Presentation to:

Rocky Mountain ASHRAE

2023 Tech Conference

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by:

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High Altitude HVAC

Design Considerations

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

- NOTE:
  - ❖ Reference numbers refer to circled number, lower right, of posted reference material.

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 Example Updates

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

- 2022
  - ❖ Equiv. Mass Transfer
  - ❖ Computer Equipment Selections
- 2023
  - ❖ Self-Contained Dehumidifiers

**Airflow Calculations
– (Sensible Only)**

- cfm = (Btu / hr) / (C_P * p * 60 * DT)

- Let C_P * p * 60 = F_{CFM}

$$F_{CFM} = \text{"CFM transfer factor"}$$

- 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		SPECIFIC VOLUME CU FT PER LB	REL DEN SP OR HP CORR FACT	AIR DENSITY LBS/CU FT	CFM TRANS. FACTOR	CFM CORRECT FACTOR
	INCHES MERCURY	LBS/SQ IN ATMOS.					
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 TRANE 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

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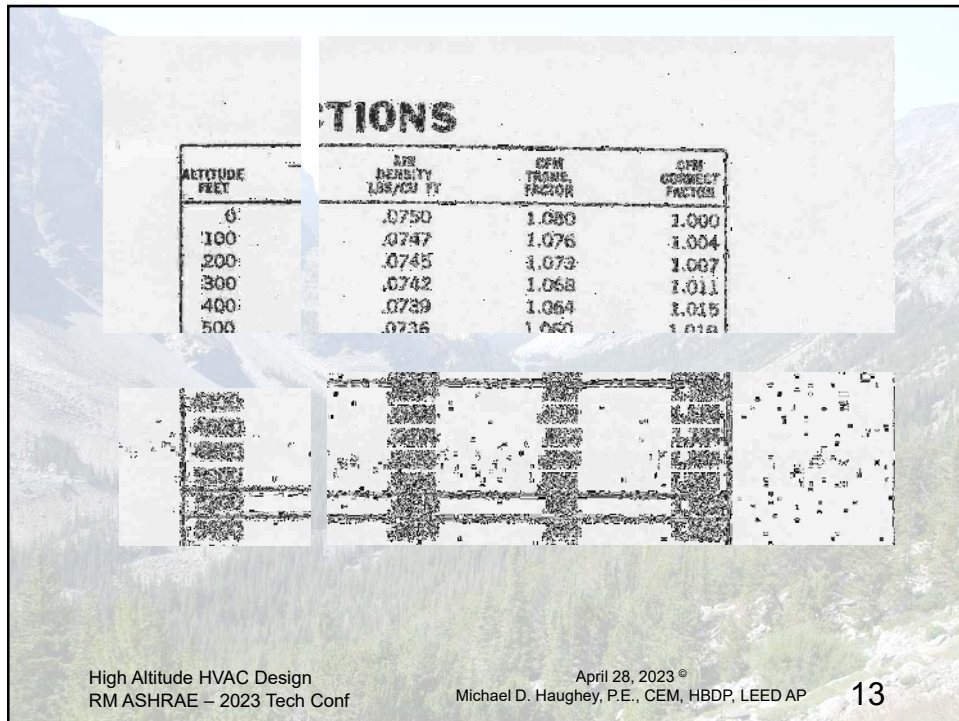April 28, 2023 ©
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Airflow Calculations (page 2)

- Example - sea level:
  - 10,000 Btuh (Sens), 20F DT: find CFM

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

  - cfm = 10,000 Btuh / (1.08 * 20) = 463

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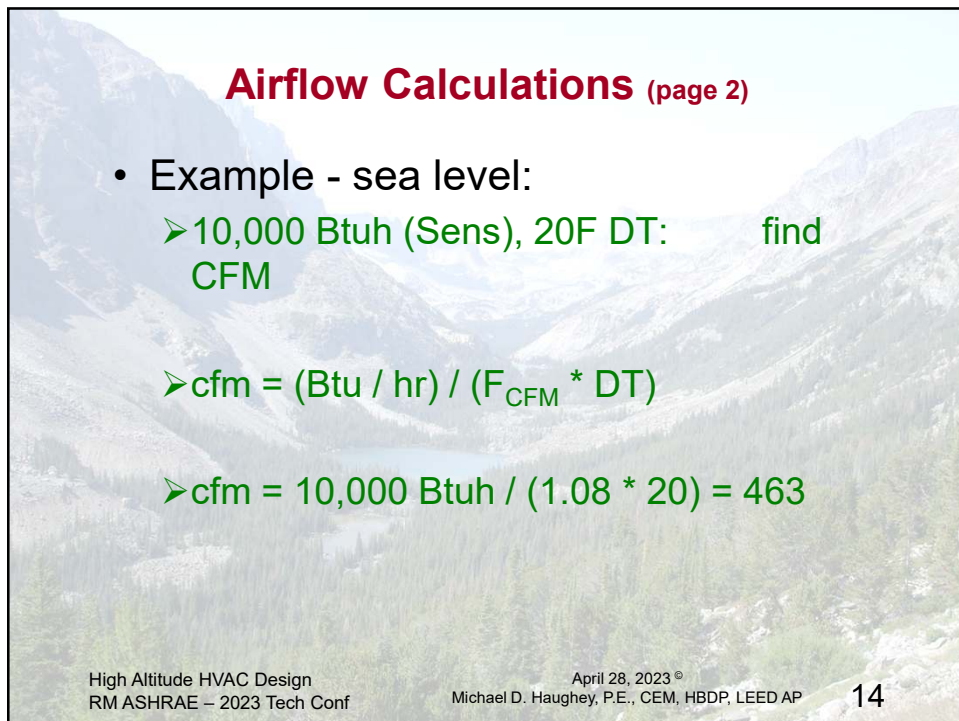## Airflow Calculations (page 3)

- 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

Equivalent Mass Transfer

- Fluid & temperatures the same
- Altitude changes

- Mass Transfer changes
- Increase CFM to achieve equivalent mass transfer

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 Sens)

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

Reference page 7

Fan Performance

Altitude Correction factors

Temperature Correction factors

Density correction

See Reference page 7 for example

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?

- Instruments without altitude input

Measurements or Data Logging
Data Logger – No Altitude Input

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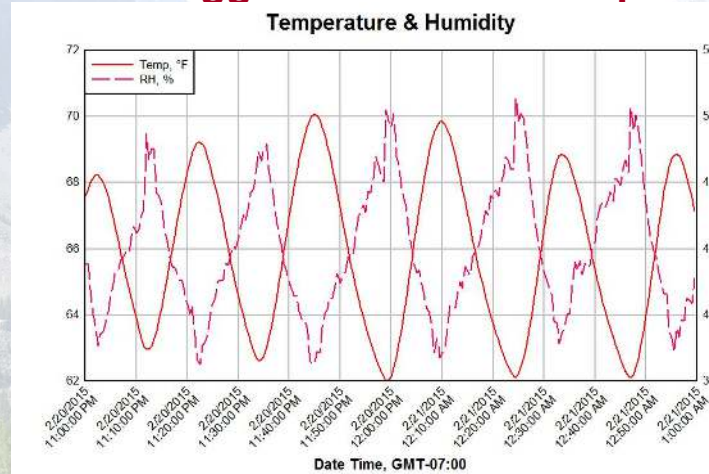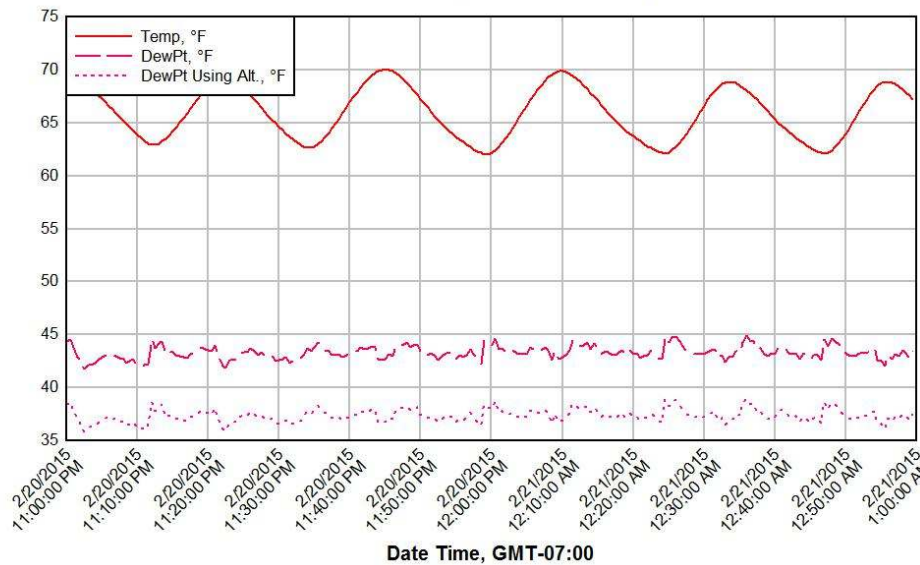Michael D. Haughey, P.E., CEM, HBDP, LEED AP

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Temperature & Humidity Ratio
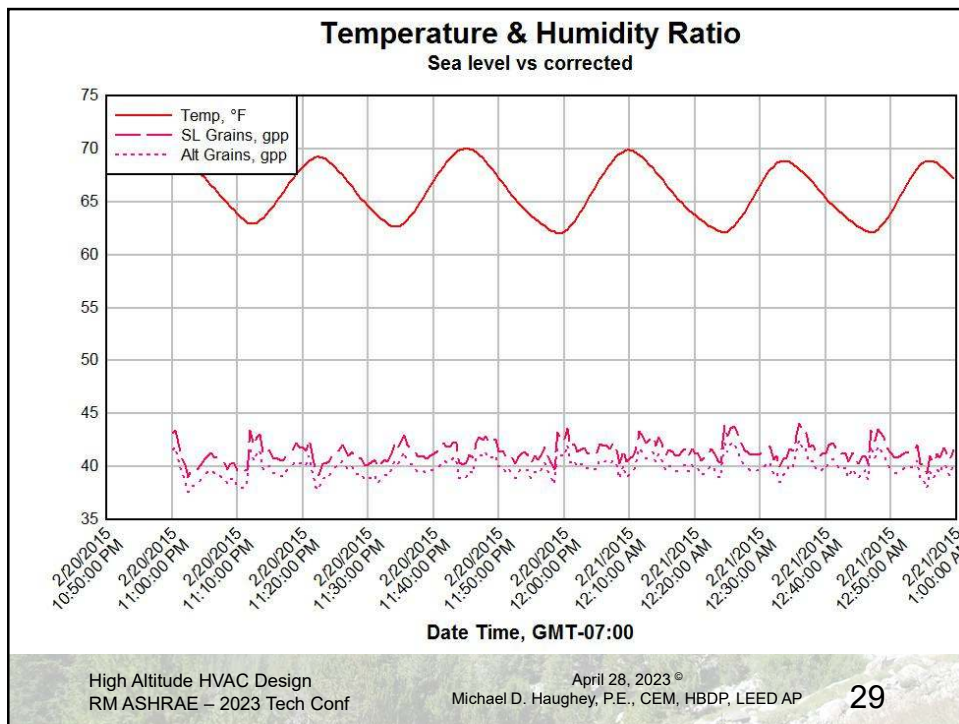Sea level vs corrected

Legend:
- Temp, °F
- SL Grains, gpp
- Alt Grains, gpp

Date Time, GMT-07:00

Computer Equipment Selections

- Confirm altitude input
- Confirm correct Altitude printed on output

- If NOT clear (altitude not on output)
  - ❖ Ask for run at SL and run at Altitude
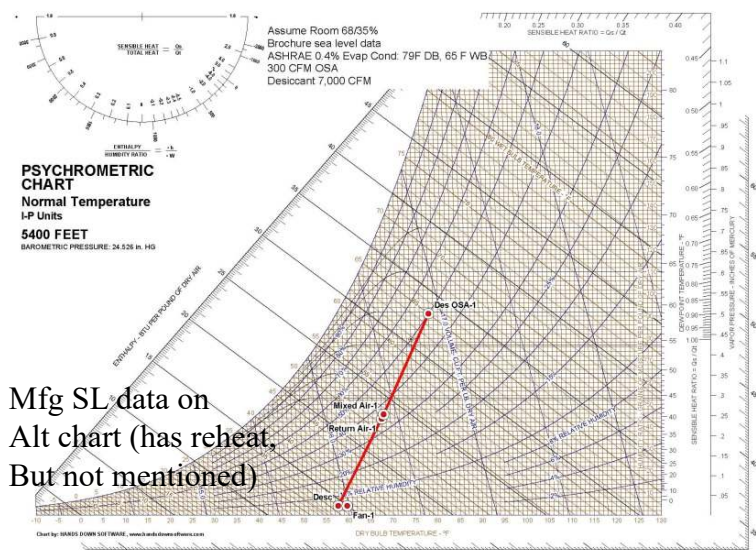 - ❖ (Also the first time using any software)

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.

Mfg SL data on
Alt chart (has reheat,
But not mentioned)

Verify if data includes reheat

Mfg computer run NIC reheat
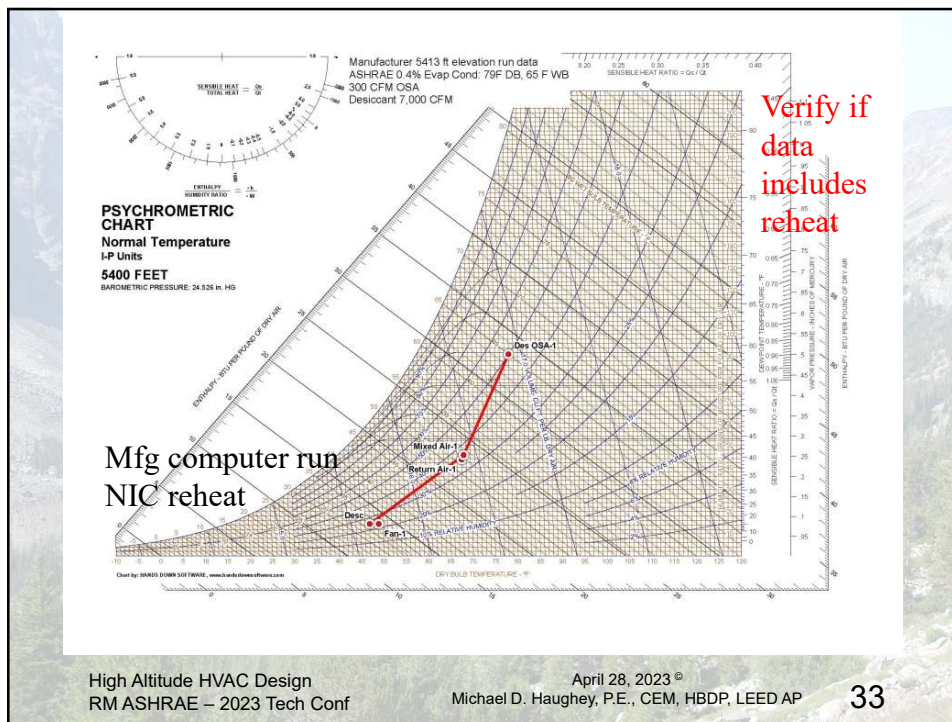
Desiccant Dehumidification

- Test density ratio:
- Sea Level data plotted on Alt chart
  - ❖ 164 MBH latent
  - ❖ 231 MBH total
- Mfg run at alt plotted on psych chart
  - ❖ 124 MBH latent
  - ❖ 256 MBH total

- 5400 ft Air density ratio: 0.819
- Note: SL data from Lit includes internal reheat. Mfg run above does not.
- 124/164 = 0.756
- Therefore density ratio not accurate

Snow Entrainment; Louvers

- High Altitude Consideration
  - ❖ Density, moisture content
  - ❖ Hard to capture & melt – especially higher and colder environment
  - ❖ Ice crystals (very light weight)

- 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
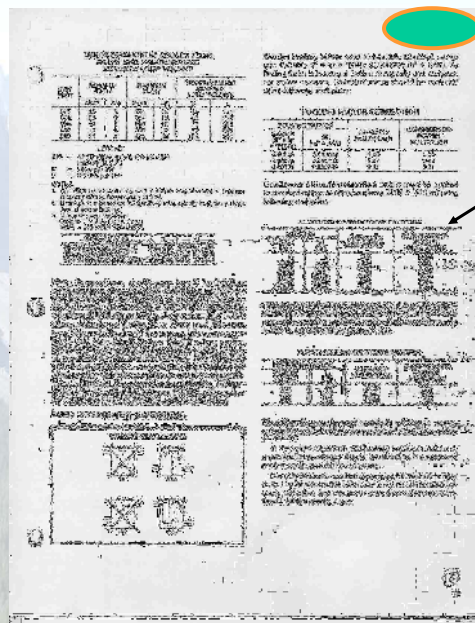
Chillers

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 (20-60 Ton Units Only)

Fouling Factor	Chilled Water ΔT	Sea Level			Altitude					
					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	0.960	0.800	1.035
	14	1.013	0.710	1.007	0.993	0.700	1.017	0.966	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

Table 18-2   Per...

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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.

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Reference page 39

Electric motors

Motor Rating limits

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.

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Reference Page 36
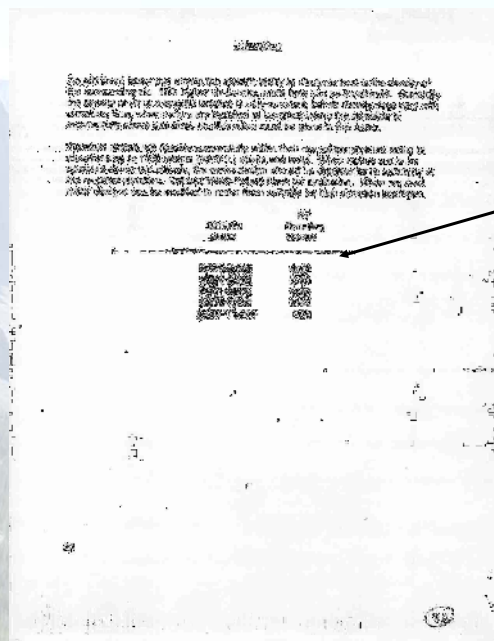
Electric motors

Altitude Correction factors

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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

Electric motors

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.
  - Utility gas heat:
    - See reference pdf pg 22, but call to verify

- 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

- Altitude 5046
- Rel density: 0.830
- Btu content: 780
- SG: 0.65
- Peoples Gas Company

- 5200
- 0.825
- 831
- 0.67
- Excel Energy

Las Animas, CO   vs. Denver

- Altitude: 3901
- Rel density: 0.867
- Btu content: 735
- SG: 0.62
- Citizen's Utility Company
  - ❖Internet search – not found
  - ❖Black Hills Energy?

- 5200
- 0.825
- 831
- 0.67
- Excel 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		Boiler Rating	
Altitude: 7800			
Load without morning warmup			
		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

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Reference Page 41

NPSH Formula

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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

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Available NPSH = Hsv
H = "head"
$$Hsv = Hp \pm Hz - Hf - Hvp$$

Hz

Hp

Hvp

Hf = friction

Impellor

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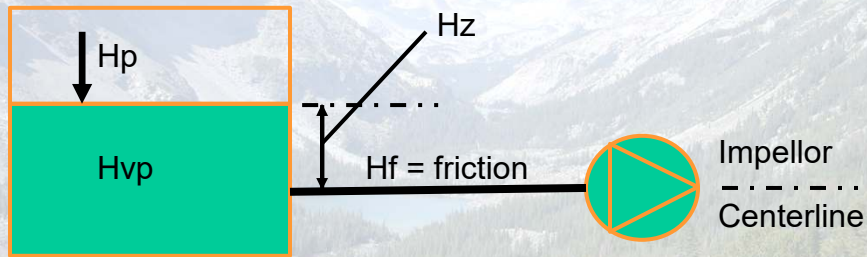
$$Hsv = Hp \pm Hz - Hf - Hvp$$

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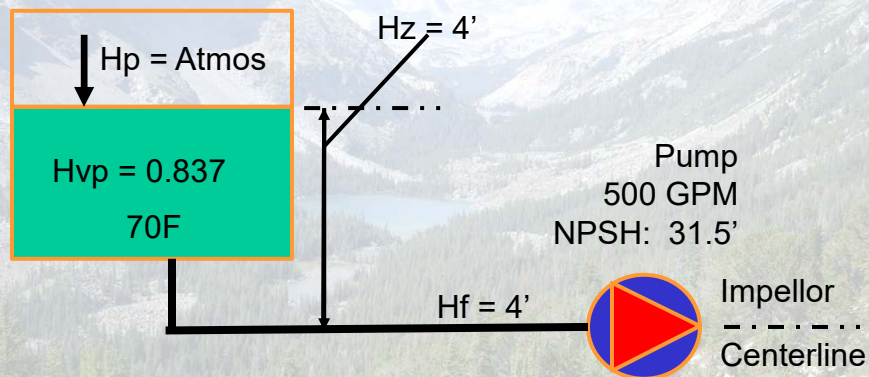
Hz = Static elevation of the liquid above, or below the centerline of the impeller, expressed in feet.

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

Hz = 4'

Hp = Atmos

Hvp = 0.837

70F

Pump
500 GPM
NPSH: 31.5'

Hf = 4'

Impellor

Centerline

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

- 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

Reference
page 47

Pumps

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

Reference Page 73

Evaporation

"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
  - ❖ https://www.coolingtechnology.org/shop
  - ❖ Couldn't find in recent search: The 3 altitude papers have been removed: TP62-04, TP82-13, & TP83-09
  - ❖ Likely replaced by computer models

Reference Page 74
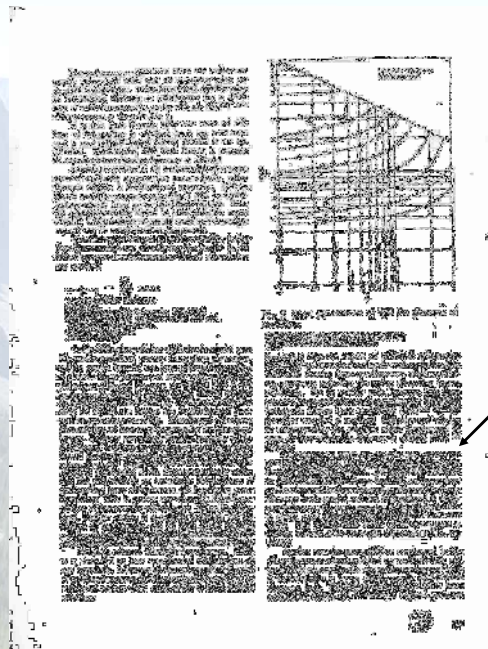
Cooling Towers

One Method

> 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-

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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

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Self-Contained Dehumidifiers

- Common use: grow facilities
- Typical rating condition:
  - ❖ 80F, 60% RH
- Altitude data often not available
- Lower temp/RH data often not avail

- Get data or don't use mfg or use huge disclaimers

Self-Contained Dehumidifiers (pg 2)

- Example product:
- 225 pints per day at 80F/60% RH
  - ❖ Assumes running 24/7
  - ❖ Adjust: 18.75 pts/hr
- Mfg altitude recom:
  - ❖ Density ratio
  - ❖ 5200 ft: 15.5 pts/hr

- Mfg est 75F/50% RH:
  - ❖ 133 pts/day
  - ❖ 4.8 pts/hr
- Mfg altitude recom:
  - ❖ Density ratio
  - ❖ 5200 ft: 3.96 pts/hr
    - ➢ 95 pts/day

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.