

nexushaus



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## ARCHITECTURE NARRATIVE

Integrated sustainable design is generally defined as combining the three principles of ecological balance, economic affordability and social justice. Rarely do visual aesthetics factor into definitions of sustainability; however, in nature abundant examples, like flowers, exist where science combines visual aesthetics and environmental performance. The NexusHaus represents a home design that combines the principles of design shape geometry, form, orientation and configuration with the integration of energy producing and water collecting surfaces, and natural materials with low-carbon embodied energy.

To meet the needs of the 2015 Department of Energy Solar Decathlon competition, a portable modular design has been developed with an assembly that enables ease of installation and both quantitative and qualitative performance in the design. The house sits lightly on the land and forms the superstructure for photovoltaic technologies, rainwater collection, aquaculture and permaculture gardening and indoor/outdoor living. The prefabricated modules can be adapted and modified for the needs of different sites and client contexts. Affordability is also a factor in the design, recognizing that consumers look to the Solar Decathlon entries for ideas of how to integrate renewable energy technologies into their own homes. In addition, several strategies exist for the future location or mass-production of the design following the competition; collaboration with a local site will provide a further reference point for informed design in Central Texas.

## DESIGN FOR TEXAS

The Sunbelt region of the Southwestern area of the United States is one of the fastest growing regions in the country, which is leading to an exploding demand for residential housing. At the same time, this region is experiencing increasing temperatures and prolonged droughts, which have strained water supplies and pushed infrastructure near its capacity.

The NexusHaus demonstrates an affordable completely solar-powered and water-efficient home, and the innovations of the house serve as catalysts for change, leading the residential housing industry toward



Fig. 1 Northwest birdseye view and interior renderings

more sustainable practices while addressing the need for well-designed, appropriately diverse, economically viable, and environmentally responsible housing. Through use of solar power and rainwater harvesting, NexusHaus offers homeowners the means to directly participate in the energy economy, moving from energy consumers to becoming energy producers.

### GREEN BUILDING DESIGN

The NexusHaus addresses the challenge of sustainable urban development in the context of energy and water resource constraints. The net-zero energy, zero water capable 784 square foot house utilizes a number of design features typical in vernacular Texas architecture. Although the design of the unit strives to be energy efficient through its envelope and mechanical systems, traditional passive approaches such as natural ventilation add not only to reduction of energy use but enhance the occupants' connection to the outdoors. For example, during times of the year when ambient conditions allow, the unit will facilitate passive means of ventilation and cooling. Because spring and autumn breezes in Austin are most active in the morning and late afternoon, cross ventilation is used during these periods for immediate cooling.

The zoning requirements for secondary lots in Austin, Texas limit the maximum dwelling footprint of 850 square feet. To provide this modest dwelling with a spacious feeling the design employs various spatial concepts: the living module consists of one open space allowing views to the outside and brings daylight from full height windows and manually operated sliding wood doors. The bedroom module defines two private areas divided by a common bath. A thickened wall on the outer west and east facade of the two module serves as a buffer zone. The interior spaces can spill out onto fully shaded generous outdoor decks. These outdoor spaces are emblematic of the Austin experience, a sociable one that takes full advantage of temperate weather in the fall, winter, and spring. The canopy has a low light-transmittance to provide shading for the full height windows and doors and also captures the rainwater. The two modules are separated by a central space that is intended to be enclosed in the winter increasing the compactness of the entire structure, and capable of transforming itself into a 'dog-trot-porch' configuration seasonally.

The NexusHaus design positively affects the energy performance of the house. The building configuration consists of two modular rectangular structures with layers and components attached that interact with the environment to provide an energy-efficient and affordable home. The thin width of each module allows for ease of highway transportation, effective cross ventilation and daylighting throughout the interior. The building orientation of the modules is designed to take best advantage of the southern exposure during the winter, and to reduce the over-bearing intensity of the sun in the afternoon hours during the hot summer months. Layered onto, and around the modules are a series of rain screens, canopies and arrays that either passively filter the sun's rays before they strike the building's skin, or actively harvest their solar energy to power the systems and appliances within the home, or to harvest rainwater and support an edible permaculture landscape. These layers also extend the threshold of the house into the landscape, providing a screen for the flow of indoor/outdoor living. Three large nine foot wide folding glass Nanawall® doors open up to connect the modules to the outdoor deck enhancing a spacious sensibility to the modest 784 square foot conditioned house.

Light is an important factor for user comfort in the relatively small spaces of the NexusHaus. The goal is to best support the occupants' visual tasks, occupancy, and security via the integration of daylight in com-

ination with artificial lighting using controls. The NexusHaus provides the best balance between illuminance levels, views, creating a sense of space, and solar heat gains via fenestration. All used light sources are highly efficient while providing task-appropriate color rendering and color temperature for best light quality.

Overall the modest wood binuclear home design utilizes three design techniques: (1) The indoor spaces are bright and spacious with an open indoor/outdoor connection; (2) the “outdoor rooms” of the house are designed as much as the indoor ones, made viable with shade in the moderate climate of the Sunbelt region; and (3) movement and view are extended along and across the modules through carefully positioned openings in the exterior, connecting the interior with the exterior and providing generous amounts of daylighting to enhance the sense of spaciousness. On the east and west of the modules, thickened multiple layers offer an additional buffer against solar gain.

Water conservation is mandatory in both Central Texas and Southern California and as such the NexusHaus design will collect rainwater that it needs to meet its potable water demand. The roof of the house and the breezeway canopy are designed to collect over 17,000-gallons of water per year in Austin, Texas. Another high demand for water are the water irrigation requirements for the food we eat. Our house employs an aquaponic garden in which fish and vegetables are grown together in a constructed aquatic ecosystem. The effluent from the fish fertilizes the water which is pumped to vegetable grow beds where bacteria convert the effluent into usable nutrients for the plants. The plants in turn absorb nutrients from the water, thereby purifying it, which flows back to the fish tank.

Our house will be Austin Green Building Certified and we will apply for LEED Platinum certification and Living Building Challenge Certification. Although photovoltaic panels power the house, our green building certification is predicated upon a whole-building performance system, including energy efficiency, efficient material use, water conservation and quality, health and safety concerns and community issues.

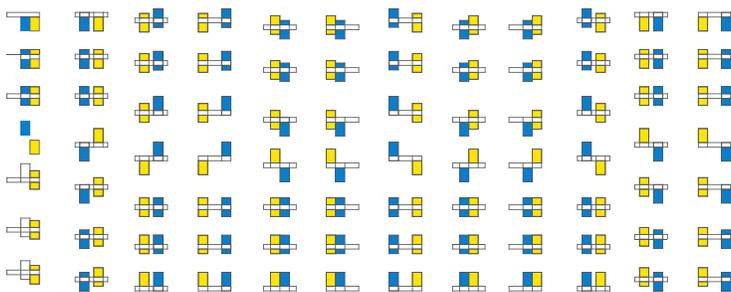


Fig. 2 Allows for flexibility on various lot sizes and shapes and can be positioned to fit the needs of the homeowner.

**MODULAR DESIGN**

The concept of the NexusHaus addresses four current challenges Central Texas is currently facing: clean energy, water restrictions, food and urban sprawl. This net-zero energy, zero water capable house accomplishes the goals of sustainable and affordable urban housing through a combination of photovoltaic electricity generation, integrated thermal/water storage systems, and cutting edge smart home management. The ultimate goal of NexusHaus is to serve as a potential prototype for a next generation modular home that could be reproduced en masse in Austin and marketed as an Accessory Dwelling Unit (ADU), or “Alley

Flat”, located on existing single-family home sites with a rear service alley. Net-zero energy ADUs are an urban infill strategy with multiple environmental benefits that address the shortage of affordable housing in Austin, Texas.

The two 392 square foot modules consist of a day module that contains living, dining, and a kitchen, and a night module with a master bedroom, studio and a bathroom. The two modules can be placed in a number of different configurations depending on the site and the needs of the client. The key for the success of integration into the single-family residential properties, which often vary in terms to the lot size, shape, and vegetation, is the flexibility that results from the modularity of the design. The team has identified over a hundred possible plan configurations for the design.

**CARBON NEUTRAL**

The design of the NexusHaus features extensive use of wood both as the structure for the house and as a finish material. Wood has many positive characteristics, including low embodied energy, low carbon impact, and sustainability.

Carbon is also sequestered in trees and remains sequestered in the lumber throughout the life of the building. At the end of our building’s life, forest resources are renewable and, with proper management, a flow of wood products can be maintained indefinitely. Using wood from sustainably managed forests actually reduces carbon dioxide emissions, as the carbon dioxide stored by the forest and in the timber product outweighs any carbon dioxide created during the production of the product. Each ton of timber used instead of other building materials (like steel) saves around a ton of carbon dioxide. Using the amount of CO2 sequestered in the wood we are using in the construction of our house we will balance the CO2 generated in the manufacturing of our other building materials used in the house. NexusHaus will be carbon neutral.

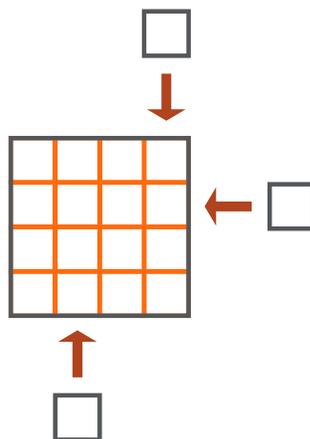
Wood is naturally beautiful and adds character and warmth, but beyond aesthetic benefits, it offers exceptional value, especially compared with other high quality materials. It also offers unique sustainable credentials – wood is a natural, renewable product.

THICKENED EAST AND WEST WALLS



Used as storage and a buffer from the exterior environment

MODULAR CONCEPT



TWO MODULE



Each module can be con i oned separately and at necessary imes

MARKET APPEAL NARRATIVE

CONCEPT HOUSE FOR A GREEN ALLEY FLAT

In 2013, the City of Austin was awarded a national Climate Leadership Award from the Environmental Protection Agency, and is the first city to receive an Organizational Leadership award for its response to climate change. As part of its Climate Protection Plan, Austin has set a goal that all new single-family homes will be net-zero energy capable starting in 2015. Also as part of Austin’s Climate Protection Plan, the City of Austin has set the goal that by 2020, 30% of all energy needs will come from renewable sources, including at least 100 MW of solar power. In order to achieve this goal, the municipally-owned electric utility, Austin Energy, offers rebates on residential solar electric and solar thermal systems, both of which are critical components of net-zero energy homes.

Our team will demonstrate the potential of combining energy and water to design a prototype of an Alley Flat, an affordable Accessory Dwelling Unit (ADU), as a unit of production that can easily augment the existing neighborhood’s infrastructure without increasing demand for energy and water. The design was developed for Central Texas to respond to its physical and cultural climate. The design concept for the NexusHaus has been driven by the following overarching ideas: urban infill strategy via ADU development, affordable green building design, energy-water nexus, space extension, and smart technology. The green approach led the team to consider current and future scalability of distributed renewable energy technologies. By establishing ADUs as units of production, we allow them to offset the costs of their own utilization by harnessing natural and other available resources that would otherwise be considered as waste and a burden on the infrastructure. Furthermore, the impact on the environment and on the regional power generation, as well as water supply and water treatment is being reduced. Collaborating with City of Austin and the Austin Community Design and Development Center aligns closely with the goals of the award-winning Alley Flat Initiative. Nexus offers a prototype for a Green Alley Flat in Austin impacting the entire Austin community.

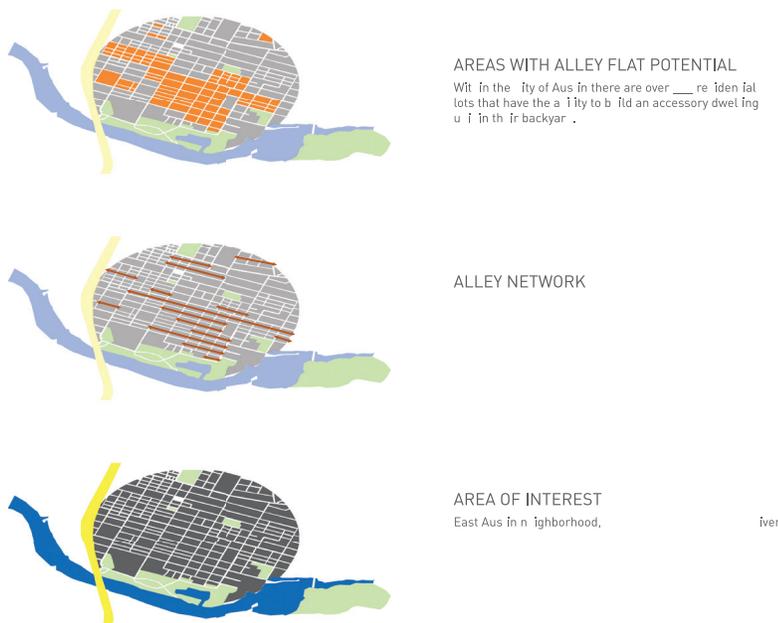


Fig. 4 Alley Flat ADU density potential

**TARGET CLIENT**

The dynamic and innovative solution provided by NexusHaus merits description of three distinct beneficiaries—the City of Austin, the property owner (client) and the unit resident (renter). As a cost-efficient solution that responds to Austin’s skyrocketing demand for urban housing, NexusHaus adds density to centrally located neighborhoods without requiring additional infrastructure through the utilization of the City of Austin’s Accessory Dwelling Unit (ADU) code. This code allows for ADUs (granny flats, alley flats, secondary dwellings, etc.) to be placed along existing alleys on more than 42,000 single-family residential lots throughout Central Austin. Many of these lots are located along existing public transportation routes and would allow residents to utilize public transit, helping to alleviate traffic and preserve quality of life for all Austinites while reducing the stress placed on Austin’s road infrastructure by the 70 cars added to Austin’s roads each day by the 110 people (net) moving to Austin. For the client (property owner), NexusHaus will serve as a unit of economic production as a potential source of rental income used to defray increasing property taxes. The energy and water concepts prevalent in NexusHaus make the house more marketable for property owners to a growing demographic of technologically savvy and ideologically motivated individuals and couples who want to have a low-impact lifestyle. The unit resident target demographic is also less interested in the total square footage of the unit but places a premium on location in a city where access to recreation and downtown is increasingly important.



Fig. 5 Life cycle diagram

**CONSIDERING THE LIFE-CYCLE**

The NexusHaus aims to use resources carefully and to their full capabilities. Different design options were evaluated considering the life-cycle performance of the house. The functional unit was the NexusHaus as a whole with the site boundaries as system boundaries and a considered time period of 40 years. The life-cycle analysis followed a cradle to grave approach, looking at the environmental impacts from resource extraction through building use and operation to deconstruction and reuse/recycling. However, the parts and/or phases differed according to the specific topics: the exterior of the NexusHaus, including the garden, the deck and the shading structure; the building systems, i.e. the structural system, the floor, the walls, the roof and the mechanical system, including the energy producing PV cells; the building’s interiors, such as interior finishes, furniture, appliances, bathroom fixtures and lights.

Advanced framing system to be the best option according to the environmental analysis compared to Standard Stick Framing and Cross Laminated Timber. For the rigid insulation, natural expanded cork outperformed the other alternatives XPS and PIR.

The life-cycle performance will be shown on each material or system during the competition with QR codes in an easy to understand way for Global Warming Potential, Non-Renewable and Renewable energy related to miles driven, savings of gallons of gasoline and savings of days for powering the NexusHaus.

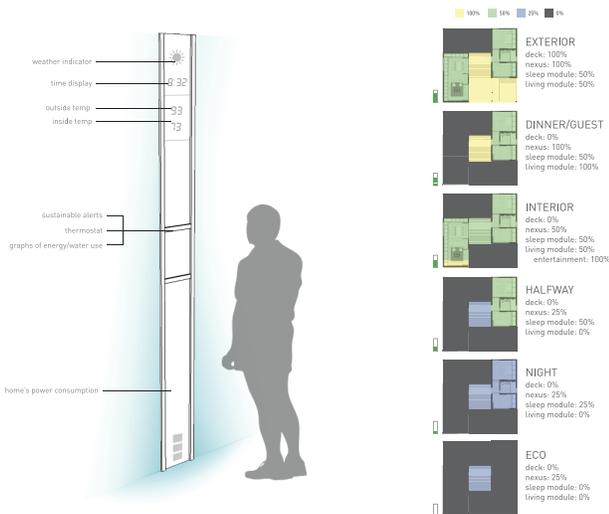


Fig. 6 Sense Bar + pre-set modes

### NexSmart

Modern day living incorporates many technologies into every facet of our lives: our work, our cars, our means of communication, etc. But what does this mean for the ancient notion of ‘shelter’? The NexusHaus can be a true ‘Smart Home.’ One that can grow, morph, and educate. Our relationship with our living spaces should be that of a symbiotic one. We care for our home, but our home also cares for us. With the mass incorporation of technology into our lives, automating aspects of our sustainable home only makes sense.

The NexusHaus not only facilitates sustainable living, but educates the users, teaching them how to live more sustainably. A major theme is ‘agency and education’ – the home should provide the means to live more sustainably while simultaneously encouraging sustainable habits. Therefore, the main objective is to educate and inform the users about their home’s self-produced resources as well as intuitively display this information in an easy-to-use, cohesive application called NexSmart. To do this, we introduce new concepts like an energy/water ‘battery’ that shows how many resources the homeowner has used of the allowed energy/water. All information pertaining to the home is accessible through NexSmart. Educating the users about the energy consumption can promote awareness of their resource footprint.

The sensors located throughout the home to collect data about various aspects display their data in a centralized location called the Sense Bar. Visually, the Sense Bar is integrated within the architecture of the home itself. In other words, the architectural expression of the Sense Bar is embedded in the wall. This is the primary way the user interacts with the system, and a mobile application available through a phone or tablet is available as well. The majority of sensors will come from a Silicon Labs PUCK device.

The NexusHaus Application is displayed in the Sense Bar via an embedded tablet in the wall. The data collected from the sensors are being processed and suggest sustainable choices. For instance, if the system detects that no user has been home for the last four hours yet the light in the kitchen has been on, the system will display a log of wasted energy and alert the user upon arrival. Weather data, which is also being collected via an on-site weather station, inform the user if outside conditions are acceptable to turn off the mechanical system and open the windows and doors. Forecast data is also being analyzed to potentially pre-cool or pre-heat the home before the homeowner arrives home. Or, the user can simply view collected data such as energy usage over time, current weather conditions, etc. The NexusHaus App functions allow for features such as a preset for the home called 'ECO-MODE,' which homeowners can select when going away for a vacation or an extended period of time. The home will reduce all energy consumption to the bare minimum while the homeowner is gone.

Examples of sustainable living alerts:

- It's a great day outside! There's enough wind and the temperature is great. Turn off the HVAC system and open the doors and windows.
- Energy score today: 80'
- There's enough daylighting. You can turn off the artificial lights!
- The door has been left open! The HVAC is working harder because of it – close the door!
- Today was a cloudy day and we weren't able to collect too much energy. Try to limit your energy use, or wash those clothes tomorrow!
- Reminder: water your tomatoes today!
- Water level is low, reduce water usage.

The technical system is revolved around a Windows Tablet and a Beagle Bone Black (BBB) which acts as the processors and temporary servers, with long-term storage located in the cloud. In this micro-controller all the sensors are controlled, like occupancy, temperature, humidity, etc.. The BBB temporary stores the collected data and perform the necessary operations. All of the sensors communicate with Beagle Bone Black wirelessly. For long-term storage, the data is sent to a cloud server where it is stored until the user views the information. The eGauge meter measures both consumption and production of electricity. The consumption can be broken down by room.

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## ENGINEERING NARRATIVE

### INTRODUCTION AND MOTIVATION

Energy and water resource consumption are underlying many major global stresses, and the combination of climate change and an increasing population might only exacerbate them. The built environment (residential and commercial buildings) are major consumers of both energy and water, both from a direct and indirect perspective. In the United States, approximately 40% of all primary energy, and about 75% of all electricity produced, are consumed within buildings<sup>1</sup>. While direct water consumption by the built environment is only about 12% of US water withdrawals, the indirect water footprint of the electricity consumed in the built environment equates to another 34% of all US water withdrawals, bringing the combined direct and indirect total to just under 50%<sup>2</sup>. In many southern states, air conditioning loads drive the overall peak load (and wholesale market price of electricity) on the electric grids. During the summer in Texas, the cumulative electric demand from residential air conditioners alone can be over 40% of the peak load on the electric grid<sup>3</sup>. With the Texas population projected to grow by 80% in the next 50 years, coupled with projected warming temperatures, residential water demands and air conditioning loads are expected to increase<sup>4</sup>. In the midst of these challenges, Texas is looking for ways to address water and energy issues.

The University of Texas (UT) and Technische Universität München (TUM) have partnered for the Department of Energy Solar Decathlon 2015 Competition to design a house addressing the Energy-Water Nexus in the context of Austin, Texas. Austin is currently one of the fastest growing cities in the United States, which is leading to an exploding demand for residential housing. At the same time, Texas is experiencing increasing temperatures and prolonged drought, which have strained water supplies and pushed infrastructure near its capacity. The UT/TUM Solar Decathlon house, NexusHaus, will address both sustainable and affordable urban housing in the context of energy and water resource constraints. This net zero energy, zero water house accomplishes these goals through a combination of photovoltaic electricity generation, integrated thermal/water storage systems, and smart home monitoring and management. The ultimate goal of NexusHaus is to serve as a potential prototype for a next-generation modular home that could be reproduced en masse in an assembly plant in Austin.

This section provides an overview of the energy and water systems employed in the NexusHaus. The following section provides a summary of the energy analysis performed during the design process.

### PHOTOVOLTAIC ARRAY DESIGN

The NexusHaus PV system is designed with a holistic approach to maximize affordability by reducing installation time through a simplified racking scheme, using quality SolarWorld® SunModule Mono 290W solar panels that have great life-time performance and warranty, and utilizing Enphase® M250 micro-inverters to maximize array generation flexibility and minimize interconnection costs.

The price of photovoltaic (PV) systems have decreased significantly over the past decade, mostly due to the decline of PV panel costs. The costs associated with inverters, PV panel racking, installation, and other 'balance of system' expenses has not declined proportionally with PV panel costs. Therefore, these balance of system costs are now making up a larger share of the total installed cost for a PV System. To address these costs, NexusHaus will utilize a ballasted PV panel racking system that can be quickly assembled, and

that doesn't require roof significant penetrations, for easier and faster installation on-site. The array has an angle of approximately 10 degrees, which maximizes overall production for the available roof area by optimizing between panel tilt and available panel spacing. While the system needs slightly more panel area to make up for the less-than-ideal angle, the idea is that the balance of system cost savings make up for the added panel expense. Additionally, since the ultimate location and orientation of the house is unknown, a ballasted array provides the ability to easily adjust panel angle and orientation for the final location.

In keeping with affordability as a goal, the system is sized to meet the electrical needs of the house, rather than just installing the largest system for the space available. In conjunction, mechanical equipment, lighting, and appliances are being chosen to reduce energy needs to further bring down the overall energy consumption, and reducing the size of the PV array needed. Based on the team's calculations, the right-sized array is approximately 8.1kW DC (approximately 7kW AC), which will provide sufficient energy for the year. Micro-inverters take the direct current (DC) generated by the PV solar cells in the panels, and converts it to alternating current (AC) at the panel level rather than having a single inverter for the entire array. These integrated inverters allow each panel to operate independently, minimizing the impacts of partially shaded panels or arrays—important for a system that will ultimately be installed in a residential neighborhood. Additionally, using micro-inverters minimizes connection complexity and wiring costs, which in turn help further reduce the overall installation time and costs.

### **HYDRONIC AIR CONDITIONING + HEATING SYSTEM WITH RAINWATER THERMAL STORAGE**

Air conditioning is an unavoidable fact of life in Texas, and the primary component of power demand and energy consumption in Texas. To alleviate afternoon electricity grid congestion, and avoid higher-priced power, the house will incorporate an Integrated Thermal Energy and Rainwater Storage (ITHERST) system to shift air conditioning load off-peak to the early morning hours. Thermal storage technology has traditionally only been employed on the large commercial and industrial scale, but NexusHaus will demonstrate the concept on a residential scale. The system operates the thermal storage tank as an auxiliary rainwater collection and storage volume which increases the effective capacity of the rainwater collection system, and makes use of an otherwise un-utilized thermal mass. Figures A.7-A.9 contain a schematic representation of the main components and operation of the ITHERST system. Analyses performed so far suggests that the ITHERST system could reduce the on-peak cooling-related electricity load (compared to the same system without thermal storage) by 75-80%, with a corresponding increase in electricity consumption of approximately 5-10%, when operating in Austin, Texas. The modest increase in energy consumption occurs during low-demand off-peak hours, when prices are lowest and West-Texas wind is typically blowing strongest.

This system, coupled with the solar PV, provides electricity to the grid on peak while simultaneously reducing the house load, as shown in Figure 7. The goal is not just to minimize air conditioning load on the grid, but to also provide as much excess energy as possible to support the surrounding neighborhood when power is needed most. Additionally, this approach benefits other grid-connected stakeholders, from customer to utility, and could therefore be a source of savings and/or revenue generation. The thermal storage system will save the home occupant on their utility bills in areas by making use of real-time or time-of-use pricing.

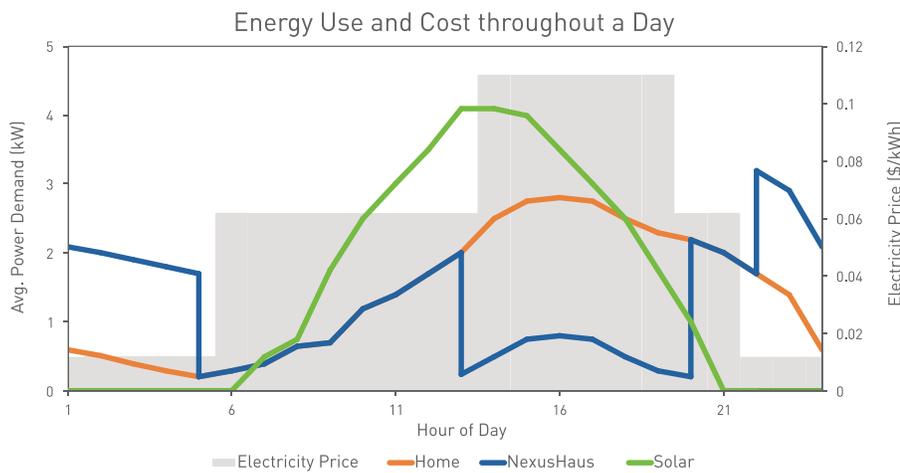


Fig. 7 Thermal storage reduces the overall load from the NexusHaus to minimize consumption during high electricity price hours, and maximize the utility of the house’s solar electricity production.

**POTABLE RAINWATER COLLECTION + GREYWATER GARDEN IRRIGATION SYSTEMS**

The NexusHaus captures rainwater to supply the majority of its potable water needs, relying on city water re-fill line only for backup during long dry spells. The potable rainwater harvesting system minimizes added stress to the region’s water supplies, and minimizes the additional load on the existing neighborhood water and wastewater infrastructure. Additionally, the on-site treatment system avoids the water losses along the municipal distribution system (approximately 10%). The thermal storage tank acts as a secondary storage volume for rainwater, giving the system additional capacity while also providing beneficial load shifting.

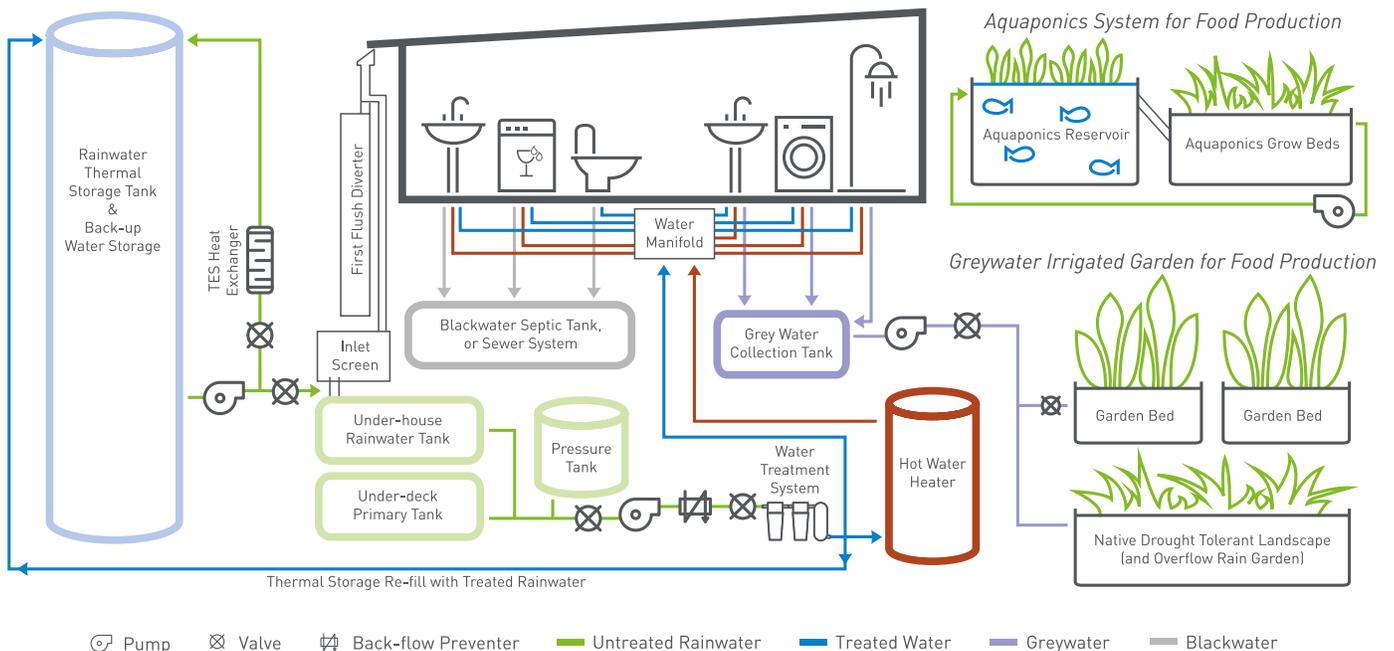


Fig.8 Schematic diagram of the rainwater harvesting system for NexusHaus.

Figure 8 shows the rainwater harvesting system portion of the IThERST system for NexusHaus. Rainwater is collected off the roof and pre-screened for large debris, and the first-flush diverter diverts the initial rainfall away from the rest of the rainwater collection system. An additional inlet may be used to screen organic matter (such as leaves, bugs, etc.) from the incoming water to minimize contaminants accumulating in the primary collection tank. The primary rainwater collection tank catches rainwater, and stores it for eventual consumption in the potable water system, or transfers it to the rainwater thermal storage tank, provided it is not full and/or occupied by thermal storage operation.

When potable water is needed in the house, rainwater is pumped from the primary storage tank through a filtration and treatment system. A pressure tank help maintain system pressure and keep the rainwater pump from short cycling. The filtration and treatment system filter and treat water to potable water standards, and then feed into a domestic water system, distributing hot and cold water to each of the end-uses. Water supplied to the kitchen sink, the dishwasher, and the toilets will be collected and conveyed to a blackwater tank (or the sewer). These sources of wastewater typically contain high levels of organic matter (and/or other pollutants), which make it unsafe to re-use without treatment. However, water supplied to the bathroom sink, the shower, and the clothes washer will be collected and conveyed to a greywater system for beneficial re-use outside of the house. The greywater collection tank accumulates greywater and periodically pumps it into a subsurface irrigation system. The garden maximizes the utility of this precious water source by featuring a landscape designed for food production as part of a sustainable garden ecosystem.

The rainwater thermal storage tank is used for the indirect water thermal storage with the hydronic cooling and heating system during the summer months when thermal storage operation is desired over additional rainwater system capacity. In the non-summer months, the rainwater thermal storage tank acts as additional capacity for the rainwater harvesting system.

### **SMART HOME TECHNOLOGIES FOR EDUCATING OCCUPANTS + INFLUENCING CHANGE**

Interactive technology is increasingly a part of everyday life, and NexusHaus will take this concept to the next level with a student-designed home monitoring and management system, called NexSmart. NexusHaus not only facilitates sustainable living, but educates the users, teaching them how to live more sustainably. A major theme is 'agency and education' – the home should provide the means to live more sustainably while simultaneously encouraging sustainable habits.

The NexSmart encourages sustainable living in an affordable manner by informing and educating the user about the energy and water that the house is both producing and consuming. In addition, the NexSmart is customizable to its inhabitants by responding to remote commands that change and morph the environment within the home so that the users can customize their own optimal lighting and thermal comfort levels. The NexSmart system monitors the house and interacts with home occupants through both a web-based phone app and custom in-house touch panels called the SenseBar. The system has preprogrammed settings for different operating modes (for example, dinner party mode, or movie night mode), as well as collect data to perform continuous system diagnostics to alert homeowners if a piece of equipment is malfunctioning or operating inefficiently.

The bar is divided into three primary sections:

- An integrated display for time, temperature, and other commonly sought after status information;
- An array of sensors to measure temperature, relative humidity, light levels, and other environmental variables;
- And a touchscreen interface for more detailed occupant interaction and information communication

The NexSmart system will be based around a Beagle Bone Black, and this microcontroller will control all the sensors (temperature, humidity, CO, etc.). The connections will be via Bluetooth Smart (BLE), and we will create a custom Bluetooth module that will have an optimal design to connect to any sensor and power/transfer any sensor. The NexSmart will be able to connect to a maximum of 7 of these sensor modules at a given time, and the modules will have memory storage capabilities so that data can be transferred once there is a connection with the Beagle Bone. Using the collected data the system then either informs the user about energy saving actions or automates some part of the home to mitigate energy loss.

### ENERGY ANALYSIS + SYSTEM MODELING

For the house to be both effective and affordable, electrical loads and thermal loads must be analyzed and minimized to properly size the PV system so that all electrical needs are met with minimal excess production. To perform this task, the team has estimated the annual expected energy consumption from indoor electrical loads (such as appliances, lighting, and various plug loads), the electric car, and the HVAC system, and used this along with modeled solar PV production data to size the array for Austin, TX. The following section summarizes the modeling effort for evaluating the performance of NexusHaus.

### ESTIMATING ANNUAL HOUSE ELECTRICITY CONSUMPTION

Estimating the electricity demands for the house was performed using a program called BEopt (Building Energy Optimization), a Dept. of Energy developed software that uses Energy Plus for the underlying energy modeling engine. BEopt was developed for quickly estimating energy consumption and savings from energy efficiency upgrades, and was designed specifically for modeling residential buildings. BEopt uses a simplified geometry builder to approximate the size and glazing of a home for energy purposes, which has been shown to be reasonably accurate at estimating actual home energy consumption from real-world benchmarking<sup>5</sup>. This program provides a good starting point for residential energy analysis and system sizing, so we modeled a simplified version of the home (see Figure 5) to get an estimate for internal electric loads and whole-home heating and cooling loads.

House insulation and glazing properties are inputs into the model, shown in Table 1. Other parameters, such as house location and orientation, number of bedrooms and bathrooms (sets occupancy), type of lighting, type of appliances, and miscellaneous loads are all factored into the model to calculate annual energy consumption. The house was modeled with LED lighting, energy efficient appliances, and typical miscellaneous loads. We were primarily after the indoor appliance and lighting loads, for which BEopt has a variety of pre-programmed values and schedules based on Building America survey data and previously validated models.

The modeled annual energy consumption from BEopt is shown in Figure 6. The category 'Lg. Appl.' includes the refrigerator/freezer, dishwasher, clothes washer, and dryer. 'Misc.' includes all plug loads that

House/Model Parameter	Value	Units (SI)	Value	Units (IP)
House Finished Floor Area	72.8	[m <sup>2</sup> ]	784	[ft <sup>2</sup> ]
Roof/Ceiling Total Insulation	6.7	[m <sup>2</sup> °C /W]	38	[ft <sup>2</sup> °R hr/BTU]
Wall Assembly Total Insulation	3.5	[m <sup>2</sup> °C /W]	23	[ft <sup>2</sup> °R hr/BTU]
Floor Assembly Total Insulation	3.33	[m <sup>2</sup> °C /W]	19	[ft <sup>2</sup> °R hr/BTU]
<i>Windows – Double pane, low-e, insulated frame, Argon filled</i>				
Window Area Ratio (BEopt input)	.18	[A <sub>Window</sub> /A <sub>Wall</sub> ]	.18	[A <sub>Window</sub> /A <sub>Wall</sub> ]
Window U Factor	0.046	[W/m <sup>2</sup> °C]	0.26	[BTU/ft <sup>2</sup> R hr]
Window SHGC	.31		.31	

Table 1: The primary thermal parameters for the house energy model

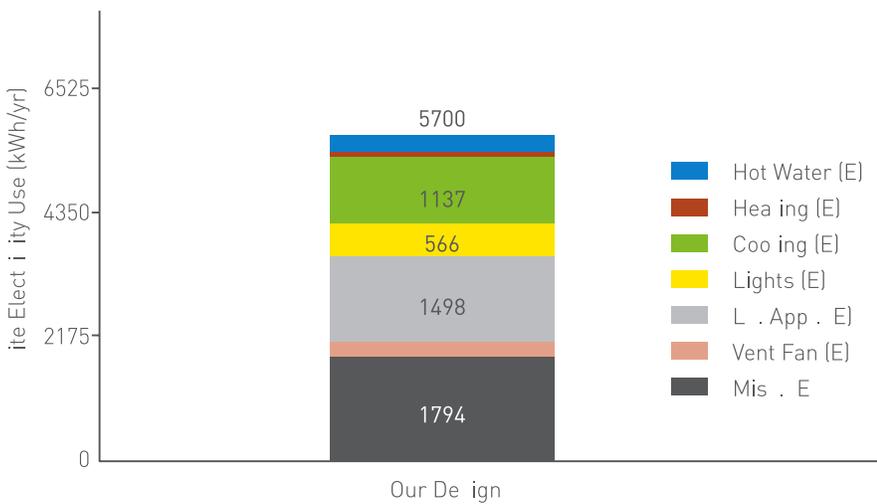


Fig. 9 The output from BEopt estimates NexusHaus' Total Annual Electricity Consumption at approximately 5700kWh for Austin, TX. This analysis used the DOE-specified comfort range year-round without any natural ventilation.

would be present in a typical house (including small electronics, computers, televisions, etc.).

For order of magnitude comparison purposes, this model run shows the energy consumption from a mini-split heat pump with SEER 18 rating (similar system efficiency to the chiller model used in the NexusHaus design). This example analysis used the DOE-specified comfort range year-round for estimating the heating and cooling load. A more complete calculation of the heating and cooling load is described below.

**ESTIMATING WATER + MECHANICAL SYSTEMS ELECTRICITY CONSUMPTION**

NexusHaus uses a hydronic heating and cooling system with indirect chilled water thermal storage utilizing rainwater—a design not typical of a normal residential home. While the BEopt model provides an order of magnitude estimate of heating and cooling energy consumption based on a heat pump system with similar efficiency, it does not have built-in hydronic fan coil options, nor the ability to model energy consumption from the rainwater system components. To calculate estimated performance of the hydronic system, and the potential energy consumption from the rainwater system, a separate post-processing step was used to calculate electricity consumption for the hydronic and rainwater systems.

The cooling load for a calendar year is taken from BEopt and used to calculate the run-time and energy consumption of the system, taking into account the outdoor air temperature.

Using this model, the total annual energy was calculated for cooling and heating the house, shown in Table 2. For this analysis, the thermal storage system was only used during the summer afternoon hours, and not during the winter.

Category	Electricity with IHERST (kWh/yr)	Electricity without IHERST (kWh/yr)
Total	3662	2540
<i>Sub-categories:</i>		
Cooling	2041	1856
Heating	740	740
Rainwater Treatment	744	744
Rainwater Pumping	137	137
<i>Note: (includes all auxiliary HVAC loads)</i>		

Table 2: Electricity consumption by end use, as calculated by BEopt energy model, for NexusHaus.

While the thermal storage can reduce on-peak load (electricity demand and energy consumption) by approximately 75-80%, it has an associated energy penalty of 7-9% beyond the regular hydronic system. Since time of use and load shifting are not accounted for in the measured energy contest, the thermal storage system will not be operated during the competition to conserve energy for the energy balance competition. Similarly, the on-site treatment system is designed to run continuously 24 hours per day as a safety precaution, so this system will be turned off during the competition to avoid unnecessary energy consumption.

**ESTIMATING ELECTRIC CAR ANNUAL ELECTRICITY CONSUMPTION**

Electric car energy consumption is not something that is modeled in BEopt. Estimation of this load was performed by multiplying the average electric efficiency of the car (in kWh/100 miles) by estimated annual miles driven. These calculations were performed for three scenarios: a low car use (10mi/day) scenario, a medium car use (20mi/day) scenario, and the average American driver (approximately 41 miles/day). Table 3 below shows the estimated annual electricity consumption based on these car usage scenarios, assuming the average car efficiency, and that all car charging is performed at home, and that the charging efficiency is included in the car efficiency.

Car Efficiency:	Miles Driven/yr		
	Low Car Use (10 mi/day)	Med. Car Use (25 mi/day)	Avg. American (41 mi/day)
27kwh/100mi			
Annual Miles	3,650	9,125	14,965
Total Annual kWh	986	2,464	4,041

Table 3: Estimated electric car electricity consumption for three usage scenarios

As shown in the table, electric car recharging loads can be quite significant, equaling over 13% of the non-car house electricity load on the low use scenario, and equal to over 54% if driven the average annual mileage for a typical American. Since NexusHaus is meant to be urban infill in the central neighborhoods of Austin, we will assume the occupant will not need to drive as far or as often, and therefore we will only evaluate PV array sizing based on the first two scenarios.

**TOTAL LOAD FOR SIZING THE SOLAR PV ARRAY**

Adding all non-HVAC house loads from BEopt, the estimated car load, and the calculated HVAC loads for the house, the total annual energy consumption estimate is shown below in Table 4.

Loads (kWh/yr)	Solar PV System Design Loads			
	W/ IOTHERST System		No IOTHERST System	
	Low Car Use	Med. Car Use	Low Car Use	Med. Car Use
Total	9,068	10,546	8,001	9,479
Total (w/o car)	8,082	8,082	7,015	7,015
Sub-Categories				
Non-HVAC House Loads	4,419	4,419	4,419	4,419
HVAC	2,782	2,782	2,540	2,540
Rainwater Systems	881	881		
Electric Car	986	2,464	986	2,464

Table 4: The BEopt model outputs, HVAC loads, and electric car estimated energy consumption were all calculated to size the solar PV array for net zero energy operation.

These numbers provide the basis for sizing the PV array to meet net zero energy operation. Looking at the differences between the annual total energy consumption, the range is from approximately 8,000 kWh on the lowest end to 10,550 kWh on the highest end. Since the goal of this house is to provide the ability to operate on a rainwater supply for domestic water, the system will be sized to accommodate the energy needs of the IOTHERST system.

Using the PV modeling capabilities of BEOpt, it is estimated that an 8.1KW (DC) array could provide approximately 10,870kWh during a typical year in Austin. Based on the DC rating of the SolarWorld panels provided (290W), an array with a 10 degree slope comprised of 28 panels yields a system capacity of 8.12kW DC.

Beyond meeting the needs for the IOTHERST System, up-sizing the PV array is also necessary to ensure the house produces enough energy for the Solar Decathlon competition. Modeling for the competition week (October 8-18) in BEOpt Estimates total energy consumption of approximately 252kWh, and solar production of approximately 277kWh. The energy consumption estimate from BEOpt is somewhat higher than our own conservative estimate (approximately 230kWh) calculated independently in Excel based on contest criteria, measured appliance performance, and name-plate ratings of light fixtures and other electric loads.

<sup>1</sup> EIA. Monthly Energy Report, U.S. Energy Information Administration, February, 2015.

<sup>2</sup> M. A. Maupin, J. F. Kenny, S. S. Hutson, J. K. Lovelace, N. L. Barber, and K. S. Linsey. Estimated Use of Water in the United States in 2010, U.S. Geological Survey, November, 2014.

<sup>3</sup> ERCOT. Report on the Capacity, Demand, and Reserves in the ERCOT Region – February 2014, Electric Reliability Council of Texas, February, 2014.

<sup>4</sup> Texas Water Development Board. 2012 Texas State Water Plan. Technical report, Texas Water Development Board, 2012.

<sup>5</sup> J. D. Rhodes, W. H. Gorman, C. R. Upshaw, M. E. Webber. Using BEopt (EnergyPlus) with energy audits and surveys to predict actual residential energy usage. Energy and Buildings 86: 808-816, November, 2014.

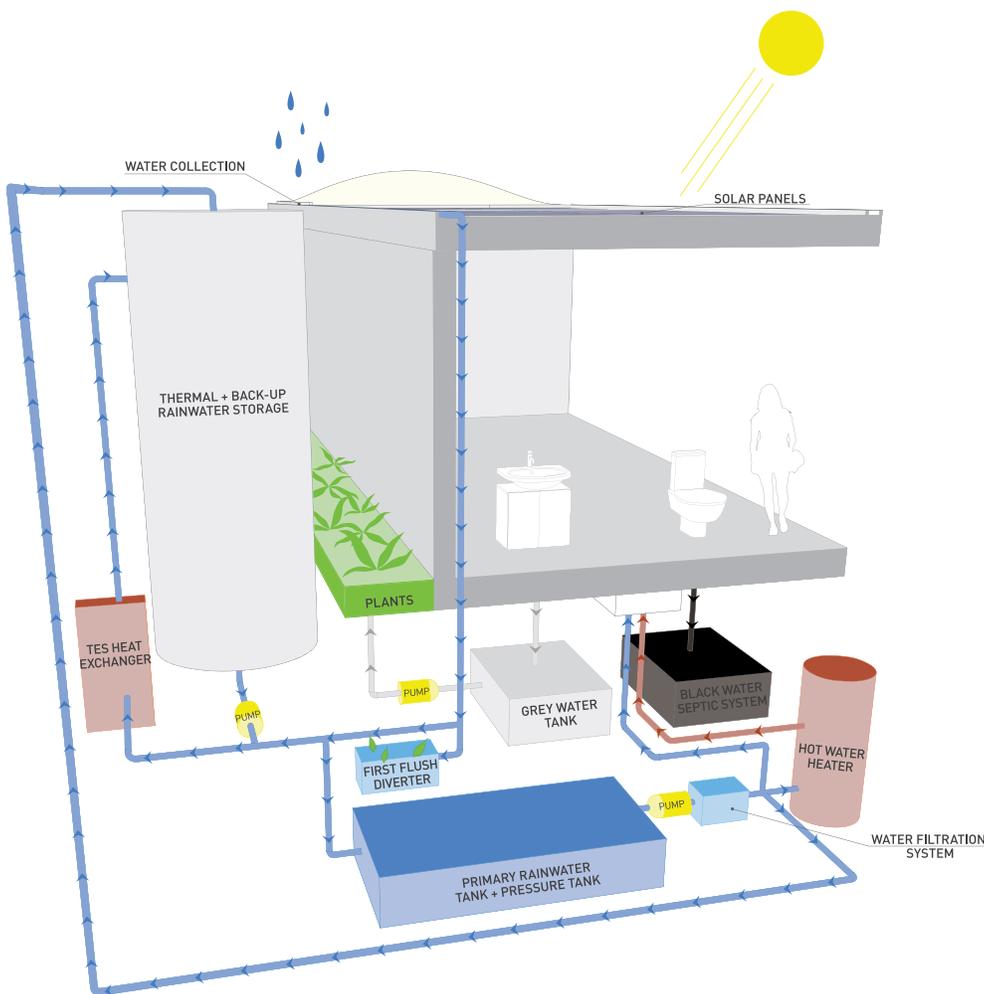


Fig. 10 3D-water system diagram

## COMMUNICATIONS NARRATIVE

### OBJECTIVES + STRATEGIES

The Nexus concept stemmed from local energy and water issues. “Energy-x-Water” and the interchange between these challenges locally were the initial seeds for the NexusHaus and the subsequent driving force behind our brand and marketing strategy. Linking concepts of energy, water, food and density propelled the architecture and engineering plans and the merging of our universities to create our team inspired the “Nexus” house or “NexusHaus”.

For communications, our three main strategies are: to educate about the four main concepts of NexusHaus highlighting our brand identity, to promote a cross-cultural international audience in both Texas and Germany, and to increase collective awareness about sustainability efforts both locally and nationally through the efforts of the Department of Energy Solar Decathlon competition.

### KEY MESSAGES + OUTLETS

Our four core concepts are the basis for our logo, they serve as inspiration for our social media strategy, and also elucidate the organization of our display and promotional materials for the competition. Our “X” logo icon represents the exchange and interdependence that each concept has with each other. Water, energy, and food are directly related through the engineering of NexusHaus and density more broadly addresses the strain on natural resources in Austin caused by extreme population growth. The colors and icons are used throughout our materials to enforce our brand identity, clean and simple.

Facebook, Twitter and Instagram have been our primary social media channels for reaching Texan, German, and other interested parties. YouTube and Flickr will become more of a focus during the competition for streaming and photo galleries. Our website, [nexushaus.com](http://nexushaus.com) is the information hub for our project, offering easily accessible information and opportunity for sponsorship. In addition, our website is the home to our blog “Nexus News,” which is the most up-to-date source for weekly articles throughout the design and construction phases. Using multiple platforms, we are able to reach both German and Texan audiences by sharing photographs and articles that pertain specifically to the competition or the goals of our house. As a prototype for maximizing the Accessory Dwelling Unit potential in the City of Austin’s zoning code, sharing the unique features of the house that homebuyers would benefit from on Twitter and Facebook generates interest in the project.

### METRICS

Using the Wordpress Jetpack plugin, we have been able to collect data that shows the international reaches of our audience and the level of engagement increasing over time. Over 20,000 visitors have explored the site from 109 countries. 11,000 viewers were located in the USA and over 5,000 in Germany, which demonstrates the international reach of our team. We have been managing our social media with a small team of students. Facebook is an on-going effort, but working with the communications staff at our respective universities, we have been able to promote the page and use it as our daily sounding board for communicating with our audience. Instagram content is a mixture of construction photos, volunteer efforts, and painting a picture of our local landscapes. Twitter is our best way to directly promote and contact sponsors and university groups, and to share links of related, but not exclusively team-produced articles.

**INTERNATIONAL AUDIENCE + APPEAL**

As only one of two teams with a European partner in 2015, our strategy has been to encourage the cross-cultural nature of our audience. Though the house was built in Austin, a significant portion of the design process and the documentation took place in Germany. In addition, our sponsors and local interest are not limited to Texas, but rather the Technische Universität München (TUM) has promoted NexusHaus at multiple expositions and has expanded international interest exponentially. At the German Construction Fair in January, NexusHaus gained exposure from materials and building contractors around the world. And more recently, the Jahresschau Architecture Exposition in Munich allowed NexusHaus to offer a status update regarding construction progress amongst architecture students and professionals locally. Due to the difference in time zones, we receive traffic on our website and social media platforms at all hours of the day. This unique aspect of our team allows us to cater specific posts to the morning in Texas and the evening in Germany.

As construction wraps up on the house, we are planning to hold a press event that would showcase what sustainable features local homeowners may be interested in purchasing for their homes. Affordability is a primary concern with the level of custom technology and appliances in the home; however, one of our goals has also been to incorporate design features that will be market-ready now or in the near future. By reaching out to local media in Austin (radio, TV, print media) we have offered a comprehensive picture of the benefits of our design and sustainable housing opportunities. NexusHaus has been featured at the two aforementioned German expos and will be featured at two symposia in Austin: Research Round-up, which took place in March through the UT School of Architecture and the UT Sustainability Symposium, which will be in September. These events are critical in spreading awareness to potential sponsors and participants about the house and on-going sustainable design efforts at UT and TUM.

We plan to increase our audience steadily as we approach the competition in Irvine by continuing to push our current strategy. In Irvine, we hope to use our house as an “event space” to bring a taste of Austin and Germany to Solar Decathlon. The energy and cultural interest in combination with increased social media content will help us stay competitive through the remainder of the competition. We plan to improve the overall number of followers, but also to promote more direct engagement with the people visiting NexusHaus. Promoting ourselves by capitalizing on the festival culture of Austin will make for a unique tour and media experience.

Our transcultural house uses challenges facing Austin directly: energy use, water collection, urban farming, and density and offers our solution as a prototype for local and global application. The global nature of our team is reflected in our communications strategy, but also in the way our cultures have been brought together through the process of designing and building the NexusHaus. Our brand is the nexus of energy, water, food, and density but also the nexus of UT and TUM.