THE ROAD MAP TO THE INTEGRATED DESIGN PROCESS OF A NET-ZERO ENERGY SOLAR HOUSE: A CASE STUDY OF A SOLAR DECATHLON COMPETITION ENTRY

Mona Azarbayjani, Benjamin Futrell, Valentina Cecchi, Thomas Gentry, and Aba Ebong

INTRODUCTION

This paper discusses the design and building 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. This project, sponsored by the Department of Energy, brought together students from architecture, engineering, and marketing departments to design and build the house of the future. The challenge was to design a net-zero energy completely solar-powered house that is economically viable, aesthetically pleasant, and completely functional as well. Given that a net-zero energy building will rely on the functional interdependency of a building's passive and active elements, the UNC Charlotte entry—the UrbanEden house—tried to effectively integrate those elements and deliver a best practice. To that end, the building envelope embraced passive strategies to minimize the annual heating and cooling loads and to optimize natural lighting. Several design ideas were tested via energy simulation to optimize energy and comfort performance. The estimated energy demand led into the design of the photovoltaic system, which has the dual function of producing energy and acting as a shading device. The modular configuration of the house accommodated the transportation of the house across the country while enhancing the future expansion of the house for bigger size applications. Daylighting simulation was performed to finalize the building openings and address the lighting needs. This paper reports a way of effectively designing and constructing a net-zero energy, comfortable, and affordable solar house.

KEYWORDS

net-zero energy, solar-powered house, modular, passive heating and cooling strategies, photovoltaics, thermal mass

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UrbanEden House designed by University of North Carolina at Charlotte. (solardecathlon.org)

1. BACKGROUND

The 2013 U.S. Department of Energy Solar Decathlon was a competition between twenty teams of students from colleges and universities across the globe. Contending teams are challenged to design and build an attractive, energy-efficient, cost-effective house that is powered entirely by the sun. The competition is sponsored by the U.S. Department of Energy and held in October in Irvine, California. The purposes of the competition are both educational and research-oriented, working to educate students and the general public, building industry, and policy makers to develop new technologies and methods. Jointly, these two objectives promote collaboration, which results in developing new strategies in construction and operation of high-performance buildings.

All the 20 participant houses were evaluated during the competition week. There were 10 contests. Each contest is worth a maximum of 100 points, for a competition total of 1,000 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).

The design and construction of a net-zero energy solar house incorporates both passive and active strategies. The UrbanEden house focuses on incorporating innovative passive strategies and developing new materials integrated with the heating and cooling systems of the house, providing better comfort for the inhabitants while reducing the negative impact on the environment.

In this paper, we discuss the road map of this experience, from its initial concept to the actual construction, which involved multi-disciplinary knowledge of architecture, civil, mechanical, and electrical engineering. This study illustrates that an integrated engineering-assisted design is feasible and helpful at the very beginning stage of a project. To develop an economically viable solar house, concerns about affordability and aesthetics become relevant. No longer can expensive technologies that have limited relevance to the budget-driven residential construction industry in the U.S. be the main driver to reach performance goals; therefore, our strategy was to achieve attractive, low-cost high-energy balance performance.

Many traditional housing systems in North Carolina are environmentally adaptive. The traditional design house utilizes an architectural form that enables efficient passive cooling through manual adjustment of the building skin. Our project, UrbanEden, is a playful nod to this legacy, combining it with the target of maximizing energy performance through integrated adaptability. This was inspired and accomplished by utilizing performance modeling and automation technologies and by maximizing the effectiveness of simple, proven, and cost-effective passive heating and cooling strategies.

In this paper we discuss the design solution and methods of integrating architectural and engineering knowledge at different stages of the design in order to achieve the mutual goals of function, aesthetics, economics, and performance.

FIGURE 1. The Solar Village on the Great Park at Irvine, California. (solardecathlon.org)

2. OVERVIEW OF HOUSE CONFIGURATION

UrbanEden is a net-zero, solar-powered prototype house designed for the climatic conditions of Charlotte, NC, and consists of four integrated interior modules, each with a corresponding exterior component. In response to Charlotte's temperate climate and the habits of Southern living, UrbanEden increases the living space with a series of connected indoor and outdoor rooms, which create a versatile environment that can be adapted to multiple uses, allowing the home to be small but feel big. The vertical garden on the south side of the porch provides privacy and natural beauty.

The house's canopy shelter at the entrance creates an inviting entry to the home while also providing a space for casual gathering.

FIGURE 2. UrbanEden concept.

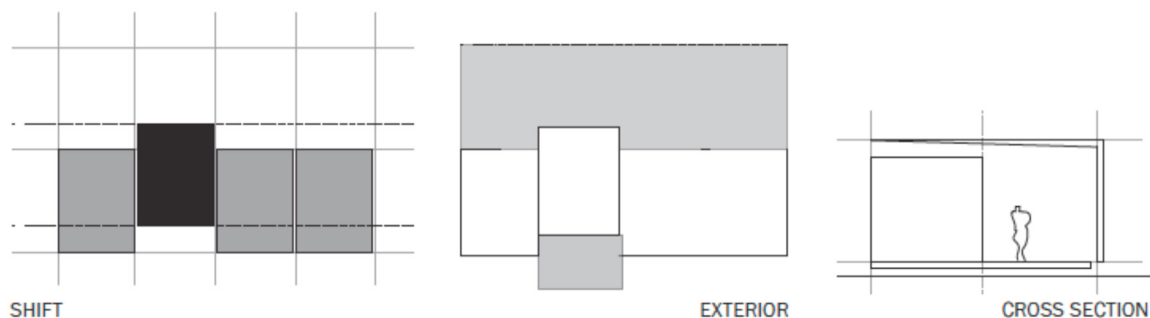SHIFT   EXTERIOR   CROSS SECTION

FIGURE 3. Floor plan of UrbanEden House.

Upon entering the house, there would be multi-purpose living, kitchen, and dining areas awash with natural light, with a lovely view to the exterior garden through the south-facing glass wall. Urban living defines the design, both interior and exterior. Emphasis is on adaptability and versatility, doing more with less.

The furniture is also reconfigurable. A table stored under the kitchen counter can be brought out to seat eight people for dinner. As depicted in Figure 4, the television pivots and the living room furniture can be moved outside to provide a sitting area for relaxing and watching TV. When guests come to stay, a Murphy bed descends from the wall, creating an extra sleeping space—indoor or out. The internal core of the house contains mechanical space, a water closet, and a day-lit full-sized bath.

At 822 square feet, the interior of the home comfortably accommodates a single occupant or couple, and by utilizing the outdoor space, the home doubles to 1644 square feet.

Modular

UrbanEden is designed to match the rhythms of urban living, maximizing customization and adaptability through a modular design. The house includes four basic modules—living room, kitchen, wet core (bathroom and mechanical room), and bedroom. Homeowners can upgrade each of these modules or add additional modules linearly. Each of these modules has their independent function, with the possibility of rearrangements, mass production, and endless opportunities to reconfigure the house. As shown in Figure 5 the modules are all lined up with the exception of one, which sets back and creates a welcoming entrance to the house.

FIGURE 4. Flexible design of the interior.
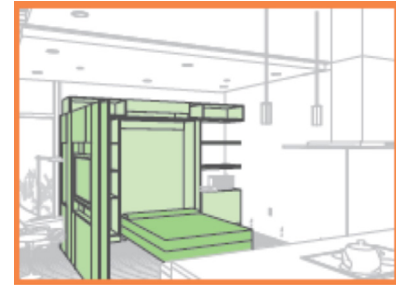
The modular design was also the result of the competition requirements of fast assembly, disassembly, and easy transportation across the country.

The modularity of the house allows the owner to make multiple decisions, catering to their needs and leading to an endless number of potential designs. The owner starts by choosing the number of bedroom modules and living modules, then chooses which order to arrange the volumes in a linear scheme, and finally chooses which modules to shift forward or backward. Arrangement possibilities include four, five, and six modules. Adding an additional bedroom or living module makes the home large enough for families or those who desire more space. In order to sift out the designs that meet the objectives of the UrbanEden house, three essential rules can be employed:

1. The kitchen module and the living room module should be placed next to each other and not separated by walls to ensure an open floor plan.
2. The kitchen module should be placed next to the core module where mechanical and plumbing functions are housed for ease of plumbing connections.

FIGURE 5. Modular design.

FIGURE 6. Examples of house plans with more modules.
a) 4 modules arrangement—1 bedroom, 1 living room, 1 kitchen, 1 core
b) 5 modules arrangement—2 bedroom, 1 living room, 1 kitchen, 1 core
c) 6 modules arrangement—2 bedroom, 2 living room, 1 kitchen, 1 core

(a)   (b)   (c)
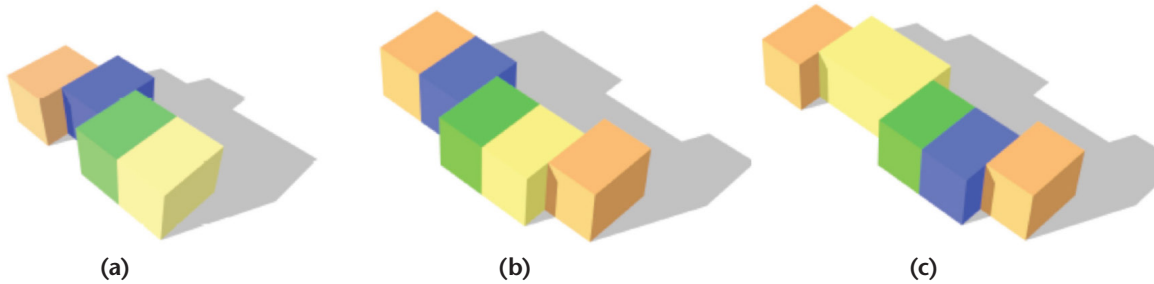
3. If there are two bedroom modules in a design, they should be placed on opposite sides of the house so that hallways do not cut through them.

Even when adhering to these rules, the number of possible arrangements is enormous. The calculations for the module numbers below do not include mirrored or flipped plan scenarios (4 Modules = 46 arrangements, 5 Modules = 112 arrangements).

3. INTEGRATED BUILDING SYSTEMS

Our systems and strategies maintain interior comfort and healthfulness, provide adequate light for the home's interior and exterior spaces, and ensure a dependable supply of hot water, while minimizing energy consumption and maximizing power generation. A high-performance envelope reduces heating and cooling loads, thus allowing the photovoltaic system to be smaller and more affordable.

Wall system

UrbanEden's envelope was designed to minimize the heat transfer through well-insulated, air-tight construction, while maximizing heat storage capacity by placing considerable mass in the living space.

UrbanEden's precast concrete walls consist of six inches of Styrofoam insulation sandwiched between two layers (or wythes) of geopolymer concrete. Unlike in post-and-beam or stud systems made of wood or steel, there are no columns in the wall to interrupt the insulation.

Traditional Portland cement concrete is responsible for 5–8% of our collective worldwide carbon footprint and manufacturing a ton of cement takes about 6.5 billion BTUs of energy. By completely eliminating Portland cement from its composition, the geopolymer cement concrete becomes a much greener product, reducing both energy consumption and carbon dioxide emissions in its production while recycling a waste product (fly ash) to beneficial use. The geopolymer concrete completely replaces Portland cement with a developed fly ash mixture that not only yields a stronger material but also makes safe use of a waste product of coal production. This process lowers concrete's carbon footprint by up to 90%. Geopolymer cement concrete is made by reacting aluminate and silicate bearing materials with a caustic activator. Commonly, waste materials such as coal combustion fly ash or slag from iron and metal production are used.
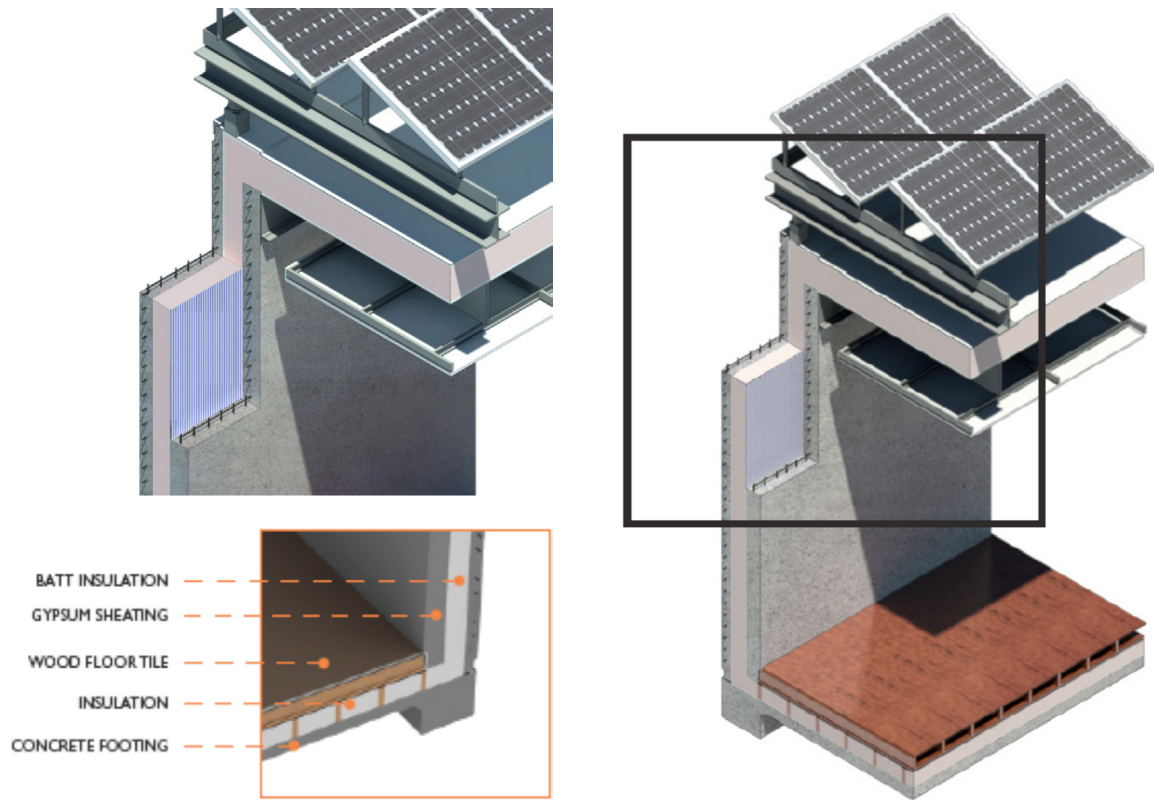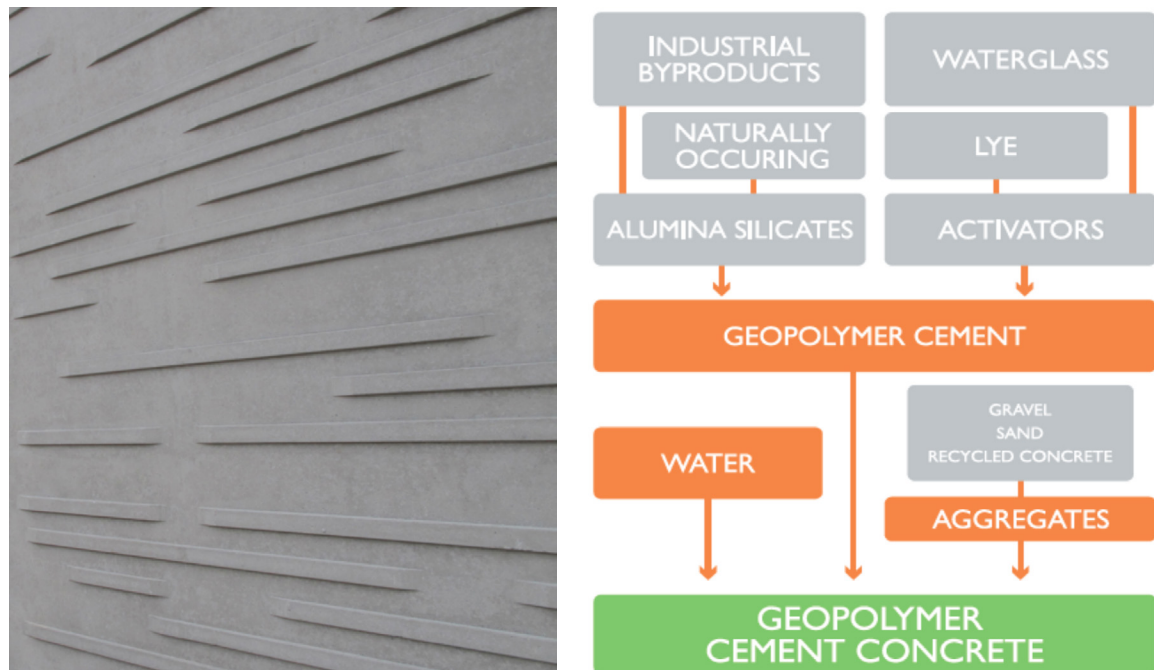
FIGURE 7. Wall system.

BATT INSULATION
GYPSUM SHEATING
WOOD FLOOR TILE
INSULATION
CONCRETE FOOTING

FIGURE 8. Geopolymer mixture.

INDUSTRIAL BYPRODUCTS
WATERGLASS
NATURALLY OCCURING
LYE
ALUMINA SILICATES
ACTIVATORS

GEOPOLYMER CEMENT

WATER

GRAVEL SAND RECYCLED CONCRETE

AGGREGATES

GEOPOLYMER CEMENT CONCRETE

Mechanical system

UrbanEden's heating, cooling, and ventilation strategy starts with basic passive solar design for the mixed heating and cooling load climate of Charlotte, NC. The approach started by orienting the building toward the south and giving it a shape that is long and thin on its east/west axis. With this configuration, the winter sun, which is low in the southern sky, streams in through the long, fully-glazed southern building facade, where the solar energy is stored as heat in the building's thermal mass. This energy is radiated back to the space at night when the sun is down, essentially taking advantage of the sun's heating potential. Next, we developed and implemented hybrid strategies that are active (use energy) to create comfort, but do so in support of a passive mechanism. Pumping liquid to roof-mounted heat exchangers to allow passive radiant heat transfer to the night sky is an example. Finally, we met our small remaining heating, cooling, and ventilation loads with the highest efficiency active systems available.

In addition, blocking the sun's heat is the central mechanism of passive solar cooling. In late spring, summer, and early fall, the small surface area of UrbanEden's east and west facades

FIGURE 9. Heating and cooling season.
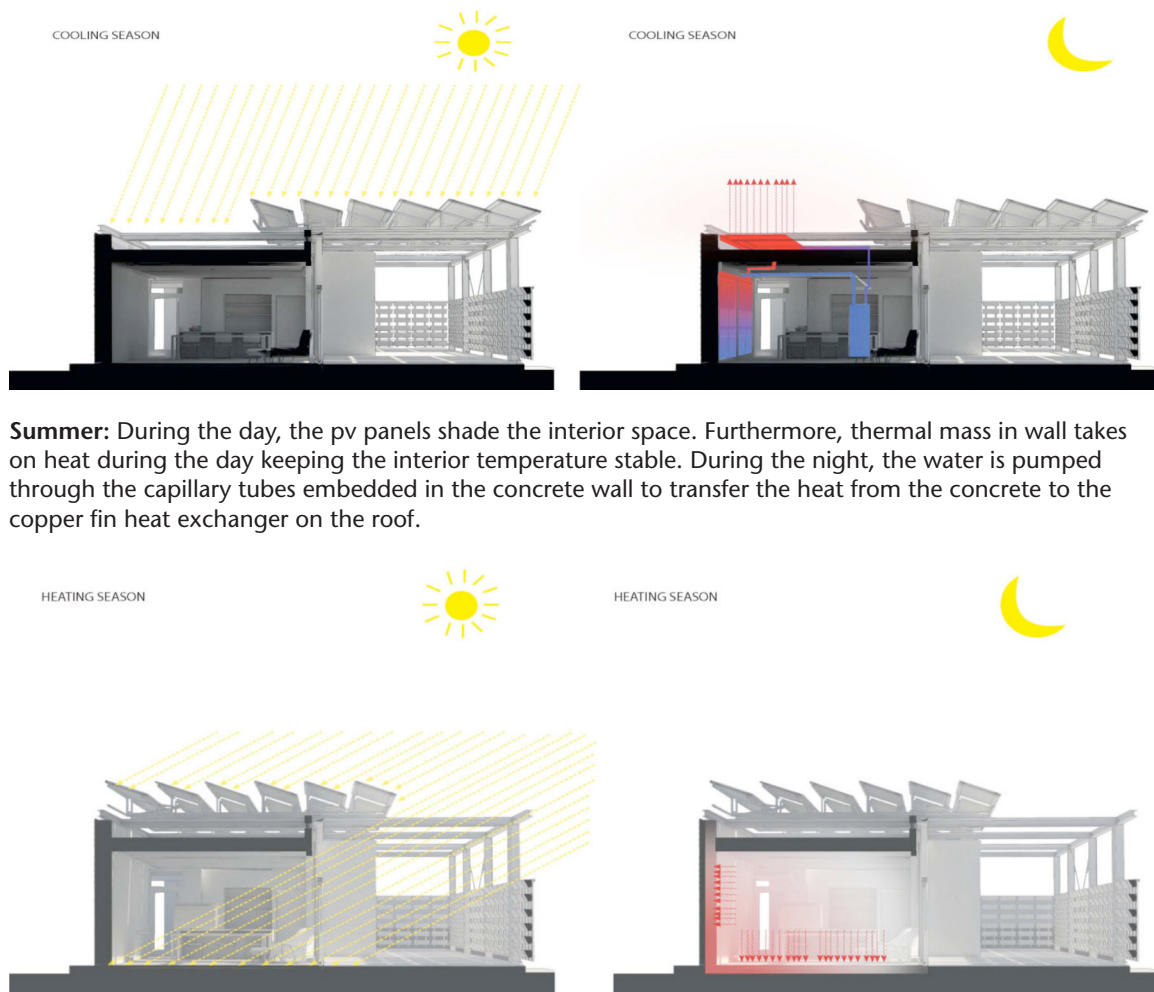
Summer: During the day, the pv panels shade the interior space. Furthermore, thermal mass in wall takes on heat during the day keeping the interior temperature stable. During the night, the water is pumped through the capillary tubes embedded in the concrete wall to transfer the heat from the concrete to the copper fin heat exchanger on the roof.

Winter: During the day the PV panels are moved in order to maximize the amount of direct gain into the interior. During the night, thermal mass in walls takes on heat during the day to keep the interior temperature stable.

minimizes exposure to low, hot morning and afternoon sunshine, while the roof blocks much of the midday sun. This basic strategy is augmented with a movable PV array that slides over the southern patio as needed, allowing for 100% shading of both indoor and outdoor rooms when desired, considerably lowering the ambient dry bulb temperature. In addition, sufficient natural ventilation through operable windows and doors further increases occupant comfort through evaporative cooling. Collectively, these strategies are the classic approach to passive solar cooling.

Another passive strategy incorporated into the UrbanEden design—thermal mass—has moved to the walls in the form of fully-insulated, precast panels instead of just being on the floor in order to increase the surface area. By markedly increasing the area and related volume of our thermal mass in the passive solar context, we have been able to implement a hybrid passive/active hydronic cooling system that, unlike conventional hydronics, uses only pump energy to accomplish temperature changes. UrbanEden's high-mass geopolymer cement concrete walls provide a container in which to store large quantities of thermal energy. As shown in Figure 9, in the summer, ambient heat soaks into the thick walls throughout the day, primarily by means of radiation. At the end of each day, this stored thermal energy can be removed from the walls by an innovative hybrid system. Hydronic, or capillary tube, mats embedded within concrete walls provide a vessel for the circulation of a water-based working fluid throughout the building's envelope, which flushes out the heat accrued during daylight hours. Once captured within the water, the thermal energy extracted from the walls must be dissipated. Dissipation of this heat is made possible by a network of custom fabricated, rooftop-mounted copper-fintube heat exchangers, designed to serve as radiation emitters. After the sun sets each evening, the water in the tubes in the walls is pumped onto the roof of the house and circulated through this heat-exchanger network. Passing through the serpentine heat-exchanger network, the warm water releases its stored thermal energy into the cool night sky; in fact, the exchange of radiant heat to the night sky is so efficient, the temperature of the fluid on the discharge side of the heat-exchanger network could potentially drop below that of ambient air.
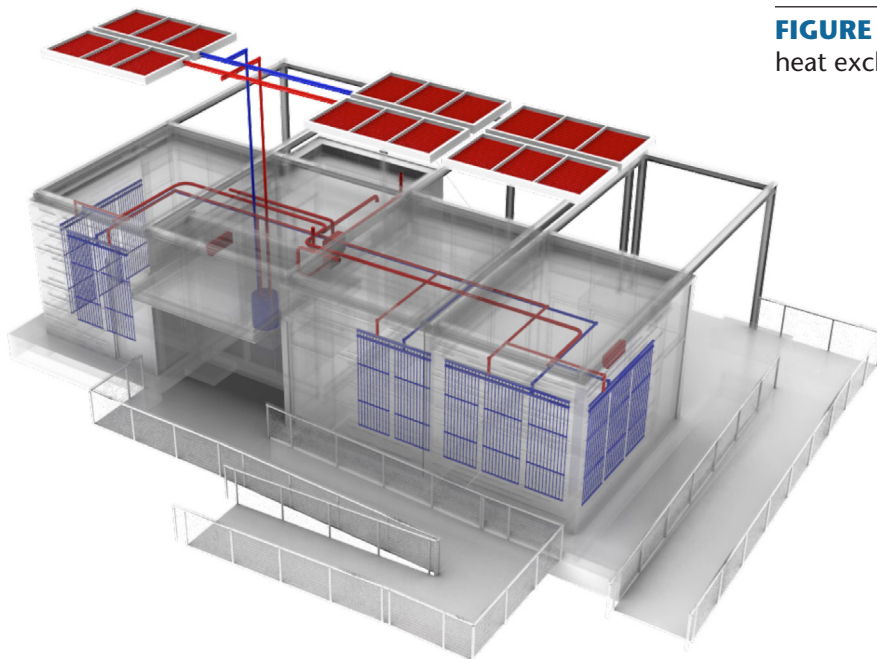

FIGURE 10. Capillary tubes and heat exchangers.

Electrical system

A 7.65-kilowatt array of photovoltaic panels was tightly integrated into the design of the house. Being fixed at an angle equal to the latitude, the array receives maximum solar exposure that rivals a sun-tracking array of the same size. The array of photovoltaic panels can be moved to provide the desired amount of shading to the windows and outdoor living area. This variable shading ability is crucial and allows the shading ratio to be optimized at different times of the year to minimize the heating and cooling loads.

Comprising the array are 30 individual photovoltaic panels by Bosch Solar Energy (Table 1). Each of the 30 panels has the potential to provide a peak output of 255 W under Standard Test Conditions (STC). As a rule of thumb, for optimal power production, the PV arrays must be south facing with a tilt angle equal to the latitude of the location. In UrbanEden's design, panel tilt angle, panel azimuth, and row spacing were ascertained by methods of parametric optimization. Optimization objectives included maximization of annual power output and minimization of panel-roof overhangs. The optimization was constrained by such factors as the width and length dimensions of the rack's structural sub-frame and the solar envelope ceiling height. Other variables included panel tilt angle, panel azimuth angle, and horizontal spacing between consecutive panel rows. The objectives of the analysis were found to be optimal when using the following variable inputs:

- panel tilt angle of 20 degrees (when measured from horizontal),
- panel azimuth angle of 180 degrees, and
- horizontal spacing of 22 inches between consecutive panel rows.

The results of the parametric optimization were factored into the design of UrbanEden's photovoltaic rack. The rack is comprised of three separate sections; each section comprises ten panels arranged in two columns and five rows. Each panel is mounted on fixed horizontal and vertical axes. One common challenge of designing a solar house is the implementation of the PV panels with the body of the house. A successful design integrates the PV system as part of the house configuration rather than leaving it as an add-on gadget. The team decided on giving a dual function to the PV system by having it serve as a shading device that enhances the look of the house while generating electricity.

Each of the rack's three sections can move independently across a 17-foot horizontal distance, parallel to the home's roof plane. The ability to adjust the sections serves multiple functions, namely, exposure of roof-mounted radiant-heat-exchangers to the cool night sky, providing shade to southern windows from direct solar gains, and bestowing a protective canopy over the home's southern patio area. Movement of the PV racks is made possible by a trolley and rail system installed atop the exterior I-beams. Torque required to move the

TABLE 1. PV Panels and Inverters Manufacturer and Ratings.

Panel Manufacturer	Model Number	Array DC Rating		
BOSCH	BOSCH Solar Module c-Si M 60 NA42117	7,650 Watts		
Inverter Manufacturer	Model Number	Voltage	Rating	Quantity
POWER-ONE	PVI-3.0-OUTD-S-US	600 V	3 kW	1
POWER-ONE	PVI-6000-OUTD-US	600 V	6 kW	1

FIGURE 11. Sunpath diagram of the house.
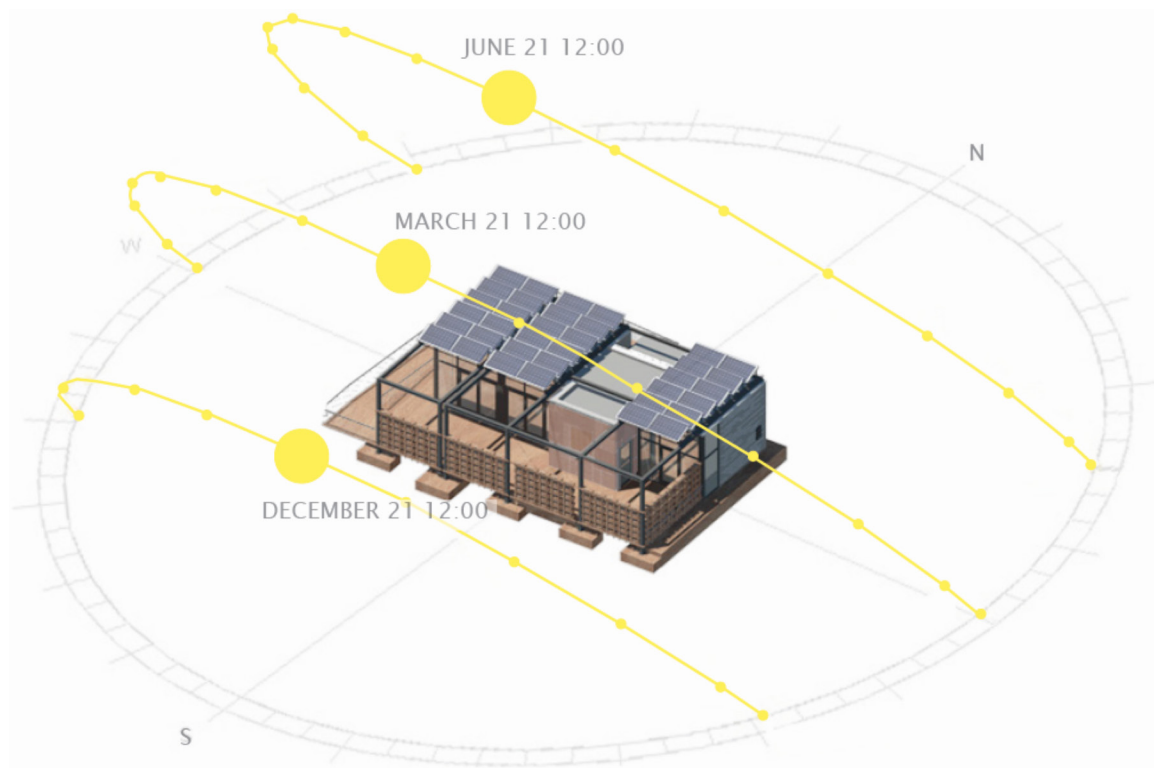
racks is provided by three independently controlled three-phase electric motors. It is stepped down using a gearbox and then transferred through a drive shaft and sprocket assembly to a chain drive mechanism. Motors, and thus, rack movement, are controlled through the home's control system and operated by the homeowner via a graphical user interface on a tablet PC.
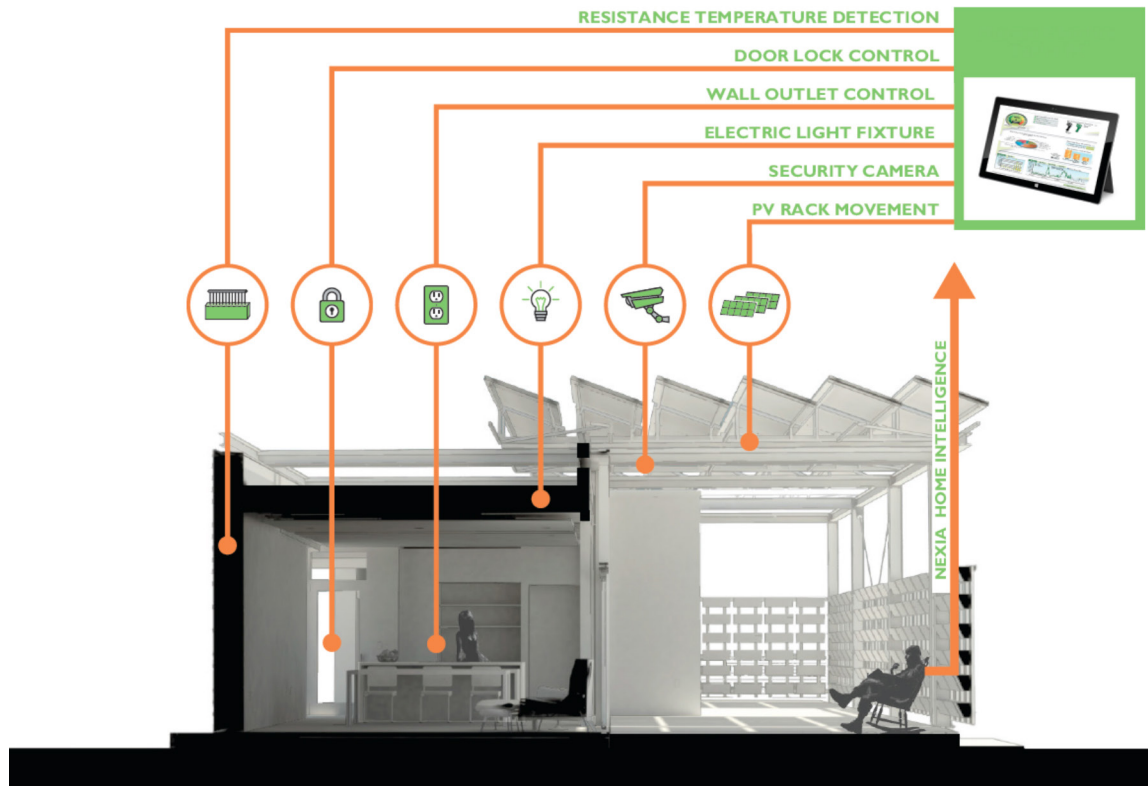
Control system

UrbanEden uses multiple hardware and software tools to achieve its primary control objectives:

1. maintaining interior comfort,
2. providing adequate light for the home's interior and exterior spaces,
3. ensuring a dependable supply of hot water,
4. minimizing annual power consumption, and
5. maximizing annual power generation.

Given the broad scope of control objectives, no single hardware or software package was suited to meet all needs, and multiple control tools were a necessity. The resulting design incorporated the following hardware/software tools:

- Programmable Logic Controllers—used to control he motorized PV rack and the capillary tube system
- A Nexia Bridge—used to monitor and control the HVAC mini splits and the door sensors/cameras/security
- An eMonitor—used as a dashboard to monitor and display energy use.

**FIGURE 12.** The UrbanEden Monitoring and Control System.

Presentation of critical information and control options to the home's occupants is made possible by way of a graphical user interface on a tablet computer (Figure 12). Central to personal interaction with the home's systems, this interface allows its occupants to monitor wall temperatures, radiant cooling system operation, dry bulb temperatures within the home, real-time energy consumption on all of the home's circuits, energy generation from the home's photovoltaic array, streaming video feeds from the homes multiple security cameras, as well as a multitude of additional monitoring functions. Control functions including thermostat set-point on the home's heat-pumps, water heater mode selection, photovoltaic array rack movement, and lighting can all be carried out directly by the homeowner via this control platform.

4. OPTIMIZATION OF DAYLIGHT STRATEGY

The design concept was to increase living space with a series of connected indoor and outdoor rooms, which led to a fully-glazed south face of the building with a high-performance triple-pane glazing window system. In a typical high-performance residential construction, high glazing is not used due to its relatively low thermal performance in comparison to insulated wall sections. UrbanEden's windows, doors, and window wall have high-performance frames that feature warm edge spacers and superior airtightness combined with triple glazing, argon gas fills, and two low-E coatings that deliver center of glass values of R-8. This advanced technology saves energy and also increases comfort through exceptional sound insulation and by keeping glass surface temperatures closer to human body temperature, thereby reducing the radiant heat loss perceived as a "draft" from a window.

FIGURE 13. Daylight analysis.
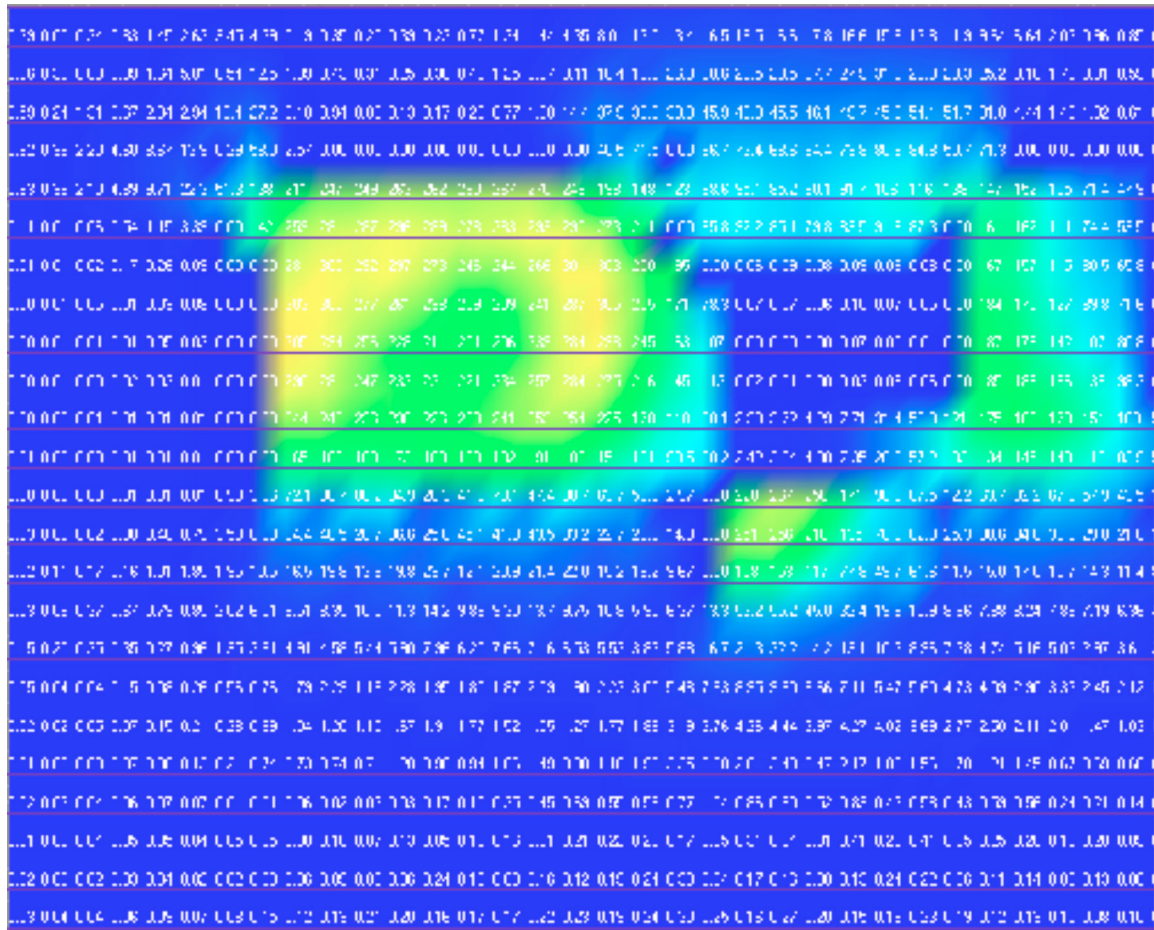
The whole south side of the bedroom and living areas is characterized by this high-performance glass curtain. There are two doors/windows on the north side of the house to balance the light that comes into the house. The strategic placement of windows also allows the house to be autonomously day-lit during the daytime.

The daylight analysis showed that just having the south glaze façade will provide enough daylight during the day. Also, all the light fixtures in the house are highly energy efficient and all use LED lighting to minimize the energy consumption.

5. ACHIEVEMENT OF NET-ZERO ENERGY PERFORMANCE

All of the innovative features of the house played an integral role in its achievement of net zero energy performance. The UrbanEden home is designed to knowingly work with the forces of nature instead of fighting against them. It is meant to be a comfortable extension of the environment instead of a retreat from it.

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 off of 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 façade of buildings. In the winter, south-facing windows utilize this heat. In the summer, this solar gain is not desirable and can easily be 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 is custom-made, high-density, fly ash–based concrete. The high-density concrete stays cool throughout the day while absorbing heat and is not warm enough to release the heat until the house needs it at night.

The integration of capillary tubes that are ⅛ inch in diameter, placed close together to maximize surface area, and embedded three inches deep in the concrete walls helped with achieving the net zero energy. The capillary tubes in the walls are zone so they can be used for precise control over the mean radiant temperature in different rooms of the house as needed.

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 tube and roof heat exchanger system. Our approach was to optimize the design of the house and its 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.

By calculations similar to the ACCA Residential Load Calculation Manual J, important envelope parameters were quickly identified for further analysis. Assumptions and calculation results are displayed in Tables 4 and 5.

By maximizing insulation in the walls, ceiling, and floor, a solid starting point for energy modeling is established. The R-values of the wall, ceiling, and floor, are about 30, 55 and 30 respectively and are made up of mostly high density concrete and extruded polystyrene insulation. The peak heat loss through the walls, ceiling, and floor is equal to 1.674 kBtu/hr. In this case the energy transfer through the insulated surfaces is relatively small.

Since continuous ventilation is required by the ASHRAE code 62.2, some of the conditioned air will be constantly lost and replaced with unconditioned air. This causes a slight increase in both the heating and cooling loads. To meet the code, the UrbanEden house requires about 23 CFM of ventilation. Supplying this ventilation and recovering some of the lost energy is 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 exhaust requirement. The heat loss of this ventilation is calculated to equal 1.7 kBtu/hr. The effect of the ventilation requirement has about the same impact on the loads as the insulation.

In a house with an average annual tightness of 0.34 air exchanges per hour, the effect on the loads is comparable to the ventilation calculated to be 1.3 kBtu/hr. The Urban Eden 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 four hundred square feet which is a large fraction of 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.

We used BEOpt to model and simulate UrbanEden's annual energy performance. BEOpt was developed by the Department of Energy's National Renewable Energy Laboaratory (NREL) and is a simple graphical interface to the robust energy modeler, EnergyPlus. BEOpt also contains optimization tools that allows one to optimize one or several design factors, such as window area or wall insulation, for annual energy performance. After outlining the critical parameters and understanding the basics of passive design, the BEopt computer model provided the speed and detail necessary to optimize the final design. Table 3 shows the significant input parameters of the UrbanEden house BEOpt model. Figures 14 and 15 compare the performance of the UrbanEden house against a similar "typical," or "code," house.

Figure 16 shows that the energy production was positive at the end of the competition week, meaning that the house loads used less energy that what was produced by the PV arrays.

The UrbanEden student team proved that a net zero energy house doesn't need to sacrifice the function or the aesthetics of a house. The design of UrbanEden demonstrated that a well-integrated solar house can be comfortable, energy efficient, and aesthetically pleasing while being affordable and marketable.

TABLE 3. Significant parameters of 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

FIGURE 14. Annual end energy consumption by end use.
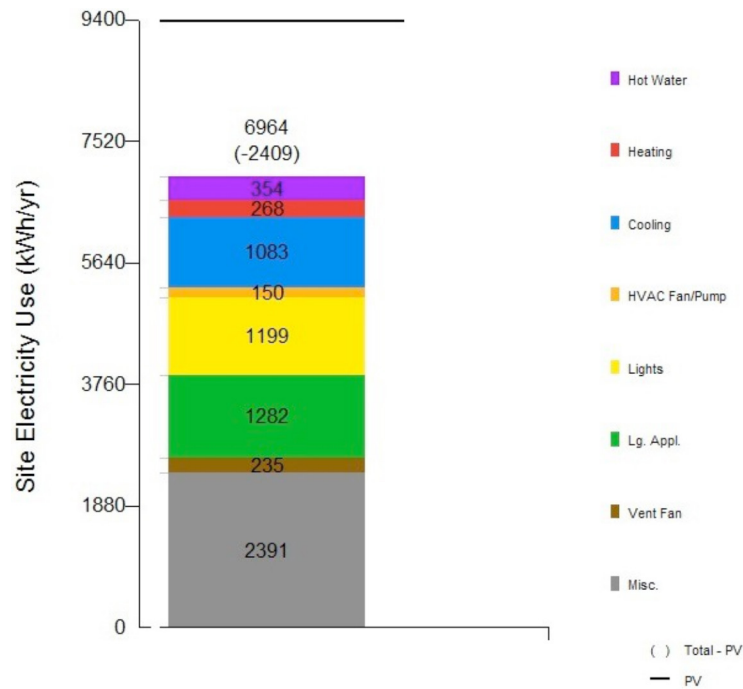

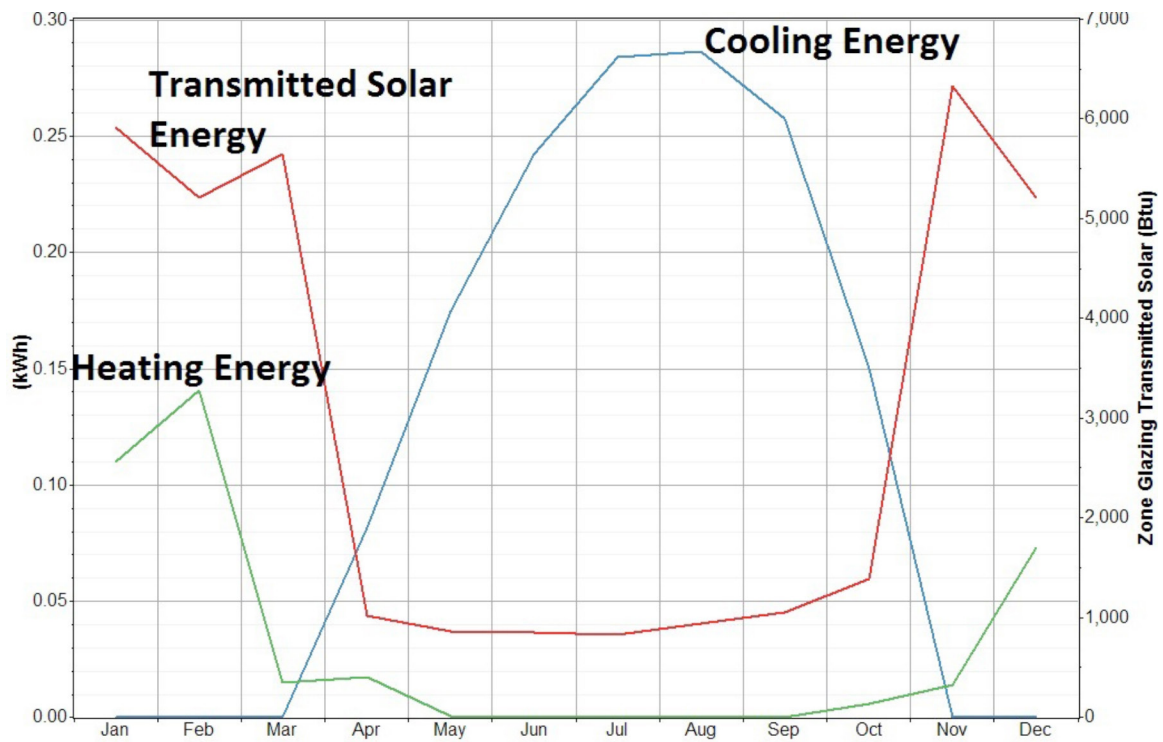**FIGURE 15.** Monthly heating, cooling, and transmitted solar energy.

**TABLE 4.** Wall assumptions for Manual J load calculations.

| Materials | R-value/in | Envelope Thicknesses | | | | | |
		Wall Layer	Inches	Floor Layers	Inches	Ceiling Layers	Inches
GeoPolyer Concrete	0.066	WT1	6	FT1	6	CT2	10
Extruded Polystyrene	5	WT2	6	FT2	6	CT6	0.625
Cement Backer	0.32			FT3	0.5	CT7	0.625
Thinset Mortar	0.4			FT4	0.25	CT8	0.625
Ceramic Tile	0.08			FT5	0.25		
Wood Fiberboard	2.7						
Fiberglass Board	4.5						
Metal	0						

TABLE 5. Envelope R-values and U-values for Manual J load calculations.

Total R-values and U-values	
Walls	RW= WT1(R1) + WT2(R2) = 30.396, UW = 1/RW = 0.033
Floor	RF = FT1(R1) + FT2(R2) + FT3(R3) + FT4(R4) + FT5(R5) = 30.676, UF = 1/RF = 0.033
Ceiling	RC = CT2(R2) + CT6(R6) + CT7(R7) + CT8(R8) = 54.5, UC = 1/RC = 0.018

TABLE 6. Peak Heating and Cooling loads of Manual J load calculations.

Components of Heat Heating and Cooling Loads in Btu/hr					
	Insulation Loss/Gain	Infiltration Loss/Gain	Ventilation Loss/Gaing	Window Loss/Gain	Total Loss/Gain
Heating Peak Load	2065	115	1700	1442	5322
Cooling Peak Load	729	41	600	509	1878

FIGURE 16. Net positive energy—verification of projected values.
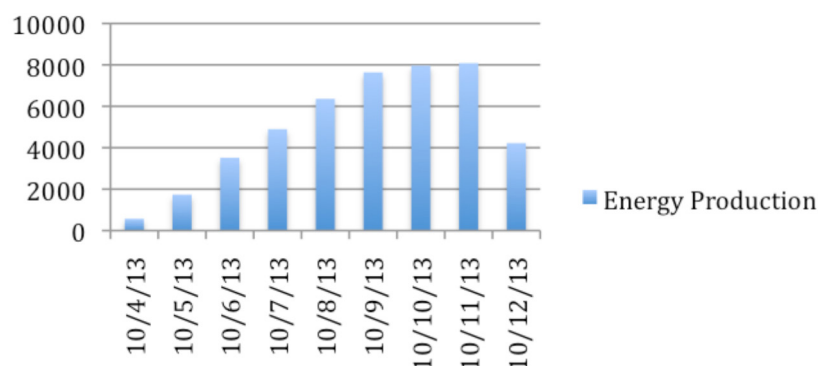
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