The Cal Poly INhouse: Intuitive, Interactive, Integrated

by

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Summary

The Cal Poly entry to the US Department of Energy (DOE) Solar Decathlon 2015, INhouse, is intelligently designed to respond to the conditions of the climate in coastal California, such that the majority of its needs for heating, cooling and lighting are addressed architecturally. The supplemental systems necessary for the remaining space conditioning, lighting, and power needs are efficient and effective. The result is a home that meets both the residents' as well as society's need for ecologically responsive housing while simultaneously creating an environment that delights the resident both experientially and thermally. Our design combines materials and systems to create a modern California aesthetic.

Intuitive: Through a precisely designed envelope and passive systems, INhouse is crafted to maximize the thermal and luminous comfort of its residents. Residents can easily learn how to operate the passive systems of the house - sliding screens, sliding glass walls, operable windows - in order to maintain their daily and seasonal comfort. Through a straightforward and intuitive control system, residents can optimize their luminous and thermal comfort by communicating on site or remotely with the supplemental systems of the house, which include heating, cooling, and lighting systems. By actively engaging with INhouse, residents can save energy, reduce costs and maximize comfort. Over time, residents will learn that small changes in their daily habits can result in a reliably comfortable living environment - one that not only elicits sensory delight but also realizes real energy efficiency.

Interactive: INhouse provides an environment that enables the resident to adjust the house to meet changing needs. When the weather is nice, s/he can open the folding glass wall between the living module and the outdoor solar bifacial room. When the sun is least harsh or views are too good to pass up, the resident can push open sliding screens along the southern edge of the bifacial room. By enjoying the bifacial room itself, the resident is directly interacting with one of the home's methods of energy production. Meanwhile, real-time feedback informs residents about energy use and production, allowing them to appropriately respond to this information. The interactive features of the home allow a fully customizable experience that can be tuned to the needs of the occupants.

Integrated: The home is designed around a core that contains its active intelligence - mechanical, electrical, plumbing, and monitoring systems. INhouse aims to unify all of the home's components into a coherent whole - from passive to active, indoor to outdoor, and architecture to engineering. All systems are integrated, creating an efficient home that is simultaneously delightful as well as user friendly. The resident dwells between the core and the wings, in open and comfortable spaces where thoughtful architectural design and mechanical systems meet.

Design Parameters

The U.S. Department of Energy Solar Decathlon challenges collegiate teams to design, build, and operate solar-powered houses that are cost-effective, energy-efficient, and attractive. The winner of the competition is the team that best blends affordability, consumer appeal, and design excellence with optimal energy production and maximum efficiency. In addition to the Solar Decathlon rules, including the requirement for net-zero energy operation, high level design parameters for INhouse are summarized in Table 1.

Table 1 – High Level Design Parameters

Location of Permanent Site	A six county region of Coastal California from San Luis Obispo County to San Diego County
Housing Type	Single Family
Target Cost	$375,000
Square Footage	1,000
Number of Bedrooms / Bathrooms	1 / 1
Number of Occupants	1 - 2
Client Demographic	An individual or couple with an eagerness to interact with and adapt to the home
Client Annual Income	$100,000

Configuration and Orientation

INhouse, as illustrated in Figure 1, is elongated on its east-west axis and includes two wings (shaded in beige) - one public and one private - linked by an active core (shaded in dark gray) that contains the home's mechanical, electrical, plumbing, and monitoring systems. The private wing is located on the north and includes a master bedroom and a flexible space which may serve as a library, office, or secondary bedroom space. The public wing on the south incorporates entertainment and dining spaces with thoughtful linkages to the exterior spaces and the views beyond. On the exterior, the core and the wings are formally and materially differentiated through volume as well as materials. The passive wings are lower, more porous, and are defined by a redwood screen designed to shade the envelope as well as to highlight the origin of our project, the central coast of California. The taller active core is more sleekly designed, using panelized construction, and enclosing the home's comfort systems. To ventilate, all the windows are operable, including the north-facing clerestories in the taller core, which are designed to promote stack ventilation.

The public wing seamlessly connects to a generous outdoor area, emphasizing the outdoor living potential afforded by the coastal California climate and doubling the home's public space. The outdoor decks provide residents with additional square footage that is essential for an otherwise modest house footprint. This outdoor space is adaptable through operable shading screens that allow user–defined comfort in response to the changing seasons.

Figure 1 – INhouse Layout

A Contemporary California Aesthetic

INhouse is designed to integrate into the landscape of coastal California, encompassing a six county region from San Luis Obispo County in Central California to San Diego County in the south. These counties have a Mediterranean climate in which the ocean moderates the temperature year around, producing milder winters and cooler summers. An important factor in these climate zones is the diurnal temperature variation, the significant difference between the maximum and minimum daily temperatures. As the biggest energy challenge is providing and maintaining thermal comfort, we worked to design a project that works with, and not despite, the climate. We utilize the diurnal variation to passively cool the house at night. Additionally, we utilize other passive design strategies to emphasize the use of building design and material metabolism as the first response to providing thermal comfort.

The exterior material on the passive public and private wings highlights one of California's most precious resources - redwood - and identifies the project as a product of its region. The redwood screen, decks, and planters at INhouse are all FSC® certified and sourced in California, including some from Cal Poly's own Swanton Ranch. On the interior of the home, bamboo flooring is used throughout INhouse. Cali Bamboo® is made from FSC® certified bamboo. Bamboo is a durable and rapidly renewable resource, making it a perfect flooring material. In addition to flooring, bamboo plywood faces appear in most of the cabinetry throughout the home. The soft rich color adds to INhouse's inviting atmosphere. (See Figure 2.)

Figure 2 – View of Interior from Deck

Interaction

The operability of INhouse extends beyond the mechanical systems of the house to its passive features. The spaces within INhouse emphasize convertibility, inhabitant comfort, and ease of use. In the living room, the 15-foot glass NanaWall® folds open completely to create a large opening to the outside. Adjacent to the living space, the kitchen has remotely operable clerestory windows, which create cross ventilation. Additionally, the central core is taller than the rest of the house and has clerestory windows located at the top. This creates a stack ventilation effect that can ventilate the entire home, insuring that the kitchen, often the hottest room in the house, can be cooled.

For our climate regions, shading the house is an important strategy to ensure optimal performance. INhouse is shaded in two ways: an awning on the south and a redwood screen on the skin. The screen is patterned as a solar thermal map of the house, as shown in Figure 3, with the denser areas indicating zones of higher solar intensity, and thus maximizing the efficiency of the shade screen. The awning integrates photovoltaic panels and sliding screens to allow residents' to customize the amount of shade to match their thermal comfort needs. These shading strategies reduce INhouse's cooling load and visually demonstrate a connection between architecture and engineering.

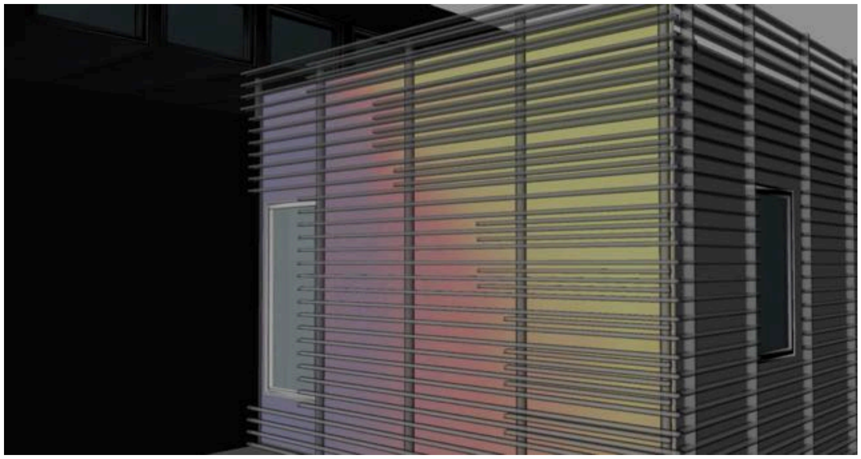

Figure 3 – Thermal Map

The bifacial room at INhouse was designed to shield inhabitants from the elements while offering adaptability to accommodate changing needs. During the summer the operable screen doors shade the deck space beneath the panels. In the winter, the screen on the south can slide to open the room to the light and warmth of the sun. The inhabitant is able to interact with the bifacial room screens in order to maximize their personal comfort in this space.

Unique Sustainable Features

Apart from the most significant energy conserving features of the home, climatic responsive design and attention to ecologically responsible materials, there are two unique design features that differentiate INhouse.

An innovative feature that contributes to the passive cooling design of INhouse is utilization of phase change material (PCM). This system is based on the simple concept that material undergoing a phase change has the ability to store or release vastly more energy than single state materials of similar size. INhouse's solution involves a thermal energy storage duct (see Figure 4) where air is passed over a staggered array of PCM cross-rods. The rods are made of conductive aluminum and filled with palm-oil based phase change material which freezes or melts around room temperature. This system cools recirculated indoor air during the day, which melts the PCM inside. At night, it is recharged using cool outside air, which solidifies the PCM for use the next day. This solution handles the base load energy required to stabilize the temperature swings that occur around a comfortable room temperature. The system is projected to reduce cooling loads by 8%.

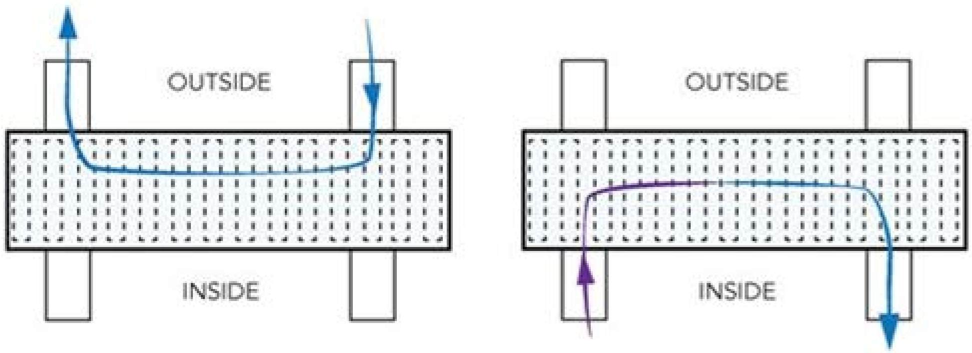

Figure 4 – Phase Change Configuration

An additional unique feature of INhouse is our use of bifacial panels, which make up half of our photo-voltaic array. These panels have photo-voltaic cells on both the top and the bottom of the panels. Bifacial panels collect most of their energy from the top, collecting additional energy from reflected light hitting the bottom of the panels. In addition to the increased efficiency, the panels allow the occupants to see how their home is collecting energy. The bifacial panels epitomize integration at INhouse, as these panels create a comfortable shady respite for residents while simultaneously generating power. As such, they tie aesthetics together with energy production to educate people about their home.

Energy Use and Production

INhouse has been designed to ensure net-zero operation based on a likely range of weather conditions and the predicted performance of the house, all while adhering to the competition energy budget of 175 kWh. Table 2 summarizes nominal energy usage for each energy consuming system over the course of the competition, or a notional 8 days of operation. In order to safely meet this requirement, the system was designed to output approximately 210 kWh during the competition which includes a 20 percent overhead.

Table 2 – Electrical Power Demand (During Competition)

Power Draw	Hours Used or # of Times Used	Kw per Hour or per Use	Nominal Energy Use
Refrigerator	191.5 Hrs	0.05 kW per Hr	9.58 kWh
Stove	5.5 Hrs	2.5 kW per Hr	13.75 kWh
Dishwasher	5 Times	1.25 kW per Use	6.25 kWh
Oven	4 Hrs	1.92 kW per Hr	7.68 kWh
Washing Machine	8 Times	0.3 kW per Use	2.4 kWh
HVAC			48.00 kWh

Inline Fan	40 Hrs		6.00 kWh
Mechanical Room Fan	0.75 Hrs	0.3 kW per Hr	0.30 kWh
Blackwater Pump	0.17 Hrs		0.21 kWh
Greywater Pump	0.17 Hrs		0.21 kWh
Lighting	26 Hrs	0.4 kW per Hr	10.40 kWh
Laptop	34 Hrs	0.06 kW per Hr	2.04 kWh
TV (32”)	37 Hrs	0.03 kW per Hr	1.02 kWh
Control System			4.00 kWh
Vehicle (i3 or eGolf)			58.50 kWh
Total			**170 kWh**

Providing this power is accomplished with a combination of standard and highly practical monofacial PV panels with the unique transparent aesthetic of bifacial PV panels, to create a system that highlights both efficiency and beauty. The monofacial PV array consists of ten panels that line the roof of INhouse’s core and provide a total rated power of 4.35 kW of DC output. The bifacial PV array consists of 14 panels that are arranged on a canopy covering the south facing patio and provide a total rated power of 4.95 kW of DC output. The monofacial and bifacial PV panels are each connected to separate transformerless grid-tie-inverters.

This setup is also optimal for yearly output, and it is expected that the array would successfully power the home year-around on the California coast by producing approximately 15,000 kWh per year, or approximately 1,250 kWh per month. Over the course of a year, INhouse is expected to use approximately 400 kWh per month, excluding charging requirements for the electric vehicle.

Other Systems

Structural insulated panels (SIPs) were used for most of the exterior walls of INhouse. SIPs function both as structural walls as well as insulation for the home. SIPs are essentially a sandwich of hard packed rigid insulating foam between oriented strand board sheathing. The 8 1/4” SIPs in the walls and ceiling provide an R value of 30.5. SIPs are ideal for a small house as they ease construction and provide maximum benefits to cooling and heating loads.

The selection of the heating, ventilating, and air conditioning system (HVAC system) was guided by the geometry and layout of the core which allows for the design of a simple duct system with access to each room of the house. A split system consisting of an outdoor heat pump and an indoor air handler was selected. This system was favored as it is a modern and proven HVAC system that has been increasingly relied upon in the HVAC industry. A heat pump was also favorable given the climate scenarios on the California coast, as it can still operate efficiently during the coldest temperatures experienced in the region.

INhouse is designed to use as little water as possible, and not a single drop of freshwater goes towards the irrigation of the landscape. The roof redirects storm water directly to the planters, which are designed as rain gardens, and all of the gray-water that the house produces is used for landscape irrigation.

A solar thermal flat plate collector system was selected to produce hot water.

Creating a delightful luminous environment is a goal of INhouse. Daylighting is the primary method of achieving this goal as it is pleasing as well as energy efficient. The electric lighting combines with the daylighting in a cohesive manner in order to be efficient, enjoyable, and functional. All of the electric lighting sources are color-consistent and highly efficient LED fixtures. INhouse manages to achieve quality lighting design while consuming only about 0.5 watts/square foot of energy.

The instrumentation and controls system contains various sensors including temperature, humidity, power usage, and power generation. The data is collected at a high level of granularity, as temperature and humidity are provided on a per room basis, power generation values for each of the two solar technologies used, and power consumption for each appliance and light. The system also optimizes the PCM duct by measuring the temperature of the PCM, the exterior temperature, and room temperatures. Then the system uses this data to determine when to open and close dampers and turn on the fan in the duct. All data is relayed back to a central database and can be mirrored on the cloud, allowing for users to monitor data remotely through a customized tablet application.

The objective of INhouse's customized application is not to control the house through technology but rather to employ computing to assist residents through data analysis. For example, the application might suggest opening windows at certain times to reduce power consumption, or it may alert users to a faulty solar panel causing an abnormal drop in power generation. It teaches residents how to live net-zero so that they can understand how to live comfortably as well as sustainably.

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