The Performance of a Net Zero Home in the Solar Decathlon 2011 and Beyond

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ABSTRACT

The Solar Decathlon is a biennial Department of Energy (DOE) collegiate contest wherein twenty universities are selected to design, build, and showcase residential structures that would ultimately be relocated to a competition campus to be viewed by the general public and judged by representatives of the DOE. The project structures are homes that are designed and built to conform to the parameters set forth by the DOE in an effort to showcase the use of solar power as a practical means of residential line voltage power supply. The projects are then judged according to how well they performed within those parameters.

The challenges involved in the design, construction, and operation of a "net-zero" house, that is a house that produces at least as much electricity as it consumes, were formidable. Equally formidable were the technical/logistical issues inherent in designing and constructing a building that could be disassembled and transported. Multidiscipline work groups analyzed the architectural, structural, mechanical, electrical, plumbing, building controls, and photovoltaic performance requirements. These systems not only had to be integrated within each other, but they also had to work within a tight construction budget and build schedule. Those requirements are challenging enough on a normal construction project. Added to the complexity is that the home was be built on the university campus and then shipped to the competition site, and then shipped back to its permanent location.

This paper highlights the process and strategies that a team utilized to design, build, operate, move, and successfully compete in the Solar Decathlon with a net zero home. It also presents the energy usage data that has been collected since it was rebuilt on a permanent location for January 2014 to July 2015.

INTRODUCTION

Architectural, engineering and construction projects typically have a very linear process. The design phase of a project starts with the proposal, and then moves to the preliminary design phase. After prelims are complete and the owner signs off, the engineering and construction drawings are completed. These drawings are sent out for bid, where contractors estimate cost and develop a construction schedule. The owner negotiates with the contractor over the cost and a budget is agreed upon.

Contracts are signed, permits are applied for, and construction is started. The construction process starts with the foundation, then the walls, then the roof. The steps through to building completion follow a step by step linear process. In the typical construction education curriculum, students learn a piece of the construction process while working on a set of construction plans. They take an estimating class and work on a set of donated project plans. They also take a scheduling class where they work on a different set of plans. The students experience a piece of the AEC process while working on these small parts of a whole project, but they never experience the process in the normal project path. In fact, they rarely get to experience the full construction process on a single project in their college career. However, those students who choose to be involved in extracurricular team projects often find themselves gaining greater experience. The Solar Decathlon project allows students to experience the entire AEC project path from start to finish.

The Solar Decathlon is a biennial Department of Energy (DOE) sponsored collegiate contest to "promote and speed to market" solar powered, residential homes (Grose, 2009). It is a student competition wherein twenty universities are selected to design, build, and showcase residential structures that would ultimately be relocated to a competition campus in West Potomac Park in Washington D.C. During the competition, homes are viewed by the general public and judged by representatives of industry professionals from the fields of Architecture, Engineering, Real Estate and Development. The challenge is to "design, build, and operate solar-powered houses that are cost-effective, energy-efficient, and attractive" (DOE). Each team's home is designed and built to conform to the parameters set forth by the DOE in an effort to showcase the use of solar power as a practical means of residential line voltage power supply. The projects are then judged according to how well they performed within those parameters.

The challenges involved in the design and construction of a "net- zero" house, that is a house that produces at least as much electricity as it consumes over the course of a year, were formidable. Equally formidable were the technical and logistical issues inherent in designing and constructing a building that could be disassembled and transported. Finally, reconstructing a residential dwelling, complete in all respects in the allotted time period of seven days created educational opportunities that mirror conditions a construction manager will face in his or her professional life.

Purdue University was one of twenty teams selected to compete in the 2011 Solar Decathlon. The INhome, short for Indiana home, was not only Purdue University's first entry in the decathlon, but also the first home to represent the State of Indiana in the competition's history. The project fielded by Team Purdue ultimately placed second in the competition.

The resolution was however only a small part of what was accomplished. All who were involved in the project came away with a new depth and a new found level of maturity within their specific fields of endeavor. While the classroom provides an educational framework for the process of construction management, student competitions like the Solar Decathlon, gives context to what is learned in the more traditional venue of the classroom. This study investigates those educational opportunities and explores how those opportunities form an essential component of the process of construction management education.

Over the two years working on the Solar Decathlon project, the students have the opportunity to work on a residential project with commercial caliber design submission requirements. To manage the workload, track the process, and keep students working, a class was created each semester for this project. The earned credits were tied to meeting the DOE deliverable due that coincided with that semester. There were over 200 students from multiple disciplines that worked on this project including: Mechanical Engineering Technology, Building Construction Management, Interior Design, Computer Graphics Technology, Civil Engineering, Mechanical Engineering, Visual Arts and Design, Hotel Tourism Management, Industrial Engineering, and Health & Safety.

The project started with a group of students visiting the Solar Decathlon 2009 to catch the vision. The next step was the proposal writing and submission process. Once the team was notified that the proposal was accepted, work groups were created to start the preliminary design process. Each group created multiple preliminary designs and then they were reviewed by the entire team. Through this process, the team was able to use the collaborative design-review approach to refine down to a single floor plan design. The class then worked in different work groups broken up by area of focus; interior & exterior finishes, structural engineering, MEP design, estimating and costing. The preliminary design was then refined, reviewed, and construction drawings were created. The groups created shop drawings, material lists, estimates, and construction schedules. This construction packet was submitted to the "owners", the Department of Energy, for review and comment. At the end of the design process, the students had created a 100 page construction document set, a Building Information Model (BIM), a 500 page project and specifications manual, and a 400 page safety manual.

Once the project was approved by the DOE, permits were pulled and the house was constructed by the students on a site located on Purdue University's campus. The students self-performed much of the home construction and worked alongside industry professionals to build and commission the home in preparation for the competition in DC. While the student construction team was working on the home, other student teams were creating the website, brochures, speaking points, tour presentations, dinner party menus and logistical plans. Once the home was completed on campus, the teams tested every system, practiced every competition, and hosted multiple open houses for the public before packing the home up for the competition. The team also spent two weeks practicing taking the house apart and putting it back together, a monumental feat unto itself. The house was taken apart for a second time and the entire project was shipped to Washington D.C. Student managers worked with teams of students to rebuild the home in seven days. Then they competed in five juried and five measured contests while hosting open houses and dinner parties for 10 days. After the commencement of the competition, the home was disassembled and cleared off the site in a mere five days. With this intense two year timeline, many of the students spent the majority of their college careers working on this project.

RESIDENTIAL ENERGY USAGE

Residential energy consumption remains the largest untapped opportunity to reduce the dependence on fossil fuels. While the public and private community continue to invest in new energy sources, today wind costs are still ranging from \$0.08/kWh - \$0.20/kWh and solar projects upwards of \$0.24/kWh for large scale productions (US DOE, 2014). By simply retrofitting residential properties, an energy company can produce savings through conservation and individualized energy production at a cost of \$0.03/kWh (Friedrich, 2009). Research in the area of specific residential applications is scarce, but with the opportunities recognized by the DOE, NREL, Berkeley labs, and research universities across the globe, new advancements are being published every day. Current related research is found in the commercial sector but has often been misused in a residential application (Yudelson, 2008). Commercial properties and occupancy habits remain fairly consistent with building practices having been standardized for years. This makes calculating energy usage and savings in the commercial sector much easier and more accurate. When dealing with a residential application, many homes built in the same period and style are often done using various framing and design techniques. Couple these building differences with the specific unique homeowner habits, and it becomes difficult to accurately use commercial science on a residential retrofit (Augenbroe, 1998; McGraw-Hill, 2008; Bowen, 2005). Seeking an opportunity to understand and reduce consumption, the scientific community has developed a number of tools and technologies in an attempt to accurately analyze energy usage. The solar-decathlon projects, specifically the Inhome allowed for the opportunity to not only predict energy consumption, but monitor the data monthly in a traditional home-owner setting.

In 2014, 41% of total U.S. energy consumption was consumed in residential and commercial buildings (Figure 1) (EIA, 2014). While the commercial sector seemed to effortlessly convert to using "green" building practices, the residential sector has been stagnant with specific pockets or communities gaining momentum only to lose it due to economic slowdown or lack of government funding (McGraw-Hill 2009; EIA, 2008). With government funded residential properties accounting for less than 1% of the entire building portfolio (NAHB, 2010), it has had little to no influence on the building practices. When trying to influence and change century old building practices, accessing and educating the commercial sector becomes a much more obtainable and effective task. Educating and training a residential sector in which 95% of the firms employ less than 10 people has often been linked to the lack of green momentum in the home building industry (McGraw-Hill, 2006). Finally, the budget allocation for energy use has not been taken into account until recent years. A commercial building can incur yearly utility bills in the tens of thousands of dollars. When commercial investors are looking at a useful life expectancy in the building for over 50 years, the investment to save 15-20% of those utility costs makes energy efficient practices such as solar financially viable. These budget opportunities quickly become constraints in the residential sector. With the average stay in a home being less than seven years (NAHB, 2010) and utility costs reaching only a few thousand dollars per year, the budget and salability of advanced energy efficient practices become difficult.

Imagine the impact if all American residences were to transition into net-zero environments. The country would drastically reduce consumption, thus resulting in major reductions of greenhouse gas emissions. Nevertheless, this scenario is utopic. "In the United States, cheap and readily available energy obtained from the burning of fossil fuels has driven economic prosperity since the end of the 19^{th} century." (NAS, NAE, & NRC, 2010) With fossil fuel based energy being accessible and affordable, marketing of the solar energy alternative must also show accessibility, affordability and increased environmental benefits in order to compete. The U.S. Department of Energy Solar Decathlon is one avenue striving to prove to the American public that solar energy in the residential sector is a viable and necessary option.

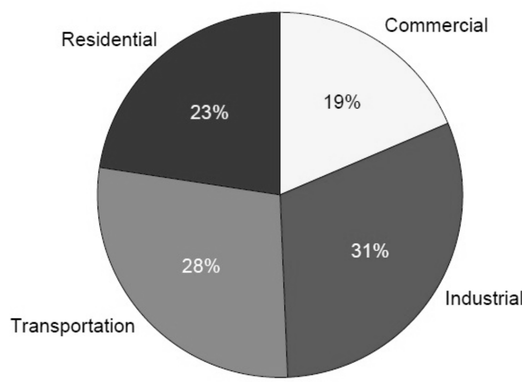

Figure 1: End-Use Sector Shares of Total Consumption *(U.S. Energy Information Administration Annual Energy Review, 2010)*

Solar Photovoltaic in Residential Applications

Understanding that the residential building community has constraints differing from those in the commercial sector does not allow researchers to ignore the rising energy consumption problem. In fact, it is the duty of the applied sciences to investigate the current limitations and identify potential solutions to the residential energy crisis. While wind and solar technologies are advancing, today kWh production from these sources range from \$0.8 to \$0.24 (US DOE, 2014). This does not include the infrastructure costs and grid updates needed to accept this energy source on large scale programs. With utility companies reaching infrastructure capacity during peak demand season, many are aggressively looking for ways to reduce demand. This opportunity for conservation has been seen as the solution with utility companies investing in conservation programs and incentives packages. Programs have allowed residents to invest in loans for HVAC upgrades, perform energy audits, and become more educated on habitual changes that can lower their energy consumption and ultimately their monthly costs. While these have been able to show an impact on a small scale, there has yet to be a model developed that shows a sustainable and large scale impact on the residential sector. The Solar Decathlon was an opportunity to highlight the influence of individual solar applications on residential properties.

Private investors, non-profits, utility, and government based programs have all attempted to infuse energy production models into the residential sector, some with more success than others. Private companies often struggle with payback projections and workforce training that makes their business unsustainable when any sort of government rebate or tax incentive runs out (McGraw-Hill, 2009). The non-profit based groups tend to focus on senior citizens or low-income families by making improvements to homes. These groups are most often mission based and narrow in focus. The utility based programs often attempt to work with the homeowners and financial loan programs. While some of these programs are effective, they are state specific, exclude solar, and still require a large financial commitment from the consumer. The long-standing government retrofit programs have exclusively targeted low-income housing, leaving 80% of the population unable to access these programs (Stern, 1986; U.S. Census, 2008). This “middle” class is the majority of homeowners that are considered too wealthy to qualify for government assistance but too poor to afford any substantial out-of-pocket upgrades.

Understanding that today’s housing stock stands at over 132 million homes (U.S. Census, 2014) and is currently replacing older homes at a pace of 700,000/year (NAHB, 2010), the development of a truly market-driven residential solar application model is not only possible, but necessary. The National Renewable Energy Laboratory has implemented a project called the “Open PV Project” that catalogues all solar photovoltaic installations in the United States. Updated on a daily basis the project has catalogued over 175,000 installations in the United States, showing a combined total installed capacity of over 2500 Mega-watts (MW). (NREL, 2012) Among these installations is Purdue University’s INhome. On an international stage in the Solar Decathlon, Purdue strove to show Americans the accessibility, affordability and practicality of solar electric installations in the residential sector in an attempt to inspire residential consumers to think of solar photovoltaic installations as a realistic option. By monitoring the energy usage after the competition, the researchers are able to add to the science of prediction monitoring and increased accuracy of residential energy consumption.

THE DESIGN OF THE INHOME

During the INhome’s conceptualization phase, Team Purdue analyzed challenges associated with solar home design for the Midwestern market and climate conditions. They looked at design strategies to maximize efficiency while minimizing costs, and prioritized the importance of creating an attractive and marketable home.

The philosophy behind the INhome’s design was to create an efficient, practical and affordable home that would appeal to the broad market of residential homebuyers. Often times consumers relate solar powered houses to modern architectural styles and high price tags. It was the team's viewpoint that in order to inspire a major shift in the way homeowners view solar installations, the team needed to create a marketable solar home that would fit into neighborhoods across the country. By utilizing rich natural resources local to the Midwest, all commercially available off-the-shelf components, user friendly controls, and open living spaces, the INhome shows consumers that they do not have to sacrifice modern comforts and amenities to live in a solar powered home. Solar homes can be comfortable, spacious, luxurious and look "normal".

Figure 2: Picture of the INhome in Washington D.C. (*The Purdue INhome Team, 2011*)

The variable Indiana climate posed a real challenge in designing a solar home for Midwest solar living. The Indiana State Climate Office describes the maximum and minimum temperature range in the State of Indiana between above 100 degrees Fahrenheit in the summer to below -30 degrees Fahrenheit in the winter. Also, average first and last freeze dates occur on October 16 and April 22. The systems and construction of the home has to be able to handle all climate extremes for the entire year. (Indiana State Climate Office)

According to the DOE, heating and cooling of the space uses the most energy, followed by heating of water, lighting, and appliance and refrigeration (see figure #3). Focusing on these areas to reduce energy consumption is the most effective strategy to use when designing a net zero home. These are the main areas that the Purdue team focused on when designing the INhome.

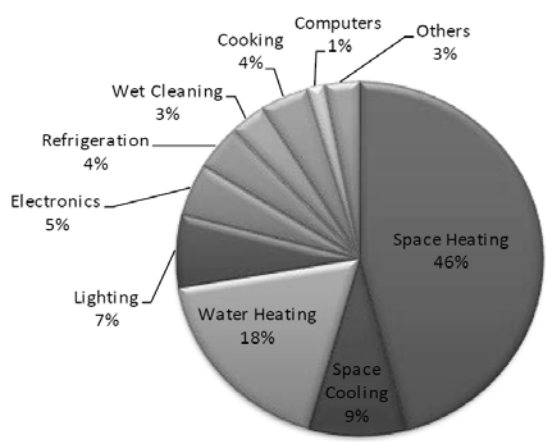

Figure 3: 2008 Residential Energy End-Use Splits. EERE Building Energy Data Book, (*U.S. D.O.E., 2011*)

Reducing the energy needs of the home is one of the crucial first steps in the design of a net zero home. (NAHB_Reserch_Center). This can be achieved through decreasing the physical space that needs to be heated or cooled. Smaller homes use less energy. Larger and or poorly designed homes use more energy or use it ineffectively. The INhome was only 984 square feet and its efficient use of space planning and multiple function travel planning within rooms allows for a very efficient floor plan. As you can see in Figure 4, there was only 20 square feet of actual hallway space.

The INhome was designed in three modules including the Public Core, Mechanical Core, and Private Core. The Public Core consisted of living and dining rooms, while the Private core included two bedrooms. The Mechanical Core housed all of the plumbing and mechanical equipment as well as the majority of electrical wiring including the bathroom with dual sinks, kitchen with bar and mechanical closet/laundry. Refer to Figure 4 for a rendered floor plan of the INhome.

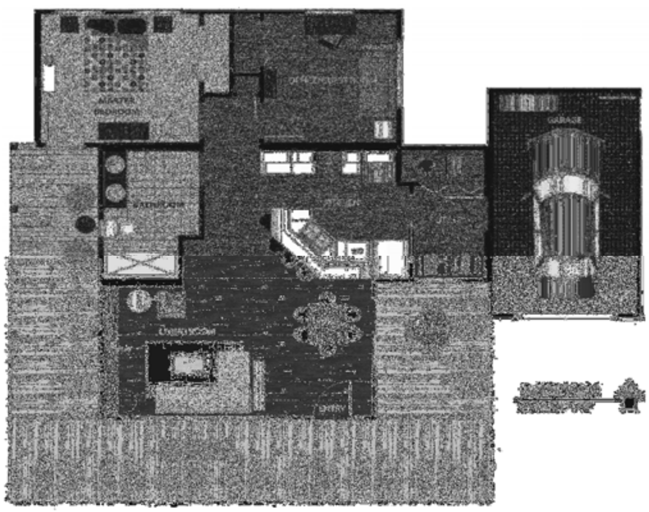

Figure 4: INhome Floor Pan – Not to Scale (*The INhome Team, 2011*)

Orientation on the lot is very important for a solar home. The INhome was located facing south. It utilized passive solar design principles with solar shading built into the east and west sides of the home. As the sun rose in the morning, the west side garage shaded the solar heat gain until the sun rose high enough in the sky to hit the solar panels of the roof. As the sun set at the end of the day, the west covered porch shaded the home from the evening solar heat gain.

Maximizing the energy efficiency of the thermal envelope through increasing insulation in the foundation, walls, and ceilings greatly reduce the energy needs of the home. (NAHB_Reserch_Center). For the competition in DC, the INhome sat on a raised open foundation system of pier pads. To create an insulated floor system, the underside of the floor joist were sheathed with 7/16 OSB and six inches of closed cell polyurethane insulation blown into the floor joist cavities. This not only provided an insulation value of R-36 in the floor, it also insulated the band joist of the entire home and sealed the entire floor system from air leakage.

The walls and roof of the INhome were constructed with a Structural Insulated Panel System (SIPS). "SIPs are engineered composite load-carrying panel products consisting of a ridged insulated foam core sandwiched between two structural facings" (Kermani, 2006). This removed typical structural stud framing in the construction of the walls. Studs not only reduce the insulation capacity of a wall, they also provide a thermal bridge and transfer energy outside the thermal envelope. The INhome's SIPs were constructed from two layers of 7/16 OSB sandwiched together with blown in closed cell polyurethane insulation. The four inch wall panel had R-24 insulation and the eight inch roof panel had R-50 insulation. The electrical boxes on exterior walls were molded into the panel and sealed completely around with blown in foam. Every panel joint, corner joint, floor to wall, and wall to roof panel joint had a double flexile foam gasket to seal the joints. This gave the INhome a very tight thermal envelope with very little air leakage. It had a 0.147 Air Exchanges per Hour (ACH) of infiltration at ambient pressure, and 0.217 ACH with the Energy Recovery Ventilator (ERV) in operation.

Using low U-Value, low-E windows and doors was also a very important part of an energy efficient thermal envelope (NAHB_Reserch_Center). The INhome's windows were triple paned low-E Argon gas filled windows with a 0.2 u-value (R-5). To take advantage of passive solar design, 73% of the INhome glazing was south facing, with only one window and door on the east side and none on the west side. The front overhangs of the home were designed to allow the sun to shine into the windows during the winter months, contributing to solar heat gain, but block the sun during the summer months. All the windows were operable, including the clerestory awning windows. This allowed the home to be passively cooled through the stack affect. As hot air existing in the home exited through the upper clerestory windows cooler air was drawn though the lower awning windows.

Among the equipment in the home were a high efficiency dual stage heat pump with an efficiency rating of SEER 19, and an air handler with variable frequency drives. Also, an energy recovery ventilator served to regulate the fresh air entering the home on an as needed basis. Need is determined by levels of carbon dioxide and volatile-organic-compounds (VOCs) in the air. A ducted dehumidifier was also placed in the home to pull moisture out of the air in an attempt to separate latent and sensible loads.

An innovative feature of the home was the Biowall. The biowall was a vertical living plant wall that housed heart-leafed philodendron. The biowall was unique because unlike a simple living wall, it was connected to the HVAC system in the home serving as a natural air purifier. As return air passed through the biowall and into a duct located on the opposite side, the philodendron removed carbon dioxide and other contaminants and used them as a food source. In a closed loop hydroponic system, the biowall was self-sufficient with light-emitting diode (LED) grow lights set on a schedule to compensate for days with minimal interior reflected daylight.

In addition to the biowall, smart home controls enabled the residents to be energy conscious about their consumption within the home, and production coming from the solar panels. This was made possible with the use of an energy monitoring system and a smart home control system. All circuits in the home were monitored via the internet as well as door locks, security cameras, light switches, and the thermostat, all the while recording usage and production trends for the user. The smart home control system was chosen for its simple user interface, wireless components, and internet access. Another aspect of the controls system was the fact that it was composed completely of off the shelf components.

To reduce the energy used to heat water, a 50 gallon heat pump water heater was installed in the INhome. The water heater absorbs the heat in the ambient air and transfers it to the water. As long as the ambient air was above 40 degrees, the water heater operated at 550 watts in heat pump mode. Below 40 degrees, it ran as a standard electric water heater at 4,500 watts. This unit was installed inside the conditioned thermal envelope of the INhome, located in the mechanical closet, where the ambient temperature should always be above 40 degrees. During the competition, it always ran in the heat pump mode and was able to produce 15 gallons of hot water (110°F/43.3°C) in 15minutes for the hot water draws.

Another way the INhome reduces energy consumption is through the lighting design. By allocating LED and compact fluorescent (CFL) lighting types in different spaces, the total interior and exterior lighting package in the home totaled no more than 600 Watts.

All appliances within the home were Energy Star rated. To coincide with the team's philosophy about solar living, the appliances were all full size including refrigerator, dishwasher, microwave/convection oven combination, induction cooktop and oven. Also a full scale washer and dryer were housed adjacent to the kitchen. These appliances minimized the INhome's power consumption needs, without sacrificing modern comfort or amenities.

The INhome's photovoltaic array was designed to achieve net zero energy consumption. Net zero is a term used to describe buildings which produce as much or more energy than the users consume over the course of a year. In order to adequately size the array, Team Purdue used energy modeling software to determine average annual energy consumption with an occupancy of three residents. Using current ASHRAE standards to set performance assumptions, the models showed estimated yearly energy consumption of the INhome at approximately 7,000 kilowatt-hours (kWh). Average daily sun exposure for the state of Indiana is four sunshine hours per day, thus calculations determined the INhome's array size at 8.64 kilowatts. This system consists of 36 240 Watt monochrystallic photovoltaic panels. The INhome's array was a grid-tied system with the local electric utility. A grid-tied system enables a withdrawal/deposit process similar to a bank account for electricity produced by the home. In summer months, or on days with extended sun exposure, the panels produce more energy than the occupants will consume; thus additional electricity produced is supplied back to the electricity grid. However, on days with minimal sunlight, the INhome is able to pull from the grid to compensate for electricity needs. This process works well for the INhome located in Indiana by ensuring homeowners of the security of access to electricity year round.

THE CONSTRUCTION OF THE INHOME

The INhome was designed as a real home to be built and lived in by a homeowner. Though it was built by students, the construction team was required to meet the same building code standards, inspections, and process that a professional builder deals with every business day. The drawings were reviewed and signed off on by the DOE. All homes had to be built to the 2009 International Residential Code (IRC) and also the regulation of the National Parks Service. All structural drawings had to be stamped by a local engineer. A local building permit was applied for and received. During the construction period, all the standard construction inspections required by the local Building Official were performed.

The students started construction by laying out the foundation systems. Since homes involved in the decathlon are designed to be moved and temporarily placed on the competition site, the INhome was built on temporary foundation systems. The foundation and floor systems were engineered to accommodate large public tours. Each of the core unit's floor systems was set in place. Plumbing supply and drain lines were run through the mechanical core floor system, and then the entire floor systems was insulated and sealed to form the bottom of the thermal envelope.

The wall and roof systems were built out of Structural Insulated Panel systems (SIPs). The panels were designed per the construction drawings of the home, with shop drawings and electrical details reviewed and signed off by the construction team. The walls were then manufactured in a factory under controlled conditions and shipped to the jobsite. Students worked alongside a professional set crew to set the wall panels over the course of a day, followed by the setting of the roof panels over the course of two days. At the end of day three, the structural walls and roof were in place, along with insulation, air and moisture barriers, exterior wall electrical boxes and conduit.

Once the structure was in place, interior partition walls were built, and the HVAC ductwork was installed. The next item completed was the plumbing rough in above the floor system, along with the sprinkler system. Finally the electrical and control systems were installed. All mechanical, electrical and plumbing (MEP) systems were built inside the thermal envelope of the home.

As mentioned above, the INhome was designed to be taken apart and moved. To get the home to the competition site, it was designed to be divided into six modules. The six modules comprised of each of the three core pieces, Public, Mechanical, and Private, as well as their corresponding roof sections, totaling six pieces. A double stud wall was constructed between each core called a marriage wall. This marriage wall enabled each core to be a standalone unit when separated. With a roof peak at almost 18 feet tall, the cores were also separated along the horizontal at the eight foot ceiling plate line to allow travel below bridges. The modules were held together by 1400 screws and bolts. Drywall was cut and exterior trim was removed at the line allowing for the easy removal of screws and bolts when the home was disassembled.

In addition to roof and base wall joints, every MEP system that passed through the marriage wall or base/roof connections were well planned out. The plumbing system was the simplest, with only one vent stack to disconnect and reconnect. The HVAC ductwork had four compression fittings that needed to be resealed after every move. The sprinkler systems had to be drained along with three compression joints that had to be disconnected. The electrical wiring was the most complicated system. The home was wired with commercial conduit and stranded wire to make the job of disconnecting and pulling new wires as simple as possible.

As the interior mechanical systems were being roughed in, the exterior shell was being made water proof. House wrap was installed over the exterior SIPs which protected the oriented strand board (OSB) from premature weathering, and it also gave another level of air penetration protection. The exterior windows and doors were installed per manufacturer recommendation and sealed with window and door flashing tape. The exterior module joints were covered over with exterior trim boards so they could be easily removed for the disassembly and reassembly of the home. Finally, the exterior fiber cement siding was installed.

The roof was covered with ice and water shield instead of roofing felt paper, as an added layer of protection due to the necessity for multiple shingle replacements during reassembly. Energy Star rated cool roof asphalt shingles were installed as the roof’s finish material. The asphalt shingles were chosen because they were affordable and could easily be replaced when needed between moves. Also, an asphalt shingled roof is common in the Midwestern market, thus incorporating these shingles into the design further promotes the marketability of the INhome.

Once all the systems were roughed-in, a blower door and a duct blaster test were performed on the INhome. This gave the team a baseline of how much air was infiltrating the home. There was also a pre-drywall inspection performed by the local building official, to certify that the systems were indeed installed per the 2009 IRC. With much planning and anticipation, the INhome passed its rough-in inspection on the first round.

Once the dry wall finish was complete, then the interior was painted with low VOC paints. Engineered hardwood flooring was installed throughout, excluding for the bathroom and laundry/mechanical closet, where ceramic tile was laid. Cabinets, interior doors, baseboards and casing were installed followed by appliances and electrical fixtures. After all aspects of finishing were complete, final inspection was performed by the local building official and a conditional Certificate of Occupancy was issued. The reason the certificate was conditional was due to the home's temporary foundation.

From the issuance of the building permit to completion, it took the student team 4-1/2 months to construct the INhome. At this time, the team began practicing for the competition in Washington D.C. A final blower door test was performed. Every measured and juried contest was simulated by team members testing energy use. And once satisfied with the home's performance, the team took the home apart for a practice reassembly. During the construction phase of the competition, every team was given seven days to complete construction on the competition site. The INhome team wanted to make sure that the design and engineering of all the systems could be reassembled in seven days, and adequately perform as intended. It was an extremely stressful week of practice, but the team pulled it off. This practice run gave the student's knowledge of potential precautions and problems that would occur on the decathlon site. They went to the completion knowing that there would be problems, but that they had done this before.

Once the home was rebuilt, it was taken apart again two weeks later. This time the entire home, furnishings, tools, and accompanying student team shipped out to Washington D.C. The team successfully reconstructed the home on the competition site within the seven allotted days and began the competition.

THE PERFOMANCE OF THE INHOME AT SOLAR DECATHLON 2011

The INhome had been modeled and built to be a net zero home. During the 10 day competition in Washington DC, it performed as a net zero home. Every system of the house was utilized and tested during the competition days. There were 18,549 visitors through INhome, including Secretary of Energy, Sr. Steven Chu.

Each night, after the house had been open all day for public tours, the HVAC system was required to heat or cool the home to maintain a comfort zone within a temperature range of 71°F (22.2°C) and 76°F (24.4°C) and a relative humidity level less than 60%. The team hosted two dinner parties and a movie night simulating a lived in environment by consuming energy through the utilization of appliances and electronics Multiple times during the week, hot water draws were performed. Teams were required to deliver 15 gallons of hot water (110°F/43.3°C) in 15minutes. The purpose of these contests was to use the home as if it was occupied by homeowners.

The final contest was the energy balance. Each team's house was equipped with a bidirectional utility meter that enabled competition organizers to measure the net energy a house produced or consumed over the course of the competition. In the Energy Balance Contest, a team received full points for producing at least as much energy as its house needed, thus achieving a net energy consumption of zero during contest week. This was accomplished by balancing production and consumption. The INhome was one of just seven teams to achieve net zero energy consumption at the decathlon, proving that is was a net zero home under contest conditions. Overall, the

INhome placed 2nd in the Solar Decathlon 2011. A major contribution to this accomplishment was the performance of the home in the measured contests with placements including: 1st place tie in energy balance, 2nd place in comfort zone, and 3rd place in hot water production.

PERMANTLY LOCATING THE INHOME

At the completion of the solar decathlon, the INhome was once again disassembled by the team, packed up, and shipped by to Lafayette, IN. Upon arrival, it was placed on a permanent crawl space foundation, on a south facing lot, in a revitalized multi and single family community redeveloped neighborhood. Due to the covenants of the subdivision, the single car garage was removed, and an insulated storage/energy monitoring utility room was built in its place. A detached 2 car garage was added to the home site. The public, mechanical, and sleeping cores were rebuilt just as it was in the competition in DC, with all the energy monitoring systems in place and installed in the new utility room.

After the home was reinstalled on the permeant foundation and given a permanent address, third party rating and certifications were applied for and achieved. Without the PV array, it has a 58 Home Energy Rating System (HERS) and a -13 with the PV array. It was also certified Energy Star v2.5, certified Gold to the National Green Building Standard (Certificate # 4113), and LEED Platinum registered. It was also nationally recognized as the 2012 Project of the Year – Single Family Concept/Research (Academic) award winner as part of the National Green Building Awards competition, through the National Association of Home Builders (NAHB).

The INhome was sold to a real homeowner and there is a five year research covenant attached to the sale, where researchers can monitor via the internet monitoring system. The new owners moved into the home near the end of 2013. They are a professional couple, age 50 to 70 years old, with one working and one retired.

UTILITY DATA ANALYSIS

At the forefront of residential efficiency analysis is the ability to accurately calculate current energy consumption and thus potential energy savings. Unfortunately baseline characteristic-driven software is inaccurate on an individual level, especially with concerns to pre-1979 single family residences (Stein, 2000). The issue then becomes the ability to access actual consumption data from either the resident directly or, more conveniently, the utility provider. This “smart” grid approach has been implemented in various regions across the country, with continuous resistance from customers who are concerned with individual privacy laws (Cummings, 2010).

The U.S. Department of Energy has acknowledged that although the current electrical grid could be viewed as one of the greatest engineering achievements of the 20th century, it is increasingly out of date and overburdened (DOE, 2008). As technologies have advanced, the opportunity to utilize the current infrastructure by implementing “smart” systems has been seen as the most viable, economic solution. As a complete package, a Smart Grid would possess the following capabilities (DOE, 2008).

- **Intelligence** – capable of sensing system overloads and rerouting power to prevent or minimize a potential outage; of working autonomously when conditions require resolution faster than humans can respond and cooperatively in aligning the goals of utilities, consumers, and regulators
- **Efficiency** – capable of meeting increased consumer demand without adding infrastructure
- **Accommodating** – accepting energy from virtually any fuel source, including solar and wind, as easily and transparently as coal and natural gas; capable of integrating any and all better ideas and technologies – energy storage technologies, for example – as they are market-proven and ready to come online
- **Motivating** – enabling real-time communication between the consumer and utility so consumers can tailor their energy consumption based on individual preferences, like price and/or environmental concerns
- **Opportunistic** – creating new opportunities and markets by means of its ability to capitalize on plug-and-play innovation wherever and whenever appropriate
- **Quality-focused** – capable of delivering the power quality necessary – free of sags, spikes, disturbances and interruptions – to power our increasingly digital economy and the data centers, computers, and electronics necessary to make it run
- **Resilient** – increasingly resistant to attack and natural disasters as it becomes more decentralized and reinforced with Smart Grid security protocols
- **“Green”** – slowing the advance of global climate change and offering a genuine path toward significant environmental improvement.

With this new smart grid movement, utility regulators play an important role in insuring the information privacy rights of individual consumers. In 2000, the National Association of Regulatory Utility Commissioners’ passed a resolution urging all state commissions to adopt general privacy principles. However, these adoptions of principles do not insure the consumer of the ever more prevalent information hackers across the globe (NARUC, 2011).

The INhome, as well as the other Solar Decathlon participants, highlights another opportunity to involve residents in utility data collection and analysis. By incorporating individual solar panels and educating the owner on a “zero-net” home, the analysis and complimentary positive results fall on that of the resident. They have a financial interest in monitoring their usage patterns and can now take a concerted effort to curtail habits that historically have been found to be poor energy habits. The results of the Solar Decathlon show an opportunity to avoid any prescriptive measure that must be adopted by the masses and simplifies energy use at the single home level or exact point of energy production.

To monitor the energy usage of the INhome, an e-monitoring circuit systems (by Nexia Home Intelligence) was installed, both for the competition and the permanent location. This allows the researcher to collect real time energy usage data from each individual circuit and the power systems of the INhome, without disrupting the homeowner's life and privacy. The homeowner can also monitor their personal usage on a daily, weekly, monthly, and yearly basis with an intelligent and efficient dashboard screen on any internet enabled device. The system dashboard reports the power being used and power production in real time, along with the top energy circuits and the 30 day Carbon Footprint of the home in comparison to the IN average (see figure 5 below).

Figure 5: INhome Energy Monitoring Dashboard

The system also reports out the energy usage for all the circuits, organized by the individual appliances, HVAC equipment, laundry and hot water usage, room lighting, and outlets. It give the homeowner recommendations to save even more electricity based on their typical usage. The system also shows them their saving history, total net metering usage, and lbs of CO2 saved. Figure 6 shows the total kWh produced by the INhome the past year (October 2014 to October 2015) was 10005, with 6,734 kWh exported to the grid. This produced a savings of $999 and 15,387 lbs of CO2.

Past Day | Past Week | Past Month | **Past Year**

kWh Produced	10005
Dollars Saved	$999
lbs CO2 Saved	15387
kWh Exported To Grid	6734
Dollars Exported To Grid	$673

Figure 6: INhome kWh Produced and CO2 Saved, October 2014 to October 2015

Over an 18 month period (1/26/2014 to 7/26/15), the INhome has operated as a net zero home, producing and saving more power than the owners need to live comfortably. Figure 7 shows the usage of the owners relative to the outdoor temperature and time of year for the stated time period. The largest power requirements occur in the winter months due to the air to air heat pump switching into electric heat backup mode when the outdoor sir temperature drops below 30 degrees. Figure 8 shows the INhome production relative to the outdoor air temp and time of year for the same time period. Production drops in the winter months due to the shorter daylight time and lower sun angle in the sky, but production peaks in the spring and summer due to the longer daylight per day and higher sun angle. Figure 9 shows the usage overlaid with production for the same time period. Though the INhome uses more power during the winter months, it over compensates in the spring and summer to have an overall less than net zero power usage every year.

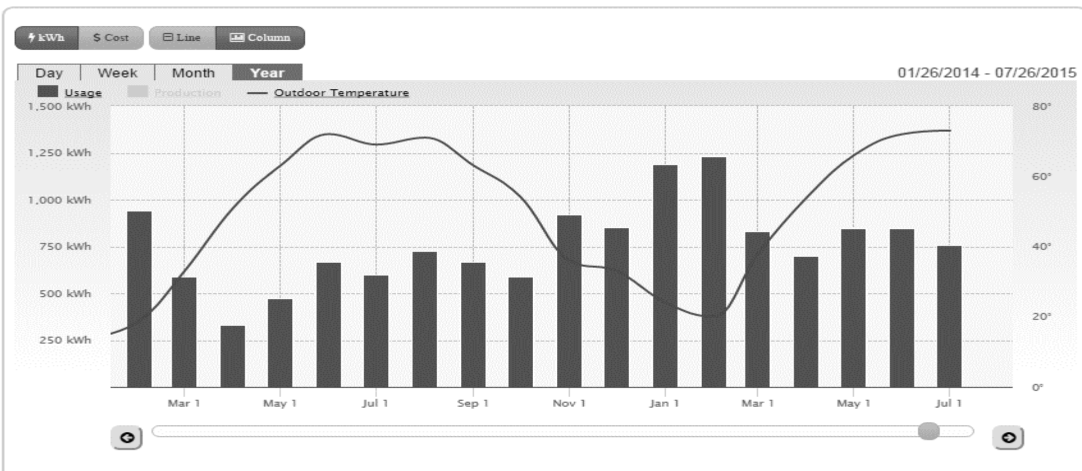

Figure 7: INhome Power Usage, January 26th, 2014 to July 26th, 2015

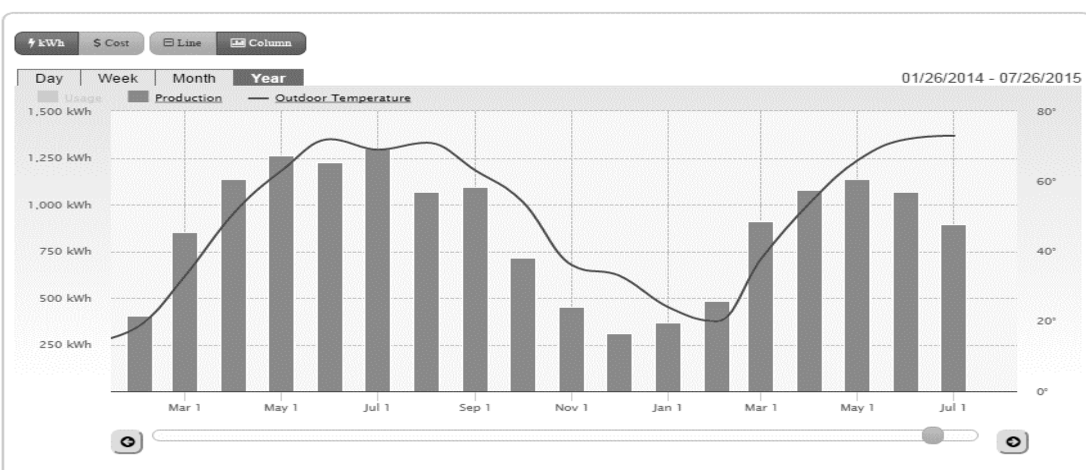

Figure 8: INhome Power Production, January 26th, 2014 to July 26th, 2015

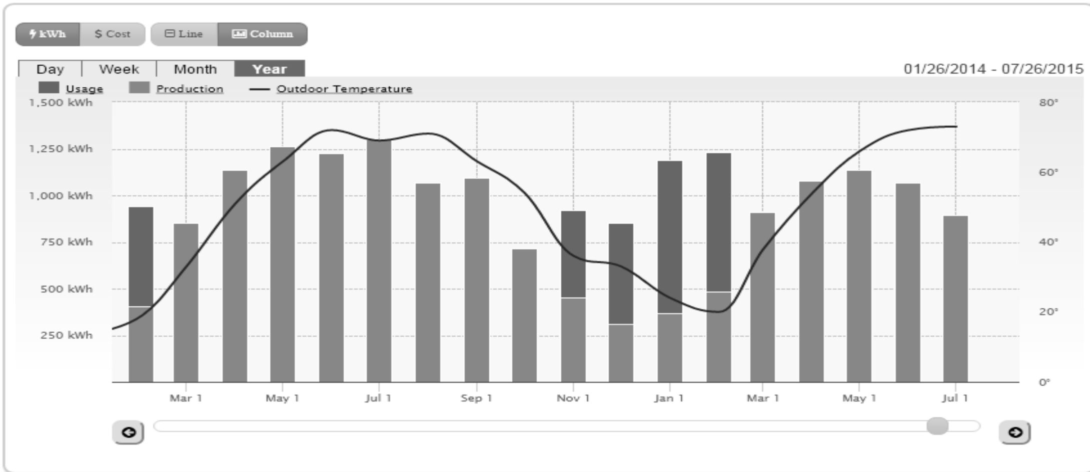

Figure 9: INhome Power Usage and Production, January 26th, 2014 to July 26th, 2015

CONCLUSIONS OF THE INHOME

The U.S. Department of Energy Solar Decathlon program creates a real-world learning environment for students that cannot be replicated in the classroom (Grose, 2009). The students and faculty involved were challenged beyond what they would have experienced in the classroom setting and what they learned could not be replicated in the traditional university learning environment. Although this learning experience was contained within the solar decathlon program, it is not limited to this program only. The process that the students went through and lessons learned can be generalized to other student teams and other experiential projects (Grose, 2009). It provides a practical application in a real world context. And collaborative and engaging learning opportunities are what students of the 21st century are wanting to be involved with (Rodgers, Runyon, Starrett, & Von Holzen, 2006).

The INhome was not only a successful learning experience, it was a successful competition home in the Solar Decathlon 2011, placing 2nd overall. This was due to the teams guiding principles of minimizing the energy loads of the home without sacrificing modern comforts, while maximizing the energy efficiency of those modern comforts, while keeping the cost within budget. It has also been a successful green certified home, through the third party certifications of Energy Start v2.5, National Green Building Standard Gold, (Certificate # 4113), and LEED Platinum registered. It was also nationally recognized as the 2012 Project of the Year – Single Family Concept/Research (Academic) award winner as part of the National Green Building Awards competition, through the National Association of Home Builders (NAHB).

The INhomes greatest success is its ongoing operation as a net zero home under normal living conditions. Every year it produces more energy than the owners need to live comfortable, giving back \$600 to \$700 worth of electricity to the grid, and saving 15,000+ lbs of CO_2 from the environment every year. This will continue year after year for the life of the home, long after the competition, awards, and research is over.

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