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Solar Tree House

Dr. Lucas Craig
MECH 477
Capstone Project

Background

Our customer, Dr. Lucas Craig, has requested that we design a tree house for his backyard (Figure 1). It must utilize his two 100 watt grape solar panels and accommodate 3 children & 2 adults at once. Other sustainable features, such as wind turbines and passive solar, must be researched as potential add-ons.

Capstone Objectives

- Research building and safety regulations
- Design a tree house and generate CAD drawings
- Find heating, cooling, stress, snow, and wind loads
- Explore various sustainability features
- Establish a bill of materials with associated costs
- Create a poster, presentation, and design report

Design Requirements

Mandatory	Desirable	Wants
Designed for a 15-in Ø pine tree	Does not exceed a budget of $5,000	Porch at the front entrance
Room size of at least 40 ft^2	Designed for year-round use	A window on every wall
Generate and supply at least 500 watts	Sustainable features provided as optional add-ons	Built-in folding tables on two sides of the interior

Figure 1: (Left) customer's tree and (top) satellite view of the backyard (red dot = tree)

Research

- A suitable tree must be dense, have a diameter greater than 1 ft, and not be too young or too old [1]
- The tree house area must be greater than 40 ft^2 to comfortably house 5 people [2], but cannot exceed 144 ft^2 without requiring a permit [3]
- For maximum safety, the tree house should be low to the ground, have barriers placed at exposed edges, and avoid using rope ladders to prevent falling [4]
- A tree house can cost as low as $4,000 to build [5]
- Weather data can provide the average sunlight hours & wind speed (Figure 2) to help find the effectiveness of solar panels & wind turbines [6]

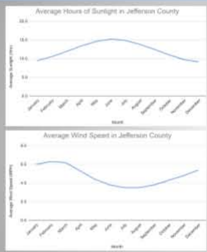

Figure 2: (Top) average sunlight and (bottom) average wind speed [6]

Figure 3: Reference material for a single-tree tree house supported by beams [7]

Preliminary Analysis

- The customer's tree exceeds minimum requirements. It is a pine tree with a 1.25 ft diameter and has matured enough to not rapidly expand.

D = C / π D = 48 in / π D = 15.3 in	Age = GFpine * D Age = 5 * 15.3 in Age = 76.4 years
D = Diameter C = Circumference = 4 ft = 48 in GFpine = Growth factor of pine = 5	

Table 1: Calculations for tree age [8]

- Due to the dense southern forest blocking the sun, the solar panels will be placed in the yard. A solar path finder was used to determine that the best position is 15 yards north.

Figure 4: (Top) A solar path finder and (left) distance from the solar path finder to the tree

- While tree houses that cost less than $5,000 are possible, they are typically a simple platform. More complex tree houses will require more materials and a carpenter for aid, who can charge $100-200/hour for labor (Figure 5). This will cause the project to go over budget.

Figure 5: Estimated costs for building a tree house [5]

Design Analysis

Item Name	Quantity	Cost
Sliding Patio Door	1	$480
Single Hung Window	3	$466
Pressure-Treated Handrail	3	$168
Vinyl Siding	21	$195.00
Tar Paper	1	$30
Galvalume Steel Roof Panels	4	$204
Fiberglass Insulation	8	$160
Exterior Plywood (0.5" x 4' x 8')	12	$515.75
Interior Plywood (11/32" x 4' x 8')	12	$292.00
Supports and Posts (4" x 4" x 8')	6	$81.50
Concrete Deck Block	6	$41.50
Ceiling / Flooring Joists (2" x 8" x 8')	8	$80
Ship Ladder Railing (2" x 12" x 8')	2	$50
Ship Ladder Steps (2" x 8" x 8')	2	$23
Total		**$2,787**

Table 2: Material costs of the tree house [7]

Figure 6: Top, front, side, and isometric views of a tree house Revit model

Heating and Cooling Loads

Heating Load

The heating load (Qh) was found by multiplying the coefficient (U), area (A), and temperature difference (ΔT)

Property	Value
Sum Heat Transfer Coefficient (ΣU)	0.8107 BTU/hr/ft^2/°F
Sum Area (ΣA)	322 ft^2
Indoor Temperature (Tin)	68°F
Outdoor Temperature (Tout)	-5.6°F
Air Volume Flow (q)	21.6 ft^3/min

Property	Equation	Answer
Difference in Temp. (ΔT)	$\Delta T = Tin - Tout$	73.6°F
Infiltration Losses (hs)	$hs = 1.1 \times q \times \Delta T$	1749 BTU/hr
Heat Transfer Rate (Qh)	$Qh = \Sigma(U \times A \times \Delta T) + hs$	**3000 BTU/hr**

Table 3: Calculation of the heating load [9]

Cooling Load

The cooling load (Qc) was found by adding the cooling loads of the room (Qr), glass (Qg), and people (Qp)

Property	Value
Room Cooling Load (Qr)	422 BTU/hr
Glass Cooling Load (Qg)	2926 BTU/hr
People Cooling Load (Qp)	1350 BTU/hr

Property	Equation	Answer
Cooling Load (Qc)	$Q = Qr + Qg + Qp$	**4700 BTU/hr**

Table 4: Calculation of the cooling load [9]

Stress Loads

Static / Live Load

The static load is the sum of all static parts, while the live load is the sum of all moving parts

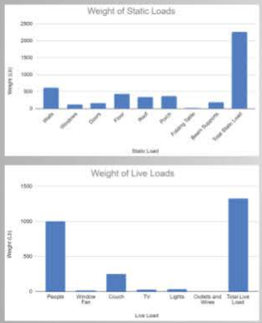

Figure 7: Graphs of the static loads and live loads [10]

Snow Load

The sloped snow load (Ps) is the maximum expected accumulation of snow

Property	Value
Roof Slope Factor (Cs)	0.475
Exposure Factor (Ce)	1
Thermal Factor (Ct)	1.2
Important Factor (Is)	1
Ground Snow Load (Pg)	60 lb/ft^2

Property	Equation	Answer
Flat Roof Snow Load (Pf)	$Pf = 0.7 \times Ce \times Ct \times Is \times Pg$	50.4 lb/ft^2
Sloped Snow Load (Ps)	$Ps = Cs \times Pf$	**23.94 lb/ft^2**

Table 5: Calculation of the sloped snow load [10]

Wind Load

The wind load (F) was found by multiplying the surface area of the wall (A) by the wind pressure (P) and drag coefficient (Cd)

Property	Value
Wall Area (Aw)	56 ft^2
Roof Area (Ar)	16 ft^2
Wind Velocity (V)	35 mph
Drag Coefficient (Cd)	2

Property	Equation	Answer
Area (A)	$A = Aw + Ar$	72 ft^2
Air Pressure (P)	$P = 0.00256 \times V^2$	3.1 lb/ft^2
Wind Load (F)	$F = A \times P \times Cd$	**2,935 lb**

Table 6: Calculation of the wind load [10]

Sustainable Analysis

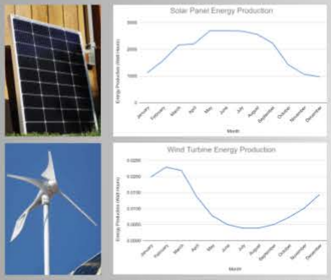

Figure 8: Energy production for two 100w solar panels (top) and a 400w wind turbine (bottom)

Sustainable Add-Ons	Pros	Cons
Passive Solar Heating	Provides natural heating during the Winter months	Needs an unobstructed view of the sun to function
Solar Shingles	More compact and durable than solar panels	Generates less energy than solar panels
Compost Toilet	Portable and creates compost for plants	Requires regular maintenance to avoid odors
Solar Post Cap Lights	Self-sustainable and provides light at night	Not as bright as battery / hardwired lights
Rainwater Filtration System	Provides filtered rainwater for drinking, cooking, etc.	Expensive and requires regular maintenance

Table 7: Evaluation of various sustainable add-ons

Results

We successfully designed a tree house for the customer's tree that utilizes solar panels, can fit the full family in the same room, and can receive additional sustainable add-ons. Unfortunately, the requirements of the project caused this project to go over budget and the troublesome aspects of the tree house's location forced several restrictions on the final design.

Contribution

Student	Deliverables
Richard Joiner	Design & Research, Materials, Misc. Sustainable Features, Snow Loads, Design Report, Poster, and Presentation
Caleb Olin	Heating Loads, Cooling Loads, Stress Loads, and CAD Model
Emanuel V Garcia-Nyers	Solar Energy, Wind Energy, CAD Model, and 3D Print

Sources

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