming daylight. The exterior lights are generally dark sky compliant, so that energy is used to provide light only where desired. The appliances are best-in-class performers, including an induction stove and heat-pump clothes dryer. The mechanical system serves four zones independently, so heating and cooling is only delivered where needed, and is provided with a high performance heat pump and air handler. Fresh air is supplied with an energy recovery ventilator.

Contribute: The energy that the house does consume is more than offset through production of electricity and hot water from the sun.

2. Live with nature: *Evoke the qualities of the outdoors with plants, light, air, material, color, and connections.*

The GRoW Home uniquely puts the occupants into regular contact with nature and the outdoors in various ways. The interior spaces are directly connected to the outside through doors opening into the expansive all-glass GRoWlarium, which flows seamlessly onto the covered deck and out to the landscape beyond. The outside conditions are readily perceived within the home, whether through the play of light and shadow from the overhead structure or the sight of snow drifting overhead while sipping a hot beverage in winter. Nature is brought directly into the home through rolling GRoW tables, which nurture seedlings through winter, and larger plants when warmer. These share the flexible living space of the GRoWlarium. Plantings in the deck and landscape further biophilia. Wood interior finishes and cladding, and a nature-inspired color palette throughout recall the tones of the outdoors.



Figure 8: Photograph showing the play of shadow on the exterior deck. Image courtesy of Carl Burdick.



Figure 9: Photograph showing the indoor-outdoor living space dubbed the "GRoWlarium". Image courtesy of Carl Burdick.

3. Think flexible functionality: *Design for a longer life with a looser fit.*

While designed for a life enriched by rituals of tending home and garden, the GRoW Home is designed to be flexible beyond the extents of the current programming. The main spaces are designed to open up easily to one another, creating overlaps which can be appropriated to serve new or changing programs. The materials are designed for functionality, but with wide bounds on the function they serve. The dark tile on the floor of the "wet" module allows the floor to absorb winter sun, but also allows GRoW tables to readily roll in when plants are ready for processing, and can be easily mopped afterward. The tiled walls and glossy laminate cabinet fronts allow messes to be easily cleaned. The wood flooring and walls of the "dry" module are warm to the eye and touch, and suggest a more relaxed program.

The canopy provides a flexible infrastructure for a range of functions. It holds photovoltaic and solar thermal systems, shading devices, and lighting. It also readily supports various planters, outdoor movie screens, tool storage, hanging outdoor furniture and any number of uses the occupants might put to it.

Custom-designed furniture pieces each serve several purposes. The entertainment center can either divide or open the bedroom and living space, and holds a TV which swivels to face either room. The kitchen table easily rolls from inside to outside, and has a rotating top with a wood surface for eating, and a stainless steel top for food processing. The outdoor benches can be stood up and opened to reveal a glazed box for sun drying vegetables before putting them in storage.



Figure 10: Photograph showing entertainment center, which can rotate 180° to serve living room or bedroom beyond. Image courtesy of Carl Burdick.

The LED track lighting can be adjusted and controlled zonally to suit preferences and use, and can easily be updated over time with new or different fixture heads.

4. Nurture active stewardship: *Empower the occupant to steward resources by engaging with energy and material use.*

The GRoW Home owners engage with the architecture and environment by managing the house like a captain would a sailboat, riding the waves of solar, wind, and thermal forces. To use another metaphor, the house is tended like a garden, where the industry of the activity is the source of joy. This home suggests a new set of domestic tasks related to climate and environment, similar in some ways to the installing stormwindows each fall, or spring cleaning. In the GRoW home, the owners put up the canopy shades in spring, and takes them down each fall; on a daily cycle they rolls the shades in the GRoWlarium up or down to suit. The owner removes ventilator insulation plugs when the spring gets warm, and replaces them when the fall gets cold; to modulate temperature on a daily basis, they open or close ventilator doors. The GRoWlarium has two large double doors to open the south façade of the house to fresh breezes, and roof and clerestory vents can be opened to exhaust heat.

A web-enabled monitoring system tracks electrical consumption and production, as well as climate conditions. The occupant views this information from a handheld device or computer, giving her further agency over the house's resource usage. The GRoW occupant is a "smart user", making savvy, informed energy consumption decisions. In other homes these might be left to "smart systems", which generate high performance while insulating the user from knowledge about the impact of decisions.

Compositional design

The GRoW Home is composed of four elements:

Deck: The raised ground plane of the deck establishes the home's extents. The deck is subdivided on a 12'-8" grid, and zoned from south to north in program-organizing bands of circulation, vegetation, habitation, and utility.

Canopy: The elevated plane of the canopy further defines the extents of the project, while keeping view and access open on all sides. Columns are located on the 12'8" module.

Modules: The "wet" and "dry" modules are inserted within columns between the deck and canopy, yet pull back slightly from the grid to read as distinct elements.

GRoWlarium: The glassy GRoWlarium nestles between the modules, crystalizing the spatial overlaps between the two. The spatial sequence from outside, to under canopy, to within GRoWlarium, to inside modules makes a fluid transition from outdoors to indoors. When it is very warm or very cold, this sequence is heightened by a shift in thermal experience as one moves from distinctly outside to distinctly inside.

The interior of the modules is composed of two pairs of programs bookending more indeterminate space. The "wet" module bookends of kitchen and bathroom are articulated with paired concave forms delineated with glossy white cabinetry and white tile. The "dry" module bookends of mechanical room and bedroom are articulated with paired masses of birch plywood. In between these bookends usage is less strictly defined ("work area" and "relaxation area"), where both space and program overlap between the modules and the GRoWlarium. These areas have great permeability to the outdoors: folding glass doors along one side, and ventilators along the other.

Integration of analysis into design

The GRoW home design incorporated analysis techniques at various points in the design process to inform and reinforce the decision-making. The first energy simulations were performed in the second of six terms of design studio, and therefore used a fairly preliminary three dimensional model of the house design. At this point, there were three primary questions: First, does the addition of an attached passive greenhouse space impose an energy penalty on the enclosed and conditioned portion



Figure 11: Floor plan showing major compositional elements of GRoW home



Figure 12: Photograph of GRoW home as exhibited at Solar Decathlon 2015. Photo courtesy of Carl Burdick.

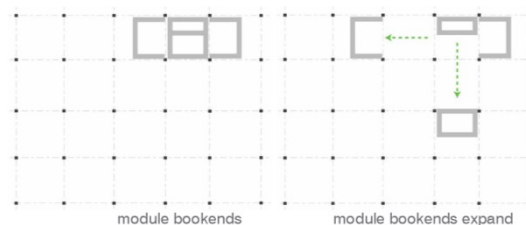


Figure 13: Diagram showing interior design "bookends" of GRoW Home.

of the home? This was broached by creating a paired set of models: a baseline house model without a greenhouse, and a design model with a greenhouse. Simulations were run in both the cloud-based Revit Energy Analysis and eQuest. These early simulations showed that, due to the added shading incorporated in the greenhouse and its role as a buffer zone, both winter and summer conditioning loads were reduced.

Solarium Study

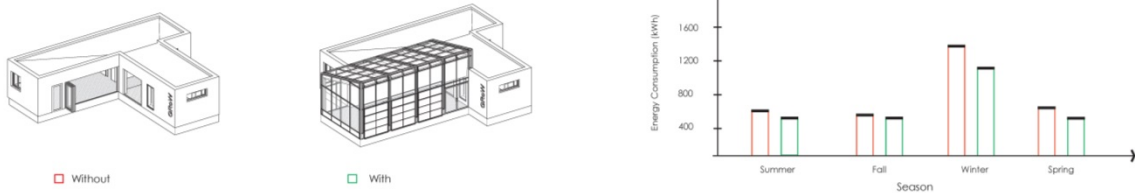


Figure 14: Results of early design-phase energy simulation runs to study attached greenhouse.

Second, where did increased thermal resistance in wall, roof, floors, and glazing begin to see diminishing returns? The design model was put to a series of sensitivity tests to determine the “sweet spot” for insulation R-value and window U-value. The results for the opaque portions of the assembly evidenced a discernable inflection point around R-40, whereas the glazing U-value assessment was inconclusive.

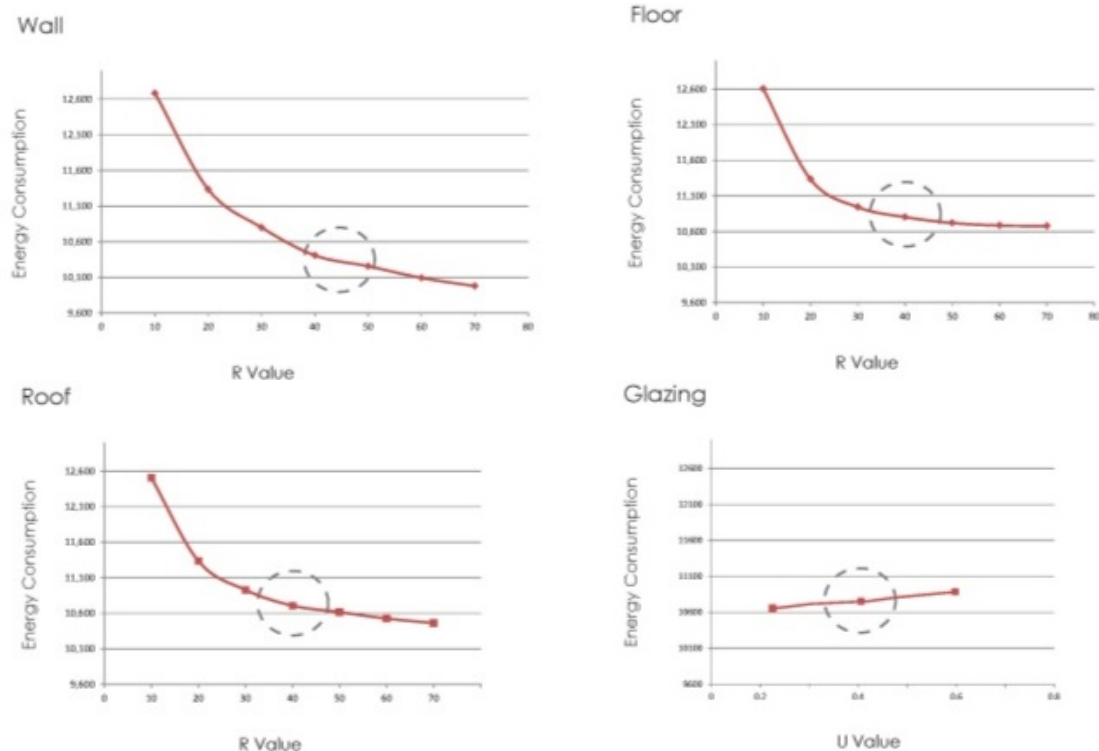


Figure 15: Results of early design-phase energy simulation runs to study optimal opaque and transparent wall resistances

Third, what was the overall annual energy production possible from the proposed size and configuration of photovoltaics in the design? A simulation using PV watts demonstrated the conditions that would provide sufficient electricity production for the predicted energy consumption during the competition period.

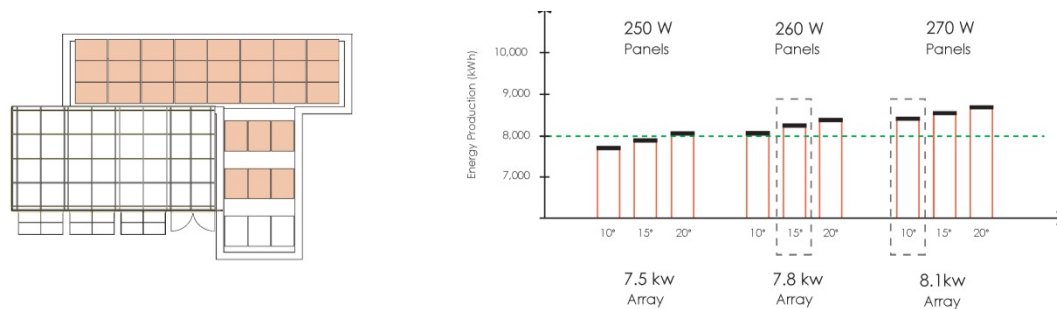
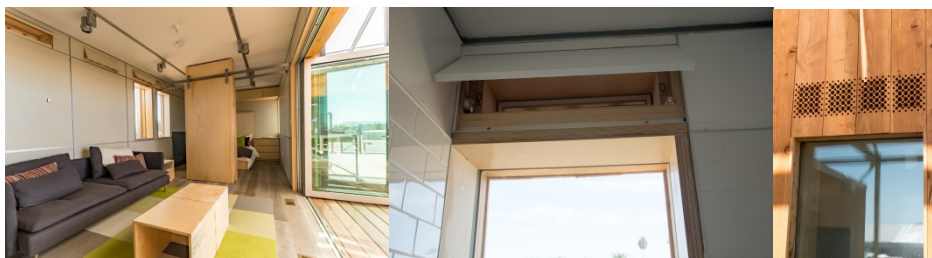


Figure 16: Results of early design-phase PVWatts studies of photovoltaic output.

In the next phase of the project, after dabbling in a somewhat time-consuming and inconclusive EnergyPlus model, a series of spreadsheet based calculations were performed to determine heating and cooling loads, using the Air Conditioning Contractors of America Association (ACCA) Manuals D and J, and the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) Standard 62.2. This allowed for the sizing of the air-to-air heat pump selected for heating and cooling.

Alongside the system selection and sizing for the mechanical system, analysis to size the passive systems of natural ventilation were also undertaken. Using the overall cooling load determined by the hand calculations described above and the average summer wind speed for Buffalo, NY, the overall size of ventilation apertures required was determined using the procedure articulated in the *Green Studio Handbook* (Kwok, Grondzik, 2007). The required area was provided on both windward and leeward sides of the building, and distributed through a series of discrete ventilators. This was a unique detail which, in contrast to a normative operable window, separated the ventilation requirements for the space from the daylighting and view requirements. The ventilators were either independent rough openings, or were constructed as part of the window rough opening in the SIP wall and subsequently framed individually. Perforations in the exterior rainscreen and an inboard insect screen, plus an interior operable aperture door provided a control mechanism for ventilation at the diurnal scale. A removable, gasketed plug of insulation allowed for ventilators to be closed on the annual scale, returning the opening in the wall to the same high-performance level as other areas of the opaque wall assembly.



Figures 17-19: Photographs showing the integration of ventilators with interior finishes, a close-up of one ventilator showing interior operable door, a close-up of one ventilator showing exterior perforations.

Given that the requirements for ventilation and lighting were disaggregated, the window placements could be driven purely by needs for daylighting and view. As an

initial set of design constraints to achieve better distribution of daylighting, windows were ideally to be provided on at least two sides of each room, located immediately adjacent to a perpendicular wall. Through this strategy light would always be bounced off multiple surfaces, improving distribution and reducing high contrast. A series of studies using Radiance through Ecotect were performed to assess daylighting quality and quantity in the space, and aperture size and number were adjusted until suitable distribution was seen in the space.

Measured Performance

The GRoW Home was exhibited at the 2015 Solar Decathlon from October 8 to October 18. As part of the requirements of the competition, the house had to perform a wide range of tasks at designated times, each of which was designed to put an energy load on the house which was representative of the loads put on a “normally” occupied home. First, the house was required to be kept within a “comfort zone” of temperature and relative humidity. Second, certain appliances had to be operated within normal ranges (refrigerator, freezer, washer, dryer, dishwasher, cooktop). Third, lighting and home electronics were required to be on; the team had to draw a fixed amount and temperature of hot water (simulating a shower) and had to host dinner parties and a movie night. Last, the team had to drive an electric car 200 miles, and end the week with it fully charged. The teams were scored in each of five measured contests based on these four requirements, and a fifth which required them to do it while using a total of 175kWh or less while remaining energy positive (producing more energy than consuming).

In these five contests, the GRoW home performed admirably. The four zone heat pump system delivered adequate cooling when required (albeit with a 2+ hour throttling period on the hottest days), and the superinsulated walls and high-performance windows kept the house at temperature with minimal added energy. This earned the house the top prize in the “Comfort Zone” contest. Excepting the nightly temperature swings in the freezer due to an auto-defrost which could not be manually deactivated, the top-of-the-line appliances performed reliably throughout, earning the team second place in the “Appliances” contest. A botched first hot-water draw marred an otherwise nearly flawless performance in the “Home Life” contest, earning the team fourth place. As with most teams, the electric car performed as expected, earning the team an 11-way tie for first place.

Most notably, however, among this performance, is that the GRoW home performed all required tasks in the 10-day period while only consuming 161 kWh. This was the lowest consumption of any team which performed all of the required tasks, and the only team to stay within the 175kWh threshold performing the tasks. (Mass/Central America did not perform many of the driving tasks, and did not always have functioning appliances and HVAC system. Texas/Germany also had problems with their HVAC system operations.)

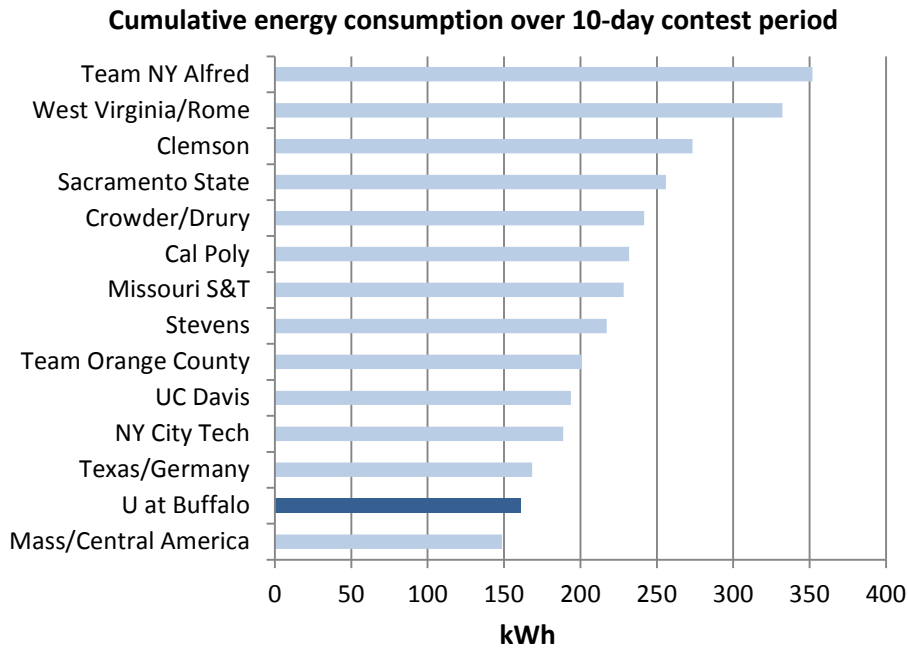


Figure 20: Chart showing each competing project's cumulative energy consumption, in kWh, over the contest period.

Along with eight of the thirteen other competitors, the GRoW home finished the contest period with a net positive energy balance. The GRoW home had the third highest energy balance, at 79kWh net positive. Arguably the PV system was designed with a larger than necessary safety factor.

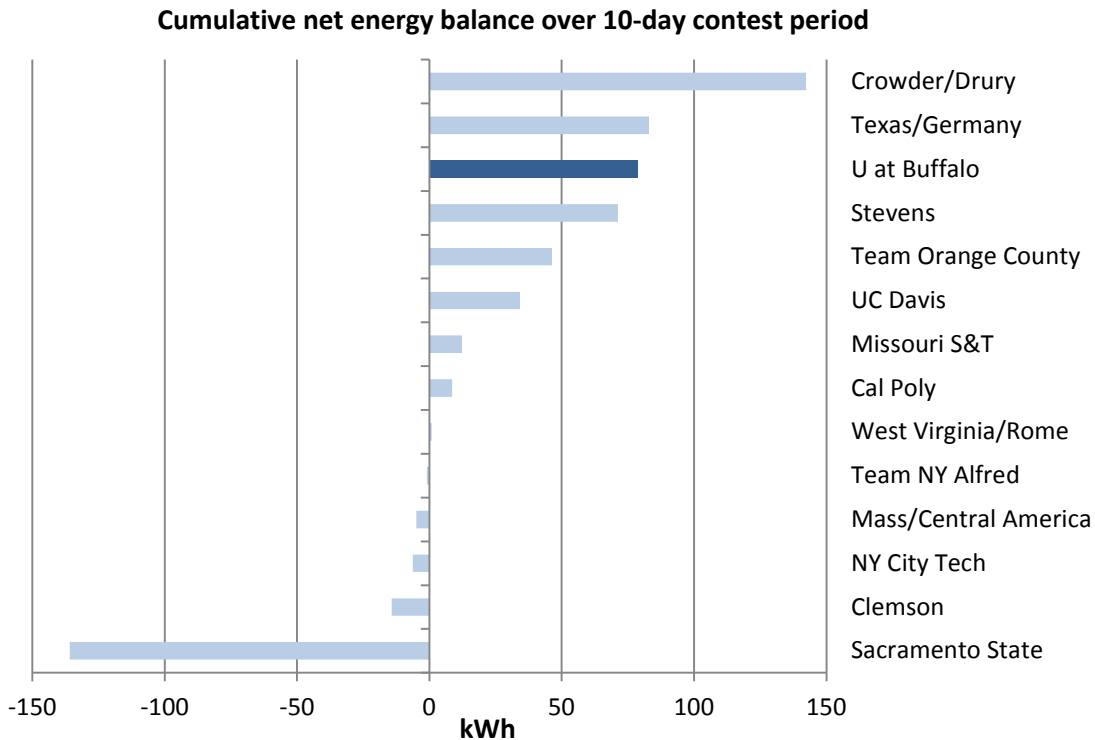


Figure 21: Chart showing each competing project's cumulative energy balance, in kWh, over the contest period.

Conclusions

The GRoW home project set out rather ambitiously to provide a unique occupant experience of solar design. Based upon feedback from and engagement with roughly 12,000 visitors during the 10-day exhibition period, it can be said that the public responded well to the sequence of spaces leading into the home, and were drawn to the core GRoWlarium space.

The public also responded well to the suggestion of new energy-based rituals of the home, from the annual installation / removal of the ventilator plugs, to the daily adjustment of shading devices, to the seasonal moving of the GRoW tables, visitors were intrigued by these elements which allowed them to take unique actions in the operation of the home. The GRoW tables were particularly popular, and many visitors remarked that they would make food cultivation so easy that they might take on gardening; several others observed how the tables accommodate gardening for children or those with limited physical ability to bend and kneel.

While we anticipate that this increased agency will engender greater stewardship of resources, this is ultimately a hypothesis, which will need to be tested over a longer period of time with a consistent occupant. The competition setting does provide a vehicle for rigorous testing of house performance, but it cannot truly test the kinds of longer-term behaviors which would emerge from interaction with an innovative residential design.

The home will be set up semi-permanently on the campus of the University at Buffalo; after an initial exhibition as a home, the building will be converted into a multipurpose space for seminars, professional education classes, and faculty research. Beyond the obvious questions about long-term performance and energy-related user behavioral choices, there has also been faculty interest in studying occupant behavior relative to food production, obesity, and food choices.

The GRoW home was proven through the Solar Decathlon contests to achieve high energy performance as a house, resulting in its second place overall finish. Also, through its conception and implementation within many constraints, it also presents an innovative and unique piece of architectural design.

Acknowledgements

The work of the GRoW home was carried out through nearly 3 years of effort by over 200 students from 14 departments across the University at Buffalo. While too many to name here, their many contributions are noted and honored.

The custom furniture described in this paper was developed in a seminar led by Assistant Professor Nick Rajkovich.

The information, data, or work presented herein was funded in part by the Office of Energy Efficiency and Renewable Energy (EERE), U.S. Department of Energy, under Award Number DE-EE0006549.

The information, data, or work presented herein was funded in part by an *agency* of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

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