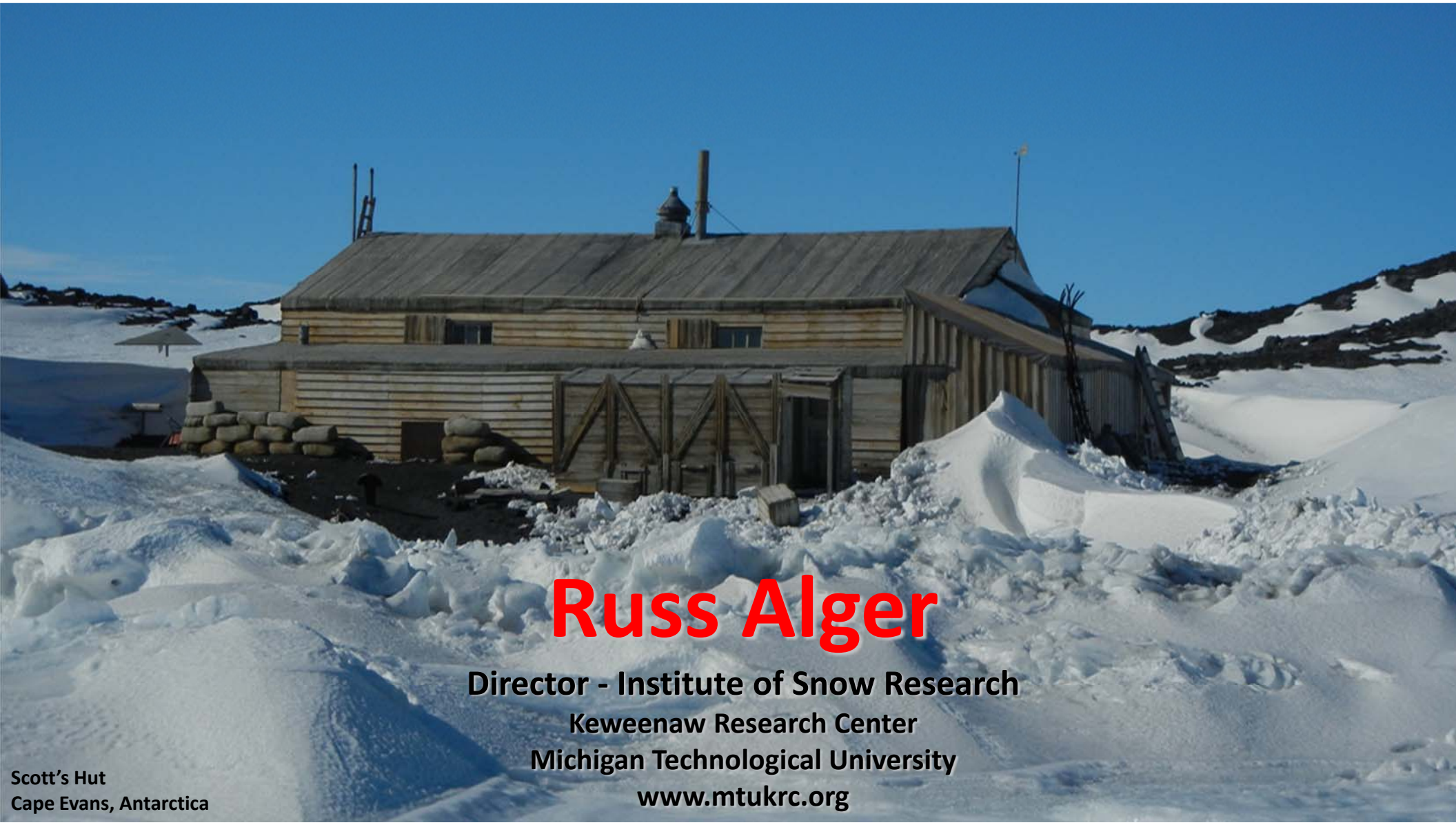


Russ Alger

Director - Institute of Snow Research

Keweenaw Research Center

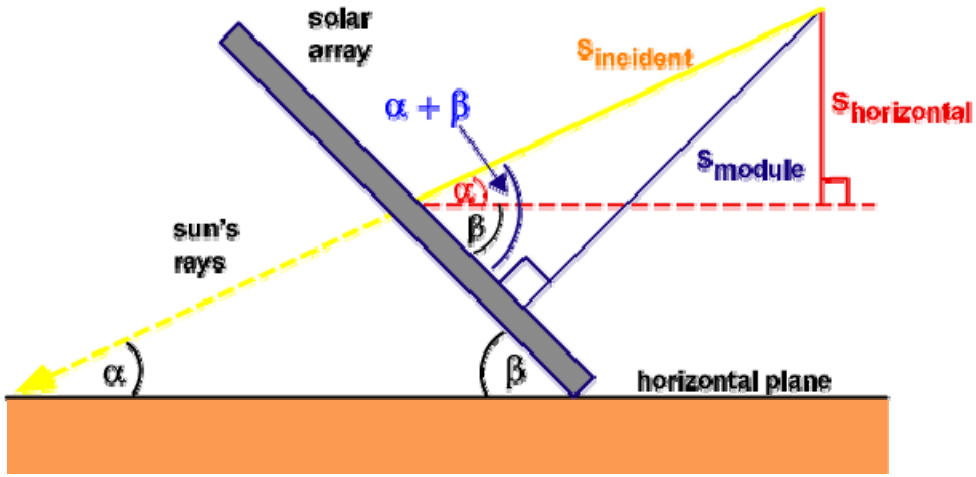
Michigan Technological University

www.mtukrc.org

Scott's Hut
Cape Evans, Antarctica

AK1

Solar Radiation on a Tilted Surface



$$S_{horizontal} = S_{incident} \sin\alpha$$

$$S_{module} = S_{incident} \sin(\alpha + \beta)$$

$$\alpha = 90 - \phi + \delta$$

$$\delta = 23.45^{\circ} \sin\left[\frac{360}{365}(284 + d)\right]$$

α is the elevation angle;
β is the tilt angle of the module measured from the horizontal;
ϕ is the latitude;
δ is the declination angle;
d is the day number;

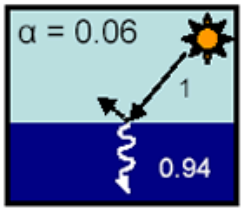
$$S_{module} = \frac{S_{horizontal} \sin(\alpha+\beta)}{\sin\alpha}$$

Source: pveducation.org

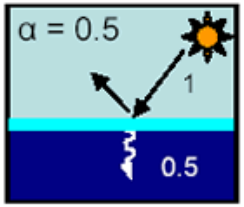
Rule of Thumb β = (Latitude * 0.89) + 24

Advantages of High Module Tilt: Albedo

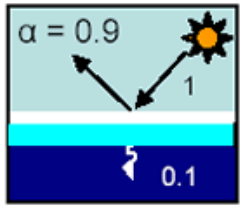
I. Open ocean



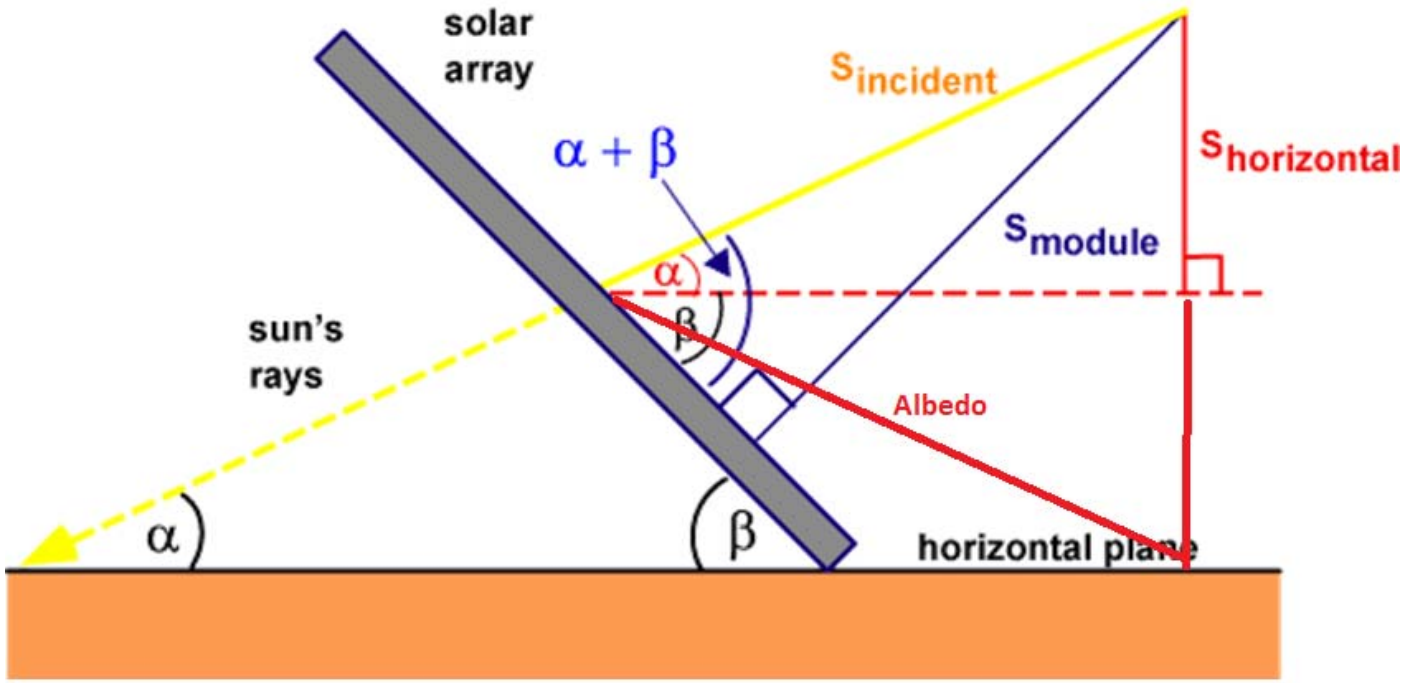
II. Bare ice



III. Ice with snow

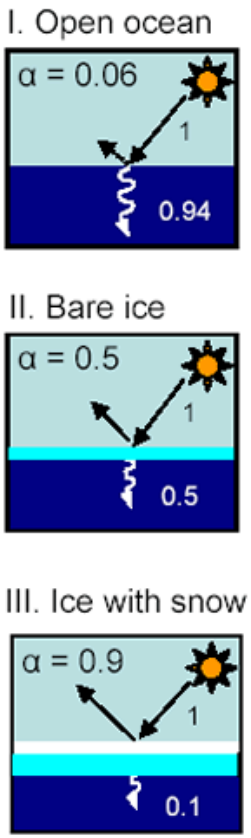


AK3



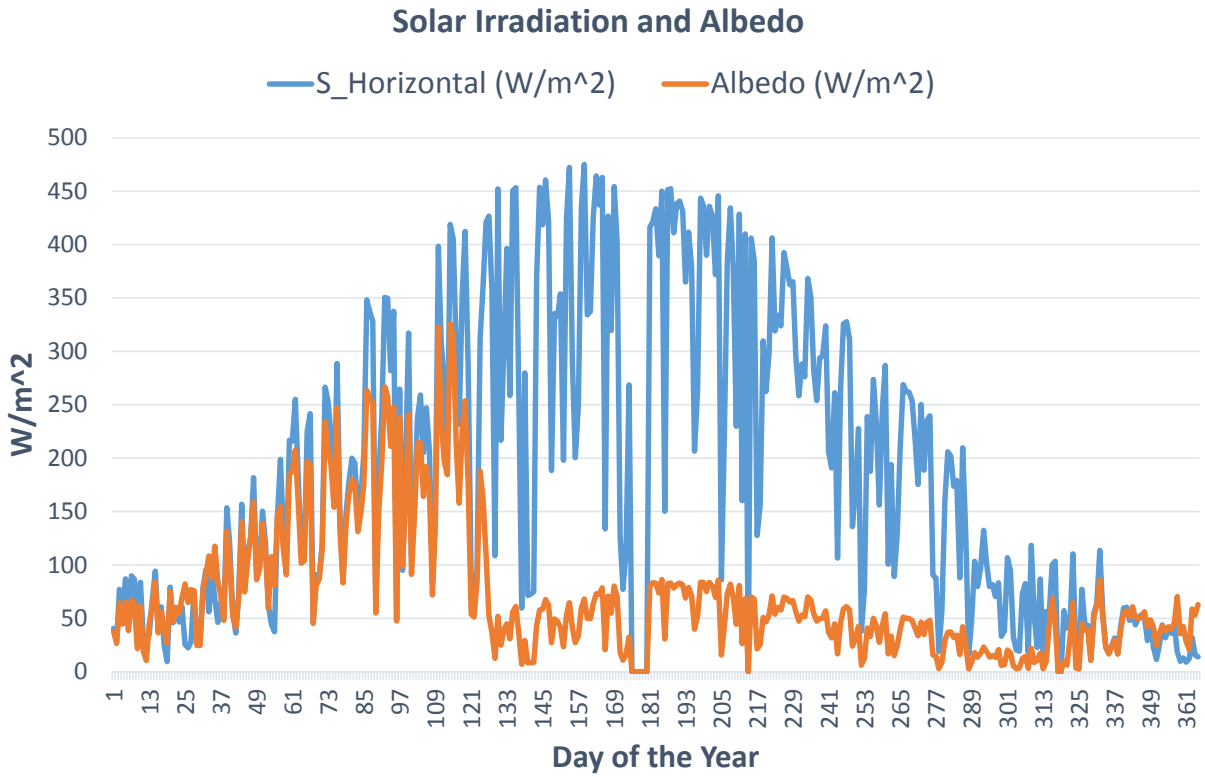
Source: nsidc.org

Advantages of High Module Tilt: Albedo



AK3

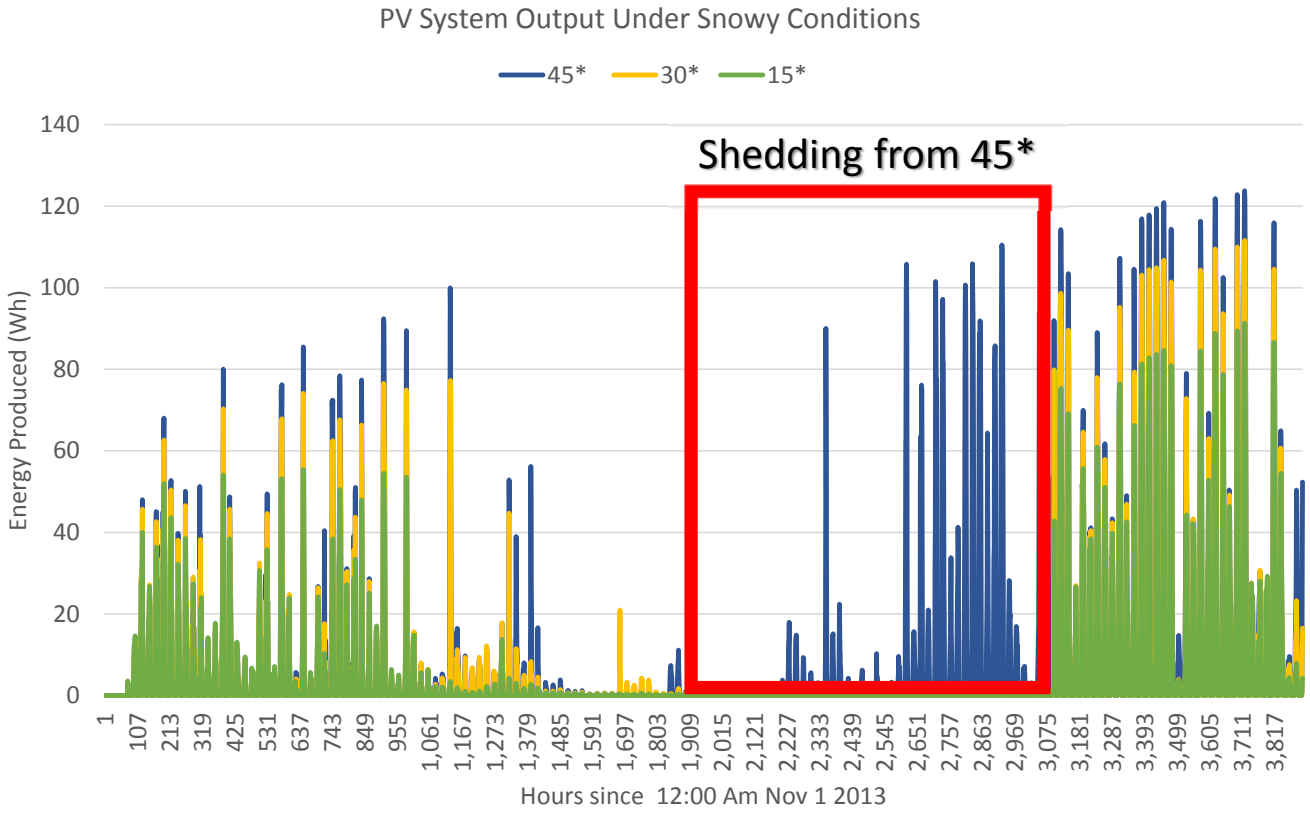
Source: nsidc.org

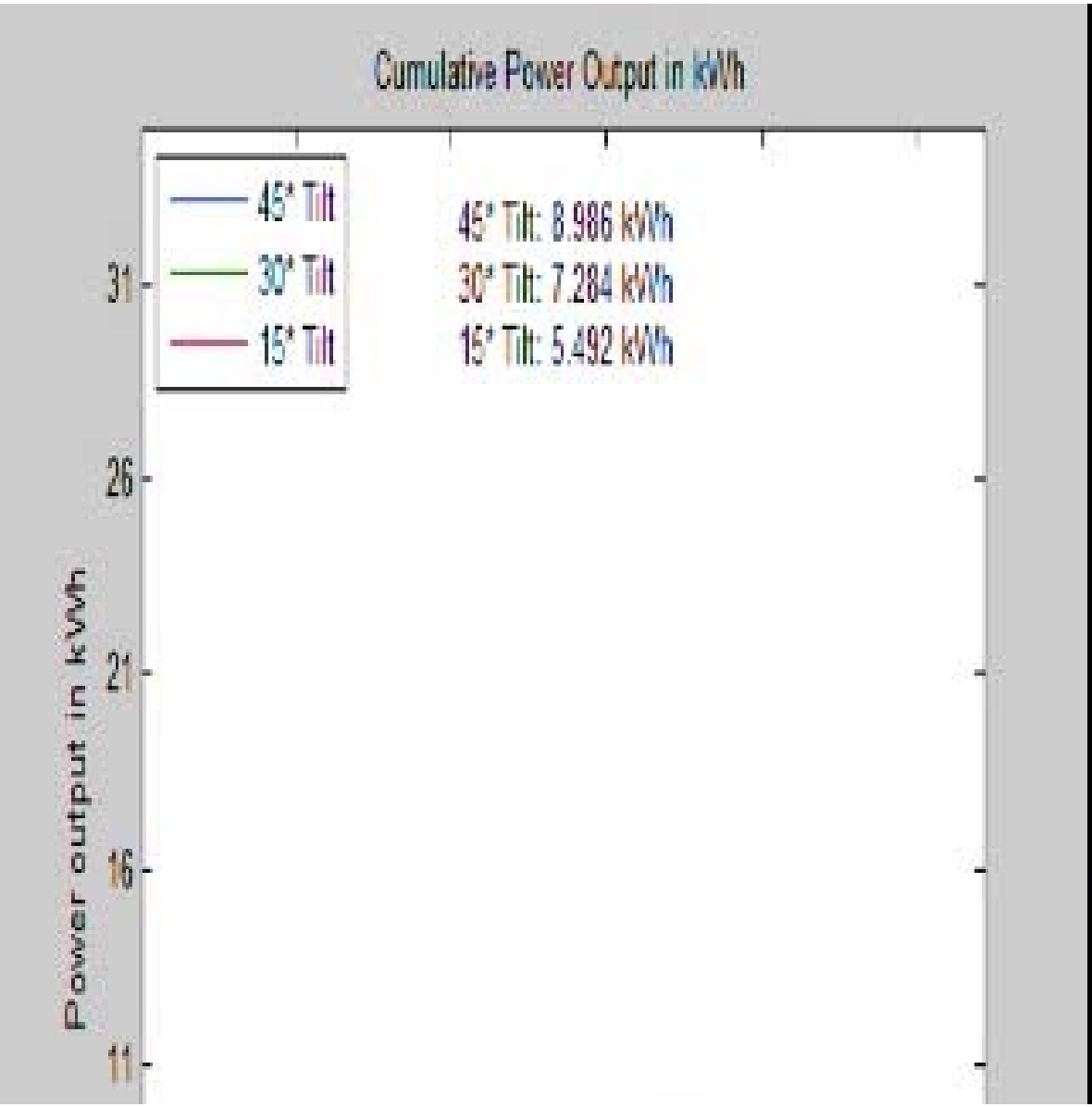


Source: MTU KRC

AK4

Advantages of High Module Tilt: Snow Shedding




Cumulative Power Output in kWh
45° Tilt
30° Tilt
15° Tilt
45° Tilt: 8.986 kWh
30° Tilt: 7.284 kWh
15° Tilt: 5.492 kWh
31
26
21
16
11
Power output in kWh

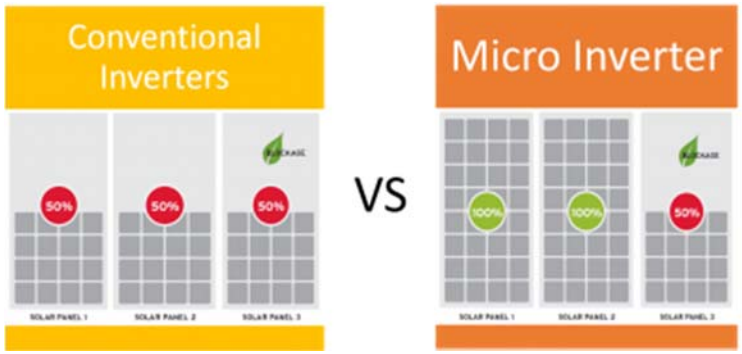
Micro Inverters

- **Smaller**
- **Built into each individual panel**
- **Convert right there into AC**
- **Each output combined and fed to home**

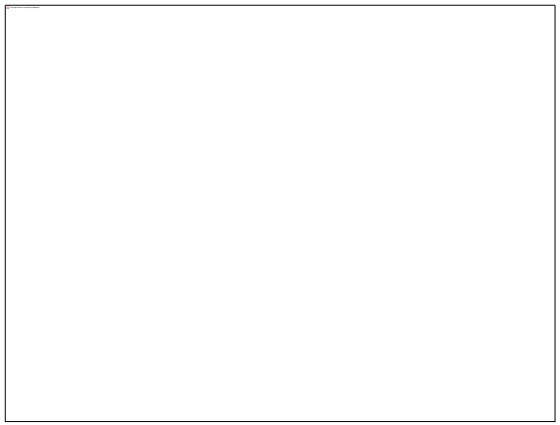
String Inverters

- **‘String’ at end of row of panels**
- **Panels connected in ‘series’**
- **Converts combined output to AC**

String Inverters vs Micro Inverters



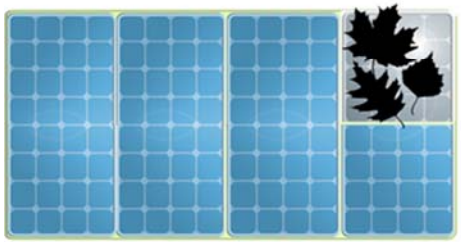
Source: SolarEnergy.com



Micro-Inverter systems vs.
Single String Inverter system.

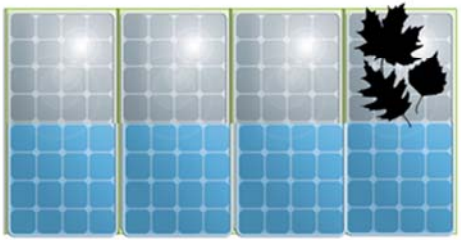
Because string inverters are installed in series strings they are subject to the Christmas Light Effect where an obstruction or failure on one module will effect the rest of the array.

Micro-inverter Solution



Micro-inverters if one panel gets shaded all other panels work to each of there maximum possible power output!

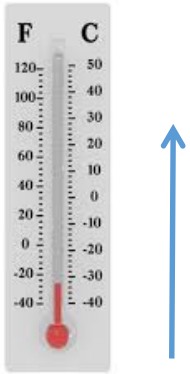
Single String Inverter



Shade one panel in a string with central inverter in a solar array all panels will reduce to the lowest common denominator of power output.

Source: SolarEase.com

Snow and Frost Melting



Energy to raise the temperature of ice 1° F is 0.51 BTU/lb.

So let's say we have 1/16" of ice covering a 60" by 30" panel at 20° F and we want to raise the temperature to just below 32° F.

This would be about 0.065 ft^3 of ice or approximately 3.66 lb. In simple terms, it would take 22.4 BTU to raise the layer 12° F.

Once the ice is brought to near the melting point, it takes a larger input of energy to move from solid to liquid (latent heat of fusion). This amount of energy is about 144 BTU/lb or about 527 BTU for the above example. This makes a total of about 550 BTU or 161 W-hr to melt the layer.

Snow and Frost Melting

This example is quite simplistic since a number of assumptions have been made including convection, solar load, energy to warm panels, etc.

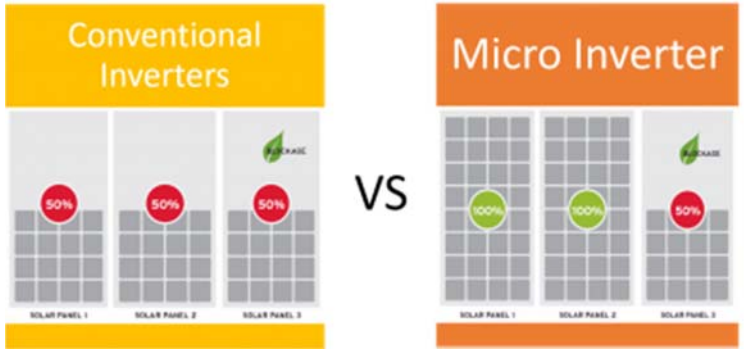
A 1/16” layer of snow or frost would take less energy to melt and the layer may slide before it is totally melted.

Sun would help, wind may slow the process, dark panels help, tilt helps, …….

Conclusions

We are working on several methods to keep panels clear of snow and ice.

Micro-Inverters can be used to help control these processes in an efficient manner.



Tilt angle and panel color can help considerably.

Taking advantage of reflected solar can make a big difference in energy production in snow covered areas.

Questions?