Lecture 15, 2001

Solar PV Panels -- Characteristics.

From MSME Thesis of Craig Connors,
"Feasibility Study of Solar Photovoltaic Energy Application in the Pacific Northwest"
UW, 2000.

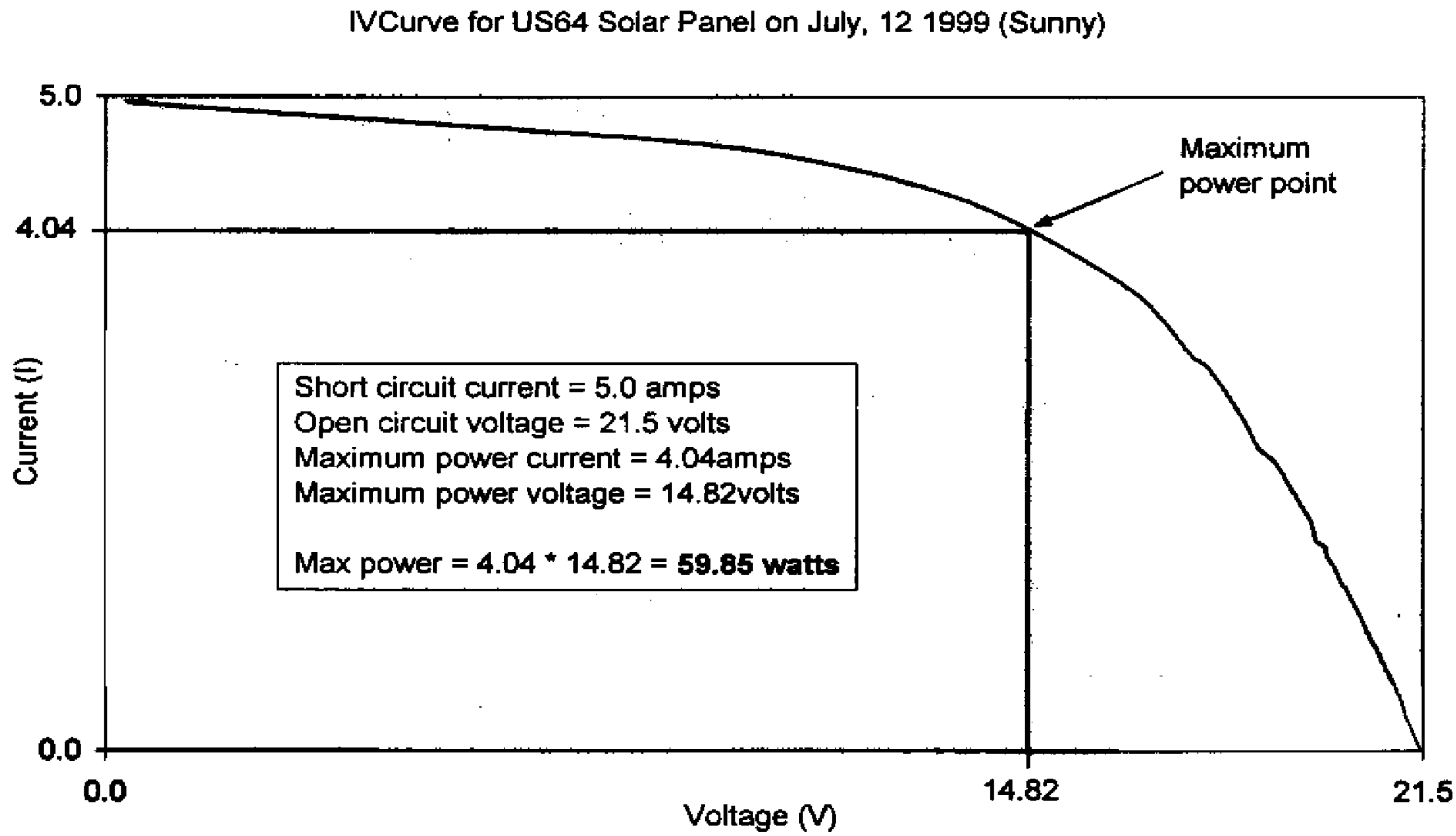


Figure 4: Typical IV curve of panel under normal operating conditions.

Manufacturer's rating = 64 watts

Site = UW

Table 1: List of factors contributing to efficiency loss in typical silicon solar cell.

Efficiency Factor	Percentage of energy loss (based on semiconductor material silicon)
▪ Portion of cell area obscured by current collecting grid.	4%
▪ Some of the photons are reflected and not absorbed.	3%
▪ Photons absorbed with energy less than the band gap of the silicon are dissipated as heat.	19%
▪ Photons absorbed resulting in an electron-hole pair but have energy beyond the band gap that is dissipated as heat.	29%
▪ Energy used to create the electron-hole pairs is greater than the energy associated with the open circuit voltage resulting in efficiency loss.	19%
▪ Electron excited into the conduction band recombines with another host atom.	4.5%
▪ Fill factor (FF<1) assuming FF = 0.78 for real solar cell.	4.7%

Note[7]*:* Data taken from *Photovoltaic Materials* by Richard Bube, p8-9, 1998.

The term fill factor (FF), which is used in Table 1, is a number used to describe the squareness of a curve. The higher the FF the squarer the curve. The FF, which has no units and is always less than one, is defined as the maximum power divided by the product of the open circuit voltage and short circuit current.

$$FF = P_{max}/(V_{oc} * I_{sc})$$

It is almost always desirable to have a high FF. Figure 6 shows IV curves for two PV cells, one with a FF of 0.75 and the other with a FF of 0.45.

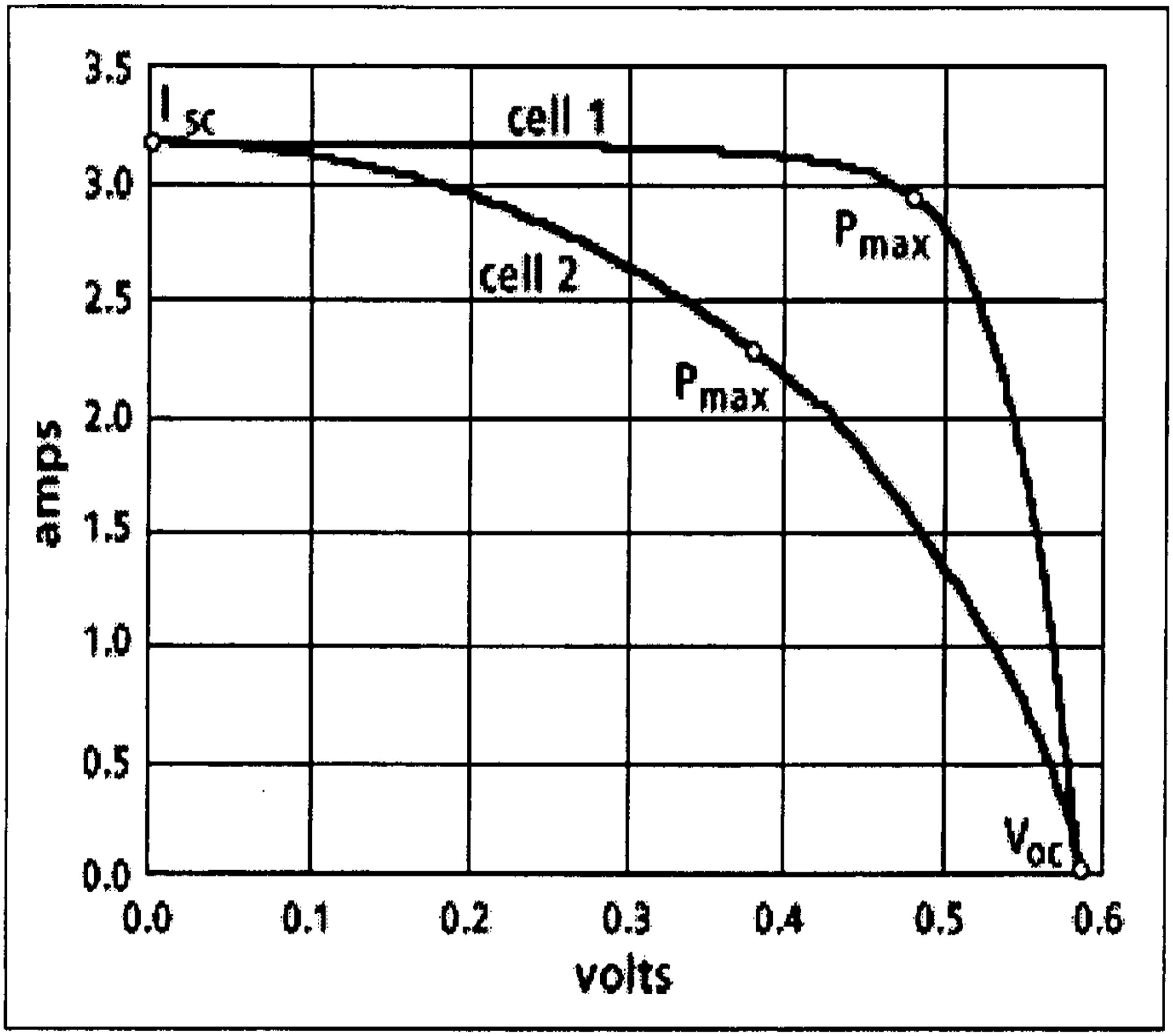


Figure 6: IV Curve of two PV cells with different fill factors[8]

Types of Solar PV Cells

- Single crystal (c-Si) – one grain > 10 cm characterizes the whole cell.
- Multi crystal (mc-Si) – number of grains present in cell range in size from 1 mm to 10 cm.
- Poly crystal (p-Si) – many grains present ranging in size from 1 μm to 1 mm.
- Micro crystal (μc-Si) – x-ray diffraction can identify single crystal grains, but size of grains is less than 1 μm.
- Amorphous (a-Si) – no single crystal structure identifiable by x-ray diffraction.

Typical Behavior:

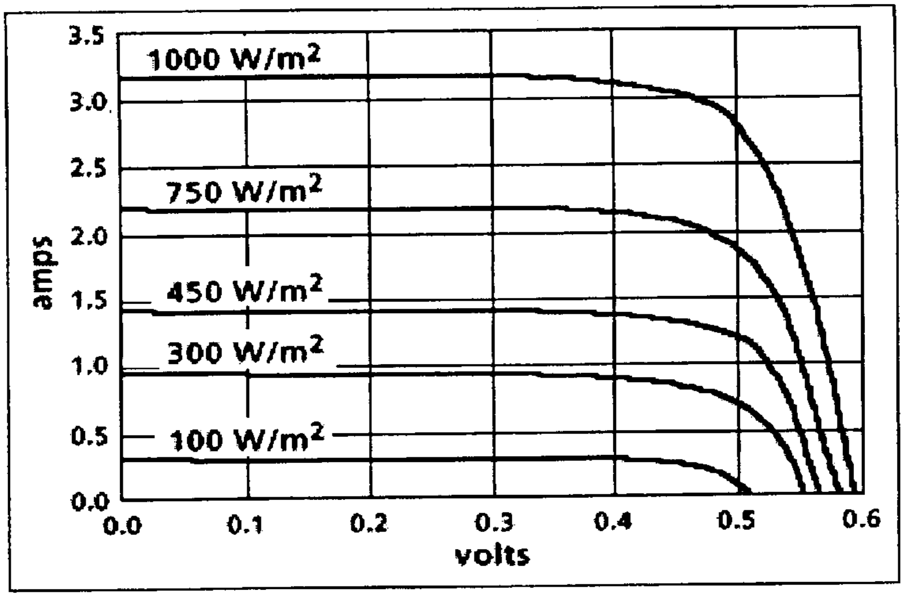


Figure 48: Relationship between incoming radiation and I_{sc}[78].

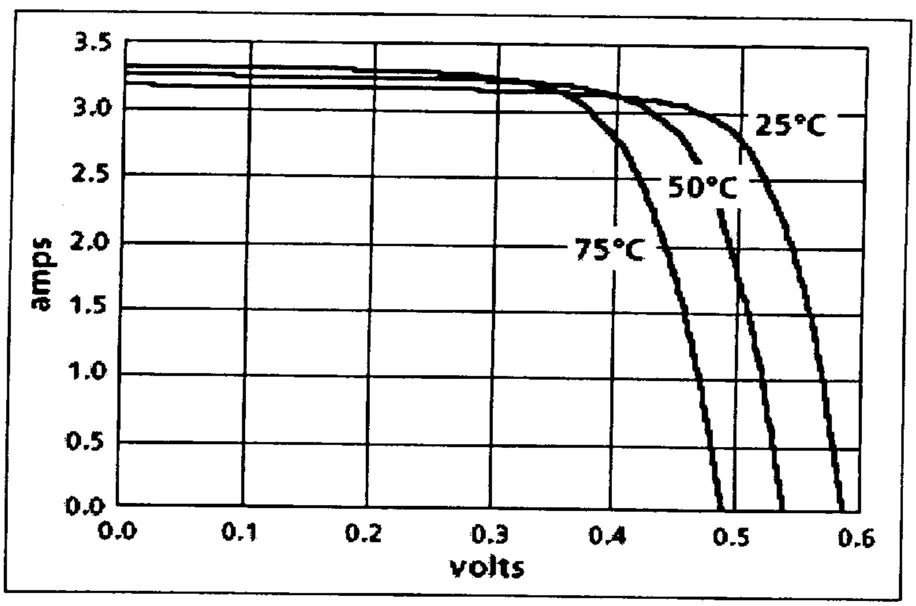
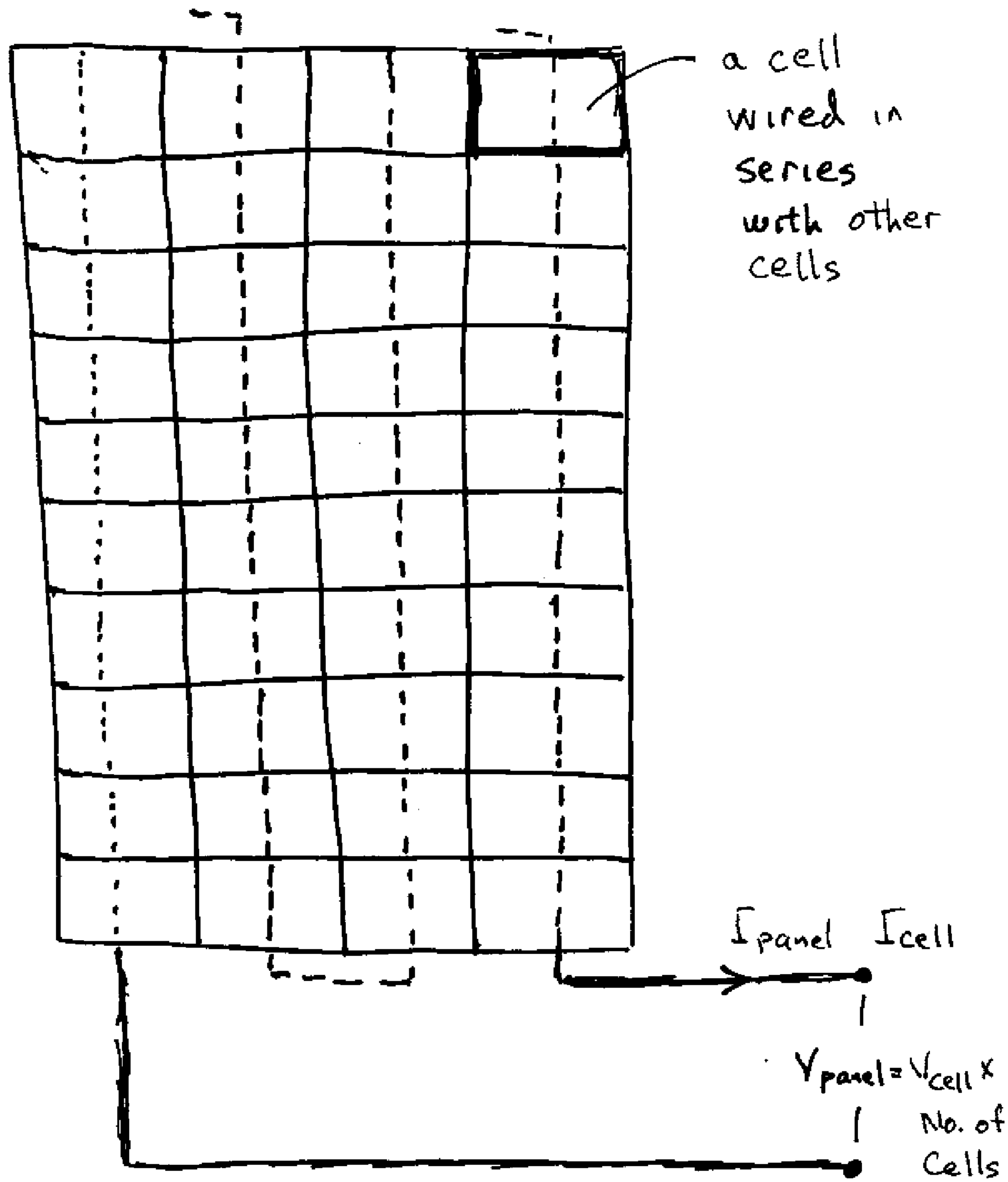


Figure 28: IV curves showing temperature variation for typical PV cell[54].

PV cells and panels rated at sunlight of 1000 W/m^2 and cell/panel temperature = 25 °C.
Rule of thumb: 0.4% power loss for every degree C above 25 °C.

Arrangement of Cells in Pane



2.1.1 PV MODULES

Cost for photovoltaic modules is usually given in dollars per watt of peak rated output, $/$W_p$, and this price depends on many factors including conversion efficiency, panel type, and quantity of purchase. The price for terrestrial solar panels can be as high as $12/$W_p$. Specialized modules, which usually have lower power ratings, can have a cost greater than $12/$W_p$. However, average price for panels ranges from $3/$W_p$ to $6/$W_p$. The low end of the range for module cost is based mainly on bulk purchases; otherwise modules usually cost $4 to $5/$W_p$ for residential users unless they are purchased through an agreement with a utility. Modules currently account for about half the cost of PV systems.

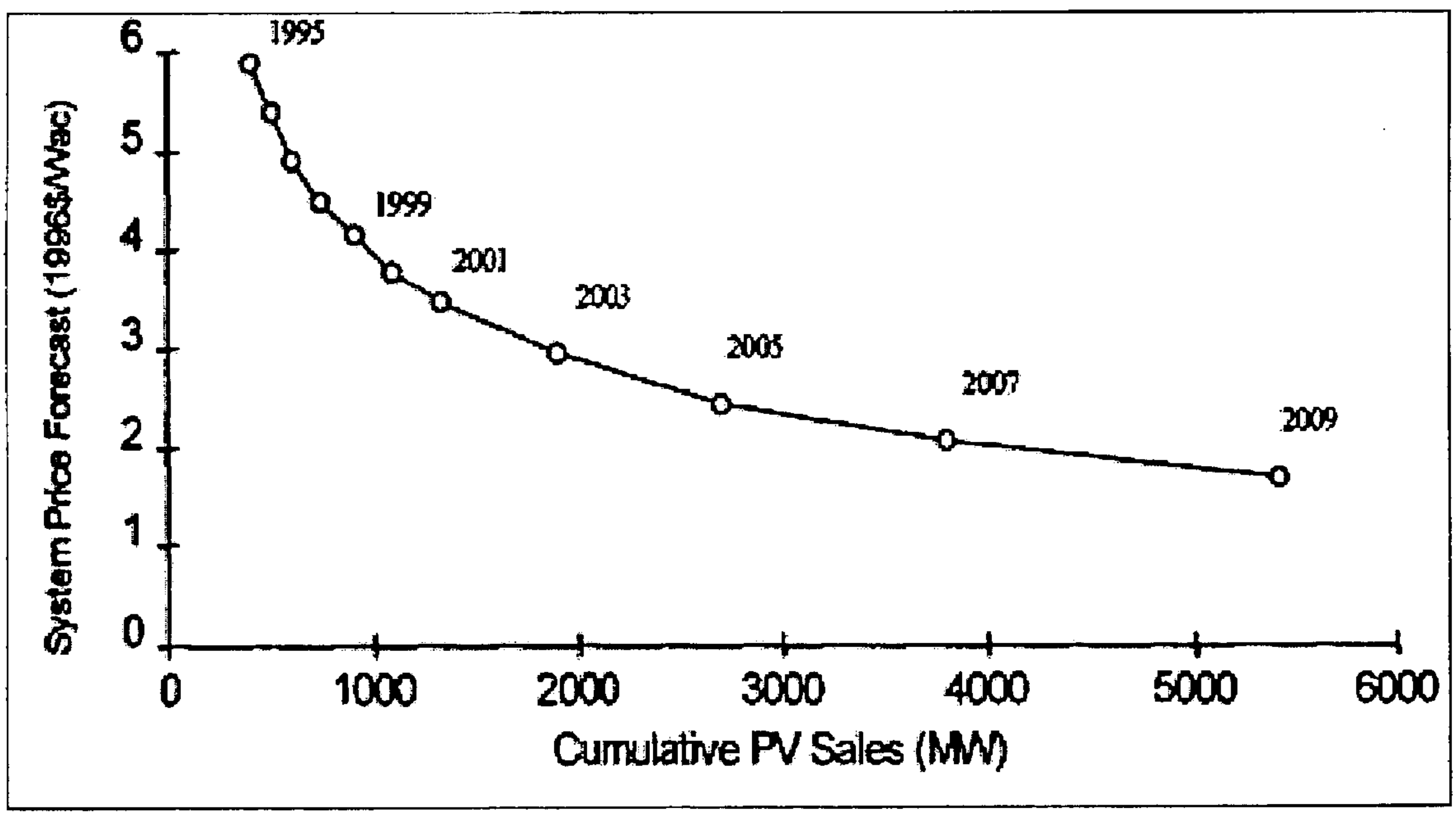


Figure 20: Forecast of PV system price based on cumulative world capacity.

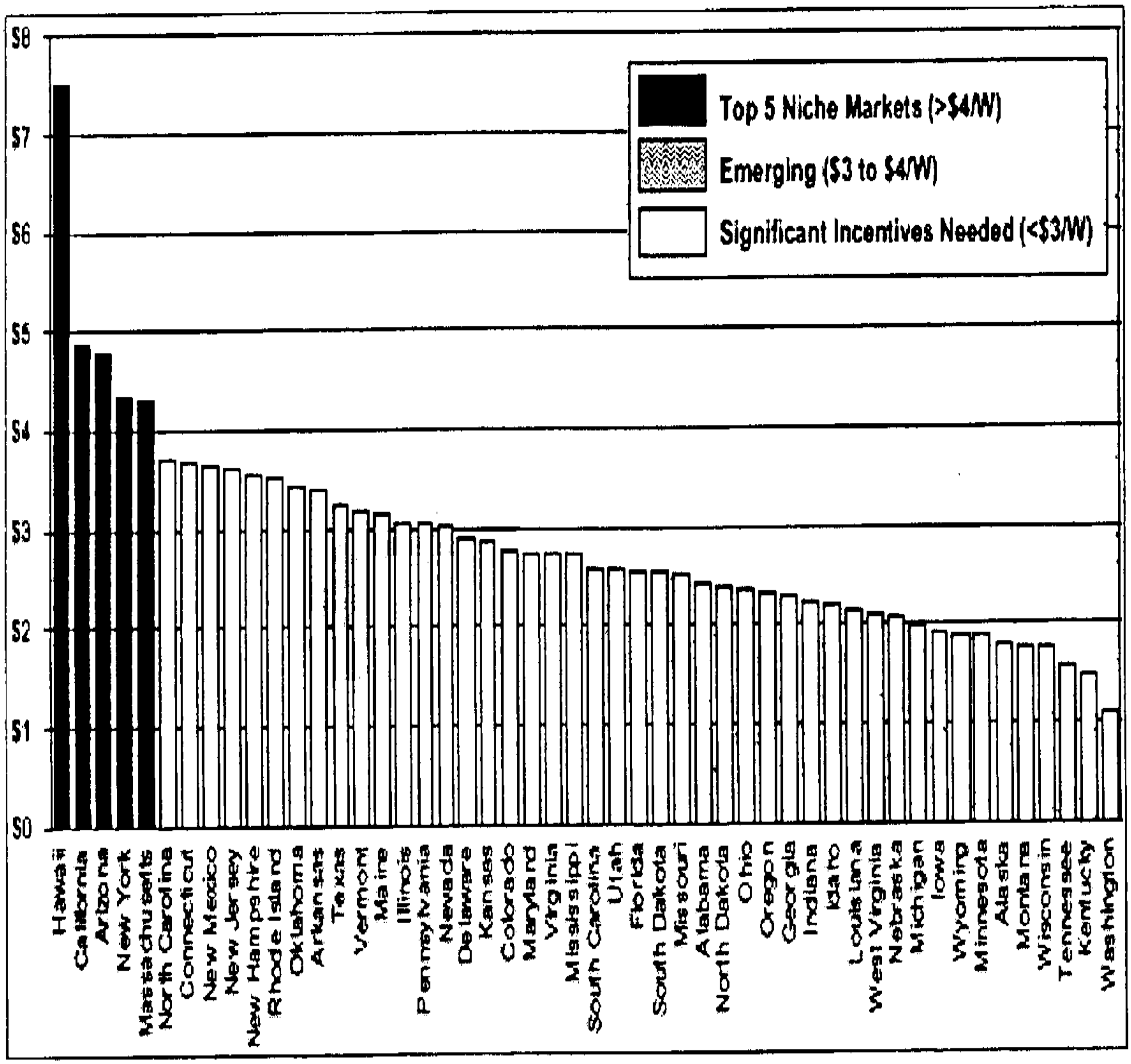


Figure 19: States ranked by PV system breakeven price ($\$/W_p$)

Integration of PV panel material into the building

1) PV panels as roofing shingles and channel

2) PV panels as siding including PV panels for combined heat and power
note about 90% of solar energy absorbed by panel is converted to thermal energy (heat)

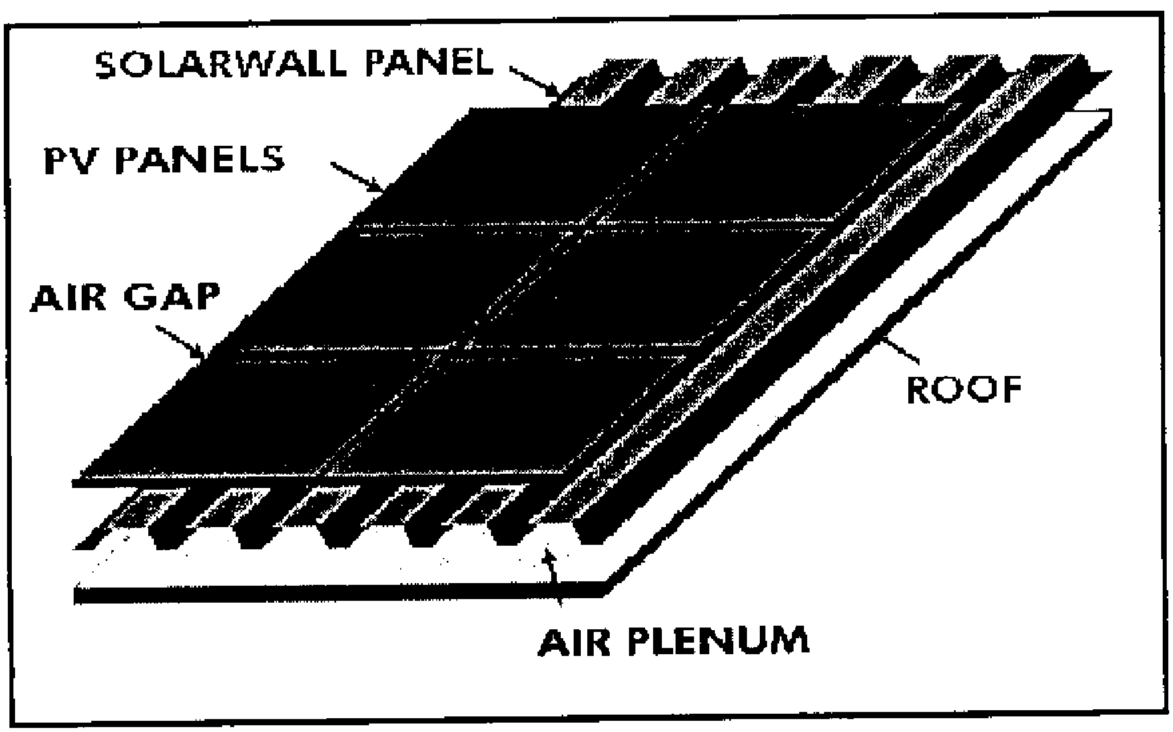


Figure 12: PV cogeneration system. (http://www.solarwall.com/)

Appicat n Vancouver, WA ste

Des gn Ana ys s

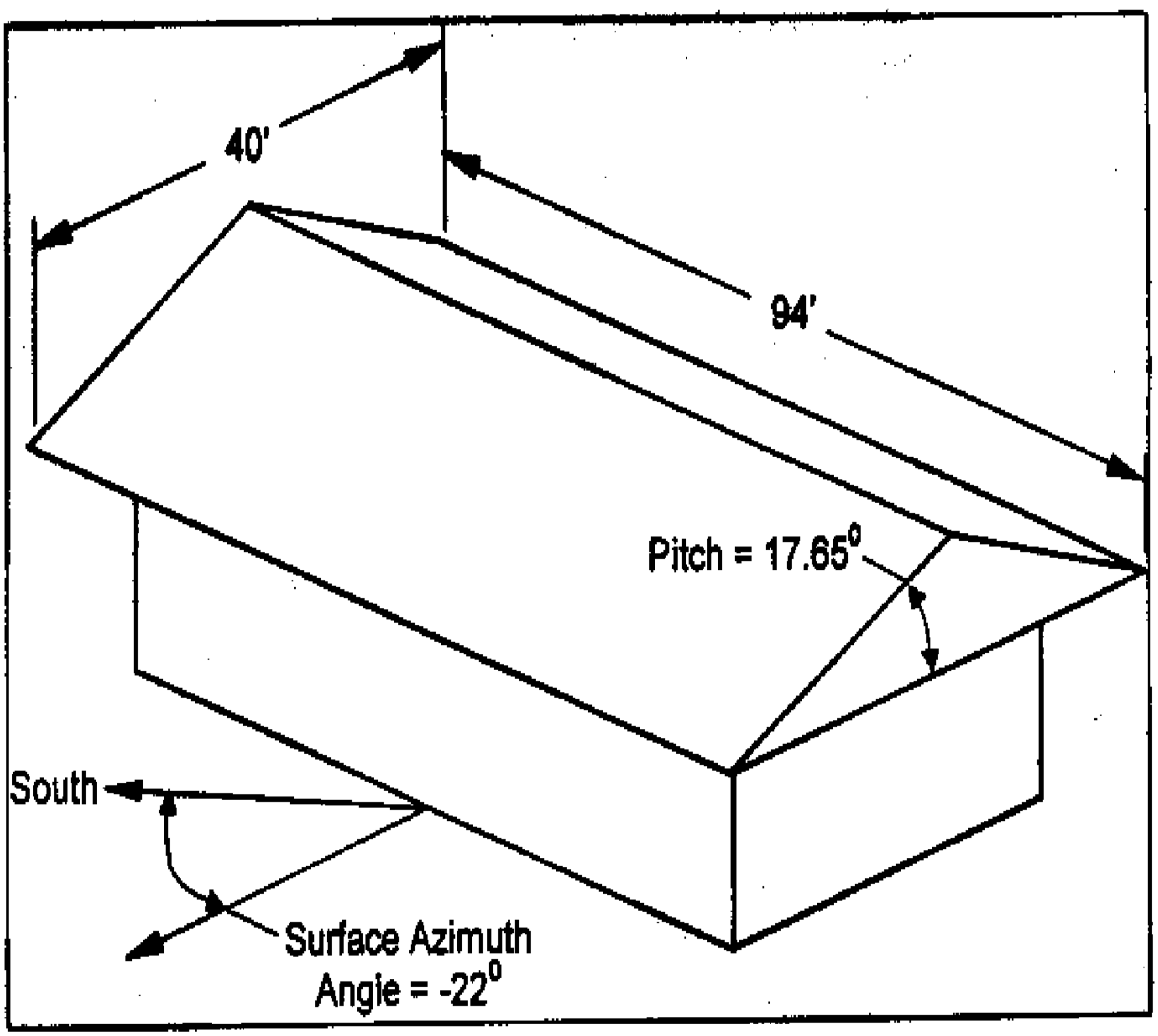


Figure 30: Dimensions and orientation of maintenance building at FOVA.

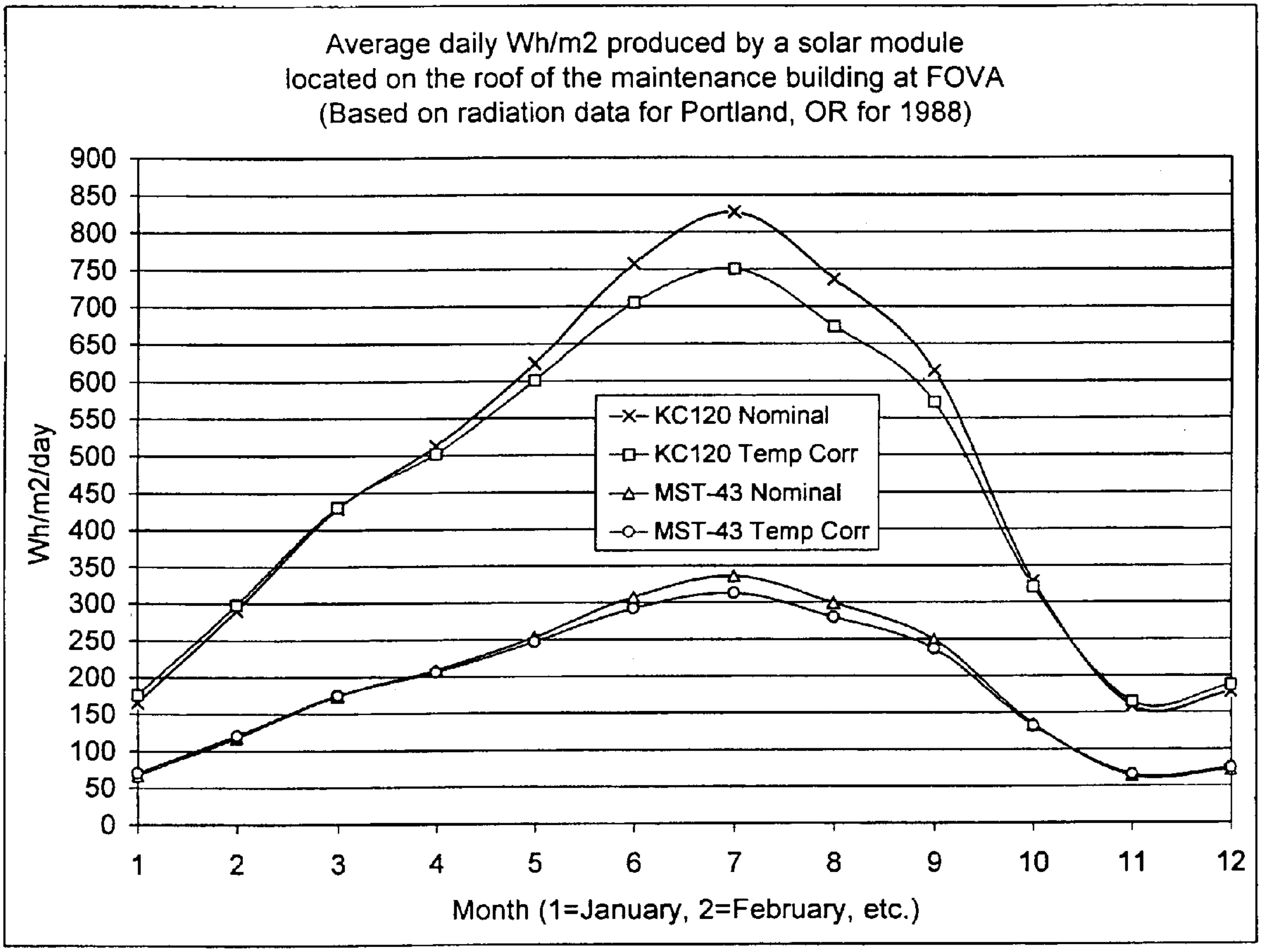


Figure 36: Output of PV modules on maintenance building (Wh/m^2/day).

Net-metering system

In addition to the PV modules, the system will require a roof mount, inverters, power disconnect, over-current protection, module interconnects and other wiring components, and other accessories. The system components other than the PV panels are referred to as the Balance of System (BOS).

Table 12: Specifications of the PV modules used in analysis for FOVA.

Characteristic	KC120	MST-43MV
Maximum Power (P_{max})	120 watts	43 watts
Voltage at P_{max}	16.9 volts	72 volts
Current at P_{max}	7.1 amps	0.6 amps
Open-circuit voltage (V_{oc})	21.5 volts	98 volts
Short-circuit current (I_{sc})	7.45 amps	0.8 amps
Maximum system voltage	600 volts	600 volts
Length	1.425 m	1.229 m
Width	0.652 m	0.687 m
Panel Area	0.929 m^2	0.844m^2
Efficiency (total-area)	12.9%	5.1%
Weight	11.9 kg	14.5 kg
Warranty	25 years	20 years

Table 15: Comparison of PV system based on MST-43 and KC120.

	MST-43	KC120
Surface Area of Modules(m^2)	175	175
Number of Modules	213	188
System Rating (kW)	9.2	22.6
Minimum Output (kWh/day)	11.6	28.7
Maximum Output (kWh/day)	54.7	131.3
Average Output (kWh/day)	32.2	78.4
Total Output per Year (kWh)	11,769	28,627

Table 17: Emissions avoided during lifetime of FOVA PV system.

	MST-43	KC120
Pollution Free Lifetime (years)	27	26
CO2 Emissions Avoided (lbs.)	435,915	1,031,186
NOx Emissions Avoided (lbs.)	108	260
SO2 Emissions Avoided (lbs.)	405	396

Table 18: Cost comparison for PV system using different panel types.

	MST-43	KC120
Module Cost ($/$W_p$)	3.50	4.00
BOS Components Cost ($/$W_p$)	2.75	3.00
System Cost ($/$W_p$)	6.25	7.00
Total System Cost ($1000)	57.5	158.2
Lifetime* production of system (kWh)	349,835	858,821
Direct cost of electricity (Cents/kWh)	16.4	18.4

*Lifetime of system assumed to be 30 years.

Application: Seattle, WA

system =
panel
+
controller
+
batteries
+
inverter
+
wiring
+
circuit
breaker
+
lightning
arrester

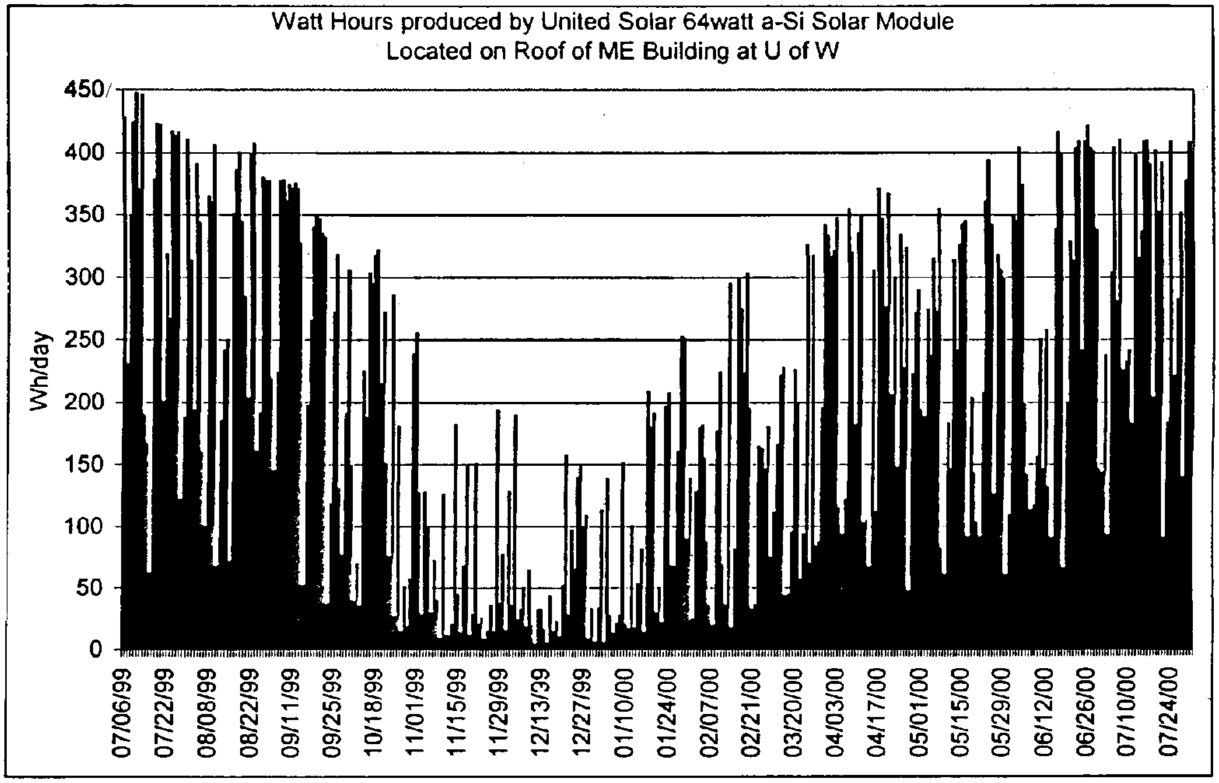


Figure 49: Daily watt-hours produced by US64 solar panel from 7/99 to 7/00.

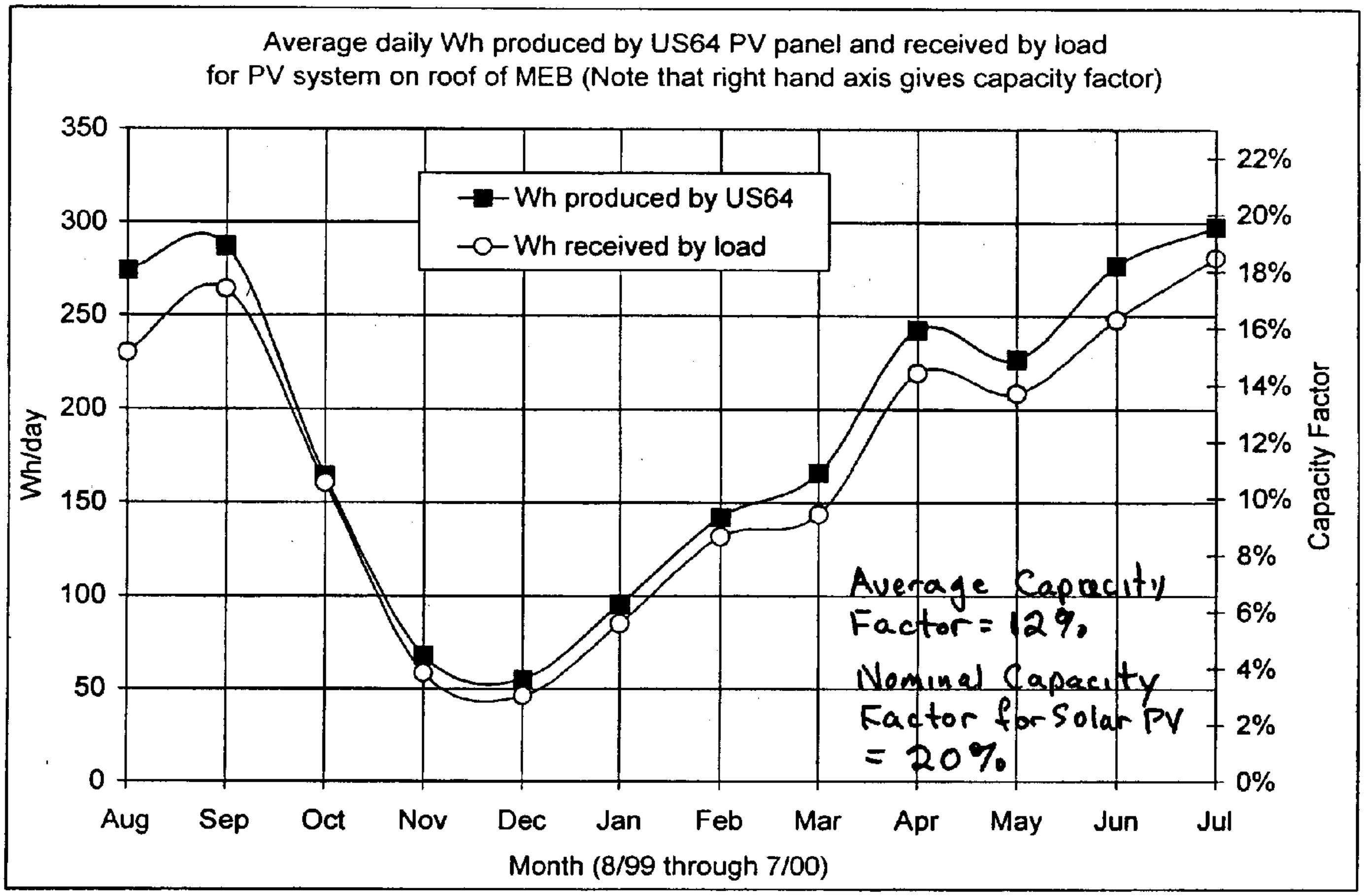


Figure 50: Comparison of production and consumption for PV system.