International Journal of Geosciences, 2025, 16(9), 590-619
https://www.scirp.org/journal/ijg
ISSN Online: 2156-8367
ISSN Print: 2156-8359

Open System Greenhouse Effect Laboratory Experiment-Original Data

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How to cite this paper: Nelson, M. and Nelson, D.B. (2025) Open System Greenhouse Effect Laboratory Experiment-Original Data. *International Journal of Geosciences*, **16**, 590-619.
https://doi.org/10.4236/ijg.2025.169029

Received: August 22, 2025
Accepted: September 20, 2025
Published: September 23, 2025

Abstract

This is the only Greenhouse Effect experiment conducted in an open system using natural conditions and concentrations. In the test, atmospheric air was blown through a chamber and exposed to infrared radiation of the type emitted by the Earth. The absorption temperature was measured by an infrared detector. The results showed that the greenhouse gases absorb the Earth's infrared radiation, and adding CO_2 into the air stream proved that it could increase the absorption temperature. As such, this laboratory experiment has confirmed the Greenhouse Effect hypothesis. However, the test data showed that it took large concentrations of the greenhouse gases to trigger any meaningful effects. The data demonstrated a logarithmic correlation with 99% accuracy. This relationship also corroborated a potential minimum activation concentration as well as a flattened peak, forming an equivalent maximum or saturation point. The data proved that water vapor constituted 93 to 97 percent of the natural greenhouse gases, and that CO_2 at its current atmospheric concentration (0.042%) had no measurable effect on the absorption temperature. The data also showed that CO_2 does not control atmospheric water vapor or absorption temperature; *i.e.*, it is not a control knob. The data revealed that CO_2 and water vapor moved in opposite directions 64% of the time, had differing paths and magnitudes 90% of the time, and exhibited an R^2 of less than 10%. Concerning CH_4, the data found no measurable infrared absorption, even at 241 times higher than its current level. The same observation occurred with O_3 when the concentration was increased 2,500 times higher than normal. All three of these greenhouse gases (CO_2, CH_4, O_3) were too low at current atmospheric concentrations to trigger a response. Water vapor was the only one that showed a measurable absorption temperature at the natural concentrations. The tests with non-greenhouse gases Ar and He ruled out interference by thermal heat transfer mechanisms.

Keywords

Climate Change, Greenhouse Effect, Open System, Laboratory Experiment, Greenhouse Gases, CO_2, CH_4, O_3, Water Vapor, Infrared Detector

1. Introduction

The Greenhouse Effect is based on low-energy infrared radiation emitted by the Earth that is absorbed by various greenhouse gases within the Earth's atmosphere, thereby increasing the atmospheric temperature. No laboratory experiments have measured this under natural conditions [1]. The Intergovernmental Panel on Climate Change (IPCC) has acknowledged that there are no laboratory experiments that prove or directly support the Greenhouse Effect hypothesis [2].

There is another problem with the existing experiments. The temperature changes observed and measured by thermometers were primarily caused by thermal heat transfer mechanisms and not by greenhouse gas infrared absorption. The closed bottle experiments showed that thermal heat transfer, not infrared radiation, was the key to the temperature change [3].

There is a third and more significant problem relating to data obtained from closed systems that are used to explain features in an open-system environment. Most people are unaware of the consequences of interchanging these data. A real-world analogy may be helpful. Imagine a cancer cell that has been taken out of the human body and placed in a petri dish in a lab. This setup is a closed system. It is sealed off from the body's complex environment. Now, suppose a small amount of arsenic is added to the dish. The cancer cell dies immediately. Based on that result, one might think arsenic might be a good cancer treatment. However, trying the same thing inside the human body, an open system, does not work the same way. The body has many moving parts: blood flow, healthy cells, organs, immune responses, detox systems, and countless chemical interactions. In that environment, arsenic would not just target cancer. It would likely damage or kill healthy tissues, poison organs, and harm the patient far more than the cancer itself. So, the simple success in a closed system does not carry over to the complex open system of the body. This is a major problem when using closed-system data in an open-system environment.

It is recognized that data obtained in closed-system experiments can be used to analyze performance in open systems. However, it requires sophisticated empirical or mathematical modeling that enables a meaningful interchange of the data. In every one of the greenhouse gas laboratory experiments using bottles, there was no attempt to compare the data to an open system [1].

2. Design of the Open System Greenhouse Effect Experiment

2.1. Test Apparatus & Operation

This experiment is based on an open system, using a heat source emitting infrared radiation at the Earth's normal temperature range, and at a concentration of greenhouse gases that currently exists in the atmosphere. A flow diagram of the test equipment is shown in Figure 1. Infrared radiation (86˚F - 194˚F) was emitted by an electric heater with a 4-inch by 4-inch center portion painted black. The heater is shown at the top of the flow diagram. An aluminum foil insulation covered the heater surface other than the black center. The heater was placed approximately 19 inches away from the test equipment box.

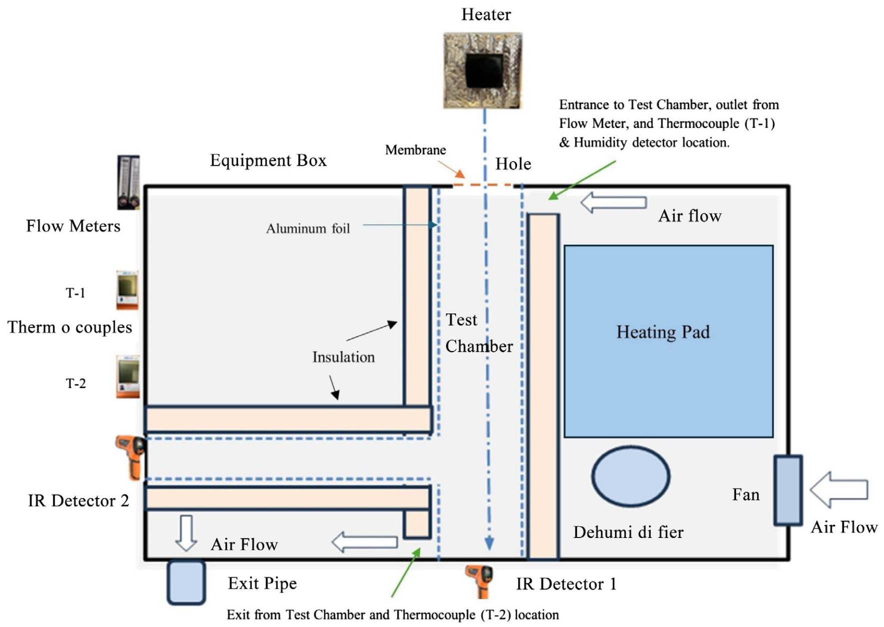

Figure 1. A flow diagram of the test apparatus used in this experiment. This equipment was built and operated by the author Michael Nelson. Additional photos are in Appendix A along with a description of the instruments and calibration curves.

The insulated equipment box was 2 feet wide, 2 feet long and 1 foot high. A 4-inch by 4-inch hole was cut into the box in front of the test chamber to allow the infrared radiation to enter. An insulated gas test chamber, 5 inches by 5 inches by 2 feet in length, was immediately behind the hole. The entire interior of the chamber was lined with highly reflective smooth aluminum foil to limit the chamber's absorption and emission of infrared radiation. A dual fan circulated 700 liters/minute of air through the chamber, resulting in a complete air exchange every 0.84 seconds. A dehumidifier and a heating blanket were used to smooth out spikes or sudden changes in the temperature and humidity of the incoming air before it reached the chamber.

The system was designed to isolate the gases being evaluated from the heater's thermal energy. This was accomplished by installing a thin 0.5 mil (1/1000 inch) polyethylene film over the hole. This blocked any direct contact between the test gases and the heat source. This kept kinetic energy from changing the temperature of the greenhouse gases. Kinetic energy transfers can cause changes in the gas molecules' vibrational states and potentially interfere with infrared absorption. It is the same mechanism that the Greenhouse Effect warms the atmosphere, except in reverse.

An infrared detector (IR-1) was positioned at the end of the chamber, directly facing the heater. This detector was used to measure the reduction in infrared radiation emitted by the heater. A second infrared detector (IR-2) was installed perpendicular to the main chamber to measure the backscattering radiation emitted by the greenhouse gases. However, the infrared detector (IR-2) was not sensitive enough to detect any backscattering, so this procedure was abandoned. Thermocouples and humidity sensors were used to monitor the temperature and humidity of the incoming air. The air entering the test chamber entered through a 4-inch diameter pipe at the front and adjacent to the hole. The air leaving the chamber was at the rear, near the infrared detector (IR-1).

Figure 2 is a photograph of the actual test equipment used. It was set up in a residential garage with ample ventilation. The flexible black exit tube released the test gases to the outside.

Figure 2. A photo of the test apparatus taken from the left rear corner. It was constructed with ½ inch thick plywood with insulated aluminum foil on the outside. The test chamber shown in the flow diagram was installed inside the insulated box.

Using a flow meter, varying levels of gases were introduced into the entrance to the chamber as shown in Figure 1. Two non-greenhouse gases (Ar & He) were introduced into the chamber to observe their effects on infrared radiation absorption and thermal heat transfer. Variable quantities of three greenhouse gases (CO_2, CH_4, & O_3) were individually introduced into the chamber. This was to determine if there were any observable changes in the infrared absorption by these gases at higher concentrations.

2.2. Calibration and Testing Procedures

The calibration of the equipment and a more detailed description of the test equipment are set forth in Appendix A. Calibration is important and takes a significant amount of time. The following is a summary. The heater was verified as accurate to within 0.1˚F between 86˚F and 194˚F using a glass laboratory thermometer. The infrared detectors and thermocouples were compared to the heater. The dual fans were calibrated at the lowest level of 11. The reduction in the infrared flux through the 0.5 mil plastic barrier was compared to that of no barrier. The presence of background radiation was compared with dark conditions. The relative humidity, CO_2 and O_3 instruments were not calibrated independently. They each have their own certification.

The incoming air was passed over a dehumidifier and an electric heating blanket. For the experiment, the fan, the dehumidifier, and the electric blanket were turned on, and the blanket heater was set approximately 2˚F above the room's temperature. The system was allowed to run for about 10 minutes to stabilize the temperature and humidity inside the chamber. The heater was set at the various test temperatures and allowed to stabilize for at least 30 seconds. The data from the infrared detectors, the two thermocouples, and the humidity were taken from inside the chamber. The CO_2 concentration was measured at the exit. Thirteen tests were conducted, starting at 86˚F and then increasing in 9˚F increments until it reached 194˚F. These thirteen tests were conducted on three groups of test gases. The minimum test temperature was 86˚F due to the higher ambient conditions at the laboratory location.

Group One contained twelve samples of unaltered, naturally occurring atmospheric air. The greenhouse gas concentrations fluctuated with humidity, ranging from 6,478 ppmv to 14,474 ppmv. Water vapor comprised between 93% and 97% of the natural greenhouse gases at this location (San Francisco East Bay Area). This first group was used to determine the relationship between the naturally occurring greenhouse gas (GHG) concentrations and the average infrared absorption temperature from a heater emitting peak wavelengths between 9.56 μm (86˚F) and 7.98 μm (194˚F). The data from this group served as a baseline for comparing samples in other gas groups, which had altered atmospheric compositions and concentrations. The expression water vapor (WV) will be used herein because H_2O is normal in the atmosphere in multiple states, *i.e.*, gas, liquid, and solid (ice). Water vapor exists only in the gas state.

Group Two contained two gases. One had added argon and the other had added helium, both non-greenhouse gases. These two gases were injected into the system at flow rates of 1 liter/minute, 3 liters/minute, 5 liters/minute and 10 liters/minute. This test was done to determine if there were any thermal heat transfer mechanisms associated with the equipment. Argon and helium do not absorb infrared radiation at the wavelengths evaluated, so the data should not show infrared absorption. Temperature changes in the observations could mean thermal heat transfer mechanisms were at work. Argon was selected because in prior closed-system tests [4] the investigators compared Ar with CO_2. Thermocouples measured the temperature changes. The temperature curves were nearly identical, yet one gas (Ar) was not a greenhouse gas, while the other (CO_2) was. Since they had the same temperature curves, it provided proof that the temperature observations were due to thermal heat transfers and not infrared absorption by greenhouse gas.

Group Three consisted of adding greenhouse gases to the air stream entering the test chamber. The three added gases were CO_2, CH_4 and O_3. The CO_2 and CH_4 gases were injected into the system at flow rates of 1 liter/minute, 3 liters/minute, 5 liters/minute and 10 liters/minute. The 100% CO_2 source was dry ice. The CH_4 source was from a large bag containing CH_4 at a concentration of 3.2% to avoid an explosive mixture. The O_3 was injected directly from an ozone generator and had a flow rate of 0.5 liters/minute, 1 liter/minute, 1.5 liters/minute, 2 liters/minute, and 2.5 liters/minute. These flow rates significantly increased the concentration of these gases inside the test chamber.

2.3. Analytical Methodology

The following is the procedure used to determine if there was any infrared absorption by the greenhouse gases. The infrared detectors do not measure temperature directly. They measure the infrared radiation intensity or flux. The infrared radiation strikes a sensor in the device, causing it to warm. This generates an electrical signal related to the intensity. The higher the voltage/current in the signal, the greater the radiation intensity hitting the sensor. An algorithm changes intensity to an equivalent temperature using the Stefan-Boltzmann equation. In short, the infrared detector serves as a temperature proxy.

An object placed between the heater and infrared detector will weaken the radiation intensity. This lowers the temperature reading on the detector. A thin polyethylene film (0.5 mil) covered the hole in the test chamber. Appendix A's calibration data shows that this membrane absorbed a portion of the infrared intensity. The absorption varied from 2.4˚F to 12˚F, depending on the heater's temperature.

The system design (**Figure 1**) allows background radiation, unrelated to the heater, to enter through the hole in the chamber. This was found to have a slight effect on the intensity measured by the infrared detector. It varied from 0˚F when the test was run after the sun went down, to 0.1˚F in the morning and late afternoon, and 0.2˚F between 11 am and 4:00 pm.

An energy balance was made to determine the amount of infrared radiation absorbed by the greenhouse gases. These values are infrared intensities converted into equivalent temperatures. This is shown in the following equation. The infrared detector values are corrected based on the calibration curves in the Appendix. The absorption temperature of the Greenhouse Gases (GHG) was calculated using the following equation.

$$\mathbf{T} = T_h + T_b - T_p - T_d \tag{1}$$

Where:

T is the infrared absorption temperature of the Greenhouse Gases in ˚F,

T_h is the temperature of the heater in ˚F,

T_b is the background temperature leaking through the hole in ˚F

T_p is the infrared absorbed by the plastic membrane in ˚F,

T_d is the temperature measured by the IR-1 detector in ˚F.

The water vapor concentration was determined by the temperature of the incoming air sample along with the measured relative humidity. The saturated water vapor expressed in ppmv was from a table generated by ChatGPT for the San Francisco Bay Area at an elevation of 351 feet. This saturated water vapor concentration was multiplied by the relative humidity to provide the actual water vapor concentration.

The sum of water vapor, CO_2, CH_4, and O_3 yielded the total greenhouse gas concentration. Water vapor made up 93% to 97% of the Earth's natural greenhouse gases at the location of this lab experiment. These percentages would be higher in more humid conditions. The following equation represents how the total greenhouse gas concentration was calculated. M in the following equation 2 represents molar concentration and is expressed in ppmv. With respect to gases, molar quantities (number of gas molecules) are the same as volume quantities. That is, the percentage of the gas in the atmosphere when measured by volume, is the same as molar quantity. That is because, when gases are involved, the volume of any gas, regardless of its molecular weight, contains the exact same number of molecules. Using "C" in the equation to represent concentration may be confused with centigrade temperature. It may also be confused with concentration based on weight (mass) such as density, as opposed to concentration based on volume. The "v" in ppmv, relates to volume percent and not mass or weight percent. Therefore, when "concentration" is used in this article it is referring to concentration by volume or molar concentration.

$$\mathbf{M} = \mathbf{M_w} + \mathbf{M_c} + \mathbf{M_m} + \mathbf{M_o} \quad (2)$$

Where:

M is the molar concentration of the greenhouse gases in ppmv;

M_w is the molar concentration of water vapor in ppmv;

M_c is the molar concentration of CO_2 in ppmv;

M_m is the molar concentration of CH_4 in ppmv;

M_o is the molar concentration of O_3 in ppmv.

The temperature **T** shown in equation 1 for each heater temperature was averaged for each sample gas. Similarly, the concentration M from equation 2 was averaged for each sample gas. Therefore, the average GHG absorption temperature was compared to the average GHG concentration. Other greenhouse gases like N_2O exist, but their concentrations are too low to be detected.

3. Test Data and Observations

3.1. Group 1: Air with Natural Greenhouse Gases

The data from this test group is critical to validating the Greenhouse Effect under realistic conditions. The actual temperature of the Earth is too low to generate visible light or high-energy infrared.

3.1.1. Initial Tests

During the initial tests, it was determined that the Infrared Detector 2 was not sufficiently sensitive to detect the backscatter radiation in the designed system. The infrared detector IR-2 appeared to only pick up the temperature of the aluminum foil from the main chamber. Most of the time, the IR-2 detector registered a constant temperature. Sometimes it would drop with increasing ambient air temperature. That appeared to be inconsistent with radiation physics. It was concluded that the infrared detector was not sensitive enough to detect the slight changes in backscatter radiation. As such, that part of the investigation was abandoned.

A calibration test set forth in the Appendix showed that both thermocouples had the identical calibration curve (X = Y) at a very narrow range of ambient conditions. It also had an R^2 of 1. As such, there was no need to correct the observed ambient temperatures. Another observation was that the thermocouple temperatures measured at the exit were the same as at the entrance. This does not support a warming of the air sample because of the greenhouse gas absorption. However, the identical temperatures likely resulted from being overwhelmed by the high flow rate of 700 liters/minute and the convective heat transfer connected to that flow rate. In addition, thermocouples only register thermal heating and do not measure infrared absorption. On the other hand, the infrared detector (IR-1) readily detected infrared radiation intensity. It detected the infrared intensity (temperature) from the heater and any reduction in that intensity. That included a reduction of the 0.5 mil plastic membrane and the absorption of infrared radiation by the greenhouse gases. In accordance with Kirchhoff's three laws of emission and absorption of radiation, gases operate very narrowly when compared to solids and liquids. According to Kirchhoff, gases absorb and emit infrared radiation based on their discrete sets of isolated spectral wavelengths. Solids and liquids, on the other hand, absorb and emit radiation over a broad spectrum of radiation. So, the amount of infrared absorption by the very thin solid membrane was expected to show significant absorption temperatures. The greenhouse gas absorption temperatures, on the other hand, were much lower.

3.1.2. Results of Laboratory Tests

The results with the Group 1 natural air samples are shown in **Figure 3**. This figure is a plot of the data from the 12 test samples of natural air. On the "T" or vertical axis is the average infrared absorption temperature in accordance with Equation 1. This showed the average temperature increase over the 13 heater temperatures from 86˚F to 194˚F. The total greenhouse gas molar concentration "M" in ppmv was determined in accordance with Equation 2. **Figure 3** shows the average molar concentration over the 13 heater temperatures.

The dotted line is called a trendline and represents the mathematical plot for the curve that best fits the data. The dotted lines before and after the data points are a projection of expected values that would follow the curve. The equation shown in **Figure 3** shows the following general expression:

$$\mathbf{T} = A \ln(\mathbf{M}) - B \tag{3}$$

Where:

T is the average absorption temperature of the greenhouse gases;

ln is a mathematical expression representing the natural logarithm;

M is the average molar concentration of the greenhouse gases;

A is a constant that sets the slope for the curve;

B is a constant that shifts the curve up and down.

As shown in **Figure 3**, when the molar concentration M is small, the slope of the curve is large. As M increases, the slope decreases. The term B is the vertical offset for the curve. Subtracting B shifts the entire curve downward. This general equation is common in the scientific world, *i.e.*, thermodynamics, radiation, chemical reactions, pH, etc. The grandfather of the Greenhouse Effect, Arrhenius (1896) [5] acknowledged a logarithmic relationship. Applying the A and B numbers shown in **Figure 3**, the final equation becomes:

$$\mathbf{T} = 2.6185 \ln(\mathbf{M}) - 21.716 \tag{4}$$

Where:

T is the average absorption temperature of the greenhouse gases;

ln is a mathematical expression representing the natural logarithm;

M is the average molar concentration of the greenhouse gases;

A is 2.6185 and once set by the data, it does not change;

B is 21.716 and once set by the data, it does not change.

The trendline shows that the best curve fitting the data points is logarithmic. It is a type of curve where the rate of change starts out steep and then flattens out. For example, **Figure 3** shows that with smaller values of the average greenhouse gas concentration (M), the average infrared absorption Temperature (T) rises much faster.

Figure 3 also indicates that the greenhouse gas concentrations above 35,000 ppmv will have a smaller and smaller effect on the absorption temperature. It appears that the maximum absorption temperature will occur somewhere around 7˚F. It further demonstrated that increasing the average greenhouse gas concentrations would cause the average absorption temperature to rise.

A vertical line drawn from 10,000 ppmv will intersect the curve at an average absorption temperature of about 2.4˚F. Extending the vertical line higher shows that this concentration is in the semi-arid zone. The ocean is represented in the figure since it constitutes 71% of the surface of the Earth and covers all the zones except arid. At an average greenhouse concentration of 20,000 ppmv, a vertical line will intersect the curve at about 4.2˚F. Hence, the doubling of the greenhouse gas concentration will increase the temperature by 1.8˚F. Drawing the line further up shows that it is in the tropical zone. This would include the land, rainforests and the more tropical climates. The temperature on Earth may increase 20 to 30˚F between these two zones, which is far greater than the temperature increases due to the greenhouse effect of 1.8˚F. The various zones are defined by the amount of water vapor contained in the air. That is because water vapor constitutes 93% to 97% of all greenhouse gases.

As shown in **Figure 3**, the curve has an R^2 of 0.9946 or 99%. That is exceptionally high, which is excellent. For example, an R^2 of 100% is a perfect fit, *i.e.*, all points lie exactly on the curve. Most scientists feel that anything over 90% is a great fit and anything over 80% is a strong fit. The lower the number, the higher the chances that a key factor has been overlooked.

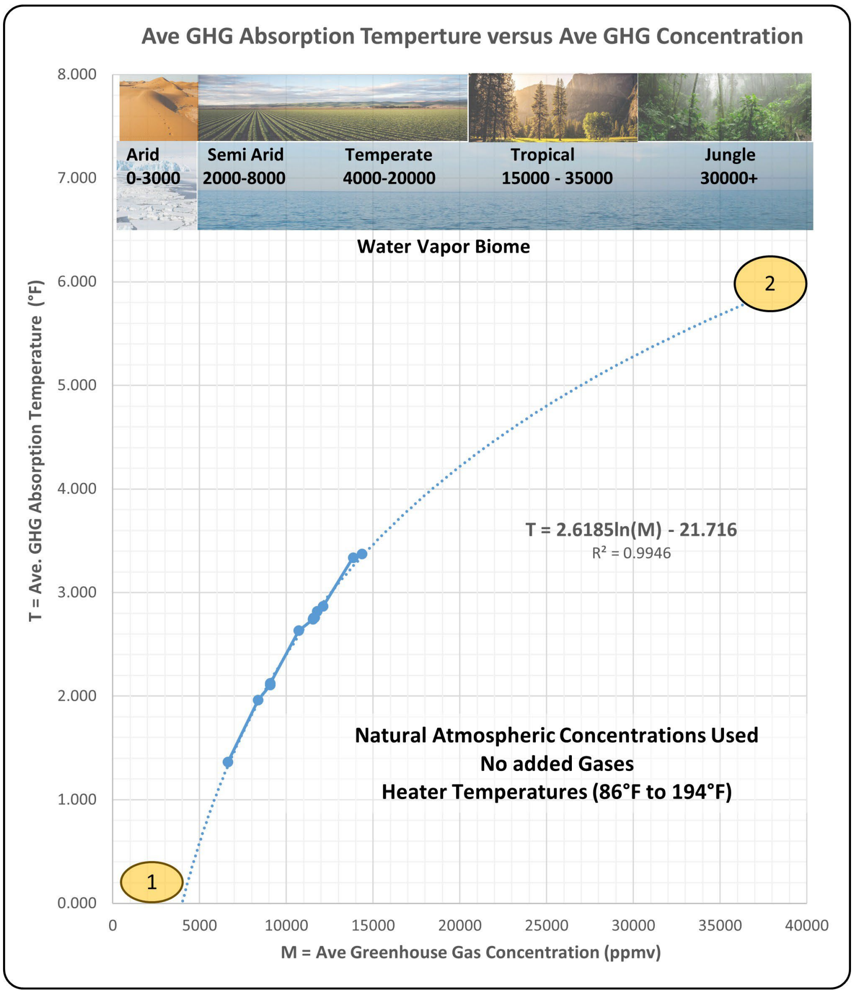

Figure 3. A plot of the average greenhouse absorption Temperature (T) on the vertical axis using Equation 1, and the average greenhouse gas molar concentration (M) on the horizontal axis using Equation 2. The solid blue line connects the data points. The equation describes the dotted line (trendline using the logarithmic type) using Equation 4.

Table 1 shows the data used in **Figure 3**. The CO_2 concentration in the laboratory was slightly higher than the Earth's average (421 ppmv). This would increase the water vapor percentage in **Table 1** by approximately 1%.

Table 1. Water vapor absorption in natural atmospheric air.

Data Point	Greenhouse Gases (ppmv)	WV (ppmv)	Percent WV	GHG Absorption Temp (˚F)	WV Absorption Temp (˚F)
1	6,629	6,168	93%	1.4	1.3
2	8,363	7,898	95%	2	1.9
3	9,074	8,520	94%	2.1	2
4	9,078	8,526	94%	2.1	2
5	10,714	10,217	95%	2.6	2.5
6	11,527	11,069	96%	2.7	2.6
7	11,563	11,051	96%	2.8	2.7
8	11,641	11,197	96%	2.8	2.7
9	11,780	11,324	96%	2.8	2.7
10	12,128	11,659	96%	2.9	3
11	13,845	13,400	97%	3.3	3.2
12	14,366	13,925	97%	3.4	3.3

Table 1 shows that the average greenhouse gas concentration without water vapor is only 0.1˚F at each data point. Given that it is the detector's lowest limit, the number might be questionable. However, it is supported statistically because all 12 tests showed the same result.

3.1.3. Findings and Conclusions

This test indicates that the Greenhouse Effect under the natural conditions on Earth is a real phenomenon. This is the first test using actual conditions that supports the validity of the Greenhouse Effect. This test is limited to clear-day environments. Since there were no clouds or rain inside the chamber, clouds and rain would likely absorb all the low-energy infrared radiation, thus dwarfing any absorption by greenhouse gases.

The Greenhouse Effect observed in this test is far less than predicted by the IPCC (pg. xiv, 1990 Assessment Report) in their mathematical models. The IPCC stated that the Greenhouse Effect was responsible for the Earth being about 58˚F warmer. [2] However, the laboratory results in this laboratory test showed that the maximum Greenhouse Effect would occur around 7˚F. The IPCC might have exaggerated the Greenhouse Effect by a factor of 5.

3.1.4. Differences between Using Averages and Individual Values

The values used in Figure 3 are based on averages of 13 data points corresponding to different heater temperatures. The individual values show deviations above and below the average value. At the lowest tested level (6,629 ppmv), the maximum variations were approximately 0.61˚F, increasing to roughly 1.18˚F at the highest level (24,770 ppmv). Figure 4 shows the same graph as Figure 3, but with individual data points instead of averages, and includes CO_2 concentrations.

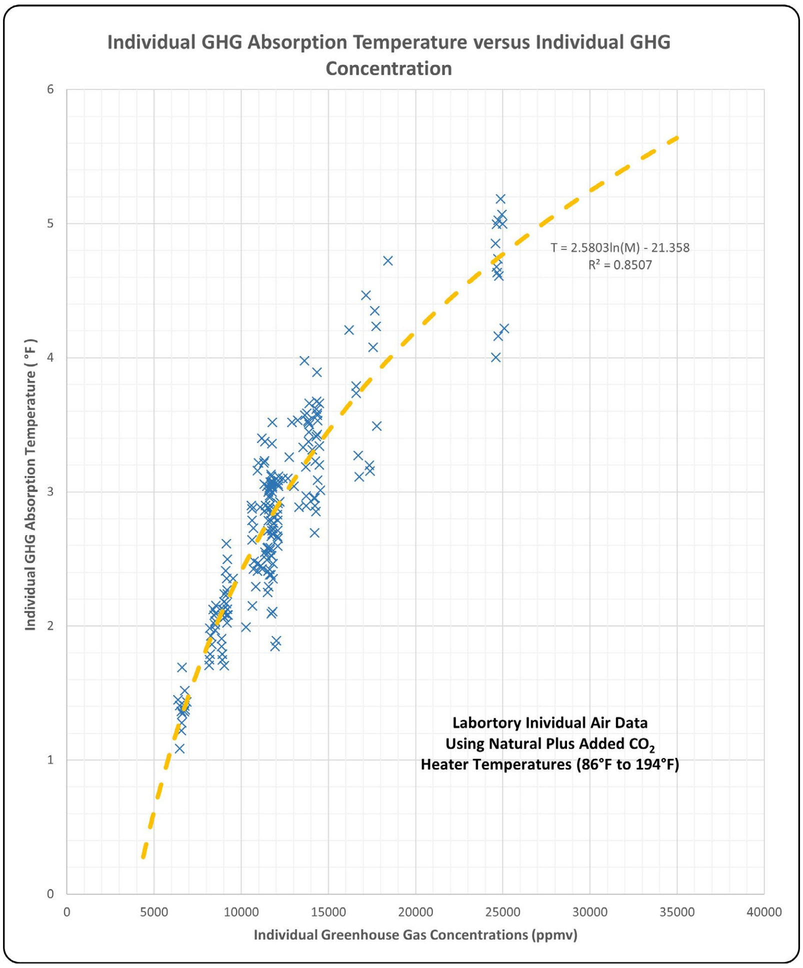

Figure 4. A graph showing the individual greenhouse gases on the horizontal axis in parts per million by volume (ppmv) as shown in equation 2. The vertical axis is the individual absorption temperature as calculated by Equation 1.

The dotted orange line in **Figure 4** represents the logarithmic trendline of all of the individual data points. The equation for the trendline curve was slightly different than that shown in **Figure 3**, *i.e.*, T = 2.5803 ln(M) - 21.358. The minor change was likely because the individual data points from the added CO_2 were included in this Figure, which were not included in **Figure 3**. The R^2 for the individual data points was 85%. This was because the variations in the individual data points above and below the line are greater than the average data points.

Average values are used in most climatological studies. Comparisons become easier with averages, minimizing variations and errors. For example, the individual temperature of the same place taken over a 24-hour period may show 15 to 25˚F swings. However, comparing daily averages to those of the same period next year could easily show a tenfold reduction.

3.1.5. Absorption Threshold

This zone in **Figure 3** is marked with a colored circle with the number 1 inside. This zone suggests that there is no average absorption temperature between 0 and about 3000 ppmv. Must a minimum concentration be present for absorption to take place? Minimum concentrations are a part of many natural and physical laws. For example, fossil fuel gases, like CH_4, will not ignite at low concentrations. Clouds will not form without a minimum water vapor concentration. Odor cannot be detected until a minimum concentration is attained. A minimum radiation intensity is required to eject an electron inside a solar cell. Therefore, a minimal level of greenhouse gases could be needed. On the other hand, the Beer-Lambert equation supports the view that absorption occurs until there is zero concentration. In **Figure 4**, the individual data points are plotted rather than the average concentration and average absorption temperature. It does not answer whether there is a minimum threshold. However, **Figure 4** continued to show a zero threshold there. In order to verify this, tests should be conducted using a natural greenhouse gas concentration of 3,000 ppmv or less. This could be achieved by conducting tests in the polar regions or dry deserts.

3.1.6. Saturation Concentration

This zone in **Figure 3** is marked with a colored circle with the number 2 inside. The trendline in this area indicates a maximum level near 7˚F. The flattening is an inherent feature of logarithmic curves. Although the saturation point differs from a maximum value, the concepts are alike.

3.2. Group 2: Adding Argon and Helium to Atmospheric Air

Argon and helium are both non-greenhouse gases. They have no spectral absorption band from infrared radiation having a wavelength between 9.56 μm (86˚F) and 7.98 μm (194˚F). It was therefore expected that no infrared absorption would be found. The reason these gases were used was to determine if there were any thermal heat transfer processes that might be changing the temperatures. The temperature taken at the entrance to the chamber and the temperature taken at the exit did not show a difference. This agrees with the fact that Ar and He are not greenhouse gases.

3.2.1. Argon

The fourth most common gas in the atmosphere is Argon. It is present at an average concentration of 9,300 ppmv (0.93%). The most prevalent atmospheric gas is nitrogen at 780,000 ppmv (78%) with oxygen coming in at 209,000 ppmv (20.9%). Water vapor comes in third with an average of 10,000 to 30,000 ppmv (1% - 3%) with 3% over the ocean [6]. **Figure 5** shows the average absorption temperature as measured by the infrared detector in accordance with Equation 1.

Argon is a non-greenhouse gas. As such, it is expected to show no absorption of the infrared radiation. It was added to the air flow through a flow meter at a rate of 0, 1, 3, 5 and 10 liters/minute. This increased the concentration from 9.300 ppmv at zero flow rate to 10,500 ppmv, 13,584 ppmv, 16,440 ppmv, and 23,580 ppmv. These are extremely high average concentrations that do not exist on Earth. The extreme conditions were used to force a response. Each gas sample's flow rate was exposed to 13 heater temperatures from 86˚F to 194˚F. The average greenhouse gas concentrations changed slightly, *i.e.*, 11,600-11,745 ppmv. That could account for a deviation of less than 0.03˚F using equation 4. This is less than the IR-1 detection temperature of 0.1˚F. As such the detection temperature would be the controlling limitation. The Ar concentration at a flow rate of 10 was about twice as high as the total greenhouse gases.

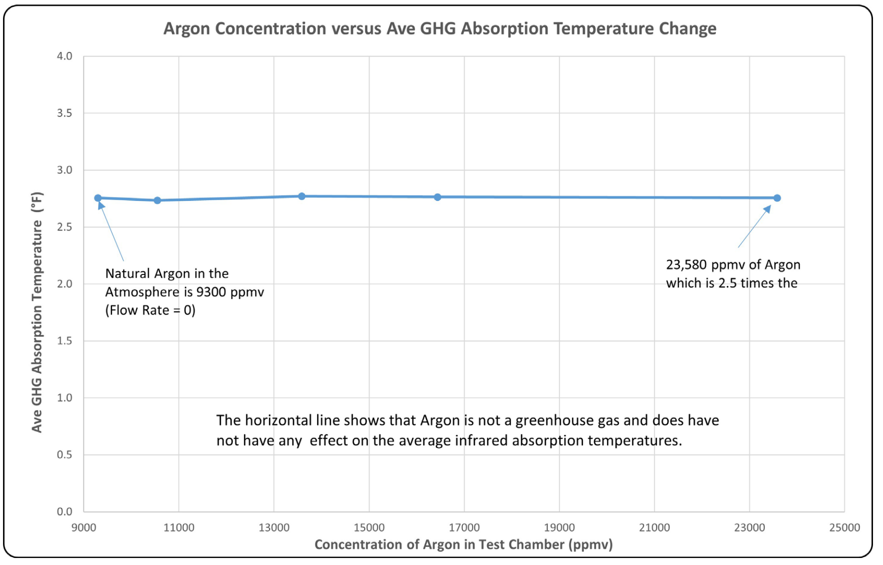

Figure 5. A plot of the average greenhouse gas absorption temperature for Argon for each flow rate and each of the 13 different heater temperatures. This value is on the vertical axis. The horizontal axis is the average concentration of Ar (not the greenhouse gas concentration) in the test chamber for 5 different flow rates starting with a zero flow rate representing the natural concentration.

3.2.2. Helium

Helium constitutes about 5 ppmv in the natural atmosphere. It, like Ar, is not a greenhouse gas and should show no absorption of the infrared radiation. It was added to the air flow through a flow meter at a rate of 0, 1, 3, 5 and 10 liters/minute. This increased the concentration from 5 ppmv (flow rate of 0) to 1,433 ppmv, 4,286 ppmv, 7,145 ppmv and 14,285 ppmv. These concentrations were determined by calculations based on the flow rate settings. Each gas sample's flow rate was exposed to 13 heater temperatures from 86˚F to 194˚F. The average greenhouse gas concentration changed slightly. This meant that the maximum He concentration was slightly higher than that of the greenhouse gas. The incoming and outgoing air temperatures remained the same. Figure 6 shows the average absorption temperature as measured in accordance with Equation 1. This figure illustrates that He had no significant effect on the absorption temperature of infrared radiation at temperatures between 86˚F and 194˚F. The slight deviation in the horizontal line was likely due to differences in water vapor during the test and to normal instrument uncertainties. The water vapor changes would be less than the IR-1 detection limitation.

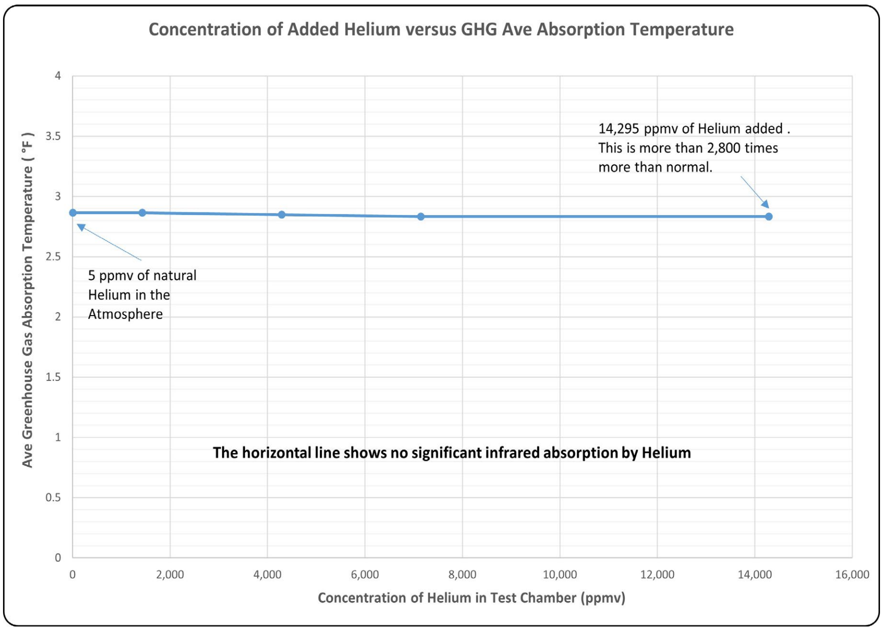

Figure 6. A plot of the average greenhouse gas absorption temperature for He for each flow rate and each of the 13 different heater temperatures. This value is on the vertical axis. The horizontal axis is the average concentration of He (not the greenhouse gas concentration) in the test chamber for 5 different flow rates starting with a zero flow rate representing the natural concentration.

The temperature (2.8˚F) was caused by the greenhouse gases in the test sample (96% water vapor). Additionally, the figure demonstrated that thermal heat transfer was not a contributing element.

3.3. Group 3: Adding Extra Greenhouse Gases to Atmospheric Air

This group of sample gases involved adding several greenhouse gases, *i.e.*, CH_4, CO_2, and O_3. This group provided a way to assess the effect of varying amounts of greenhouse gases on the absorption temperature. Large amounts were used to trigger a reaction. Absence of a response at the highest concentrations would demonstrate a lack of causation under natural conditions.

3.3.1. Methane

CH_4 has been urged by the media and the IPCC to have a particularly strong effect on increasing the atmospheric temperature. This test directly addresses this point. CH_4 was added to the sample atmospheric air stream through a flow meter at a rate of 1 liter/minute to 10 liters/minute. This increased the natural concentration of CH_4 to 1.9 ppmv. Table 2 illustrates the concentration increase with each flow rate.

Table 2 illustrates the concentration increase with each flow rate. The third column shows the magnitude of the increased concentration over the natural atmospheric concentration. Column four shows the absorption temperature at the various concentrations.

Table 2. CH_4 flow rate, concentration & absorption temperature.

Flow Rate (liters/min)	Concentration (ppmv)	Multiple of Natural	CH_4 Absorption Temp (˚F)
0 (natural)	1.9		<0.1
1	46	24	<0.1
3	139	73	<0.1
5	230	121	<0.1
10	459	241	<0.1

For each flow rate, the heater's temperature was raised 13 times, from 86˚F to 194˚F. The average concentration of CH_4 was determined by calculations from the flow rates as opposed to direct measurements by an instrument. **Figure 7** shows the average absorption temperature as measured by the infrared detector in accordance with Equation 1.

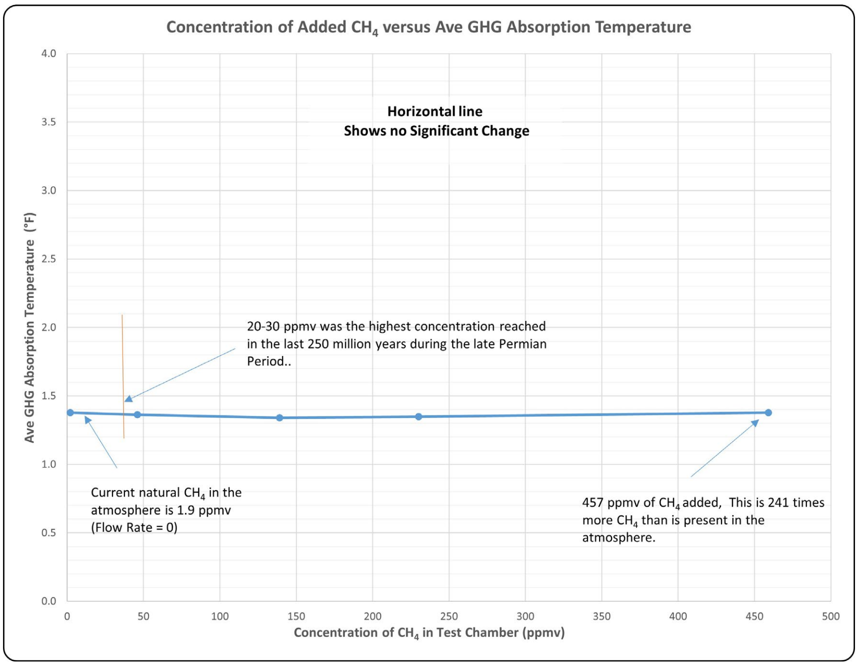

Figure 7. A plot of the concentration of CH_4 in the test chamber (horizontal axis) versus the average greenhouse gas absorption temperature (vertical axis). The horizontal line indicates that there is no meaningful change in the temperature for increasing CH_4 concentrations, up to and including 241 times higher than normal.

This figure illustrates that CH_4 had no significant effect on the absorption temperature of infrared radiation used. The slight deviation in the horizontal line is most likely due to the normal instrument uncertainties. The temperature (1.4˚F) was caused by the greenhouse gases in the test sample (93% water vapor). This is directly inconsistent with the position taken by the IPCC, an entity associated with the United Nations. The IPCC proposed a mathematical model known as the Global Warming Potential (GWP). This model was used to determine the potential of various greenhouse gases on the absorption temperature. However, the equation is based on a ratio of the concentration of the gas as it relates to CO_2. There is no factor relating to the sun's radiation, cloud cover, water vapor, or any other factor unrelated to CO_2. GWP further assumed that CO_2 is the switch and control knob for water vapor.

This study used actual lab data, unlike a mathematical model. There is an estimated 5.4 **trillion** tons of CH_4 in the Earth's atmosphere based on a concentration of 1.9 ppmv. Cows produce about 80 million tons/year of CH_4. According to Table 2, 457 ppmv of CH_4 had no measurable effect on the average absorption temperature. So, if the Earth had twice as many cows as it has now, it would take 8 million years to hit the 457 ppmv mark, assuming all yearly CH_4 accumulated in the atmosphere without any losses. And it would still have no measurable effect on the absorption temperature. This does not include the fact that 600 million tons of CH4 are removed from the atmosphere each year because they react with hydroxy radicals, oxygen, and O_3 in the atmosphere.

3.3.2. Carbon Dioxide

This experiment with CO_2 is one of the most important tests in this study. Pure CO_2 was added to the sample atmospheric air stream through a flow meter at a rate of 1 liter/minute up to 10 liters/minute. This increased the natural concentration of 421 ppmv. However, this natural concentration was higher in this experiment because it was conducted inside a well-ventilated building. Humans exhale CO_2, which causes the concentration inside buildings to become higher. In this test, the CO_2 concentration inside the building varied from 440 to 525 ppmv. Table 3 shown below illustrates the concentration increase with each flow rate.

For each flow rate, the heater's temperature was adjusted 13 times. The concentration of CO_2 was determined by an instrument identified in Appendix A. Figure 8 is a graph of the average absorption temperature as measured by the infrared detector in accordance with Equation 1. For each flow rate, the heater's temperature was adjusted 13 times.

Table 3. Flow Rate and CO_2 Concentration.

Flow Rate (liters/min)	Concentration (ppmv)	Multiple	Biology-History (years ago)	CO_2 Absorption Temperature (˚F)
0 (Lab)	495			0.1*
1	1,437	3	50 million	0.1*
3	3,420	7	410 million	0.6
5	7,383	15	520 million	1.2
10	14,775	30	Never	2.1

*Detection limits. See **Appendix A** for the limits on the various devices.

Table 3 is a spreadsheet showing the flow rate, the measured CO_2 concentration, the multiple of the CO_2 concentration in with a flow rate in row 1 divided into added concentrations, the biological history when natural CO_2 was at that level, and the absorption temperature applicable to CO_2.

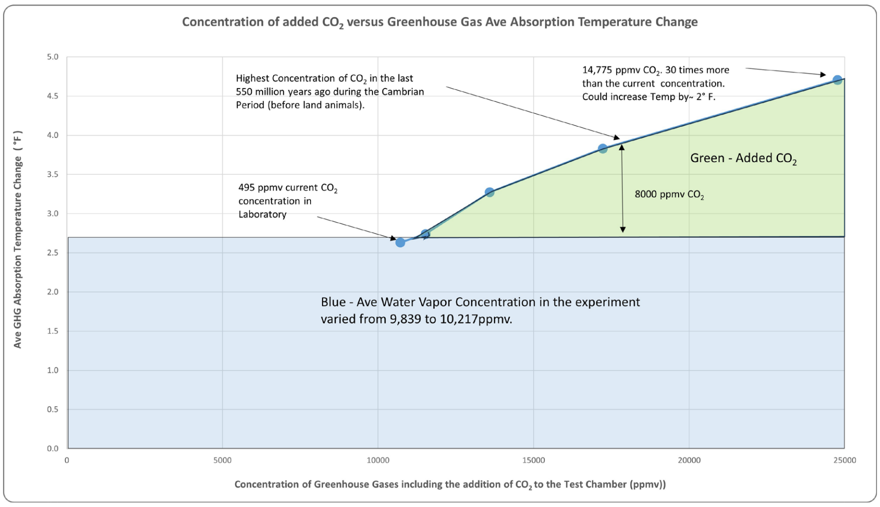

Figure 8. A graph representing the absorption temperature (vertical axis) with changes in the CO_2 concentration (horizontal axis). CO_2 was added to the atmospheric air sample and measured by an instrument identified in **Appendix A**.

The concentration of CO_2 was determined by an instrument identified in Appendix A. An exception occurred at a flow rate of 10. The maximum concentration the instrument could manage was 10,000 ppmv. Therefore, for a flow rate of 10, the concentration of the CO_2 was based on flow rate calculations. See Appendix A for the fan calibration.

Figure 8 illustrates that CO_2 can have a significant effect on the absorption temperature at high concentrations. Therefore, it supports the position that the Greenhouse Effect is real and that CO_2 can increase the absorption of heat. This is the first test using an open system and a low-energy infrared radiation source that has proven the Greenhouse Effect and that CO_2 can increase the absorption temperature. Joseph Fourier first addressed the Greenhouse Effect in 1824 and it was expanded to include CO_2 by John Tyndall in 1859 and Svante Arrhenius in 1896. However, there were some scientists who questioned this, and particularly the CO_2 extension.

This study supports the view that the Greenhouse Effect is real and that CO_2 can cause an increase in absorption temperature.

But there are three major caveats.

1) It depends on the concentration of greenhouse gases. There may be an absorption threshold concentration (see ¶ 3.15) and a flattening of the logarithmic curve near 7 degrees (see ¶ 3.16).

2) Water vapor, because of its high concentration, overwhelmingly dominates the infrared absorption temperature.

3) The sun intensity, Milankovitch cycles, cloud cover, albedo, thermal heat transfers, oceans, life, natural events, catastrophic extra-terrestrial occurrences, and other factors dominate and control the long term and short-term thermodynamics of the Earth's atmosphere.

Based on **Figure 8** and **Table 3**, the absorption temperature rose 1.2˚F when the CO_2 concentration increased from 495 ppmv to 7,383 ppmv. This constituted a 15-fold increase in CO_2. This is directly inconsistent with the 2007 IPCC assessment report [7] which predicted that if the natural CO_2 concentration were doubled to 842 ppmv, it would increase the atmospheric temperature by 5.4˚F based on mathematical modeling. In this laboratory test, a 15-fold increase only raised the absorption temperature by 1.2˚F. This means the IPCC's mathematical model was off by a factor of 31 times over the laboratory-measured amount. Comparing the other data points in **Table 3** confirmed the discrepancy. The second data point was triple the first, and the absorption temperature went up 0.1˚F. This time, the error was 54 times greater. That is an equivalent error percentage of 5,300%.

3.3.3. Ozone

O_3 is a greenhouse gas but is present in the atmosphere at extremely low concentrations. It has a high absorption spectral peak (90%) at a wavelength of 9.2 μm (107˚F). But using the average temperature of the heater (86˚F and 194˚F) it was reduced to about 44%. Water vapor and CO_2 each have a low absorbance (3%) at the temperature of the heater. However, O_3 has an incredibly low natural concentration at 0.01 ppmv. In accordance with the Beer-Lambert laws the total absorbance is related to the concentration multiplied by the absorptivity. Because the concentration is so low, there was no expectation of seeing a response. O_3 is a highly reactive and dangerous gas. It could only be produced in California by a system generating a maximum concentration of 25 ppmv. The O_3 concentration was measured by an instrument set up at the exit from the chamber. See the flow diagram in **Figure 1**.

Table 4 shown below illustrates the concentration increase with each flow rate and provides a column for the product of the concentration and absorbance (0.44).

Table 4. O_3 flow rate, concentration & absorption temperature.

Flow Rate (liters/min)	Concentration (ppmv)	Concentration times Absorbance	Multiple of Natural)	O_3 Absorption Temperature (˚F)
0 (Natural)	0.01			<0.1
0.5	4	1.8	180	<0.1
1	11	4.8	480	<0.1
1.5	17	6.7	670	<0.1
2	20	7.9	790	<0.1
2.5	25	11	1,100	<0.1

The following **Figure 9** shows the average absorption temperature as measured by the infrared detector in accordance with Equation 1. It illustrates that at a concentration of 25 ppmv there is an insufficient concentration to effect any change. The concentration of water vapor during this test was 10,982 ppmv. Factoring in 3% water vapor absorbance, the analysis still shows 74,877 water vapor molecules absorb radiation for every O_3 molecule at its natural concentration. That gives water vapor a 99.999% advantage.

O_3 molecules were simply too few to make any measurable difference. The absorption temperature shown in **Figure 9** at approximately 2.7˚F was caused by other greenhouse gases, mainly water vapor (96%).

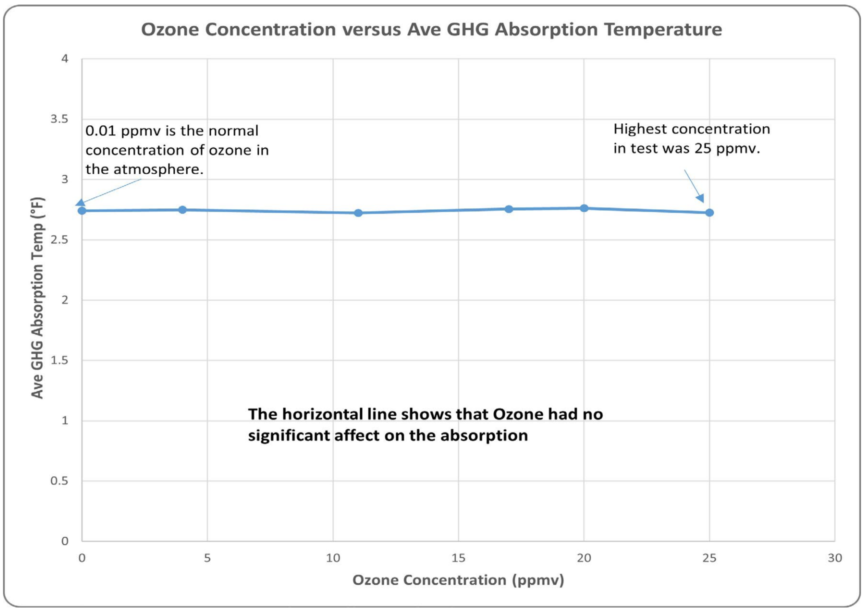

Figure 9. A graph of the absorption temperature on the vertical axis versus changes in the O_3 concentrations identified on the horizontal axis. The O_3 concentration was measured by an instrument identified in Appendix A.

4. Comments, Limitations, and Recommendations

4.1. Repeatability

Reproducibility is indispensable and forms the cornerstone of the scientific method. This is the first open-system laboratory experiment that addressed the Greenhouse Effect using temperatures actually produced at the surface of Earth, with greenhouse gases that are present in the atmosphere at the tested concentrations. This study shows that such an experiment can be done. However, unless it is repeated, it is only anecdotal. It is requested that this type of laboratory experiment be conducted at numerous locations and facilities inside and outside academia. Tests in varied climates covered by the two circles in **Figure 3** would be particularly helpful. This could verify or reject a threshold or a saturation concentration. This includes areas like polar/desert regions, and tropical jungles.

4.2. Possible Uncertainties

There are many areas where improvements can be made. First, use equipment that is more sensitive. The controlling limitation was probably the IR-1 detector restrictions of 0.1˚F. Hence, a photon counter would be a nice option. A system that can detect backscattered infrared radiation would be helpful as a secondary verification. The plastic membrane separating the test sample from thermal heat transfer has a high absorption temperature. Therefore, reducing the thickness of this membrane or even eliminating it would be helpful, provided it does not introduce a thermal heat transfer problem. This study was conducted near sea level in the troposphere, which is the atmospheric layer that constitutes more than 70 percent of the entire atmospheric mass. It is not a study of the Greenhouse Effect that may or may not take place in spheres above the troposphere.

4.3. Steady State

This issue involves a condition in which certain properties of a system do not change significantly over time, even though processes may still be occurring within the system. A steady state is a time period in which the physical or chemical property of a system stops changing with the passage of time. An example would be helpful. If you turn on the faucet to an empty bathtub and partially open the drain valve. As the water level in the tub rises, more and more water will be forced to drain out. At some point in time, the water draining from the tub will equal the amount of water coming in, and the water level will remain constant. The water level has reached a steady state.

Steady state is different from equilibrium. In equilibrium, there is no net change in the system, and that includes net flow of energy or matter. A steady state is when one or two properties become constant over time. Equilibrium rarely occurs in an open dynamic system like the atmosphere.

A question arises as to whether the greenhouse gases inside the chamber absorbed all of the infrared radiation. If that occurred then it did not reach steady state. At 700 liters/minute, the gas sample inside the chamber would be present for only 0.84 seconds. Was this long enough to absorb all the radiation it could? There are several factors to consider. First, the speed of infrared radiation is the speed of light. That means the infrared radiation would pass through the 2-foot-long chamber in 1.7 nanoseconds. That is about 500 million times faster than the 0.84 seconds that the test sample is inside the chamber. Next, how much time does it take for the radiation to be absorbed by the greenhouse gas molecules? Sources have reported that the absorption time is about 10 to 100 femtoseconds. That is more than 10,000 times faster than the speed of light. Studies have shown that it is possible to measure things in femtoseconds [8]. Hence, according to mathematics and physics, the greenhouse gases will reach a steady state 500 million times sooner than needed.

In order to verify this point in this lab experiment, the fan speed was increased to the maximum of 4,813 liters/minute. At that volume flow rate, it would take 0.12 seconds to exchange the air in the chamber. The infrared detector found no changes at the higher flow rates across all 13 temperatures. Therefore, the laboratory observations showed that a steady state in greenhouse gas infrared absorption occurred prior to 0.84 seconds. That is consistent with the laws of physics discussed earlier.

4.4. Is CO_2 the Control Knob for Water Vapor

The IPCC contends that CO_2 is a forcing agent and directly causes temperature changes. Their argument is that warmer air retains more water vapor, and since CO_2 warms the air by absorbing infrared radiation, it causes the atmosphere to hold more water vapor. Based on this logic, they conclude that water vapor is a feedback mechanism based on CO_2. This is called the control knob hypothesis. They cite no laboratory experiment that supports this position. In science there are three major principles involved in proving a hypothesis. These are: a. Causality. This means significant evidence showing cause and effect. b. Temporality. This means the effect always follows the cause. c. Exclusivity. This means all other options have been excluded. The exclusivity analysis is used extensively in the medical field under the name of differential diagnosis. This is where all other diseases are excluded and therefore the patient must have the non-excluded one.

a. Causality. The IPCC's definition of a feedback mechanism implicitly negates direct causation, *i.e.*, CO_2 controls water vapor. By using the feedback argument, the IPCC inserted an intermediate step between CO_2 and water vapor, *i.e.*, temperature. But there are hundreds of factors that affect temperature which have no relationship to CO_2. Some of the more major ones include the sun, oceans, clouds, changes in albedo, orbital deviations, catastrophic events, etc. The IPCC's "GWP" equation fails to include any of those other factors. This equation also assumes that CO_2 resides longer in the atmosphere than water vapor and therefore it has more time to affect changes in the temperature. They contend that water vapor only lasts a brief time period because it condenses out as rainwater. This is misleading. Water vapor resides in the lower elevations of the troposphere indefinitely. Only water vapor in the higher elevations condenses into rain. Although CO_2 does not condense like water vapor, it is nevertheless washed out by the very raindrops that form when water vapor condenses. Absorption of CO_2 by the raindrops is directly related to their surface area. And raindrops start out as extremely tiny spheres with enormous surface areas. It does not appear that the IPCC considered raindrop surface area in calculating residence times of CO_2 in the atmosphere. In addition, CO_2 is 1.5 times heavier than air (1.96 kg/m^3 versus 1.29 kg/m^3) and therefore sinks toward the oceans, which then absorbs the CO_2, and toward the land, which is promptly consumed by the plants. A comparison of historical data over the last 500 million years has likewise negated a CO_2 control knob relationship. A study of temperature and CO_2 over 500 million, 5 million and 1 million years also showed a negative or absent relationship 70% of the time [9]. Hence, the control knob hypothesis does not satisfy the "*Causality*" analysis.

b. Temporality. Numerous studies have shown that the temperature changed first and then there was a response by CO_2 [9]. The IPCC also acknowledged this. They stated:

"*However, it now appears that the initial climate change preceded the change in CO2 but was enhanced by it* (*Section* 6.4)" (IPCC 2007 Assessment Report, pg. 105 [7].

A review of Section 6.4 did not provide evidence to support an enhancement theory. [9] Thus, the control knob hypothesis does not appear to satisfy the "*Tem-*

porality" analysis.

c. Exclusivity. This analysis does not apply since none of the conditions that affect the temperature as listed earlier (sun, oceans, clouds, etc.) have been specifically ruled out or excluded. Historical records over the last 500 million years are also inconsistent with the control knob hypothesis and such analysis has not been excluded [9].

Laboratory Observations

The data shown in **Figure 3** were plotted to find out if changes in CO_2 concentration had any direct effect on the water vapor concentrations. The results are shown in **Figure 10**. If CO_2 were the control knob, the graph would show a relationship, *i.e.*, when the CO_2 knob is turned up, the water vapor responds accordingly. **Figure 10** shows no correlation because the points are scattered randomly. There are 4 points where the CO_2 and water vapor moved in the same direction. That is, if the CO_2 goes up, then water vapor goes up, and vice versa. However, there are 7 points (64%) that are negative, meaning the CO_2 concentration is moving in the opposite direction as water vapor. This means if the CO_2 concentration goes up, the water vapor concentration goes down, and vice versa. Hence, the control knob theory is inconsistent with the laboratory observations. The data also shows divergent paths and large magnitude variances 90% of the time. This observation is also inconsistent. The R^2 was less than 10% for this plot (0.0949). In physics an R^2 of less than 10% usually means the model is not valid or useful. Thus, this shows the data is mathematically inconsistent with the control knob theory.

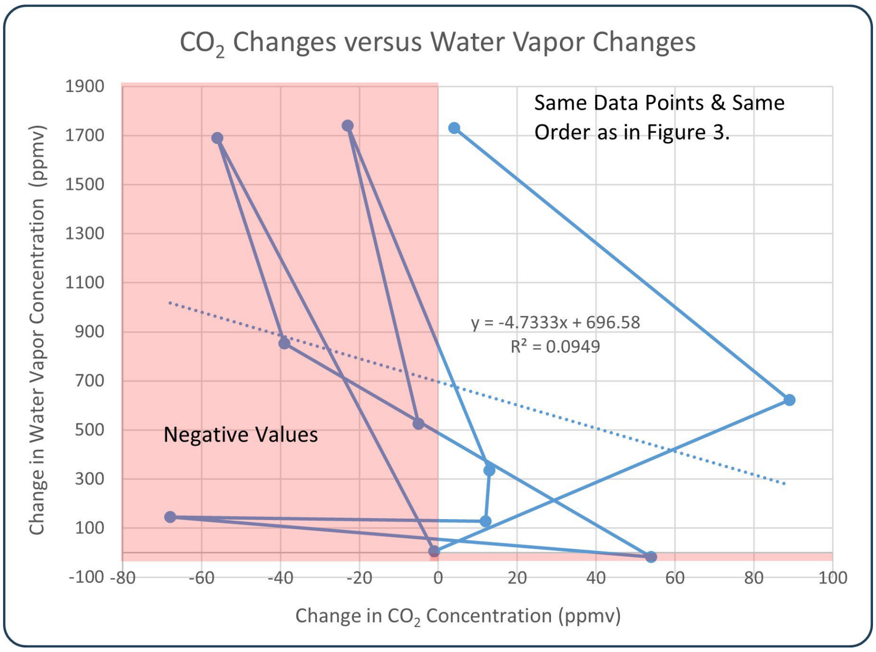

Figure 10. Comparing the CO_2 changes (horizontal axis) to the water vapor changes (vertical axis) regarding the concentrations. These are the same data points as set forth in **Figure 3** and **Table 1** and in the same order. The areas in red are negative values showing that the changes were going in opposite directions.

A different comparison was also made. This time changes in the average CO_2 concentration were compared with changes in the average greenhouse gas absorption temperature. The laboratory observations also showed a negative relationship, major differences with similar divergent paths and magnitudes, and an exceptionally poor R^2 of 17% (0.1699). On the other hand, the comparison of average water vapor concentration to the average greenhouse gas absorption temperature resulted in the same curve as shown in Figure 3 except with a slightly **higher** R^2 (99.49% versus 99.46%). Based on this comparison, water vapor governs the infrared absorption temperature of all greenhouse gases, while incorporating CO_2 diminished the accuracy.

5. Conclusions

This is the only laboratory Greenhouse Effect experiment conducted in an open system with a natural infrared source using greenhouse gases at their natural concentration. In this experiment, atmospheric air was blown through an insulated aluminum foil chamber that was exposed to varying amounts of infrared radiation. An infrared detector measured the intensity of infrared radiation absorbed by the greenhouse gases and converted that intensity into an equivalent temperature. The results showed that the greenhouse gases do, in fact, absorb low energy (also referred to as long wavelength) infrared radiation. It therefore confirms the viability of the Greenhouse Effect. Adding CO_2 to the air stream proved that it could increase the absorption temperature. Hence, the Greenhouse Effect concept was confirmed. The lab test also showed that massive amounts of greenhouse gases are used to produce any measurable effect. A summary of the tests is illustrated in Table 5.

Table 5 shows that the natural water vapor concentration in the air varied from 6,100 ppmv to 14,000 ppmv and constituted 93 to 97 percent of all the infrared absorption temperature. CO_2 at its natural concentration of 421 ppmv had no measurable effect on the absorption temperature. Raising the CO_2 concentration to 14,775 ppmv (a 34-fold increase from the current concentration) only raised the absorption temperature 2.1˚F. The IPPC contended that a simple doubling of the CO_2 concentration would raise the temperature 5.4˚F. This shows an overstatement error of 3,300%.

Table 5. Summary of tests.

Type of Gas	Natural (ppmv)	Added Gas (ppmv)	Above Natural	Absorption Temp (˚F)	Biological History
Greenhouse					
WV	6,168	0	0	1.3 (93%)	Today
WV	10,217	0	0	2.5 (95%)	Today
WV	13,925	0	0	3.3 (97%)	Today
CO_2	421	1,016	3 times	0.1	50 million years ago
CO_2	421	6,962	15 times	1.2	520 million years ago
CO_2	421	14,354	34 times	2.1	(Never No records)
CH_4	1.9	457	241 times	<0.1	Billions of years ago
O_3	0.01	25	2,500 times	<0.1	Unknown

Continued

Non Greenhouse					
Ar	9,300	14,280	1.5 times	<0.1	Currently the highest ever
He	5	14,280	2,856 times	<0.1	Billions of years ago

Table 5 lists the type of gas and the atmospheric natural average concentration in columns 1 and 2. Column 3 is the amount of gas added and column 4 is the multiple over the natural concentration. Column 5 is the average absorption temperature. In rows 1 - 3 of column 5, the percentage of water vapor to the total greenhouse gases is also presented. In Column 6 is the number of years during which the concentration in Column 3 existed in the past.

The laboratory data strongly dispute the hypothesis that CO_2 controls the water vapor concentration or the absorption temperature.

Conflicts of Interest

The authors have no conflicts of interest regarding the publication of this paper. Michael Nelson purchased all the equipment without refund or payment by any other person or entity. All the data was collected by the author Michael Nelson, without the assistance of others. The authors received no money, grants, or other consideration from others in this study.

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Appendix A Photos, Equipment, and Calibration

a. Equipment List. The heater was a Keenwise Model HP-E2020 high-efficiency heater for electronic physics, biological, chemical lab reactions, and microbial culturing experiments. It has intelligent temperature control. The heater was sold by Amazon.com and manufactured by Keenwise. The heater was calibrated over the range of 86˚F to 194˚F with a glass thermometer made by Alla France. A CO_2 /Humidity Detector used in the test was an AZ Instrument Corp, Model AZ 7552, with a measuring range of 0 to 9999 ppm with an accuracy of ±50 ppm of CO_2. It has a humidity range from 0.1% to 99.9% Relative Humidity with a resolution of 0.1%RH. The infrared detectors were a high-accuracy Mestek Infrared Detector model IRO5A-OR with a response time of 0.5 microseconds and a resolution of 0.1 degrees Fahrenheit. Elitech GSP-6 was manufactured by Elitech Technology Inc. San Jose, CA 95131. It has a temperature range from −40˚F to 158˚F and a humidity range was 10% to 99% with an accuracy of 3% and a resolution of 0.1%RH. Loddery Ozone Meter Model QQ1567X manufactured by Loddery. It has a range of 0.01 to 50 ppm ozone. A2Z Ozone Inc. of Louisville, Ky was the manufacturer of the Aqua 6 Ozone Generator. It is capable of making 600 mg of Ozone/hour. ProBreeze Dehumidifier manufactured by Pro Breeze is capable of removing 0.27 liters/day with a capacity of 12 cubic meters/hour. Seedfactor heating pad UPC 752454318834 manufactured by Seedfactor. Capable of providing an adjustable constant temperature between 75˚F and 85˚F. Flow meter 1 - 10 liters/minute model number Yanmisfqto6sybmd manufactured by Yanmis. It has an accuracy of 5%. Wathai Big Airflow dual computer fan with a variable speed controller manufactured by Wathai in China. These two fans produce a total of 4,813 liters/minute (170 cubic feet/minute).

b. Photos. Pictures of different views of the test apparatus.

Figure S1. The Keenwise Heater with the outer portion covered with aluminum foil insulation. The inner 4-inch by 4-inch center painted black was used to produce the infrared radiation at various temperatures.

Figure S2. The view from the right side showing the fans and controller for the Seedfactor blanket heater.

Figure S3. A top view with the cover removed. In the upper right portion it shows the dehumidifier and in the upper left portion it shows entrance to the test chamber. The slower portion shows the top of the side chamber that was to be used to detect backscattering. That backscattering test was abandoned. The bottom left portion shows the tubes from the flow meter and wires for the thermocouples and humidity detector.

c. Calibrations. The following are various calibrations of the laboratory system.

1) The IR-1 Calibration curve.

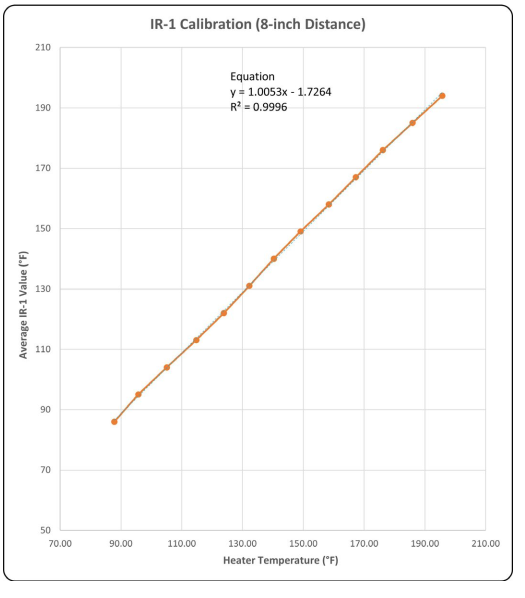

Figure S4. The calibration curve for Infrared Detector IR-1 temperatures as compared to the heater temperatures. This was done by placing the detector 8 inches from the heater and **outside** of the equipment box as shown in Figure 2. The data points were taken at heater temperatures of 86˚F taken at 9˚F increments up to 194˚F. The average IR-1 value from three tests is shown as the IR-1 Correction value. The temperature values from the IR-1 measurement were remarkably close to the heater temperature with an R^2 value of 0.9996%.

2) The absorption temperature of the 0.5 mil plastic membrane calibration.

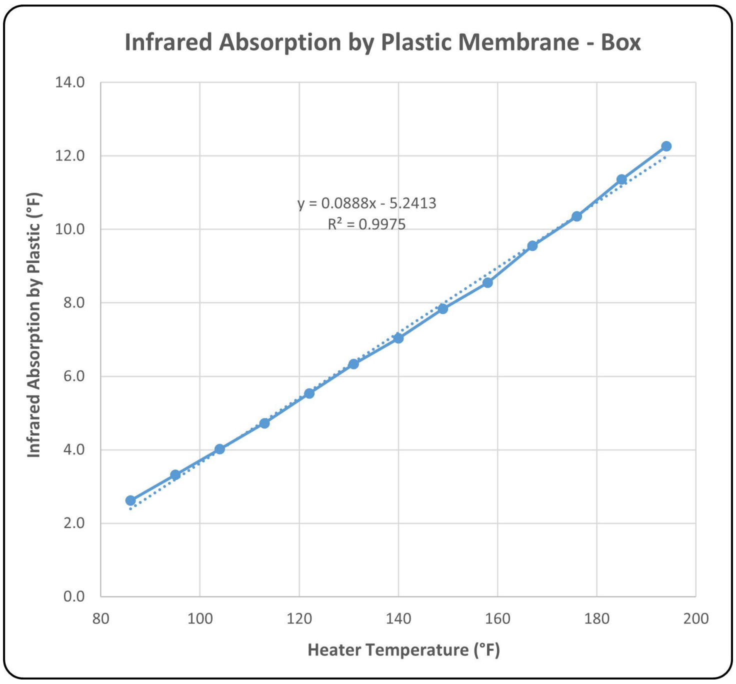

Figure S5. The calibration of the Absorption by Plastic Membrane. This was done by taking a reading by the IR-1 detector with and without the plastic membrane covering the hole in the equipment box. The temperature values from the IR-1 measurement were compared to the heater temperature. It produced an equation with an R^2 value of 0.9975. The equation showed that the plastic membrane absorbed from 2.4˚F at a heater temperature of 86˚F up to 12˚F at a heater temperature of 194˚F. The ambient temperature, humidity, and CO_2 concentration remained the same during the test.

3) Fan Calibration

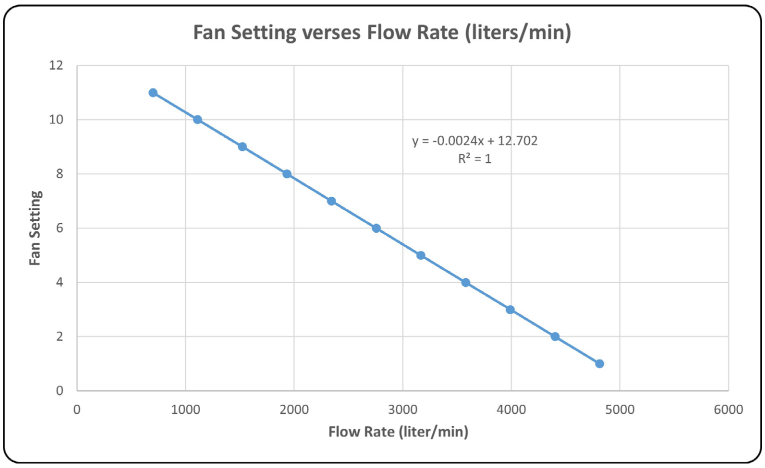

Figure S6. The fan calibration based on the maximum flow rate identified by the manufacturer and the measured minimum flow rate. The minimum flow rate was measured by discharging the existing air flow into a plastic bag over 3 and 5 seconds and measuring the contents with a syringe and averaging the difference.

4) Thermocouple Calibration

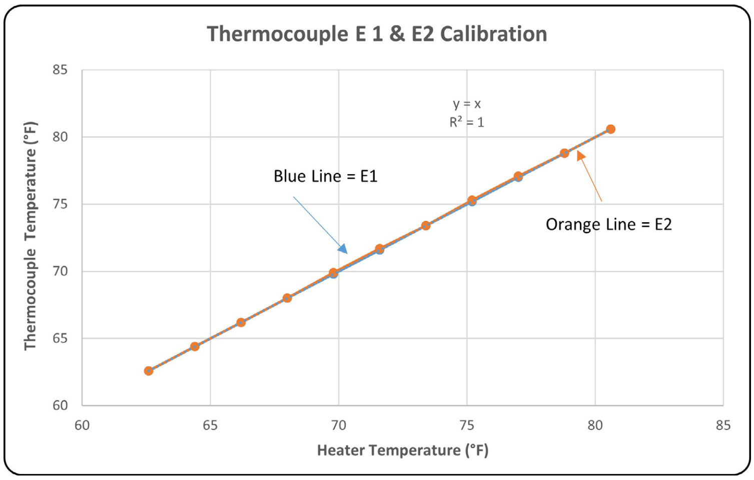

Figure S7. The calibration curves for thermocouples E1 and E2. These thermocouples were taped to the heater, and the heater temperature was raised in 1.8˚F increments. The thermocouples were used to measure the ambient conditions. Both thermocouples matched the heater's temperature in this narrow range.