Connecting Industry to Mathematics Instruction
NSF ATE Award # 1954291

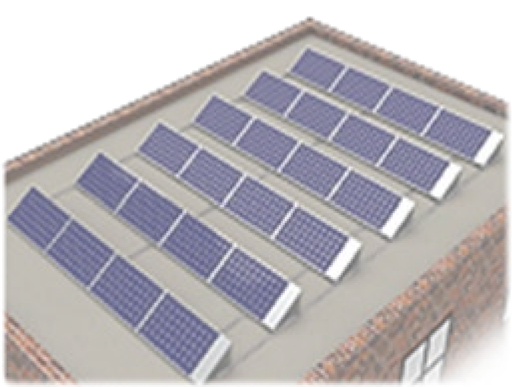
Solutions: Solar Energy

What is the maximum annual energy output for your school's roof?

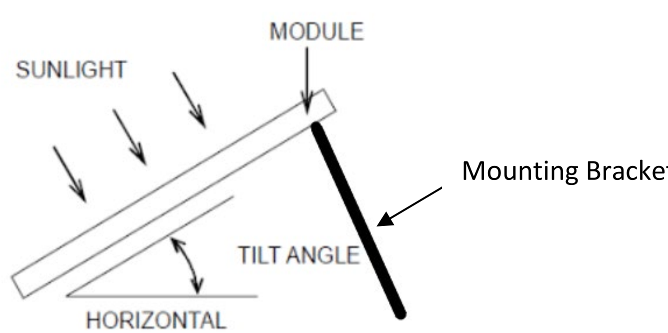
Your school is planning on adding solar panels (also called modules) to a flat roof. You are working to maximize the annual energy output of a rooftop solar **photovoltaic (PV) array**.

Photovoltaic (PV) – a process that converts light energy (photo) into the flow of electricity (voltaic).
PV panels – "solar panels" utilize thin wafers of crystalline silica to convert the sun's light energy into usable electricity.
Array – a group of multiple PV panels linked together to generate electricity. This electricity can either be used by the building and/or sold back to the electric grid for use by other customers.
Solar Radiation Angle – the angle between the suns rays and the horizontal plane as pictured in the figure in part 2 of the project.
Tilt Angle – The angle the solar panel makes with the roof.

- Each PV panel is approximately 3' H x 5' L x 0.5' D
- Panels can be placed next to one another to form long continuous rows.
- Maintain a distance of at least 4' between PV panels and roof edges.
- There's a simple rule of thumb for determining the best **tilt angle** for fixed-mount solar panels. The tilt angle should be equivalent to the latitude of the location.
- The **solar radiation angle** is 30° at Garner Magnet High School.



https://www.solarelectricsupply.com/resi



Task 1:

Goal: Determine the best Mounting Bracket Length and Angle with Solar Panel is best for Wake Tech.

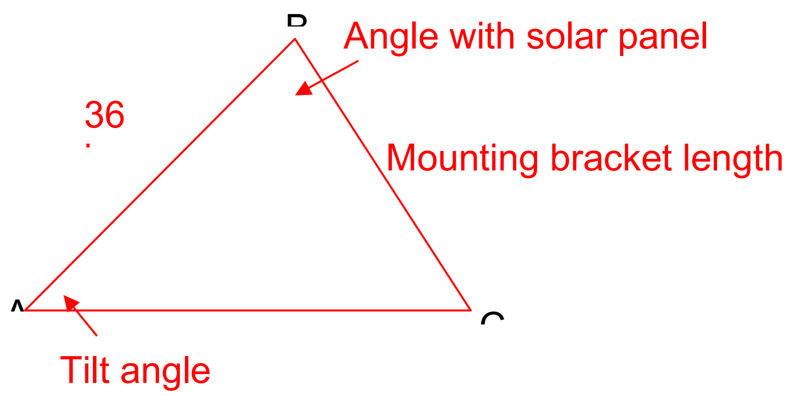
You have five options to choose from. These five options are outlined in the table below. There's a rule of thumb for determining the best **tilt angle** for fixed-mount solar panels. This means that the tilt angle should be equivalent to the latitude of the location.

1. What is the tilt angle (latitude) for Garner, NC? (Hint: a quick google search will help you with this one)

36º

2. For each of the following bracket lengths and angles, determine the corresponding "tilt angle". **Show all algebraic work for full credit.**

Mounting Bracket Length	Angle with Solar Panel
20"	105°
25"	85°
29"	85°
30"	70°
33"	55°



20" 105º

$$b^2 = 36^2 + 20^2 - 2 \cdot 36 \cdot 20cos(105)$$
$$b = 45.5in$$
$$\frac{sin(105)}{45.5} = \frac{sinA}{20}$$

$A = 25.1^o$ Corresponds to Miami

25" 85º

$$b^2 = 36^2 + 25^2 - 2 \cdot 36 \cdot 25cos(85)$$
$$b = 42in$$
$$\frac{sin(85)}{42} = \frac{sinA}{25}$$

$A = 36.4^o$ Corresponds to Raleigh

29" 85º

$$b^2 = 36^2 + 29^2 - 2 \cdot 36 \cdot 29cos(85)$$
$$b = 44.2in$$

$$\frac{sin(85)}{44.2} = \frac{sinA}{29}$$

$A = 40.8^o$ Corresponds to NYC

30" 70º

$$b^2 = 36^2 + 30^2 - 2 \cdot 36 \cdot 30cos(70)$$
$$b = 38.2in$$
$$\frac{sin(70)}{38.2} = \frac{sinA}{30}$$

$A = 47.6^o$ Corresponds to Seattle

33" 55º

$$b^2 = 36^2 + 33^2 - 2 \cdot 36 \cdot 33cos(55)$$
$$b = 32in$$
$$\frac{sin(55)}{32} = \frac{sinA}{33}$$

$A = 57.6^o$ Corresponds to Juneau

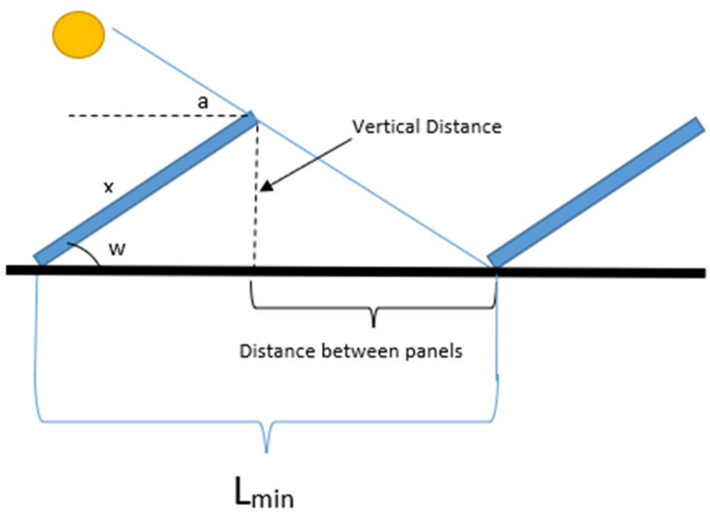
3. Based on your answers to #1 and #2, which bracket length and Angle with Solar Panel should be used for Garner, NC?

Bracket Selected: Length______25"________ Angle with Solar Panel_______85º_______
This length and angle pair correspond to Raleigh/Garner NC.

Task 2:
Goal: To determine the distance between panels.

Being able to fit more panels on a roof usually increases output, but not when panels start to shade one another. To eliminate your solar panels from casting a shadow on the panels in front of them, you need to determine the distance between each row.

L¬min is the distance from the front of one panel to the front of the next. The general dimensions of a Solar Panel is 3’ H x 5’ L x 0.5’ D. Figure 2 is the image of solar panels mounted on a flat roof. **Remember to show ALL algebraic work!**



$$L_{min} = x\left(\frac{\sin(w)}{\tan(a)} + \cos(w)\right)$$

x = solar panel length
w = tilt angle
a = solar radiation angle

1. Determine L¬min for the Solar Panels.

$$x = 3ft$$
$$\alpha = 30^o$$
$$\omega = 36.4^o$$
$$L_{min} = 3\left(\frac{sin36.4}{tan30} + cos36.4\right) = 5.5ft$$

2. What is the distance between the Panels?

$$cos(36.4) = \frac{distance\ under\ panel}{3ft}$$

distance under the panel = 2.4 ft

distance between panels = 5.5 - 2.4 = 3.1ft

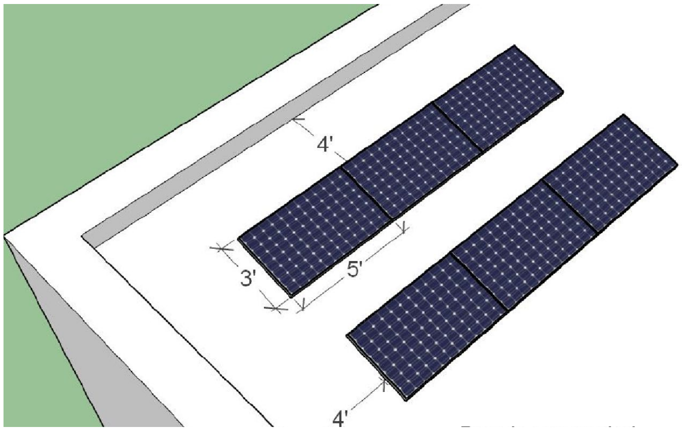
3. Why is it important to install the panels with the distance you found in #2 between them?

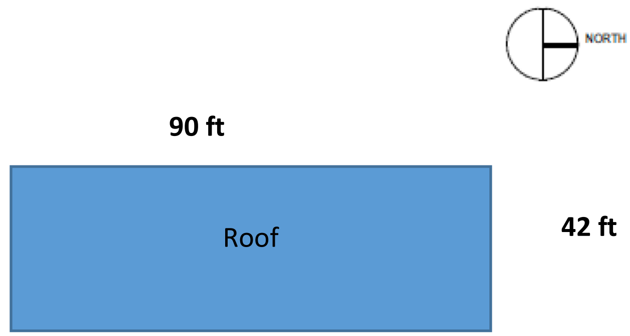
Answers will vary but need to include a discussion of shadowing other panels.

Task 3:

Goal: Determine the Maximum Energy Output for Garner Magnet High School.

Now that we know which Mounting Bracket to use and the spacing between the rows, we need to decide how many panels are needed and how they will be arranged. Remember that each PV panel is approximately 3’ H x 5’ L x 0.5’ D, they can be placed next to one another to form long continuous rows, and you must maintain a distance of at least 4’ between PV panels and roof edges. **Remember to show ALL algebraic work for full credit.**





1. Determine the number of panels required if you faced them:

    North: ____________

    East: ______________

    South: ____________

    West: _____________

North or South:

42 ft - 8 ft = 34ft (accounting for roof border)
34/5 = 6.8 at most 6 panels across

90 ft - 8 ft = 82ft (accounting for roof border)
82/5.5 = 14.9

14 * 5.5 = 77 ft, which leaves 5 feet extra space so we can add in one row extra because no shadow space is needed on the last row.

6 panels in each row, 15 rows 6*15 = **90 panels**

East or West:

90 ft - 8 ft = 82ft (accounting for roof border)
82/5 = 16.4 at most 16 panels across

42 ft - 8 ft = 34ft (accounting for roof border)
34/5.5 = 6.2

6*5.5 = 33 ft which only leaves 1 foot extra space, so no extra row can be added.

16 panels in each row, 6 row 16*6 = **96 panels**

Now that we know how many solar panels can fit on the roof, we can calculate the maximum annual energy output for Garner's roof.

2. Using the table for energy output, determine the energy produced for each configuration:

Annual Energy Output for PV Panels in Garner, NC

Panel Direction	**Annual Energy Output (kWh Per Panel)**	**Total Annual Energy Output (kWh)**
North	312	28080
South	592	53280
East	474	45504
West	471	45216

3. What is the maximum annual energy output for your school's roof? 53,280 kWh (south facing)