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Impact of Altitude and Climate on Energy Measures

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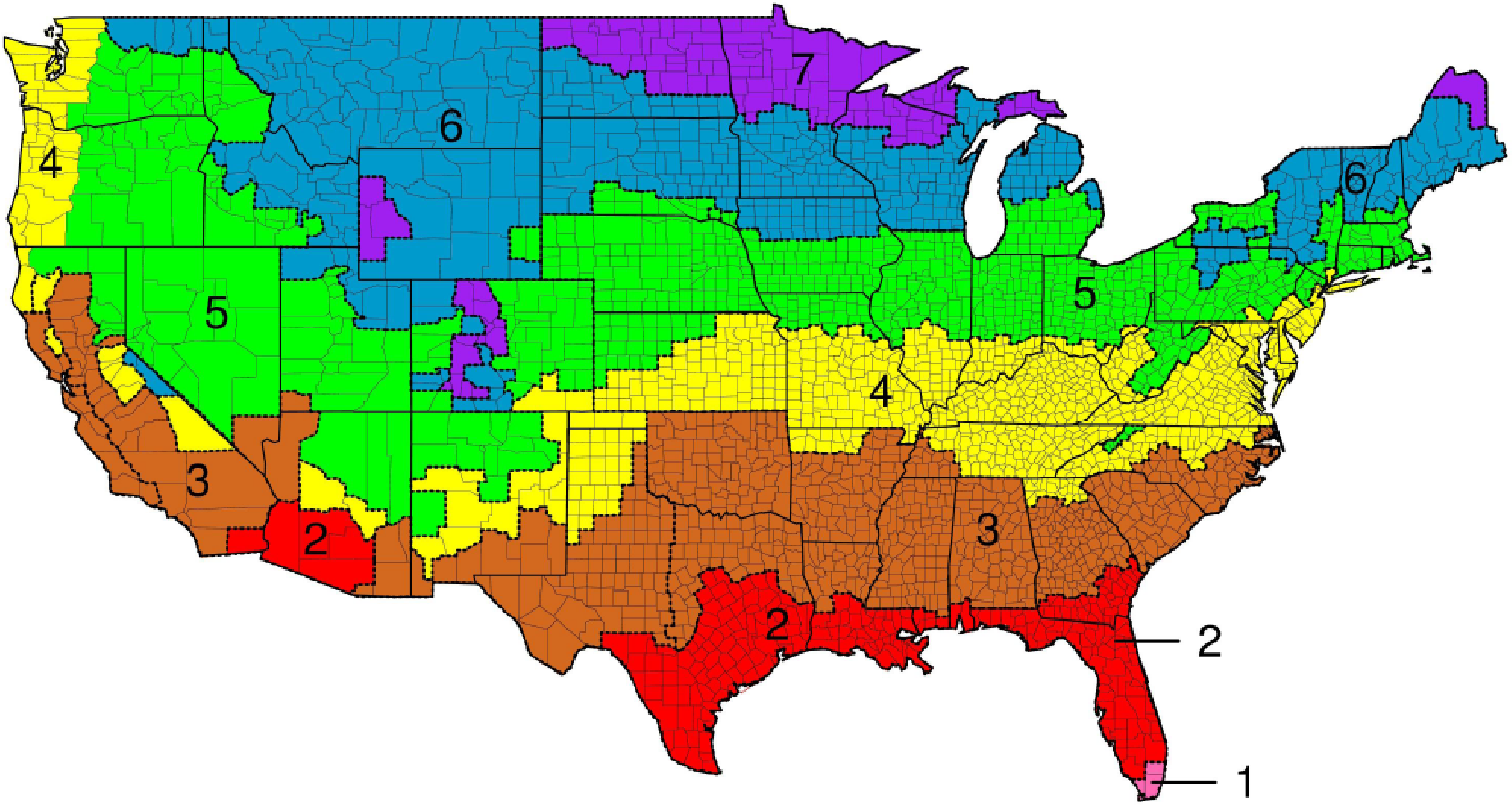
Overview and Goals

- Energy measures often perform differently at high altitudes (above 3,000 ft)
  - Measure sizing, performance, efficiency and lifetimes may vary
- To give you some tools to determine whether measure savings might need to be reassessed for programs in high altitudes

Energy Code Climate Zones



Source: IECC

Primary Differences - Air

- Relative to sea level, we in the Rocky Mountains, have:
  - Reduced Air Pressure/Density
  - Low Humidity
  - Temperature swings
- These impact:
  - Thermal capacity
  - Combustion efficiency
  - Solar intensity
  - Dielectrics
  - Vapor pressures

Energy Measures Impacted

- Motors
- Chillers/cooling towers/evaporative coolers/air conditioners
- Furnaces
- Boilers
- Gas water heaters
- Solar/PV systems
- Pumps
- Gas-filled windows/Plasma TVs
- Air compressors
- Fans
- Lighting with ballasts

Energy Measures Not or Minimally Impacted

- Non-sealed windows
- Compressors – Refrigeration
- Non ballast lighting
  - (including incandescent/halogen)
- Closed systems (steam)
- Insulation/sealing
- Electric water heaters

Specific Measures

- Motors
- Air conditioners and furnaces
- Fans
- Chillers
- PV Systems

Motors

- Motor output (hp) and efficiency decreases as temperature increases.
- At altitude, motors are less efficient at dissipating heat and therefore must be derated.
- Service factors can compensate for output, but not for efficiency.

Motor Derating Factors

- Manufacturer/motor specific
  - Example from Siemens

Altitude Above Sea Level (meters)	Ambient Temperature						
	30°C	35°C	40°C	45°C	50°C	55°C	60°C
1000	1.06	1.03	1.00	0.96	0.92	0.87	0.82
1500	1.03	1.00	0.97	0.93	0.89	0.84	0.80
2000	1.00	0.97	0.94	0.90	0.86	0.82	0.77
2500	0.95	0.93	0.90	0.86	0.83	0.78	0.74
3000	0.91	0.89	0.86	0.83	0.79	0.75	0.71
3500	0.87	0.84	0.82	0.79	0.75	0.71	0.67
4000	0.82	0.79	0.77	0.74	0.71	0.67	0.63

(http://www.sea.siemens.com/us/internet-dms/dt/StandardMotorsandDrives/NEMAMotors/docs/App%20Man%20Section%205%20Part%207%20Reduction%20Factors%20Info.pdf)

  - Efficiency = Power out / Power in
  - May be equivalent savings – but have to look at manufacturer ratings

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Heating and Cooling Systems

- Similar derating tables

Manual S Capacity Correction Air Cooled Condenser Air Cooled Packaged	
Altitude Ft.	**Correction Factor**
2,000	0.98
4,000	0.97
6,000	0.95
8,000	0.92
10,000	0.90

Manual S Capacity Correction Gas Furnace	
Altitude Ft.	**Correction Factor**
2,000	0.92
4,000	0.84
6,000	0.76
8,000	0.68
10,000	0.60

*Natural draft

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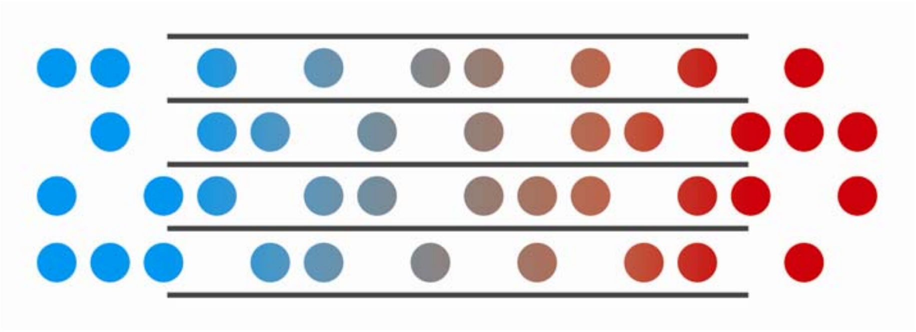
Mass = Heating/Cooling Capacity

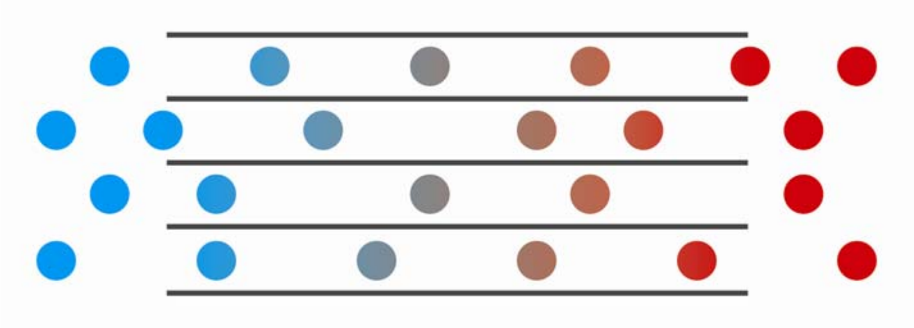
- More CFM required at altitude to provide same cooling (or heating) capacity as sea level unit.
- Can compensate with higher blower speed or larger blower resulting in increased power draw.

Air Density and Heat Exchangers - Heating

Sea Level



Higher Altitude



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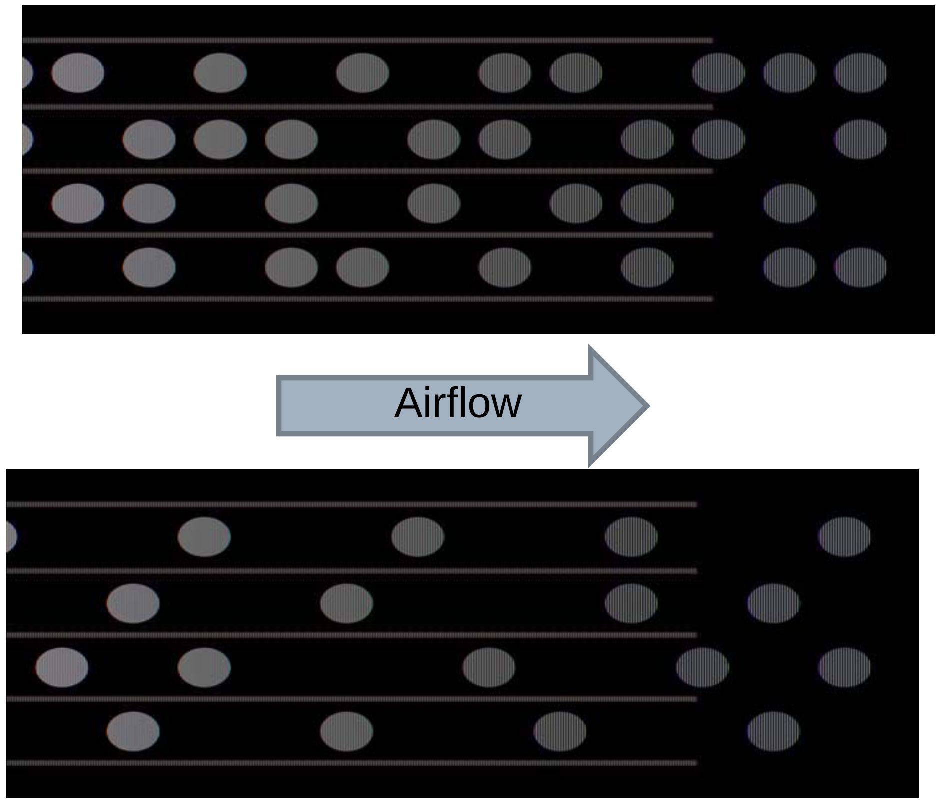
Air Density and Heat Exchangers - Cooling

Sea Level

Higher Altitude



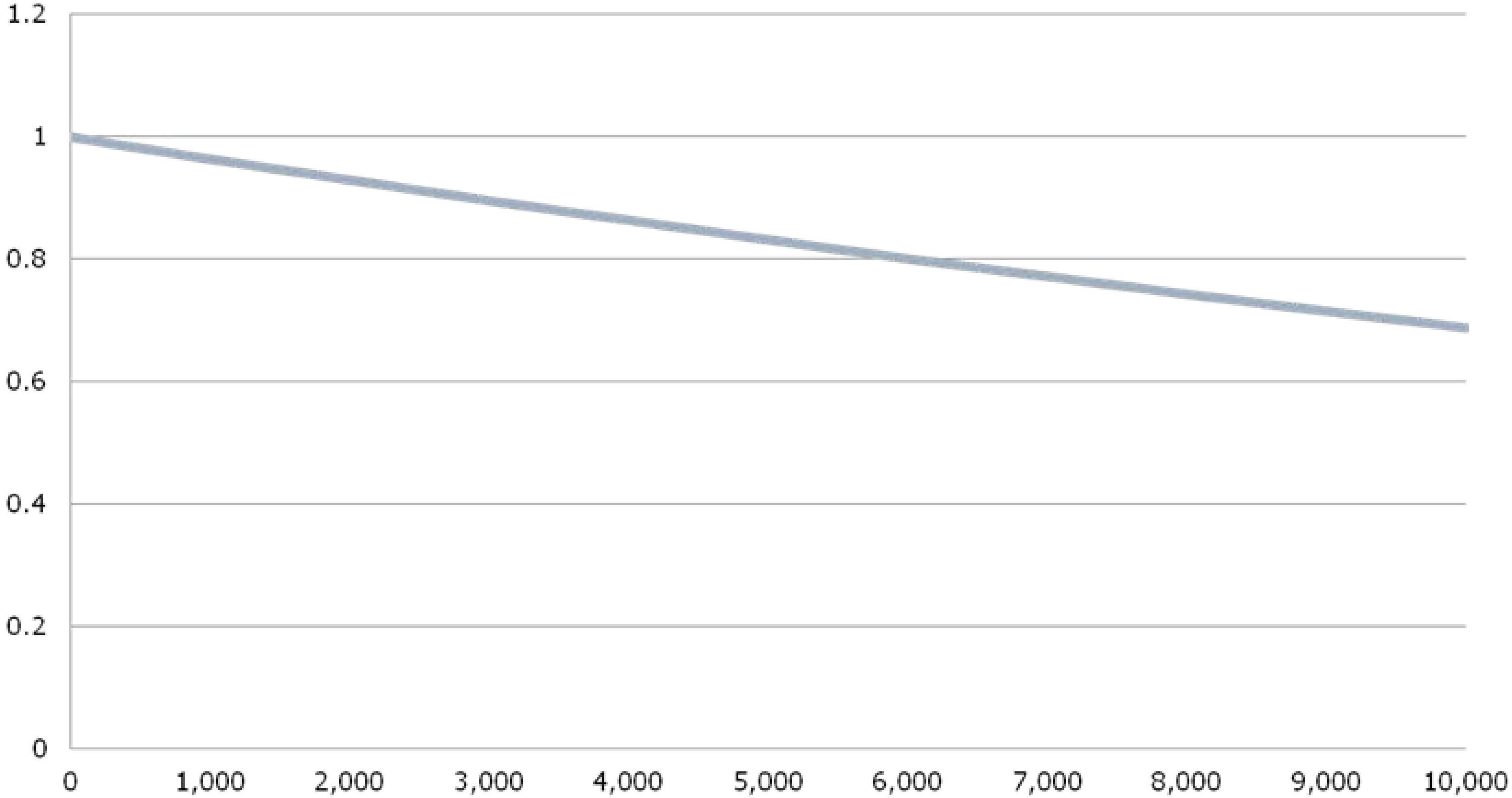
Fan Power Consumption

Corrected BHP = Altitude Correction Factor X Design BHP

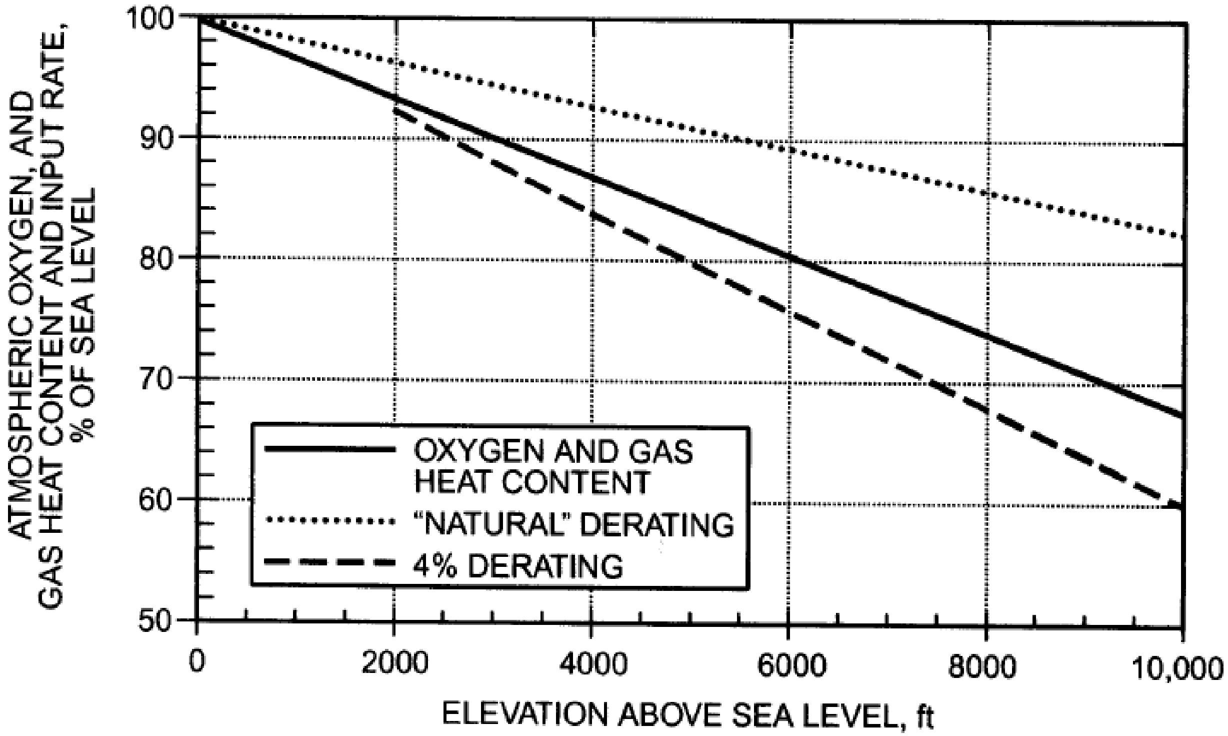
TABLE 7 – ALTITUDE-CORRECTION FACTORS

Air Temp	Altitude (feet)										
	0	**1000**	**2000**	**3000**	**4000**	**5000**	**6000**	**7000**	**8000**	**9000**	**10000**
40	1.060	1.022	0.986	0.95	0.916	0.882	0.849	0.818	0.788	0.758	0.729
50	1.039	1.002	0.966	0.931	0.898	0.864	0.832	0.802	0.772	0.743	0.715
60	1.019	0.982	0.948	0.913	0.880	0.848	0.816	0.787	0.757	0.729	0.701
70	1.000	0.964	0.930	0.896	0.864	0.832	0.801	0.772	0.743	0.715	0.688
80	0.982	0.947	0.913	0.880	0.848	0.817	0.787	0.758	0.73	0.702	0.676
90	0.964	0.929	0.897	0.864	0.833	0.802	0.772	0.744	0.716	0.689	0.663
100	0.946	0.912	0.88	0.848	0.817	0.787	0.758	0.730	0.703	0.676	0.651

Fan Power Consumption (70 degrees)



Combustion Efficiency



Note: Natural derating applies for fixed injector (orifice) size and pressure.

Examples of Savings Adjustments Relative to Sea Level

Measure		Efficiency	Altitude Correction 5,000ft	Altitude Correction 10,000ft
Furnace		78%	N/A	N/A
		85%	1- 2%	2-4%
		90%	1-3%	3-7%
		95%	2-4%	5-10%
Central AC		SEER 13	N/A	N/A
		SEER 15	1-3%	2-4%
		SEER 17	2-4%	3-5%

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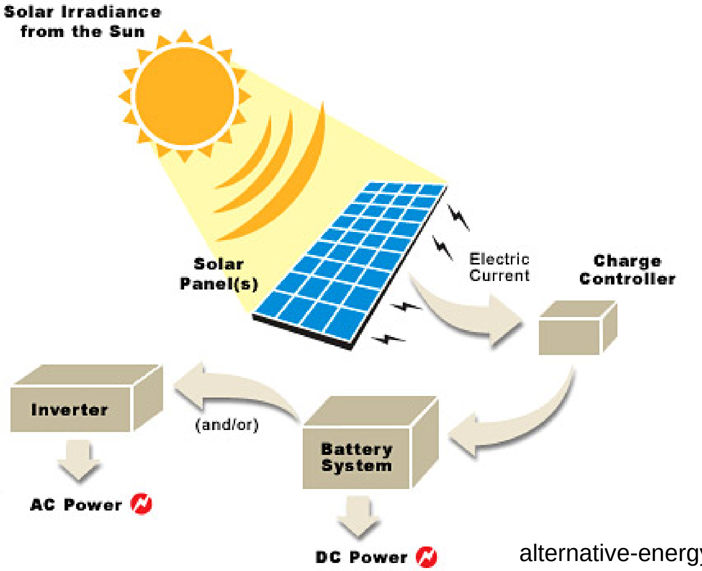
Solar Radiation – PV and Thermal

Dogfunk.com

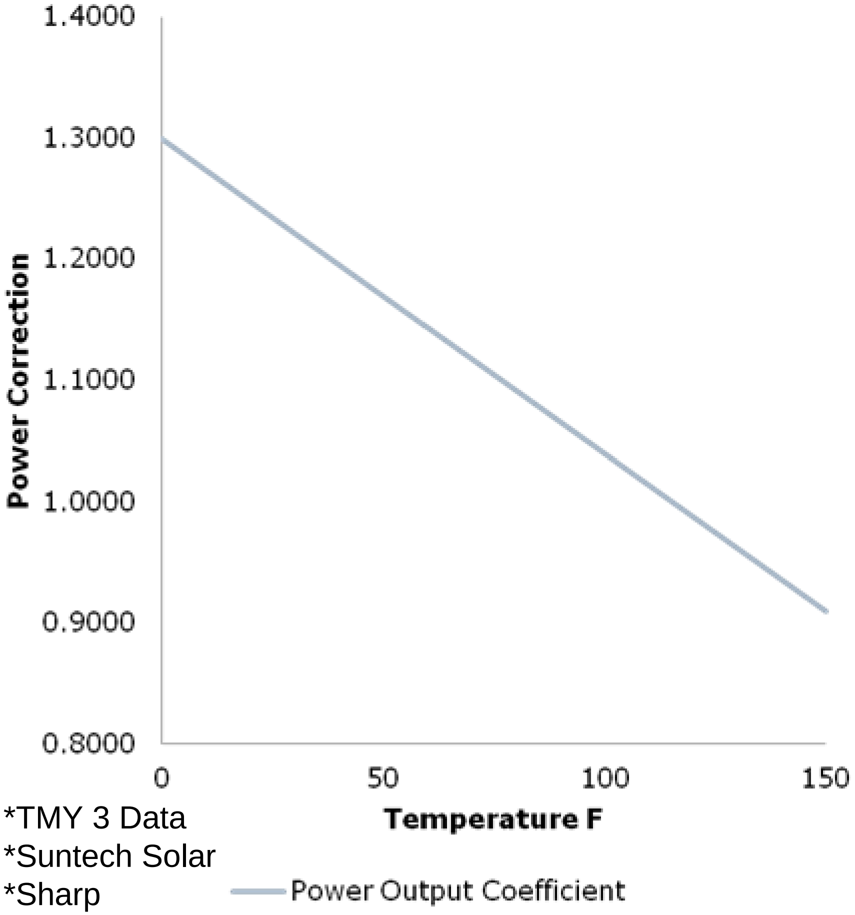
The thin air and low humidity at high altitudes reflect and absorb less solar radiation than at sea level. Anyone with a goggle tan has experienced this effect.

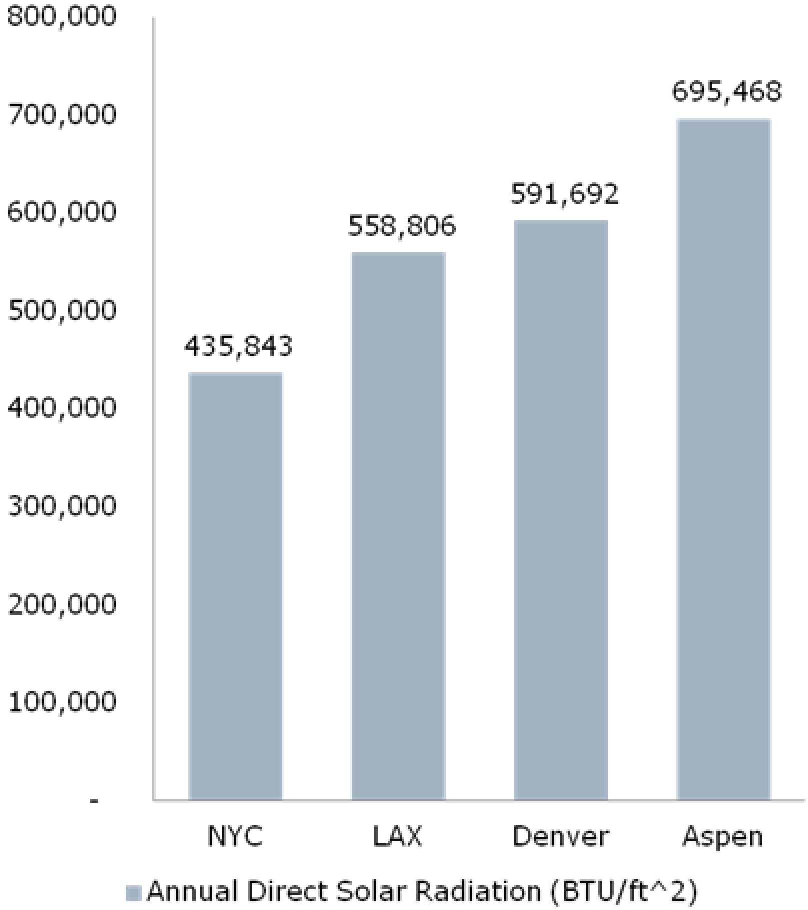


alternative-energy-news.info

Solar thermal and photovoltaic systems can capitalize on this high intensity of sunlight hitting the ground.

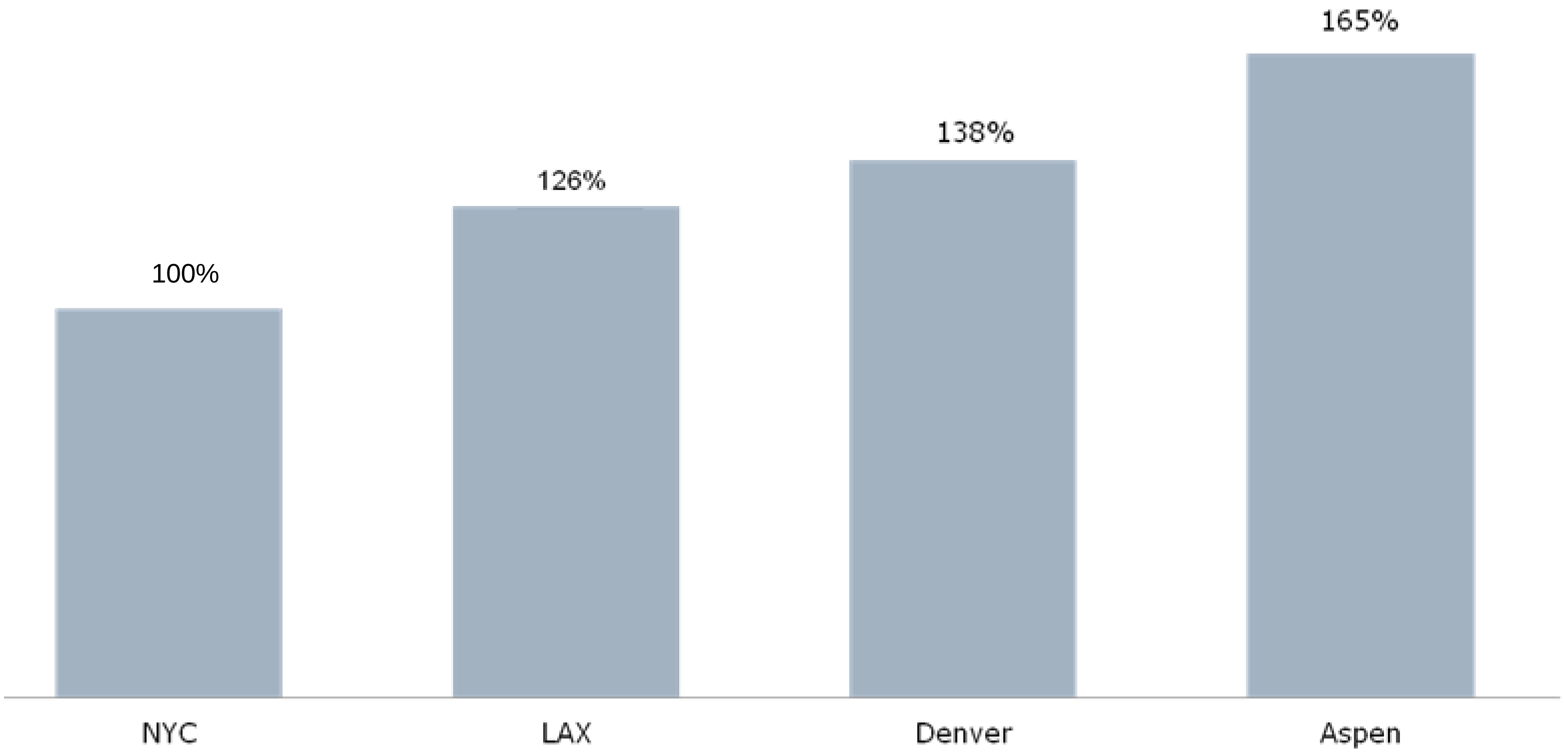
Solar PV





*TMY 3 Data
*Suntech Solar
*Sharp

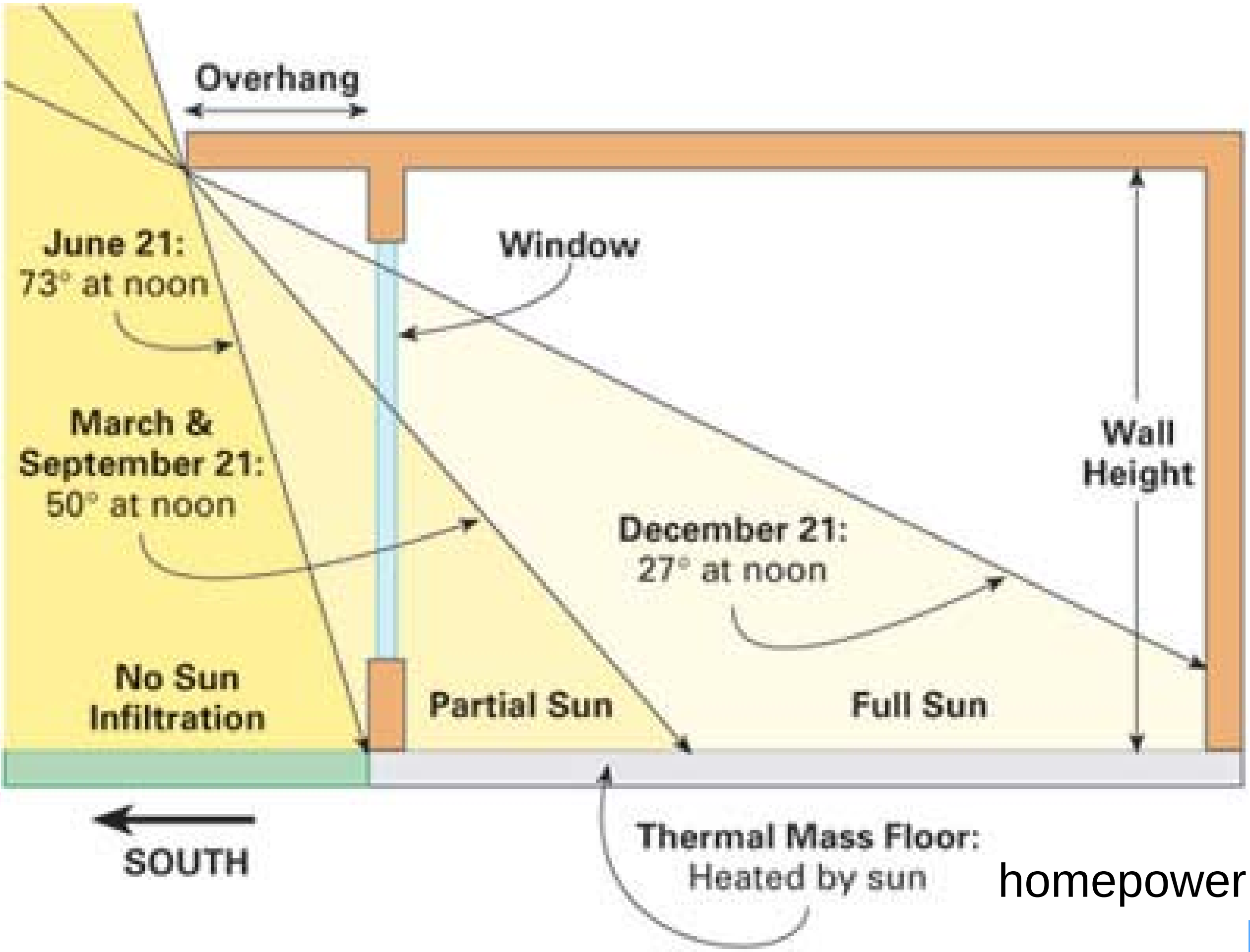
PV System Output



Solar Heat Gain Through Windows

- Provides free heat in the winter.
  - High solar heat gain is effective.
- Adds to cooling load in summer.
  - Low solar heat gain is effective.

Passive Solar Design



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Conclusion

- Air density affects equipment performance
  - Heat transfer
  - Combustion
  - Solar radiation/heat gain
- Have to consider derating

Questions

ADDITIONAL RESOURCES

Equipment size increase to achieve sea level output.

Item	2000 m	3000 m	4000 m	5000 m
Diesel engines	25%	40%	55%	70%
Air compressors	35%	55%	75%	95%
Vacuum pumps	20%	30%	40%	50%
Transmission lines	10%	20%	30%	40%
Transformers	5%	15%	25%	35%
Electrical machines	5%	15%	25%	35%

Jimenez, D., Chapter 25: High altitude intermittent chronic exposure: Andean mines. Source unknown.

Altitude Corrections

Altitude (Feet)	Barometer Inches Mercury	Barometer Lbs / Sq In Atmosphere	Specific Volume Cu Ft/Lb	Rel. Dens. SP or HP Corr. Factor	Air Density Lbs/Cu Ft	CFM Transport Factor	CFM Correction Factor
0	29.92	14.7	13.34	1	0.075	1.08	1
100	29.81	14.64	13.389	0.996	0.0747	1.076	1.004
200	29.7	14.58	13.439	0.993	0.0745	1.073	1.007
300	29.6	14.52	13.488	0.989	0.0742	1.068	1.011
400	29.49	14.46	13.538	0.985	0.0739	1.064	1.015
500	29.38	14.4	13.587	0.981	0.0736	1.06	1.019
5000	24.89	12.2	16.035	0.832	0.0624	0.899	1.202
5200	24.71	12.12	16.167	0.825	0.0619	0.891	1.212
5400	24.52	12.04	16.299	0.819	0.0614	0.884	1.222
5600	24.34	11.96	16.431	0.813	0.061	0.878	1.232
5800	24.16	11.88	16.563	0.807	0.0605	0.871	1.242
6000	23.98	11.8	16.695	0.799	0.0599	0.863	1.252
6200	23.8	11.7	16.803	0.794	0.0596	0.858	1.26
6400	23.62	11.6	16.911	0.789	0.0592	0.852	1.268
6600	23.45	11.5	17.018	0.784	0.0588	0.847	1.276
6800	23.27	11.4	17.126	0.779	0.0584	0.841	1.284
7000	23.09	11.3	17.234	0.774	0.0581	0.835	1.292
7200	22.9	11.22	17.397	0.767	0.0575	0.828	1.304
7400	22.7	11.14	17.56	0.76	0.057	0.821	1.316
7600	22.51	11.06	17.724	0.753	0.0565	0.814	1.329
7800	22.31	10.98	17.887	0.746	0.056	0.806	1.341
8000	22.12	10.9	18.05	0.739	0.0554	0.789	1.353

SEER / EER Climate/ Condition Adjustments

Carrier AC Model 24ACB4 Cooling Capacities

24ACB4

DETAILED COOLING CAPACITIES#

EVAPORATOR AIR		CONDENSER ENTERING AIR TEMPERATURES °F (°C)																	
		75 (23.9)			85 (29.4)			95 (35)			105 (40.6)			115 (46.1)			125 (51.7)		
CFM	EWB °F (°C)	Capacity MBtuh		Total Sys. KW**	Capacity MBtuh		Total Sys. KW**	Capacity MBtuh		Total Sys. KW**	Capacity MBtuh		Total Sys. KW**	Capacity MBtuh		Total Sys. KW**	Capacity MBtuh		Total Sys. KW**
		Total	Sens‡		Total	Sens‡		Total	Sens‡		Total	Sens‡		Total	Sens‡		Total	Sens‡	
24ACB418A30 Outdoor Section With CAP**2414A** Indoor Section																			
525	72 (22.2)	21.57	11.21	1.17	20.52	10.80	1.32	19.45	10.39	1.49	18.33	9.97	1.67	17.18	9.55	1.88	15.93	9.09	2.11
	67 (19.4)	19.60	13.63	1.18	18.65	13.23	1.33	17.57	12.81	1.50	16.65	12.40	1.69	15.60	11.96	1.90	14.46	11.51	2.13
	62 (16.7)	17.82	16.04	1.19	16.96	15.63	1.34	16.08	15.22	1.51	15.18	14.79	1.70	14.29	14.29	1.91	13.44	13.44	2.13
	57 (13.9)	17.16	17.16	1.20	16.49	16.49	1.35	15.79	15.79	1.51	15.06	15.06	1.70	14.29	14.29	1.91	13.44	13.44	2.13
600	72 (22.2)	22.01	11.78	1.19	20.92	11.37	1.34	19.79	10.95	1.51	18.62	10.52	1.70	17.42	10.09	1.91	16.12	9.62	2.14
	67 (19.4)	20.03	14.54	1.21	19.03	14.13	1.36	18.00	13.71	1.53	16.94	13.28	1.71	15.84	12.84	1.92	14.66	12.37	2.15
	62 (16.7)	18.27	17.29	1.22	17.38	16.86	1.37	16.50	16.41	1.54	15.70	15.70	1.72	14.86	14.86	1.93	13.95	13.95	2.16
	57 (13.9)	17.96	17.96	1.22	17.23	17.23	1.37	16.48	16.48	1.54	15.70	15.70	1.72	14.87	14.87	1.93	13.95	13.95	2.16
675	72 (22.2)	22.34	12.32	1.22	21.20	11.90	1.37	20.03	11.47	1.54	18.83	11.04	1.72	17.58	10.60	1.93	16.24	10.13	2.16
	67 (19.4)	20.35	15.42	1.23	19.31	15.00	1.38	18.25	14.57	1.55	17.15	14.13	1.74	16.02	13.68	1.95	14.80	13.21	2.18
	62 (16.7)	18.68	18.46	1.24	17.86	17.86	1.39	17.06	17.06	1.56	16.22	16.22	1.75	15.33	15.33	1.95	14.37	14.37	2.18
	57 (13.9)	18.63	18.63	1.24	17.86	17.86	1.39	17.06	17.06	1.56	16.22	16.22	1.75	15.33	15.33	1.95	14.37	14.37	2.18

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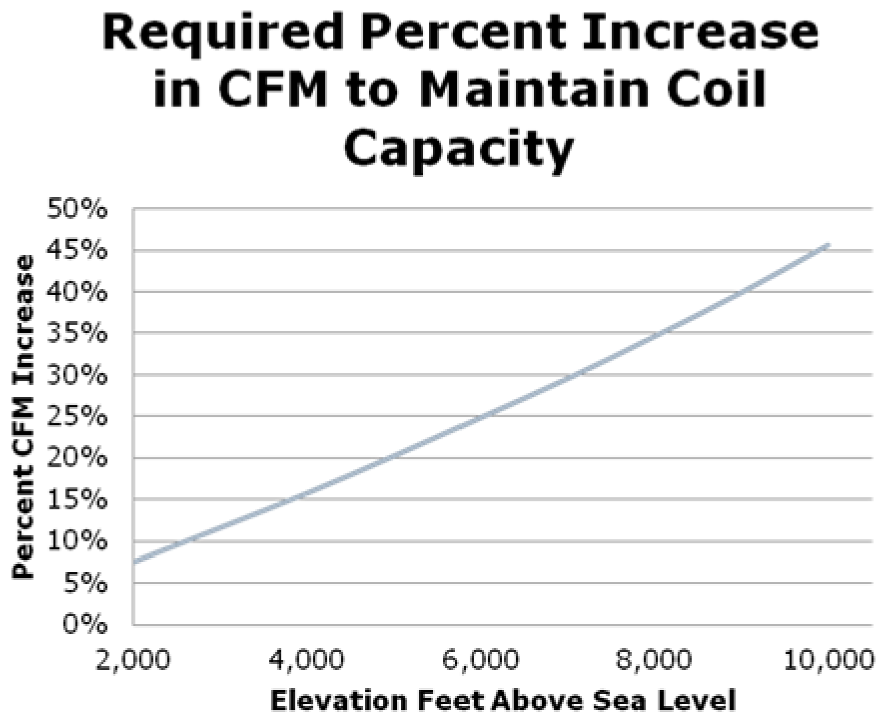
DETAILED COOLING CAPACITIES#

EVAPORATOR AIR		CONDENSER ENTERING AIR TEMPERATURES °F (°C)					
		75 (23.9)			85 (29.4)		
CFM	EWB °F (°C)	Capacity MBtuh		Total Sys. KW**	Capacity MBtuh		Total Sys. KW**
		Total	Sens‡		Total	Sens‡	
24ACB41							
525	72 (22.2)	21.57	11.21	1.17	20.52	10.80	1.32
	67 (19.4)	19.60	13.63	1.18	18.65	13.23	1.33
	62 (16.7)	17.82	16.04	1.19	16.96	15.63	1.34
	57 (13.9)	17.16	17.16	1.20	16.49	16.49	1.35
600	72 (22.2)	22.01	11.78	1.19	20.92	11.37	1.34
	67 (19.4)	20.03	14.54	1.21	19.03	14.13	1.36
	62 (16.7)	18.27	17.29	1.22	17.38	16.86	1.37
	57 (13.9)	17.96	17.96	1.22	17.23	17.23	1.37
675	72 (22.2)	22.34	12.32	1.22	21.20	11.90	1.37
	67 (19.4)	20.35	15.42	1.23	19.31	15.00	1.38
	62 (16.7)	18.68	18.46	1.24	17.86	17.86	1.39
	57 (13.9)	18.63	18.63	1.24	17.86	17.86	1.39

Air Flow Calculations

$$Required\ CFM\ at\ Altitude = \frac{Required\ Sea\ Level\ Flow\ Rate}{Density\ Ratio}$$

Manual S Air Density Correction	
Altitude Ft.	Density Ratio
1,000	0.964
2,000	0.93
3,000	0.896
4,000	0.864
5,000	0.832
6,000	0.801
7,000	0.772
8,000	0.743
9,000	0.715
10,000	0.687



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Unit Capacity = kBuh
100 = conversion from kBtuh to therms

Furnace TRM Savings

$$Therm\ Savings = Unit\ Capacity * \left(\frac{1}{78\ AFUE - AFUE_{EE}}\right) * \frac{Heating\ Load\ Hours}{100}$$

Unit Capacity = kBtuh
100 = conversion from kBtuh to therms

AC Energy and Demand Savings

$$\Delta kW = Capacity * \left(\frac{12}{13\ EER} - \frac{12}{EER_{EE}}\right)$$

$$\Delta kWh = \Delta kW * EFLH$$

EER = Energy Efficiency Ratio
EFLH = Equivalent Full Load Hours