The Effects of Temperature and Barometric Pressure on CO_2 Sensors

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Carbon Dioxide (CO_2) in air is normally measured in Parts Per Million (ppm). At 1,000 ppm CO_2, a volume or air containing one million air molecules would contain a mixture of 999,000 air molecules and 1,000 CO_2 molecules.

The volume of air necessary to contain one million air molecules is affected by air temperature and air pressure, also called Barometric Pressure. As the pressure decreases, the volume needed to contain one million air molecules increases. The opposite is true of temperature. As the temperature decreases, the volume of air needed to contain one million molecules decreases. Although the volume of air is affected by temperature and pressure, the concentration of CO_2 is not affected. If you started with 1,000 ppm of CO_2, then you finish with 1,000 ppm of CO_2 despite the changes in the air volume.

The most common CO_2 sensors are known by the engineering term Non-Dispersive InfraRed, or NDIR. An NDIR CO_2 sensor shines infrared light through a gas sample in a sample chamber. Sensitive photo-detectors measure the intensity of the infrared light after it passes through the gas sample. CO_2 molecules are opaque to 4.26 micron infrared light while the rest of the air molecules are not. So the intensity of the infrared light is diminished proportionally to the number of CO_2 molecules that are present. Measuring the resultant light intensity measures the number of CO_2 molecules present.

The size of the NDIR sampling chamber is fixed and is open to the atmosphere so that air can move in and out. As explained above, the number of air molecules in a given volume is affected by temperature and air pressure but not the concentration of CO_2. At low pressures or high temperatures, there will be fewer air molecules in the sample chamber, so there will also be fewer CO_2 molecules, even though the ppm of CO_2 hasn't changed. Fewer CO_2 molecules "fools" the sensor into thinking that the CO_2 concentration is lower than it really is. At high pressures or low temperatures, there are more air molecules in the sample chamber and more CO_2 molecules, even though the CO_2 concentration hasn't changed. More CO_2 molecules "fools" the sensor into thinking that the CO_2 concentration is higher than it really is. Therefore a CO_2 sensor calibration will only be accurate at one temperature and one air pressure.

Calculating Temperature and Barometric Pressure Effects on CO_2 Measurement

The following formula derived from the Ideal Gas Law relates changes in air volume to temperature, pressure and the number of molecules present:

$$\text{ppm } CO_{2\,corrected} = \text{ppm } CO_{2\,measured} * ((T_{measured} * p_{ref}) / (p_{measured} * T_{ref}))$$

- $p_{measured}$ = Current pressure, in the same units as reference pressure (not corrected to sea level)
- T_{ref} = reference temperature, usually 25°C, 77°F, converted to absolute (298.15 for °C, 536.67 for °F)
- $T_{measured}$ = Current absolute temperature, °C + 273.15, °F +459.67
- p_{ref} = reference Barometric Pressure, usually sea level, 29.92 in Hg, 760 mm Hg, 1013.207 hPa or 14.6959 psi

Table 1: CO_2 Measurement Change With Temperature

Temp. in °F	CO_2 Measured in PPM	Temp. in °F	CO_2 Measured in PPM	Temp. in °F	CO_2 Measured in PPM
32	1092	60	1033	85	985
35	1085	65	1023	90	976
40	1074	70	1013	95	968
45	1063	75	1004	100	959
50	1053	77	**1000**	105	950
55	1043	80	994	110	942

Table 1 uses the Ideal Gas Law formula above to show how the uncompensated CO_2 measurement would change with temperatures from 32 °F to 110 °F. Initial conditions are 1,000 ppm CO_2, 77°F and sea level Barometric Pressure. As seen in Table 1, the CO_2 concentration varies by 150 ppm.

Barometric Pressure is directly affected by altitude, and **Table 2** uses the Ideal Gas Law formula to show how the uncompensated CO_2 measurement would change with altitudes of -1,000 to 10,000 feet. Initial conditions are 77°F and 1,000 ppm CO_2 at sea level. As seen in Table 2, the CO_2 concentration varies by 349 ppm.

Table 2: CO_2 Measurement Change with Altitude and Barometric Pressure

Altitude in Feet	Barometric Pressure in inches Hg	CO_2 Measured in PPM
-1000	31.02	1037
0	29.92	**1000**
1000	28.85	964
2000	27.82	930
3000	26.82	896
4000	25.84	864
5000	24.9	832
6000	23.98	801
7000	23.09	772
8000	22.23	743
9000	21.39	715
10000	20.58	688

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Weather Effects on Barometric Pressure and CO_2 Measurement

Heat entering our atmosphere creates weather patterns, and these patterns affect the Barometric Pressure by forming high pressure systems and low pressure systems. Fast moving storms can dramatically change the atmospheric pressure and effective altitude in only a few minutes.

About 15 miles from BAPI's headquarters is an internet enabled weather station on the Mississippi River bluffs above the small town of DeSoto. Looking at historical data from that weather station from 2003 to 2011, the highest pressure, the lowest pressure and the biggest one-day pressure swing are shown in Table 3.

If the actual CO_2 level was 1,000 ppm at sea level, then Table 3 shows what the measured CO_2 concentration would be in DeSoto on those days. From January 15, 2005 until October 26, 2010, weather patterns alone changed the CO_2 measurement by 75 ppm, which is the entire accuracy specification for a typical NDIR CO_2 sensor.

On the single day of January 18, 2005, weather patterns changed the CO_2 measurement by 35 ppm, which is almost 50% of the specified accuracy specification of a typical NDIR CO_2 sensor.

Table 3: CO_2 Measurement Change with Weather Patterns

Date	Barometric Pressure in inches Hg	Measured CO_2 in PPM
1/18/2005	30.71	1026
1/18/2005	29.64	991
1/15/2005	30.78	1029
10/26/2010	28.53	954

The Combined Effect of Temperature and Barometric Pressure on CO_2 Measurement

Temperature and Barometric Pressure affect CO_2 measurement individually as well as in combination. **Table 4** shows the measured CO_2 concentration for the range of Barometric Pressures recorded in DeSoto from 2005 to 2010 along with temperatures from 50 to 90°F.

If the actual CO_2 concentration was 1,000 ppm at 77°F and sea level, the measured CO_2 concentration would vary by 161 ppm across the various temperature and Barometric Pressure ranges. That variance is more than the specified accuracy of the NDIR CO_2 sensor.

Table 4: CO_2 Measurement Change with Temperature and Barometric Pressure Combined

		Barometric Pressure in Inches Hg						
		28.5	29	29.5	29.92	30	30.5	31
Temperature in °F	50	1003	1021	1038	1053	1056	1073	1091
	55	993	1011	1028	1043	1046	1063	1080
	60	984	1001	1018	1033	1035	1053	1070
	65	974	991	1009	1023	1026	1043	1060
	70	965	982	999	1013	1016	1033	1050
	75	956	973	990	1004	1006	1023	1040
	77	953	969	986	**1000**	1003	1019	1036
	80	947	964	980	994	997	1014	1030
	85	939	955	971	985	988	1004	1021
	90	930	946	963	976	979	995	1012

Dynamic CO_2 Measurement Compensation

Due to the constantly changing nature of Barometric Pressure and temperature and their effect on CO_2 measurement, the only way to get an accurate CO_2 measurement with an NDIR sensor is through temperature and Barometric Pressure compensation. That's why all BAPI CO_2 sensors have a built in Barometric Pressure sensor and temperature sensor.

Every eight seconds the BAPI sensor takes a CO_2 reading then compensates that value based on the current temperature and Barometric Pressure. That's one reason why BAPI's CO_2 sensors are the most accurate in the HVAC/R industry. There is also no need for an HVAC technician to spend valuable time manually entering the altitude value for the location into each and every sensor when it is installed. This makes the BAPI CO_2 sensor one of the easiest to install, saving time and money.