Chapter 61
The Road to Integrated Design Process of Net-Zero Energy Solar House

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Abstract *An integrated design proce*ss encourages holistic collaboration of the design team to optimize solutions in an iterative development of a building design. This chapter discusses the design process of a net-zero energy solar-powered house developed for the 2013 solar decathlon competition to promote high-performance design while using traditional passive strategies. The University of North Carolina Charlotte (UNC Charlotte) entry tries to effectively integrate building systems' components to minimize energy consumption while optimizing comfort. To that end, each component delivers multiple functions.

Being part of a large and varied team, seeing a project from the preliminary design phase to construction and commissioning, the students were provided a true multidisciplinary hands-on opportunity. The opportunity proved to strengthen their technical skills, acquired in the regular curriculum, via integration of theoretical knowledge and practical experience. Moreover, organized in a multidisciplinary format, students were then able to share their strengths across disciplines and contribute to a synthesis of process and product. The greatest learning experience for the students occurred in the *integrated design process*—across engineering disciplines, architecture, and business—the student team members also learned how to raise funds, procure materials and construction equipment, and how to interact with one another. *This chapter reports a way of effectively designing and iteratively modeling process to inform the design decisions.*

Keywords Energy codes · Ventilation code · GPRS · Green building code

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61.1 Introduction

UrbanEden house was one of the 19 houses built through an international competition sponsored by US Department of Energy (DOE)-Solar Decathlon. The challenge was to design and build an affordable, innovative, and fully functional energy-efficient home that addressed each team's local geographic setting. The home was then to be deconstructed, transported, and reconstructed at the Marine Corp Air Station El Toro, a closed airstrip that is now part of Orange County Great Park in Irvine, CA.

The 19 participant houses were evaluated during the competition week. There were 10 contests. Each contest was worth a maximum of 100 points, for a competition total of 1000 points. These contests included juried contests (engineering, architecture, market appeal, communications, and affordability), and measured contests (comfort zone, hot water, appliances, home entertainment, and energy balance).

In this chapter, the road map to this experience from its initial concept to the real construction is presented. This study illustrates that an integrated engineering-assisted design is feasible and helpful at the very beginning stage of a project. To develop an economical viable solar house, concerns about affordability and aesthetic become relevant. No longer can expensive technologies that have limited relevance to the budget-driven residential construction industry in the USA be the main driver to reach performance goals. Therefore, our strategy was to achieve attractive, low-cost high-energy balance performance (Fig. 61.1).

The name of the project was derived by combining its two key environmental influences: "Urban," representing Charlotte's urban, densely populated geographical makeup and "Eden," aptly symbolizing a quiet and lush garden. "The whole concept was to build a house that brings the garden into the city." Students and faculty, from different colleges took the original design submission and began shaping concept into reality. This mix of academic backgrounds provided a wide range of ideas and collaboration. It would not have been feasible without a cross-disciplinary approach and that will lead into best results.

Fig. 61.1 The solar village on the great park at Irvine, California. (Credit: solardecathlon.org)

Our team was composed of experienced faculty, in addition to enthusiastic faculty and students. This project brought together a diverse team of faculty, scientific staff, and students to both lead and organize the project. Although support is being drawn from many colleges within the University, much of the project direction stems from the Colleges of Arts and Architecture (architecture, graphic design, and communication), Engineering (electrical engineering, computer science, building technology, project management, and civil and mechanical engineering), and Business (business administration, finance, and marketing).

Our first task was to publicize the Solar Decathlon project to the student body through a lecture series and invite students from architecture, engineering, and business. Approximately 100 students from architecture, engineering, and business have been regularly involved in research, planning, and strategy meetings. Fifty of these students were in attendance at a single design charrette in the spring. About 20 undergraduate and graduate architecture students took the results of this collective work and generated the conceptual design materials represented in the proposal. The next task was to meet with the administration, including the deans and the department chairs to solicit their support and initiate the advisory board. Student and faculty representatives from these varying backgrounds worked together to provide a well-rounded perspective of the project goals, so that integrated design, energy, affordability, and marketing goals and considerations were met.

61.2 The Design Process

The students involved with the Solar Decathlon project drew all of their strengths and skills to troubleshoot, communicate, dream, and build an original solar-powered house. The competition challenged them to think about energy in new ways and to consider the impacts it has on their everyday lives. With the expertise of our team and the intelligence and will of our students, this project helped advance the research and development of energy efficiency and energy production technologies. The students fully understood, from the outset, that the house must be powered entirely by the sun (Fig. 61.2).

Fig. 61.2 Design charrette

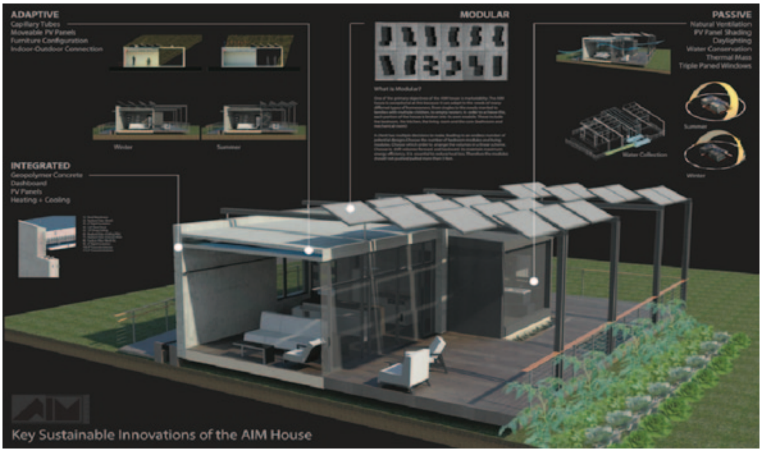

Fig. 61.3 Key sustainable features

61.2.1 Design Objectives

The overall objective of the competition was to design and build a maximum 1000 SF solar powered house. The design and construction of a net-zero energy solar house incorporated both passive and active strategies. The UrbanEden house focused on incorporating innovative passive strategies and developing new material, integrated with heating and cooling systems of the house, allows to provide a better comfort for the inhabitants while reducing the negative impact on the environment (Fig. 61.3).

61.2.2 Design Team and Design Process

Several design charretes were used during the beginning of design process to generate multiple concept and ideas. Several students from different levels and disciplines came together voluntarily to initiate the design ideas. First charrette comprised 50 architecture students. Each team created multiple preliminary designs which were then reviewed by the entire group. Through this process, the team collaboratively selected a single-floor plan design.

61.2.3 Selection of the Final Design

After the charrette series and preliminary design stage, the students finalized the house's concept in summer 2012. The integrated studio in the summer comprised 20 architecture students and about 8 engineering students who worked together

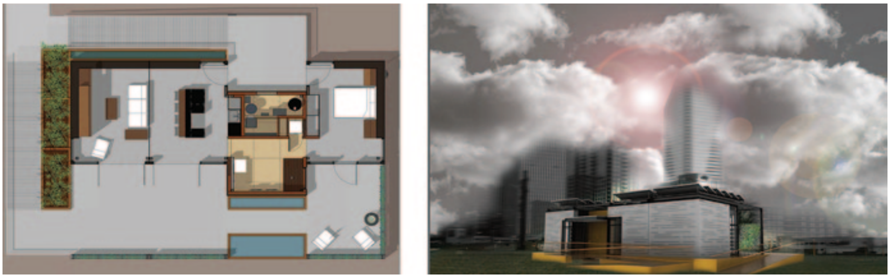

Fig.61.4 Selected design, *Left*: plan drawing, *Right*: rendered model

Fig. 61.5 Selected design concepts

to finalize the concept of the house, basic structure, and the materiality under the supervision of the faculty mentors and advisors (Figs. 61.4, 61.5).

61.2.4 Net-zero Energy Performance Parameter of the Design

A thorough energy analysis was executed to understand the energy consumption implications of each aspect of the design. To achieve net-zero energy performance, the design of the house itself was first analyzed. Before any energy modeling or climate analysis was done, an overall design theme was created based on one simple idea: the house is continuously transferring energy to and from the environment and it is our job to precisely regulate this energy exchange to naturally maintain comfort. This fundamental idea was behind all of the team's passive strategies and techniques and led to the highly integrated and efficient design of the house. The team's approach started from basic climactic principles: the main source of energy on planet earth is the sun, and in the northern hemisphere during the winter, most of its radiation is received on the southern facade of buildings. In Charlotte, in the winter, south-facing windows utilize this heat. In the summer, this solar gain is not desirable and can be easily avoided by overhangs on the roof, which are long enough to block the summer sun. The strategic placement of windows also allows the house to be autonomously daylit during the daytime.

The traditional passive solar strategy of thermal mass storage was also an integral element of our strategy to achieve net-zero energy. Since a massive object can absorb large amounts of heat without rising much in temperature, it is able to build up heat energy and still maintain its temperature gradient with the outside environment. It effectively stores energy in the form of heat and will release it once the ambient temperature drops. This simple fact is exploited in the UrbanEden house by using thick concrete slabs for the walls. The concrete used in the UrbanEden house, is custom-made, high-density fly ash based concrete. High-density material, such as concrete, absorbs heat when the temperature around it is higher and gives off heat when the surrounding temperature is lower. Our geopolymer walls store and release solar heat in the winter and pull heat out of the air in the summer, reducing temperature fluctuation in the house.

An innovative passive/active hybrid cooling system features roof mounted heat exchangers connected to small plastic tubes embedded in the concrete walls. On a hot day, flowing cool water removes the heat absorbed by the walls and releases it into the evening sky. This process is through integration of capillary tubes that are1/8th of an inch in diameter. These tubes are places close together and imbedded 3inches deep inside of the walls.

The house was primarily designed for Charlotte's climate. Manual J load calculations and BEOpt energy simulations were used to inform design decisions. The house energy and load modeling analysis was done independently of the design of the capillary tubes and roof heat exchangers system. Our approach was to optimize the design of the house and its heating, ventilation, and air conditioning (HVAC) systems, per se, and treat the capillary tube/roof heat exchanger system as a "bonus" to the energy performance of the house. Any cooling load met by the capillary tube/roof heat exchanger system would remove this load from the mini-split heat pump. Assumptions and calculation results are displayed in Table 61.1.

To meet the code the UrbanEden house requires about 23 CFM of ventilation. Supplying this ventilation and recovering some of the lost energy is energy recovery ventilation (ERV) which will run at 50 CFM. The required rate of ventilation is doubled because the return duct is located in the bathroom supplying its 50 CFM

Table 61.1 Significant parameters of Building Energy Optimization (BEOpt) energy model

Energy model parameter	Setting
Wall insulation	R-30
Floor insulation	R-30
Roof insulation	R-55
Continuous ventilation (based on ASHRAE 62.2)	25 CFM
Water heater	Heat pump water heater
Window shading summer	90 %
Window shading winter	5 %
Infiltration (based on Passivhaus standards)	0.03 ACH
Window U-value	0.2
Window SHGC	0.5

ASHRAE American Society of heating, Refrigeration and Air Conditioning, *U-value* opposite of R value, rate of heat transfer, *SHGC* Solar Heat Gain Coefficient, *ACH* Air Change per Hour, *R-30* thermal resistance, *CFM* cubic feet per minute exhaust requirement. This heat loss of this ventilation is calculated to equal 1.7 kBtu/hr. The UrbanEden house is designed to achieve an average annual infiltration rate of 0.03 air changes per hour. In that case the effect on the load is negligible and is calculated to be 115 Btu/hr. Since this parameter is not certain, it is modeled at a couple different values.

After simple calculations, it is easily seen that the windows are the critical factor in the design. They take up an area of about 400 sq ft which is a large fraction of the total wall area. The windows have an R-value that is about 10 times less than the walls. 75 % of the windows are on the southern wall where most of the desirable solar radiation is directed. This design works well for passively meeting winter heating loads but posed a problem of increasing the summer cooling loads. The solution to this problem was found in two places, the window construction and, more importantly, the window shading. Shading provides an easy way to block undesired solar gain and can cut the cooling load in half. The total peak heat loss through all of the windows is 1.468 kBtu/hr. This is even less than the load contributed by the insulation and ventilation showing that with high-quality windows the loads can be kept down while still retrieving plenty of sunlight.

BEOpt used to model the house, contains optimization tools that allows one to optimize one or several design factors, such as window area or wall insulation, for annual energy performance. Table 61.1 shows the significant input parameters of the UrbanEden house BEOpt model. Figure 61.6 compare the performance of the UrbanEden house against a similar "typical," or "code," house.

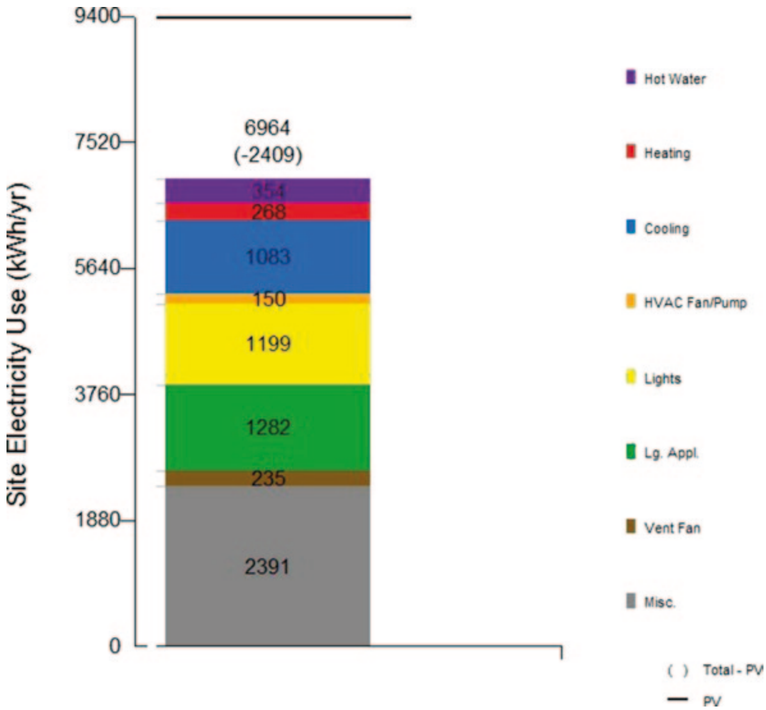

Fig. 61.6 Annual end energy consumption by end use

61.3 Strategy for Project Execution

The studio in the fall semester 2012 then worked in different work groups broken up by area of focus: interior design, exterior (envelope), structure and material development, estimating the cost, and exterior landscape design. The preliminary design was then refined, reviewed, and construction drawings were created. The groups created material lists, estimates, and construction schedules. This construction packet was submitted to the DOE for review and comment through the process. At the end, the students had created around 100 pages of construction documents, a BIM model, and 600 pages project manual.

Once the project and all the construction documents were approved by DOE, and the permits were gathered for state construction, the students started to construct the house on a site located on campus near engineering departments. The students themselves built much of the house except the concrete walls and floors, which were poured in a local plant, in addition the steel manufacturer built and erected the steel structure. Students worked with industry professionals to build and commission the home in preparation for the competition in Irvine California. While the student construction team were working on the home, other team members were working on finalizing the website, brochures, talking points and tour presentations, dinner party menus and logistical plans (Fig. 61.7).

Once the home was completed on campus, the teams hosted multiple open houses for the public before packing the home up for transportation. The house was taken apart and shipped to the competition site in California. Students along with faculty mentor, construction and project managers rebuilt the home in 7 days. They, then, competed in five juried and five measured contests while hosting open houses and dinner parties over the course of 10 days. Then, the home was disassembled in 4 days and shipped back to North Carolina.

Fig. 61.7 Construction on campus

Fig. 61.8 UrbanEden house completed on the site. (Photos:Solardecathlonorg)

61.3.1 Construction and Transportation

The core crew under the supervision of construction and project managers planned, scheduled and controlled the procurement, material deliveries, and the construction.

After over a year of countless planning meetings, design work refinements and securing donor commitments, UrbanEden was ready for construction. Four months later, UrbanEden had become the long-awaited, tangible reality. Days later, the steel beams, concrete foundation, solar panels, decking—every piece of UrbanEden—was painstakingly disassembled by the team. Using two large forklifts, everything was slowly loaded onto five flatbed trailers and two box trucks. As with any large-scale logistics effort, there were challenges (Fig. 61.8).

61.4 Roadmap for the Future

The ultimate goal of the UrbanEden was the establishment of a living lab, solar energy research center. The house will reside permanently on UNC Charlotte's campus, near the EPIC building. Several interdisciplinary research projects and classwork will emerge in this "living" laboratory. Many plans to work with a team "to collaborate on measurements, verification and monitoring of the house when it's reassembled." Graduate students pursue their thesis, studying the UrbanEden's integrated systems.

61.5 Outcomes of Solar Decathlon

Stretching every last watt of electricity that is generated by solar–electric panels or saved by passive heating and cooling features, the students treated energy as a precious commodity; they strived for innovation through the use of high-tech materials and ingenious applications of design elements. During the process, the students learned how to collect supplies, talk to subcontractors, raise funds, meet budgets, communicate across disciplines, and build their solar house. This problem-based and active learning model reinforced and advanced the kinds of nontraditional education known to deepen learning and build professional development skills.

With integrated business, construction management, and communication expertise, we committed to strong internal and external communication efforts. We anticipated a highly student-driven problem-based learning process that would be mission driven and life-changing for student participants as they begin their careers. Through the design and creation of our decathlon entry, our focus was on both student and community education. Our House is a bridge into the future for students. It demonstrated the inspiration and guidance the University can bring to the community and the contributions we can make to advancing sustainable technologies and practices for businesses and municipal agencies in our region.

Upon completion, thousands of visitors toured the competing houses for 8 days. UrbanEden team members proudly introduced their entry, demonstrating all of its sustainable features from a revolutionary geo-polymer concrete to flexible rooftop solar panels. Its lush, 7 ft tall "L" shaped vertical garden was a particular crowd favorite.

61.6 Conclusion

This chapter tried to present the story of the journey of Solar Decathlon project. To accomplish the project, students not only represented their individual discipline but also they mostly integrated in different areas to accomplish the goal of the project. Our 2013 Solar Decathlon effort was very successful and enjoyed tremendous campus support. Just making it to the competition site in California and competing was a huge accomplishment. Finishing third place in engineering and winning the People's Choice Award, showed that people liked the house and felt it was comfortable and livable.

With integrated business, construction management, and communication expertise, we committed to strong internal and external communication efforts, diligent scheduling and project management, skilled budgeting and fund-raising efforts, and creative technical expertise that had engineers and architects working in tandem to attend to every detail of design. It was a highly student-driven problem-based learning process that was mission driven and life-changing for student participants as they begin their careers. The faculty team and advisors committed and successfully and strategically integrated the project into the curricula and they guided and supported our student team throughout the process. Through the design and creation of our decathlon entry, our focus was on both student and community education. Our House is a bridge into the future for students. It demonstrated the inspiration and guidance the University can bring to the community and the contributions we can make to advancing sustainable technologies and practices for businesses and municipal agencies in our region.

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Further Readings

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