DESIGN AND IMPLEMENTATION OF

SOLAR POWERED PARKING

SYSTEM

by

MUSTANSIR HUSAIN

Presented to the Faculty of the Honors College of

The University of Texas at Arlington in Partial Fulfillment

of the Requirements

for the Degree of

HONORS BACHELOR OF SCIENCE IN CIVIL ENGINEERING

THE UNIVERSITY OF TEXAS AT ARLINGTON

May 2023

ACKNOWLEDGMENTS

I would like to take this opportunity to thank the UTA Civil Engineering department and the Honors College and I am deeply appreciative of their support. I would like to extend my gratitude to Dr. Tamer Eljufout for providing his invaluable guidance and assistance throughout the project. Additionally, I would like to acknowledge the contribution of my Civil Engineering Senior Design team members: Janet Hamidovic, Caleb Kocmick, Carlos Alberto, Kassi Bryan and Tebessa Ketchersid.

May 02, 2023

ABSTRACT

DESIGN AND IMPLEMENTATION OF

SOLAR POWERED PARKING

SYSTEM

Mustansir Husain, B.S. Civil Engineering

The University of Texas at Arlington, 2023

Faculty Mentor: Tamer Eljufout

The demand for sustainable designs in civil engineering is increasing and the use of renewable resources is encouraged to reduce the environmental impact and increase industry standards. A solar powered system installation not only prioritizes sustainable development but also helps economically by reducing electricity costs. This report discusses the schematic design plans for a solar powered system installed over a parking lot, to generate green energy and minimize long-term running costs. This utilizes the parking space to provide shade to the vehicles along with stations to power the electric vehicles. The site features two different canopies, placed over the parking area of an industrial site. This report provides the structural designs for both the shades and analyses the strength of the design. By determining the area and location of the structure, the number of panels that are installed can be calculated and the power output can be estimated.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

CHAPTER 1

INTRODUCTION

1.1 The Need for Sustainability in Civil Engineering

Civil Engineering plays a critical role in shaping society and directly impacts the environment and economy. With the increase in the need of sustainable solutions due to the depletion in resources, engineers call for innovation even in areas like construction and development to reduce the resource usage but deliver a more enhanced design. The American Society of Civil Engineer states the first and foremost duty of an engineer is to promote health, safety and public welfare and create safe, resilient, and sustainable infrastructure.

1.2 Use of Solar-Powered Systems

Solar powered systems generate clean and renewable energy that reduces the dependency on fossil fuels and mitigates the environmental impact of using the non-renewable resources, at the same time. Solar energy is the most efficient in reducing the carbon footprint and greenhouse gas emission. Although the initial cost of setting up a solar powered system may seem high, overall, these systems can prove to be cost-effective. These panels cost significantly less today, as compared to a few years ago and provide relatively more efficiency as well. This report provides design schematics for a solar-powered parking shade and although it focuses on the structural elements, the report discusses the power output of the system as well and shows how much energy can be saved using solar devices

1.2.1 Benefits of Solar Parking

This report proposes a solar power system designed over a parking lot to provide power supply to the parking area as well as the commercial site. As mentioned above, generating solar power reduces electricity bills significantly as it provides power for lighting, signage, and other utilities in the parking lot, also reducing the reliance on grid supply. Moreover, placing EV Stations to power vehicles can prove to be useful when the shift towards electric vehicles is expected to grow exponentially by the end of this decade. This system is placed over a steel structure, which provides shade to the parked vehicles and appeals aesthetically as compared to traditional open and empty parking lots. Overall, this design provides a range of benefits to improve standards, keeping the future needs in mind.

CHAPTER 2

DESIGN OVERVIEW

2.1 Project Description

The project site is Arlington Business Center, located in Arlington, Texas, at the Southwest Corner of Bardin Road and planned Dr. Martin Luther King Jr. Boulevard extension. The project involves land development of a 28-acre site, featuring two industrial warehouse buildings, as shown in Figure 2.1.

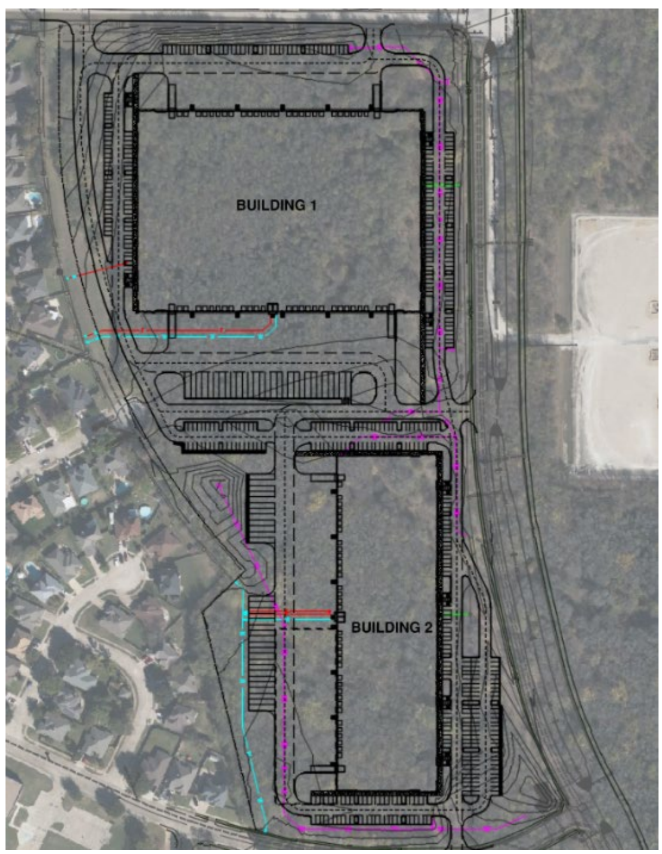


Figure 2.1: Overall Site Plan

The project required the following deliverables to be provided to the client: Site Plans, Pavement Plans, Grading and Erosion Control Plans, and Utilities including Water plans, Sanitary plans, Strom-water plans and Fire-water plans. I designed all the utilities for the site, provided design calculations, and pipe network profile plans. The project is currently under construction and is directed by MMA Engineering firm in Arlington, TX.

2.2 Honors Contribution

To meet the requirements of the Honors Capstone Project, the additional component included the creation of a structural design of a solar-powered system which is proposed to be placed along the parking space of Arlington Business Center, as part of a sustainability initiative. This innovative system leverages photovoltaic technology, employing solar panels or cells to generate electricity from sunlight. By concentrating on the structural aspects, the project meticulously considers load calculations and conducts thorough structural analyses using advanced software. The goal is to ensure the stability and durability of the solar parking system, optimizing its performance and efficiency. Furthermore, the project provides valuable insights into the power generation potential of the system, along with estimated cost savings.

2.3 Shade Placement

The site features parking at all sides of the buildings; however due to utilities and spacing limits, the shade can only be placed over some constrained areas. The structure is placed to avoid storm draining areas, easement areas, truck docking areas and the panels shall be placed in open areas to ensure sunlight as well. As shown in Figure 2.2, the canopies are placed at the North and Southeast parking side of the site as locations meet all the requirements or objectives for the placement.

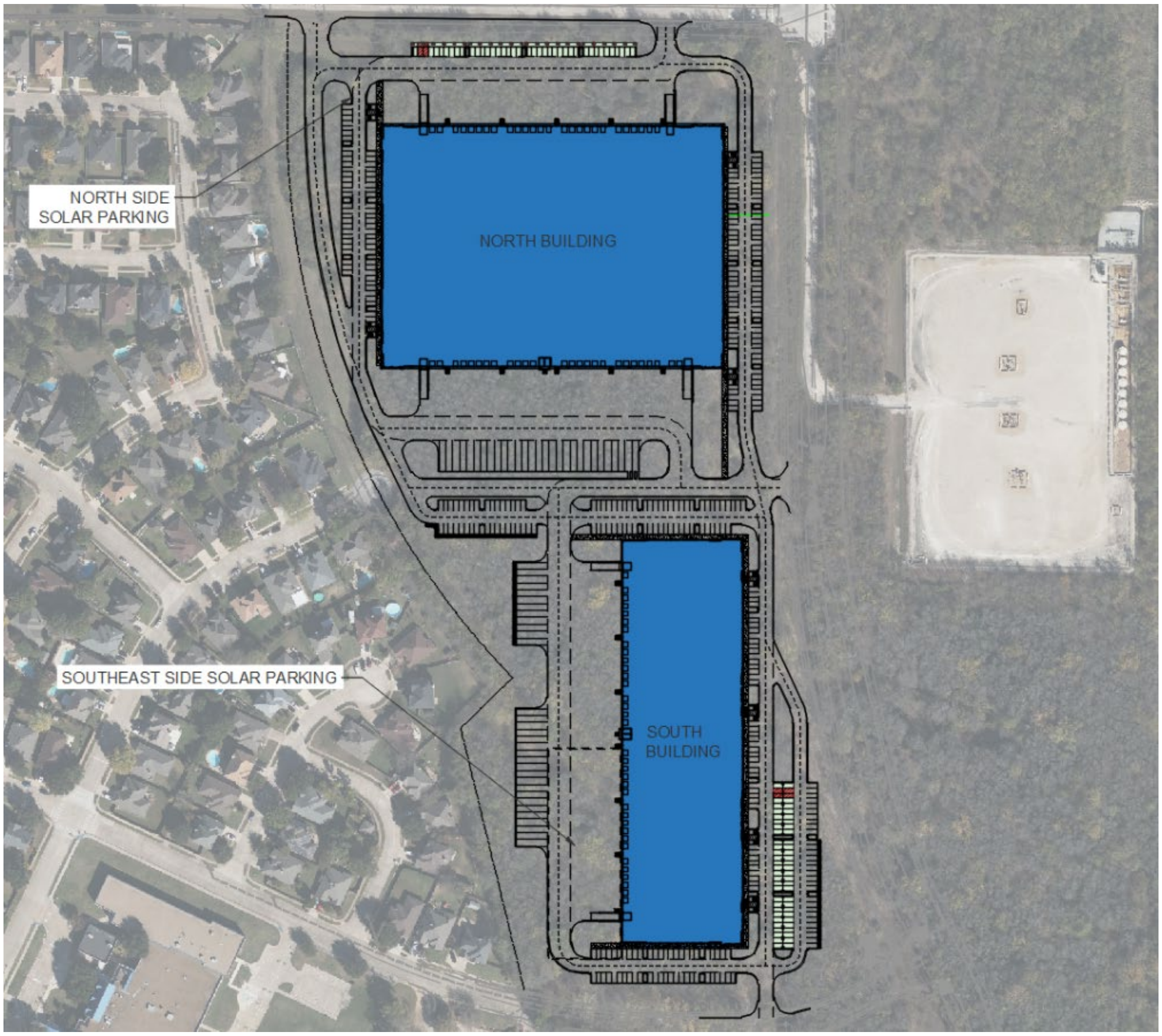


Figure 2.2: Solar Shade Placement

2.4 Panel Design

The site uses industrial panels, used for commercial purposes, providing higher output and greater efficiency than regular residential solar panels. Considering the shade area, a 60-cell panel can be used with a 320 watts panel (Taylor, 2021), having the dimensions as shown in Figure 2.3.

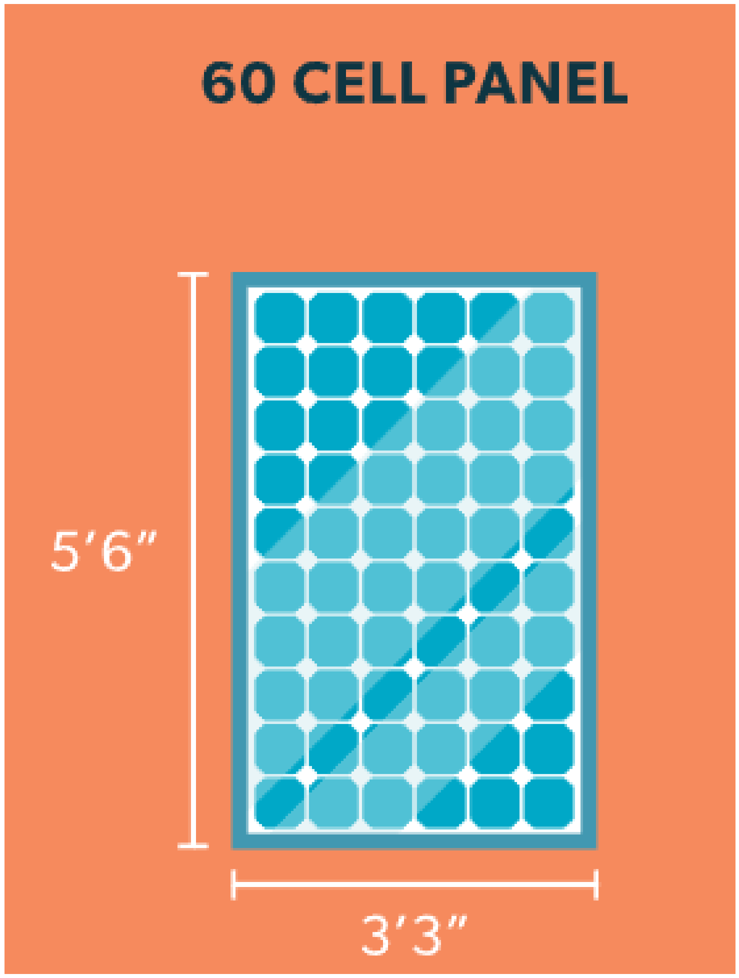


Figure 2.3 Panel Design (Taylor, 2021)

2.5 Tributary Area Calculations

Tributary area refers to the portion of a floor or roof that is supported by a structural member like a beam or column. It is required to design and analyze the required strength and size of the members so it can sustain the load.

2.5.1 Single-sided Shade

Figure 2.4 shows the plan view of the North side parking which features four, single sided, solar shades. The North shades expand 95 feet with a width of 25.75 feet. Based on these dimensions we get a total area of one shade as 2,446.25 square feet. A three-inch spacing is used between two consecutive panels and thus a single shade can hold 112 panels. Thus, the total number of panels that could be installed over the North parking, for four shades is 448.

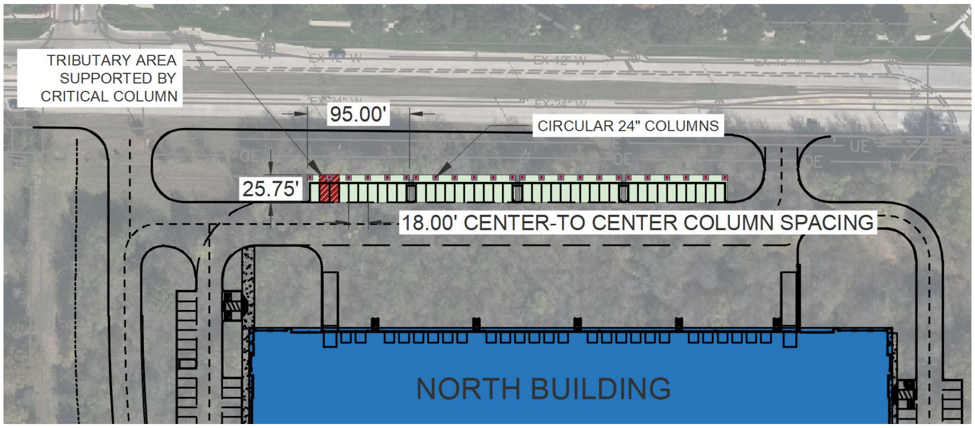


Figure 2.4 North Parking Plan View

The tributary area, shown in Figure 2.5, is calculated for the critical column as 464 square feet (25.75 ft x 18.00 ft).

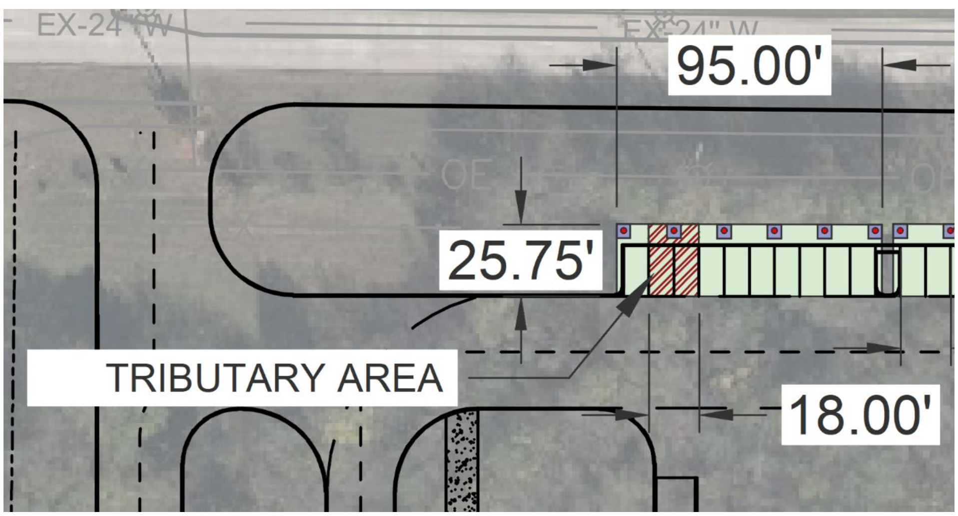


Figure 2.5 Single-Sided Shade Tributary Area

2.5.2 Double-Sided Shade

The South parking shade also expands 95 feet over its length, however, a double-sided canopy is used which has a width of 36 feet, as shown in Figure 2.6. Using the same design approach of the North, the total area of one shade is found to be 3,420 square feet. This makes a total of 480 panels that can be placed over three shades.

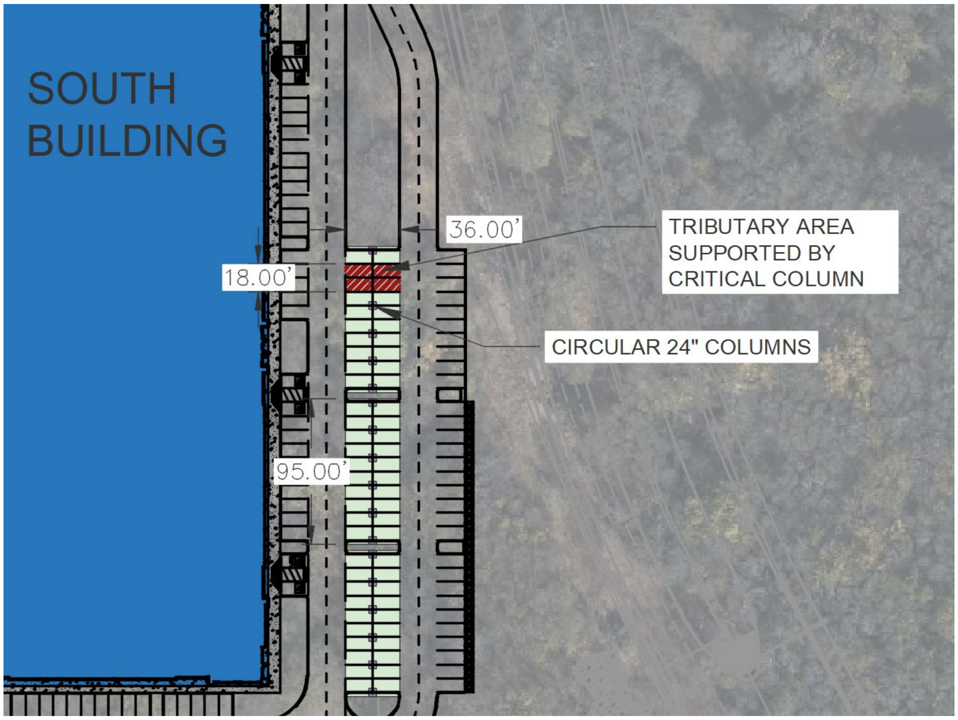


Figure 2.6 Southeast Parking Plan View

The tributary area supported by the critical column for this shade is 648 square feet and is shown in Figure 2.7.

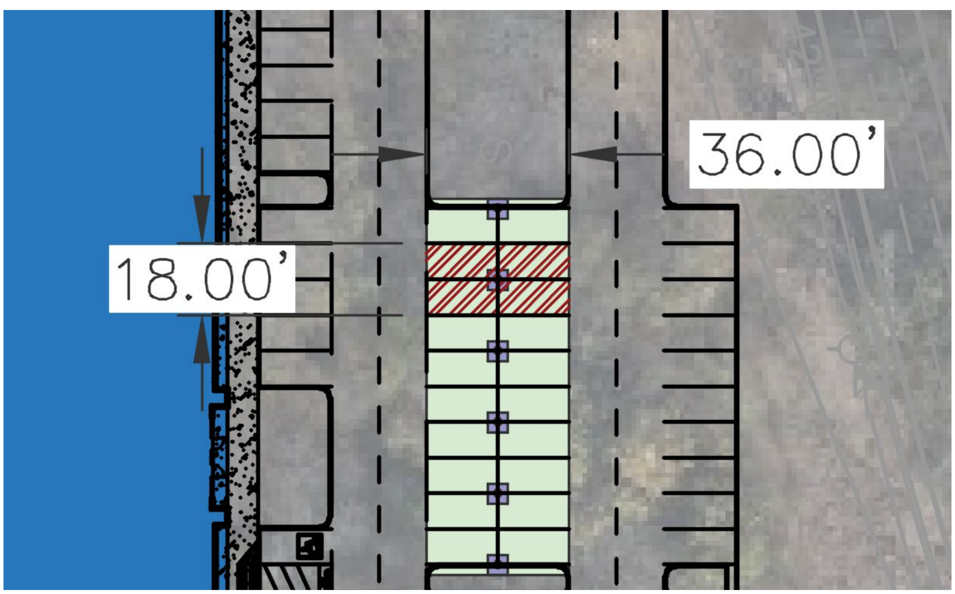


Figure 2.7 Double-Sided Shade Tributary Area

2.6 Proposed Shade Design

A combined 928 panels are used in total for both the parking areas as discussed in the previous section. Figure 2.8 shows the cross-sectional view with structural details of the proposed design for both north and southeast side parking. Both the parking shades use similar structural components discussed later in the report. Figure 2.9 and Figure 2.10 show visual images and model view of both the structures.

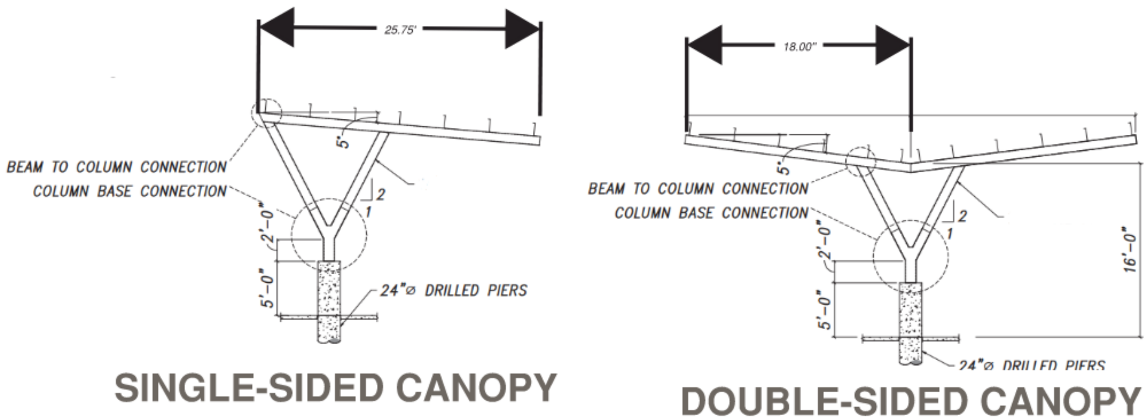


Figure 2.8 Structural Details (University of Colorado, 2020)


Figure 2.9: Single-Sided Shade


Figure 2.10: Double-Sided Shade (Franklin, 2022)

CHAPTER 3

STRUCTURAL DESIGN

For the structural design calculations, environmental conditions need to be evaluated as it significantly changes the design consideration factors. The current project site is situated in Arlington, Texas, and the design values for wind load, snow load, etc. are set according to the location. The solar panels are placed at an angle of 5 degrees to provide better efficiency. The dynamic pressure for the current conditions is 0.09725 psi (Maus, 2023).

3.1 Design Load Calculations

3.1.1 Dead Load Estimation

Dead load is the weight of the structure and any permanently attached elements. It is also called self-weight of the structure and is an important consideration in structural design as it affects the strength and stability of the structure. For the shade design, the deadload the members must carry is from the Solar panels, installation devices and, the galvanized corrugated sheets over which the panels will be installed.

The panel design recommends a dead load of 3 pounds per square foot (psf) to be considered for the dead load (UpCodes, 2015). The combined deadload for all the elements used for this design is 5 psf.

3.1.2 Live Load Estimation

Live load refers to the weight of temporary or movable elements that are placed on a structure such as human load or equipment's. This design follows Arlington design code manual and includes snow load, wind loads, and human load, required for maintenance and operation purposes, as follows:

Wind Load: 577lbs = 1.25 psf (Maus, 2023)

Snow Load: 5 psf (ATC, 2023)

Human Load: 300 lbs = 0.65 psf

Total Live Load= 6.9 psf

3.1.3 Factored Design Load

According to the design manual, the structure should be designed for a factored load, representing the maximum amount of load on the member. This load is calculated by multiplying the total dead load and live load by a load factor specified in the design code (International Code Council, 2023).

Factored Dead load = 1.2 x (Total dead load) = 1.2 x 7 = 8.4 psf

Factored Live load = 1.6 x (Total live load) = 1.6 x 6.9 = 11.04 psf

Total Factored Design Load = 19.44 psf

3.2 Beam Design

Beams are used to support loads and transfer them to underlying structure (columns). It is subjected to the factored load that is calculated and is designed without exceeding the allowable stress and deflection limits. Beams provide support only to the moment and some important properties are considered during the design, such as modulus of elasticity, cross-sectional area, moment of inertia and section modulus.

3.2.1 Beam Capacity

The beam used for the design is a Square HSS Beam. An HSS beam consists of a box section structure, which is helpful to withstand lateral torsion or rotation. Its hollow structure also provides a better strength-to-weight ratio than wide flange beams. Since the shade is placed in an open space, HSS beams are aesthetically more pleasing than W-beams. The following are the material and geometric properties (American Institute of Steel Construction, 2017, p. 106) for the selected beam type:

Dimensions: 8” x 8” x ½”

Plastic Section Modulus, Z_x= 37.5 in^3

Yield Strength, F_y = 50 ksi

Maximum Moment, $M_n = F_y * Z_x$ = 37.5 x 50 = 1875 kip. in

Strength Reduction Factor, Φ = 0.9

Thus, Φ M_n = 1687 kip. in = 140.67 kip. ft

3.2.2 Beam Design for Single Sided Shade

For the single sided shade, the design calculations are solved manually and then verified through the SkyCiv software to get the deflection. The load is uniformly distributed over tributary area and then the load on the beam is calculated by multiplying the beam width.

Tributary area= 464 square feet

Load on the beam= 19.44 psf x 18 ft = 350 lbs/ft

Maximum moment = 49 kip. ft > 140.67 kip. ft (Provided strength > Required)

Figure 3.2 shows the bending moment diagram for the beam design and the maximum bending moment the beam is subjected to is approximately 49 kip. ft.

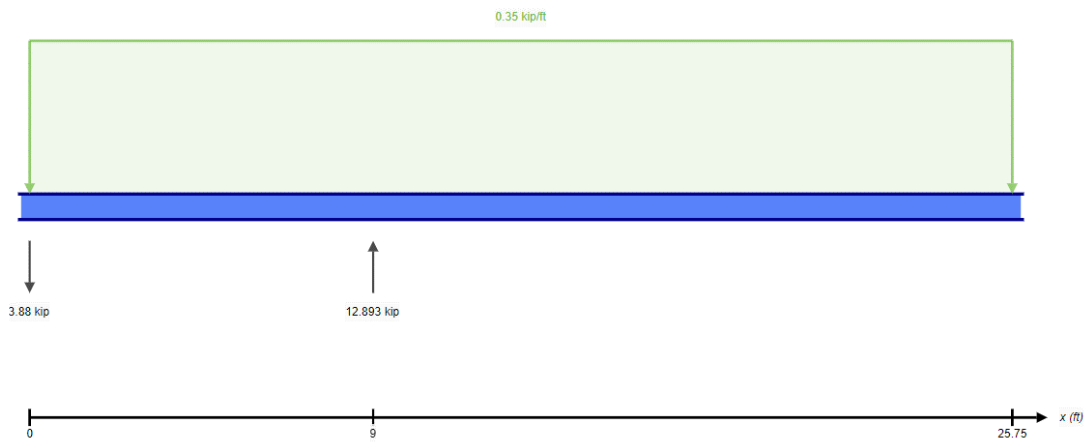


Figure 3.1: Beam Diagram

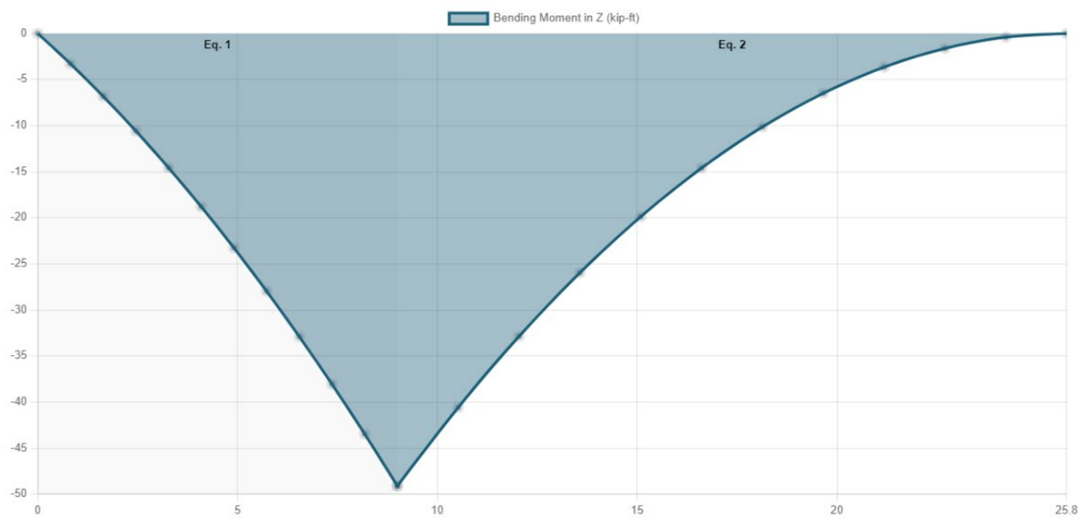


Figure 3.2: Bending Moment Diagram

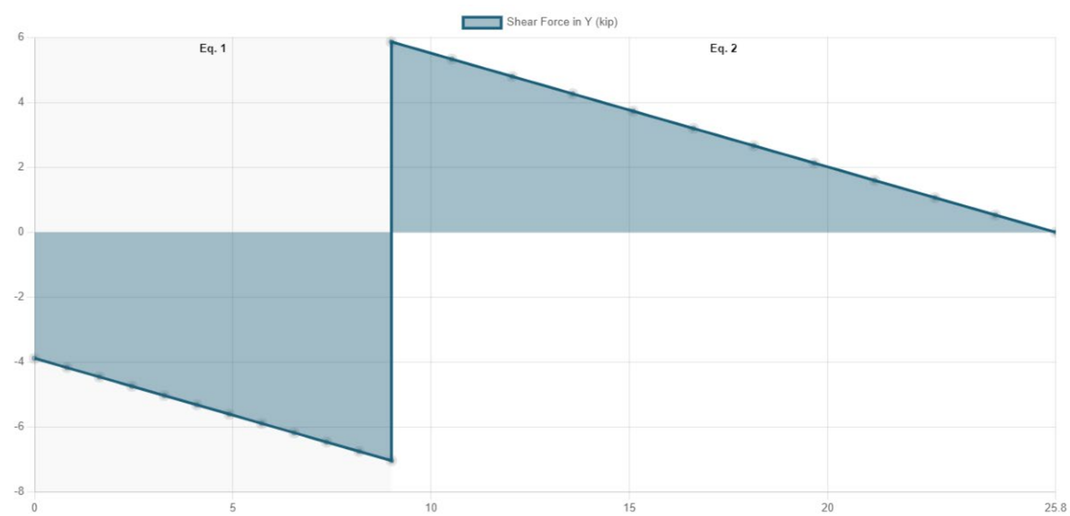


Figure 3.3: Shear Force Diagram

3.2.3 Beam Design for Double Sided Shade

For the double-sided shade, the design is directly solved through the Risa software which provides us the maximum moment on the beam (shown in Figure 3.5)

Tributary area = 648 square feet

Load on beam = 350 lbs/ft

Maximum moment = 30.9 kip. ft > 140.67 (Provided strength > Required)

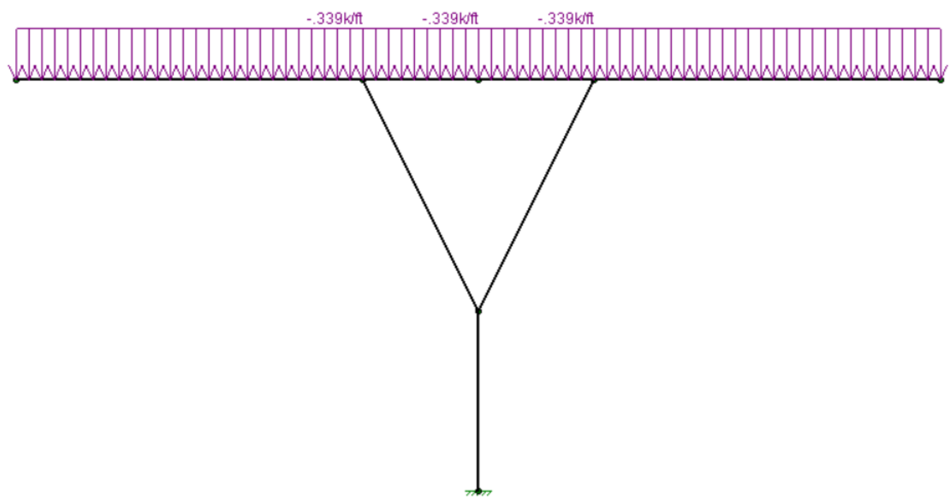


Figure 3.4: Risa Design Simulation

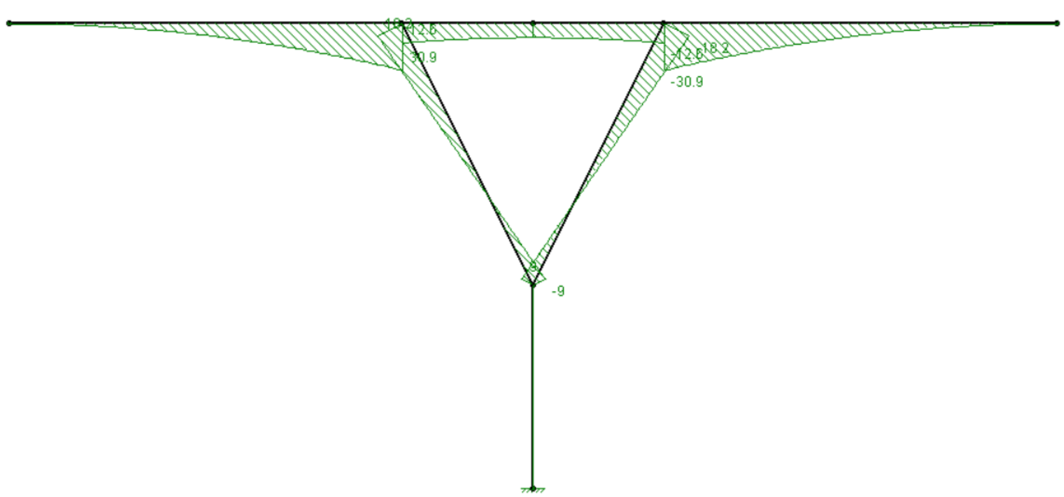


Figure 3.5: Risa Bending Moment Analysis

3.3 Column Design

Columns support the weight of the building or the structure and essentially are designed to carry all the load transferred from the beams and girders. It provides supports in moment and axial loading and for this design we used a STD 4” x 4” x ¼” pipe having the material properties (Engineers Edge, 2023) provided below:

Axial Strength = 12.2 kips (American Institute of Steel Construction, 2017, p. 506)

Moment = 18.2 kips

$\Phi P_n = 454$ kips

$\Phi M_n = 140.67$ kip. ft

Pr/Pc = 12.2/454 = 0.03

Using the equation provided below, we analyze the design strength:

$$\frac{P_r}{P_c} < 0.2,$$

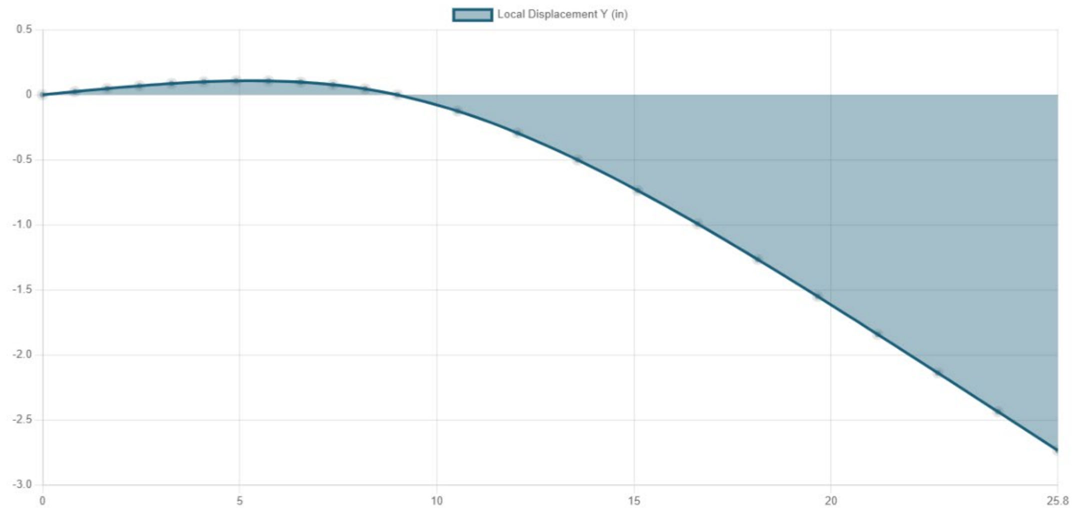
$$\frac{P_r}{2P_c} + \left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1.0$$

12.2/ (2*454) +(30.9/140.67) = 0.73 <1 (satisfied)

The design strength provided is significantly higher than the required strength and the section or member sizes can be reduced and reanalyzed. However, the design still needs to account for the deflection, discussed in the next section.

3.4 Structural Analysis

The single-sided shade is analyzed using SkyCiv software to check the deflection, which is found to be approximately 2.7 inches, as shown in Figure 3.6. The double-sided structure is analyzed through Risa software and the deflection is around 2.2 inches as shown in Figure 3.7.



Location (ft)	Total Deflection (in)	Span
0	0 in	-
4.909	0.107 in	L/1009
9	0 in	-
25.75	2.733 in	L/73

Figure 3.6: Beam Deflection Using SkyCiv

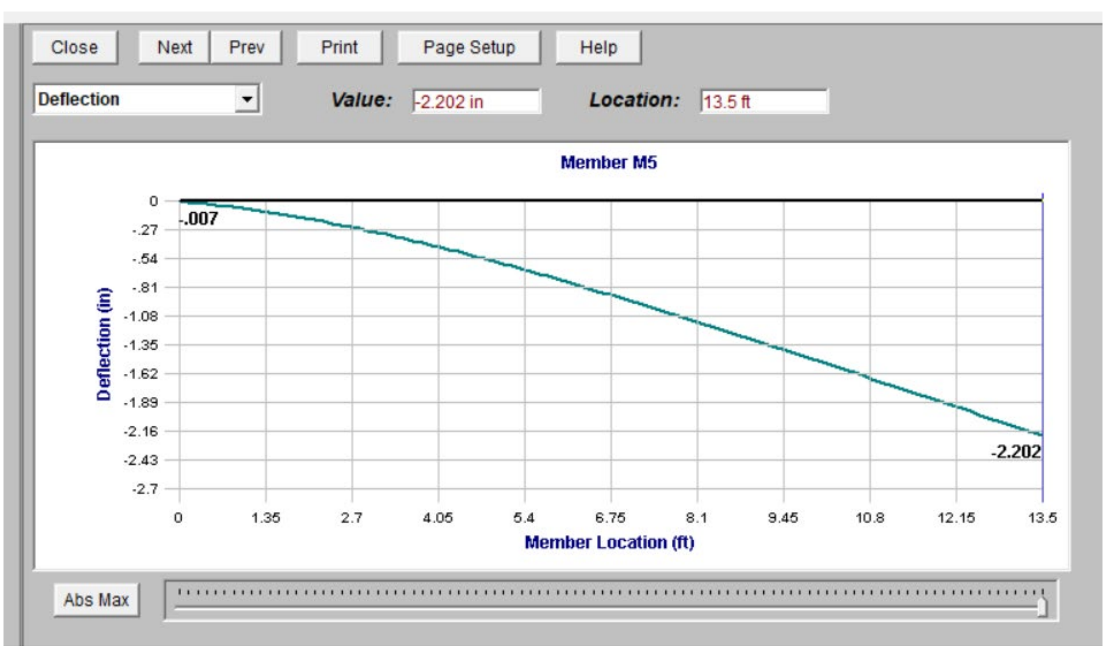


Figure 3.7: Beam Deflection Using Risa.

CHAPTER 4

SOLAR POWER OUPUT

The energy output is estimated based on the determined areas of both the north and southeast side parking at the site location to get precise results. Some of the assumptions include selection of a standard module and fixed/open-rack array type and the detailed report is provided in Appendix B (National Renewable Energy Laboratory, 2023).

The north side parking shade consists of 448 panels. Therefore, the combined capacity is 448 panels x 320 watts/panel = 143.36 kW. This shade faces the south side and is tilted with a surface angle of five degrees. The total panel area for this side is 8008 square foot which is equivalent to 743 m^2. The estimated power output for the single-sided shades is 205,508 kWh/year. The south side parking shade consists of 480 panels which gives us a net capacity of 153.6 kW. The total array area for this side is 8580 square feet, equivalent to 798 m^2. Using all the data, we get a system output of 212,058 kWh/year.

The combined output of the solar powered system for the site is 417,539 kWh/year. The typical electricity rate for the site location is $0.11/kWh, that is, the value of the generated electricity would be approximately $46,000 per year.

CHAPTER 5

CONCLUSION

Solar parking shades provide an advanced solution to generate green energy using photovoltaic energy and utilizing space as well as providing shade to cars. A 320-watt industrial solar system costs around $300 per panel and thus the total cost for 928 panels would be around $275,000. Equipment like branch connectors, PV cables, and combiner boxes would be required for operations and adding up the installation fees, the total cost would be approximately $350,000 (The Inverter Store, 2023). A cantilever wing cabled double slanted shade steel structure can cost $35,000 and a single sided cantilever shade costs around $20,000. The total costs for steel shades would be $200,000 (Cantilever Wing Cabled Shade Structure, 2023). Even though the initial installation cost might be high for these structural placements and the panels, the savings generated over time with added environmental benefits like reduced carbon emission can help to mitigate the impact of urbanization on the ecosystem.

In conclusion, the solar parking provides an innovative solution to sustainable engineering and the design uses careful planning with considerations given to the placement and orientation of the panels to maximize the performance and efficiency of the system.

APPENDIX A

REFERENCE DESIGN TABLES

Table 4-4 (continued)
Available Strength in Axial Compression, kips
Square HSS

HSS4

F_y = 50 ksi

Shape		HSS4×4×									
		3/8		5/16		1/4		3/16		1/8	
t_{des}, in.		0.349		0.291		0.233		0.174		0.116	
lb/ft		17.27		14.83		12.21		9.42		6.46	
Design		P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Effective length, L_c (ft), with respect to least radius of gyration, r_y	0	143	215	123	184	101	152	77.2	116	53.0	79.6
	1	142	214	122	184	100	151	76.9	116	52.8	79.3
	2	140	211	120	181	99.1	149	75.9	114	52.1	78.3
	3	137	206	118	177	96.8	146	74.3	112	51.0	76.7
	4	132	199	114	171	93.8	141	72.0	108	49.5	74.5
	5	127	190	109	164	90.0	135	69.2	104	47.7	71.7
	6	120	180	103	156	85.6	129	66.0	99.2	45.5	68.4
	7	113	169	97.3	146	80.7	121	62.3	93.7	43.1	64.8
	8	105	157	90.6	136	75.4	113	58.4	87.7	40.5	60.8
	9	96.4	145	83.6	126	69.8	105	54.2	81.4	37.7	56.6
	10	87.9	132	76.4	115	64.0	96.1	49.8	74.9	34.8	52.2
	11	79.4	119	69.2	104	58.1	87.4	45.5	68.3	31.8	47.8
	12	71.0	107	62.0	93.2	52.3	78.7	41.1	61.8	28.9	43.4
	13	62.8	94.4	55.1	82.8	46.7	70.2	36.8	55.4	26.0	39.1
	14	55.0	82.7	48.5	72.8	41.3	62.1	32.7	49.2	23.2	34.8
	15	47.9	72.0	42.2	63.5	36.1	54.3	28.8	43.2	20.5	30.8
	16	42.1	63.3	37.1	55.8	31.7	47.7	25.3	38.0	18.0	27.1
	17	37.3	56.1	32.9	49.4	28.1	42.3	22.4	33.6	16.0	24.0
	18	33.3	50.0	29.3	44.1	25.1	37.7	20.0	30.0	14.2	21.4
	19	29.9	44.9	26.3	39.6	22.5	33.8	17.9	26.9	12.8	19.2
	20	27.0	40.5	23.8	35.7	20.3	30.5	16.2	24.3	11.5	17.3
	21	24.4	36.7	21.5	32.4	18.4	27.7	14.7	22.1	10.5	15.7
	22	22.3	33.5	19.6	29.5	16.8	25.2	13.4	20.1	9.53	14.3
	23	20.4	30.6	18.0	27.0	15.4	23.1	12.2	18.4	8.72	13.1
	24	18.7	28.1	16.5	24.8	14.1	21.2	11.2	16.9	8.01	12.0
	25					13.0	19.5	10.4	15.6	7.38	11.1
	26									6.82	10.3

Properties

Property	3/8	5/16	1/4	3/16	1/8
A_g, in.^{2}	4.78	4.10	3.37	2.58	1.77
$I_x = I_y$, in.^{4}	10.3	9.14	7.80	6.21	4.40
$r_x = r_y$, in.	1.47	1.49	1.52	1.55	1.58

ASD	LRFD	
$\Omega_c = 1.67$	$\phi_c = 0.90$	Note: Heavy line indicates L_c/r_y equal to or greater than 200.

(American Institute of Steel Construction, 2017, p. 506)

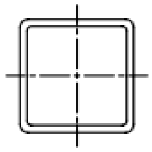
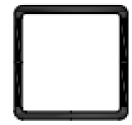


Table 1-12 (continued)
Square HSS
Dimensions and Properties

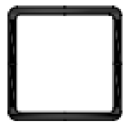


HSS10–HSS6

Shape	Design Wall Thickness, t	Nominal Wt.	Area, A	b/t	h/t	I	S	r	Z	Workable Flat	Torsion J	Torsion C	Surface Area
	in.	lb/ft	$in.^2$			$in.^4$	$in.^3$	in.	$in.^3$	in.	$in.^4$	$in.^3$	ft^2/ft
HSS10×10×3/4	0.698	89.50	24.7	11.3	11.3	347	69.4	3.75	84.7	6 5/8	578	119	3.13
×5/8	0.581	76.33	21.0	14.2	14.2	304	60.8	3.80	73.2	7 3/16	498	102	3.17
×1/2	0.465	62.46	17.2	18.5	18.5	256	51.2	3.86	60.7	7 3/4	412	84.2	3.20
×3/8	0.349	47.90	13.2	25.7	25.7	202	40.4	3.92	47.2	8 5/16	320	64.8	3.23
×5/16	0.291	40.35	11.1	31.4	31.4	172	34.5	3.94	40.1	8 5/8	271	54.8	3.25
×1/4	0.233	32.63	8.96	39.9	39.9	141	28.3	3.97	32.7	8 7/8	220	44.4	3.27
×3/16	0.174	24.73	6.76	54.5	54.5	108	21.6	4.00	24.8	9 3/16	167	33.6	3.28
HSS9×9×5/8	0.581	67.82	18.7	12.5	12.5	216	47.9	3.40	58.1	6 3/16	356	81.6	2.83
×1/2	0.465	55.66	15.3	16.4	16.4	183	40.6	3.45	48.4	6 3/4	296	67.4	2.87
×3/8	0.349	42.79	11.8	22.8	22.8	145	32.2	3.51	37.8	7 5/16	231	52.1	2.90
×5/16	0.291	36.10	9.92	27.9	27.9	124	27.6	3.54	32.1	7 5/8	196	44.0	2.92
×1/4	0.233	29.23	8.03	35.6	35.6	102	22.7	3.56	26.2	7 7/8	159	35.8	2.93
×3/16	0.174	22.18	6.06	48.7	48.7	78.2	17.4	3.59	20.0	8 3/16	121	27.1	2.95
×1/8	0.116	14.96	4.09	74.6	74.6	53.5	11.9	3.62	13.6	8 7/16	82.0	18.3	2.97
HSS8×8×5/8	0.581	59.32	16.4	10.8	10.8	146	36.5	2.99	44.7	5 3/16	244	63.2	2.50
×1/2	0.465	48.85	13.5	14.2	14.2	125	31.2	3.04	37.5	5 3/4	204	52.4	2.53
×3/8	0.349	37.69	10.4	19.9	19.9	100	24.9	3.10	29.4	6 5/16	160	40.7	2.57
×5/16	0.291	31.84	8.76	24.5	24.5	85.6	21.4	3.13	25.1	6 5/8	136	34.5	2.58
×1/4	0.233	25.82	7.10	31.3	31.3	70.7	17.7	3.15	20.5	6 7/8	111	28.1	2.60
×3/16	0.174	19.63	5.37	43.0	43.0	54.4	13.6	3.18	15.7	7 3/16	84.5	21.3	2.62
×1/8	0.116	13.26	3.62	66.0	66.0	37.4	9.34	3.21	10.7	7 7/16	57.3	14.4	2.63
HSS7×7×5/8	0.581	50.81	14.0	9.05	9.05	93.4	26.7	2.58	33.1	4 3/16	158	47.1	2.17
×1/2	0.465	42.05	11.6	12.1	12.1	80.5	23.0	2.63	27.9	4 3/4	133	39.3	2.20
×3/8	0.349	32.58	8.97	17.1	17.1	65.0	18.6	2.69	22.1	5 5/16	105	30.7	2.23
×5/16	0.291	27.59	7.59	21.1	21.1	56.1	16.0	2.72	18.9	5 5/8	89.7	26.1	2.25
×1/4	0.233	22.42	6.17	27.0	27.0	46.5	13.3	2.75	15.5	5 7/8	73.5	21.3	2.27
×3/16	0.174	17.08	4.67	37.2	37.2	36.0	10.3	2.77	11.9	6 3/16	56.1	16.2	2.28
×1/8	0.116	11.56	3.16	57.3	57.3	24.8	7.09	2.80	8.13	6 7/16	38.2	11.0	2.30
HSS6×6×5/8	0.581	42.30	11.7	7.33	7.33	55.2	18.4	2.17	23.2	3 3/16	94.9	33.4	1.83
×1/2	0.465	35.24	9.74	9.90	9.90	48.3	16.1	2.23	19.8	3 3/4	81.1	28.1	1.87
×3/8	0.349	27.48	7.58	14.2	14.2	39.5	13.2	2.28	15.8	4 5/16	64.6	22.1	1.90
×5/16	0.291	23.34	6.43	17.6	17.6	34.3	11.4	2.31	13.6	4 5/8	55.4	18.9	1.92
×1/4	0.233	19.02	5.24	22.8	22.8	28.6	9.54	2.34	11.2	4 7/8	45.6	15.4	1.93
×3/16	0.174	14.53	3.98	31.5	31.5	22.3	7.42	2.37	8.63	5 3/16	35.0	11.8	1.95
×1/8	0.116	9.86	2.70	48.7	48.7	15.5	5.15	2.39	5.92	5 7/16	23.9	8.03	1.97

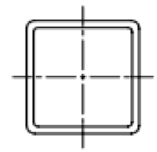
Note: For width-to-thickness criteria, refer to Table 1-12A.

(American Institute of Steel Construction, 2017, p. 106)



HSS5 1/2-HSS3

Table 1-12 (continued)
Square HSS
Dimensions and Properties



Shape	Design Wall Thickness, *t*	Nominal Wt.	Area, *A*	*b/t*	*h/t*	*I*	*S*	*r*	*Z*	Workable Flat	Torsion *J*	Torsion *C*	Surface Area
	in.	lb/ft	in.^{2}			in.^{4}	in.^{3}	in.	in.^{3}	in.	in.^{4}	in.^{3}	ft^2/ft
HSS5 1/2×5 1/2×3/8	0.349	24.93	6.88	12.8	12.8	29.7	10.8	2.08	13.1	3 13/16	49.0	18.4	1.73
×5/16	0.291	21.21	5.85	15.9	15.9	25.9	9.43	2.11	11.3	4 1/8	42.2	15.7	1.75
×1/4	0.233	17.32	4.77	20.6	20.6	21.7	7.90	2.13	9.32	4 3/8	34.8	12.9	1.77
×3/16	0.174	13.25	3.63	28.6	28.6	17.0	6.17	2.16	7.19	4 11/16	26.7	9.85	1.78
×1/8	0.116	9.01	2.46	44.4	44.4	11.8	4.30	2.19	4.95	4 15/16	18.3	6.72	1.80
HSS5×5×1/2	0.465	28.43	7.88	7.75	7.75	26.0	10.4	1.82	13.1	2 3/4	44.6	18.7	1.53
×3/8	0.349	22.37	6.18	11.3	11.3	21.7	8.68	1.87	10.6	3 5/16	36.1	14.9	1.57
×5/16	0.291	19.08	5.26	14.2	14.2	19.0	7.62	1.90	9.16	3 5/8	31.2	12.8	1.58
×1/4	0.233	15.62	4.30	18.5	18.5	16.0	6.41	1.93	7.61	3 7/8	25.8	10.5	1.60
×3/16	0.174	11.97	3.28	25.7	25.7	12.6	5.03	1.96	5.89	4 3/16	19.9	8.08	1.62
×1/8	0.116	8.16	2.23	40.1	40.1	8.80	3.52	1.99	4.07	4 7/16	13.7	5.53	1.63
HSS4 1/2×4 1/2×1/2	0.465	25.03	6.95	6.68	6.68	18.1	8.03	1.61	10.2	2 1/4	31.3	14.8	1.37
×3/8	0.349	19.82	5.48	9.89	9.89	15.3	6.79	1.67	8.36	2 13/16	25.7	11.9	1.40
×5/16	0.291	16.96	4.68	12.5	12.5	13.5	6.00	1.70	7.27	3 1/8	22.3	10.2	1.42
×1/4	0.233	13.91	3.84	16.3	16.3	11.4	5.08	1.73	6.06	3 3/8	18.5	8.44	1.43
×3/16	0.174	10.70	2.93	22.9	22.9	9.02	4.01	1.75	4.71	3 11/16	14.4	6.49	1.45
×1/8	0.116	7.31	2.00	35.8	35.8	6.35	2.82	1.78	3.27	3 15/16	9.92	4.45	1.47
HSS4×4×1/2	0.465	21.63	6.02	5.60	5.60	11.9	5.97	1.41	7.70	–	21.0	11.2	1.20
×3/8	0.349	17.27	4.78	8.46	8.46	10.3	5.13	1.47	6.39	2 5/16	17.5	9.14	1.23
×5/16	0.291	14.83	4.10	10.7	10.7	9.14	4.57	1.49	5.59	2 5/8	15.3	7.91	1.25
×1/4	0.233	12.21	3.37	14.2	14.2	7.80	3.90	1.52	4.69	2 7/8	12.8	6.56	1.27
×3/16	0.174	9.42	2.58	20.0	20.0	6.21	3.10	1.55	3.67	3 3/16	10.0	5.07	1.28
×1/8	0.116	6.46	1.77	31.5	31.5	4.40	2.20	1.58	2.56	3 7/16	6.91	3.49	1.30
HSS3 1/2×3 1/2×3/8	0.349	14.72	4.09	7.03	7.03	6.49	3.71	1.26	4.69	–	11.2	6.77	1.07
×5/16	0.291	12.70	3.52	9.03	9.03	5.84	3.34	1.29	4.14	2 1/8	9.89	5.90	1.08
×1/4	0.233	10.51	2.91	12.0	12.0	5.04	2.88	1.32	3.50	2 3/8	8.35	4.92	1.10
×3/16	0.174	8.15	2.24	17.1	17.1	4.05	2.31	1.35	2.76	2 11/16	6.56	3.83	1.12
×1/8	0.116	5.61	1.54	27.2	27.2	2.90	1.66	1.37	1.93	2 15/16	4.58	2.65	1.13
HSS3×3×3/8	0.349	12.17	3.39	5.60	5.60	3.78	2.52	1.06	3.25	–	6.64	4.74	0.900
×5/16	0.291	10.58	2.94	7.31	7.31	3.45	2.30	1.08	2.90	–	5.94	4.18	0.917
×1/4	0.233	8.81	2.44	9.88	9.88	3.02	2.01	1.11	2.48	–	5.08	3.52	0.933
×3/16	0.174	6.87	1.89	14.2	14.2	2.46	1.64	1.14	1.97	2 3/16	4.03	2.76	0.950
×1/8	0.116	4.75	1.30	22.9	22.9	1.78	1.19	1.17	1.40	2 7/16	2.84	1.92	0.967

Note: For width-to-thickness criteria, refer to Table 1-12A.
– Indicates flat depth or width is too small to establish a workable flat.

AMERICAN INSTITUTE OF STEEL CONSTRUCTION

(American Institute of Steel Construction, 2017, p. 109)

Designation = Diameter x Diameter x Wall Thickness
wt./ft = Weight in Lbs pet foot
Wall t = Wall thickness decimal
Area = Material cross section area in sq inches
Ixx, Iyy = Moment of Interia
Sx, Sy = Section Modulus
rx = Radius of Gyration
Zx, Zy = Section Modulus
Sx, Sy = Elastic Section Modulus
Polar Moment of Inerita

Desig.	wt./ft.	Wall t	Area	Ixx, Iyy	Sx, Sy	rx, ry	Zx , Zy	J
32x32x5/8	259.83	0.625	76.4	12300	771	12.7	890	19700
32x32x1/2	210.72	0.5	61.9	10100	634	12.8	727	15900
32x32x3/8	159.37	0.375	46.8	7750	485	12.9	553	12000
5x5x3/8	22.3	0.349	6.18	21.7	8.68	1.87	10.6	36.1
5x5x5/16	19	0.291	5.26	19	7.62	1.9	9.16	31.2
5x5x1/4	15.6	0.233	4.3	16	6.41	1.93	7.61	25.8
5x5x3/16	12	0.174	3.28	12.6	5.03	1.96	5.89	19.9
5x5x1/8	8.15	0.116	2.23	8.8	3.52	1.99	4.07	13.7
4.5x4.5x1/2	24.9	0.465	6.95	18.1	8.03	1.61	10.2	31.3
4.5x4.5x3/8	19.7	0.349	5.48	15.3	6.79	1.67	8.36	25.7
4.5x4.5x5/16	16.9	0.291	4.68	13.5	6	1.7	7.27	22.3
4.5x4.5x1/4	13.9	0.233	3.84	11.4	5.08	1.73	6.06	18.5
4.5x4.5x3/16	10.7	0.174	2.93	9.02	4.01	1.75	4.71	14.4
4.5x4.5x1/8	7.3	0.116	2	6.35	2.82	1.78	3.27	9.92
4x4x1/2	21.5	0.465	6.02	11.9	5.97	1.41	7.7	21
4x4x3/8	17.2	0.349	4.78	10.3	5.13	1.47	6.39	17.5
4x4x5/16	14.8	0.291	4.1	9.14	4.57	1.49	5.59	15.3
4x4x1/4	12.2	0.233	3.37	7.8	3.9	1.52	4.69	12.8
4x4x3/16	9.4	0.174	2.58	6.21	3.1	1.55	3.67	9.96
4x4x1/8	6.45	0.116	1.77	4.4	2.2	1.58	2.56	6.91
3.5x3.5x3/8	14.6	0.349	4.09	6.49	3.71	1.26	4.69	11.2
3.5x3.5x5/16	12.7	0.291	3.52	5.84	3.34	1.29	4.14	9.89
3.5x3.5x1/4	10.5	0.233	2.91	5.04	2.88	1.32	3.5	8.35
3.5x3.5x3/16	8.13	0.174	2.24	4.05	2.31	1.35	2.76	6.56
3.5x3.5x1/8	5.6	0.116	1.54	2.9	1.66	1.37	1.93	4.58
3x3x3/8	12.1	0.349	3.39	3.78	2.52	1.06	3.25	6.64
3x3x5/16	10.5	0.291	2.94	3.45	2.3	1.08	2.9	5.94
3x3x1/4	8.78	0.233	2.44	3.02	2.01	1.11	2.48	5.08
3x3x3/16	6.85	0.174	1.89	2.46	1.64	1.14	1.97	4.03

(Engineers Edge, *ASTM Steel Tube Section Properties)*

APPENDIX B

SOLAR ARRAY OUTPUT REPORT

RESULTS

205,508 kWh/Year*

System output may range from 200,371 to 210,440 kWh per year near this location.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	3.50	12,624
February	3.74	12,064
March	4.91	17,054
April	5.71	18,887
May	6.43	21,487
June	6.98	22,022
July	6.89	22,344
August	6.75	21,689
September	5.88	18,818
October	4.55	15,634
November	3.72	12,762
December	2.80	10,124
Annual	**5.16**	**205,509**

Location and Station Identification

Requested Location	bardin road arlington
Weather Data Source	Lat, Lng: 32.69, -97.06 1.4 mi
Latitude	32.69° N
Longitude	97.06° W

PV System Specifications

DC System Size	143.36 kW
Module Type	Standard
Array Type	Fixed (open rack)
System Losses	14.08%
Array Tilt	5°
Array Azimuth	180°
DC to AC Size Ratio	1.2
Inverter Efficiency	96%
Ground Coverage Ratio	0.4%
Albedo	*From weather file*
Bifacial	No (0)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Monthly Irradiance Loss	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Performance Metrics

DC Capacity Factor	16.4%

(National Renewable Energy laboratory, 2023)

RESULTS

212,058 kWh/Year*

System output may range from 206,757 to 217,148 kWh per year near this location.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	3.14	12,038
February	3.48	11,986
March	4.73	17,581
April	5.62	19,906
May	6.42	23,038
June	6.98	23,644
July	6.87	23,889
August	6.63	22,842
September	5.67	19,432
October	4.28	15,694
November	3.38	12,345
December	2.53	9,664
Annual	**4.98**	**212,059**

Location and Station Identification

Requested Location	bardin road arlington
Weather Data Source	Lat, Lng: 32.69, -97.06 1.4 mi
Latitude	32.69° N
Longitude	97.06° W

PV System Specifications

DC System Size	153.6 kW
Module Type	Standard
Array Type	Fixed (open rack)
System Losses	14.08%
Array Tilt	5°
Array Azimuth	270°
DC to AC Size Ratio	1.2
Inverter Efficiency	96%
Ground Coverage Ratio	0.4%
Albedo	*From weather file*
Bifacial	No (0)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Monthly Irradiance Loss	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Performance Metrics

DC Capacity Factor	15.8%

(National Renewable Energy laboratory, 2023)

REFERENCES

American Institute of Steel Construction. (2017). “Steel Construction Manual” (Fifteenth Edition).

ATC. (2023). *Hazards by Location.* Retrieved from https://hazards.atcouncil.org.

Cantilever Wing Cabled Shade Structure. (2023). *WillyGoat Toys & Playgrounds*. Retrieved from: https://willygoat.com/collections/cantilevered-shades/products/cantilever-wing-cabled-shade-structure.

Engineers Edge. (2023). *ASTM Steel Tube Pipe Section Properties.* Retrieved from: https://www.engineersedge.com/standard_material/aisc-steel-tube.htm

Franklin, G. (2022). Beautiful Solar Carports Ideal for Shade & Clean Energy Production! *Lumos Solar*. Retrieved from https://lumossolar.com/beautiful-solar-carports-ideal-for-shade-clean-energy-production/.

International Code Council (ICC). (2023). *2018 INTERNATIONAL BUILDING CODE (IBC) | ICC DIGITAL CODES*. Retrieved from https://codes.iccsafe.org/.

Maus, P. (2023). “Wind Load Calculator.” *How Much Force Does the Wind Produce?* Retrieved from https://www.omnicalculator.com/physics/wind-load.

National Renewable Energy laboratory (NREL). (2023). *PVWATTS Calculator.* Retrieved from https://pvwatts.nrel.gov/.

Taylor-Parker, P. (2021). “Solar Panel Size Guide: How Big Is A Solar Panel?” *Unbound Solar*. Retrieved from https://unboundsolar.com/blog/solar-panel-size-guide.

The Inverter Store. (2022, August 1). *330 WATT SOLAR PANEL MONO 6 PACK EFFICIENT*. Retrieved from: https://theinverterstore.com/product/330-watt-solar-panel-mono-6-pack-more-multipacks-available-eta-february-copy/.

University of Colorado (2020). "University of Colorado East Campus Solar Schematic Design." Retrieved from https://www.cu.edu/doc/apr2020att4bouldermulti-sitesolar2pdf.

UpCodes. (2015). *Texas Building Codes | UpCodes*. Retrieved from: https://up.codes/codes/texas

BIOGRAPHICAL INFORMATION

Mustansir Husain is a senior pursuing an Honors Bachelor of Science degree in Civil Engineering. His work experience lies in site-development where he worked on hyperscale data center projects involving due diligence, prototype development, site design, utility management and site grading. His senior design project involved land development of a 28-acre site in Arlington.