CO_2 Based Control System for Demand Control Ventilation

MENG 3211 LABORATORY REPORT
TUESDAY – GROUP A

		Contribution
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We certify that the narrative, diagrams, figures, tables,
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ABSTRACT

For this project, a mathematical formula was developed to control the opening and closing of a damper depending on the CO_2 reading. The amount of CO_2 in the air was detected by a sensor and the mathematical formula was programmed into an Arduino program. The use of the Arduino code allowed for the mathematical determination of the CO_2 change and then subsequent degrees the damper needed to open or close. The Arduino code also allowed for the tracking of the dampers’ location relative to the x-axis.

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INTRODUCTION

In residential and commercial buildings, it is necessary to maintain fresh air; this has most commonly been accomplished using HVAC systems. In such systems, each vent has a damper that controls how much fresh air flows into a space. Normally these dampers are set at an angle when the air ducts get installed that can be manually or electronically adjusted according to the needs of the space. In recent years, CO_2 based demand control ventilation (DCV) has been modified to be used in residential HVAC systems. The use of DCV systems allows for the determination of the necessary amount of fresh air flow into a room based on a reading of CO_2 by a sensor placed in or near the return duct. Jemaa, et. al, showed that DCV CO_2 sensors can be calibrated using various equations to estimate ventilation demands. One sensor can be used; however, it was shown that multiple sensors are preferable to obtain the optimal comfort and to conserve energy use [1].

There are many methods to determine the ventilation rate, as seen in the figure below, with the most accurate way being a measurement of the amount of CO_2 in the space. This way allows for the movement of dampers based on the readings output from a CO_2 sensor. By reading the CO_2 in the air, buildings can save energy as they are only introducing fresh air when it is necessary.

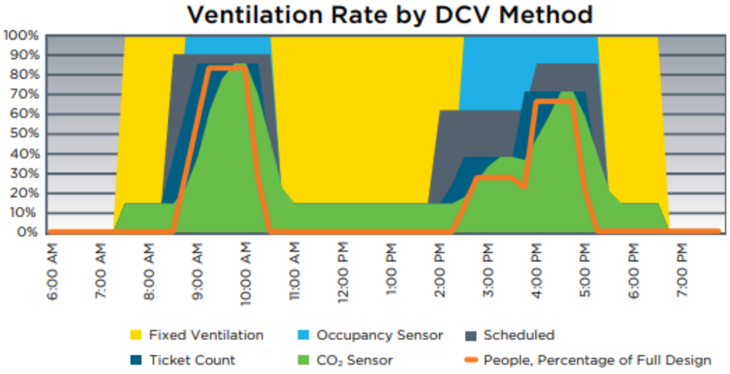

Figure 1. Various Methods of Demand Controlled Ventilation Activation Comparison [2]

METHODOLOGY

Equipment and Materials List

- Elegoo MEGA 2560 Arduino Board
- MHZ-19B CO_2 Sensor
- Breadboard
- Dual Relay Switch
- Electric Motorized Damper
- Jumper Wires
- 18 Gauge Wire
- Arduino Compatible LCD Screen
- 10k Potentiometer
- Transformer

Experimental Apparatus

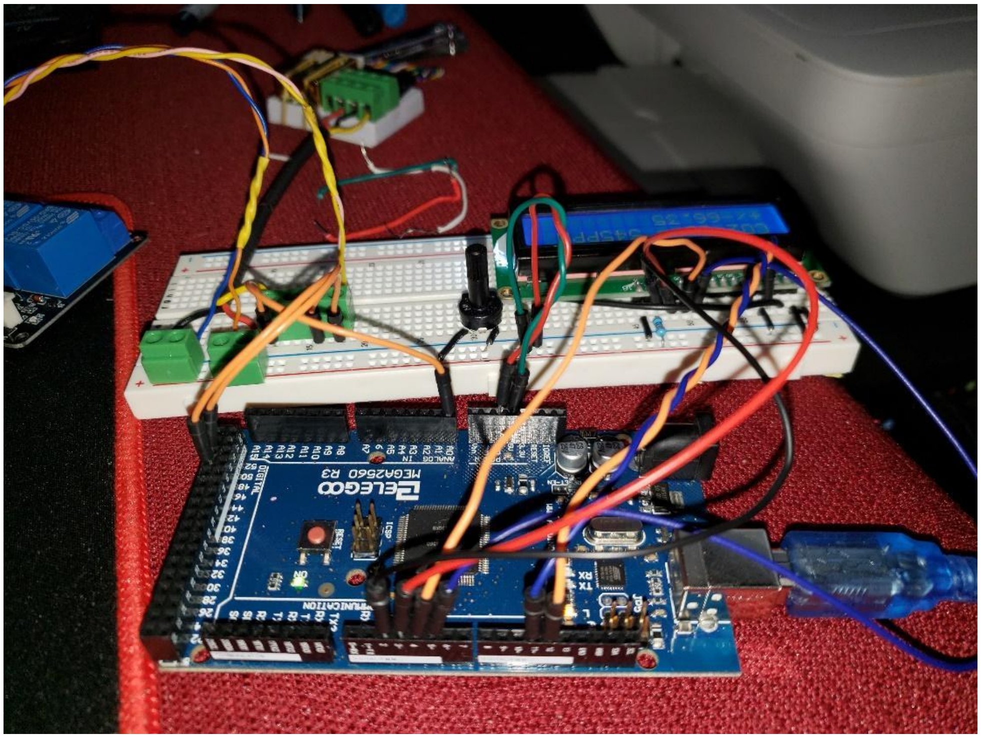

Figure 2. Breadboard and Elegoo MEGA2560.

Figure 3. Damper with Dual Relay connected.

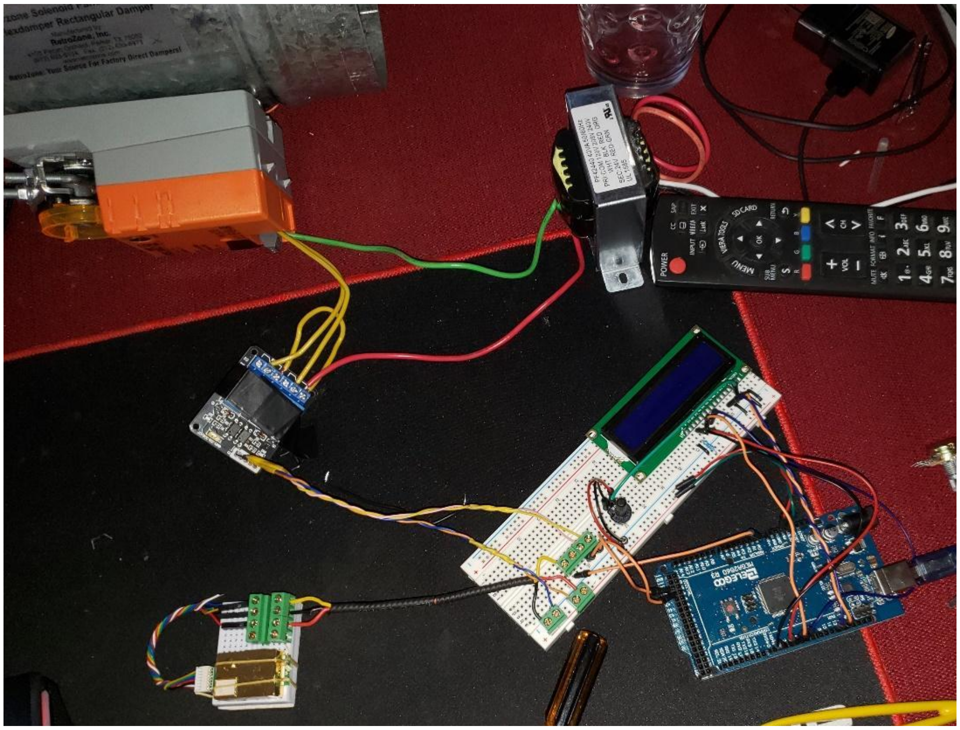

Figure 4. Damper, Relay, Sensor, and Transformer wired together with the Arduino board.

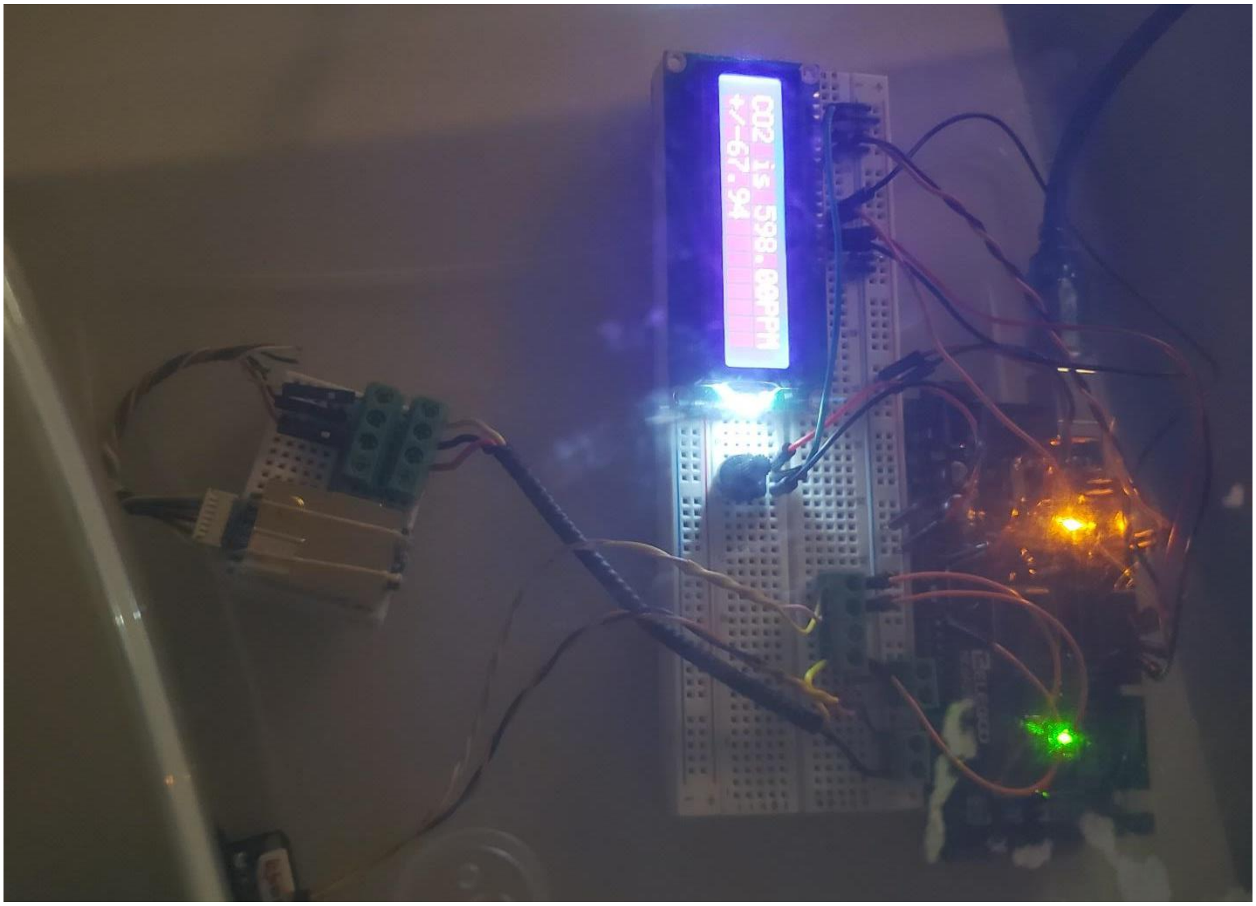

Figure 5. System running with Sensor values displayed.

Experimental Procedure

Begin by wiring the LCD Screen, CO_2 Sensor and Relay Switch to the breadboard and connect the breadboard to the Elegoo MEGA2560 Arduino board. Connect the red power cable of the transformer to the relay switch in the center slot. Connect the green ground cable of the transformer to the grounded terminal of the damper. Connect an 18-gauge jumper wire from the center slot of the 1st relay switch with the power cable to the other center slot of the 2nd relay switch. Connect the left terminal of relay 1 to the positive power terminal of the damper using an 18-gauge wire, then connect the left terminal of relay 2 to the negative power terminal of the damper using another 18-gauge wire. For a detailed schematic of this process, see Figure A.1 in

Appendix A. Figures 2-5 show the equipment used and the experimental setup. Plug in the transformer and then plug the Arduino board into the computer where the Arduino code is contained and upload the code to the board. At this point, if everything has been wired correctly, the sensor should be taking readings of CO_2 and the relays should be adjusting the damper appropriately.

To prove that the damper is working effectively, allow the sensor to acclimate to the environment for at least 5 minutes, then exhale onto the CO_2 sensor from a distance approximately 5 inches away. Prior experiments have shown that held breath yields a greater difference in CO_2 concentration, where the longer the breath is held, the higher the concentration. The damper should adjust to the appropriate degree of openness due to this change in CO_2 concentration. The flow chart of the control logic of the sensor/damper interface can be found in Appendix B. Allow the sensor to equalize once again and note that the damper will close once appropriate levels of CO_2 are reached.

RESULTS

The following data was gathered from the experiment, the first and last three readings are shown below with the complete data set shown in Appendix C.

Table 1. Data from experiment with movement time as it relates to CO2 reading and position of the damper.

	1	**2**	**3**	**13**	**14**	**15**
Sensor Reading (ppm)	624	632	628	644	646	**783**
Uncertainty (±)	68.72	68.96	68.84	69.32	69.38	73.49
Change in CO2 (ppm)	0	8	-4	2	2	**137**
Movement Time (sec)	0.00	0.76	-0.38	0.19	0.19	**13.02**
Damper Position (degrees)	11.16	11.88	11.52	12.96	13.14	**25.47**
Direction	CLOSE	OPEN	CLOSE	OPEN	OPEN	**OPEN**

From this data, it can be seen that with a greater change in CO_2, a greater degree of openness is achieved. The minimum safe level of CO_2 was set at 500 ppm for the experiment due to levels being under this in the environment and the need to show a variable change. Measurement 15 was taken after the sensor was exhaled upon, and a clear spike in CO_2 concentration was observed to a value of 783 ppm. This caused the damper to open for approximately 13 seconds to a position of 25.47^o.

DISCUSSION

After much research, a formula was derived, shown in Equation (1), based upon a mixture of gases in a constant volume with a mass flow of air in and out of the system at some determined rate. This research was abandoned; however, as the flow rate of the system was unknown. Instead, new directions were pursued which relied solely on the measurement of CO_2 in the system and will adjust the damper based on this value. This allows for actual real-time measurements of the system and for adjustments to be made automatically in order to maintain a safe range of carbon dioxide. With this in mind, a simple formula was derived, this is shown in Equation (2).

$$t = \frac{lnln\ \left(\frac{\left(c_o - \frac{q}{nV} - c_i\right)}{\left(c_1 - \frac{q}{nV} - c_i\right)}\right)}{n} \tag{1}$$

$$\frac{Time\ to\ Fully\ Open * 90^o}{90^o * Maximum\ \Delta CO_2}\ yields \rightarrow\ \frac{95\ seconds}{1000\ ppm} \tag{2}$$

This new formula allowed for coding to be completed in the Arduino programming language with only rudimentary knowledge of coding languages and the task was completed successfully. The sensor reads values of CO_2 in the system every 30 seconds and uses the change in the level of CO_2 to determine whether the damper needs to be opened or closed. If the level of CO_2 is below the minimum safe level for the system, the damper will remain closed; likewise, if the critical level of CO_2 is exceeded, the damper will remain fully open until a sub-critical level is achieved. Between these values, the damper will open to a certain degree based upon the level of CO_2 and the time required to get to that degree of openness.

The degree of openness of the damper relative to the x-axis was also calculated, as shown in Equation (2). This equation allowed for the determination of the dampers position at all time throughout the experiment.

There is room for more preciseness in the flow through the damper, as the elliptical cross-sectional area of the damper as it opens was not considered in the time calculations. The reasoning for this was that the flow through was mostly linear except for the first 10% and the last 20% of the damper’s openness; also, the difference from a completely linear trend was minor. Thus, a purely linear relationship was determined to be sufficient.

CONCLUSION

From this experiment, it was shown that a CO_2 sensor could open and close a damper based on the readings of CO_2 from a space. Through trial and error, mathematical equations were produced. These mathematical equations were then coded into an Arduino. This logic calculated the change in CO_2 and opened or closed the damper. If the CO_2 change was greater than the baseline the damper would open. This would allow for the introduction of fresh air into a space. If the change was less than the baseline the damper would close, as fresh air would not be necessary. The location of the damper was also calculated relative to the x-axis. The tracking of the position allowed for the confirmation that the logic was sound.

REFERENCES

1. Jemaa, K.B.; Kotman, P.; Graichen, K. Model-Based Potential Analysis of Demand-Controlled Ventilation in Buildings. *IFAC-Pap.* **2018**, *51*, 85-90
2. U.S. Department of Energy, "Demand Control Ventilation." 2012 IECC.

APPENDIX A

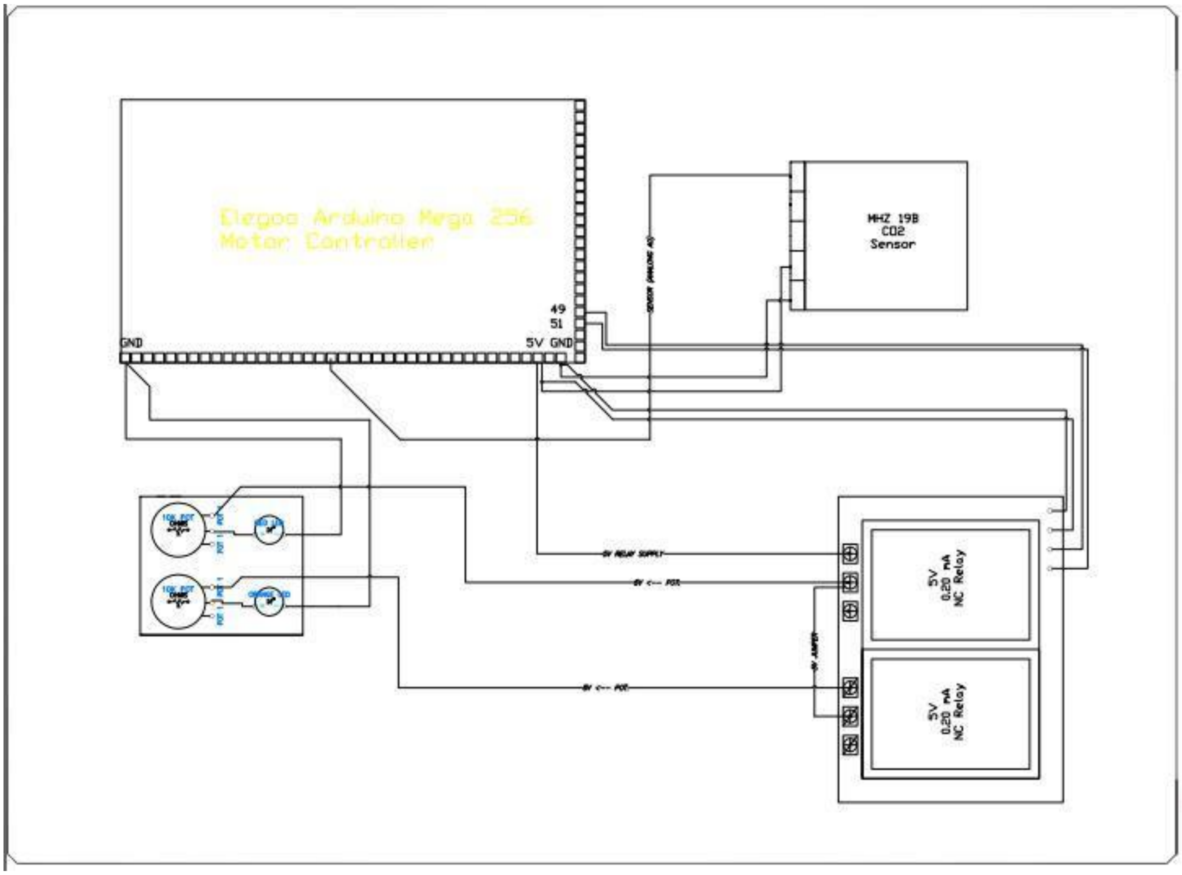

Figure A.1. Electric Schematic of Arduino, Relay Switch, MHZ-19B CO_2 Sensor, and Damper.

APPENDIX B

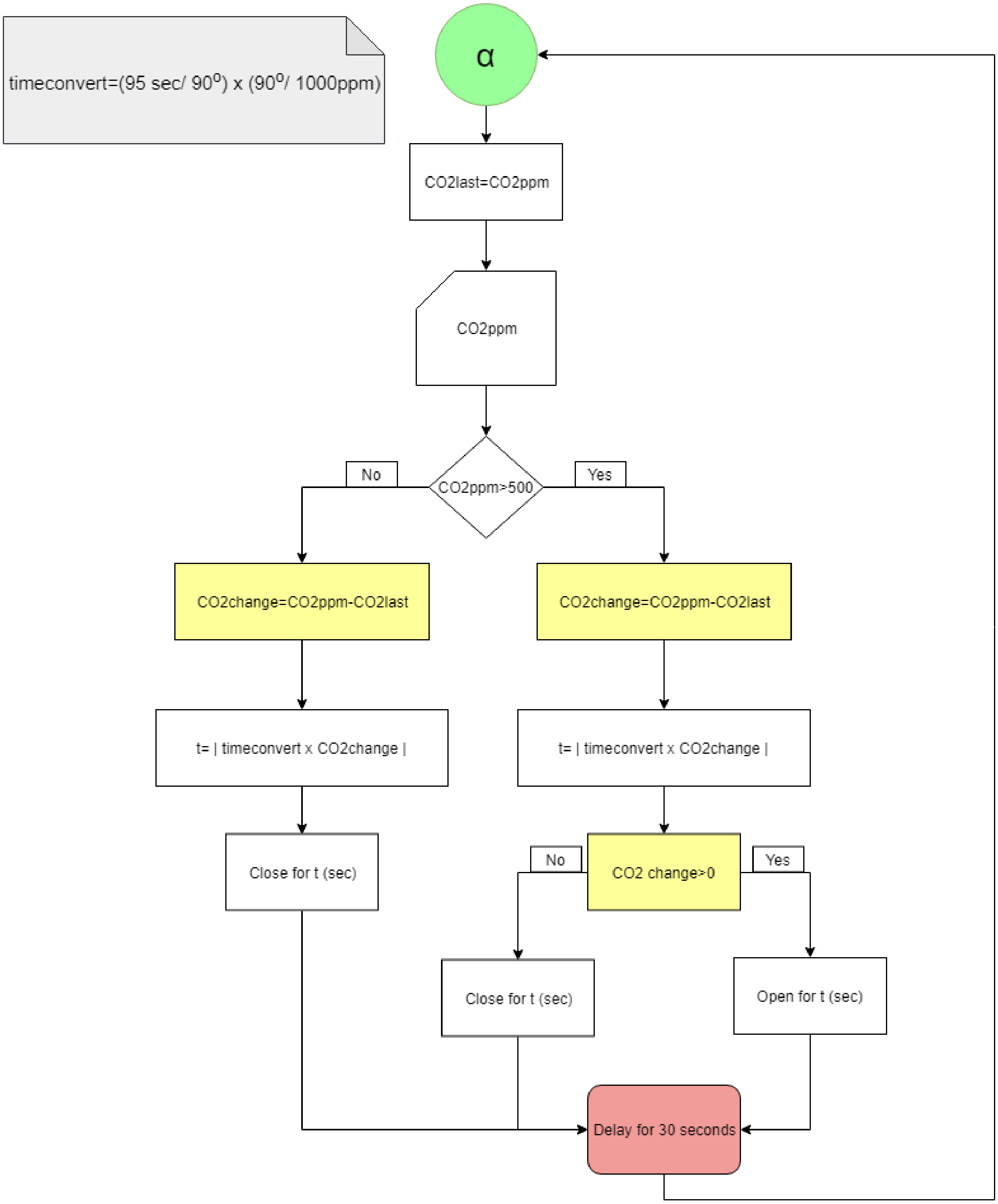

Figure B.1. Flow chart of control logic.

APPENDIX C

Table C.1. Data from Experiment

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sensor Reading (ppm)	624	632	628	633	637	629	636	635	641	637	640	642	644	646	**783**
Uncertainty (±)	68.72	68.96	68.84	68.99	69.11	68.87	69.08	69.05	69.23	69.11	69.2	69.26	69.32	69.38	73.49
Change in CO2 (ppm)	0	8	-4	5	4	-8	7	-1	6	-4	3	2	2	2	**137**
Movement Time (sec)	0.00	0.76	-0.38	0.48	0.38	-0.76	0.67	-0.10	0.57	-0.38	0.29	0.19	0.19	0.19	**13.02**
Damper Position (degrees)	11.16	11.88	11.52	11.97	12.33	11.61	12.24	12.15	12.69	12.33	12.6	12.78	12.96	13.14	**25.47**
Direction	CLOSE	OPEN	CLOSE	OPEN	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE	OPEN	OPEN	OPEN	OPEN	**OPEN**