U.S. DEPARTMENT OF ENERGY
SOLAR DECATHLON

SOLAR TEXAS

Texas A&M University

Solar Texas

Engineering Jury

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Structural Calculations

Solar Texas is using an integrated design approach to provide a long-term, resilient, urban response to ensure the structural system is designed to be code compliant and will protect the health, safety, and welfare of the occupants of the home. Health is defined as those aspects that improve the physical, emotional, and social well-being of the occupants and any others affected by the building project. Safety refers to those aspects of structural design that are designed to protect occupants, users, and any others affected by our house and our building site from harm. Regarding welfare, the structural design team, specifically of the innovative and unique roof monitor design will enable equitable access to natural daylighting to help elevate the human experience, to encourage positive educational and social interactions, and to provide an overall benefit to the indoor environmental quality. These three goals have been especially key in recent years as more family members are working from home and children are engaged in homeschooling.

With an increased focus on climate change and resilience related to structural engineering, traditional structural materials including concrete and steel have been scrutinized. As such, the *Solar Texas* team focused on a wide range of efficient strategies, from choosing locally sourced materials to applying design strategies that center on durability. The structural system of the *Solar Texas* house was designed in collaboration with Dudley Engineering, a professional structural engineer who after returning to College Station to pursue a graduate degree in structural engineering from Texas A&M University, started his own firm. He is a regular contributor to multiple programs on campus and has served as an Adjunct professor.

With his help and oversight, the team will use a pre-tensioned slab set on helical piers. This approach develops primarily due to the site's expansive clays but also enables a metaphorical "level playing field" for the target market from which to build. The primary structural elements will include a 3D printed concrete core or safe room that serves as a centrally located bathroom. The remaining structural elements will consist of locally sourced yellow-pine CLT panels. The combination of concrete and CLT will enable file-to-factory and file-to-site fabrication and on-site construction methods. *Solar Texas* incorporates high-quality and durable materials for all surfaces and systems. The *Solar Texas* team will select materials for environmental stewardship, recyclability, reuse, repurposing, and remanufacturing capabilities.

A general procedure of designing a structural system (called structural planning) consists of the following phases:

- Conceiving of the basic structural form.
- Devising the gravity and lateral force-resisting system.
- Roughly proportioning the component parts.
- Developing a foundation scheme.
- Determining the structural materials to be used
- Detailed proportioning of the component parts

Surface-forming structure, such as structural sheathing or decking distributes the applied load to its supporting joists or beams in the form of a distributed load. Beams transfer the applied distributed load horizontally to supporting girders, trusses, columns, or bearing walls.

The tributary width contributing to the load on a joist is 1/2 the distance between adjacent joists on both sides (which happens to be the joist spacing). Since wood joists are spaced relatively closely together, the load on the supporting beam is assumed to be uniform. The load condition of the joist and beam are shown in Figure 1.

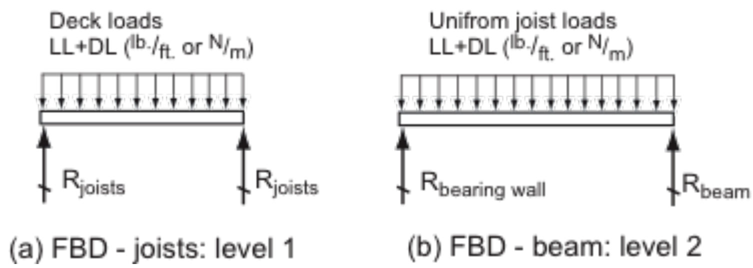

Figure 1: Load Condition of the Joist and Beam

A minimum of three lateral resisting vertical planes and the horizontal roof or floor plan must be present in a framework to resist gravity loads and lateral forces from two orthogonal directions.

Building Material Weights:

Assembly	lb./ft.²	kN/m²
Roofs:		
3-ply and gravel	5.5	0.26
5-ply and gravel	6.5	0.31
Wood shingles	2	0.10
Asphalt shingles	2	0.10
Corrugated metal	1-2.5	0.05-0.12
Plywood	3 /inch	0.0057/mm
Insulation - fiberglass batt	0.5	0.0025
Insulation - rigid	1.5	0.075
Floors:		
Concrete plank	6.5	0.31
Concrete slab	12.5 /in.	0.59/mm
Steel decking w/concrete	35-45	1.68-2.16
Wood joists	2-3.5	0.10-0.17
Hardwood floors	4 / in.	0.19/mm
Ceramic tile w/ thin set	15	0.71
Lightweight concrete	8/in.	0.38/mm
Timber decking	2.5/in.	0.08/mm
Walls:		
Wood studs (ave)	2.5	0.012
Steel studs	4	0.20
Gypsum drywall	3.6/in.	0.17/mm
Partitions(studs w/drywall)	6	0.29

Figure 2: Building Material Weights

<u>Live Load Requirements:</u>

Occupancy/Use (Uniform load)	$lb/ft.^2$	kN/m^2
Apartments:		
Private dwellings	40	1.92
Corridors and public rooms	100	4.79
Assembly areas/theaters:		
Fixed seats	60	2.87
Stage area	100	4.79
Hospitals:		
Private rooms and wards	40	1.92
Laboratories / operating rooms	60	2.87
Hotels:		
Private guest rooms	40	1.92
Corridors/public rooms	100	4.79
Offices:		
General floor area	50	2.40
Lobbies/first floor corridor	100	4.79
Residential (Private):		
Basic floor area and decks	40	1.92
Uninhabited attics	20	0.96
Habitable attics/sleeping areas	30	1.44
Schools:		
Classrooms	40	1.92
Corridors	80-100	3.83-4.79
Stairs and exits:		
Single family/duplex dwellings	40	1.92
All other	100	4.79

Figure 3: Live Load Requirements

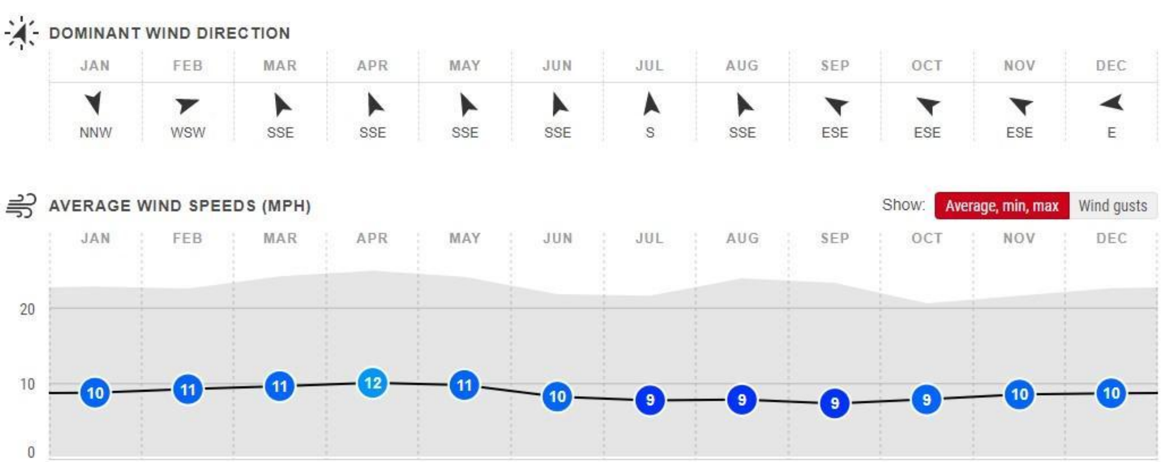

Figure 4: Monthly Dominant Wind Directions and Average Wind Speeds

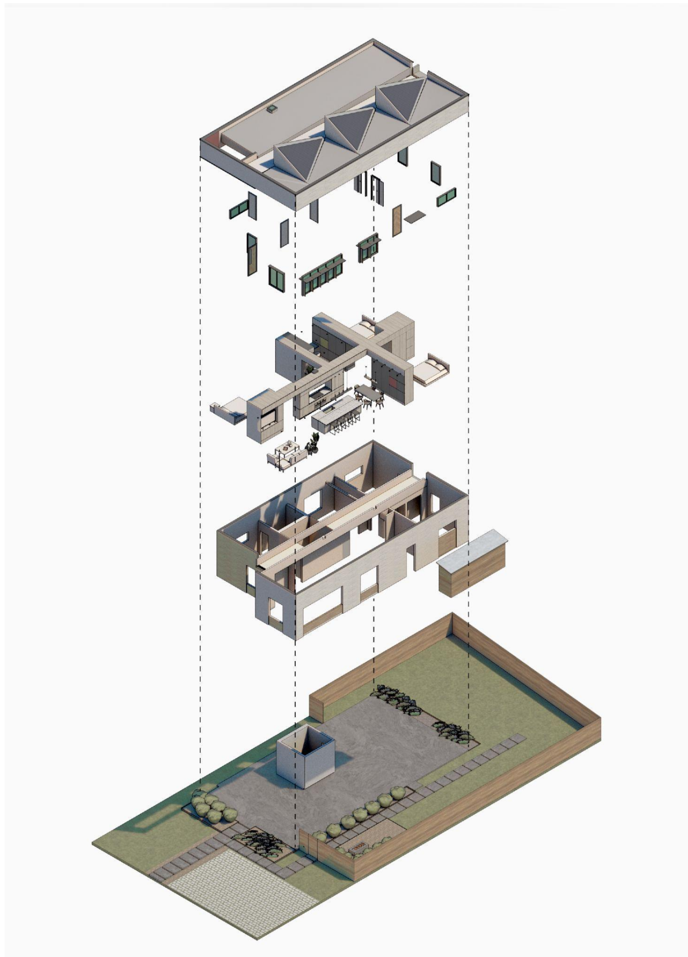

Figure 5: Exploded Axonometric of Building Components with FEMA Safe Room

Construction Materials

Building Assemblies

Building orientation: Although the building's axial orientation is constrained by the site, our photovoltaics will orient toward the sun. Functionally the living room, kitchen, and dining room will be set on the southwest side, enabling the winter sun to enter while buffering the sun from entering these spaces during the summer cooling months.

Floor slab: Whereas the typical best case scenario is to build a slab-on-grade foundation, given the expansive clay soils in the region, the *Solar Texas* team is validating cost-to-benefit analyses of two design solutions - one for a stiffened slab on grade with grade beams that require 3'-0" of cut soil to be replaced with select structural fill and another with helical piers installed at engineered intervals along with the footing forms and tied into the steel gridwork before pouring concrete footings. The helicical pier design solution will incorporate a prestressed concrete slab. In both cases the *Solar Texas* team will integrate solar heated hydronic radiant flooring systems. The floor R-value will be R15.00.

Site drainage: The lot will be properly graded - 5% grade slope - to drain away from the structural foundation. The site will use Low-Impact Development (LID) strategies such as biophilic "ecoregional" green vegetated swales (goal: to manage, retain and delay stormwater runoff, mitigate ecological imbalances caused by urbanization, conserve energy in the building, further reduce urban heat islands, provide biophilic benefits) and pervious pavers to minimize runoff and lessen impacts on municipal sewer systems.

Roof: A combination of a cool, reflective roof (goal: to reduce the roof surface temperature by more than 50-degrees, reduce air conditioning load, solar heat gain, and negative heat island effect, improve interior comfort level), reduce building life-cycle costs, and provide restorative well-being for the homeowners, and adequately ventilated, radiant barrier, and well-insulated roof to equalize interior and exterior temperatures. The roof will use a fully adhered roofing membrane at eaves and gable ends, butyl-based adhesive back flashing strips on roof sheathing joints, and hurricane-rated BIPV tiles/shingles. This will include installation of hurricane strapping, rods, and bolts per code. The roof R-value is 42.00.

Wall construction: Wood frame Wall R-value R27.04 (goal: to create a tight thermal envelope, install a positive pressure ventilation system, in a well-insulated, bridge-free construction that eliminates all thermal bridging, integrative use of vapor barrier on the exterior side of the exterior insulation, properly sealed). The team is looking at cost-to-benefit options various products, from structural insulated panels (SIPs) to autoclaved, high-performance insulated concrete panels to standard 2"x6" nominal wood framing with 2" of continuous XPS insulation. The exterior skin of the building will be brick that uses a roman brick sized profile.

Exterior envelopes: The *Solar Texas* house will use high-performance, low-emissivity windows with low solar heat gain coefficient, with windows located to maximize views and take advantage of breezes. The installed windows will use sill wrap, corner shields, and adhesive flashing tape to protect against water intrusion. The *Solar Texas* house uses a combination of overhangs, covered porches, light shelf awnings, and strategically placed shade trees to minimize solar heat gain and maximize the use of natural daylight light.

Envelope, Windows, & Doors: As an integral part of the proposed development for the Essential Aggies, *Solar Texas* will utilize predominantly south-facing for higher solar panel exposure to the sun. Given the site location in Climate Zone 2 (Figure1), windows must have at least the following performance factors: Window U-factor ≤0.40, Window SHGC ≤0.25, Skylight U-factor ≤0.65, and Skylight SHGC <0.25. Door U-Value: Door SHGC: 0.40 in CZ 2 0.25 in CZ 2; Opaque: 0.17 Opaque: Any ≤1/2 lite: 0.25 ≤1/2 lite: 0.2 >1/2 lite: 0.25 in CZ 2, Infiltration rates: 4 ACH50 in CZ 2; ENERGY STAR windows and doors. The team will continue to examine tilting the windows relative to the sun's angle, maximizing reflection in the summer and minimizing reflection in the winter months. The energy simulations used a window U-value of 0.13 and a Solar Heat Gain Coefficient (SHGC) of 0.28 which exceeds the AIA 2030 Challenge goals. The design infiltration rate is 0.220 cfm/ft[2].

Seal and Insulate with ENERGY STAR®
Savings Analysis Measure Upgrade Assumptions

Measure Name	Baseline	Upgrade
Insulating Attic	CZ 1-3: R-13 CZ 4-8: R-15	2012 IECC: CZ 1: R-30 CZ 2-3: R-38 CZ 4-8: R-49
Insulating Basement/Crawlspace	Uninsulated	2012 IECC: Floor above Unconditioned Basement/Crawlspace: CZ 1-2: R-13 CZ 3-4: R-19 CZ 5-6: R-30 CZ 7-8: R-38 Conditioned Basement Walls: CZ 1-2: None CZ 3-5: R-13 CZ 6-8: R-19
Whole House Air Sealing	CZ 1-3: 18.2 ACH50 CZ 4-8: 17.4 ACH50	25% infiltration reduction: CZ 1-3: 13.7 ACH50 CZ 4-8: 13.1 ACH50
Air Sealing Attic	CZ 1-3: 18.2 ACH50 CZ 4-8: 17.4 ACH50	20% infiltration reduction: CZ 1-3: 14.6 ACH50 CZ 4-8: 13.9 ACH50
Air Sealing Basement/Crawlspace	CZ 1-3: 18.2 ACH50 CZ 4-8: 17.4 ACH50	2.5% infiltration reduction: CZ 1-3: 17.7 ACH50 CZ 4-8: 17.0 ACH50
Air Sealing Windows Doors and Walls	CZ 1-3: 18.2 ACH50 CZ 4-8: 17.4 ACH50	2.5% infiltration reduction: CZ 1-3: 17.7 ACH50 CZ 4-8: 17.0 ACH50

Figure 6: Seal and Insulate with ENERGY STAR Savings Analysis Measure Upgrade Assumptions
Reference: Savings Analysis Measure Upgrade Assumptions (energystar.gov)

Interiors: The *Solar Texas* building design does not have an attic space; therefore, the roof and the ceiling have the same R-value: 42.00. The design specifies an installation of non-paper-faced, mold-resistant, fiberglass-mesh-covered drywall products.

Systems: As the *Solar Texas* house will elevate above the ground due to the expansive soils of the Bryan-College Station area, the team will examine the costs and performance of a combinatory system of geo-exchange ground source heat pumps and earth tube with an earth-to-air heat exchanger. The balanced whole-house ventilation system will use either an Energy Recovery Ventilation (ERV) or Heat Recovery Ventilation (HRV) unit that vents through the roof. The *Solar Texas* team will examine duct-free, mini-split systems with individual HVAC units in each space, each with its own indoor and outdoor component to eliminate ductwork. The design will compare the mini-split system to a packaged system that combines heating and cooling capabilities in one unit. In each scenario, the system will incorporate a thermostat with humidity controls, a dehumidifier to control seasonal humidity, and ceiling fans for comfort.

Cooling Equipment: Cooling equipment will be modeled at the applicable efficiency levels at 20 SEER / 12 EER AC.

Heating Equipment: For the energy performance simulations, the design uses heating equipment modeled at the applicable efficiency levels and is dependent on fuel and system type, 8.2 HSPF / 20 SEER / 12 EER air-source heat pump with electric or dual-fuel backup.

Water Heater, Thermostat, & Ductwork: The design integrates programmable thermostats, with all ducts and air handlers within a conditioned space.

Lighting & Appliances: ENERGY STAR light bulbs modeled in 90% of ANSI / RESNET / ICC Standard 301-defined Qualifying Light Fixture Locations. The *Solar Texas* house will maximize available natural lighting, thus reducing electrical lighting during daylight hours. The *Solar Texas* team will examine the use of window coverings on the inside and outside of the building to control lighting levels and maximize privacy. Lighting throughout the house will incorporate light-emitting diode (LED) solid-state lighting for ambient, general, and task lighting. All lights will have dimmable controls at a CRI color temperature of 2900K. Controls include timers, automatic daylight shut-off, motion sensors, and photocells that automatically turn lights on or off when not in use. Appliances will include ENERGY STAR refrigerators, dishwashers, induction cooktops, and ceiling fans.

The *Solar Texas* project is a 2018 IECC International Code Council code-compliant building developed and an energy-compliant residential project that incorporates passive solar design features situated on a site in Bryan/College Station. The project goal is to be carbon neutral and net-zero. The project uses a combination of site orientation (east-west orientation), properly sized and shaded windows and doors, optimized to reduce solar gain and cooling demands in relation to baseline building types to achieve this goal. The team intends to measure and reduce emissions through integrative building design strategies and energy efficiency measures such as incorporating carbon-free on-site renewable energy systems to meet its energy needs. The team goal is to reduce emissions from the baseline building by 90%.

Possible Construction Elements and Materials:

- Installing air conditioning systems
- Water supply and drainage systems
- Firefighting systems
- Electrical power and lighting systems including transformer substations and emergency power generators
- Alarm systems
- Security access and surveillance systems
- Foundation
- Wall assemblies
- Roofing systems
- Doors and doorways
- Windows
- Chimneys
- Vents

- Steel
- Concrete
- Wood
- Stone
- Brick/Masonry
- Vinyl Siding
- Drywall/Plasterboard

Building Code Enforcement

Since September 21, 2017, the city of Bryan has enforced 2015. The International Code Council's guidelines. This includes Fire Code, Building Code, Existing Building Code, Residential Code, Mechanical Code, Fuel Gas Code, and Energy Conservation Code. In addition to these codes, the city also enforces The National Fire Protection Association, 2014 National Electrical Code. ADA standards are not applicable to single-family homes. As of September 21, 2017, the City of Bryan has enforced 2015 The International Code Council's guidelines, including Fire Code, Building Code, Existing Building Code, Residential Code, Mechanical Code, Fuel Gas Code, and Energy Conservation Code. In addition to this, the city also enforces The National Fire Protection Association 2014 National Electrical Code. ADA standards are not applicable to single-family homes. The city has divided building types into certain categories, for our single-family home, it falls into the building subset that is Residential District-5000 (RD-5). RD-5 rules are enforced when it comes to building residential and commercial buildings such as duplexes, patio homes, townhomes, twin homes, professional offices, and community centers. Within this subset certain building regulations apply to us on top of the codes that were listed above. Building regulations that are applicable to our Solar Decathlon project are a front setback of 25’, a setback to an abutting building of 7.5’, maximum lot coverage of 75%, minimum lot size of 5,000sf, minimum lot width of 50’, minimum lot depth of 100’, maximum build height of 35’, and 15% of the lot must be for landscaping. In addition to this substructures are permitted within the city's rules and regulations, which allows for us to have one detached shed within our project.

In regards to Solar Photovoltaic systems pertaining to our project the NFPA is the standard for this, they have standards pertaining to Fire Code, Electrical Code, Electrical Equipment, Electrical Safety, and Building Construction and Safety Code. The goal of the NFPA is to create a universal standard that will make these Solar Photovoltaic systems more reliable and safer for their clients. The NFPA requires that Solar Photovoltaic installations be up to their standards when it comes to installing them, this is so in case of an emergency in relation to the system the first responder knows where to look due to the universal standard of the NFPA. On our system, we must have markings on system to indicate what it is, within the system, there must be markings for the DC conduit and the main service disconnect. In addition to this when installing the system it must have a setback of 3’ from the roof pitch for Solar Photovoltaic systems.