**POW 3 – PART 1: Research and Calculations**

**You will complete all your work in this document, preferably with a partner (1 other person). Use non-bold text to answer the questions. Insert diagrams and excel graphs where indicated. Have fun learning about solar panels and applying what you know about trig/mathematics!**

**PROBLEM:** What is the optimal combination of azimuth and tilt to maximize solar gain (kWh per year) from a 5kW photovoltaic system in La Plata County, Colorado?

**RESEARCH (10 pts)**

Do some research on photovoltaic systems using the NREL site and other sites as indicated. List your sources. Define/explain the following terms: You may directly quote the NREL site, but please indicate this in your definitions, i.e. “According to NREL, the tilt is “…..”

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| What are photovoltaic cells (i.e. solar panel cells)? Briefly describe how they work. | 1. According to the NASA website, “when light energy strikes the solar **cell**, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current -- that is, electricity.” |
| SOURCE FOR ABOVE INFO: | science.nasa.gov/science-news/science-at-nasa/2002/solar**cells**/ |
| What is NREL? | The NREL is the National Renewable Energy Laboratory. It is the only federal laboratory for renewable energy and energy efficiency research and development and is located in Golden Colorado. |
| What is the PVWatts Calcuator by NREL? What does it do? | The PVWatts Calculator calculates the kWh per year for solar panels on a specific mount with a specific system loss, tilt and Azimuth. |
| SOURCE FOR NREL INFO: | http://pvwatts.nrel.gov/pvwatts.php |
| **Define/explain the different SYSTEM INFO settings for the PVWatts Calculator (1-5 sentences for each, use more if needed and include diagrams if needed):** | |
| System Size | The system size is the power rating in direct current of the modules in ideal conditions. |
| Module Type | The module types describe the photovoltaic modules. There are three different types of modules, Standard, Premium, and Thin film. A Standard module has an approximate efficiency rate of 15%, a Premium one is 19%, and the Thin film is 10%. |
| Array Type | The Array type is how the photovoltaic module is mounted. There are two different mounts, they are fixed or tracking. Those then fall into more categories. Fixed arrays can be open rack or roof mount. Open racks are optimal for arrays mounted on the ground, while roof mounted systems are designed for roofs. |
| System Losses | The system loss is the percent of energy that the system losses due to such factors as shading and wiring. |
| System Loss Categories (List) | The system loss categories include soiling, shading, snow, mismatch, wiring, connections, light-induced degradation, nameplate rating, age, and availability. |
| **Tilt \* MOST IMPORTANT!** | Tilt is the angle from flat ground to the Photovoltaic modules. The tilt is found by taking the tangent of the pitch of the roof. |
| **Azimuth – What is it? How’s it relate to true North? \*MOST IMPORTANT!** | The azimuth is the angle clockwise of true North describing which direction something is facing. For example, an object with azimuth of 180º is facing South. |
| DC to AC Size Ratio | The DC to AC size ratio is the ratio of the panel’s direct current rated size to the inverter’s alternating current rated size.  It compares the power of the solar array to the inverter capacity. |
| Inverter Efficiency | The inverter efficiency is the rate at which the direct current converts to alternating current. The average value is 96%. |

**SYSTEM PARAMETERS TO INPUT:**

**DC System Size (kW):** 5

**Module Type:** Standard

**Array Type:** Fixed Roof Mount

**System Losses (%):** 18

\*We will vary Tilt and Azimuth below and look at how this affects kWh per year output from the PV system by graphing the results we find.\*

**PLAYING WITH TILT (10 pts)**

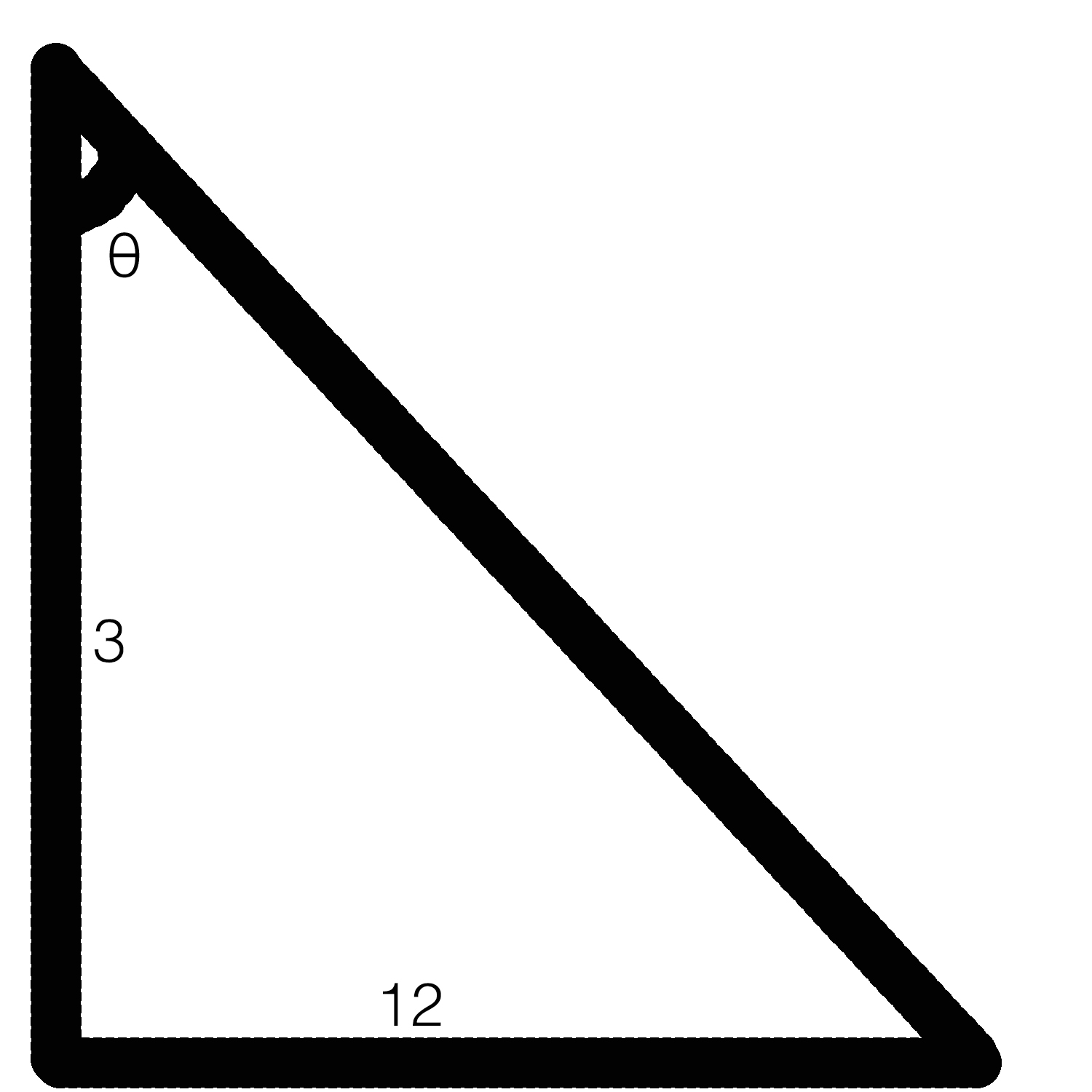
**Step 1: Choose an azimuth to test: 45o, 90o, 180o, 225o, 270o, 315o**

**Which azimuth did you choose: 90º**

**Step 2: Vary the tilt of the solar panels according to the chart below and record the power output per year in the table below.**

**YOU MUST CALCULATE THE TILT USING TRIG. Explain your steps to determine the tilt given the pitch below, INCLUDE A DIAGRAM.**

To find the tilt by using the pitch of a roof, I first chose a pitch, and then I drew a triangle I labeled it as shown. I then took the inverse tangent of 3/12,. I then solved the equation got an answer of 14.0º for theta in the equation .



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| --- | --- | --- |
| **Roof pitch as rise/run** | **Tilt (degrees)** | **kWh per year output for a given azimuth** |
| 3/12 | 14.0 | 7,291 |
| 4/12 | 18.4 | 7,318 |
| 5/12 | 22.6 | 7,343 |
| 6/12 | 26.6 | 7,361 |
| 7/12 | 30.3 | 7,372 |
| 8/12 | 33.7 | 7,386 |
| 9/12 | 36.9 | 7,399 |
| 10/12 | 39.8 | 7,407 |
| 11/12 | 42.5 | 7,412 |
| 12/12 | 45 | 7,416 |

**Step 3: Graph the kWh per year output (y-axis) versus Tilt (x-axis) using Excel. Label your axes and scales. Use a line graph to plot. Insert graph below.**

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**Step 4: Answer this question. Based on this graph, what is the optimal tilt (max kWh per year) for this azimuth?**

The optimal tilt for an azimuth of 90º is 45º.

**PLAYING WITH AZIMUTH (10 pts)**

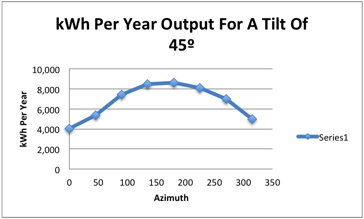
**Step 1: Choose a tilt to test from the table above.**

**Tilt Kept Constant at:** 45º

**Step 2: Vary the tilt of the solar panels according to the chart below and record the power output per year in the table below.**

|  |  |
| --- | --- |
| **Azimuth** | **kWh per year output for a given azimuth** |
| 0 | 4,035 |
| 45 | 5,378 |
| 90 | 7, 416 |
| 135 | 8,448 |
| 180 | 8,607 |
| 225 | 8,086 |
| 270 | 6,988 |
| 315 | 4,985 |

**Step 3: Graph the kWh per year output (y-axis) versus Azimuth (x-axis) using Excel. Label your axes and scales. Use a line graph to plot. Insert graph below.**



**Step 4: Answer this question. Based on this graph, what is the optimal azimuth (max kWh per year) for this tilt?**

**The optimal azimuth for a tilt of 45º is 180º.**

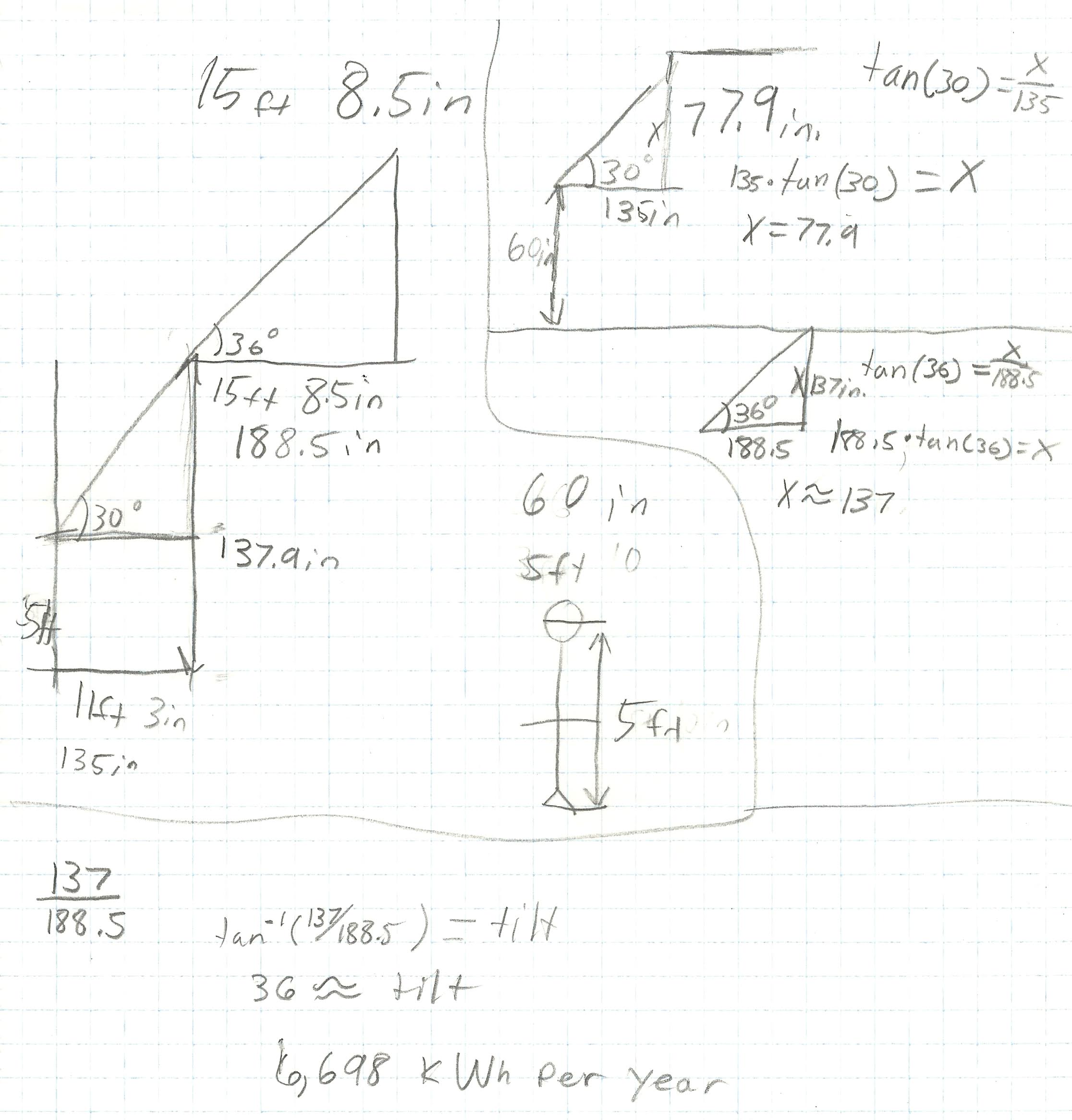
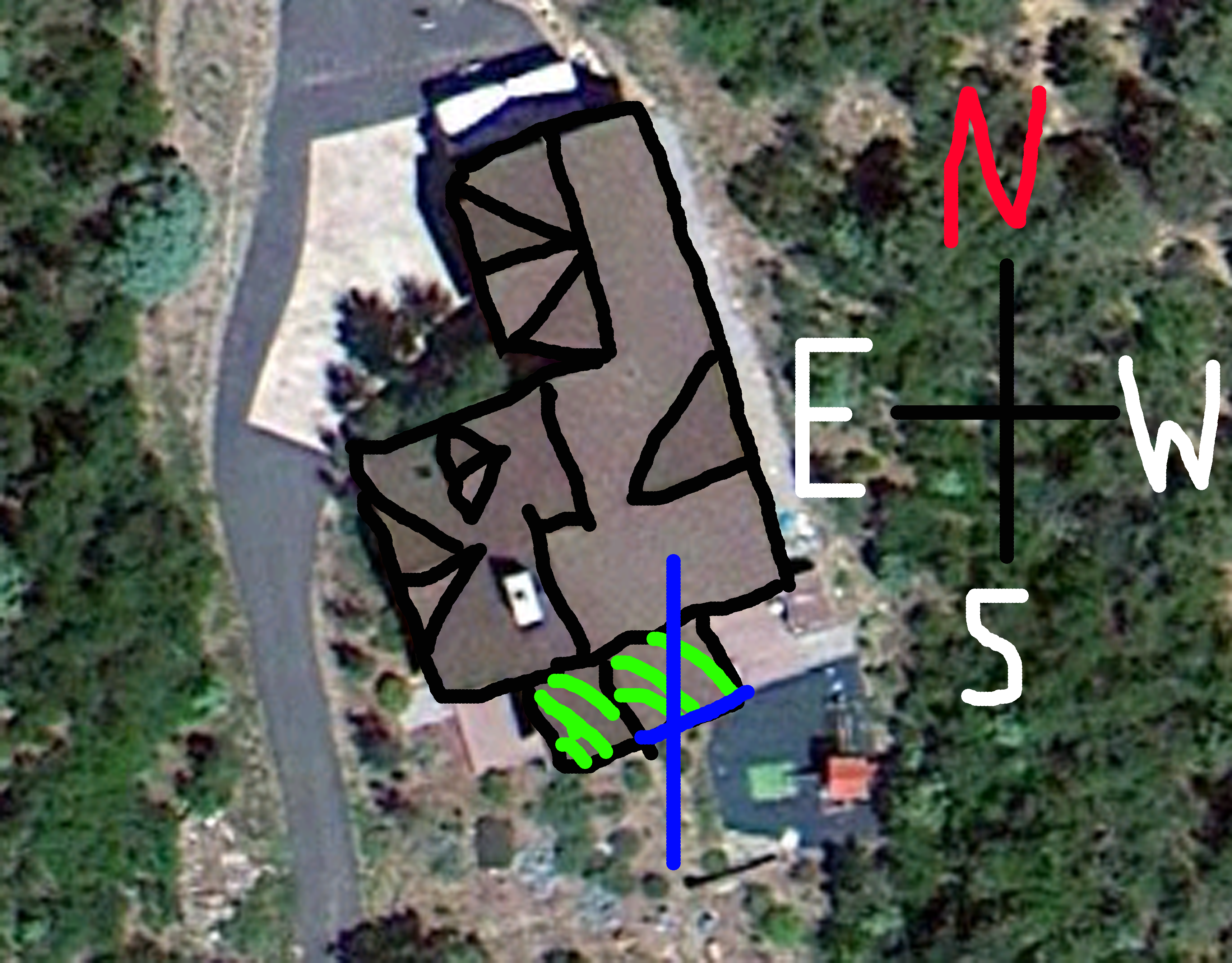
**CONCLUSIONS: Based on the above calculations, what do you think the optimal combination of azimuth and tilt is for optimizing kWh per year output from a 5kW PV system in La Plata County? How can you test this?**

**The optimal azimuth would be 180º and the optimal tilt would be 45º. One could test this by imputing different values for the azimuth and tilt into the calculator, while keeping track of the kWh per year.**

**CHALLENGE EXTENSION- CHOOSE ONE:**

1. **Measure the pitch of two roof lines on your house or a house you can access. And determine the azimuth of these two roof lines. Then use the calculator and the parameters above to calculate the kWh per year output for each roof line. Which roof would you put the 5kW system on?**

As shown by the image, I decided to use the two rooflines colored in green. I drew a compass on the image to help me find the azimuth. I then drew a straight line intersecting the roof and another line that followed the edge of the roof. After that, I used my protractor to find the angle clockwise of true North that the roof faced. I then calculated the pitch of the roof. Next, I used the pitch of the roof to determine the tilt of said rooflines.

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