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Energy technology and lifestyle: A case study of the University at Buffalo 2015 Solar Decathlon home

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ABSTRACT

This paper reports the design process and measured performance of the University at Buffalo's net-zero energy prototype, the GRoW home, designed for the 2015 Solar Decathlon in Irvine, CA. Sustainable design intentions and pragmatic constraints are discussed in addition to the energy considerations for each design element. The GRoW home includes features designed to support a unique lifestyle, including an integrated greenhouse (the "GRoWlarium") and various operable systems under the occupant's control. Whole-building energy simulations, spreadsheet calculations, daylighting simulations, and proprietary sizing software were used in design decision making. Energy performance predictions and measured results from the 2015 competition are discussed. The home was predicted to consume 177.11 kWh, and produce 238 kWh during the competition; it actually consumed 161 kWh, and produced 191 kWh, an error of 3% and 8%, respectively. The GRoW home ultimately had the lowest energy consumption of any SD 2015 house which successfully performed all competition-required tasks.

1. Introduction

Buildings use a tremendous amount of energy and are thus responsible for between 25 and 40% of greenhouse gas emissions globally, and 40% of total US carbon dioxide emissions [1]. US buildings as a group represent 7.4% of total global carbon dioxide emissions [2]. The societal challenge from building energy consumption is at once technological and cultural, but building professionals such as architects and engineers are well positioned to deal with this sort of problem [3]. If the built environment is to reduce consumption of energy and emissions of CO2 it will require grappling not only with technological aspects of building systems and assemblies, but also with aesthetic and behavioral aspects of how spaces look, feel, and work [4,5].

In addition to problem solving directly about energy, the building professions can use design to galvanize public consciousness about energy consumption issues [6]. However, one study indicates that mainstream construction of more sustainable housing does not challenge normative ideals of urban housing standards, lifestyles and household configurations; rather it treats the high-performance home as just another energy-efficient building, ignoring the uniqueness inherent in designing homes [7]. At the same time, some researchers have explored mechanisms for improving energy performance through strategies which are both technical and behavioral. For example, autonomous house prototype projects from the 1970s like the Biotechnical Research and Development project and the Centre for Alternative Technology sought to support a different way of life, and incorporated not only energy efficiency and energy production, but also food production, and water treatment and collection [8]. Current "smart" residential energy approaches focusing on smart grids, meters and appliances suggest a particular lifestyle coordinated with the use of these technologies [9,10]. Based on the state of the art, it seems that neither lifestyle changes nor technological solutions alone are sufficient to bring down residential energy consumption. Meeting aggressive energy reduction goals requires both lifestyle adjustments and building optimizations [11].

The Solar Decathlon is one program promoting innovations in making and occupying homes. The Solar Decathlon is a biennial event hosted by the U.S. Department of Energy (DOE) which is at once competition, exhibition, and teaching tool.

First, and most obviously, it is a competition for collegiate schools to design, build and operate exceptionally high-performing single-family houses [12]. Competing homes are required to meet exact criteria and perform specific tasks; they are scored in ten separate, equally weighted categories as well as overall. These contests are as follows [13]:

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1. Architecture: The house had to demonstrate architectural conceptual coherence, merit and integration, and be well documented. (Juried)
2. Market Appeal: The house had appeal to a team-defined client market. (Juried)
3. Engineering: The house had to exhibit engineering innovation, functionality, efficiency, and reliability, and be well documented. (Juried)
4. Communications: The team had to educate the public well about their project through materials online and on-site, as well as public tours. (Juried)
5. Affordability: The house had to be professionally estimated to cost under $250,000 to earn full points. (Juried)
6. Comfort Zone: The house had to be kept within a comfort zone of 71–76 °F (21.7–24.4 °C) and less than 60% rH. (Measured)
7. Appliances: Certain appliances (refrigerator, freezer) had to remain on in a “normal” fashion, while others (washer, dryer, dishwasher, cooktop) had to be operated in a normal fashion at prescribed times in the competition period. (Measured)
8. Home Life: Lighting and home electronics were required to be on during specified hours, and the team had to draw a fixed amount and temperature of hot water (simulating a shower) and host dinner parties and a movie night for a group. (Measured)
9. Commuting: The team had to drive an electric car 200 miles (322 km), and end the competition week with a fully charged internal battery. (Measured)
10. Energy balance: The teams were required to use a total of 175 kWh or less while at the same time producing more energy than they consumed. (Measured)

Second, the Solar Decathlon is an exhibition. Its structure yields a set of houses which demonstrate the newest market-ready domestic energy technology in an accessible, public-friendly tour format. In recent years, Solar Decathlon projects have displayed increasingly ambitious design agendas. Many teams have found ways to incorporate additional design objectives without compromising the measured performance required for competition success. For example, the SU + RE house demonstrated resilient design strategies appropriate to the coastal flooding vulnerabilities in its home city of Hoboken, NJ, which was hard hit in Superstorm Sandy in 2012 [14]. The ShelteR^3 house was able to function not only as a house but also as a disaster response command center or relief housing following a tornado, a common weather event in its Missouri home [15]. The Watershed house included water collection and treatment strategies to protect its local watershed, and by extension the threatened Chesapeake Bay ecosystem [16]. Perhaps because the competition criteria are intended to achieve the overall mission of the Solar Decathlon to “accelerate the adoption of energy-efficient products and design” the contest categories and criteria do not overtly reward these kinds of design augmentations [13]. One could argue, however, that juries take these agendas into account when evaluating projects subjectively.

Third, the Solar Decathlon is an intense post-secondary teaching tool. For at least two years leading up to the competition, teams from participating universities collaboratively conceptualize, design, analyze, document, construct and test their homes. These tasks require assimilation of known best practices and innovation of novel techniques in order to achieve exceptionally high levels of performance.

This paper presents details from the design process of the GRoW Home, the University at Buffalo's entry into the 2015 Solar Decathlon, and describes the way in which energy design and analysis tools were deployed to create a well-integrated, conceptually innovative, high-performance solar home. Photos of the GRoW Home are shown in Figs. 1 and 2, and a floor plan is shown in Fig. 3. The GRoW home came in second place overall in the 2015 Solar Decathlon, just 9 points out of 1000 from the top position, and placed first in energy balance, thermal comfort, and commuting. Notably, the home consumed only 161 kWh during the 8-day contest. This was the lowest consumption of any team which completed all tasks, and the only team to stay within the contest's 175 kWh threshold while doing so.

2. Design intentions

In the GRoW Home early design phases, the team made an effort to situate the project within the thinking of architectural practitioners and theoreticians, and respond critically to their ideas. For example, historian and citric Reyner Banham recognized that advanced space conditioning systems arising during early modernism led to a decoupling of architectural design from the responsivity to climate, and argued that recoupling these would again allow for differentiation within formal responses [17]. Picking up on this line of thought, the GRoW home reasserts the duty of the architect to inflect spatial design based on the particular climate resources available; its walls are thick and openings modest to reflect the cold winter climate in Buffalo, yet an untempered glass room (called the “GRoWlarium”) allows the occupant to tune the space to his/her taste during the swing seasons with operable windows, doors, and shading. From French architecture firm Lacaton & Vassal came the idea that flexible, indeterminately

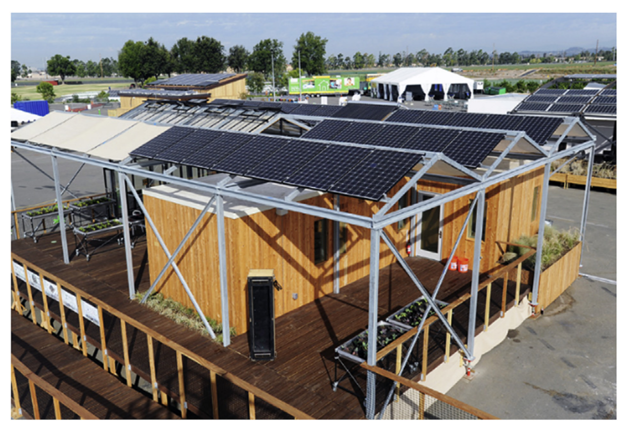

Fig. 1. The GRoW Home by day at the competition site in Irvine, CA. Photos by Thomas Kelsey/U.S. Department of Energy Solar Decathlon.

Fig. 2. The GRoW Home by night at the competition site in Irvine, CA. Photos by Thomas Kelsey/U.S. Department of Energy Solar Decathlon.