Solar Array Design for Commercial Style Buildings

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By Tony Zante
ISA Corporation
3213 Whipple Road
Union City CA 94587
www.isa-corporation.com
Today’s Discussion

Initial Evaluation – Sizing up for Solar
• Building Size/Obstacles
• Desired capacity vs. space available
• Capacity Alternatives
• Preliminary layout/support concept

Full Evaluation
• Review & Update Design
• Structural review & analysis
• Putting it all together for permitting

Elevated Racking Products
• Descriptions & Procedures
Which Building Roofs Qualify?

They all qualify!
• With the appropriate mounting system

Newer buildings - More Mounting Options
• Roofs have higher load capacity
• Ballasted and Mounted usually both work

Older Buildings – More Challenging
• Ballasted may not work
• Limited Mounting options
• Harder to figure out but less competition!
Solar Roof Challenge – Example 1

Problem

• **Old Building**
• **Fails Structural**
  Even without solar
• **Valleys - Snow Drift**
• **Weak Purlins**
  – Must Double up Purlins
  – Cost is a Deal killer
Solar Roof Challenge – Example 1 (cont.)

Solution:
• Anchor to Girders
  – Bypass the Purlins
• Cover Whole Roof
• No Live Load
• No Snow Load
• No Snow Drift
• Reduces Roof Posts
Solar Roof Challenge – Example 2

Problem
• Lots of AC units
• Superstructures
• Wall Shading
Eliminates almost all potential Solar Area
Solution:
Elevated Array
• 4 feet Above AC units
• Extends to roof edge
• Fire Access
Corridor is under the Array
(Corridor Size Varies)
Use Online information for Initial Evaluation

A Lot can be done without a Site visit

- Arial & Ground Views of building - Online
- Google Earth Tools
  - Roof Dimensions
  - Roof Equipment Sizes
  - Parapet Wall Heights
- Bing Map – Perspectives
- Other Commercial Mapping Tools
Initial Building Evaluation

Solar Requirements vs. Limitations

• Capacity - Enough usable roof area?

• Roof Area losses:
  – Wall/AC Unit Shading
  – Fire & Safety Access

• Weight Limitations

• Mounting Limitations
  – Roof Support Locations
Initial Evaluation

Building Construction

Quick Look:

• **General Construction** - Steel, Wood, Concrete
  – If Concrete, roof it should support any size or type array

• **Building Age** – Decade of Construction
  – If 2000 or later, probably supports most array options
  – Older buildings – 60’s & 70’s - consider a preliminary (low cost) analysis on purlins – or plan to anchor to Girders
Initial Evaluation - Capacity

- Roof Geometry/Area
- Equipment Height
- Parapet Wall Height
- Fire Access Areas
- Racking Layout/Type
- Calculate Usable Solar Area
- Does it meet desired Capacity requirements?
- Alternatives to increase capacity
Building Example

Standard Flat Roof Building

- 56 Feet North/South x 90 Feet East/West
- Roof Height: 20 Ft.
- Parapet Wall:
  1 Ft. Thick x 3 Feet High

- Area inside Parapet Wall:
  54 Ft. x 88 Ft.
= 4752 Sq. Ft.
Fire Access Clearances

Perimeter - 4 Ft.
Hatches – 4 Ft.
Skylights – 4 Ft.

Diagram 8
Solar Array Example - Small Commercial (605.11.3.3.1 Ex)
8' Walkways

(The walkways shall be over areas capable of supporting the live load of fire fighters accessing the roof.)
Fire Access Calculations

Perimeter Distance: 268 Feet
Perimeter Access Area: 268x4 Ft. = 1072 Sq. Ft.
Hatch Size: 2.5 ft.x2.5 Ft.
Clearance: 4 Ft.

= 110 Sq. Ft.

Total Fire Access
1072 +110
= 1182 Sq. Ft.
Finding Heights by using Shadows

1. Measure shadow length of 5 Ft. high car roof
2. Measure shadow length of AC Unit

*If AC Unit shadow length is the same as car shadow length, it is also 5 Ft. high*
Shading from Parapet Walls

Estimate solar area shaded by parapet walls:

1. Choose a shading ‘length to height ratio’
   - height above array

   Ratio depends on latitude and personal experience

   Many choose 2:1 - two foot lost to shading for every foot of height above array

2. Calculate the shaded areas – on South, East & West parapet walls
Parapet Wall Shading Calcs.

**Shade Ratio of 2:1**

**Height of Parapet Wall: 3 Feet**

Shading Width: $2 \times 3 \text{ Ft.} = 6 \text{ Ft.}$

Shading Width past Fire Access: 2 feet

North, East & West Length: $= 168 \text{ Ft.}$

Additional Shaded Area: $168 \text{ Ft.} \times 2 \text{ Ft.} = 336 \text{ Sq. Ft.}$
HVAC Shading

AC Unit Dimensions:  3.5 Ft. X 5 Ft.
Assume Height: 4 Ft. Above Array
Equipment Shade Calculation

Total Area: 185 Sq. Ft.

Height Above Array: 4 Ft.
### Impact of Equipment Height above Solar on Shaded Space

<table>
<thead>
<tr>
<th>Height Above Solar, Feet</th>
<th>Shaded Area, Square Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Ft.</td>
<td>260</td>
</tr>
<tr>
<td>4 Ft.</td>
<td>185</td>
</tr>
<tr>
<td>3 Ft.</td>
<td>122</td>
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<tr>
<td>2 Ft.</td>
<td>74</td>
</tr>
<tr>
<td>1 ft.</td>
<td>37.5</td>
</tr>
</tbody>
</table>

#### Shaded Area, Sq. Ft.

![Bar Chart](chart.png)
Total Roof Space Reduction

Summary of Areas Lost to Fire Access & Shading:

- Parapet Wall: -336 Sq. Ft.
- Equipment: -185 Sq. Ft.

Total Lost: -1703 Sq. Ft.

Initial Area: 4752 Sq. Ft.

Remaining: 3049 Sq. Ft.

Percent Reduction: 36%
Tilt Angle vs. Spacing

Production per module increases with tilt angle

But: Spacing required for shade allowance reduces module area.
## Number of Modules vs. Tilt

<table>
<thead>
<tr>
<th>Tilt Angle, Degrees *</th>
<th>Module Space Available, % *</th>
<th>60 Cell Modules <em>(Low Mount)</em></th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
<td>174</td>
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<tr>
<td>5</td>
<td>85</td>
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<td>15</td>
<td>67</td>
<td>117</td>
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<td>20</td>
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<td>25</td>
<td>57</td>
<td>99</td>
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<tr>
<td>30</td>
<td>54</td>
<td>93</td>
</tr>
</tbody>
</table>

*Based on: Shade factor of 2:1, 3049 Sq. Ft., 33 Deg. Latitude*
% of Max. Solar & Efficiency vs. Tilt

Based on Shade Factor of 2:1

Module Efficiency

% of Maximum Solar Production

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What’s the Optimum Tilt?

Depends on project goals:

- If **Cost per Watt** is main driver - use **higher** tilt
- If **Limited Space** is main driver - use **lower** tilt.

Remember:

- **Lower Tilt** _always_ increases overall production
- **Higher Tilt** _always_ increases module efficiency but lowers production
Elevated Solar: An Option to Increase Solar Production

Elevated Solar is used when:

- Solar area must be maxed out on the roof and space is limited
  And/Or
- Significant roof shading – caused by Rooftop Equipment and high parapet walls
Example - Ballasted/Low Mount

149 Modules
38.7 kWDC
Space was needed for:
• Access
• Shading
Example - Mid-Height Mount

190 Modules

47.5 kW DC

• No shade from Walls
• Modules removed over HVAC
Example - Elevated Mount

234 Modules
58.5 kWDC

- Maximum Roof Space Utilization
- Fire Access Clearance is under panels
- 3-4 foot height clearance over HVAC
## PV System Capacity Comparison

<table>
<thead>
<tr>
<th>Ballasted/Low Mount Array</th>
<th>Mid-Height Array</th>
<th>Elevated Array</th>
</tr>
</thead>
<tbody>
<tr>
<td>38.72 kWDC, 149 Modules</td>
<td>47.5 kWDC, 190 Modules, 29% more</td>
<td>58.5 kWDC, 234 Modules, 59% more</td>
</tr>
</tbody>
</table>

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What’s the Maximum Allowable Solar?

Maximum weight for Additions without doing full structural analysis:

10% of Building Weight

(In accordance with International Building Code Section 3404.21 and ASCE 7-10)

- More than 10% requires a full analysis of the building structure – expensive & may not pass

- Worth checking if majority of roof has solar.
Maximum Solar vs. Building Weight (Cont.)

**Step 1: Building Area:**
- Roof: 56x90 = **5040**.
- East & West Walls: 56x23x2 = **2576**
- North & South Walls: 90x23x2 = **4140**
- Total: **11,756 Sq. Ft.**

**Step 2. Building Weight**

Assume 13 Lbs./Sq. Ft.

11,756 x 13 = **152,828 Lbs.**

Note: conservative: does not include siding
Maximum Solar vs. Building Weight (Cont.)

Step 3. Maximum Solar Weight
(1/10) x 152,828 = 15,283 Lbs.

Step 4. Maximum Solar Panels
For Mounted: @4 Lbs./Sq.Ft
218 Modules
For Ballasted: @8 Lbs./Sq.Ft.
109 Modules

Conclusion:
Type of Mounting impacts solar limit for weight limited building.
Important Consideration: Cost impact of Roof Penetrations

A major soft cost is sealing roof mounting posts

- Mounted Racking systems may use 1 post for every 1 or 2 modules.
- Based on Sealing Cost of $100/post and 275 watts/module the cost of sealing is:
  18-36 cents per watt
- Sealing cost may exceed racking system cost!

Conclusion
- Reduce Number of Posts if possible
Cost Impact of Roof Penetrations

Cost Per Watt vs. Modules Per Post

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$-$ $0.05 $0.10 $0.15 $0.20 $0.25 $0.30 $0.35 $0.40

1 2 3 4 5 6 7 8 9 10 11 12
Proposal Layout Drawing

Benefits of a realistic proposal drawing:
• Great selling tool
• Helps the customer visualize what it looks like
• Reduces possible misunderstandings

What does the customer want to see?
• Appearance – what it looks like from the ground and on the roof. 3D views are most helpful
• Maintenance – shows access for servicing roof & equipment
• Safety – shows fire access clearances
Initial Evaluation Summary

This completes the initial evaluation session

We’ve discussed the following:

• Determining Solar Capacity based on Area
• Determining Solar Capacity based on Weight
• Tilt and Elevation considerations
• Racking considerations
• Basic layout of system

Now on to full evaluation
Full Evaluation - Capacity of Roof

First step - check out roof structure Consistent with the proposed array?

- **Sheathing** – Can it support solar directly?
- **Purlins** - Type, Strength, Positions match up with proposed racking mounts?
- **Girders** – Consider as an alternative mounting scheme
Roof Girder Structures

Concrete Slab

Steel Beam

Glulam Beam

Open Web Joist - Steel

Open Web Joist - Wood
Load Capacity of Girders - Ranking

• Concrete Slab - Excellent

• Steel Beam – Excellent

• Glulam – Excellent

• Open Web Joist – Steel
  Lower Point Load Capacity

• Open Web Joist – Wood
  Lowest Point Load Capacity
Will the Building Pass?

How do you increase your confidence that the building will qualify structurally?

• Preliminary review of plans or site inspection
  – Get Structural Engr. to preview roof plans
  – Or do quick look with Structural Engr.
  For go/ no go

• Backup mounting plan – anchoring to main girders – usually a safe bet

• Input from racking supplier(s) on their experience with similar structures
Full Evaluation & Preparation for Permitting

Once you’re ready to move forward:

• Choose a Structural Engineer to do analysis
• Get the Pertinent Building Drawings
• Finalize type of racking system
• Generate Layouts and Assembly Details
• Prepare documents for Permitting
Choosing a Structural Engineer

- **Structural Engineer** - or Civil Engineer with structural experience (Except Schools & Hospitals)
- **Consider using local sources** – They can help you with site inspection & obtaining drawings
- **Cost:** $1,000-$5,000 – depending on building size and complexity
  - Consider lower cost Preliminary Review
    - to qualify building
Typical Roof Framing Drawing
Building Drawings

What Drawings are Needed by Structural:

• Roof Framing Drawings - Most important
• Section Views (S1, S2, S3, etc.)
• Roofing & Insulation Details
  – Helps to determine the roof weight & sealing costs
• Wall Details
  – Shows Materials used – helpful for determining final building weight
Getting Roof Framing Drawings

Where are the Drawings?
• Owner may have a set
• City Building Department almost always has these
  – Available for viewing – usually cannot be copied without Structural Engineer of Record authorization – Must be formally requested through building department

If Roof Framing Drawings are not available?
• Site inspection will be required
  – Structural engineer can help
Important Dimensions of Girders

Glulam Beam

Open Web Joist

Wide Flange Beam
Glulam Roof – Required Dimensions

Photograph What you Can’t Measure & Scale Later

Required Dimensions

- Purlin Dimensions
- Column Dimensions
- Girder Dimensions
- Girder Overhang Dimension

Dimensions:
- Beam Splice: 2'-0" x 3'-7"
- Column: 16'-6" x 15'-10"
- Overall Dimensions: 20'-0" x 20'-0"

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Steel Frame Roof – Required Dimensions

Photograph What you Can’t Measure & Scale Later

Required Information

[Steel frame diagram with dimensions and labels]
Example - Building Checklist

Checklist

• Organizes data collection
• Substitutes for Drawings
• PV Racking and Mounting Details – also required
# Building Weight Worksheet

<table>
<thead>
<tr>
<th>Decking</th>
<th>PSF</th>
<th>Roofing</th>
<th>Roof Framing</th>
<th>Wall</th>
<th>Wall Framing</th>
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<td><strong>Roof Framing</strong></td>
<td><strong>Wall</strong></td>
<td><strong>Wall Framing</strong></td>
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<td>Plywood</td>
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<td>Bitumen</td>
<td>Main Beam WF</td>
<td>Stucco</td>
<td>Main Beam WF</td>
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<tr>
<td>3/8”</td>
<td>1.2</td>
<td>Tar &amp; gravel</td>
<td>Width</td>
<td>Stucco</td>
<td>Width</td>
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<tr>
<td>1/2”</td>
<td>1.7</td>
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<td>Height - Ave.</td>
<td></td>
<td>Height - Ave.</td>
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<td>Rigid - 4”</td>
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<td>12 ga. (.108”)</td>
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<td>Width</td>
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<tr>
<td>14 ga. (.073”)</td>
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<td>Width</td>
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What’s Needed for Permitting

Structural Analysis – and the following – which the structural engineer also needs for his analysis

• Load Positions for ballasted systems, or Post Mounting Positions for mounted systems
• Roof/Post Attachment Positions and Details
• Solar Array Dimensional Layout – including elevation views
• Racking System Engineering Details
Post Hole Mounting Pattern
Roof Post Mounting Details

1. Install End Post on 1/4" Drop-In Anchors as shown.
2. Torque Anchor Stud Bolts to 10-15 Ft-Lbs.
3. Seal Post to Roof
4. 2 Anchor Studs, 24 Locations

1. Install Center Post on Anchor Studs as shown.
2. Torque Anchor Stud Nuts to 35 Ft-Lbs.
3. Seal Post to Roof
4. 2 Anchor Studs, 24 Locations

DETAIL A
SCALE 1/50

DETAIL C
SCALE 1/25

DETAIL D
SCALE 1/25
Solar Assembly Drawing
Full Evaluation Summary

This completes discussion of the Full Evaluation covering the following:

• Reviewing & ranking roof types
• Obtaining the building documents
• Obtaining building site structural information
• Finding a structural engineer
• Preparing documentation for permitting

Now we discuss elevated racking & installation
CSS-24 Tiltable Rack

10'-0" 72-144 Range  End Post

C-Clamp (Outer)  Waffle Clamp (Inner)

1/4-5/16 Anchor or Lag Screw  2 ea.

Hilti Anchor 1/2" x 3-3/8" Long, 2 ea.

1/2 Lag Bolt, 4 ea.

Tilt Bar, 2 ea.

SureGrip Concrete Roof  Glulam Roof

ISA Corporation
3213 Whipple Road, Union City, CA 94587
Tel: 510-324-3755 Fax: 510-324-3701
Email: info@isa-corporation.com
Website: www.isa-corporation.com
WSS-24 Elevated Rack

ISA Corporation
3213 Whipple Road, Union City, CA 94587
Tel: 510-324-3755 Fax: 510-324-3701
Email: info@isa-corporation.com
Website: www.isa-corporation.com
FSS Flush Mount Rack

End Post  SureGrip  Concrete Roof  Glulam Roof

1/4-5/16 Anchor or Lag Screw 2 ea.

4 7/8"  6"

5"

5" 3"

ISA Corporation
3213 Whipple Road, Union City, CA 94587
Tel: 510-324-3755 Fax: 510-324-3701
Email: info@isa-corporation.com
Website: www.isa-corporation.com
CSS Layout
East-West Building Girders

South
CSS-90 Layout
North-South Building Girders
WSS Trellis Layout

10 foot Girder or Purlin Span
WSS Elevated Layout
10 Foot Girder/Purlin – East West
Methods of Attachment

Concrete

Wide Flange

End Post to Z Purlin

Glulam
SureGrip Claw Installation
Alternate Roof Post Mounting
Corrugated Roof Attachment

- Retainer Channel
- Truss Angles
- Spacer Block
CSS Long Span Assembly

WF38 Flatwasher (3)
WL38 Lockwasher (3)
N38 Nut (3)

HHCS38450 Hex Head Cap Screw (3)
B328 Bushing
B356 Bushing (2)
WF38 Flatwasher (3)

HHCS31125 Hex Head Cap Screw (3)
WF31 Flatwasher (3)
NB2 Nutbar, 2 Hole (3)
6 Places
End Post Connection With Tilt Bar

Operating Position

Service Position
Module Rail Mount
Completed Module Rail Assembly
CSS Tandem Mounted
Module End Clamp Attachment
Inner Clip Attachment
Suggested Grounding Method

Module to ISA Rail Grounding
Inner Clip

5/16-18 Hex Screw
304 SST
12-15 Ft-Lb. Torque

ISA Waffle Clip
Module Frame
ISA 3x2 Module Rail
ISA AN31 Angle Nut

Module to ISA Rail Grounding
Edge Clip

5/16-18 Hex Bolt
304 SST
12-15 Ft.-Lb. Torque

ISA C-Clip
Module Frame
ISA 3x2 Module Rail
ISA AN31 Angle Nut
W-Frame Assembly
Main Strut Assembly

Slide Nut Bar in Strut Slot & Secure to Bracket with 5/16 bolts 2 ea., 6 Places
Summary of Steps for Proposing & Installing CSS, WSS & FSS Racking

Step 1 – At Time of Proposal:
• Contractor Identifies building – address or drawing
• Contractor Indicates: kW DC, Module size & Tilt
• ISA provides: proposal drawing showing array on bldg.

Step 2 - When Project is started:
• ISA provides: building structural details, racking post locations, dimensional details of array for permitting
• Contractor or ISA provides structural analysis for permitting
• ISA provides racking once permit is granted.
CSS on Steel Beams with SureGrip
FSS on Open Steel Beams with SureGrip
WSS on Steel Beams with SureGrip
CSS on Glulams with Flanged Base
WSS on Concrete Roof with Flanged Base
CSS on Concrete Roof With Flange Base
FSS on Concrete With Flanged Base
WSS on Corrugated Steel with Toggle Clamps
Typical Installation