Presentation to:

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High Altitude HVAC

Design Considerations

by:

Michael D. Haughey, PE, HBDP, CEM, LEED™ AP

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Integrated Engineering Consultants

MichaelH@SilvertipLLC.com

www.SilvertipConsultants.com

HIGH ALTITUDE HVAC DESIGN CONSIDERATIONS

- Goals
  - ❖ Overview
  - ❖ A Few Examples
  - ❖ Thought Process
  - ❖ Why
  - ❖ (In the words of...) Understand, rather than......
- NOT
  - ❖ Cookbook
  - ❖ Substitute for engineering

Altitude Effects
Understanding Why

- Baseball
  - ❖Home run distance
  - ❖Curve ball
- Basketball
  - ❖Doug Moe Era
- Football
  - ❖Field goal distance

- Similarities???
  - ❖Relation to air density
  - ❖Gravity???
  - ❖Function of oxygen content
  - ❖Heat Rejection
    - ➢Sensible?
    - ➢Latent?

Mitigating Factors

- Equipment counteracts using:
  - ❖Temperature
  - ❖Pressure
  - ❖Humidity
  - ❖Heat transfer
  - ❖Equipment design basis

Altitude Dependent System/ Equipment Examples

- Airflow calculations
- Fans, ductwork (sizing, pressure)
- Air-cooled equipment
  - Condensers, chillers
  - Motors, electrical and electronic equipment
- Combustion equipment
  - Boilers, furnaces, generators, engines, gas absorption
- Pumps
- Evaporative coolers, Cooling towers
- Balancing, VAV box

Altitude Dependent System/ Equipment Examples

- New 2017
  - Desiccant Dehumidification
- New 2018
  - Snow Entrainment
  - Load calculations
- New 2019
  - Boilers

Airflow Calculations – (Sensible Only)

- cfm = (Btu / hr) / (C_P * p * 60 * DT)
- Let C_P * p * 60 = F_{CFM}

  F_{CFM} = "CFM transfer factor"

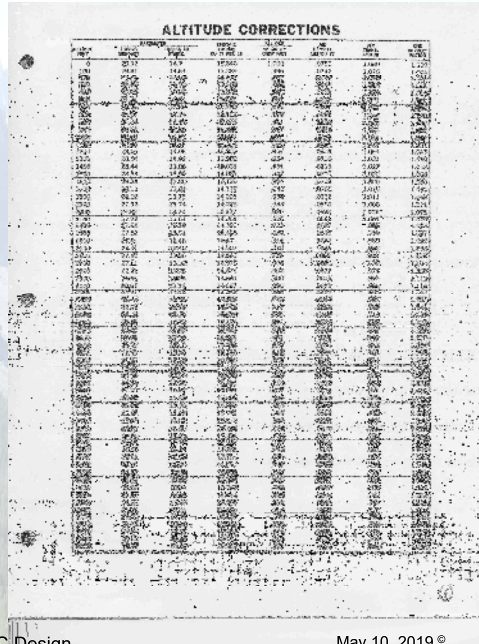
- cfm = (Btu / hr) / (F_{CFM} * DT)

Airflow Calculations – (Sensible Only)

OR

- cfm * F_{CFM} * DT = Btu / hr
- Look up F_{CFM} in tables (handout, 1st page), THEN
- Check on Psych Chart

Reference page 1



ALTITUDE CORRECTIONS

ALTITUDE FEET	BAROMETER INCHES MERCURY	BAROMETER LBS/SQ IN ATMOS.	SPECIFIC VOLUME CU FT PER LB	REL DEN SP OR HP CORR FACT	AIR DENSITY LBS/CU FT	CFM TRANS. FACTOR	CFM CORRECT FACTOR
0	29.92	14.7	13.340	1.000	.0750	1.080	1.000
100	29.81	14.64	13.389	.996	.0747	1.076	1.004
200	29.70	14.58	13.439	.993	.0745	1.073	1.007
300	29.60	14.52	13.488	.989	.0742	1.068	1.011
400	29.49	14.46	13.538	.985	.0739	1.064	1.015
500	29.38	14.40	13.587	.981	.0736	1.060	1.019
600	29.28	14.36	13.636	.978	.0734	1.057	1.022
700	29.17	14.32	13.686	.975	.0731	1.053	1.026
800	29.06	14.28	13.735	.971	.0728	1.048	1.030
900	28.96	14.24	13.785	.967	.0725	1.044	1.034
1000	28.85	14.20	13.834	.964	.0723	1.041	1.037
1100	28.75	14.14	13.883	.960	.0720	1.037	1.041
1200	28.65	14.08	13.933	.957	.0818	1.034	1.045
1300	28.54	14.02	13.982	.954	.0716	1.031	1.049
1400	28.44	13.96	14.031	.951	.0713	1.027	1.052
1500	28.33	13.90	14.081	.947	.0710	1.022	1.056
1600	28.23	13.86	14.130	.944	.0708	1.020	1.060
1700	28.13	13.82	14.179	.940	.0705	1.015	1.064
1800	28.02	13.78	14.228	.936	.0702	1.011	1.068
1900	27.92	13.74	14.278	.933	.0700	1.008	1.071

TIONS

ALTITUDE FEET	AIR DENSITY LBS/CU FT	CFM TRANS. FACTOR	CFM CORRECT FACTOR
0	.0750	1.080	1.000
100	.0747	1.076	1.004
200	.0745	1.073	1.007
300	.0742	1.068	1.011
400	.0739	1.064	1.015
500	.0736	1.060	1.018
[illegible]	[illegible]	[illegible]	[illegible]

Airflow Calculations (page 2)

- Example - sea level:
  - 10,000 Btuh, 20F DT: find CFM
  - cfm = (Btu / hr) / (F_{CFM} * DT)
  - cfm = 10,000 Btuh / (1.08 * 20) = 463

Airflow Calculations (page 3)

- Example - 5,200 ft. elevation
  - 10,000 Btuh, 20F DT
  - cfm = (Btu / hr) / (F_{CFM} * DT)
  - cfm = 10,000 Btuh / (0.891 * 20) = 561
  - Note, for simplicity, many applications are close enough using 0.9 in lieu of o.891

Standard and Actual Air

- Standard air, SCFM, is at sea level and 70°F
- Actual air, ACFM, is at actual conditions
- To convert, correct for density change due to both altitude and temperature
- For altitude: SCFM = ACFM * (density ratio)
- Example, 1000 CFM at 5,200 ft. elevation (equiv. mass):
  - 825 SCFM = 1,000 ACFM * 0.825

Fan and Duct System Pressure Drop Calculations (Example)

- Separate items using sea level data from items using altitude data (e.g. duct friction)
- Example (5,200 ft. elevation, 10,000 CFM)

Example (5,200 ft. elevation, 10,000 CFM)

	Sea level DP " w.c.	Alt. DP " w.c.
Cooling coil (computer sel.)		0.6
Heating coil (computer sel.)		0.2
Ductwork (ductilator)	1.5	
Fittings (ASHRAE tables)	2.0	
Other (diffuser, louvers, dampers)	1.5	
Total	5.0	0.8

Example (5,200 ft. elevation, 10,000 CFM) (page 2)

- (example continued)
  - Correct sea level items:
    - Density ratio = 0.825 at 5200 ft
    - 5.0 * 0.825 = 4.125
  - Total = 4.125 + 0.8 = 4.925 at alt.
  - At sea level = 4.925/.825 = 6”
- Fan selection chart – SL or Alt?
- Use computer selection at altitude, OR

Example (5,200 ft. elevation, 10,000 CFM) (page 3)

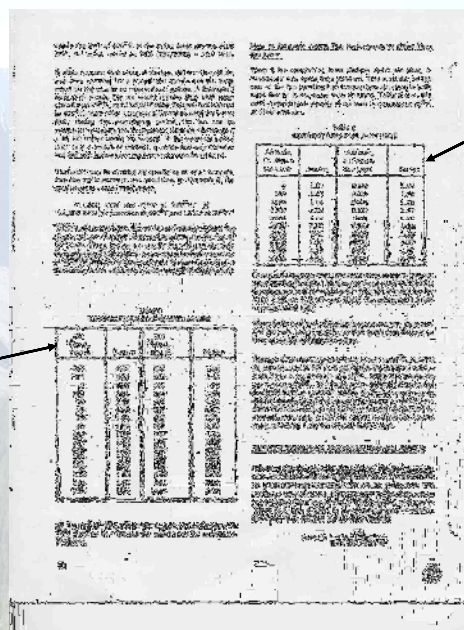
- Select from sea level tables or graphs:
  - RPM is the same at higher altitude (e.g. 1200 RPM)
  - CFM is the same at higher altitude (e.g. 10,000 CFM)
  - Correct brake horsepower by density ratio, for example 10 HP from sea level chart becomes 10 * 0.825 = 8.25 at 5,200 ft. altitude
- (More on pg. 7 of handout)

Fan and Duct System Calculations (page 4)

- The selection is thus 10,000 CFM, 1200 RPM, 4.9” s.p., AT 5200 FT. ALTITUDE **– or**
- 10,000 CFM, 1200 RPM, 6.0” s.p., AT SEA LEVEL
- Remember, derate the motor due to less motor cooling at higher altitude and add appropriate safety factors

Fan Performance

Reference page 7



Density correction

Table 1
CORRECTIONS FOR TEMPERATURE

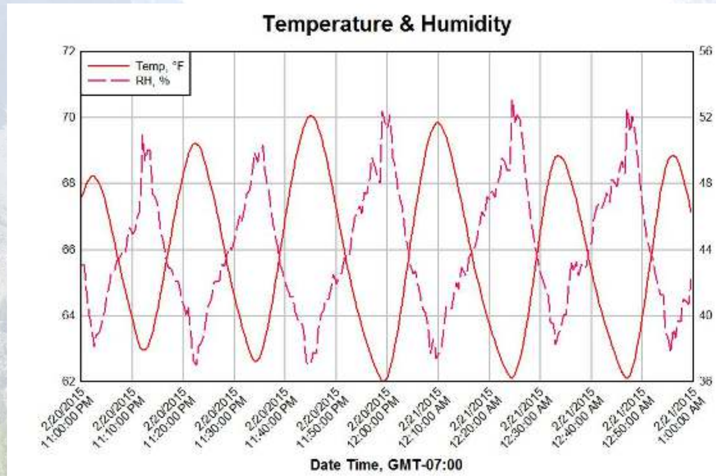
Air Temp., Deg. F.	Factor	Air Temp., Deg. F.	Factor
—50	0.77	275	1.39
—25	0.82	300	1.43
0	0.87	325	1.48
+20	0.91	350	1.53
40	0.94	375	1.58
60	0.98	400	1.62
70	1.00	450	1.72
80	1.02	500	1.81
100	1.06	550	1.91
120	1.09	600	2.00
140	1.13	650	2.10
160	1.17	700	2.19
180	1.21	750	2.28
200	1.25	800	2.38
225	1.29	900	2.56
250	1.34	1000	2.76

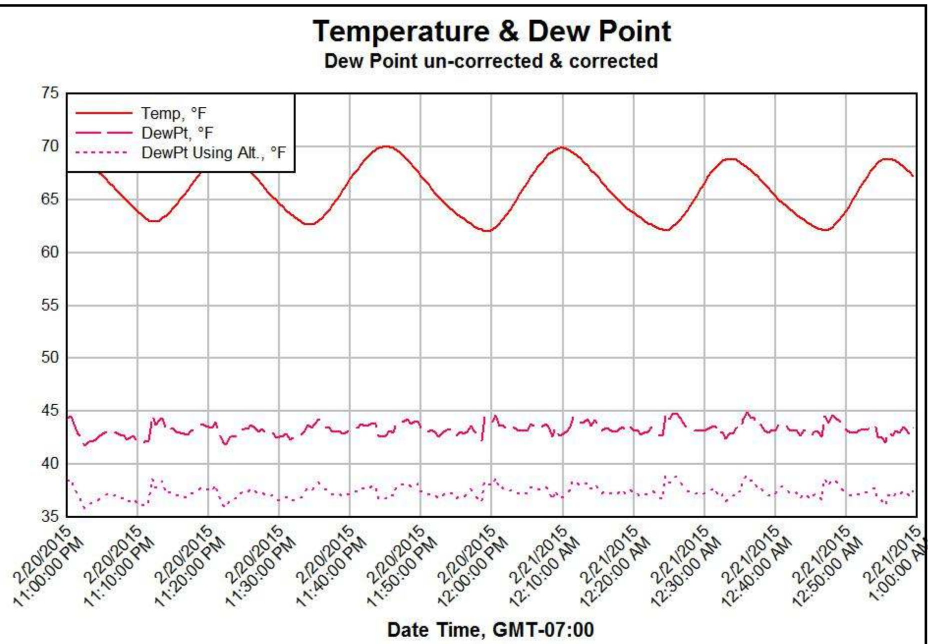
Table 2
CORRECTIONS FOR ALTITUDE

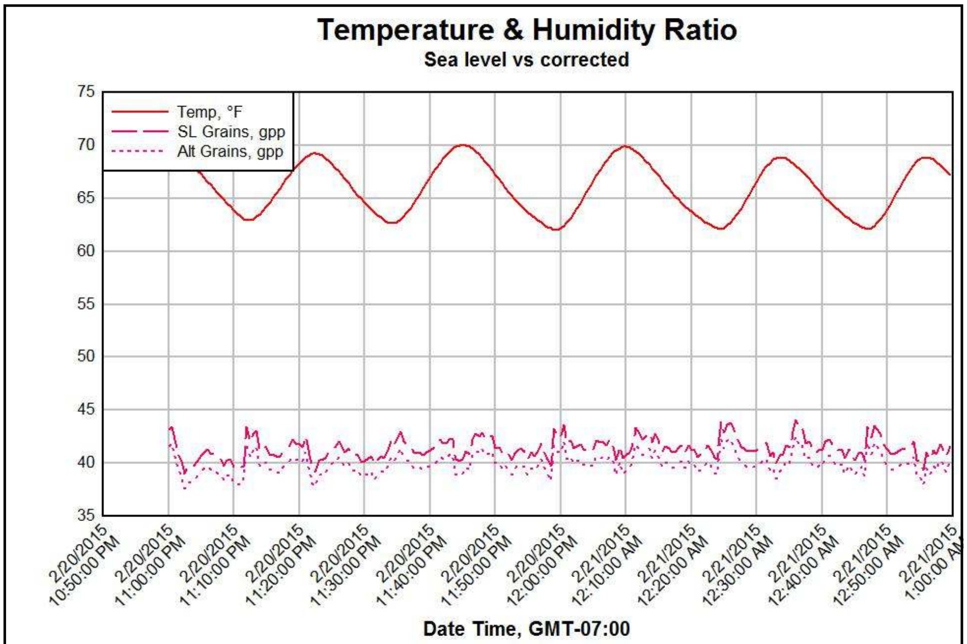
Density correction

Altitude, Ft. Above Sea Level	Factor	Altitude, Ft. Above Sea Level	Factor
0	1.00	5000	1.20
500	1.02	5500	1.22
1000	1.04	6000	1.25
1500	1.06	6500	1.27
2000	1.08	7000	1.30
2500	1.10	7500	1.32
3000	1.12	8000	1.35
3500	1.14	8500	1.37
4000	1.16	9000	1.40
4500	1.18	10000	1.45

Measurements or Data Logging
What needs correction?

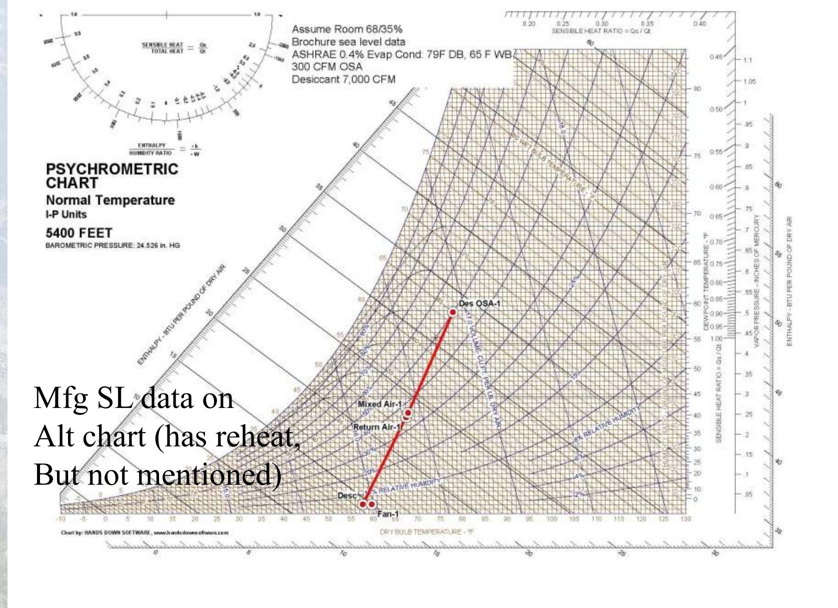






Desiccant Dehumidification

- Function of mass transfer & heat transfer, plus …
- Air is less dense at altitude
  - ❖ Less dehumidification capacity
- Use manufacturer's data if avail & if trust
- Otherwise, approx.: try derate of latent capacity by density ratio
  - ❖ Plot on psych chart using same CFM to determine dew point, etc.



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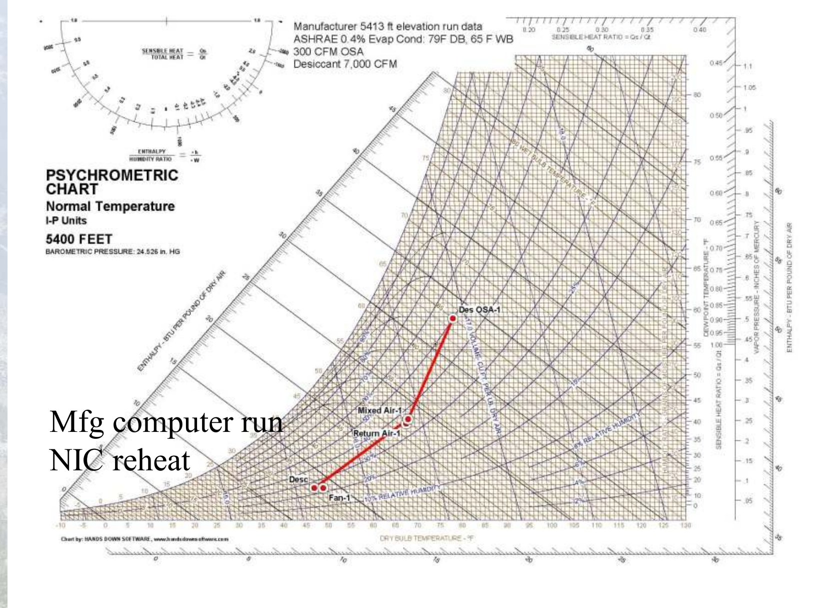
27



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28

Desiccant Dehumidification

- Verify if data includes reheat
- Example
- Sea Level data plotted on Alt chart
  - ❖164 MBH latent
  - ❖231 MBH total
- 5400 ft Air density ratio: 0.819
- Mfg run at alt plotted on psych chart
  - ❖124 MBH latent
  - ❖256 MBH total
- Note: SL data from Lit includes internal reheat. Mfg run above does not.
- Ratio, Latent: 0.756

Snow Entrainment; Louvers

- High Altitude Consideration
  - ❖Density, moisture content
  - ❖Hard to capture & melt – especially higher and colder environment
  - ❖Ice crystals
- No hard rules, except one:
  - ❖The space the architect allocated for louvers isn't enough

Snow Entrainment Louvers Guidelines

- Space to let snow drop out
- Space to melt
- Something to stop snow – not paper filters
- Easy access for frequent unplugging
- Location, location, location
- Typ 400 to 700 fpm Free area velocity, but won't stop light or wind-driven snow

Load Calculations: solar load Older data

- Due to altitude and location, a clearness factor of at least 1.15 is recommended (ASHRAE Applications, Chapter 33, Figure 5).
- https://en.wikipedia.org/wiki/Air_mass_%28solar_energy%29

Load Calculations: solar load Newer Data

- ASHRAE location data
- Monthly noon:
  - ❖ clear sky beam & diffuse optical depth
  - ❖ clear sky normal & diffuse horizontal irradiation (radiative energy flux)

Load Calculations (solar load):

- Using interpolation between stations
- Adjust for altitude
  - ❖ Call load program author
  - ❖ Guess at 2% to 3% per 1000 ft
- Adjust for cloudiness, pollution, local shading, humidity, …

Condensers, Air-cooled Chillers

- Packaged equipment:
  - ➢ Lower air density = less heat rejection = higher temperatures = more heat rejection
  - ➢ Therefore, counteracting forces. Net capacity reduction is typically less than air density ratio

Packaged equipment (page 2)

- ➢ Function of specific equipment design, refrigerant pressures, operating conditions, etc. Use manufacturer published corrections for altitude or call the manufacturer.
- ➢ Note in one Mfg's literature that correction factors for 5000 ft. elevation for air cooled condensers is 0.90 and for air cooled chillers is 0.97 for SPECIFIC series of equipment.

Air-cooled Chillers (page 1)

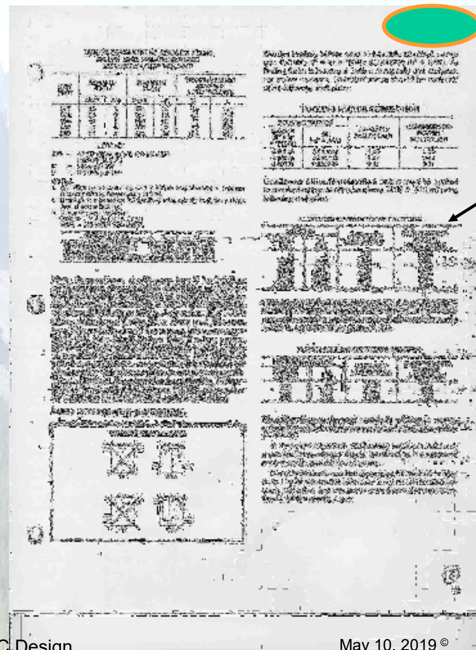
- Note Mfg A, Model B chiller data lists an 0.97 capacity correction factor for 6000 ft. altitude.
- Get the data for your specific application and selection if you need the accuracy.

Air-cooled Chillers (page 2)

- Mfg C, Model D literature lists capacity correction factors which combine fouling factor, chilled water DT, and altitude,
- and varies from 0.871 to 0.96 for 6000 ft. altitude. The correction from the standard condition (sea level, 10F DT, 0.00025 fouling factor, is 0.94.

Chillers

Reference
Page 3



Altitude
Correction
factors

Chillers

ALTITUDE CORRECTION FACTORS

ALTITUDE		CAPACITY MULTIPLIER	COMPRESSOR POWER MULTIPLIER
English (ft)	SI (m)		
0	0	1.00	1.00
2,000	610	0.99	1.01
4,000	1220	0.98	1.02
6,000	1830	0.97	1.03
8,000	2440	0.96	1.04
10,000	3050	0.95	1.05

Chillers

Reference Page 5

Performance Adjustment Factors (Cont.)

Chillers

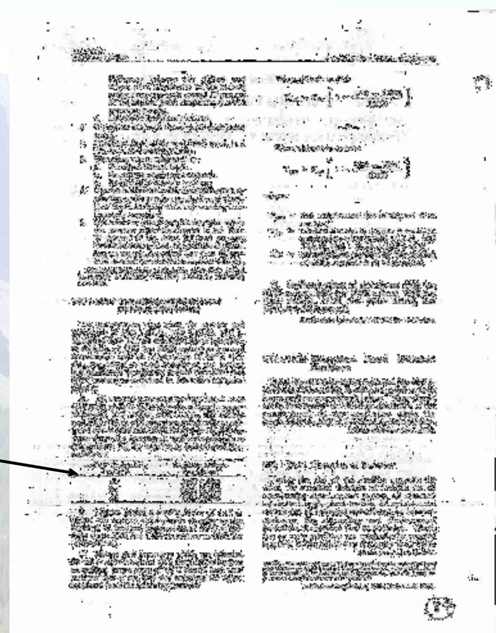
Performance Adjustment Factors (20-60 Ton Units Only)

Fouling Factor	Chilled Water ΔT	Altitude								
		Sea Level			2,000 Feet			4,000 Feet		
		CAP	GPM	KW	CAP	GPM	KW	CAP	GPM	KW
0.00025	6	0.987	1.650	0.993	0.967	1.640	1.003	0.952	1.620	1.019
	8	0.993	1.250	0.997	0.973	1.240	1.007	0.956	1.220	1.025
	10	1.000	1.000	1.000	0.980	0.990	1.010	0.960	0.970	1.030
	12	1.007	0.820	1.003	0.987	0.810	1.013	0.966	0.800	1.035
	14	1.013	0.710	1.007	0.993	0.700	1.017	0.972	0.680	1.038
	16	1.020	0.640	1.010	1.000	0.630	1.020	0.980	0.620	1.040
0.001	6	0.957	1.615	0.979	0.953	1.600	0.989	0.931	1.570	0.990
	8	0.964	1.215	0.982	0.959	1.210	0.992	0.937	1.180	0.994
	10	0.970	0.965	0.985	0.964	0.960	0.995	0.943	0.940	0.998
	12	0.976	0.785	0.989	0.966	0.790	0.998	0.945	0.770	1.007
	14	0.982	0.675	0.993	0.968	0.670	1.001	0.947	0.650	1.016
	16	0.989	0.620	0.996	0.970	0.600	1.004	0.949	0.590	1.025
0.002	6	0.916	1.565	0.951	0.913	1.550	0.969	0.896	1.490	0.975
	8	0.923	1.245	0.958	0.919	1.170	0.972	0.898	1.110	0.979
	10	0.930	0.925	0.965	0.925	0.920	0.975	0.900	0.890	0.982
	12	0.934	0.810	0.969	0.927	0.750	0.978	0.908	0.730	0.986
	14	0.938	0.695	0.973	0.929	0.640	0.981	0.916	0.620	0.989
	16	0.948	0.580	0.976	0.931	0.580	0.983	0.924	0.580	0.993

Air-cooled Electric Motors

- Limited by allowable temperature
- Higher altitude = less air = less cooling = lower rated capacity
- Standard motors rated at 1,000 meters (3,300 ft.) altitude
- Again, manufacturer's design details are a factor. When critical, get data from the selected manufacturer.

Reference page 39



Electric motors

Motors with Class A or B insulation altitude rating increases as ambient temperature is lowered

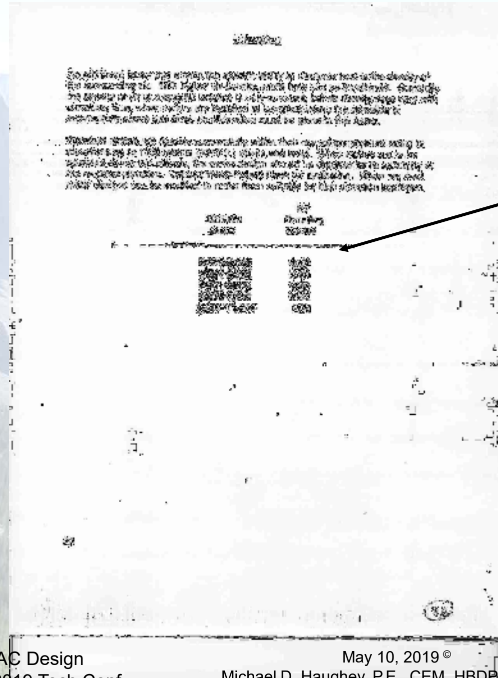
Ambient Temperature, Degrees C	Maximum Altitude, Feet (Meters)
40	3300 (1000)
30	6600 (2000)
20	9900 (3000)

Air-cooled Electric Motors (page 2)

- ANSI / NEMA Standard MG-1
  - Motors rated at 40C which are intended for use above 1000 meters should have the allowable temperature rise reduced in accordance with mfg's formula
- Mfg E listed a correction factor for their Model F induction motor of 0.94 at altitudes from 5,001 ft. to 6,600 ft.

Reference
Page 36

Electric motors



Altitude Correction factors

Electric motors

Altitude (feet)	HP Derating Factor
3,300-5,000	0.97
5,001-6,600	0.94
6,601-8,300	0.90
8,301-9,900	0.86
9,901-11,500	0.82

Combustion Equipment

- Gravity, packaged equipment, AGA: de-rate by 4% / 1,000 ft. (volume of combustion air & flue gas increases about 4%/1,000 ft.)
  - Typically de-rate when above 2,000 ft. elevation
  - Often reduce gas orifice size to match gas input to altitude air
  - Some boiler manufacturers have condensing boilers with "lower altitude derates".

Combustion Equipment (page 2)

- Design Options
  - Decrease gas manifold pressure
  - Increase gas orifice pressure loss (smaller orifices)
  - Increase airflow (mass flow) with power burner fan, forced draft fan, or induced draft fan

Combustion Equipment (page 3)

- Gas Heat Content
  - Reduces according to the air density ratio
  - Typically 1,000 BTU per Cu. Ft. at sea level, 830 BTU per Cu. Ft. at 5,000 ft. altitude, etc.
- Some utilities vary the heat content, therefore call the utility for the specific location. Some increase the heat content to achieve 1,000 BTU per Cu. Ft. at 5,000 ft. altitude.

(see "Boiler House Journal", near end of handout)

Hugo, CO vs. Denver

Hugo, CO	Denver
Altitude 5046	5200
Rel density: 0.830	0.825
Btu content: 780	831
SG: 0.65	0.67
Peoples Gas Company	Excel Energy

Las Animas, CO vs. Denver

Las Animas, CO	Denver
Altitude: 3901	5200
Rel density: 0.867	0.825
Btu content: 735	831
SG: 0.62	0.67
Citizen's Utility Company	Excel Energy

- Citizen's Utility Company
  - ❖ Internet search – not found
  - ❖ Black Hills Energy?

Combustion Equipment (page 4)

- Flue Design
  - ➢ Available draft decreases substantially at higher altitudes
  - ➢ Follow the manufacturer's procedures or ASHRAE procedures, which account for altitude barometric pressure

Packaged Boilers

Boiler Options			
Altitude: 7800			
Load without morning warmup		Boiler Rating	
		Alt	Eff
Existing Boiler: Mfg A Model A Gravity		0.768	0.82
Mfg A Model A Gravity		0.768	0.82
Mfg B Model A Condensing		0.766	0.95
Mfg A Model B High Altitude Condensing		1	0.95
Mfg C Model A Condensing		0.766	0.95
Mfg B Model B cast iron - copper fin tube		0.688	0.85
Mfg D Model A		0.768	0.82
Mfg E Model A		0.768	0.833
Cast Iron models, high eff:			
Not available			
Sealed Combustion, modulating:			
Mfg B Model C	No longer made?	0.688	0.85
Mfg F Model A	A little too small with alt derate	0.768	0.88
	Alt derate at 50% max Flue/CA	0.797	0.88

Packaged Boilers

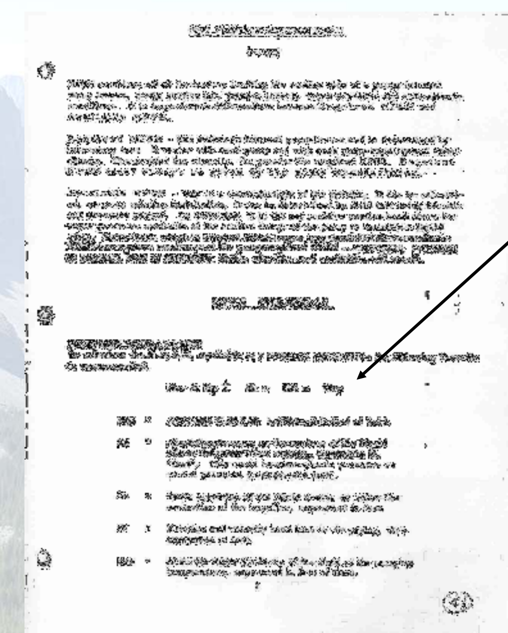
- Cf = 1-(((Alt-2000)/1000)*0.04)
  - ❖For a particular gravity boiler
- Cf = 1-((Alt/1000)*0.03)
  - ❖For a particular condensing boiler
- Cf = 1-((Alt/1000)*0.04)
  - ❖For a particular gravity boiler
- Alt derate at 50% max Flue/CA = 0.797
  - ❖For a particular sealed combustion boiler

Pumps

- Three concerns:
  - NPSH
  - Cavitation
  - Motor cooling / rating
- All are air density related
  - Use the standard formulas with actual barometric pressure data
- NPSH: less barometric pressure on open systems, 6 ft. less at 5000 ft. altitude
- Cavitation: less barometric pressure on open systems

Pumps

Reference
Page 41

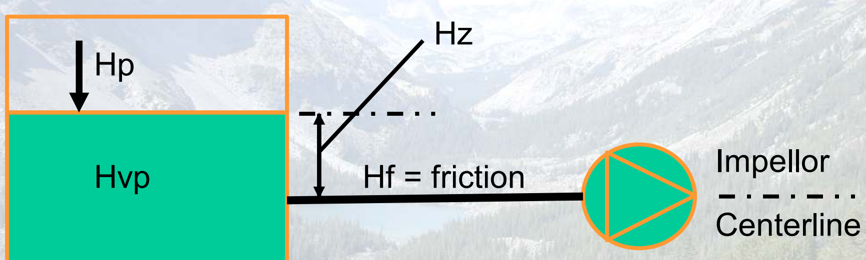


NPSH
Formula

NPSH

- Hsv = available NPSH in ft of fluid
- Hp = absolute pressure on liquid surface, ft
- Hz = height of liquid surface above impellor centerline, ft
- Hf = friction and velocity head loss, ft
- Hvp = absolute vapor pressure at pumping temperature, ft

Available NPSH = Hsv
H = "head"
Hsv = Hp ± Hz – Hf - Hvp



$$Hsv = Hp \pm Hz - Hf - Hvp$$

Hsv = Available N. P. S. H. expressed in feet of fluid.

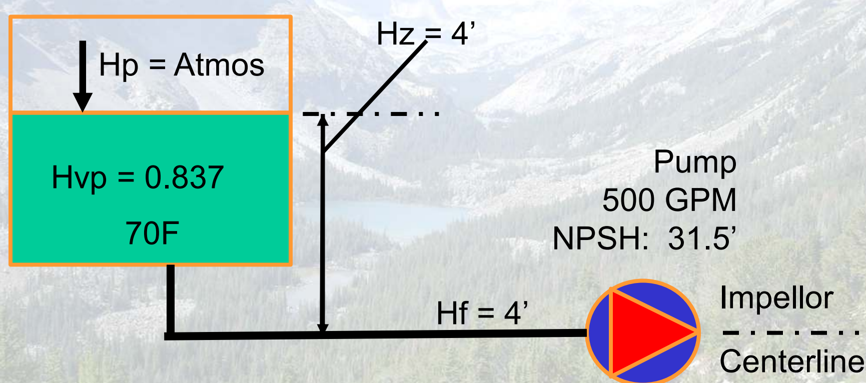
Hp = Absolute pressure on the surface of the liquid where the pump takes suction, expressed in "feet". This could be atmospheric pressure or vessel pressure (pressurized tank).

Hz = Static elevation of the liquid above, or below the centerline of the impeller, expressed in feet.

Hf = Friction and velocity head loss in the piping, also expressed in feet.

Hvp = Absolute vapor pressure of the fluid at the pumping temperature, expressed in feet of fluid.

Example – Cooling Tower



Hsv = Hp ± Hz – Hf - Hvp

- Sea Level
  - ❖Hsv = 34’ + 4’ – 4’ – 1’ = 33’
  - ❖OK
- 5000 ft
  - ❖Hsv = 28’ + 4’ – 4’ – 1’ = 27’
  - ❖Will cavitate

Another NPSH Formula

- For your homework
- Use the formula on Reference page 47

Pumps

Reference page 47

NPSH Formula

Pumps

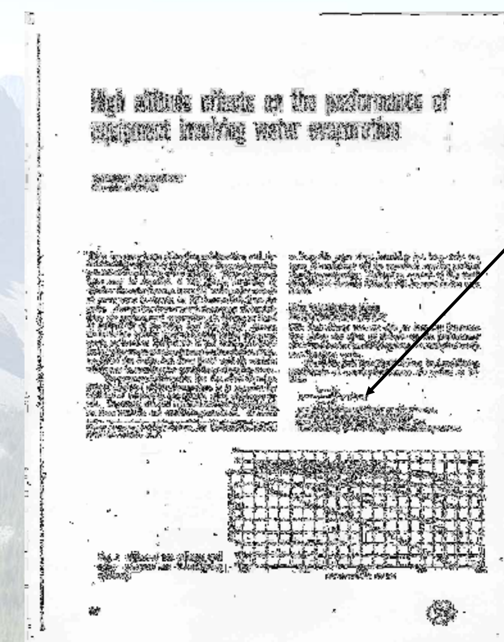
Reference page 47

Evaporative Coolers

- Significant Parameters
  - Mass Velocity
  - Air Density
  - Heat Transfer Coefficient, turbulence at boundary layer
  - Water Vapor Pressure
- Density and heat transfer coefficient and vapor pressure effects are compensating
  - Data hard to find, typically not derated for altitude
  - Accurate selections typically not needed

Evaporation

Reference Page 73



“Humidification Effectiveness Formula

Effectiveness

Evaporation

$$\eta = \frac{t_E - t_L}{t_E - t'}, \text{ where}$$

η = humidifying efficiency or effectiveness,
t_E = entering dry-bulb temperature,
t_L = leaving dry-bulb temperature, and
t' = entering (and leaving) wet-bulb temperature.

Cooling Towers

- Some controversy before computer selections
  - ❖Don't derate but increase fan motor HP
  - ❖Don't derate
  - ❖Don't derate and reduce fan motor HP
  - ❖Add capacity at higher altitude

Cooling Towers

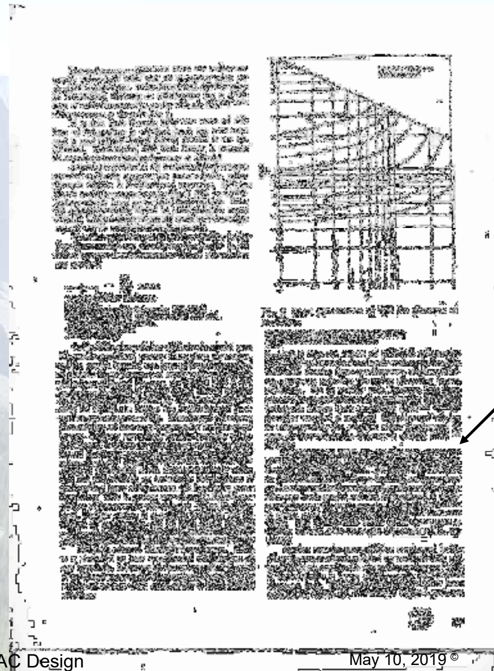
- For some (or most typical, higher WB) operating conditions, increased water partial pressure at higher altitudes may have a greater effect in increasing capacity than reduced density does in reducing capacity
- Cold air operation – economizers: less capacity.

Cooling Towers

- Data hard to find, normally included in selection software
- Some info at CTI.org/tech_papers

Reference Page 74

Cooling Towers



One Method

Cooling Towers

Correspondence from one manufacturer states emphatically that he does *not* derate evaporative type equipment for the effect of altitude. All equipment is selected as if it were to perform at sea level, i.e., rating systems are based on sea level test data and psychrometric charts. However, he does point out that he has found it neces-

Cooling Towers (page 2)

- Increased capacity factor due to increased enthalpy at higher altitudes is more pronounced at higher entering wet-bulb temperature.
- Per one manufacturer's representative, 1/2% per 1000 ft. for 65F EWB and 1.25% per 1000 ft. for 78°F EWB.

Cooling Towers (page 3)

- What about much lower EWB, such as hydronic economizer applications???
- Lower density overpowers the added capacity from increased vapor pressure at higher altitude
- Therefore at lower temperatures there is a net reduction in capacity

Summary

- Use Mfg data where available, BUT check it to be sure reasonable
- Consider
  - ❖density
  - ❖Heat transfer
  - ❖Motor cooling
  - ❖Vapor pressure
  - ❖Mass flow
- Be aware of counteracting factors
- Use altitude psych charts
- Be sure of the altitude for data
- Use absolute barometric pres.

Questions & Comments?