STUDENT SENSOR PROJECT

MENG 3210 LABORATORY REPORT

TUESDAY – TEAM 3

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ABSTRACT

Demand Control Ventilation (DCV) is a method for introducing fresh air, as necessary, to a space, utilizing the installed HVAC system and a sensor that monitors CO_2 levels. These sensors help to accurately determine when levels drift out of safe ranges, necessitating a greater influx of fresh air; conversely, when CO_2 levels are within a safe range, energy can be saved by recycling the already conditioned air, reducing the strain on the AC system. For this project, a sensor that could accurately measure CO_2 levels which would reasonably be encountered in a residential space was to be selected. This sensor was then wired to a purchased Arduino-compatible board, along with an LCD screen for displaying measurements and relevant text, 3 LED lights for rapid status acquisition and accompanying resistors, jumper cables and other necessary equipment for basic electronic function. Two major experiments were performed; one for basic function/calibration testing and the other for comparison to control sensors in order to test the accuracy of the student developed system. This project was carried out in order to develop a greater understanding of both DCV as a field, and to cultivate knowledge of all relevant tasks associated with completing such a project, including programming in Arduino, wiring/electronic work, calibration of sensors and fostering teamwork.

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INTRODUCTION

For this project, multiple facets were taken into consideration, including: the necessary range and accuracy of the sensor to be used, cost of materials, the skill level of the experimenters, the desired utilization and the ease of use for the end user. To this end, research was conducted in order to better understand the topic of Demand Control Ventilation, the available sensors on the market, programming languages and methods of wiring consumer-level sensors to programmable boards.

To become familiar with the concept of DCV, a research paper, "*A Healthier, More Energy Efficient Approach to Demand Control Ventilation*," was selected. This detailed the basic idea and some of the more common issues that others have faced when dealing with DCV. The general idea behind DCV is to monitor CO_2 levels in a designated space to determine when fresh air is needed to maintain a healthy and safe indoor air quality (IAQ). [1] This is beneficial because cooling/heating outside air to a comfortable temperature requires far more energy than recycling the already conditioned air; however, discomfort can arise at CO_2 concentrations greater than 1,000 ppm and serious dangers begin at prolonged exposures of 5,000 ppm or greater. [2] This necessitates that fresh air from outside be cycled into the space and the polluted air from the inside flushed out. This occurs with all current HVAC systems, but large inefficiencies become apparent when fresh air is cycled into an empty space at the same rate as when dealing with peak occupancy.

With this knowledge, a sensor that could read CO_2 levels from 0 – 5000 ppm was selected in order to cover the entire acceptable range. Low-cost, consumer grade sensors were researched and the MH-Z19B CO_2 sensor was selected due to the necessary range of 0 – 5000 ppm and an accuracy of ± 50 ppm + 3%. [3] This is a non-dispersal infrared (NDIR) type sensor that detects levels of CO_2 by directing a known amount of infrared light at a wavelength of 4.2-microns, which is close to the 4.26-micron absorption band of CO_2. As gas passes through the control volume, the detector measures the difference from the total output of infrared light and the absorbed amount of infrared light, this difference is converted to a value of the parts-per-million of CO_2 in the gas that is measured.

Having selected the sensor, a compatible, programmable, board was chosen. A kit which contained multiple bread boards, resistors, jumper cables, potentiometers, sensors, etc. was selected for convenience and cost effectiveness; this was the Elegoo EL-KIT-001 UNO R3. Utilizing this kit, the sensor was attached to the bread board by removing the original connector and preparing the bare wires for connection to the bread board. The purchased LCD screen was installed and wired, along with the LED lights and the required resistors and potentiometers.

Once the hardware was installed, the Arduino program that came as part of the kit was utilized to program the output of the sensor, perform calibrations and set ranges for safe, cautionary and dangerous levels of CO_2. The Arduino programming was streamlined and utilized to output a real-time value for the parts per million as well as text information of the status of the IAQ. The ranges were set, and from 0 – 400 ppm was considered “Safe”, 400 – 800 ppm was considered as a “Warning” zone, and greater than 800 ppm was considered to be a “Danger” for the purposes of this project. These values were later changed and will be discussed later in this report.

METHODOLOGY

The CO2 Based Control System for Demand Control Ventilation Student Design Laboratory Project consists of creating software and hardware capable of sensing a change in CO2 and generating a trigger indicating the change. The project including researching a CO2 sensor, developing skills and knowledge in testing procedures, and developing teamwork. Additionally, skills were developed included computer coding for Arduino devices as well as the hardware associated with the Arduino. Using these skills, the group developed a working prototype for detecting a change in CO2 and generating a signal.

Equipment and Materials List

Equipment needed for the CO2 Based Control System for Demand Control Ventilation or DCV includes the following. Hardware needed includes an Elegoo EL-KIT-001 UNO R3 processing board, jumper wires, connection breadboard, potentiometer, resistors, LED’s, small LCD screen, and a MH-Z19 CO2 sensor that is compatible with an Arduino processor. Software requirements include code that can display data on an LCD screen, code specific to the CO2 sensor, and code that will generate a signal that can be visible from an LED. Powering the processor can be done with a 9V AC adaptor, 5V USB connection, or a 9V battery.

Experimental Apparatus

The Laboratory Project includes 2 activities. Each activity will be using the equipment listed as well as additional equipment needed for each specific activity. The description of each activity will be described within each Sub-Sub Heading below.

Activity 1. As seen in Figure 1.1. Hardware setup includes the Elegoo EL-KIT-001 UNO R3 processing board, jumper wires, connection breadboard, potentiometer, resistors, LED's, small LCD screen, and a MH-Z19 CO2 sensor that is compatible with an Elegoo processor. Additional equipment needed for activity 1 includes a tall jar with lid, baking soda, and vinegar. For the setup of the experiment clean the jar of any contaminants and have the sensor on and reading measurements.

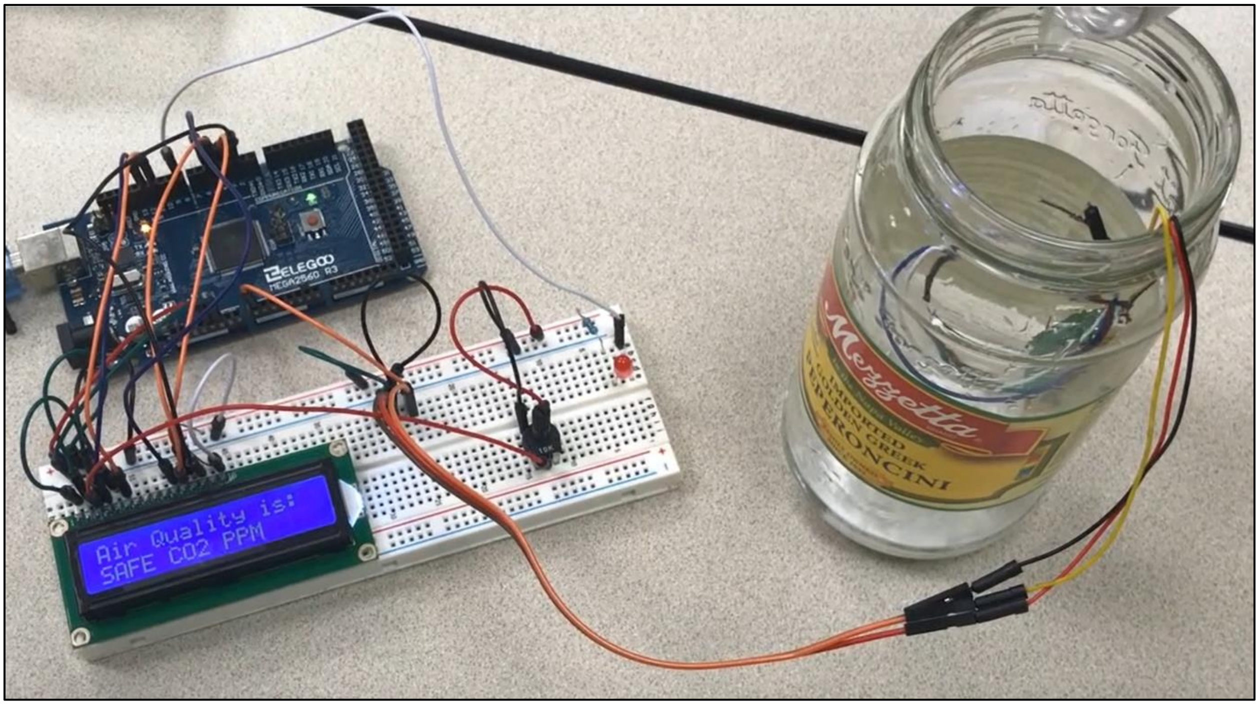

Figure 1.1. Image of the experimental setup for Activity 1.

Activity 2. As seen in Figure 2.1 Hardware setup includes the Elegoo EL-KIT-001 UNO R3 processing board, jumper wires, connection breadboard, potentiometer, resistors, LED's, small LCD screen, and a CO2 sensor that is compatible with an Elegoo processor. Additional equipment includes 2 factory calibrated sensors, a power source for the sensors, the data logging device "laptop", large clear storage container with a lid, and a small fan. Access to an outdoor area is also needed for calibration and additional testing.

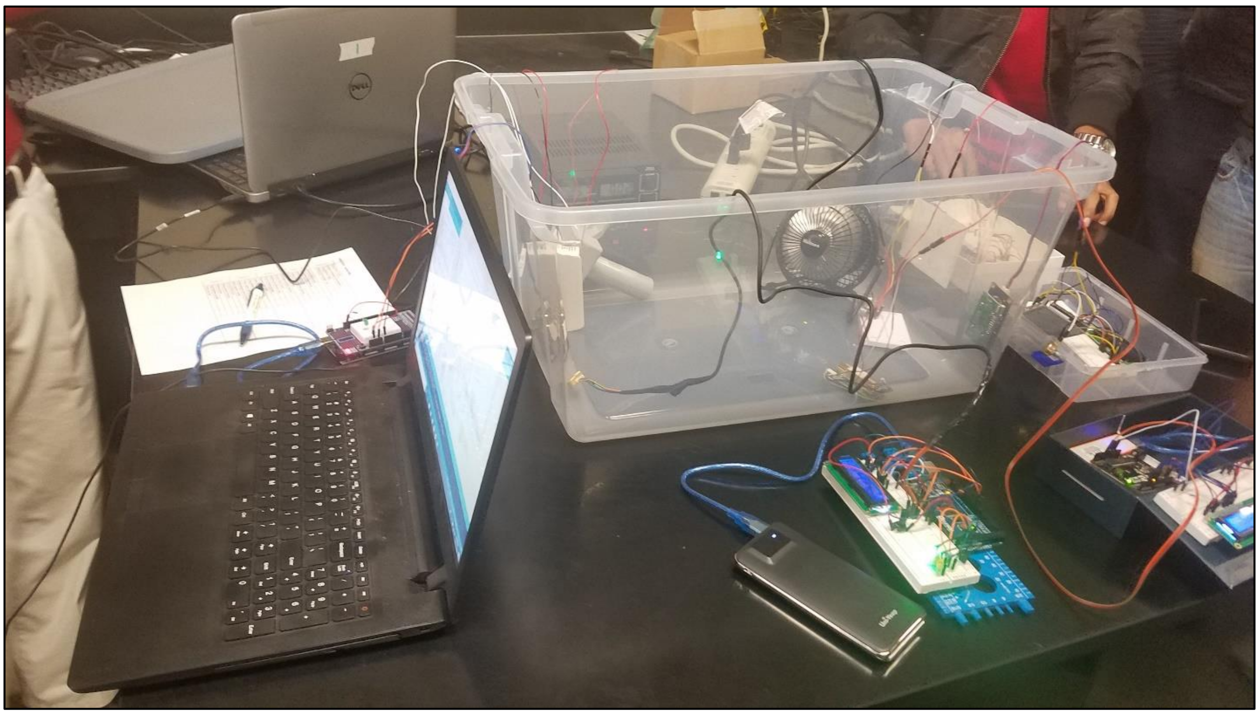

Figure 2.1. Image of the experimental setup for Activity 2.

Experimental Procedure

Activity 1. Is to use a chemical reaction between baking soda and vinegar to create CO2 in a confined space to trigger the MH-Z19 CO2 sensor. The first step in the procedure is to turn the CO2 sensor on and verify that it is reading properly. After the sensor has been verified thoroughly clean the jar of any contaminants. For the first step of the chemical reaction place a small amount of baking soda into the jar. Next, pour in enough vinegar to comply cover the baking soda. A chemical reaction will begin to produce CO2 that will cause the sensor to signal a change. As seen in Figure 3.1 the red LED is showing a change in CO2 levels.

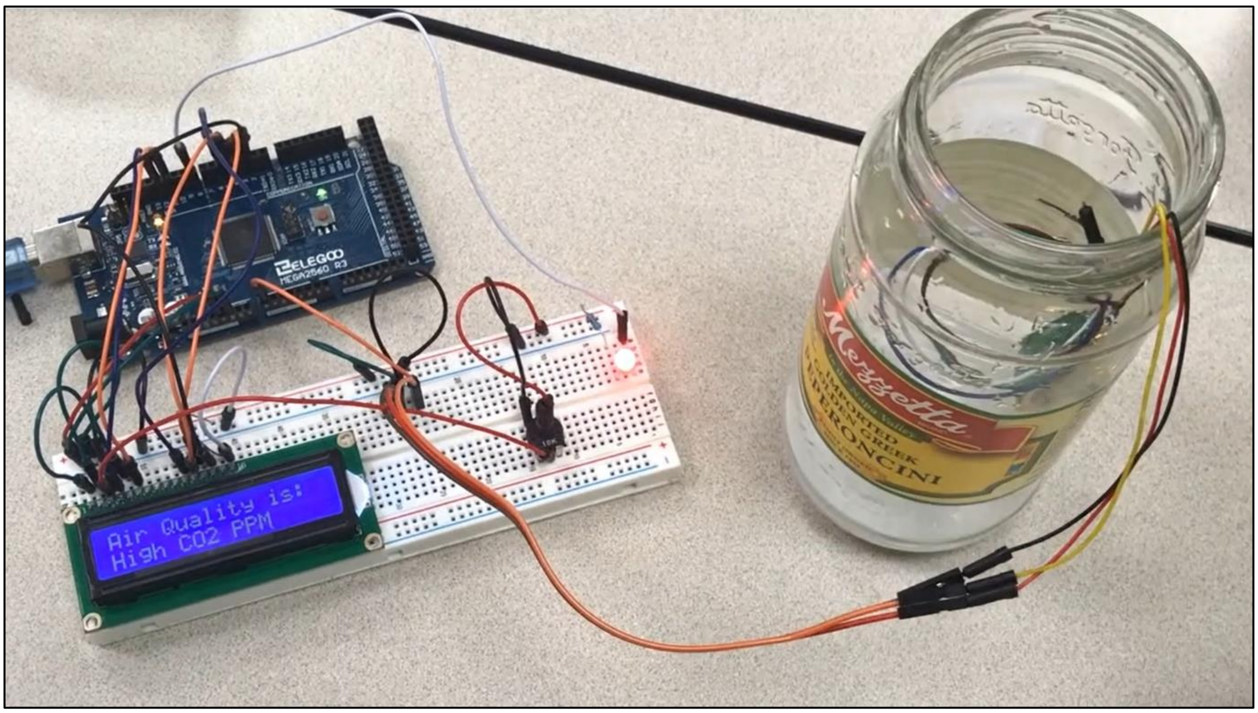

Figure 3.1. Image of the experimental results from Activity 1 showing the signaling of the red LED.

Activity 2. This activity consists of 2 parts. The first part of the experimental validation consists of comparing the sensor to the standard sensors. Simply move the testing equipment outside to begin reading the outdoor CO2 levels. The readings should show levels near 400ppm. If the sensor is not reading near these levels calibrate the sensor. For the second part of the validation place both the standard sensors and the project sensor in a large container with a small fan running. Allow the sensors to warm up and stabilize the reading. Once stabilized begin by checking the if the levels are elevated from the outdoor air. If the levels are not substantially higher simply breath into the box by slightly cracking the lid as to contain the CO2 in the box. Keep repeating this until the sensor trigger with the LED. Once the LED triggers are sure to record the reading of both the standard sensors and the project sensor.

RESULTS

Table 1 below outlines the results from each test performed in the Experimental Validation Lab performed on November 27th, 2018. The table shows the actual experimentally determined PPM (parts per million) values from both the outside and inside experimental setups.

Table 1. Results from Inside and Outside CO_2 Concentration tests.

Experimental Procedure	Group Measured Data (PPM)	Uncertainty (PPM)	Instructor Measured Data (Avg)	Uncertainty (PPM)	Within Acceptable Range
1 (Inside)	365	± 60.95	365.5	± 50.5	Yes
2 (Outside)	606	± 68.18	791	± 63.5	No

Uncertainty

The uncertainty associated with the measured experimental data has been considered throughout the entire experimental process. However, for the experiment two separate CO_2 sensors were provided to act as the standard by which each sensor validated against. The sensor used in the experimental setup had a defined uncertainty from the manufacturer of ± 50 ppm + 3%. Equation **(1)** below is used in conjunction with the manufacturers provided data to determine the uncertainty of the experimental data.

$$\boldsymbol{Sample\ Value\ N \pm 50\ ppm + 3\%\ measured\ value} \qquad \textbf{(1)}$$

<u>Outside CO_2 Measurement</u>

$$606 \pm (50\ ppm + (.03\ x\ 606\ ppm)) = \boldsymbol{606\ \pm 68.18\ ppm}$$

<u>Inside CO_2 Measurement</u>

$$365\ \pm \big(50\ ppm + (.03\ x\ 365\ ppm)\big) = \boldsymbol{365 \pm 60.95\ ppm}$$

As seen in Table 1, Equation (1) was used to account for the group sensors uncertainty of the experiment, a similar equation was also used to determine the uncertainty of the instructor's data values as seen in Table 1.

DISCUSSION

Though an experiment was performed to establish that the sensor was working and measuring a difference in CO_2 levels with 5% distilled white vinegar and baking soda, there was little quantitative data recorded; however, this experiment did establish a baseline measurement and proved the efficacy of the programming and hardware that was utilized. The remainder of this discussion will refer to the final experiment that was performed in which the sensor was tested against a control sensor in both and indoor and outdoor environment.

The indoor/outdoor experiment demonstrated that there was a large difference in the CO_2 concentration between a confined space and the outdoors. Moreover, that the interior concentration is nearly twice that of what is considered as “fresh” air. In this regard, the experiment was a success.

As seen in Table 1 above, the outdoor portion of the experiment yielded a highly accurate reading, having only a ~0.07% error; however, during the indoor experiment, this error was much larger at 13.24%. This percentage error was calculated using Equation **(2)**.

$$\%\,\boldsymbol{Error} = \frac{|\boldsymbol{measured\ value} - \boldsymbol{accepted\ value}|}{\boldsymbol{measured\ value} + \boldsymbol{accepted\ value}} * \mathbf{100} \qquad \textbf{(2)}$$

The cause of this discrepancy is unknown but is believed to be a short in the system wiring, as values were often erratic, especially when motion was involved, and the position of the sensor could sometimes drastically change the reading. When attaching an extension from the output device to the sensor, not all wires were properly separated and insulated from one another. Another potential cause is the quality of the sensor itself, low-cost consumer sensors often do not possess the same high-quality detectors and emitters that professional quality sensors do.

There are several improvements that could be made for future iterations of the device. A higher quality sensor could be implemented, along with more careful wiring and greater attention to calibration. During the experiment, it was found that the sensor’s range of 0 – 400 was too narrow for properly noting what level was acceptable, this was adjusted to a range of 0 – 500. This adjustment necessitated another warm-up period for the sensor, so a better understanding of the environment to be tested should be considered prior to the experiment in the future.

Utilizing the sensor assembly in a DCV system will require a separate device to power the motor responsible for modulating the damper. However, the concept and design of the system has shown that CO_2 levels can be detected and monitored, and with extra care given to calibration and elimination of hardware malfunctions, this system will form a solid platform for future implementation.

CONCLUSION

Experimental validation tests were performed to determine the efficacy of a student developed CO_2 concentration sensing unit. Three separate tests were performed in the course of determining the validity of the groups sensing unit. Initially, Activity 1 was implemented to verify the sensors ability to detect any change in the concentration levels in an environment. Activity 2 was a furtherance of Activity 1 with the addition of a ‘standard’ by which to compare the group’s sensor against. The results obtained from the Activity 2 Validation Lab indicated that the groups selected sensor was adequate in measuring an environments concentration of CO_2. The results of the semester project show that a student group is capable of researching Demand Control Ventilation systems, a variety of CO_2 sensors and control logic systems. Obtaining said logic system and sensor, as well assembling each component into a cohesive functional sensing unit. Before finally implementing the completed and tested units into a physical environment to verify the efficacy of the design.

REFERENCES

[1] A Healthier, More Energy Efficient Approach to Demand Control Ventilation. (2006) *OptiNet Applications, White Paper Series.* 39 Chapel Street, Newton, MA: Aircuity, Inc., pp2-3.

[2] "What are safe levels of CO and CO_2 in rooms?". (2018) Retrieved from https://www.kane.co.uk/knowledge-centre/what-are-safe-levels-of-co-and-co2-in-rooms

[3] Zhengzhou Winsen Electronics Technology Co., Ltd. (n.d.) *Intelligent Infrared CO2 Module (Model: MH – Z19B) User's Manual*. Retrieved from https://www.winsen-sensor.com/d/files/infrared-gas-sensor/mh-z19b-co2-ver1_0.pdf

APPENDIX A

Product Model	MH-Z19B
Target Gas	CO2
Working voltage	4.5 ~ 5.5 V DC
Average current	< 60mA (@5V)
Peak current	150mA (@5V)
Interface level	3.3 V(**Compatible** with 5V)
Measuring range	refer to Table 2
Output signal	UART(TTL interface level 3.3V)
	PWM
	DAC(default 0.4-2V)
Preheat time	3 min
Response Time	T_{90} < 120 s
Working temperature	0 ~ 50 ℃
Working humidity	0 ~ 90% RH (No condensation)
Dimension	33 mm×20 mm×9 mm (L×W×H)
Weight	5 g
Lifespan	> 5 years

Table 1 Main Technical Parameters

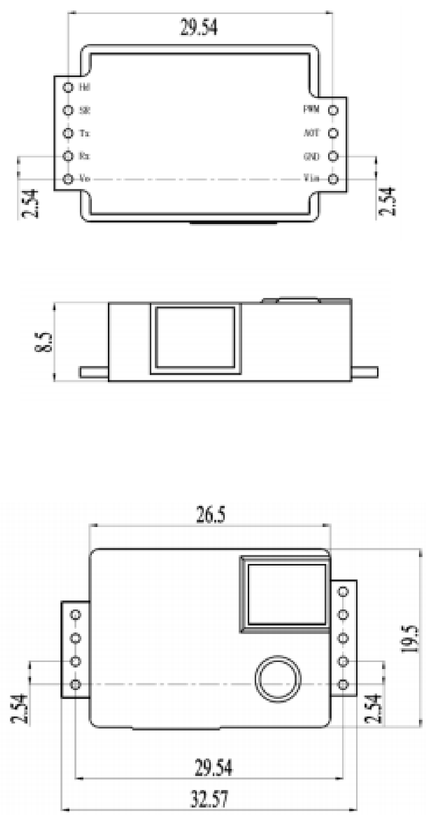

Figure 1 Structure

Figure A.1. Specifications for MH-Z19B CO_2 Sensor.