



How Ambient Conditions Impact the Rating of Electrical Equipment

An Online Continuing Education Course for Engineers

Course Number: E-1015

Credit: 1 Hour / 1 PDH / 1 CPD

How Ambient Conditions Impact the Rating of Electrical Equipment

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Background

A large array of electrical equipment is cooled using air. Manufacturers providing ratings for electrical equipment based on a defined air density, ambient temperature and other environmental factors. Electrical equipment ratings will be affected by these changing conditions.

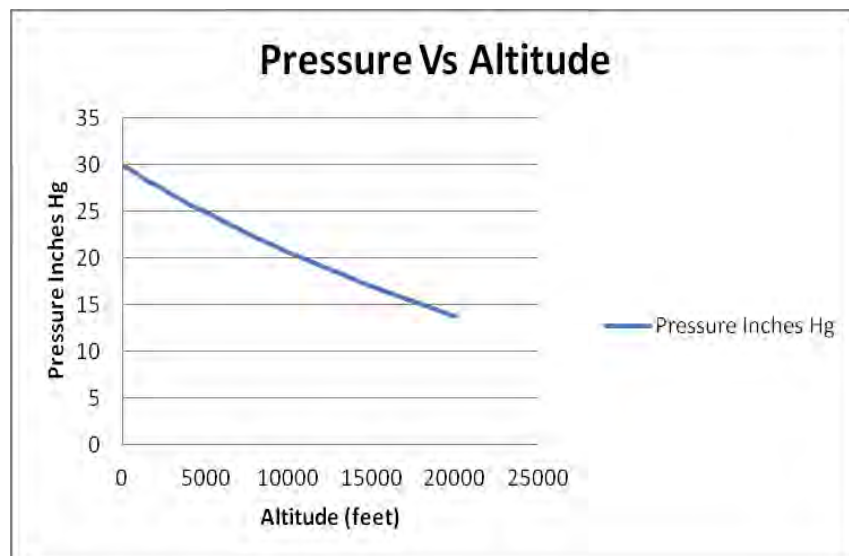
For example, air density is dependent upon altitude. If the equipment is utilized beyond the manufacturer's defined specifications, the equipment should be altered accordingly.

The purpose of this course is to discuss how to rate electrical equipment at various ambient conditions in order to estimate sizes for project costs and space requirements. As we shall discuss, these rating factors will modify the nameplate ratings for electrical equipment. Equipment can be reduced or modified to account for altitude, temperature and humidity.

Air Density

As altitude increases, air pressure decreases, which in turn reduces the air density. Air density plays a key role in the ability of air to remove heat. As the air density decreases, the ability for the air to cool the equipment decreases. This is an issue for installations in which the altitude is more than 3,280 feet above sea level (ASL).

The following table and graph illustrate the relationship between altitude and air pressure.



Elevation Feet	Pressure Inches Hg
0	29.9
500	29.4
1000	28.9
1500	28.3
2000	27.8
2500	27.3
3000	26.8
3500	26.3
4000	25.8
4500	25.4
5000	24.9
6000	24
7000	23.1
8000	22.2
9000	21.4
10000	20.6
15000	16.9
20000	13.8

The following formula is used to determine how air density affects cooling ability. The cooling capacity of air is expressed in British Thermal Units (BTU):

$$\text{Cooling BTU's} = (\rho \times 60) \times \text{CFM} \times \text{Change in Enthalpy}$$

Where ρ is the density of air expressed as:

$$\rho = 1.325 p_{in\ Hg} / T_R$$

And:

$$T_R = (T_F + 460.7)$$

$$\rho = \text{density (lb/ft}^3\text{)}$$

$$p_{in\ Hg} = \text{absolute pressure (inches Hg)}$$

$$T_R = \text{absolute temperature (Rankine)}$$

$$p_{psia} = \text{absolute pressure (psia)}$$

$$p_{psig} = \text{gage pressure (psig)}$$

$$T_F = \text{temperature (}^\circ\text{F)}$$

$$\text{CFM} = \text{cubic feet per minute}$$

Example:

What is the cooling BTU's of 70 °F air at sea level and at 8,000 feet ASL for 1 cubic foot for minute (CFM) and 1 BTU/lb change in Enthalpy?

At sea level

$$\begin{aligned}\rho &= (1.325 \times 29.9 \text{ inHg}) / (70 \text{ }^\circ\text{F} + 460.7) \\ \rho &= 39.618 / 530.7 \text{ }^\circ\text{R} \\ \rho &= 0.075 \text{ lb/ft}^3\end{aligned}$$

$$\begin{aligned}\text{Cooling BTU's} &= (\rho \times 60) \times \text{CFM} \times \text{Change in Enthalpy (BTU/lb)} \\ \text{Cooling BTU's} &= (0.075 \text{ lb/ft}^3 \times 60 \text{ m}) \times 1 \text{ ft}^3/\text{m} \times 1 \text{ BTU/lb} \\ \text{Cooling BTU's} &= 4.5\end{aligned}$$

At 8,000 feet ASL

$$\begin{aligned}\rho &= 1.325 \times 22.2 \text{ inHg} / (70 \text{ }^\circ\text{F} + 460.7) \\ \rho &= 29.41 / 530.7 \text{ }^\circ\text{R} \\ \rho &= 0.055 \text{ lb/ft}^3\end{aligned}$$

$$\begin{aligned}\text{Cooling BTU's} &= (0.055 \text{ lb/ft}^3 \times 60 \text{ m}) \times 1 \text{ ft}^3/\text{m} \times 1 \text{ BTU/lb} \\ \text{Cooling BTU's} &= 3.3\end{aligned}$$

From the above example, the reduction in cooling capacity from sea level to 8,000 feet ASL is:

$$\% \text{ change} = (3.3 / 4.5 \times 100\%) - 100\% = -26.67\% \text{ reduction of cooling capacity of air}$$

This will have an impact on THE equipment's ability to cool devices which require air flow for cooling. To compensate for the decreased cooling capacity of air at higher altitudes, an increase in cooling methods is required in order to maintain electrical ratings. Alternatively, the equipment can be de-rated from the nameplate values in order to avoid overheating.

Ambient Air Temperature

As altitude increases, the ambient air temperature generally decreases. The effect is related to the fact that the air expands as its density decreases. When air expands, its temperature decreases. Typically, this is approximately 4 degrees F per 1,000 foot elevation gain. This temperature decrease somewhat offsets the loss in CFM, but not to the degree required in order to maintain the sea level rating.

Elevation Feet	Temp Deg F
0	59
1000	55.4
2000	51.9
3000	48.3
4000	44.7
5000	41.2
6000	37.6
7000	34.1
8000	30.5
9000	26.9
10000	23.4
11000	19.8
12000	16.2
13000	12.7
14000	9.1

Humidity

Humidity is a measurement of the water content or moisture in air at a given volume.

There are two standard definitions for humidity measurement:

- Absolute Humidity (ah): the water content of air.
- Relative Humidity (rh): the absolute humidity relative to the maximum of humidity for the given temperature, expressed as a percentage. 0% is absolute dry air, and 100% is totally saturated air. Relative humidity is most often used in the rating of electrical equipment.

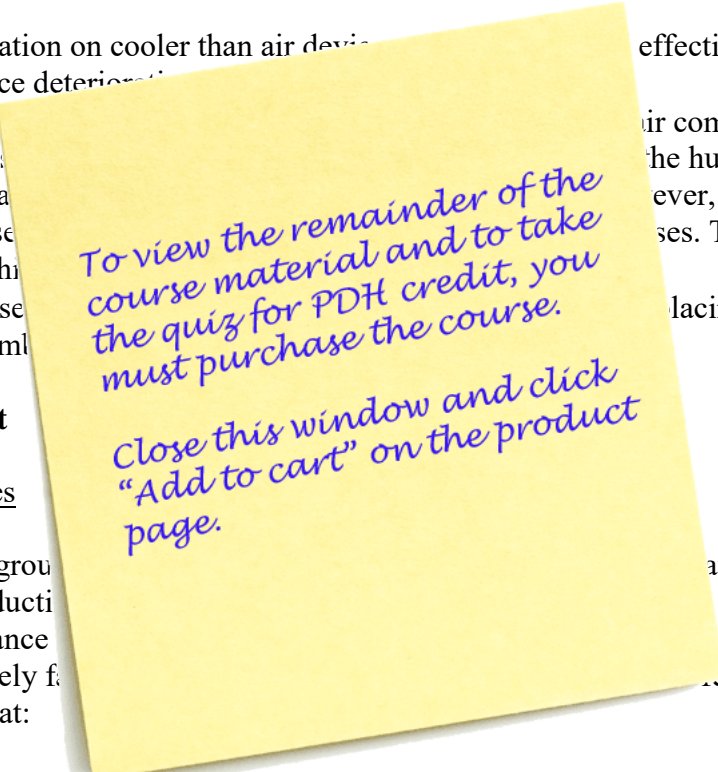
Humidity has the following affects on electrical equipment:

- As humidity increases, the thermal conductivity of air decreases. This will have a slight impact on equipment. Additional de-rating factors are generally not considered.
- Humidity affects the dielectric strength of air. Estimates and approximations should be applied to determine the dielectric strength at various conditions.
- High humidity environments will cause condensation on cooler devices. Motors, generators, and electronic devices which are shut down and allow cooling will be at risk for condensation. This condensation will lead to corrosion and/or failure of the device and if the condensation not managed.

- Recently, articles have been published discussing oil filled transformers with radiators and the affect that high humidity environments may have on transformer cooling. Experimental data indicates that an environment in a high humidity (50% rh or greater) area may increase the temperature rise in distribution transformers up to 5 degrees C.

It is also important to note there are several other implications when dealing with high humidity environments. High humidity climates will:

- Cause condensation on cooler than air devices, reducing their effectiveness and leading to device deterioration.
- Increase the horsepower required for air compressors and internal combustion engines. As the humidity decreases, the density of the air increases. However, since the air density decreases, more CFM is required for the same horsepower.
- Cause a decrease in the efficiency of combustion, requiring more oxygen for combustion.



Effects on Equipment

Semiconductor Devices

Semiconductors are a group of materials. Resistance is varied between conductors and insulators. Heat is generated in the device by resistance. As the temperature of the device will ultimately fail. Heat sink mechanisms are used to remove this heat:

- Conduction: heat transfer from one atom to another. Substances vary in their thermal conductivity.
- Convection: removal of heat by flow of air or water across objects whose temperature is higher than that of the air or water.
- Radiation: heat transferred from an object and it's environment via electromagnetic waves.

Of these three, conduction and convection play the largest roles in removing heat from a semiconductor device.

Conduction is used to remove heat directly from the semiconductor device by adding a heat sink with radiator fins. Heat is moved from the device junction to the heat sink, where contact with the air provides cooling. Devices without fans rely on the natural convection of heat from the hot device to the cooler air to circulate air.