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THE 2005 SOLAR D HOUSE

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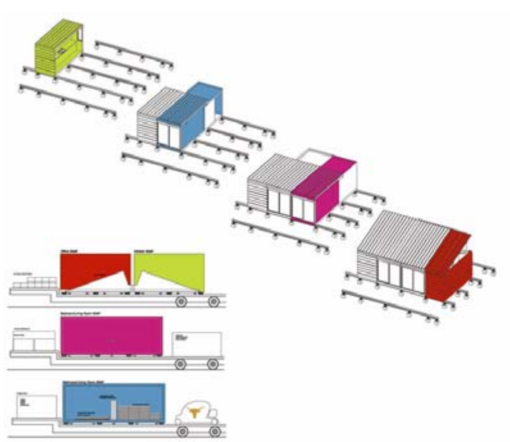
ABSTRACT

The Solar Decathlon provided a national forum for competition among eighteen university student teams, each of which designed, built, and operated a totally solar-powered home with a home office and their transportation needs using a solar-charged vehicle. Organized by the U.S. Department of Energy and the National Renewable energy Laboratory, the Solar Decathlon competition challenges university teams to design and build an 800-square foot, totally solar-powered house. The competition took place on the National Mall in Washington D.C., where each house was constructed and operated from September 28 to October 19, 2005. The competition consisted of ten contests focusing on ingenuity, energy production, energy-efficiency, design, thermal comfort, refrigeration, lighting, communication and transportation.

Professor Michael Garrison, Assistant Professor Samantha Randall and Lecturer Elizabeth Alford of the School of Architecture were the faculty advisors for the University of Texas at Austin (UT) Solar Decathlon student team, which included more than 40 graduate and undergraduate architecture, landscape architecture, and engineering students.



The team developed a design that features four pre-fabricated modules that can be snapped together in order for the house to be transported from Austin, Texas to Washington D.C. and back again. An innovative foundation system of rails and rollers allow each module to be lowered off a truck onto the rails and rolled into place.

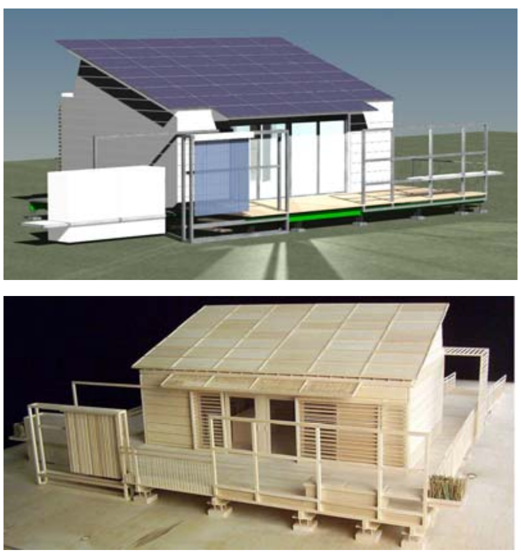
2005 UT SolarD House

DESIGN

The UT Solar D house presents itself with two richly contrasting materials: cool-colored zinc siding and warm, reclaimed redwood rain screen. The entry appears welcoming, framed with a steel pergola. The entry combines privacy with security in the unique sidelight. When a visitor arrives the glass is milky white, but with a simple switch, the homeowner can turn the glass transparent, allowing them to see who's at the door. Once inside, an open plan with vaulted ceilings allows the spaces to flow together, yet retains some distinctive areas.

This space is lit with clerestory windows and opens up through two southern-facing glass doors onto an expansive deck. External sliding shading panels can provide both privacy and shading for the south facing glass door. The ability to open up completely encourages indoor-outdoor living. Especially in the south, the ability to enjoy lazy days outside, barbequing and making sun tea on the deck, means that the house doesn't really need as much conditioned floor area. The backyard becomes an extension of your house.

The home office is built into the east wall in a manner that allows it to close up when not in use, which helps keep a tidy appearance, as well as to keep some distinction between work life and home life. Mounted in the face of the office wall is a touch-screen SNAP Com panel. This interactive surface displays temperature and humidity conditions as well as energy consumption levels, enabling residents to monitor and adjust their use, while learning from their house.



UT Solar D House

This isn't the only technology that makes life easier in this house. Besides a bevy of energy efficient appliances and lighting, which reduce energy costs, there's so much more. Even the appliances contribute, with features like a removable condiment tray in the refrigerator door. It simply gets removed at mealtime, set on the table for easy use, and then returned to the fridge once the meal has ended. Another example is the built-in folding shelf, which mounts between the stacked washer and dryer units.

In the kitchen, variety is the spice of life. To accommodate a range of meals, the oven has standard, convection, and also microwave heating, plus smooth-rolling racks on ball bearings. The induction cooktop uses magnetic technology to heat food directly saving energy and eliminating the need for an exhaust hood. For smaller meals, fewer dishes are dirtied, so you can set the dishwasher on a one-tray cycle and save water. Sorting is made extremely easy with a built-in recycling center under the sink.

Space-saving features are valuable elements in flexible design. An example is where sliding doors allow flowing, uninterrupted movement. When entertaining, the large panel door to the bedroom can be slid open, and the bed can be converted to a couch for a secondary, more intimate conversation space.

Between the bedroom and bathroom there is a telescoping pocket door. This bed/bath wall also shares storage for both rooms, and the translucent panels above the countertops serves as an ambient light in two ways. First, daylight is constantly filtering from one room to the other through this wall, reducing the need for artificial lighting in both rooms. Second, color-changing LED lights mounted inside the wall provide interesting ambient lighting effects while entertaining or as a nightlight.

UT Solar D House

After the competition in Washington, D.C., the house will be transported back to Austin, Texas and donated to a local non-profit, where the house will be used as a learning center for low-income families as transitional housing. As part of their mission statement, the UT SolarD Team hopes to inspire the Austin public about the benefits of solar-powered, energy-efficient, and sustainable building practices through public outreach workshops and house tours.

Interior of UT Solar D House: photo by Lamar Smith

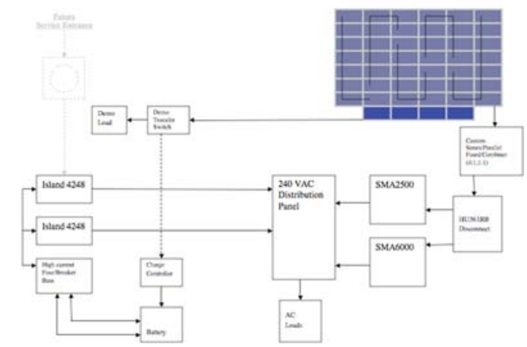
Energy Systems

The Texas solar decathlon house is solar-powered and utilizes the latest energy efficiency technologies and sustainable building materials. The Energy saving features of the house include, a 7.9 kW photovoltaic solar power system, evacuated tube "heat pipe" solar water collectors, a high efficiency HVAC system and an energy conserving design that achieves a ratio of one ton of air conditioning per 933 square feet of conditioned space. The HVAC system combines a variable-speed Inverter compressor mini-split heat pump with an energy recovery ventilator, a separate refrigeration whole-home dehumidifier and a horizontal direct-drive chilled water DHW/Air Coil heat exchanger. The four components work together to assure a narrow interior comfort zone of between 72˚F and 76˚F and a humidity range of between 45 and 50% relative humidity. To control the components the team developed a computer controlled smart building technology that allows the building to be controlled on the mall from Austin, Texas.

Photovoltaic Solar System

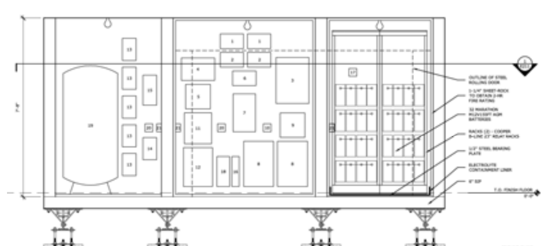
The Texas 2005 solar decathlon house is designed to be energy efficient and is a stand-alone system, which does not use electric utility power. Photovoltaic panels provide direct DC power when sunlight is available. If power is needed when sunlight is not available, batteries will be required to store power for the times when the sun is not shining.

The Texas 2005 solar decathlon house has 42-175 W BP polycrystalline panels and 4 Romag-Beyond Petroleum custom-translucent thin film panels that comprise the 7.9 kW PV system. For our area, we multiplied the rated wattage by 5.1 to get the average Wh (watt hours) amount produced in one day. The 5.1 factor equals the viable operating hours per day and accounts for the fact that there will be more sun available in the summer and less in the winter (7.9 kW x 5.1 = 40.29 Wh).



The UT Solar D House PV system

The 42 BP 4175 modules are mounted on the roof canted at 20 degrees. The 4 BP-Romag custom modules are cantilevered off the roof, shading the southern glazing. Single insulated conductor MC USE-2 cables are used to connect the modules in free air to roof-mounted fuse/combiner boxes. The PV array is divided into three inverter groupings; 4 parallel/8 series BP 4175B modules for the SB6000U inverter and 10 series BP4175B modules for the SB2500U inverter. All series strings first go through fuses in pullout holders before any combing of parallel circuits through a terminal block. After the combiner boxes, conductors are run from the roof to the electrical closet.



Electrical and Mechanical closet along west wall of the house

The electrical section of the closet contains the disconnect switch and over current devices for the PV array, the inverters, the DC circuit breakers, and the AC distribution panel. A contiguous, but separated section of the closet is used to store the 32-Marathon 12V batteries. The system is dependent on the inverters to perform all necessary ground fault detection and interruption (GFDI) of ungrounded and grounded conductors to prevent fire on the roof mounted system.

Although the solar decathlon competition requires a stand-alone system for the competition on the National Mall, this system will be adapted to a grid connected system upon the redeployment of the house in Austin, Texas after the competition. In the grid connected system PV's can, provide power directly to the user and to the centralized power grid when PV power exceeds the user's requirements. The Austin solar decathlon house will use power from the central utility when needed and supplies surplus home-generated power back to the utility. It is termed a "parallel" system by Austin Energy. The power produced will be metered so that when power is produced by the PVs and sent into the grid the meter will run backwards, thus allowing for a discount in consumption costs.

Evacuated Tube Solar Water Heating

The 2005 Texas solar decathlon house utilizes Sunda's Seido evacuated tube solar water collectors, which function as heat pipes. A heat pipe acts like a low-resistance thermal conductor. Due to its thermal-physical properties, its heat transfer rate is a thousand's times greater than that of the best solid heat conductor of the same dimensions. Sunda's Seido heat pipe is a closed system comprised of two meters of copper tubing, an evaporator section, a capillary wick structure, a condenser section and a small amount of vaporizable fluid. The heat pipe employs an evaporating-condensing cycle. The evaporator section is tightly bonded to the absorber plate, where it captures the heat from the absorber and evaporates the liquid to steam, which moves up to the condenser section. The condenser protrudes out from the evacuated tube and is inserted into the heat exchanger manifold. There this steam is condensed by water flowing through the manifold. Latent heat energy is released to the process water through this phase change of vapor to liquid. In vacuum tube solar collectors, the condensation zone is at a higher level than the evaporation zone. The transport medium condenses and returns to the evaporation zone under the influence of gravity. This process is repeated continuously thereby heating the water in the closed loop.

To achieve the highest efficiency of heat transfer the absorber is treated with an aluminum-nitride selective coating, which is applied using a magnetic sputtering technique. This special optical coating transforms more than 92% of the incoming solar radiation into heat.

Heat pipes are inserted into the aluminum absorbers forming assemblies, which in turn are inserted into the glass tubes. The tubes are made of borosilicate glass, which is strong and has a high transmittance for solar irradiation. In order to reduce the convection heat lost, glass tubes are evacuated to vacuum pressure of <10-3 Pacal. By evacuating air out of the glass tube the absorber material and selective coating are protected from corrosion and other environmental influences. This ensures a lifetime of at least 15 years without loss of efficiency.

Energy Conservation

The 2005 Texas solar decathlon house utilized a number of energy conservation design standards to improve thermal performance, including site planning and building configuration, thermal capacitance; thermal insulation; glazing type, amount and orientation of windows and air flow.

The UT solar decathlon house is elongated on an east-west axis which is the most efficient shape for most U.S. climates because it captures low-angled solar radiation in winter, which minimizes heating requirements and, with a properly designed shading overhang, minimizes cooling requirements in the summer.

Thermal capacitance describes the amount of heat that can be stored in a particular type and thickness of material. The thermal capacitance of a material is a product of the material's density times its specific heat and is measured over time. Houses with a high thermal capacitance have a high time lag, which is the time it takes for ambient conditions on the outside of a wall to affect the ambient conditions inside.

Because the diurnal temperature swing during the summer months in Washington D.C. and Austin, Texas is relatively low, the likelihood of inadequate night time flushing of a high thermal capacitance design led our team to a strategy of light frame construction. Light frame construction also allows the HVAC system to respond more adequately to a rapidly changing exterior climate.

The next consideration is the type of wall, roof, and foundation system to be used and the R-value that will be achieved. R-value represents resistance to heat flow, the higher the R-value, the better a wall's efficiency. High R-values can be achieved with any type of construction: standard "stick-built" or alternative wall construction methods such as structural insulated panels, insulating concrete forms, or straw bale construction. Our team chose to use 6-inch thick structural insulated panels, which are rated at R-30.

Windows, which have a much smaller R-value than walls, can have a large impact on the energy efficiency of a building. For this reason, one step towards efficiency is to minimize window area, which for our building represents less than 13% of our wall area. There are several other factors to consider when choosing windows including, frame material, glass coatings (such as low-e), gas-fill between the panes, overall U-value, solar heat gain coefficient (SHGC), and ultraviolet (UV) and visible light transmittance (VLT). Windows specified for the Texas Solar Decathlon House are Comfort Line fiberglass Low-E, argon filled. These windows have a typical U value of .24 and a SHGC value of .38. The fiberglass frames do not expand and contract with water or differences in temperature, they have a strong strength to weight ratio, do not degrade due to sunlight and contain a recycled glass content.

Keeping air from leaking in and out of a building can dramatically reduce energy needs. Air infiltration, which occurs naturally through small gaps and cracks between a wall and foundation, around windows and doors, and through utility penetrations between conditioned and unconditioned spaces, can be a big source for energy loss. Air infiltration can draw in humidity during the cooling season, and create uncomfortable drafts during the heating season. To improve comfort and reduce energy use created by air infiltration, our team caulked and sealed all the air leaks of the house during the framing and finishing process of construction.

Taken together the energy conservation techniques utilized in the UT solar decathlon house provided an energy efficient design with a ratio of 933 square feet of space per ton of air conditioning.

Material Systems

The UT SolarD Team has chosen to think beyond the competition requirements of solar power and energy efficiency by embracing the full spectrum of sustainable design. This strategy includes resource efficiency and the use of recyclable, recycled, reused, and local underutilized materials. Recyclable materials include the house’s exterior zinc siding, the galvalume roofing, the stainless steel trim and the structural steel foundation rails. Building materials made from recycled materials include, the exterior decking, which is made from recycled plastic and wood scrap, the bathroom tile, which is made from recycled glass and granite scrap, the bathroom wall panels made of Ecoresin recycled plastic and the redwood trellis rain screen made from reclaimed redwood. Examples of reused materials include aluminum shingles, which are reused newspaper litho plates from our school newspaper the Daily Texan. Local and underutilized green materials are also used as well. These include the use of mesquite wood flooring, cabinets made from MDF agricultural waste straw fiber and trim made from local reclaimed cypress. In addition to using green materials to construct the house the team recycled all the jobsite construction wastes

Structural Insulated Panels (SIPs) are an innovative green-engineered material system used to construct the UT SolarD House. SIPs replace conventional stud or "stick frame" construction. They were made in a factory and shipped to our job site where they were connected together to frame the walls, floor and roof of the house.

A SIP consists of an engineered sandwich or laminate with a solid expanded polystyrene foam core 6” thick and structural galvalume facing on each side. The facing is glued to the foam core and the panel is pressed in a vacuum to bond the sheathing and core together. SIPs structural characteristics are similar to a steel I-beam. The skins act like the flanges of an I-beam, and the rigid core provides the web of the I-beam configuration. This composite assembly yields stiffness, strength, and predictable performance.

Metals USA SIP wall and floor panels

The greatest advantage of these panels is that they provide superior and uniform insulation in comparison to more common methods of house construction. SIP walls are superior to conventional walls in a number of ways. SIPs combine a high insulation R-value with speed and ease of construction. The solid foam core eliminates air movement within the walls and minimizes thermal bridges through wood studs. Together, all these reduce air infiltration, and make a tightly sealed/easy to build structure. This makes the building more comfortable, energy-efficient, and quieter.


Metals USA SIP wall and floor panels

In regard to Fire safety, SIPs have performed well in combustion tests. When the interior of the SIP is covered with a fire-rated material such as gypsum board, the fire resistance of gypsum board protects the SIP facing and foam long enough to give building occupants a good measure of escape time.

Water Conservation

There are techniques and products that help lower buildings' water consumption. To meet water conservation standards, flow rates. for plumbing fixtures are limited to 2.20 gallon per minute (GPM) or less for faucet flow at 60 pounds per square inch (PSI), showerhead flow is less than 2.50 GPM at 80 PSI, and toilet water usage does not exceed 1.6 gallons per flush.

The horizontal axis clothes washer unit uses only 11 gallons per normal cycle, and heats its own water. The ASKO Unit has a modified Energy Factor of 1.74 and its average energy use is calculated to be 189 kWh/yr. The ASKO dishwasher is extremely energy efficient with a modified energy factor of 1.11 and an estimated annual energy use of 194 kWh/yr. The ASKO dishwasher is also very water efficient. The unit uses only 3.4 gallons per normal cycle or approximately 731 gallons per year to operate.

The 2005 solar decathlon house uses a Stebel Eltron SBB 400+ Twin Coil tank that is designed to work with solar water collectors. The 108.6-gallon incorporates an upper and a lower glass lined coil type heat exchanger. The upper heat exchanger coil is linked to a booster heater. The lower coil is to be connected to the solar panels. The tank has low standby losses due to 3'' foam insulation. Standby losses in a 24-hour period are rated at less than 2.2 kWh.

Manifold plumbing systems are a new method for residential water distribution that is gaining acceptance in the home building industry. Manifold plumbing systems are control centers for hot and cold water that feed flexible supply lines to individual fixtures. Plastic manifolds together with flexible plastic piping offer installation-related cost and water saving advantages over conventional plumbing systems.

Separate manifolds serve hot and cold water lines. The cold-water manifold is fed from the main water supply line and the hot water manifold is fed from the hot water heater. Water pressure in the manifolds is maintained by the incoming service line. A dedicated water supply line feeds each fixture from a port in the manifold.

The thermoplastic manifold is lightweight, corrosion resistant, and easily connected to fixture lines and main service. Manifolds are 11⁄4 inches in diameter -- larger than most service lines -- to enable adequate water flow to individual fixtures. A continuous built-in reservoir provides equalized water flow and helps maintain constant water pressure in all supply lines. Shutoff valves are built into each port for individual control of lines and of flow to individual fixtures.

Manifold systems use 3/8-inch supply lines for individual fixtures because fewer fittings are required (hence, less pressure drop occurs in the lines) compared to traditional, rigid 1/2-inch lines. Cross-linked polyethylene (PEX) piping is used because of its resistance to temperature extremes, chemical attack, and creep deformation, and its suitability for hot water use.

Plumbing manifolds can be installed more quickly than rigid plumbing systems with fewer fittings and without the need for piping tees and elbows. The system permits several fixtures to be used simultaneously without dramatic pressure or temperature losses. By downsizing supply piping, water velocity is increased and delivery of hot water to fixtures is faster. Heat loss in the piping may be less than a copper system because plastic has better thermal insulating properties.

Maintenance is relatively simple with plastic manifolds because valves at the manifold for each fixture line permit individual fixture control, shutoff, and maintenance.

With the manifold system, every sink, toilet and shower gets its very own dedicated hot and cold water lines. The lines are made of PEX (cross-linked polyethylene) tubing, connected directly from the fixture to one of the central manifold control units installed in the hot water closet.

Water conservation is another issue to consider. The manifold system helps conserve water. Since each fixture gets its own line, the water literally has less friction resistance. Manifold systems, as a result, can deliver larger quantities of water more quickly than two-pipe systems.

In a traditional two-pipe system, the entire line must be purged of cold water — a process that can take a minute or two — before hot water can be delivered to any given fixture. By contrast, it takes only 10 to 15 seconds for hot water to reach any fixture with a manifold system. That translates into a savings of up to three gallons of otherwise wasted water each time a faucet is turned on, which is important in drought prone areas like Austin, Texas.

Health and Safety

Snap House: bedroom interior

Health concerns have increased in prominence as buildings have become tighter and more energy-efficient. In addition, modern building materials and products are typically more processed and may contain chemical compounds that are irritants to some people when used under certain conditions. The most effective way to maintain good indoor air quality is to remove indoor sources of pollution and increase outside air ventilation. Large quantities of outdoor fresh air are introduced into the indoor environment with the use of a heat recovery ventilator.

The UT solar D house uses no or low-VOC (volatile organic compounds) sealers and paints to seal and finish interior surfaces. The wood finishes are sealed with extremely low-VOC water based wood sealer and finished with a low-VOC water-based oil/wax system

Interior wood surfaces are finished using Velvit oil wood stain sealer. Velvit oil **is a** Penetrating soybean-based oil that adds the "hard" to "hardwood" flooring. Natural oils are blended with wax to create a durable finish that won't crack, flake, peel or blister. Velvit Oil is solvent free and is micro porous so it penetrates into the wood surface keeping it elastic so there are no condensation problems under opaque finishes. The wood can breathe and moisture can evaporate. Velvit Oil is a low VOC product that has no added biocides or preservatives

Interior cabinets are made from formaldehyde free materials. The 2005 Texas solar decathlon house interior cabinet materials are made of Columbia Forest Products ecocolors. EcoColors™ line of tinted, FSC-certified particleboard panels is designed as an environmental alternative to melamine and other decorative surfaces. Ecocolors are made from M3-grade particleboard that carries the Forest Stewardship Council's ecolabel. The panels are finished on both sides with a durable, zero-emissions UV cured acrylic finish that is tinted in a range of color options.

Environmental concerns of construction adhesives include their process of manufacture, emission of volatile organic compounds, application tool cleanup, and disposal. Choosing products or applications that use little or no adhesives is preferred. The 2005 Texas solar decathlon house flooring is primarily Mesquite wood flooring that is installed without the use of adhesives. The solid wood strip and plank tongue and groove wood is nailed down onto a plywood sub-floor.

Process Conclusions

To provide for a pedagogical method to link architectural theory to practice, the hands on experience of the solar decathlon gave architecture students proper grounding in action and immediate experience and argues in favor of experiential knowledge over ungrounded abstract knowledge.

This experience allowed students to develop the knowledge of how to apply and test out their ideas and theories on sustainable design. This kind of knowledge is rooted in the realms of value. And these kinds of values and consequences are acquired through the actual building experience. In this way the students are able to evaluate the performance of design decisions. Hands-on learning seeks to re-establish the continuity and inter-relationship between the processes of conceiving, making, and using buildings. In architect Samuel Mockbee's words, "its the importance of making and thinking at the same time."

The "hands-on" process fosters a pedagogical approach that encourages faculty and students to discover how buildings really work as they are constructed and occupied. Through observation, simulation, and data gained by designing and then building the design, students discover lessons on the success and failure of different design approaches. Analysis of the material observed in the field, along with comparisons to values derived by model studies, computer simulation and calculations, gives students an opportunity to assess whether the stated design intent has been achieved and to understand and describe the variety of ways occupants actually experience a building.

This level of understanding involves both disciplinary and interdisciplinary learning. It is this area that the solar decathlon experience is especially potent as the forum in which disciplinary knowledge and interdisciplinary understanding take place.

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