EE 495/695
Stand-Alone PV System:

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1. Water Pumping

- Normally, not battery back-up is required in water pumping.
- Parameters needed for sizing the pump motor and the PV array:
  - Daily water needs
  - Vertical pumping distance
  - Pumping rate, given the number of hours per day available for pumping.
- Pump sizing
- PV array sizing

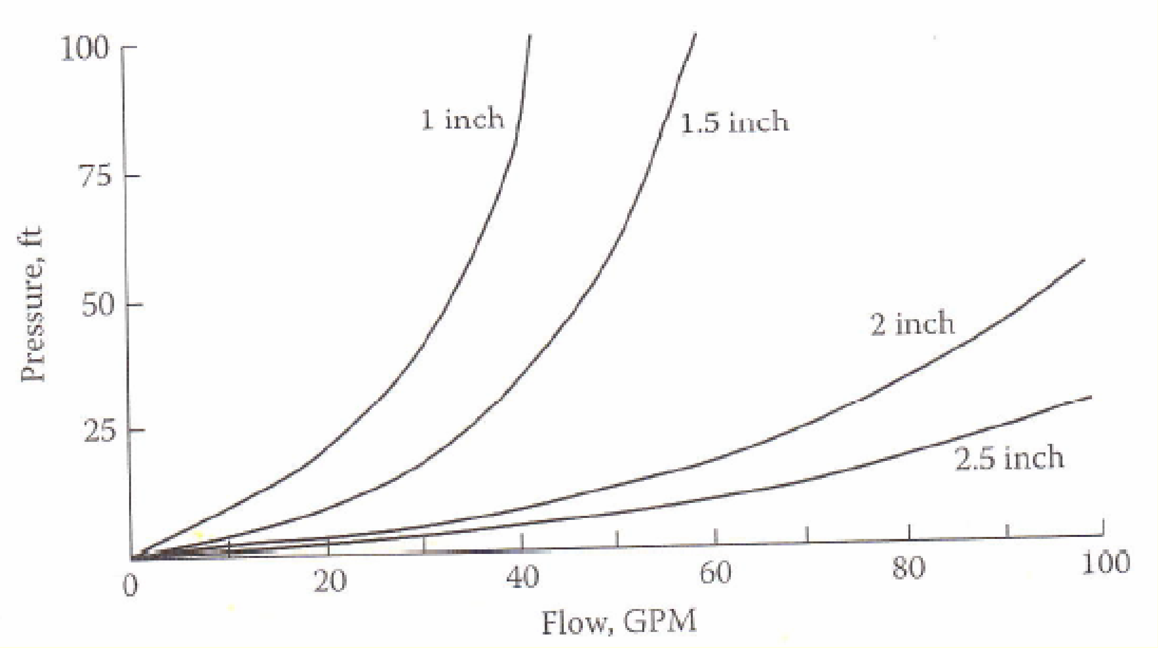
Pump Horsepower – simplified approach

$$HP = 4.66(10^{-6})\frac{(GPD)(h)}{(PT)(PTF)\eta}$$

- GPD: Gallons per Dar
- h: effective pumping height (≈ 1.05 the actual height to account for piping friction losses)
- PT: pumping time (peak sun hours)
- PTF: pumping time factor (modifier to account for the use of MPPT, or a tracking array mount ≈ 1.2)
- η: wire-to-water efficiency of the pump-motor combination – supplied by the manufacturer (≈ 0.25 for fractional horsepower pumps).
- In reality, a pump motor does not produce constant horsepower as as the flow and pressure are varied.

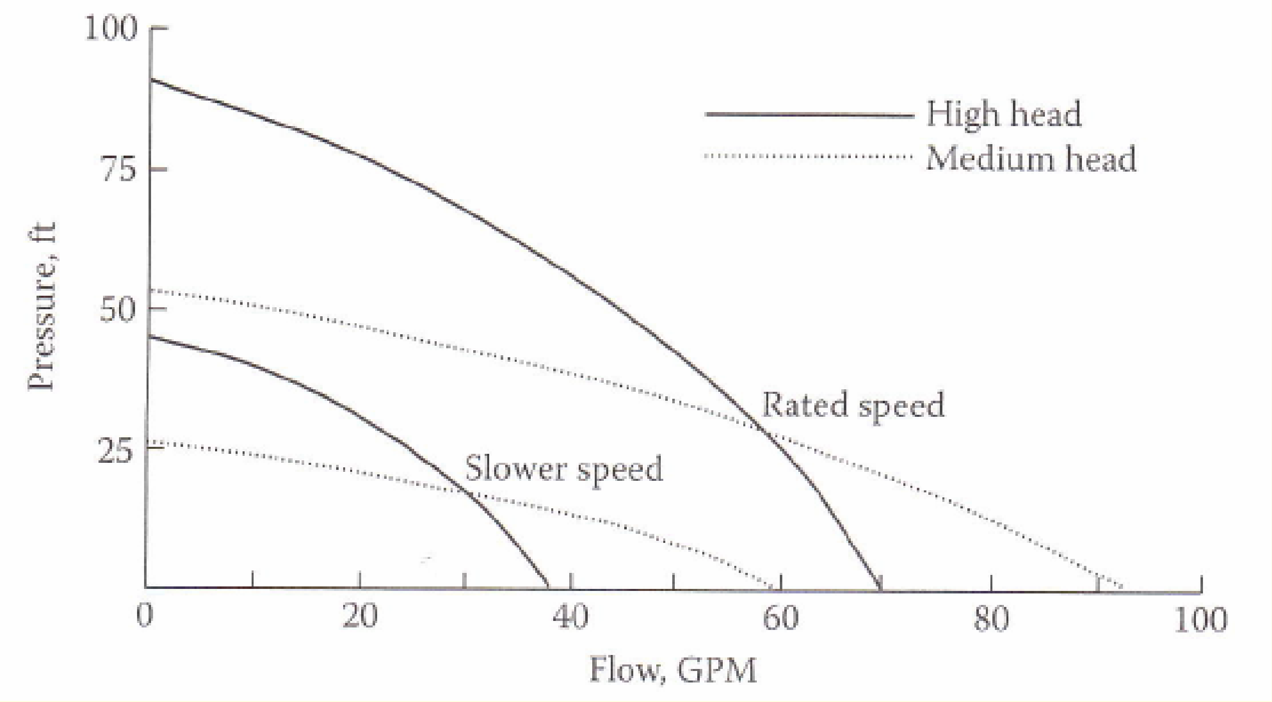
Pressure versus flow rate for different pipe diameters.

- Piping friction loss is determine by the diameter of pipe used and flow rate (equivalent to voltage drop which depends on wire size and amount of current flow)..
- But unlike the I-V of a wire, the relationship between pressure and flow rate is nonlinear.



Pressure vs. flow rate of high- and medium-pressure pumps of same hp

- Note that the medium head pump delivers more volume at low pressure that the high head pump.
- The performance of the pump depends on the speed at which it is operated.



Design of a simple pumping system

- Need 2,000 GPD,
- 200 ft pumping height
- 6 hours of sunlight
- → 2000/(6x60) = 5.56 GPM must be pumped a height of 200x1.05 = 210 ft to account for piping losses.
- Use Table 7.1 of one model of DC submersible pumps. Note that PV Watts = 1.25 times the pump voltage times the pump current.
- By interpolation → PV Watts = 712 W
- Use the pump power-voltage relation to the right to determine the pump voltage = 97.4 V and current = 7.31 A

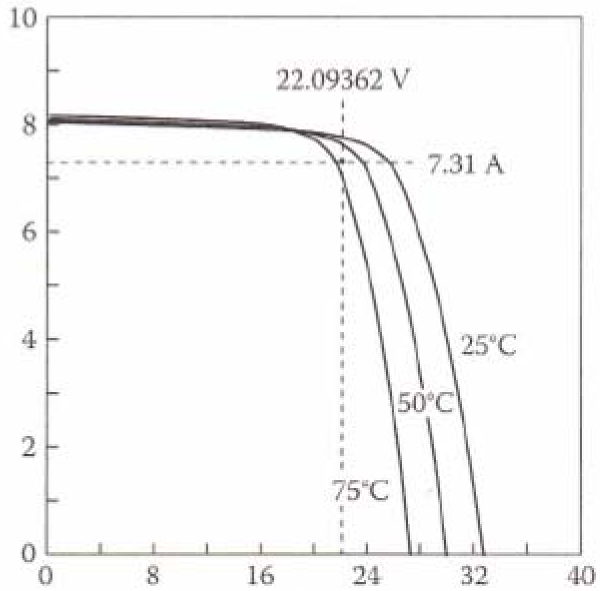
Table 7.1 Pumping Characteristics of a Typical DC Submersible Pump

Lift (ft)	GPM	Pump Current	Pump Voltage	PV Watts
150	6.4	6.00	90	675
150	12	8.95	120	1340
175	6.2	5.56	90	625
175	13.7	8.82	120	1320
200	7.6	6.64	105	875
200	11.0	8.42	120	1260
250	6.4	7.76	120	1164

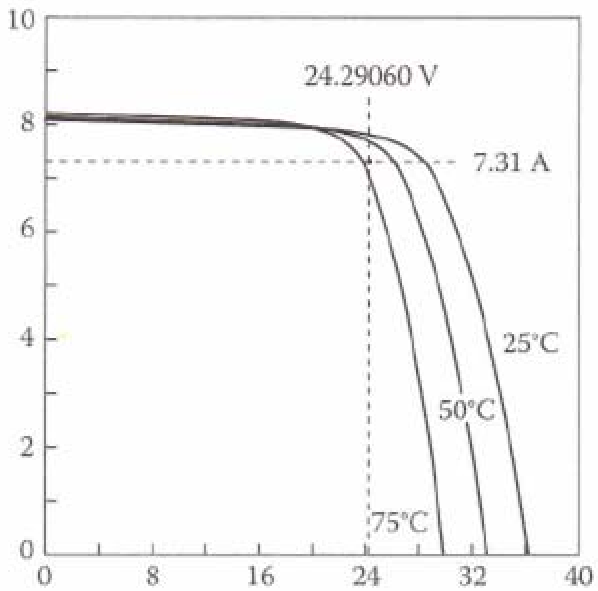
$$P_2 / P_1 = (V_2 / V_1)^{2.73}$$

Module Selection

- Pump manufacturers recommend over sizing the PV array by 25% due to mismatch …. They also recommend using a MPPT (or LCB).
- Use I-V curve at 75^{o}C to remain on the conservative side.
- Refer to the I-V curves of two possible modules below. Five A modules or four B modules are necessary to produce the needed voltage and current.



(a) 190 W Module



(b) 216 W Module

2. Parking Lot Lighting System

- Determine illumination level, i.e., amount of light needed and coverage area.
- Illumination can be measured in W/m^2, but the foot-candle (f-c) is used in the US.
- 1 foot-candle is the amount of light received at a distance of 1 foot from a standard candle (a candle that emits a total amount of light equal to 4π lumens: 1 f-c = 1 $lumen/ft^2$
- The illumination Engineering recommends 1 f-c for parking. For comparison purposes, 50 f-c is recommended for a desk. Furthermore, direct sunlight provides about 10,000 f-c.
- Luminous efficacy of a source is a measure of the efficiency with which the source transforms electric energy into light energy. It is measured in lumens/W

Luminous Efficacy of Typical Light Sources and their Lifetime

Source	Luminous Efficacy (l/W)	Lamp Lifetime (h)
25 W incandescent	8.6	2500
100 W incandescent	17.1	750
100 W long-life incandescent	16.0	1125
50 W quartz incandescent	19.0	2000
T-8 fluorescent	75–100	12,000–24,000+
Compact fluorescent	27–80	6,000–10,000
Metal halide	80–115	10,000–20,000
High-pressure sodium	90–140	10,000–24,000+
3.6 W LED array	~130	100,000+

Wattage needed

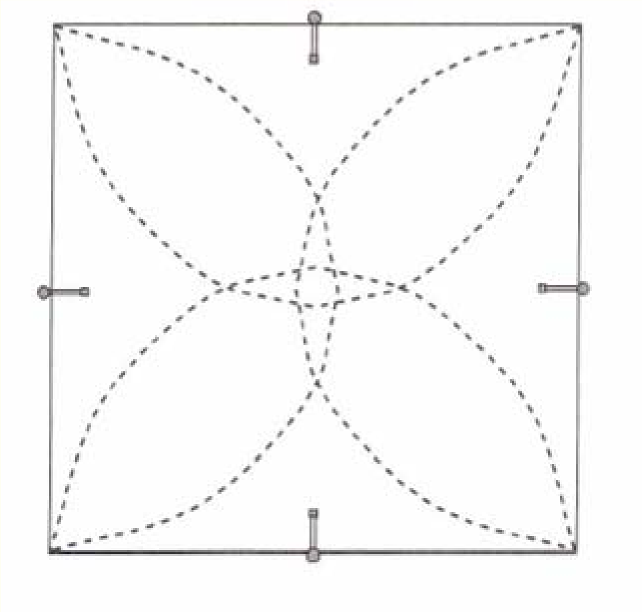
- Wattage of light needed depends on the required illumination level, luminous efficacy of the light source, and area to be lighted.
- Once the light source is chosen, the available light is computed by

  Lumens = (FC x Area)/(CUxMFxRCR)

  - FC: illumination level in f-c
  - Area: space to be illuminated (ft^2)
  - CU: coefficient of utilization (fraction of light directed to surface to be illuminated – typically more than 0.8)
  - MF: maintenance factor (due to dirt) – typically more than 0.9
  - RCR: Room cavity ratio (typically assumed to be equal to 1 for outdoors. For indoor applications, this depends on room size, wall colors, etc …)

Parking Lot Example

- Location: Miami, FL
- Lot size: 160’x160’ = 25,600 ft^2
- The lights are to come ON 15 min after sunset and turn OFF 15 min before sunrise.
- Desired illumination level: 2 f-c
- Four metal halide lamps are to be used (≈ 100 lumens/W)
- Distance between sources: 113 ft, pole height: 28’
- Coefficient of utilization: 0.8
- Maintenance factor: 0.9
- → total lumens = 71,111
- → lumens from each lamp: 17,778
- → lamp wattage: 178 W
- Wattage of available lamps: 175 W



Battery Size

- Metal halide is a gas discharge lamp that operates with a ballast (assume 10% in ballast). Hence 200 W is used as load demand.
- The maximum amount of time the light source will need to operate is 13 hrs during the month of December. (During the month of June: 9.8 hrs).
- The winter worse-case daily Wh = 2,600 Wh.
- Battery Storage requirements: assume 2 days of storage, battery voltage is 24 V, 2% wiring losses and maximum depth of discharge of 80% → battery capacity = 275 Ah @ 24 V.

Array Size:

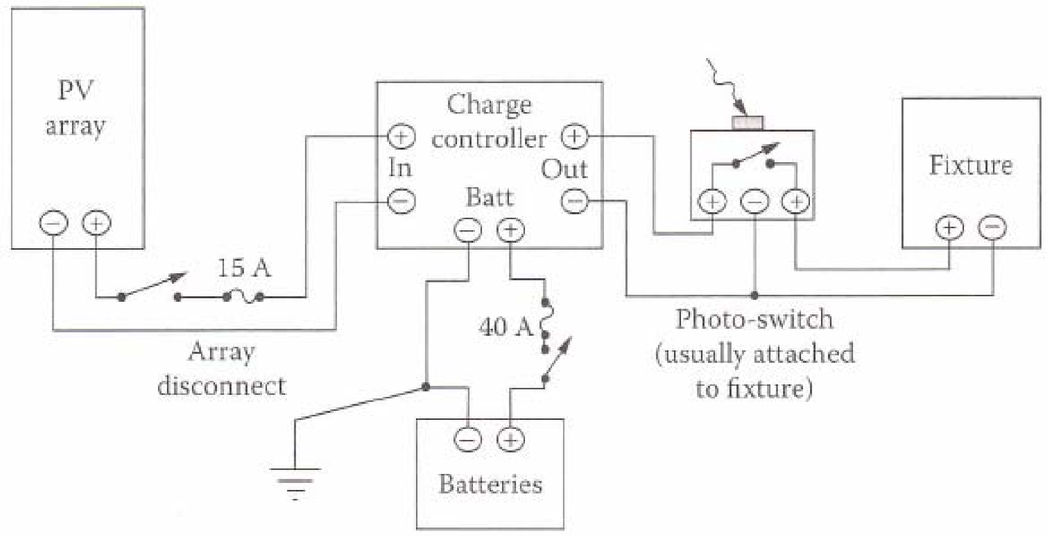
- Energy that must be supplied to the battery, assuming 2% wiring loss and 90% round-trip battery efficiency, and 96% MPPT-charge controller efficiency, 12% array loss due to elevated temperature and mismatch: 3,490 Wh/day.
- Peak sun hours in December in Miami, FL for a tilt angel equal to latitude +15^o (to optimize winter performance) is 4.9, → the array rating is 712 W.
- Four 180 W panels (≈ 720 W) in series will do the job.

Final Items

- Check daily load versus supply.
- Charge controller output current – 30 A is satisfactory.
- Wire size – include de-rating due to temperature, and check voltage drop.
- If 24 V light fixtures cannot be found, the a 24 VDC to 120VAC inverter is needed – inverter losses need to be taken into account.

Table 7.3 Comparison of Daily Loads (Wh) and Energy Availability (Wh) for Lighting System

	Jan	Feb	Mar	Apr	May	Jun
Load	2560	2440	2300	2140	2020	1960
Avail	2683	2897	3005	3058	2683	2414
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Load	1980	2100	2260	2400	2540	2600
Avail	2575	2683	2629	2736	2629	2629



3. Critical Need Refrigeration System

- Load Determination
  - 10 ft^3 refrigerator rated at 171 kWh/year or 470 Wh/day – compressor runs 6 h/day, power = 78W.
  - Inverter: input =12 VDC, output = 120 VAC, efficiency = 94%
  - Wiring loss 2%, battery charge/discharge loss =12%.
  - → load on the battery = 470/(0.94 x 0.98 x .88) = 580 Wh/day
- Battery sizing :
  - Ah = (Ah/day)*days/(D_T*D_{ch}*DOD_{max})
  - where D_T is the temperature derating factor, and D_{ch} is the charge/discharge derating factor.
  - For lead-acid batteries, $D_T \approx 0.00575T + 0.54$ where the battery temperature T is in ^oF.

- Assume maximum DOD = 80%, then for one day battery operation, we need 580/0.8 = 725 Wh or 725/12 = 60.4 Ah.
- Further assume 10 days of autonomy, the a total of 604 Ah @12 V of storage at a C/240 rate will be needed.
- Two 12 V batteries connected in parallel (each rated at 305 Ah @ C/120) will fit nicely.

- Array Size: must meet the daily corrected load during the month with the lowest peak sun hours. In this case, 3.92 h for tilt angle of latitude + 15^o.
- Assuming all losses add up to 15%, the array unit must produce 580/0.85 = 682 Wh/day or 682/3.93 = 174 W
- A 175 W panel with MPPT will do the job.

Final Configuration