2019

VibCo Live Bottom Bin Internal Vibratory Fixture

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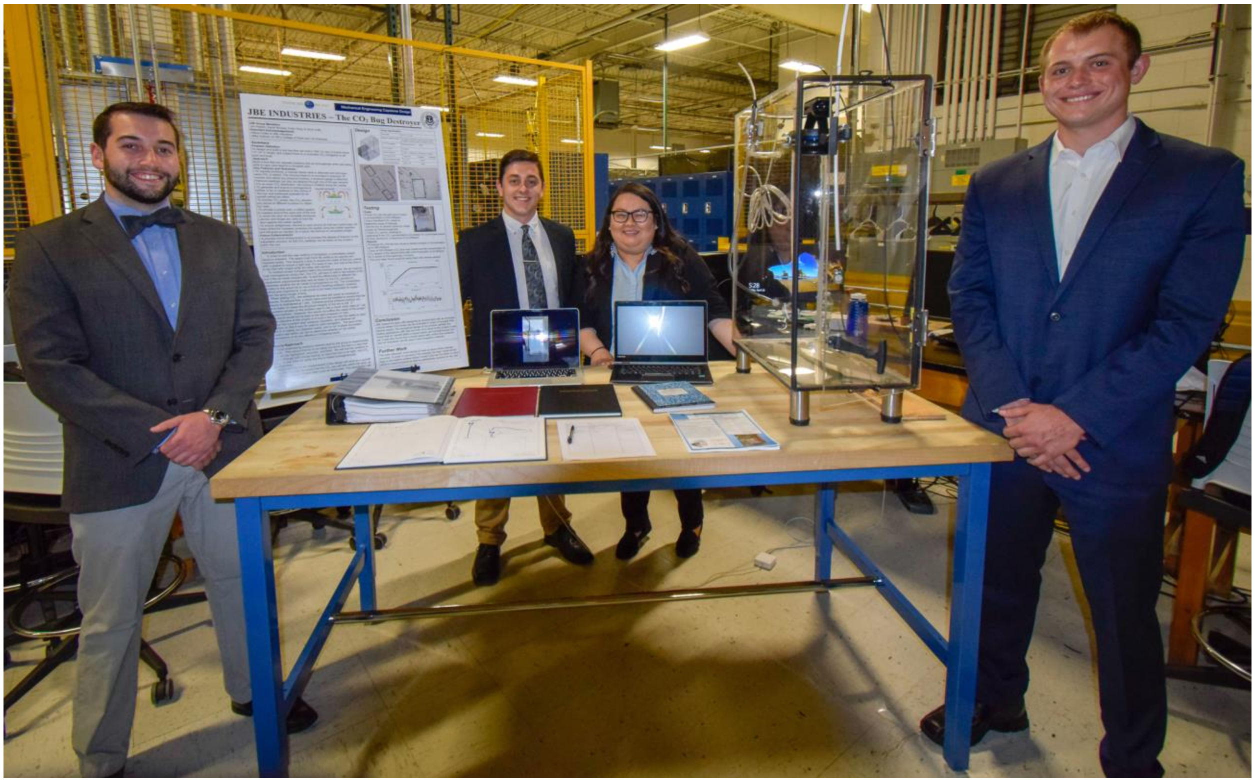
Recommended Citation

Duffy, Chris; Hallam, Ian; Nicosia, David; and Yang, Emily, "VibCo Live Bottom Bin Internal Vibratory Fixture" (2019). *Mechanical Engineering Capstone Design Projects.* Paper 54.
https://digitalcommons.uri.edu/mechanical-engineering-capstones/54

CO_2 Bug Destroyer (CBD)
Team 5 - The Ventilators



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University of Rhode Island
Fall 2018-Spring 2019
Submitted 5/6/19

Abstract

Early in the Fall semester, JBE Industries presented one of their current challenges inside their facility. Their indoor cultivation facility has an issue with the control and mitigation of pests and diseases. The use of pesticides on medicinal plants is heavily regulated because these plants are mainly ingested through combustion, sublimation, and inhalation (smoking). Within JBE's facility, they have implemented a CO_2 fumigation system in the flower room to optimize pest mitigation and plant growth. Fumigation is classified as pumping gas (in this case CO_2) into an enclosed volume at high concentrations for an extended period of time. JBE has challenged the engineering team to design a test box that will be able to hold test plants (clones) and fumigate said plants at different concentrations for specific set amounts of time. The purpose for this is to prove the hypothesis that the CO_2 fumigation will be successful in fumigating the pests while not damaging the plant. Proving this on a small scale before the installation of a fumigation system at the JBE facility will decrease the risk of the hypothesis not being correct and therefore wasting excess money on the large scale fumigation system. In order to design the small scale fumigation device, the engineering team has utilized engineering techniques and analysis to determine a design that fulfills all the specifications required by JBE and even incorporates parameters that were not originally considered. A few things that must be taken into control when constructing this box other than CO_2 concentration level include humidity, temperature, and pressure. The engineering team was successful in achieving the fumigation parameters JBE set forth, multiple CO_2 tests took place during the spring semester in which the team was successful in reaching and maintaining the level of CO_2 JBE desired. More detailed testing notes and matrices can be found under the testing section of this report. The engineering team is planning on doing a live fumigation test with plants and pests to prove the fumigation hypothesis. Within this report, the engineering teams research, analysis, design, and proof of concept (POC) are presented in a concise manner that encompasses all the work completed throughout the Fall 2018 and Spring 2019 semesters.

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List of Acronyms

QFD - Quality Function Deployment

FDA - Food & Drug Administration

PDS - Product Design Specification

POC - Proof of Concept

PPM - Parts Per Million

CDR - Critical Design Review

CO_2 - Carbon Dioxide

SCFH - Standard Cubic Feet per Hour

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Introduction

The growing of medicinal plants has become a flourishing industry, and has started to be widely accepted by the public. Some states are passing laws for the legalization of marijuana both recreationally and medicinally. As the industry expands, the standards for these harvested products will greatly increase and using pesticides on medicinal plants has become highly regulated for a variety of reasons. Here in Rhode Island, pesticide use is limited to 25b, food safe pesticides, approved for use only in the vegetative growth stage (defined by light cycle). A simpler, safer, and more effective concept to pest mitigation is being pioneered and tested to see if it could be implemented in the growing process. The purpose of this project is to create a chamber that can be used to experiment with and evaluate the functionality of CO_2 fumigation on Arthropod pests.

CO_2 Fumigation uses high concentrations of carbon dioxide for pest mitigation, ranging from 100,000-500,000 parts per million. The concentration of CO_2 as well as the necessary time of fumigation required to successfully mitigate Arthropod pests has yet to be identified. This report is focused on designing a test box that will be able to hold cloned plants, test different concentrations of CO_2, and test fumigation time to determine the optimal requirements for successful fumigation. Multiple CO_2 sensors and computer software programs are utilized to monitor concentrations, as well as to make sure that there are no outside factors left unchecked. These factors include gas leakage, overwhelming pressure, and a lack of air flow within the encapsulated space.

It is important to have a proper design for fumigation because the practice can be dangerous if neglected. General CO_2 safety suggests that between 800-2,500 ppm is regarded safe for humans. However, 8,000-10,000 ppm is regarded as deadly to humans and leaving the area immediately is recommended. Without a proper design and understanding of the project and its safety parameters, serious consequences could occur during testing. To achieve the testing goals that JBE put forth, the test box should be able to hold cloned plants at a maximum height of 18”, sustain a near homogeneous environment of 60,000-500,000 ppm of CO_2 for 2-6 hours, and be observable to the human eye whether or not there is a 100% mitigation of Arthropod pests. The test chamber was built successfully to meet all project requirements.

Patent Searches:

Patent searches are necessary and important to the research process for the overall design of the project. Patent searches help utilize previous work and come up with ideas that build upon what has been searched. It also helps know what is on the market so there is no waste in the research process. Reviewing previous patents also makes sure that the team is not replicating an original idea done years back which helps ensure that there is no legal trouble. Patent searches also optimize research in that there are ways to improve on flawed designs to bolster the originality of the design in this report.

US8,728,442/ Method of controlling the growth of microorganisms by a composition containing isolated or in vitro synthesized nitrosamines

Date: May 20, 2014
Rights owned by: Bayer CropScience LP
Abstract: The present invention relates to novel compounds and compositions and the use of them for the control of fungal and bacterial pathogens, insect pests, acari, nematodes and other invertebrate pests including, but not limited to post-harvest and soil diseases, building mold remediation, and seed and grain sanitation.

Relevance: This patent is relevant to the design because there are tests of chemical compounds on microorganisms and the effects that the compounds do to the organisms. Although the design only works with CO_2 and Arthropod pests, the patent helps the team get a better understanding of concentrations and ways to implement the concentrations to an enclosed space on live plants and Arthropod pests.

US4,823,505/ Fumigation system for exterminating insects in an existing building

Date: April 25, 1989
Rights owned by: "John C. Jackson"
Abstract: This invention relates to a novel system for exterminating insects in a building, and particularly, to such a system which may be installed after the building is completed. This system includes a tunnel device which provides access to the cavity between the interior and exterior walls of a building. The installation of this device in the interior wall of an existing building provides more effective access of fumigant to pests which may be living in the space between the interior and exterior walls. This tunnel device can be concealed from view or provided with a decorative cover plate. The other component of this system includes a reservoir of fumigant which can be matingly engaged with the tunnel device and dispense and effective dosage of pesticide into the cavity between the interior and exterior walls.

Relevance: This patent relates to the project goal in the way that both designs are intended to exterminate pests. Specifically using a method of fumigation, however this patent using a type of fumigant which most likely consisted of chemicals. The test box will fumigate using CO_2 in order to kill pests without the use of pesticides.

US4,934,255/ Food treating apparatus and method

Date: May 6, 1988
Rights owned by: "Gerald F. McDonnell"
Abstract: Method and apparatus for treating fruits including use of an air plenum above palletized boxes of fruit to force air through the plenum and to the front of the trailer containing the palletized fruit. The air in very high volume per minute is forced downwardly and drawn through the fruit to provide controlled temperature and humidity. A portion of the exhaust air is recirculated while maintaining high humidity of at least 75% and temperature difference between inlet and exhaust air of no greater than 5.degree. F.

Relevance: This patent is for a method of air implementation that has proven effective in keeping plants at healthy levels of air concentration, temperature, and humidity. In JBE's facility, there is system of direct air distribution for the plants that has overlapping similarities this the system represented by this patent. Recirculating air has proven effective for plant growth, especially when the air is being run directly past the base of a plant. The already near-ideal air should be warmed and regulated for humidity before re-implementation, preventing the consumption of a larger sum of energy to be used idealizing free, outside air.

US9,028,750/ Fumigation system and process with temperature control, filtration, and air-reintroduction

Date: May 12, 2015
Rights owned by: Fernandez; Manuel A.
Abstract: Fumigation systems and processes that are especially applicable for the fumigation of perishable (or otherwise sensitive to temperature) agricultural products as the temperature conditions under which the product is being treated are closely controlled to advantageously prevent the product from being exposed to temperature drops and/or spikes during the fumigation cycle. In addition, the present invention incorporates an air filtration system as a part of the fumigation system to substantially remove the toxic fumigant residuals from the air before it is exhausted into the open atmosphere, which typically occurs at the completion of a fumigation cycle. As such, the harmful effect of the fumigant on the products and the surrounding environment and work areas is greatly minimized. In summary, the systems and processes of the present invention provide the ability to conduct fumigations in a well-controlled

environment.

Relevance: The patent involves a system similar to the project where pesticides are used in an controlled environment to fumigate agricultural plants and have an air filtration system to purge any toxic residue in the air. Their method includes sensors and computer controlled software similar to the idea of this project.

Evaluation of the Competition:

Utilizing CO_2 in order to fumigate pests on marijuana plants has never been done or proven. If the initial hypothesis of using a non-chemical gas (CO_2) to fumigate pests on flowering marijuana plants proves correct than this will be new information on the subject of non-chemical fumigation that could prove to be invaluable. Marijuana cultivation companies are currently required by law to empty and clean their entire facilities in the scenario of a bug infestation, since there are no pesticides currently approved for use on marijuana plants. If CO_2 fumigation of marijuana plants can be proven effective through the use of the CO_2 Bug Destroyer, then this could revolutionize how to treat bug infestations in the medical marijuana industry. These cultivation companies could save hundreds of thousands of dollars by simply fumigating their grow rooms with CO_2 to mitigate pests instead of having to throw out all affected plants and clean the entire facility. It is safe to say that the future of this research is very promising with incredibly high potential.

One competitive product known for pest mitigation using CO_2 gas is the Mosquito Magnet. Although there is some debate over whether the two products are similar when it comes to pest mitigation using CO_2, the products are drastically different. The main gas used in the Mosquito Magnet is propane gas. Mosquito Magnet works by burning of propane gas to create carbon dioxide, and in this burning process the newly generated carbon dioxide is released into the surrounding area to attract nearby mosquitos. Since the pests are attracted to carbon dioxide, they fly towards the source, where they are then sucked in with a fan into a death trap. The CO_2 Bug Destroyer also makes use of carbon dioxide gas in pest mitigation. The pests, specific to marijuana, along with the marijuana plants are subjected to high concentrations of CO_2 in a controlled environment for a specified amount of time for pest mitigation. The theory behind this, is that the high levels of CO_2 will suffocate the bugs. Since plants consume CO_2, it is theorized that the high levels of CO_2 will cause no harm to the plants up to a certain concentration threshold and time period. Although the Mosquito Magnet was made for a very different function than the CO_2 Bug Destroyer and uses carbon dioxide in a very different way, they are both impressive innovations that achieve the same goal using different methods in different environments.

Specifications Definition:

TABLE 1: PRODUCT IDENTIFICATION

Product name	Carbon-Dioxide Bug Destroyer (CBD)
Basic functions of the product	-Uses large concentrations of CO_2 to fumigate medicinal plants for pest control -Monitors and regulates gas and air flow within the test box -Monitors CO_2, Temperature, Pressure, and Humidity levels.
Special features of the product	-Pressure relief system with manual check value - Use of computer software to monitor and analyse live data -Adjustable sensor height
Key performance targets	-Ability to homogeneously contain an environment with 60,000-500,000 ppm of carbon dioxide for 2-6 hours
Service environment	-Closed vacuum sealed box. -Temperature, Pressure and Humidity Controlled
User training required	-Minimal operational training required once program is configured -Safety and evacuation training required

TABLE 2: MARKET IDENTIFICATION

Description of target market and its size	Market: Horticulture Size: Specific to cannabis companies
Competing products	Prescription medication Plant Pesticides
Branding strategy (trademark, logo, brand name)	JBE Industries

TABLE 3: KEY PROJECT DEADLINES

Predetermined Deadlines	Literature Search - 10/11 PDS (Design Specifications) - 10/11 30 Concept Generation - 10/18 QFD Analysis - 10/18 Group Presentations - 10/23 through 10/30 Updated Design Specifications - 11/6 POC Presentations - 11/27 through 12/4 Preliminary Report Due with all electronic files - 12/17 Build/ Test Review - 3/20 Design Build, Test & Redesign Presentation - 4/10 Design Showcase - 4/26 Final Report Due with all electronic files - 5/6
Time till Completion	April-May 2019

TABLE 4: PHYSICAL DESCRIPTION

What is known (or has already been decided) about the physical requirements	-CO_2 fumigation levels in the range of 60,000-500,000 ppm -Able to fit a flat of 12-18” live clones with 6” clearance
Design variable values that are known or fixed prior to the conceptual design process	-Flat Dimensions: 10.5” x 21” x 2.25”
Constraints that determine known boundaries on some design variables	-Different life cycle/stages of the medicinal plant requires different concentrations of CO_2

TABLE 5: FINANCIAL REQUIREMENTS

What are the assumptions of the team about the economics of the product and its development?	-Low-budget -Look to moving towards more efficient materials and design
Pricing policy over life cycle(target manufacturing cost, price, estimated retail price, discounts)	-Set price over lifetime, until competition arises

TABLE 6: LIFE CYCLE TARGETS

What targets should be set for the performance of the product over time?	-Durable -Further research into low cost material -Sustained efficiency throughout lifetime
Maintenance schedule	-JBE’s discretion

TABLE 7: SOCIAL, POLITICAL AND LEGAL REQUIREMENTS

Are there opportunities to patent the product or some of its subsystems?	-Anything developed for the project is under an IP contract so there is no potential for a patent
Safety and environmental regulations	-Safety guidelines/protocols
Government regulations	-State and Federal law will be monitoring day to day operations -Many states do not permit the crop this product is mainly used for
Safety and product liability	-To be determined by JBE Industries based on any government regulations and restrictions

TABLE 8: MANUFACTURING SPECIFICATIONS

Which parts or systems will be manufactured by the team?	-The box will be built by the team -Individual parts will be bought and assembled by the team
Which parts may be outsourced	-Carbon Dioxide w/ tank -Copper piping(if required) -Various Sensors(humidity,temperature,CO2)

TABLE 9: CUSTOMER/ENGINEERING REQUIREMENTS

Customer Requirements	**Engineering Requirements**
Must be able to hold plant tray: 21” x 10.5” x 2.25”	Size of Plant Box: H=30”, L=24”, & W=12”
Must hold maximum height of plants in test box	18” : Must have 6” clearance to account for leaves
Target Humidity	46%
CO_2 Concentration	60,000-500,000 ppm
Desires Pressure	1 Atm = 14.6959 psi
Time Duration	2-6 hours

Conceptual Design:

Chris Duffy's Concepts and Evaluations

1) Concept Generated: **Idea #1**
   Evaluation of Concept: JBE operates a two-tier grow system. To ensure homogenous airflow, add CO_2 dispensers at a height of 12.5' and 5.5', this will allow the CO_2 to reach the first tier plants.

2) Concept Generated: **Idea #2**
   Evaluation of Concept: Install recirculating fans that pull ar from the floor level and sends it above the 2nd tier of plants. This is based off the theory that CO_2 will tend to sink to the ground due to its density.

3) Concept Generated: **Idea #3**
   Evaluation of Concept: This is a simple "if,then" based system. Programmed to release CO_2, "if" the CO_2 sensors reach 400,000 ppm "then" CO_2 release is halted.

4) Concept Generated: **Idea #4**
   Evaluation of Concept: Place 5-2000 CFM fans in the marked positions of the room (figure 1). Having five smaller fans creates airflow throughout the room without having any plants due to high turbulence.

5) Concept Generated: **Idea #5**
   Evaluation of Concept: Section the flower room into two-sectors. One sector will undergo the fumigation process at a time. When the desired time is reached, the purging process will purge the high CO_2 levels into the other sector.

6) Concept Generated: **Idea #6**
   Evaluation of Concept: Install two-10,000 CFM Fans at the bottom opposite corners of the room(Figure 2). Position the oscillations of the fans along the copper piping to better spread out the dispensing of CO_2.

7) Concept Generated: **Idea #7**
   Evaluation of Concept: Program the dystec control system, while undergoing the fumigation process, "if" CO_2 levels reach 400,000 ppm "then" CO_2 dispensing is halted. "If" CO_2 levels dip to 100,000 ppm "then" CO_2 is dispensed, operates for a duration of two hours.

8) Concept Generated: **Idea #8**
   Evaluation of Concept: Program the dystec control system, while undergoing the fumigation process, "if" CO_2 levels reach 250,000 ppm "then" CO_2 dispensing is halted. "If" CO_2 levels dip to 200,000 ppm "then" CO_2 is dispensed, operates for a duration of four hours.

9) Concept Generated: **Idea #9**
   Evaluation of Concept: Section off the room into 8-sectors, each sector has plants at different life cycles(Figure 3). Different life cycles require varying amounts of CO_2 caused by consumption of the plants. Sectioning off the room will allow more precise CO_2 dispensing

10) Concept Generated: **Idea #10**
    Evaluation of Concept: The purge fans are close enough to the plants that damage could occur. To alleviate this long tubing is attached to the floor of the room compared to all airflow being taken in by the back wall (Figure 4).

11) Concept Generated: **Idea #11**
    Evaluation of Concept: Position CO_2 sensors in each of the moveable flats where the plants are flowering. Doing so would more accurately measure the CO_2 levels in the room, better assuring a homogenous environment.

12) Concept Generated: **Idea #12**
    Evaluation of Concept: Section off the room into 4-quadrants(figure 5). This allows JBE to fumigate only the sections of the room that need fumigation in order to save the company money.

13) Concept Generated: **Idea #13**
    Evaluation of Concept: Program the dystec control system, while undergoing the fumigation process, “if” CO_2 levels reach 400,000 ppm “then” CO_2 dispensing is halte. “If” CO_2 levels dip to 350,000 ppm “then” CO_2 is dispensed, operates for a duration of two hours.

14) Concept Generated: **Idea #14**
    Evaluation of Concept: Develop a similar “if,then” program which activates a visual and audio alarm. “If” CO_2 levels reach 2,000 ppm, “then” alarm is set off and magnetic locks(already installed) lock the flower room from the outside.

15) Concept Generated: **Idea #15**
    Evaluation of Concept: Install copper piping into the carts that are used to hold the plants(Figure 6). Adding additional outlets closer to each individual plant will enable a more consistent CO_2 level throughout the flower room.

16) Concept Generated: **Idea #16**
    Evaluation of Concept: Program the dystec control system, while undergoing the fumigation process, “if” CO_2 levels reach 150,000 ppm “then” CO_2 dispensing is halted. “If” CO_2 levels dip to 100,000 ppm “then” CO_2 is dispensed, operates for a duration of six hours.

17) Concept Generated: **Idea #17**
    Evaluation of Concept: Install multiple 2000-CFM fans along the side walls, oscillating in the direction of the plants(Figure 7). This will eliminate the chance of one plant being over fumigated. Also increases airflow which enables CO_2 sensors to more accurately monitor CO_2 levels.

18) Concept Generated: **Idea #18**
Evaluation of Concept: Program the dystec control system, while undergoing the fumigation process, “if” CO_2 levels reach 450,000 ppm “then” CO_2 dispensing is halted and purging fans are activated.

19) Concept Generated: **Idea #19**
Evaluation of Concept: Add large ground fans up to 5000-CFM along the side walls to prevent the CO_2 from collecting on the ground due to its high density(Figure 8).

20) Concept Generated: **Idea #20**
Evaluation of Concept: Add additional rubber piping that goes from the copper outlets into the rubber tubing which has multiple outlets for its single inlet. The rubber outlets are flexible and can be placed in areas that CO_2 originally had difficulty reaching.

21) Concept Generated: **Idea #21**
Evaluation of Concept: Install multiple 2000-CFM fans located above the moveable carts (figure 9). These fans are positioned vertically downward and oscillate airflow over each cart.

22) Concept Generated: **Idea #22**
Evaluation of Concept: Install Titan Controls CO_2 Regulator on each of the copper outlets to enable total control of airflow through each outlet.(Figure 11).

23) Concept Generated: **Idea #23**
Evaluation of Concept: Install rubber tubing that stems off the CO_2 outlets. The configuration of these tubes can be changed easily to allow the physical insertion of the tube into the soil in order to kill soil borne pests.

24) Concept Generated: **Idea #24**
Evaluation of Concept: Install manifolds into the grow control room, Model No. PGR15. These manifolds will better enable a homogenous environment throughout the grow room.

25) Concept Generated: **Idea #25**
Evaluation of Concept: Install purge fans that blow air inside the model along with the already installed purge fans the pull air from inside and out put outside.

26) Concept Generated: **Idea #26**
Evaluation of Concept: Install small oscillating fans on the walls facing the CO_2 outlets(Figure 11). Smaller fans will be used for the scaled down model.

27) Concept Generated: **Idea #27**
Evaluation of Concept: Install CO_2 sensors in all six corners of the room along with three more placed at the varying heights down the length of the model(figure 12).

28) Concept Generated: **Idea #28**
Evaluation of Concept: Replace the rigid copper piping with the insulated rubber tubing that can be rearranged for the need of that specific fumigation process. It could vary based on which carts are at the life cycle where fumigation would happen.

29) Concept Generated: **Idea #29**
Evaluation of Concept: Place nine CO_2 sensors around specific points in the room. Three of the nine sensors will be placed at the same height as each other and approximately 20' distance from each other(Figure 13).

30) Concept Generated: **Idea #30**
Evaluation of Concept: Instead of having multiple CO_2 outlets as shown in figure 13. Simply have all outlets closed except for four of them. Two towards the far left wall and two towards the far right wall. On the wall will be oscillating fans 5000-CFM fans which act to spread out the high CO_2 levels throughout the room(Figure 14).

Concept Sketches are provided on the following page

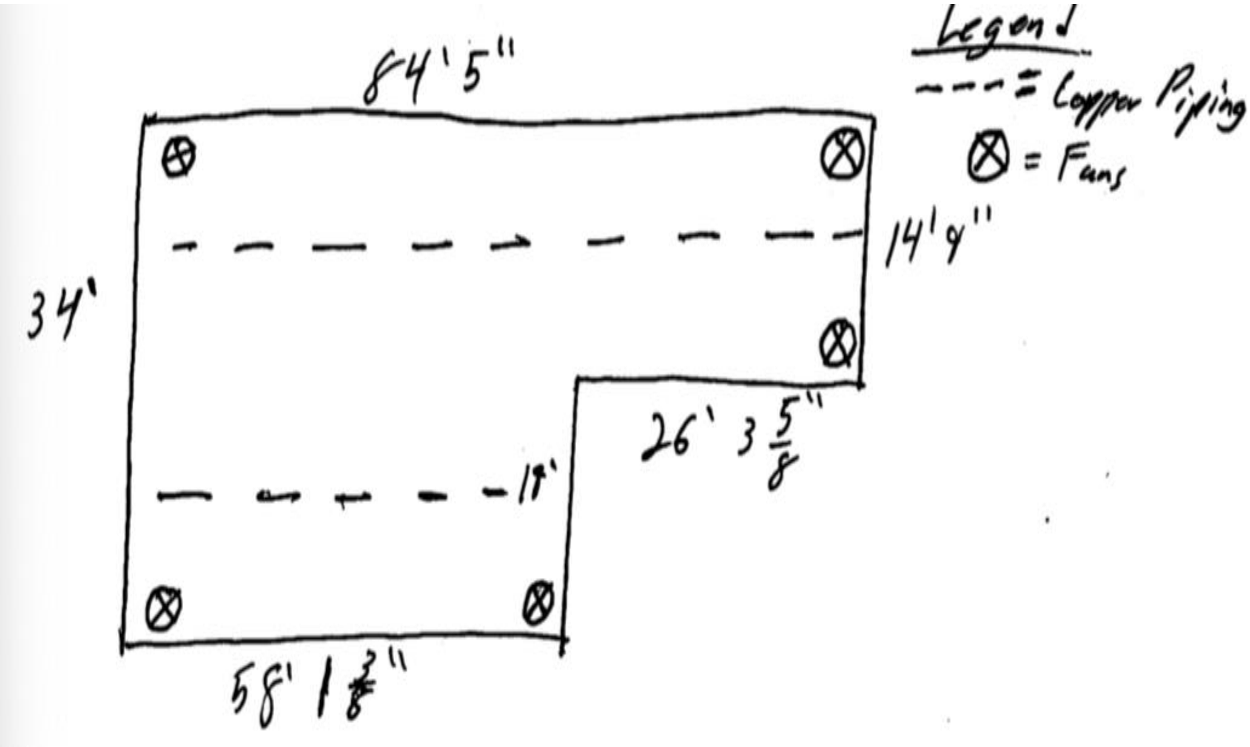


FIGURE 1: DUFFY DESIGN REFERENCE 1

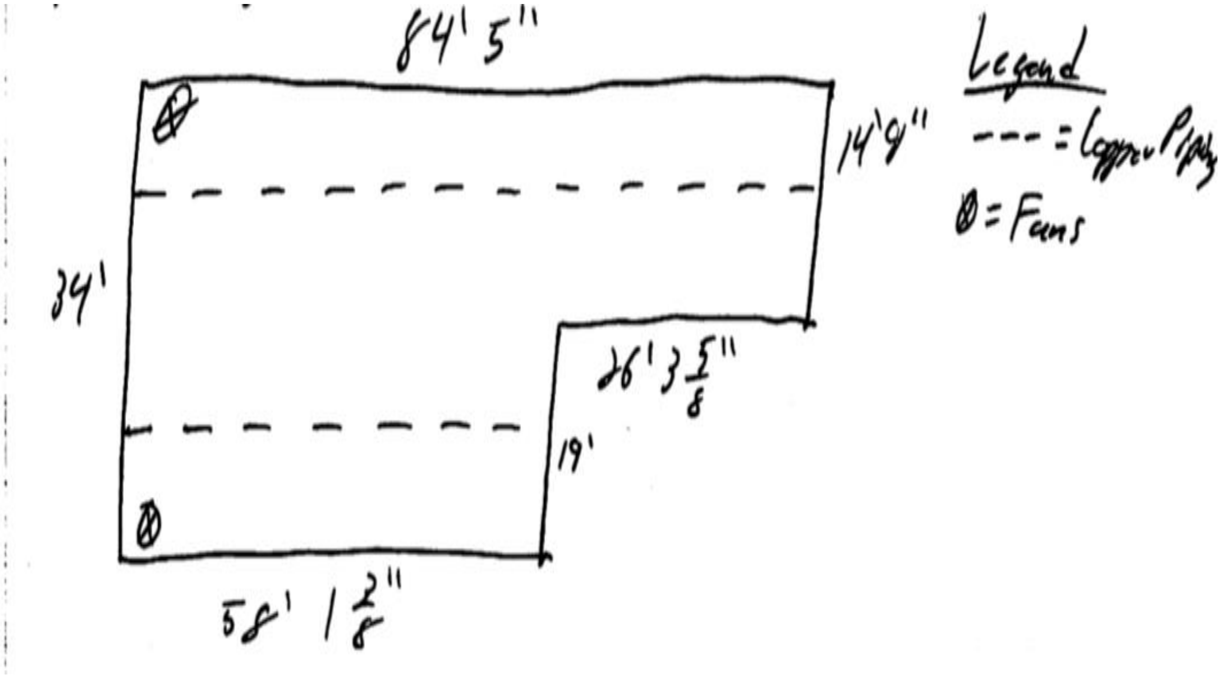
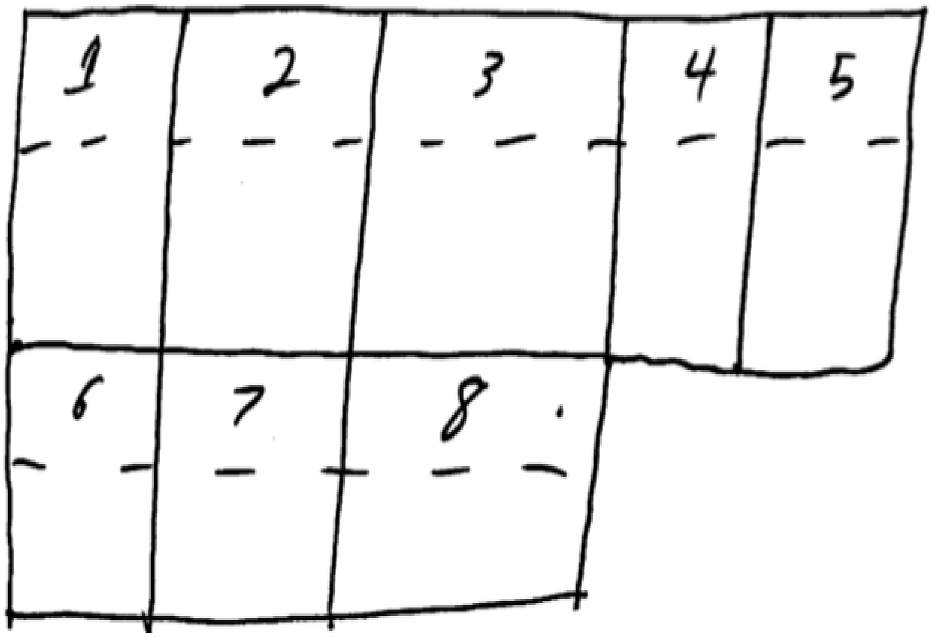


FIGURE 2: DUFFY DESIGN REFERENCE 2



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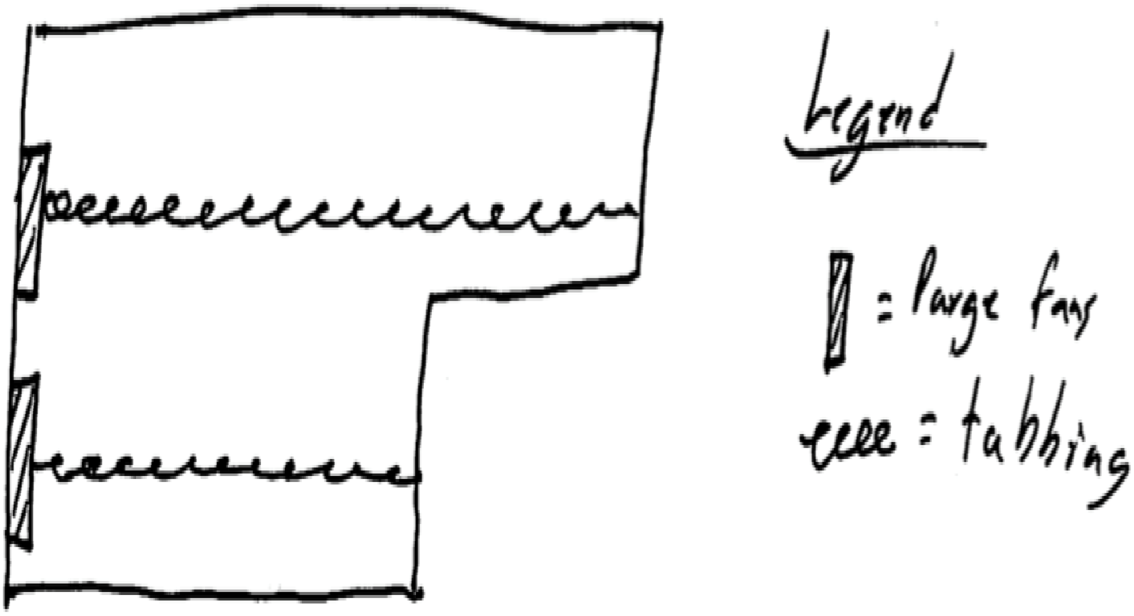

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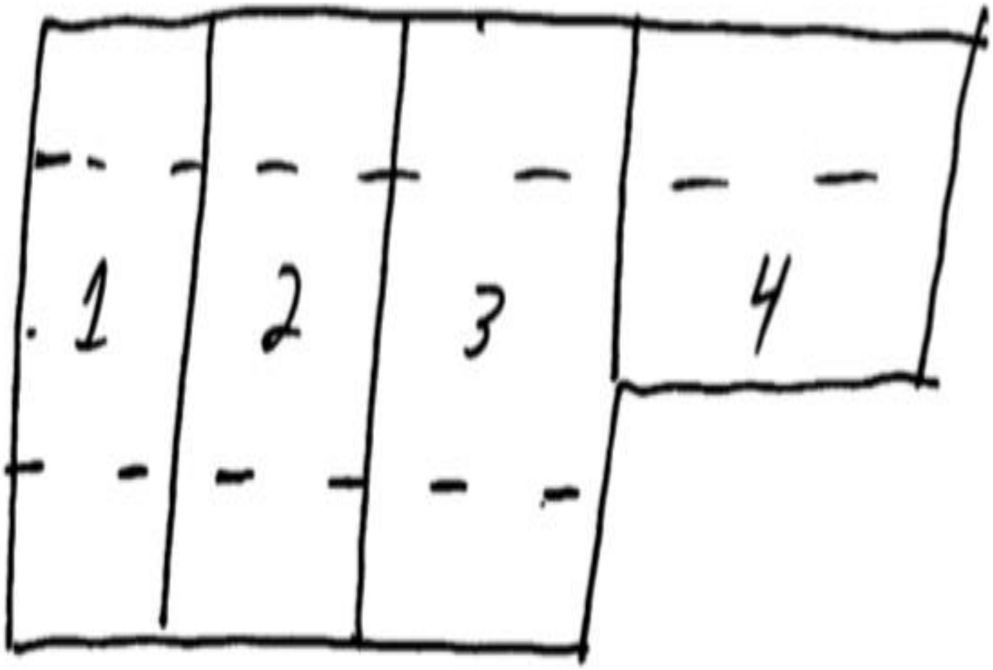

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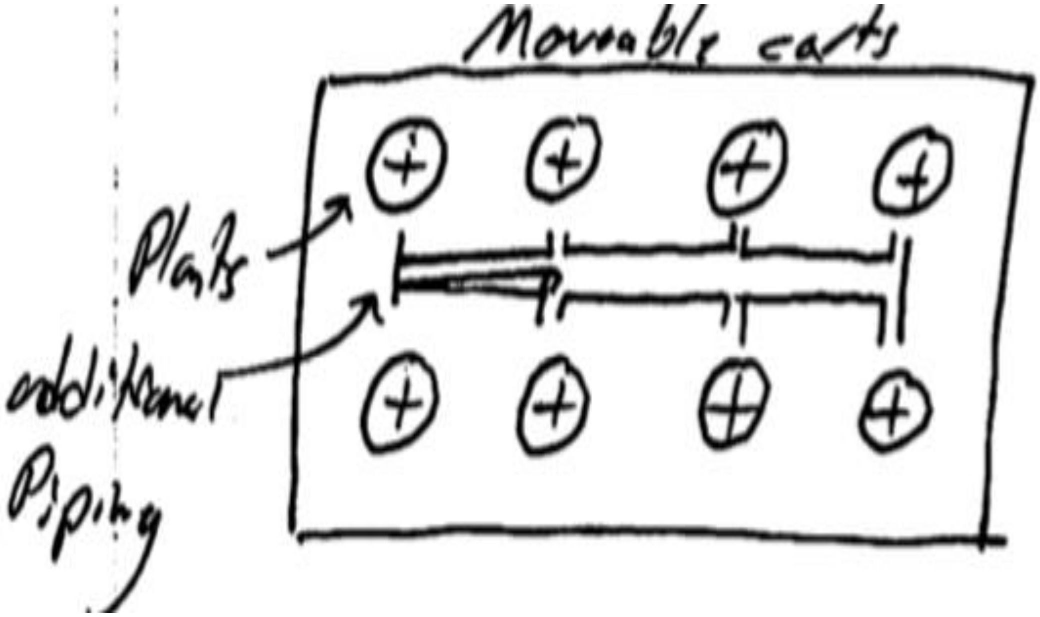

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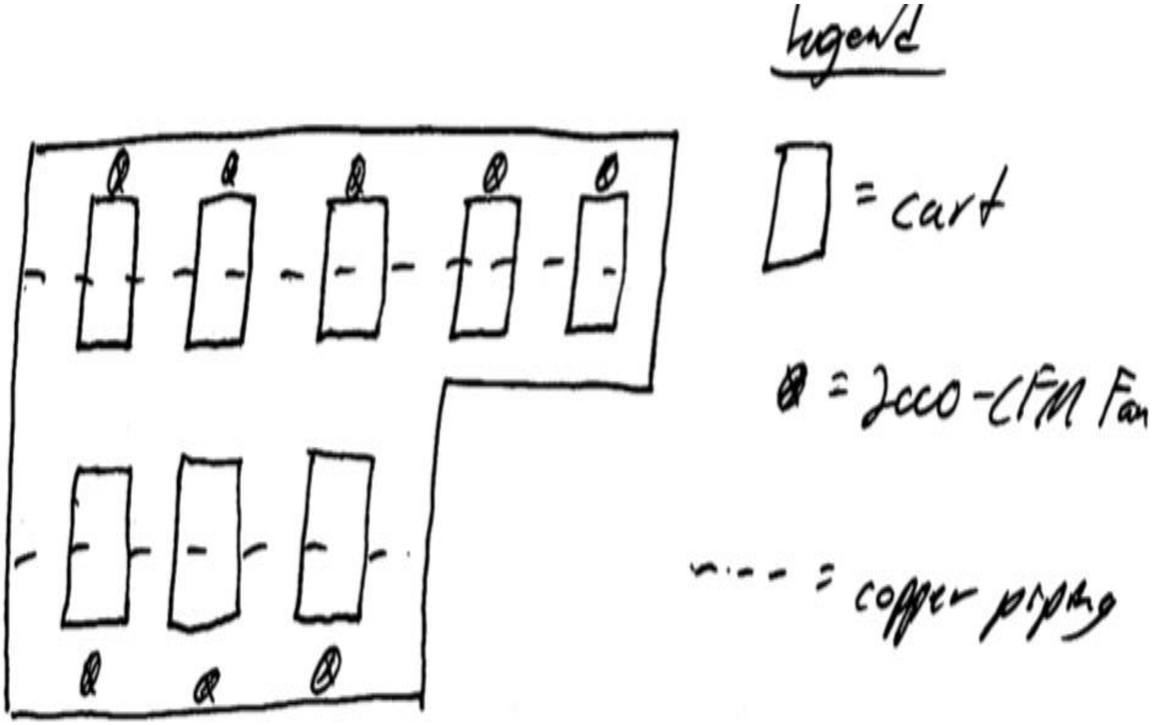

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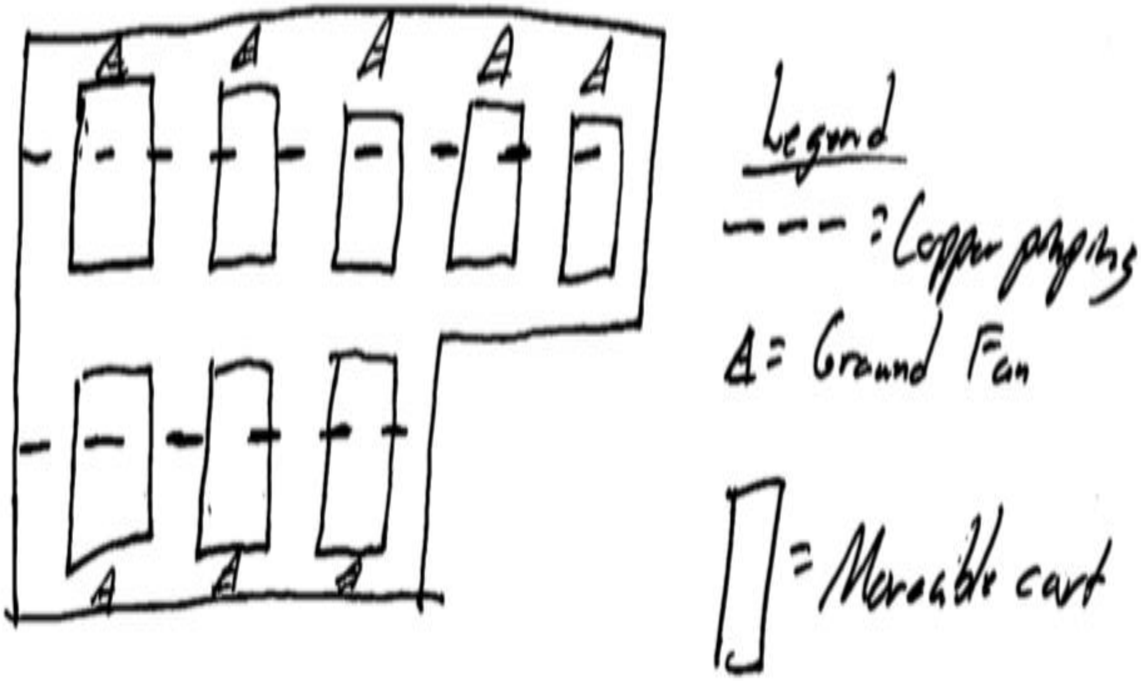


FIGURE 8: DUFFY DESIGN REFERENCE 8

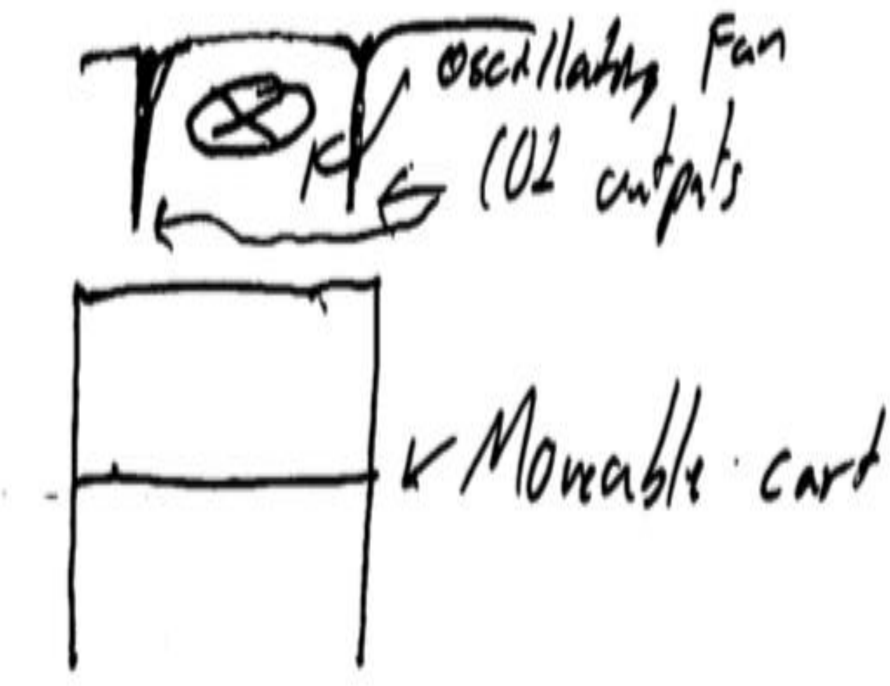
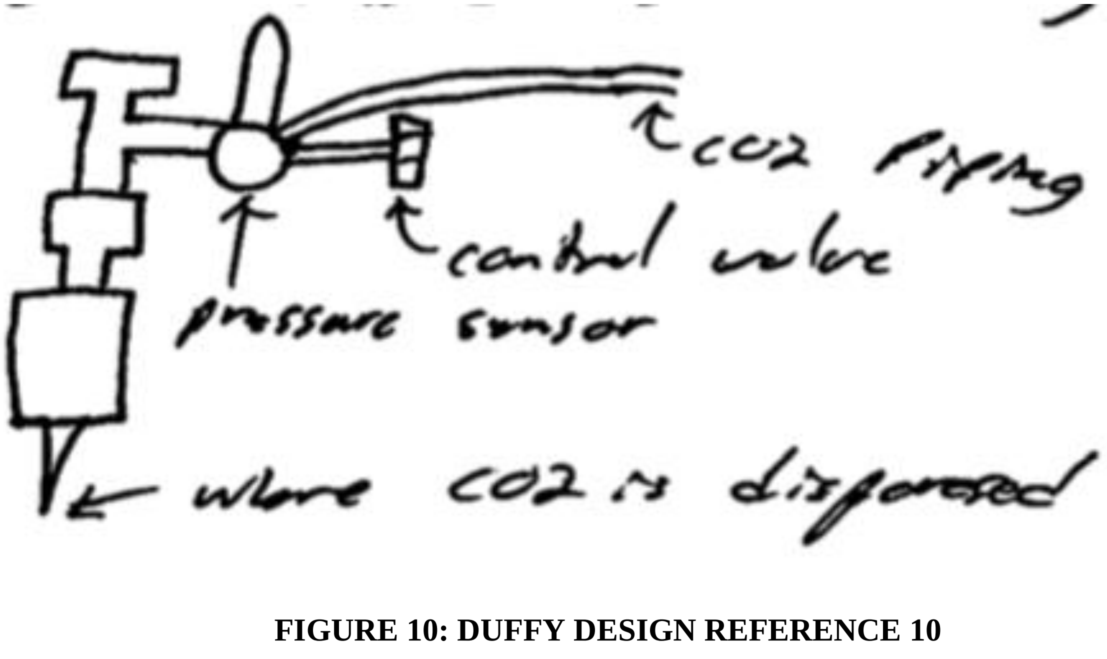


FIGURE 9: DUFFY DESIGN REFERENCE 9



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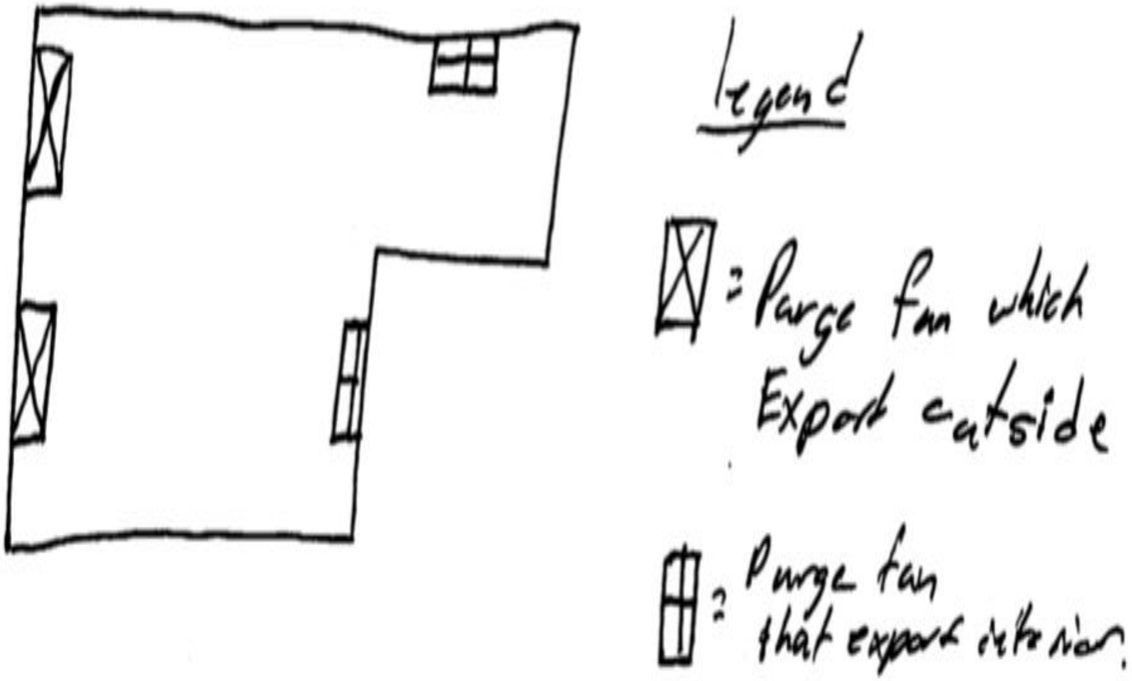

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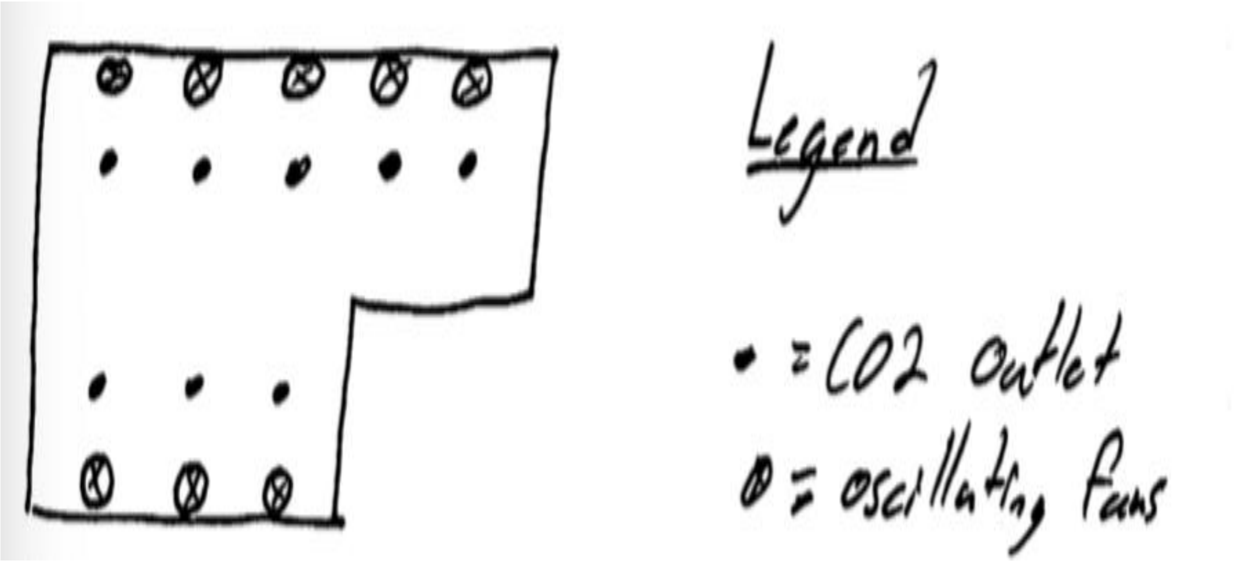

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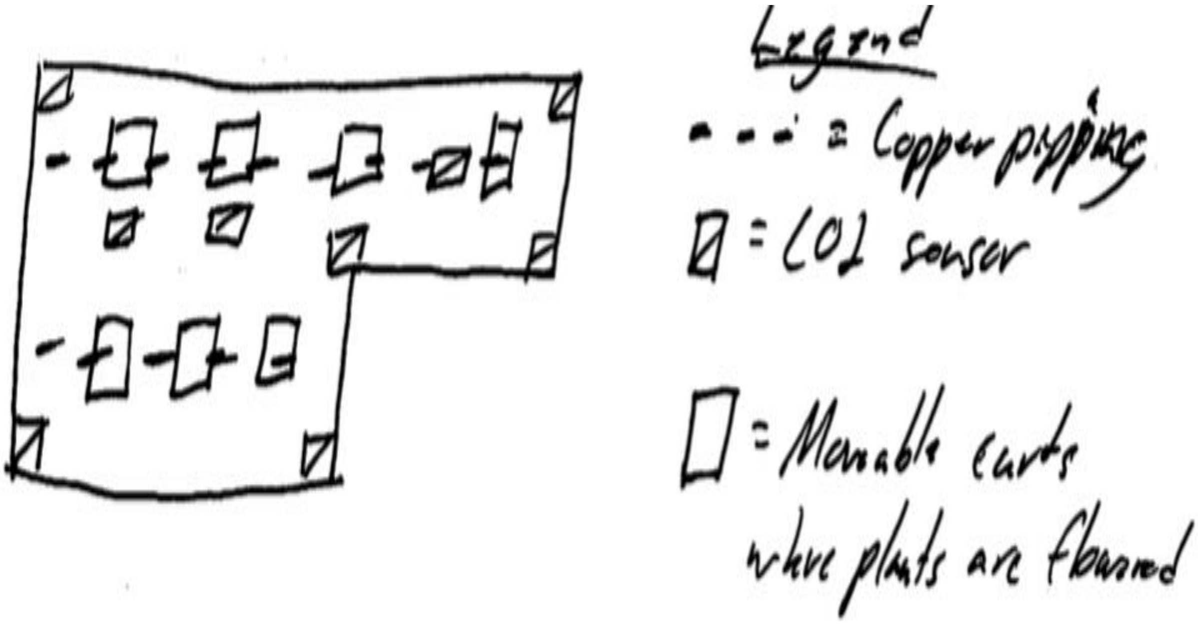


FIGURE 13: DUFFY DESIGN REFERENCE 13

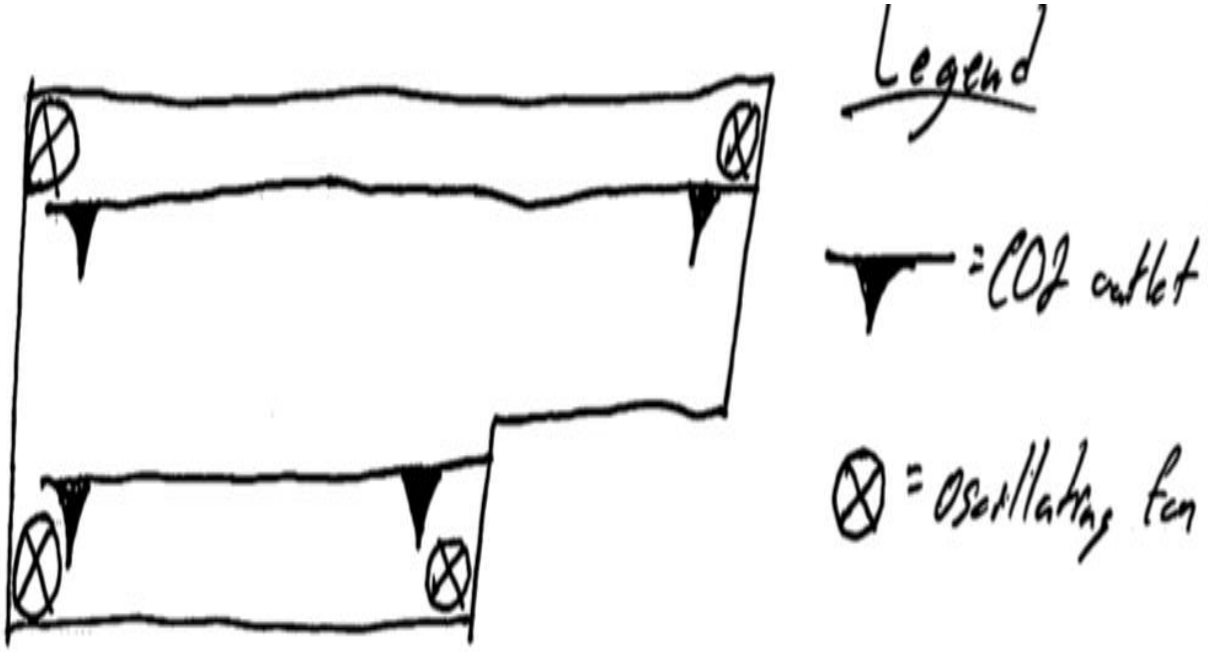


FIGURE 14: DUFFY DESIGN REFERENCE 14

Ian Hallam's Concepts and Evaluations:

1) Concept Generated: (**Flower Room 1)**
Evaluation of Concept: (This design represents the layout of the flower room JBE Industries has at their facility. To idealize air flow, the design suggests to use a Hurricane SHO Oscillating Wall Mount Fan at the corners in the flower room. CO_2 concentrations would be at 100,000 ppm and the fans operate at 2540 ft3/min for 2 hours.)

2) Concept Generated: (**Flower Room 2)**
Evaluation of Concept: (The design goes more in depth by adding CO_2 sensors at the ventilation fans and at the ceiling. Increase the CO_2 concentration to 200,000 ppm and keep the run time at 2 hours.)

3) Concept Generated: (**Flower Room 3)**
Evaluation of Concept: (Similar to the previous designs, the flower room will operate at 100,000 ppm but run for 6 hours. By leaving a similar concentration but increasing the time span, pest mitigation can be observed.)

4) Concept Generated: (**Flower Room 4)**
Evaluation of Concept: (This design increases both the concentration and time span of fumigation compared to the third concept generated. All other parameters as stated before stays the same.)

5) Concept Generated: (**Test Box 1)**
Evaluation of Concept: (This design incorporates the test box that JBE is looking for as a finished product. 12" Horizontal Air Flow Fan's are placed at a specific orientation to optimize air flow. The fans will run at 1460ft3/min. 5 CO_2 sensors are placed at the end of the trays and one near the exhaust mode piping system.)

6) Concept Generated: (**Test Box 2)**
Evaluation of Concept: (Because of the specific dimension of the test box (less than 60'), the fan placement is able to stay at the same orientation. CO_2 concentrations will be put at 100,000 ppm for 6 hours.)

7) Concept Generated: (**Test Box 3)**
Evaluation of Concept: (CO_2 concentrations will be set at 200,000 ppm and be fumigated for 2 hours in this design. The design will also have more CO_2 sensors by the clone plants.)

8) Concept Generated: (**Test Box 4)**
Evaluation of Concept: (This design will have the CO_2 concentration levels set at 200,000 ppm and increase the fumigation time to 6 hours.)

9) Concept Generated: (**Test Box 5)**
Evaluation of Concept: (When looking at the drawing, there is a divider through the middle of the test box (represented by dotted lines). Now that the test box is divided into two sections, the design will add another CO_2 tank and an exhaust mode.)

10) Concept Generated: (**Test Box 6)**
Evaluation of Concept: (Now by implementing the divider, one section of the test box will run at 100,000 ppm and the other section will run at 200,000 ppm. The fumigation will take place in both sections for 2 hours.)

11) Concept Generated: (**Test Box 7)**
Evaluation of Concept: (Similar to the previous design, one side will run at 100,000 ppm and the other will run at 200,000 ppm. However, in this design, the fumigation will take place over the course of 6 hours.)

12) Concept Generated: (**Piping System 1)**
Evaluation of Concept: (A copper pipe (which is already set up in the flower room at JBE) will release CO_2 into the flower room. The sensors are attached to the valves and they will send a feedback system to control CO_2 levels at different parts in the room.)

13) Concept Generated: (**Piping System 2)**
Evaluation of Concept: (Instead of using the copper pipe, this design would implement an aluminum material.)

14) Concept Generated: (**Piping System 3)**
Evaluation of Concept: (This design will use steel instead of aluminum. CO_2 gas is a dense gas and will act differently to different materials. It is unsure which material is best suitable to transport the gas into the flower room.)

15) Concept Generated: (**Piping System 4)**
Evaluation of Concept: (The material being used in this design will be PEX material and have the same configurations as the previous designs.)

16) Concept Generated: (**Piping System 5)**
Evaluation of Concept: (This design will use a plastic material in order to transport the CO_2 gas throughout the system.)

17) Concept Generated: **(Piping System 6)**
Evaluation of Concept: (Another concept to transport the gas is to change the material of the pipes to a rubber material.)

18) Concept Generated: (**Piping System 7)**
Evaluation of Concept: (Iron will be the material used instead of copper in this design.)

19) Concept Generated: (**Test Box with Piping System 1)**
Evaluation of Concept: (This design incorporates the original concepts for a test box and piping system and collaborates them together. Here the test box is split into 4 quarters and the piping system is installed at the top of the test box. This way, the test box can utilize 1 CO_2 tank.)

20) Concept Generated: (**Test Box with Piping System 2)**
Evaluation of Concept: (Steel will be used for the piping instead of copper but there will be multiple inlets on the piping system to allow gas to flow through each section of the test box.)

21) Concept Generated: (**Test Box with Piping System 3)**
Evaluation of Concept: (Instead of using copper, aluminum will be used for the piping system. Incorporating the sensors at the valves, the inlets will be able to adjust the CO_2 concentrations at each inlet so that certain areas of the test box will receive more CO_2 than others.)

22) Concept Generated: (**Test Box with Piping System 4)**
Evaluation of Concept: (PEX material will be used instead of copper in the piping system and all other design aspects from the previous designs are implemented.)

23) Concept Generated: (**Test Box with Piping System 5)**
Evaluation of Concept: (The design will have an individual CO_2 tank at each section of the test box. Sensors will control the CO_2 concentration levels at each section and they will be fumigated at different time spans in order to test different parameters in one test run.)

24) Concept Generated: (**3D Test Box 1)**
Evaluation of Concept: (The concept incorporates the test box with piping system on a 3 dimensional image. The test box will be made of a glass material in order to be see through.)

25) Concept Generated: (**3D Test Box 2)**
Evaluation of Concept: (Instead of using a glass material for the test box, this design will use a plastic material.)

26) Concept Generated: (**3D Test Box 3)**
Evaluation of Concept: (To simulate the flower room as closely as possible, this design will use a material similar to the material JBE uses for their flower room.)

27) Concept Generated: (**3D Test Box 4)**
Evaluation of Concept: (The 3D concept replicates the idea of each section within the test box. This concept would add 2 more horizontal fans at the corners of the section to increase more air flow in the system.)

28) Concept Generated: (**3D Test Box 5)**
Evaluation of Concept: (This concept will add oscillating fans at the top of the test box along with the horizontal fans to increase airflow in the system.)

29) Concept Generated: (**3D Test Box 6)**
Evaluation of Concept: (Airflow may be too much in the test box and the plants aren't being fumigated properly, a concept to resolve the issue is to remove the horizontal fans and keep the oscillating fans within the test box)

30) Concept Generated: (**3D Test Box 7)**
Evaluation of Concept: (To ensure that the clone plants are being fumigated at the optimal level, all fans in the test box will be aimed at the clone plants so that the plants will receive the most concentration of CO_2 possible.)

Concept sketches are provided on the following page

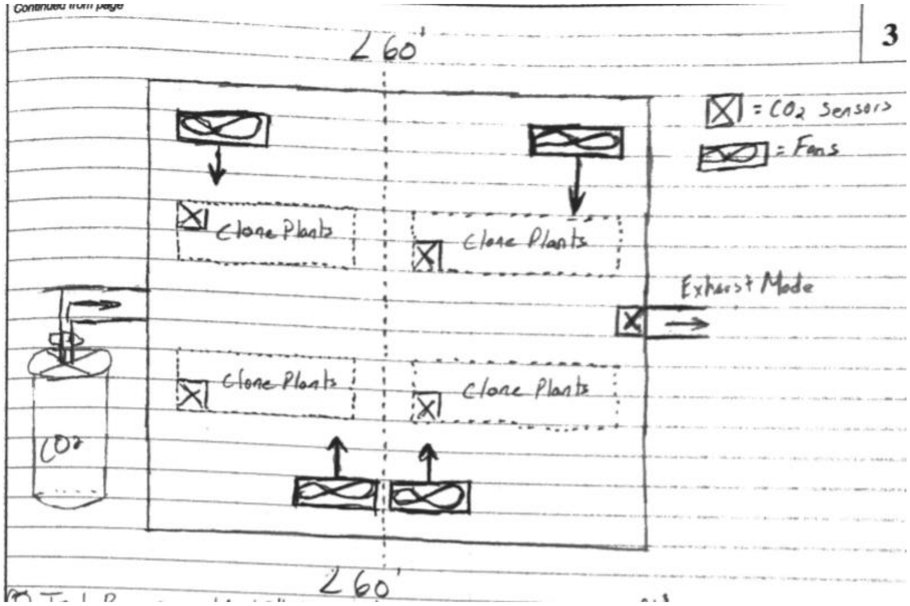


FIGURE 15: TEST BOX

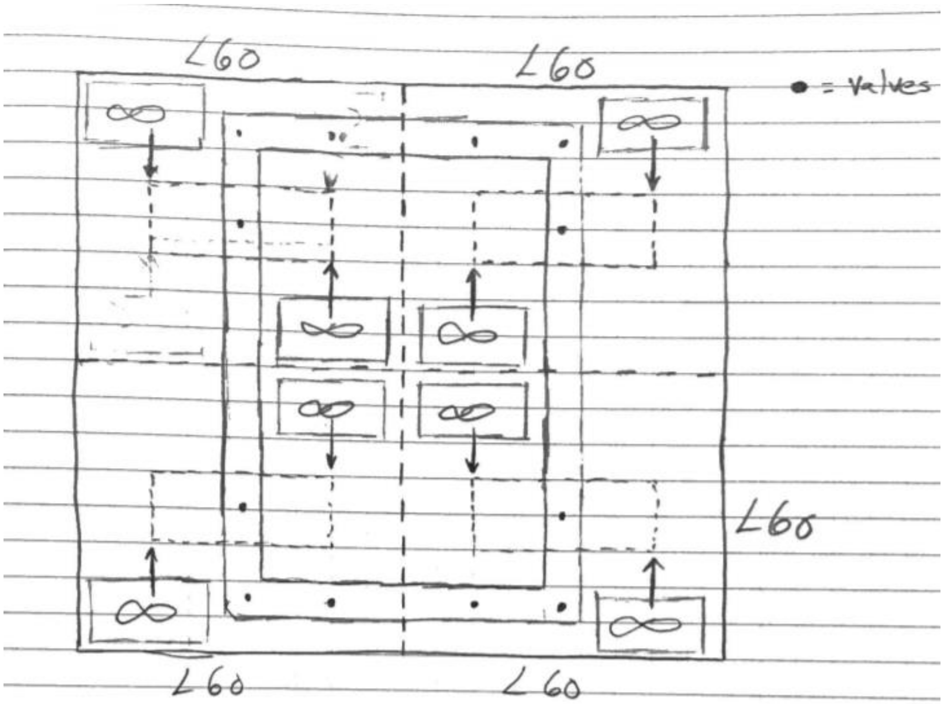


FIGURE 16: TEST BOX WITH PIPING SYSTEM

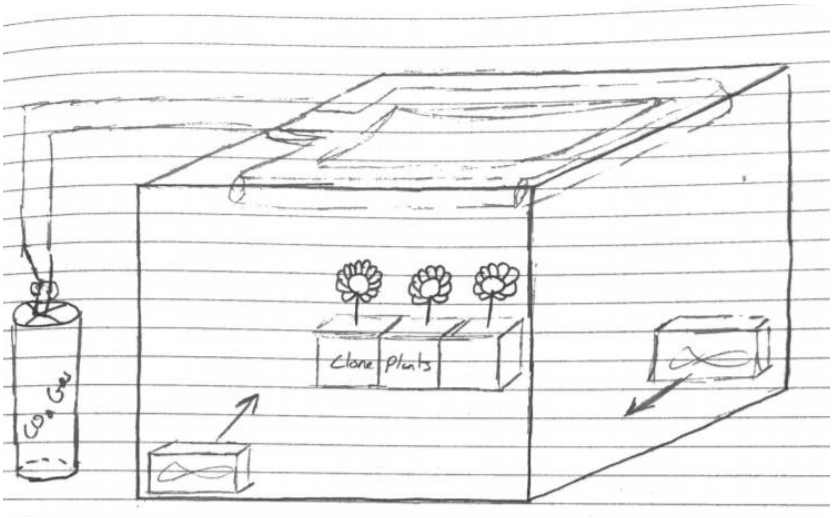


FIGURE 17: 3D TEST BOX

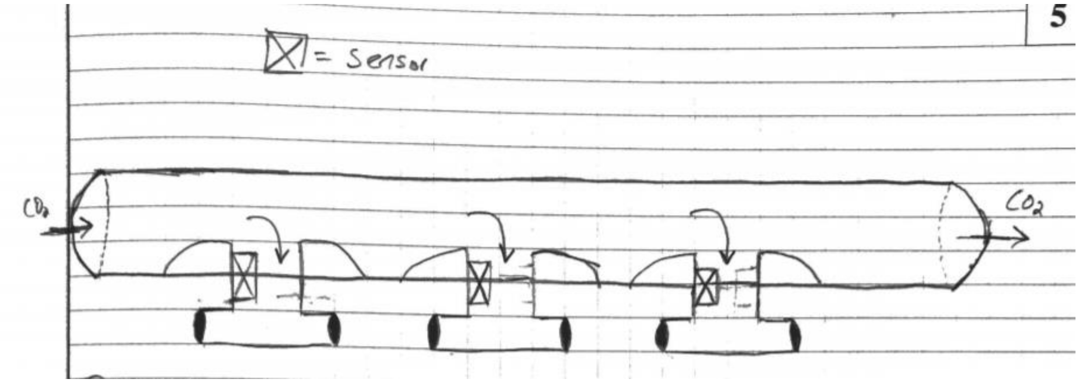


FIGURE 18: PIPING SYSTEM

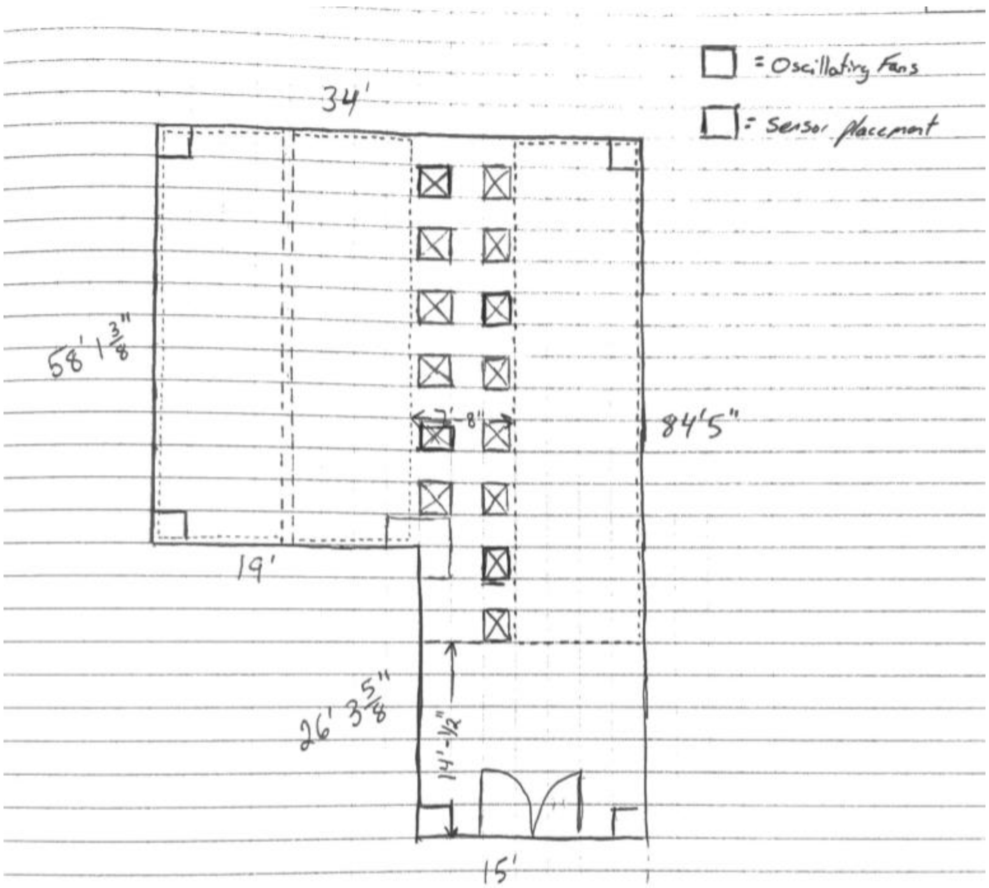


FIGURE 19: FLOWER ROOM

David Nicosia's Concepts and Evaluations

*****Reference the figure following these ideas for the fan locations.*****

1) Concept Generated: **Oscillating Only #1**
   Evaluation of Concept: Place Hurricane® Oscillating fans at positions ***d***, ***e***, and ***f***. All fans should be positioned halfway up the wall and have their midpoint of oscillation pointing towards the center of the room.

2) Concept Generated: **Oscillating Only #2**
   Evaluation of Concept: Place Hurricane® Oscillating fans at positions ***d***, ***e***, and ***f***. The fans positioned at ***e*** and ***f*** should be on the ground while the fan at position ***d*** should be mounted along the ceiling. Each fan's focal point of oscillation should be facing the center of the room.

3) Concept Generated: **Oscillating Only #3**
   Evaluation of Concept: Place Hurricane® Oscillating fans at positions ***d*** and ***e*** along the top of the wall. Place more of the same type of fans at positions ***f*** and ***g*** along the bottom of the wall. Each fan's focal point of oscillation should be facing towards the center of the room.

4) Concept Generated: **Oscillating Only #4**
   Evaluation of Concept: Place Hurricane® Oscillating fans at positions ***d*** and ***e*** along the bottom of the wall. Place more of the same fans at positions ***f*** and ***g***, mounted along the top of the wall. The midpoint of each fans oscillation should be pointing towards the center of the room.

5) Concept Generated: **Oscillating Only #5**
   Evaluation of Concept: Mount Hurricane® Oscillating fans along the ceiling of the room at positions ***d***, ***e***, and ***f***. Each fan's focal point of oscillation should be facing towards the center of the room.

6) Concept Generated: **Oscillating Only #6**
   Evaluation of Concept: Put Hurricane® Oscillating fans in positions ***d***, ***e***, and ***f*** along the bottom of the wall. The midpoint of each fans oscillation should be pointing towards the center of the room.

7) Concept Generated: **Oscillating Only #7**
   Evaluation of Concept: Place Hurricane® Oscillating fans at positions ***d***, ***e***, ***f*** , and ***I***, all located halfway up the wall with their midpoint of oscillation directed toward the center of the room.

8) Concept Generated: **Oscillating Only #8**
Evaluation of Concept: Place Hurricane® Oscillating fans at positions ***d***, ***e***, ***f*** , and ***I***, all directed towards the center of the room. The fans located at ***d*** and ***e*** must be placed along the ground, while the fans at ***f*** and ***I*** must be mounted along the ceiling.

9) Concept Generated: **Oscillating Only #9**
Evaluation of Concept: Place Hurricane® Oscillating fans at positions ***d***, ***e***, ***f*** , and ***I***, with each of their midpoints of oscillation directed towards the center of the room. Each fan should be mounted to the ceiling.

10) Concept Generated: **Oscillating Only #10**
Evaluation of Concept: Place Hurricane® Oscillating fans at positions ***d***, ***e***, ***f*** , and ***g***, with each focal points of oscillation directed towards the center of the room. All fans should be mounted halfway up the wall.

11) Concept Generated: **Oscillating Only #11**
Evaluation of Concept: Place Hurricane® Oscillating fans at positions ***d***, ***e***, ***f*** , and ***g***. Aim each fan's center of oscillation towards the center of the room, and mount them along the ceiling.

12) Concept Generated: **20" Fans #1**
Evaluation of Concept: Place four 20" fans at ***e*** (pointing south), ***d*** (pointing east), ***g*** (pointing north), and ***f*** (pointing west). Each fan should be mounted about halfway up the wall.

13) Concept Generated: **Mixed Fans #1**
Evaluation of Concept: Place four 20" fans at ***e*** (pointing south), ***d*** (pointing east), ***g*** (pointing north), and ***f*** (pointing west). Each fan should be mounted about halfway up the wall. A Hurricane® Oscillating fan should be positioned halfway up the wall at ***h***. This oscillating fan should have its center of oscillation pointing northeast.

14) Concept Generated: **Mixed Fans #2**
Evaluation of Concept: Place Hurricane® Oscillating fans at positions ***h*** (pointing northeast) and ***g*** (pointing northwest) about halfway up the wall. Also place a 24" horizontal fan at position ***d*** (pointing northeast) halfway up the wall.

15) Concept Generated: **24" Fans #1**
Evaluation of Concept: Place a 24" fan at both position ***b*** and ***c***. Both fans should be mounted halfway up the wall, and pointing south.

16) Concept Generated: **20" Fans #2**
Evaluation of Concept: Place 20" fans pointing south at positions ***b*** and ***c***, mounted halfway up the wall.

17) Concept Generated: **Oscillating Only #12**
Evaluation of Concept: Place Hurricane® Oscillating fans at positions ***a*** (pointing south), ***d*** (pointing northeast), and ***I*** (pointing northwest). All fans should be mounted halfway up the height of the wall.

18) Concept Generated: **Oscillating Only #13**
Evaluation of Concept: Place Hurricane® Oscillating fans at positions ***a*** (pointing south), ***d*** (pointing northeast), and ***g*** (pointing northwest). All fans should be mounted halfway up the height of the wall.

19) Concept Generated: **Oscillating Only #14**
Evaluation of Concept: Place Hurricane® Oscillating fans at positions ***a*** (pointing south), ***d*** (pointing northeast), ***I*** (pointing northwest), and ***g*** (pointing northwest). All fans should be mounted halfway up the height of the wall.

20) Concept Generated: **8" Fans #1**
Evaluation of Concept: Along the bottom of the wall and pointing south, place 8" horizontal fans at positions ***e***, ***b***, ***a***, ***c***, and ***f***.

21) Concept Generated: **12" Fans #1**
Evaluation of Concept: Along the bottom of the wall and pointing south, place 12" horizontal fans at positions ***e***, ***b***, ***a***, ***c***, and ***f***.

22) Concept Generated: **Mixed Fans #3**
Evaluation of Concept: Place a 20" horizontal fan along the ground and pointing south at both positions ***b*** and ***c***. Also place a 24" horizontal fan along the ceiling at position ***h*** (pointing north).

23) Concept Generated: **24" Fans #2**
Evaluation of Concept: Place two 24" fans at points ***b*** and ***c*** along the base of the wall and pointing south. Also place a 24" fan at position ***h***, pointing north and mounted to the ceiling.

24) Concept Generated: **Oscillating Only #15**
Evaluation of Concept: Place Hurricane® Oscillating fans along the ground at positions ***d*** and ***e***, and along the ceiling at positions ***f*** and ***I***. All of these fans should be pointing towards the center of the room. In addition to these, mount two more oscillating fans halfway up the wall at positions ***h*** and ***g***, pointing north.

25) Concept Generated: **20" Fans #3**
Evaluation of Concept: Mounted halfway up the wall and pointing south, place 20" horizontal fans at positions ***e***, ***b***, ***c***, and ***f***.

26) Concept Generated: **Mixed Fans #4**
Evaluation of Concept: Place 24” fans along the ground and pointing north at positions ***h*** and ***g***. Add oscillating fans halfway up the wall at positions ***I*** and ***f***. The center of oscillation of both of these fans should be aimed west.

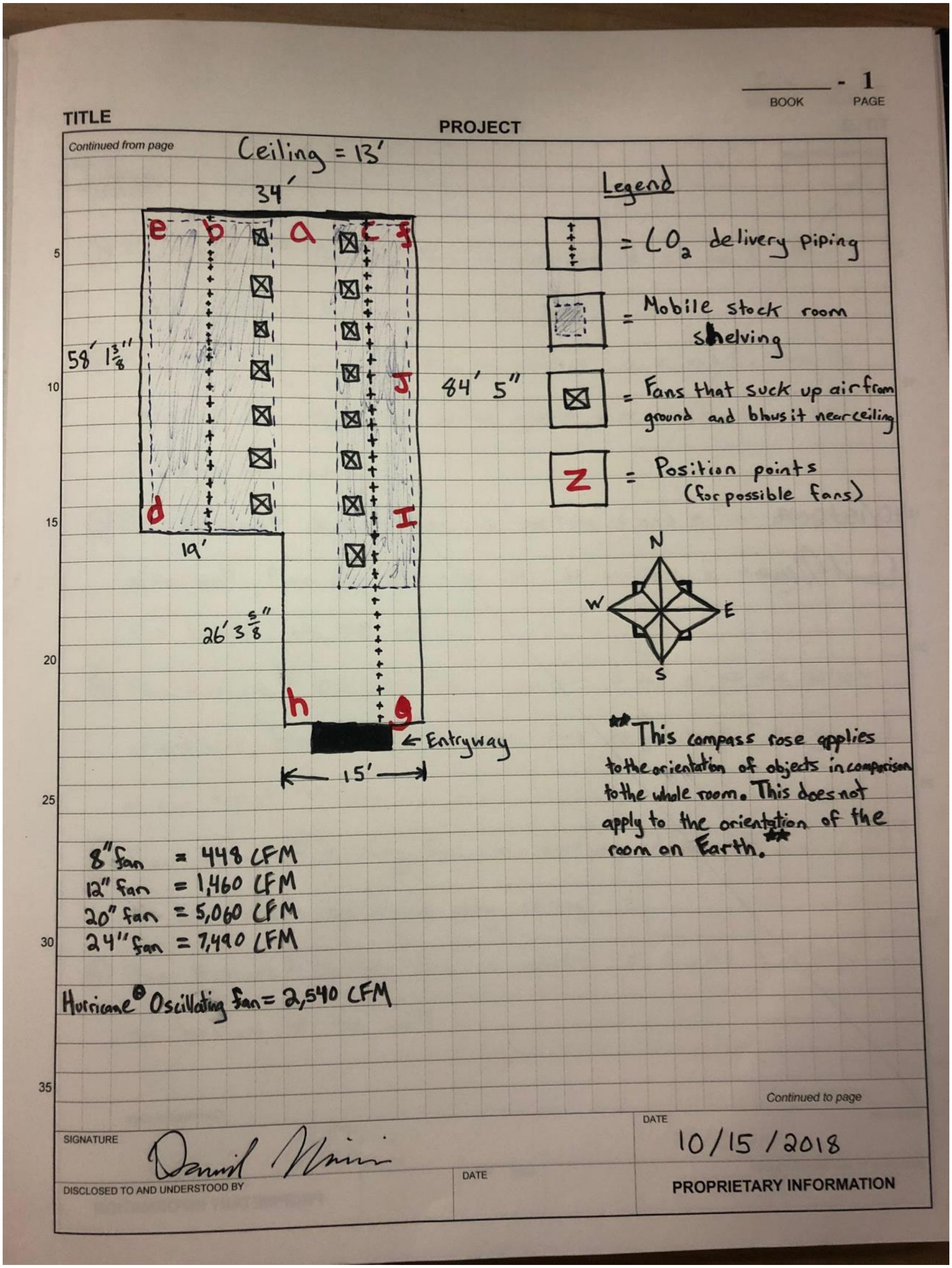
27) Concept Generated: **Mixed Fans #5**
Evaluation of Concept: Place a 8” fan at mid-height of the wall and pointing east at positions ***e*** and ***d***. Also, place a 20” fan halfway up the wall at position ***J*** pointing west.

28) Concept Generated: **Oscillating Only #16**
Evaluation of Concept: Place Hurricane® Oscillating fans halfway up the wall at positions ***d*** (pointing northeast), ***e*** (pointing southeast), and ***J*** (pointing west).

29) Concept Generated: **Oscillating Only #17**
Evaluation of Concept: Place Hurricane® Oscillating fans halfway up the wall at positions ***d*** (pointing northeast), ***e*** (pointing southeast), ***J*** (pointing west), ***I*** (pointing west), and ***f*** (pointing southeast).

30) Concept Generated: **Mixed Fans #6**
Evaluation of Concept: Place a 24” fan along the ceiling and pointing south at position ***a***. Also place a 24” fan along the ground and pointing north at position ***h***. Include Hurricane® Oscillating fans at half the height of the wall at positions ***e*** (pointing southeast), ***d*** (pointing northeast), and ***J*** (pointing west).

Concept sketch provided on the following page



Legend

- ┼ = CO_2 delivery piping
- ▨ = Mobile stock room shelving
- ⊠ = Fans that suck up air from ground and blows it near ceiling
- Z = Position points (for possible fans)

This compass rose applies to the orientation of objects in comparison to the whole room. This does not apply to the orientation of the room on Earth.

8" fan = 448 CFM
12" fan = 1,460 CFM
20" fan = 5,060 CFM
24" fan = 7,490 CFM

Hurricane® Oscillating fan = 2,540 CFM

DATE 10/15/2018

FIGURE 20: NICOSIA DESIGN REFERENCE 1

Emily Yang's Concepts and Evaluations

1) Concept Generated: **Idea 1: CO_2 Sensor**
   Evaluation of Concept: Makes use of the "AirSense Model 400 OEM Infrared Carbon Dioxide Sensor" made by Digital Control Systems, Inc. This product is I2C and RS-232 compatible, is advertised to reduce energy cost, uses dual-beam technology and uses gold plated optics. It has a measurement range of 0-20% (0-200,000 ppm) of CO_2 and measurement accuracy of ∓5% of reading. The sensor will be used with current fertilization system. Programming will be done to calibrate into the current Distec Control System which has a RS-232 interface.

2) Concept Generated: **Idea 2: CO_2 Control: Gas Detection System**
   Evaluation of Concept: This idea makes use of the gas detection system made by KundxT. It consists of a CO_2 sensor unit, a CO_2 warning unit, a AM/AM plus add on module, a distributor, a switching unit, a signal unit, an alarm unit and a luminous panel. This system was intended for use towards the production of the test box and a possible substitute for the current JBE system.

3) Concept Generated: **Idea 3: Growth Chamber Design 1**
   Evaluation of Concept: The design pertains to the Growth Chamber (model#PGR15) with the Conviron CMP6050 control system made by Conviron. It was suggested by Plant Science Professor and JBE Inc partner, Michael Sullivan that this unit can be experimented on and implemented for use in the project.This system will replicate row (or 2 rows of shelving) of the flower room. There is a fan on the top tier and two on the bottom to create and move CO_2 circulation to the bottom tier. There will be two sensors (one bottom, one top) to monitor CO_2 levels on each tier. Airflow is theorized to circulate like the diagram. The chamber should be able to test 5-10 live clones that are 10-12" in height for plant/leaf foliage and pest mitigation. Some chamber specifications to note are and area of 16.1 ft^2 and growth space height of 4.75 ft.

4) Concept Generated: **Idea 4: Growth Chamber Design 2**
   Evaluation of Concept: This design is similar to Idea 3, however uses different fan placement for the circulation of the chamber. It will have the same external fan on the top right side. In this design, a fan is angled 45° downward and located on the top. An additional fan will be mounted at a height centered with the bottom of tier 2. This is predicted to create the flow shown in the diagram.

5) Concept Generated: **Idea 5: Flower room Homogenization Design 1**
   Evaluation of Concept: This design negates one row/box on the right end and sections or walls off the entryway. This concept is hypothesized to create extra safety measures during any emergency exiting. It has two columns of CO_2 piping and has 6 outlets each column. The design also creates for a more symmetric/uniform distribution system. Idea 5 is aimed toward the homogenization of the flower room.

6) Concept Generated: **Idea 6: CO_2 Outlet Diffusion/ Group A**
   Evaluation of Concept: The circulation design in Idea 6 is based on Chapter 11 of McQuiston's Heating, Ventilating and Air Conditioning textbook. It uses a Group A diffusion method where the diffusion is mounted in or near the ceiling that discharges air horizontally.

7) Concept Generated: **Idea 7: CO_2 Outlet Diffusion/ Group E**
   Evaluation of Concept: Similar to Idea 6, this concept uses the theory of airflow of Group E diffusion method. Group E diffusion has diffusers mounted in or near the ceiling that projects air vertically.

8) Concept Generated: **Idea 8: COZIR-Wide Range CO_2 sensor Model GC-0016**
   Evaluation of Concept: Design Concept 6 makes use of the current layout (flower room) and conditions with the addition of several of the COZIR sensors in model GC-0016. The sensor is able to measure 0-100% CO_2 levels which goes far beyond the estimated levels of CO_2. It has a measurement accuracy of ∓700 ppm, ∓5% of reading. The sensor cost $109.00 USD for the sensor alone. With the development kit, $159.00 USD.

9) Concept Generated: **Idea 9: COZIR-Wide Range CO_2 sensor Model GC-0007**
   Evaluation of Concept: This design uses the same conditions in Idea 6. It makes use of the current layout (flower room) and conditions with the addition of several of the COZIR sensors in model GC-0007. The sensor is able to measure 0-60% CO_2 levels. It has a measurement accuracy of ∓700 ppm, ∓5% of reading. The sensor cost $109.00 USD for the sensor. With the development kit, $159.00 USD.

10) Concept Generated: **Idea 10: eSense CO_2 Alarm**
    Evaluation of Concept: (Model: SE-0010) Idea 10 uses the eSense CO_2 alarm for the test box. In the event the current alarm system is unavailable due to cost and complexity. The alarm system in the flower room currently is calibrated with a magnetic door lock system which is likely not needed in the test box. The product has a life expectancy of 15 years, has an audible alarm and mute button, and is currently calibrated to display: green at 0-800 ppm; yellow at 800-1400 ppm; and red at ppm >1400. This unit cost $229.00 USD.

11) Concept Generated: **Idea 11: Link Conn 1000 Software**
    Evaluation of Concept: Uses the software by company Link4. The software cost $1,599.00 USD. It can monitor up to 128 Link4 iGrow controllers, it records to PC, can program control parameters on PC and is password protected. This design can be used for the flower room in the case that programming the current system is not allowed or can be used as the test box control system.

12) Concept Generated: **Idea 12: Link4 iGrow 800 Controller w/ VC&S**
    Evaluation of Concept: The unit cost $1,295.00 USD. Makes use of the Link4 iGrow 800 controller as the central controller to navigate and control the test box. This controller will be implemented into a scaled down version of the flower room system in addition to the programming of new fumigation and exhaust modes.

13) Concept Generated: **Idea 13: Flower room Homogenization Design 2**
    Evaluation of Concept: Fan 1 and 2 will be oscillating and on the floor angled upward at 45° angles. Fans 3,4,5 and 6 will be mounted at a height aligned with the CO_2 outlet and located at each corner of the room., These fans will be angled downward.

14) Concept Generated: **Idea 14: Test Box Design 1/ scaled down by 6**
    Evaluation of Concept: This design is a scaled down version of the flower room. Assuming already homogeneous, this design will be able to test on live clones of up to 4 inches. Will have 2 CO_2 outlets as shown in the diagram.

15) Concept Generated: **Idea 15:Test Box Design 2 w/ CO_2 outlet conditions**
    Evaluation of Concept: Uses the scaled down by 6 conditions in Idea 14 with 2 additional CO_2 outlets. The outlets will administer CO_2 at a rate half that of the original by scaled down by 6 version. Placement of the outlets are shown in the diagram. Can test up to 4" live clones.

16) Concept Generated: **Idea 16: Test Box Design 3/ factor 5**
    Evaluation of Concept: This idea is similar to Idea 14 and 15, however is reduced by a factor of 5. The design enables test on plants up to 4.8 inches.

17) Concept Generated: **Idea 17: Test Box Design 4**
    Evaluation of Concept: The design equates to a quarter of the flower room. The test box will be reduced by factor of 6. It will have 1 CO_2 outlet and able to test on up to 9.3" clones. It has a height of 4.3 ft.

18) Concept Generated: **Idea 18: Fan Placement for Purge 1**
    Evaluation of Concept: The design consists of Fans 1 through 8 and predict the purge/exhaust mode of the system. Fan placement and angles are provided in the diagram. The blue rectangles labelled A and B are Idea 19.

19) Concept Generated: **Idea 19: Fan Placement for Purge 2**
    Evaluation of Concept: Consists of everything in Idea 18's design with 2 additional fans. These two fans are interior wall fans mounted on the wall near floor. Classified as Group D distribution.

20) Concept Generated: **Idea 20: Flower room Homogenization Design 3**
    Evaluation of Concept: Six hanging vent fans in center of room aligned. The left figure shows position and direction facing. The right figure shows theorized air flow. The centrifugal fans suck in CO_2 on the bottom and distributes.

21) Concept Generated: **Idea 21: Flower room Homogenization Design 4**
    Evaluation of Concept: Fans will oscillate in a specified pattern all at the same time. The fans are mounted on the ceiling in Between each outlet.

22) Concept Generated: **Idea 22: Flower room Homogenization Design 5**
Evaluation of Concept: Divide the room up for different concentrations or time. Different life stage of plants withstands different CO_2 levels. THis design is based off of fan arrangements given by JBE.

23) Concept Generated: **Idea 23: Flower room Homogenization Design 6**
Evaluation of Concept: Connect CO_2 tubing to copper outlets. Tubing will run along each other row on each tier. Will have even distributed holes to administer the CO_2 gas (aka rain pipe tubing). Lower tier will be calibrated/programmed to administer a percent less than the top and will depend on sensors located on tier 1.

24) Concept Generated: **Idea 24: Fan Placement for Purge 3**
Evaluation of Concept: Fan 1 and 3 on top corner are angled 45° downward. Fan 2 and 4 are placed vertically on the floor and are angled 45° toward the exhaust fans as shown in the figure.

25) Concept Generated: **Idea 25:Growth Chamber Design 2**
Evaluation of Concept: Run tubing with even distributed holes along shelving. There will be a total of 8 fans at each corner of the chamber room. Placement of the fans are shown in the figure.

26) Concept Generated: **Idea 26: Flower room Homogenization Design 7**
Evaluation of Concept: This design is based on the theory behind ceiling fans. Will need two ceiling fans of different sizes to circulate the flower room or test box. Placement is shown in the figure.

27) Concept Generated: **Idea 27: CO_2 Distribution Valve**
Evaluation of Concept: A ceiling at entryway to regulate that specific portion of room. Will be two-headed valve outlets for CO_2 distribution. Location is shown in the figure. Fans will be placed at each corner of the room.

28) Concept Generated:**Idea 28: Centrifugal Fan Design 1**
Evaluation of Concept: Plans for CO_2 outlet to be along the bottom wall. Placement and location is shown in the figure.

29) Concept Generated: **Idea 29: Centrifugal Fan Design 2**
Evaluation of Concept: The addition of centrifugal fans/vents on each shelving unit. The figure will display a better understanding of the placement and air flow pattern.

30) Concept Generated: **Idea 30: Overall System**
Evaluation of Concept: The diagram represents the possible overall feedback system of the fumigation.

Concept sketches are provided on the following page

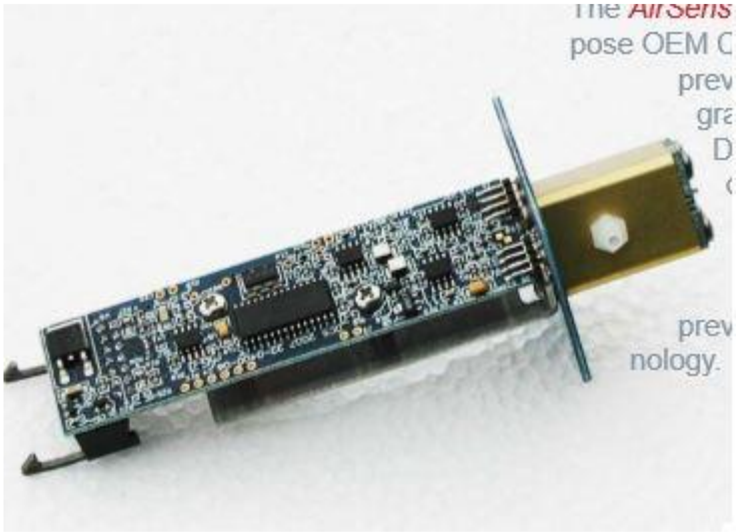


FIGURE 21: IDEA 1: CO_2 SENSOR

FIGURE 22: IDEA 2: CO_2 CONTROL: GAS DETECTION SYSTEM

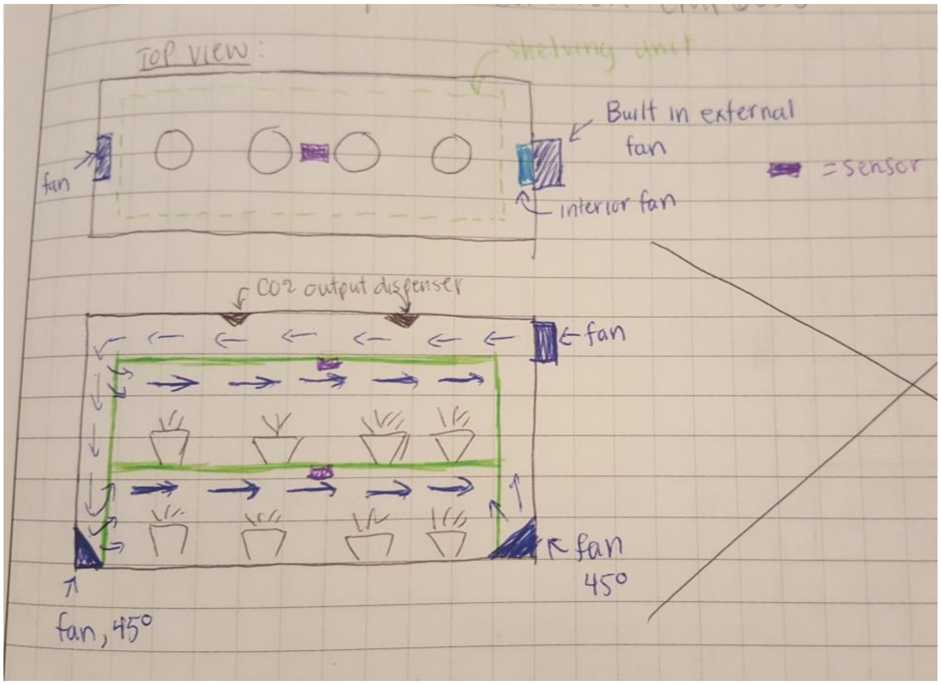


FIGURE 23: IDEA 3: GROWTH CHAMBER DESIGN 1

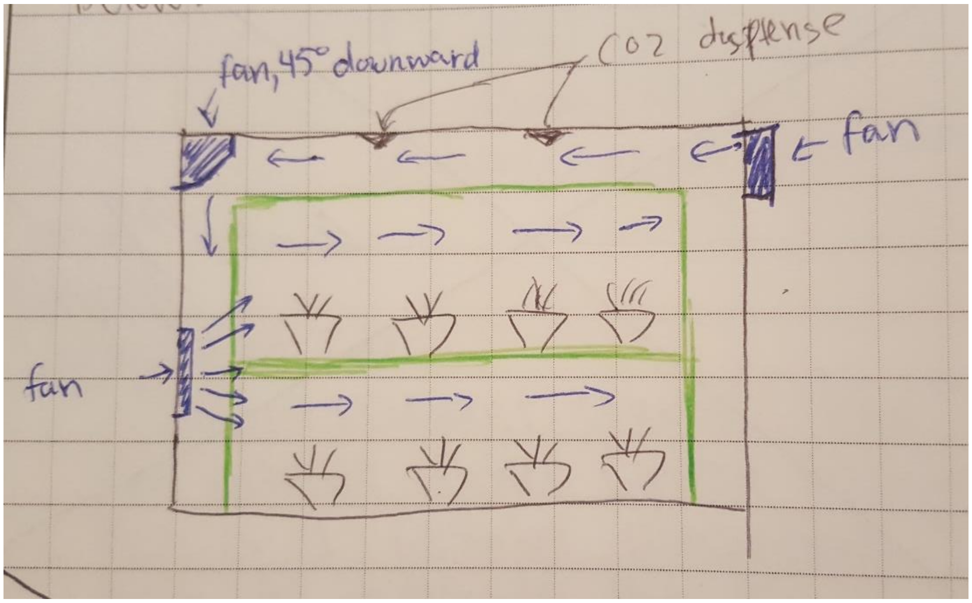
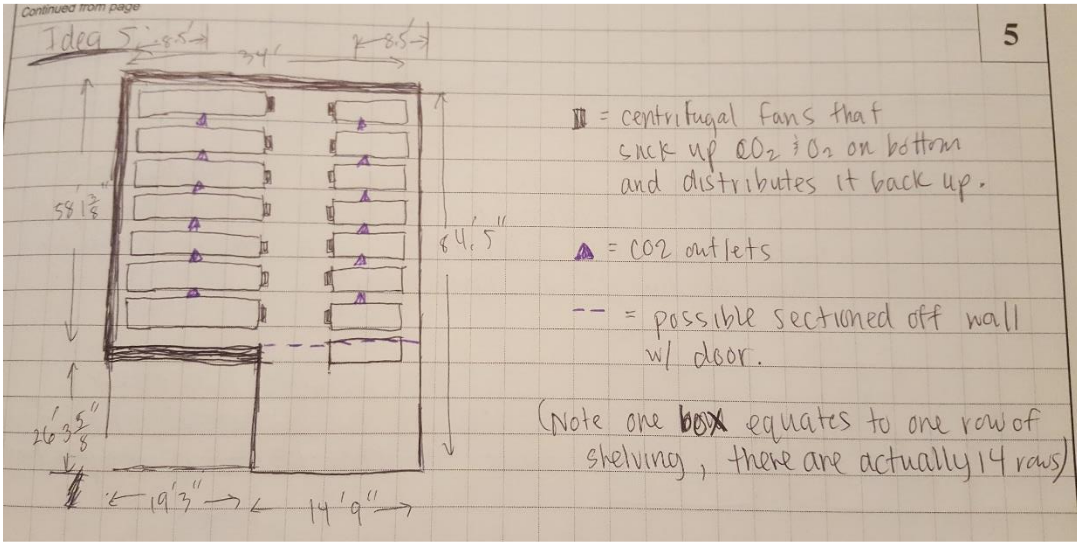


FIGURE 24: IDEA 4: GROWTH CHAMBER DESIGN 2



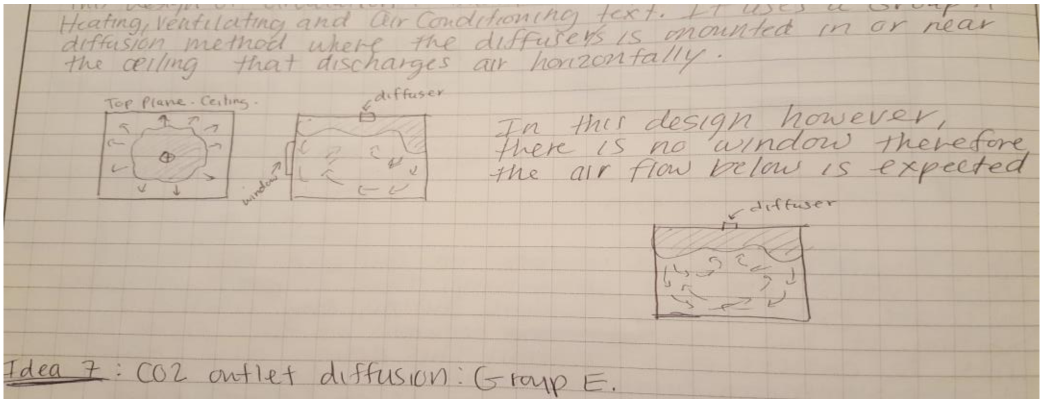
▥ = centrifugal fans that suck up CO2 & O2 on bottom and distributes it back up.

▲ = CO2 outlets

-- = possible sectioned off wall w/ door.

(Note one ~~box~~ equates to one row of shelving, there are actually 14 rows)

FIGURE 25: IDEA 5: FLOWER ROOM HOMOGENIZATION DESIGN 1


Heating, Ventilating and Air Conditioning text. It uses a Group A diffusion method where the diffusers is mounted in or near the ceiling that discharges air horizontally.

In this design however, there is no window therefore the air flow below is expected

Idea 7: CO2 outlet diffusion: Group E.

FIGURE 26: IDEA 6: CO_2 OUTLET DIFFUSION/ GROUP A

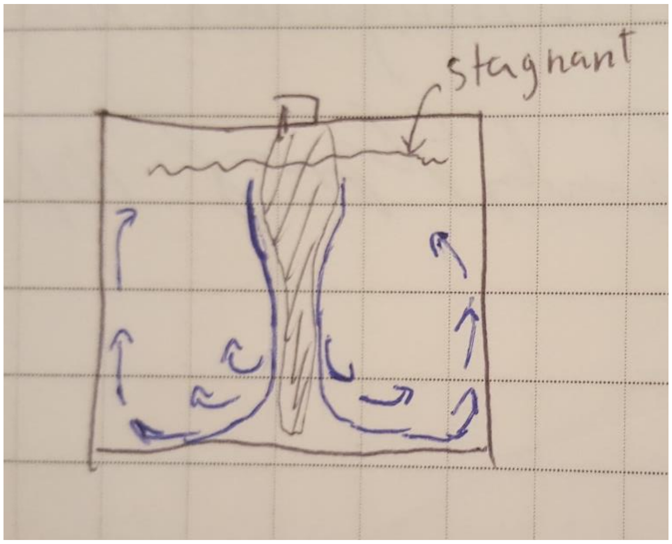


FIGURE 27: IDEA 7: CO_2 OUTLET DIFFUSION/ GROUP E

FIGURE 28: IDEA 8 AND IDEA 9: COZIR-WR CO_2 SENSORS

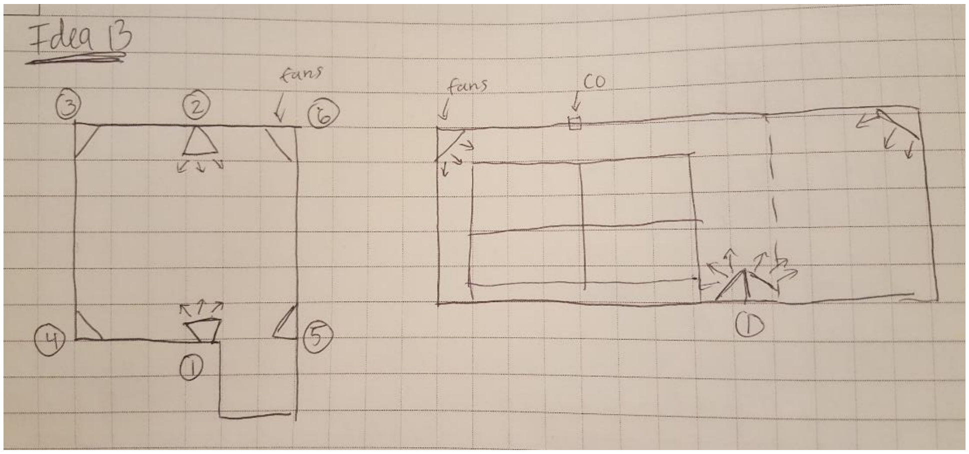


FIGURE 29: IDEA 13: FLOWER ROOM HOMOGENIZATION DESIGN 2

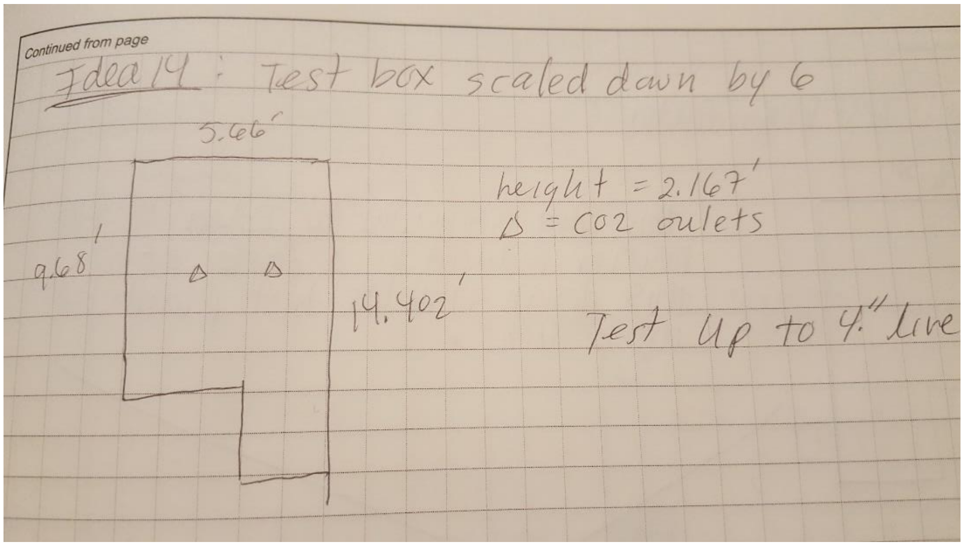


FIGURE 30: IDEA 14: TEST BOX DESIGN 1/ SCALED DOWN BY 6

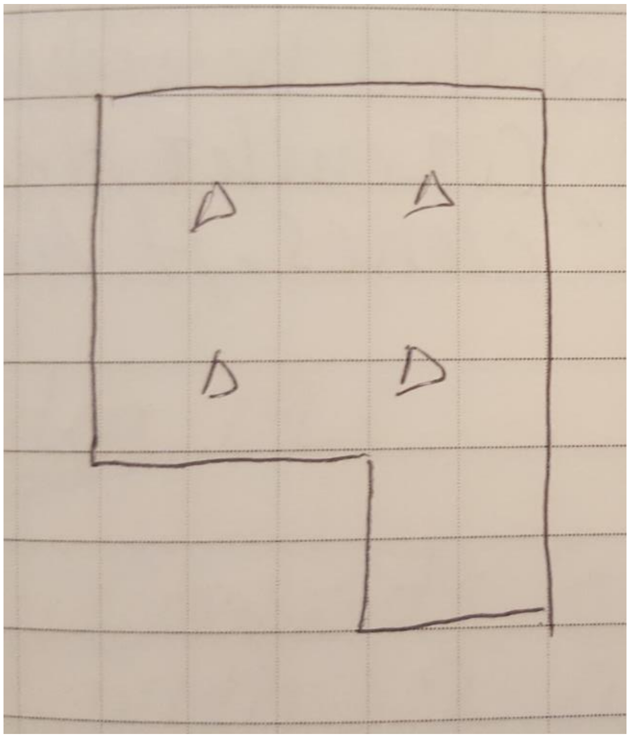


FIGURE 31: IDEA 15:TEST BOX DESIGN 2 W/ CO_2 OUTLET CONDITIONS

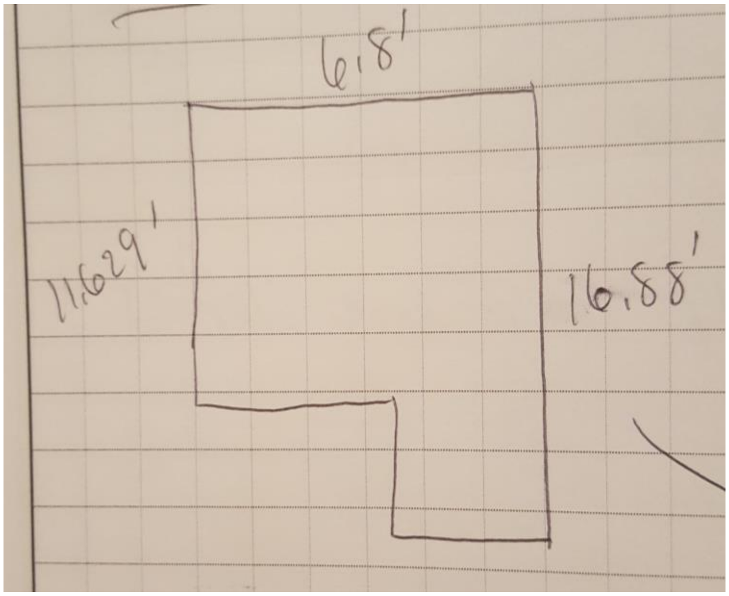


FIGURE 32: IDEA 16: TEST BOX DESIGN 3/ FACTOR 5

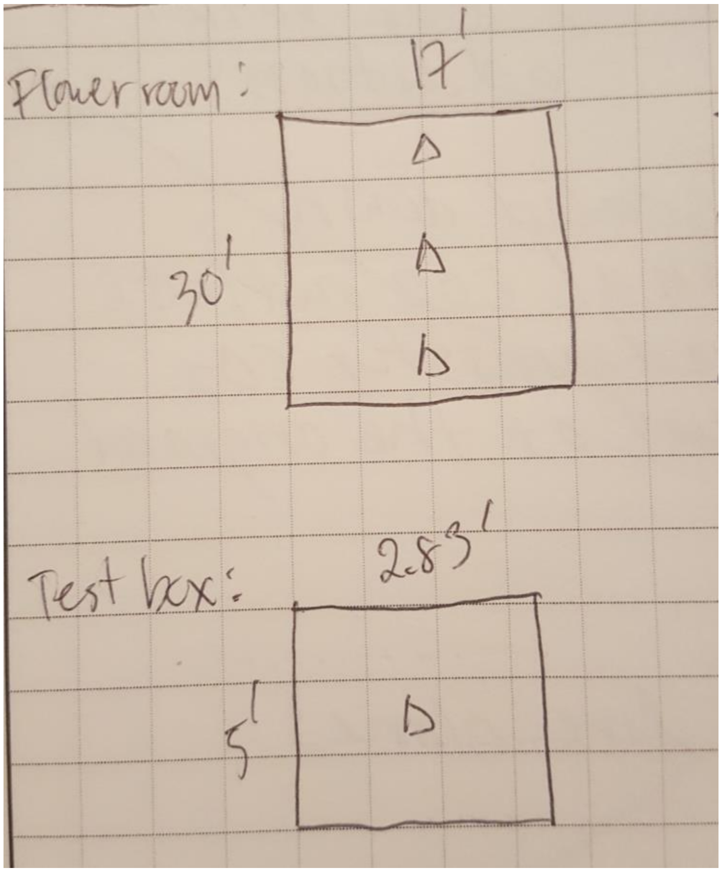


FIGURE 33: IDEA 17: TEST BOX DESIGN 4

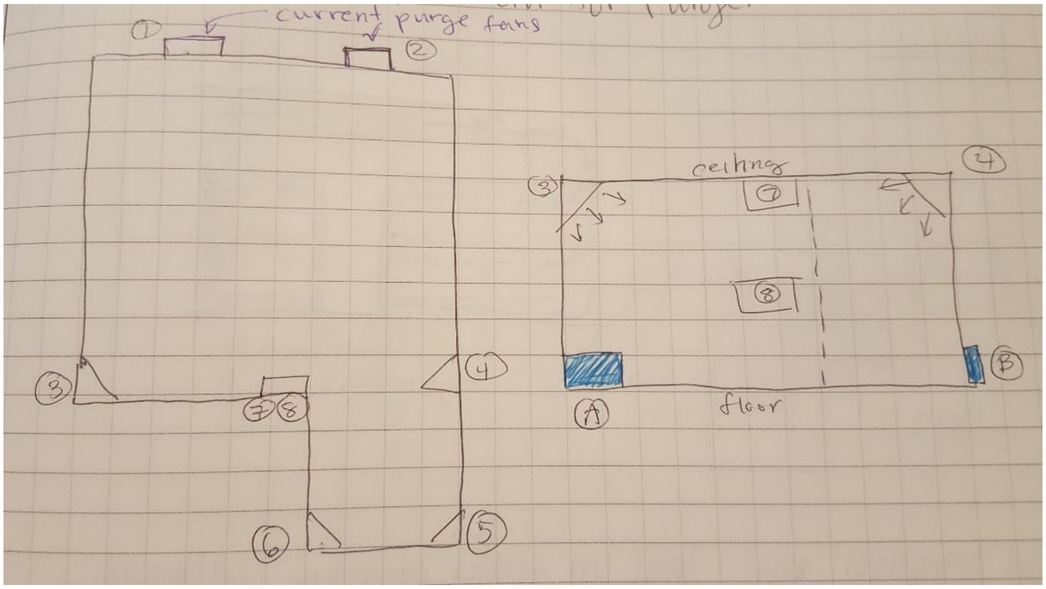


FIGURE 34: IDEA 18 AND 19: FAN PLACEMENT FOR PURGE 1 AND 2

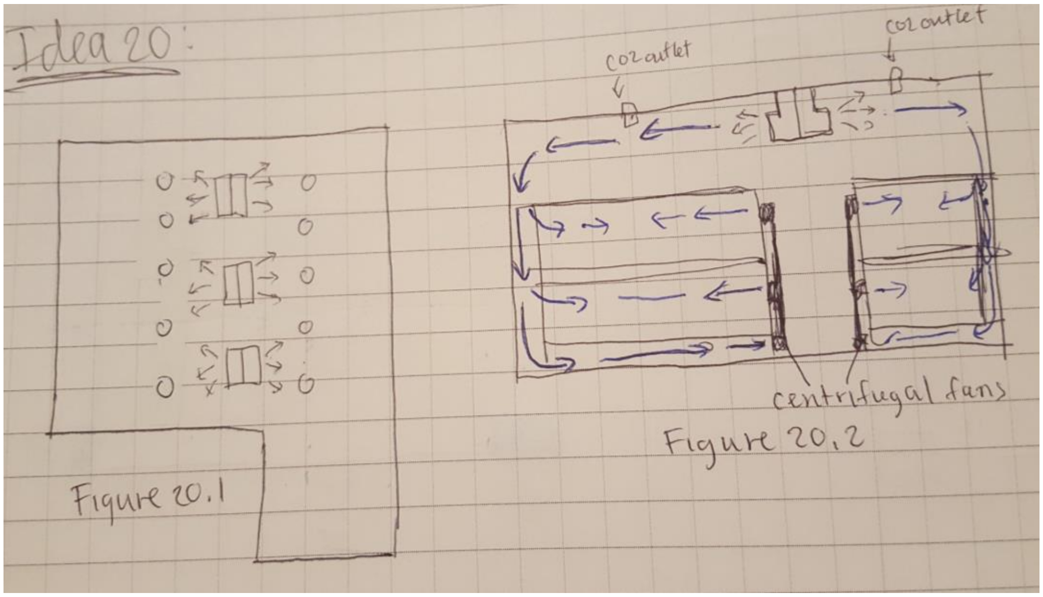


FIGURE 35: IDEA 20: FLOWER ROOM HOMOGENIZATION DESIGN 3

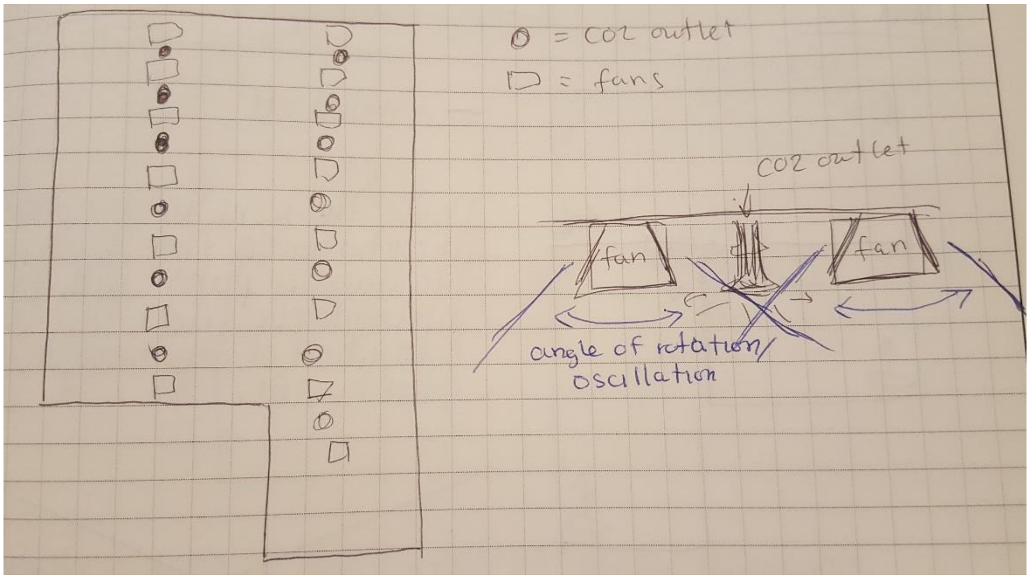


FIGURE 36: IDEA 21: FLOWER ROOM HOMOGENIZATION DESIGN 4

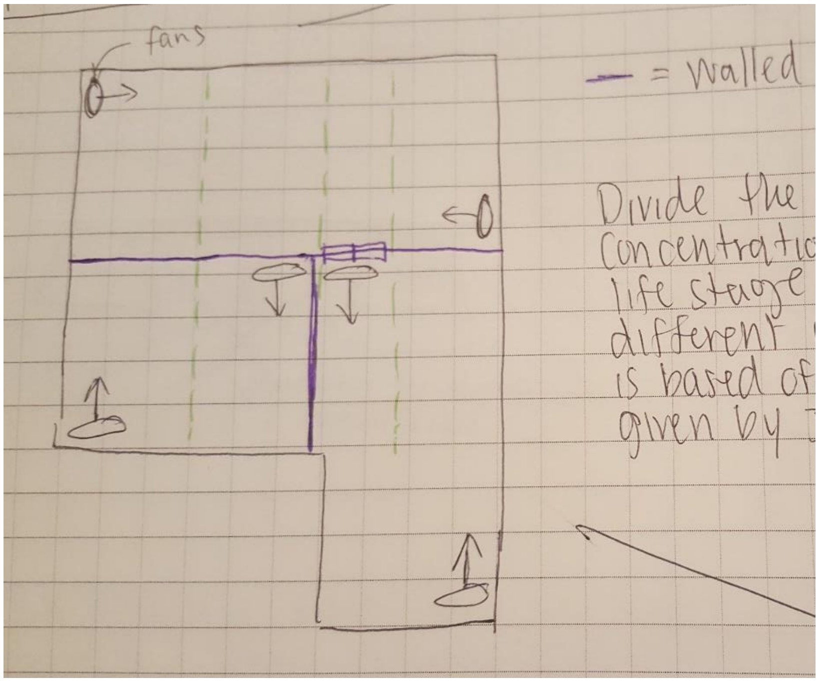


FIGURE 37: IDEA 22: FLOWER ROOM HOMOGENIZATION DESIGN 5

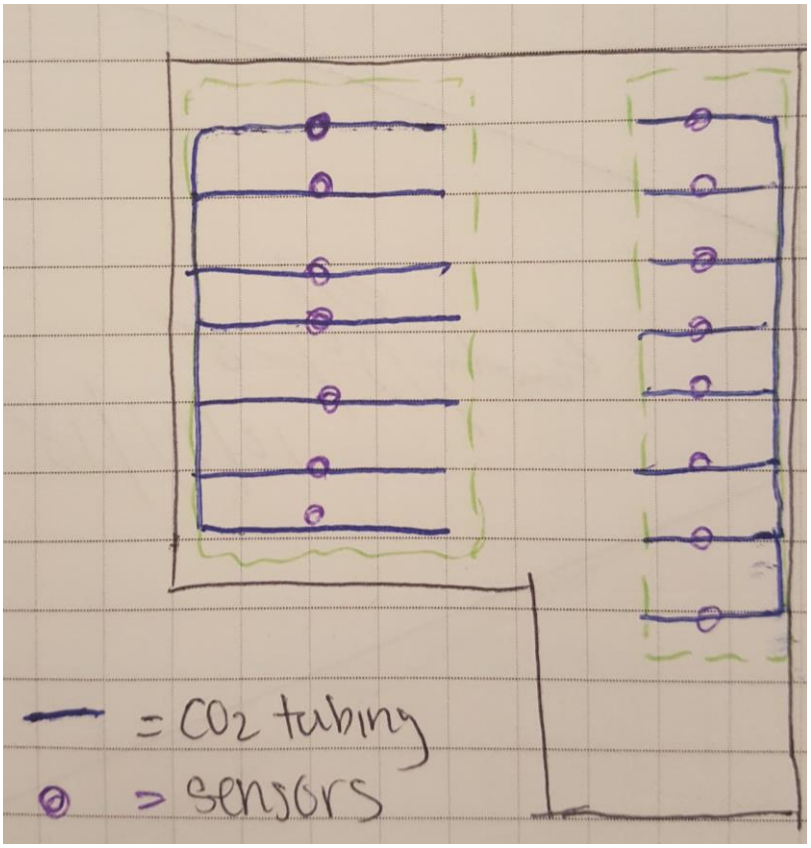
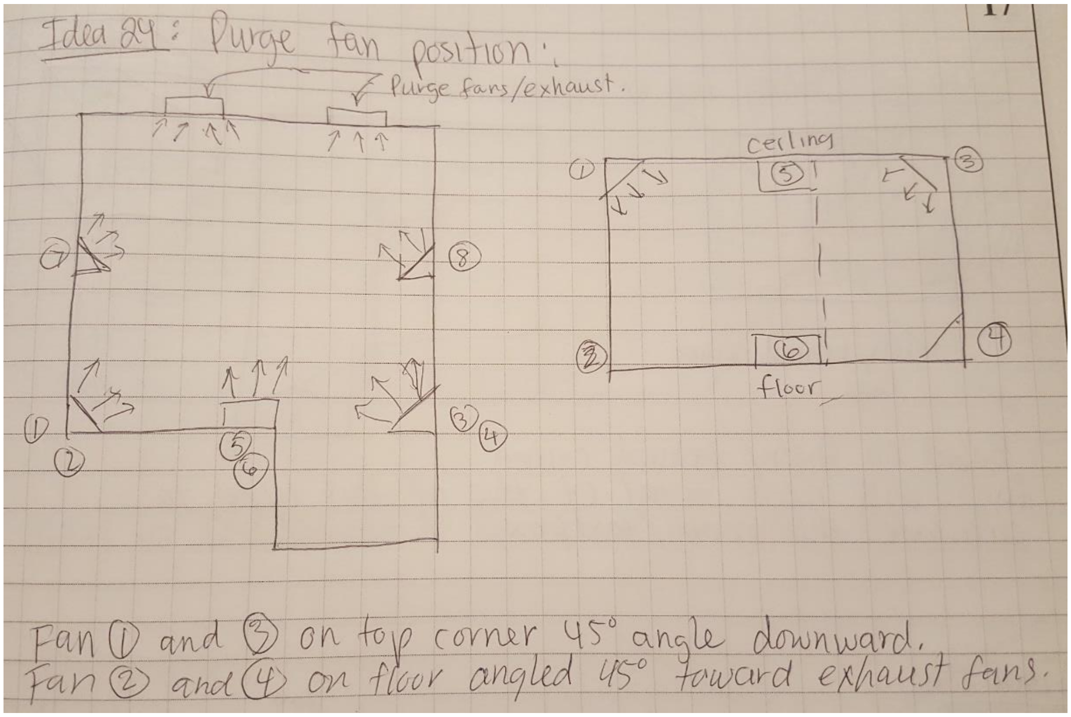


FIGURE 38: IDEA 23: FLOWER ROOM HOMOGENIZATION DESIGN 6



Fan ① and ③ on top corner 45° angle downward.
Fan ② and ④ on floor angled 45° toward exhaust fans.

FIGURE 39: IDEA 24: FAN PLACEMENT FOR PURGE 3

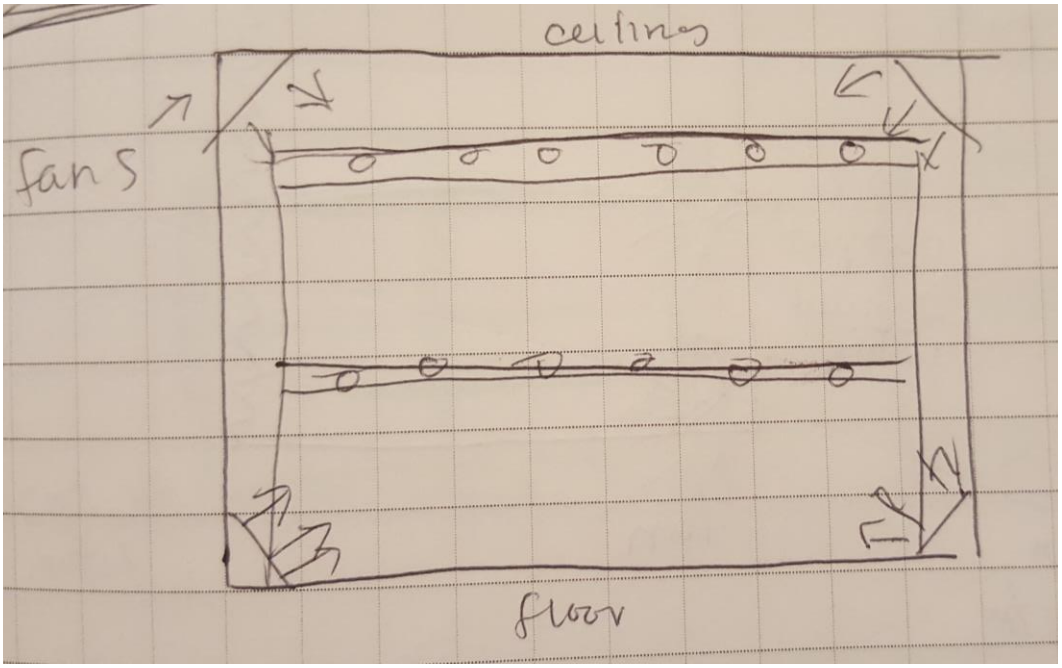


FIGURE 40: IDEA 25: GROWTH CHAMBER DESIGN 2

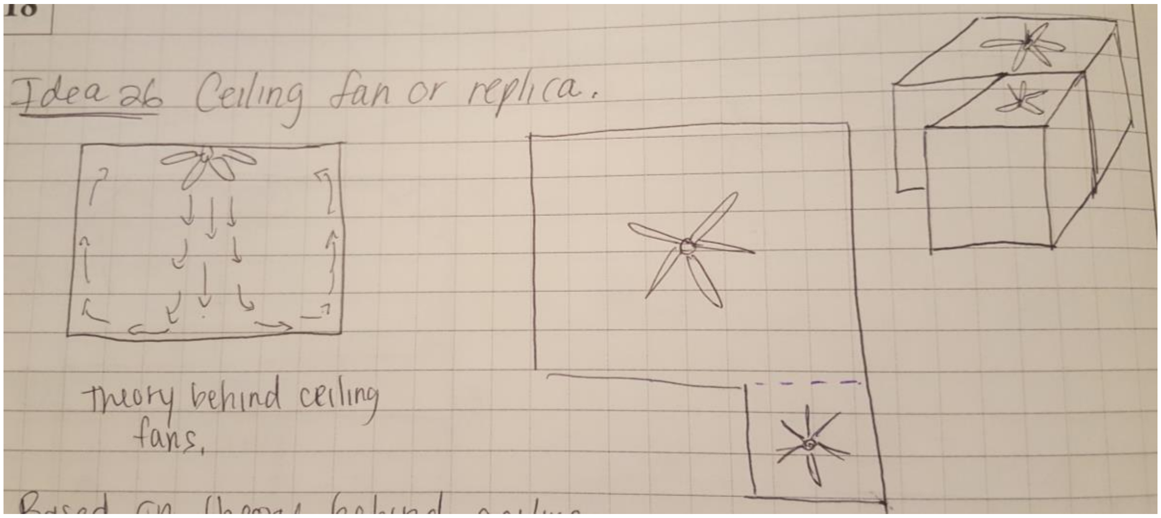


FIGURE 41: IDEA 26: FLOWER ROOM HOMOGENIZATION DESIGN 7

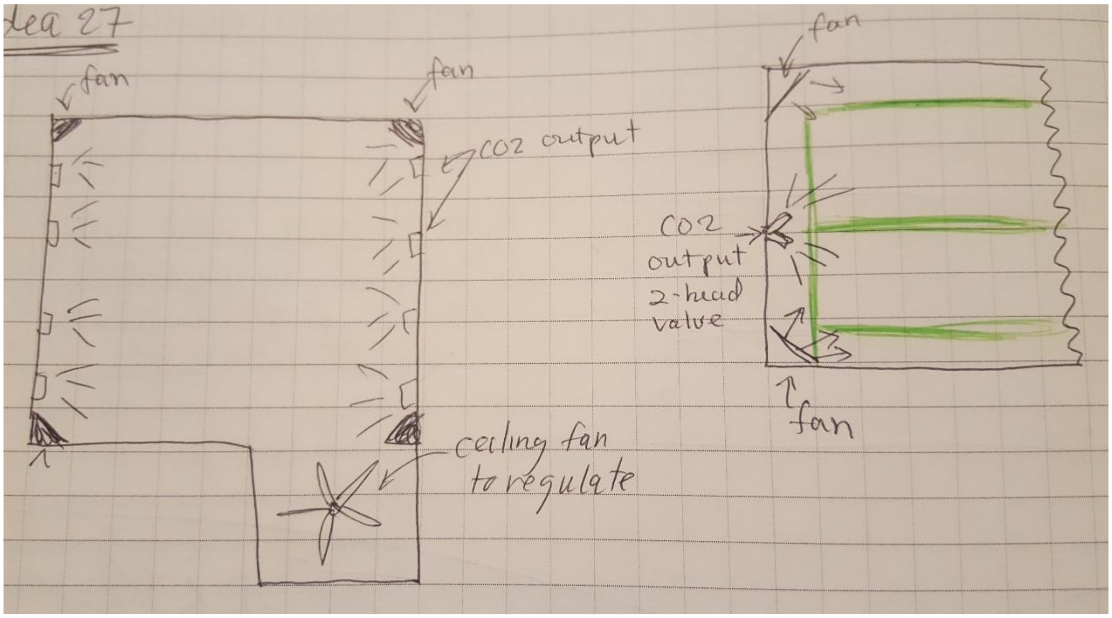


FIGURE 42: IDEA 27: CO_2 DISTRIBUTION VALVE

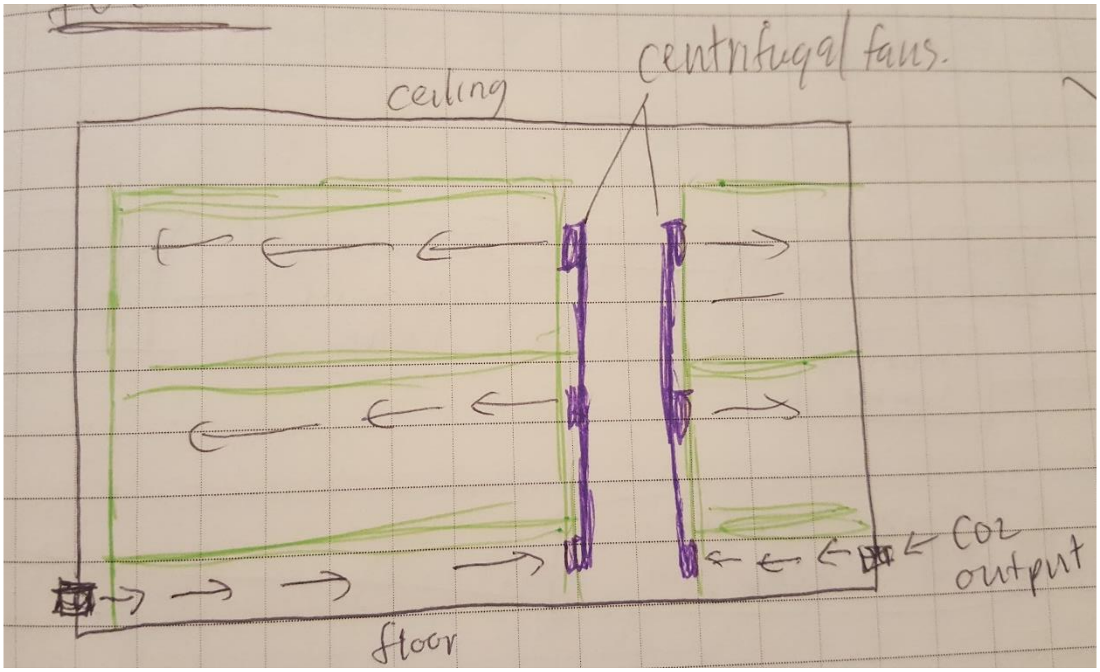


FIGURE 43: IDEA 28: CENTRIFUGAL FAN DESIGN 1

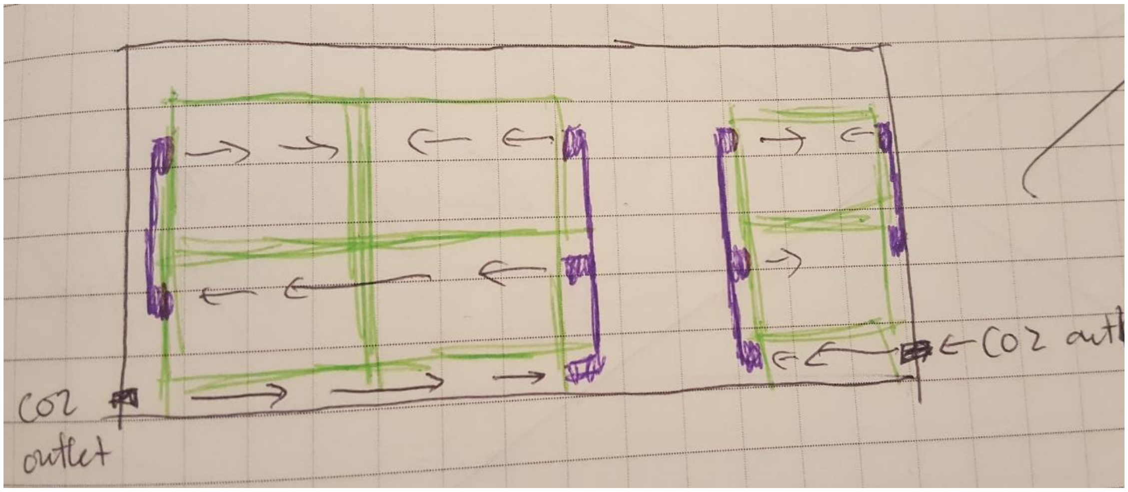


FIGURE 44: IDEA 29: CENTRIFUGAL FAN DESIGN 2

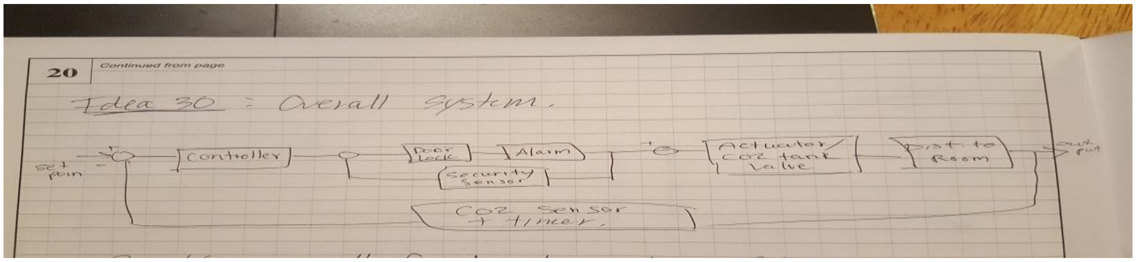


FIGURE 45: IDEA 30: OVERALL SYSTEM

QFD:

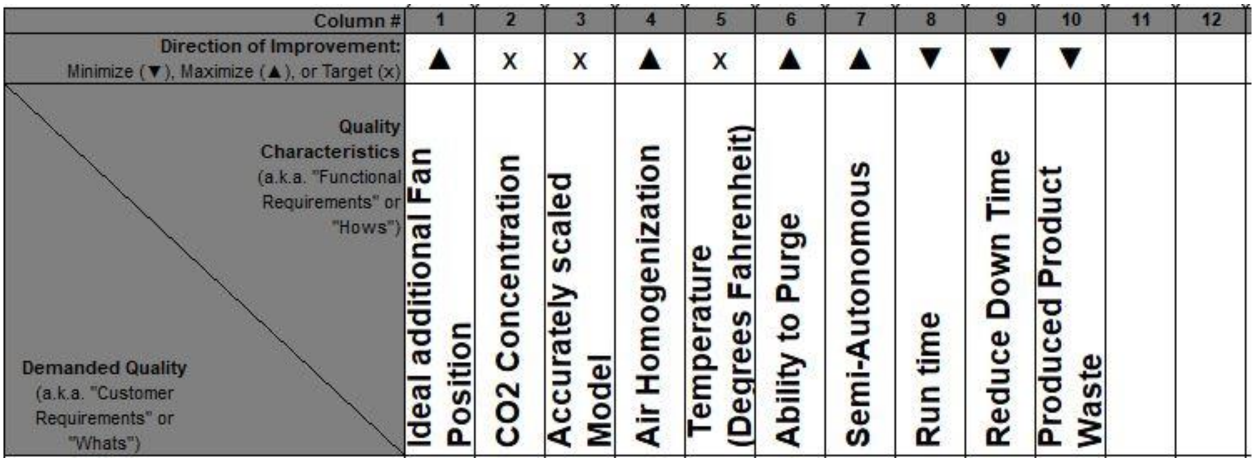
The growing of medicinal plants is becoming a flourishing industry. As the legalization of marijuana becomes more of a reality, products will be put at a higher standard than ever before. Mass production is vital for an industry and it is important that the product is checked regularly to ensure high quality. Thousands of plants are being grown and harvested on a weekly basis and it is unrealistic for a company to check each individual plant for pests that might otherwise taint the product to be sold.

Industries in this particular field have few processes to mitigate pests. Pesticide use and fumigation are two popular techniques; however, the use of pesticides are strictly regulated and fumigation is a difficult process and is best optimized in an enclosed volume. Each technique is unique and best used according to the area in which the plants are being grown. To better understand, Rhode Island is a difficult place to grow medicinal plants because of the harsh weather conditions year round. It would be preferable to grow indoors thus encouraging the use of fumigation in the pest mitigation process. The design in this report is intended for industries with very specific processes in their production. The consumers for our product are those who grow indoors and use a fumigation system as a method to ensure high quality product. The conceptual design and purpose of the fumigator can be scaled to each consumers specific needs. The original purpose of the product is for industrial use, however as recreational home grows are increasingly popular in certain states, this product could be sold for the broader market of the at home recreational marijuana cultivator.

Knowing the customer, it is easy to determine how best to develop a design that incorporates requirements mandated by industries. This was completed by implementing a QFD analysis. Using this type of analysis, benefits and drawbacks of a specific design can be seemingly highlighted. Comparing customer requirement to functionality requirements also easily displays the relationships between different aspects of the design. This can be used to show what aspects of the overall design need improvement and which seem to suffice their needs. For example, in this project reducing product waste and the function efficiency should be directly related. The efficiency of the system should be based on how much product waste is prevented, and showing that our design directly relates these two aspects proves that we have designed in the correct way. Following the QFD chart located in the appendix, all relations of our design can be easily seen.

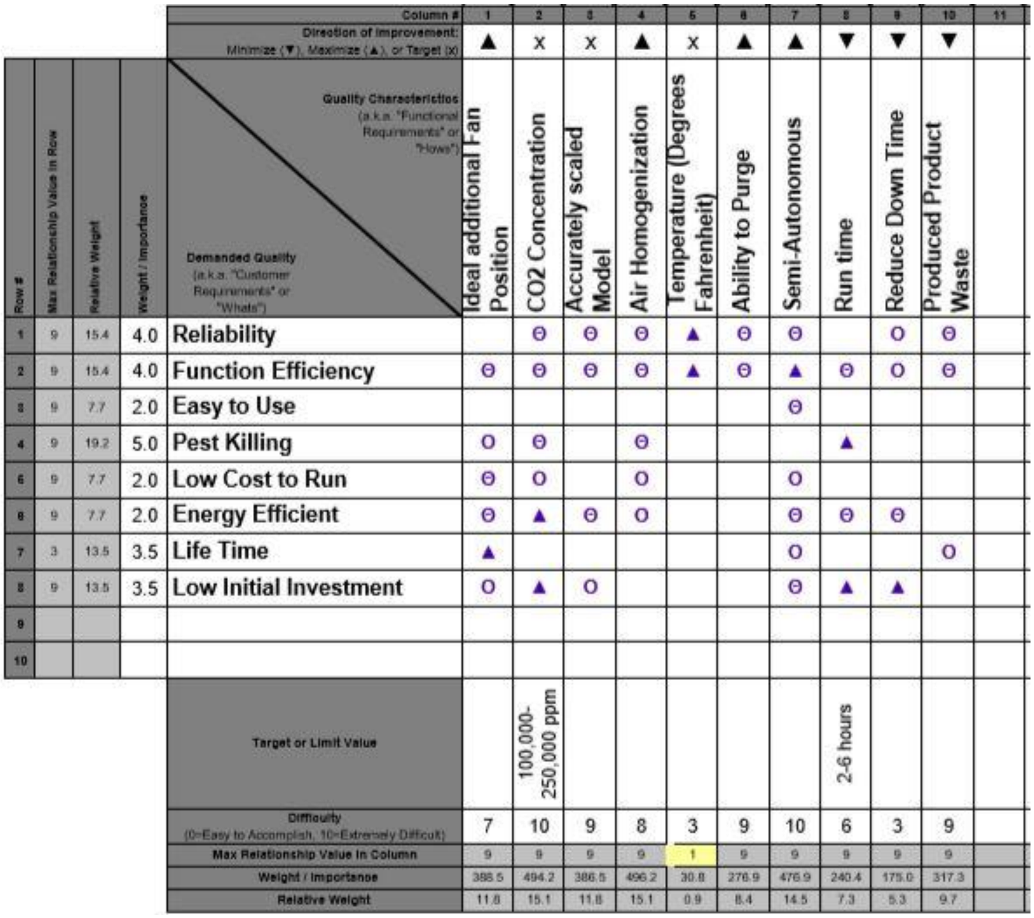
Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / (a.k.a. "Functional Requirements" or "Hows")
1	9	15.4	4.0	Reliability
2	9	15.4	4.0	Function Efficiency
3	9	7.7	2.0	Easy to Use
4	9	19.2	5.0	Pest Killing
5	9	7.7	2.0	Low Cost to Run
6	9	7.7	2.0	Energy Efficient
7	3	13.5	3.5	Life Time
8	9	13.5	3.5	Low Initial Investment

FIGURE 46: QFD CUSTOMER REQUIREMENTS



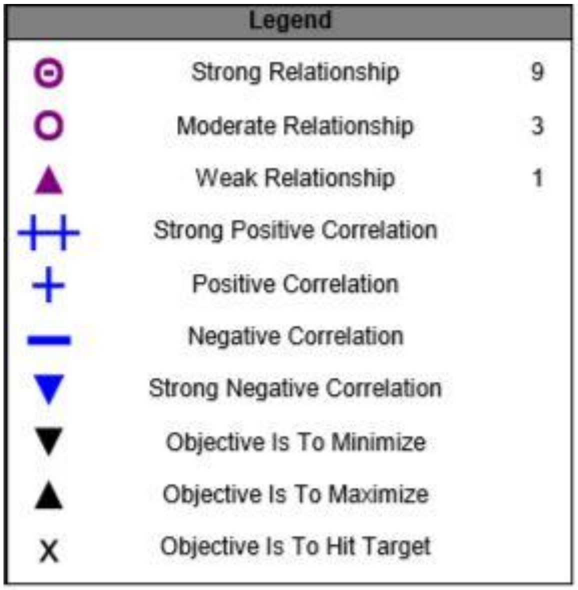
Column #	1	2	3	4	5	6	7	8	9	10	11	12
Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	x	x	▲	x	▲	▲	▼	▼	▼		
Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Ideal additional Fan Position	CO2 Concentration	Accurately scaled Model	Air Homogenization	Temperature (Degrees Fahrenheit)	Ability to Purge	Semi-Autonomous	Run time	Reduce Down Time	Produced Product Waste		

FIGURE 47: QFD QUALITY REQUIREMENTS



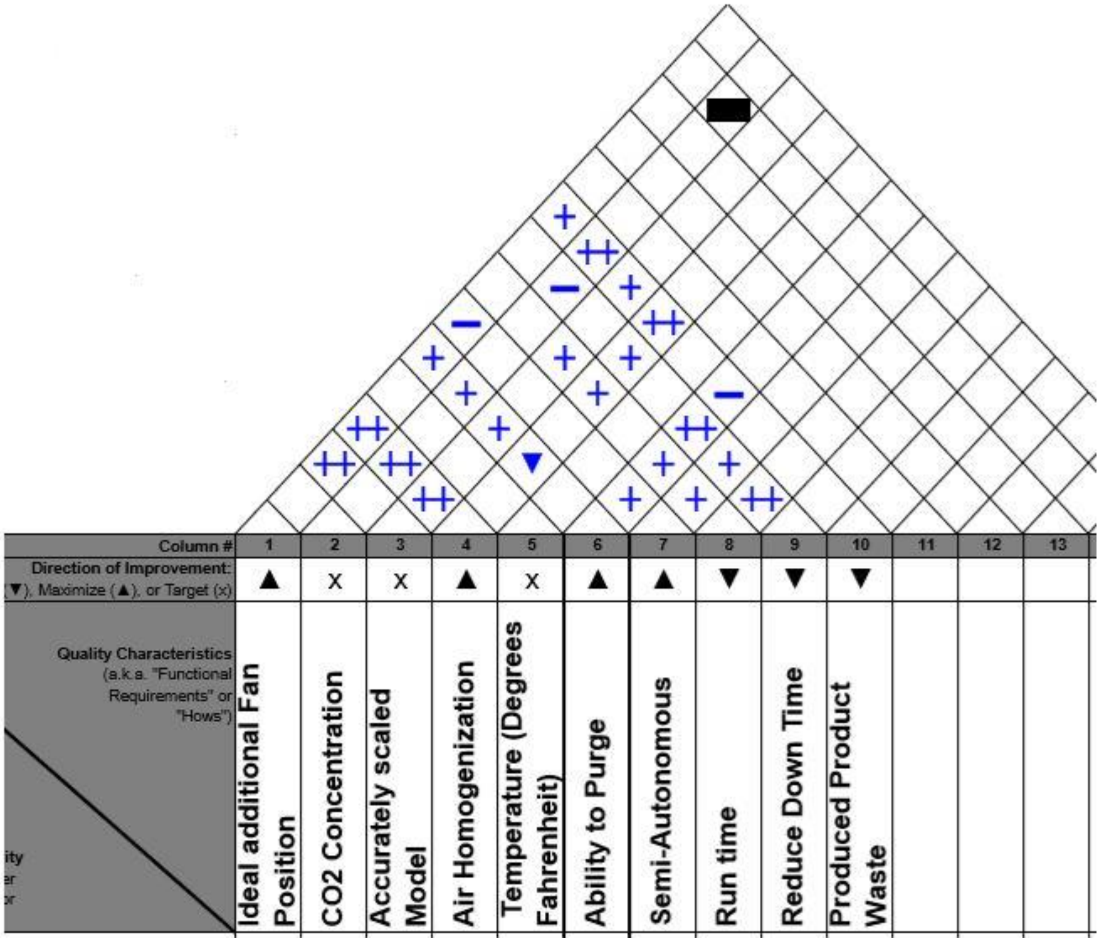
Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11
				Direction of improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	x	x	▲	x	▲	▲	▼	▼	▼	
				Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Ideal additional Fan Position	CO2 Concentration	Accurately scaled Model	Air Homogenization	Temperature (Degrees Fahrenheit)	Ability to Purge	Semi-Autonomous	Run time	Reduce Down Time	Produced Product Waste	
1	9	15.4	4.0	Reliability		Θ	Θ	Θ	▲	Θ	Θ		O	Θ	
2	9	15.4	4.0	Function Efficiency	Θ	Θ	Θ	Θ	▲	Θ	▲	Θ	O	Θ	
3	9	7.7	2.0	Easy to Use							Θ				
4	9	19.2	5.0	Pest Killing	O	Θ		Θ				▲			
5	9	7.7	2.0	Low Cost to Run	Θ	O		O			O				
6	9	7.7	2.0	Energy Efficient	Θ	▲	Θ	O			Θ	Θ	Θ		
7	3	13.5	3.5	Life Time	▲						O			O	
8	9	13.5	3.5	Low Initial Investment	O	▲	O				Θ	▲	▲		
9															
10															
				Target or Limit Value		100,000-250,000 ppm						2-6 hours			
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	7	10	9	8	3	9	10	6	3	9	
				Max Relationship Value in Column	9	9	9	9	1	9	9	9	9	9	
				Weight / Importance	388.5	494.2	386.5	496.2	30.8	276.9	476.9	240.4	175.0	317.3	
				Relative Weight	11.8	15.1	11.8	15.1	0.9	8.4	14.5	7.3	5.3	9.7	

FIGURE 48: QFD AND REQUIREMENTS AND CHARACTERISTIC CORRELATION



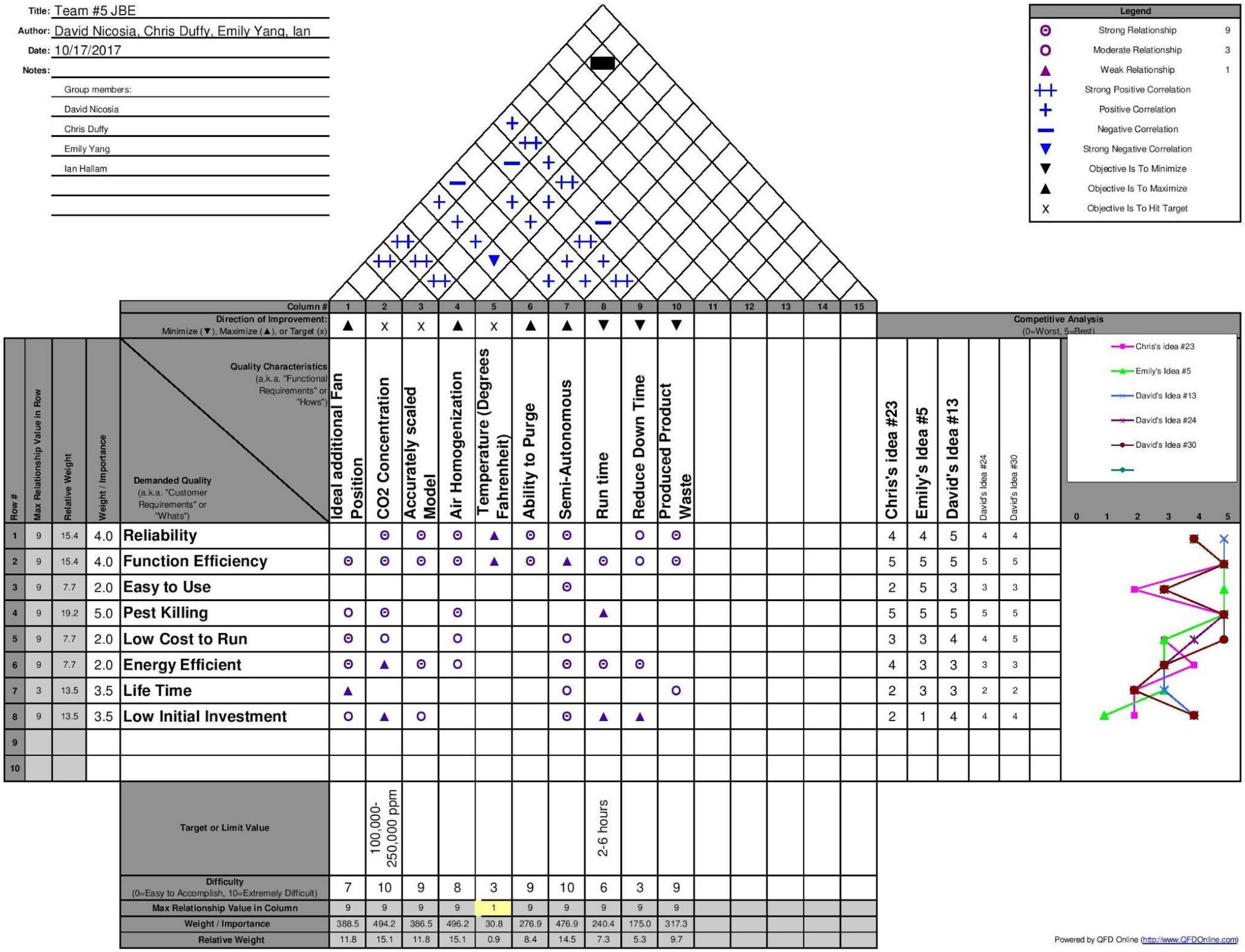
Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	

FIGURE 49: QFD LEGEND



Column #	1	2	3	4	5	6	7	8	9	10	11	12	13
Direction of Improvement: (▼), Maximize (▲), or Target (x)	▲	x	x	▲	x	▲	▲	▼	▼	▼			
Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Ideal additional Fan Position	CO2 Concentration	Accurately scaled Model	Air Homogenization	Temperature (Degrees Fahrenheit)	Ability to Purge	Semi-Autonomous	Run time	Reduce Down Time	Produced Product Waste			

FIGURE 50: CORRELATION BETWEEN QUALITY CHARACTERISTICS



Title: Team #5 JBE
Author: David Nicosia, Chris Duffy, Emily Yang, Ian
Date: 10/17/2017
Notes:
Group members:
David Nicosia
Chris Duffy
Emily Yang
Ian Hallam

Legend		
⊙	Strong Relationship	9
○	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Chris's idea #23	Emily's Idea #5	David's Idea #13	David's Idea #24	David's Idea #30
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	x	x	▲	x	▲	▲	▼	▼	▼										
				Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Ideal additional Fan Position	CO2 Concentration	Accurately scaled Model	Air Homogenization	Temperature (Degrees Fahrenheit)	Ability to Purge	Semi-Autonomous	Run time	Reduce Down Time	Produced Product Waste										
1	9	15.4	4.0	Reliability		⊙	⊙	⊙	▲	⊙	⊙		○	⊙						4	4	5	4	4
2	9	15.4	4.0	Function Efficiency	⊙	⊙	⊙	⊙	▲	⊙	▲	⊙	○	⊙						5	5	5	5	5
3	9	7.7	2.0	Easy to Use							⊙									2	5	3	3	3
4	9	19.2	5.0	Pest Killing	○	⊙		⊙				▲								5	5	5	5	5
5	9	7.7	2.0	Low Cost to Run	⊙	○		○			○									3	3	4	4	5
6	9	7.7	2.0	Energy Efficient	⊙	▲	⊙	○			⊙	⊙	⊙							4	3	3	3	3
7	3	13.5	3.5	Life Time	▲						○			○						2	3	3	2	2
8	9	13.5	3.5	Low Initial Investment	○	▲	○				⊙	▲	▲							2	1	4	4	4
9																								
10																								
				Target or Limit Value		100,000-250,000 ppm						2-6 hours												
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	7	10	9	8	3	9	10	6	3	9										
				Max Relationship Value in Column	9	9	9	9	1	9	9	9	9	9										
				Weight / Importance	388.5	494.2	386.5	496.2	30.8	276.9	476.9	240.4	175.0	317.3										
				Relative Weight	11.8	15.1	11.8	15.1	0.9	8.4	14.5	7.3	5.3	9.7										

Powered by QFD Online (http://www.QFDOnline.com)

FIGURE 51: QFD

Design For X:

A - Design For Safety

When dealing with such high concentrations of CO_2, it is an absolute necessity that safety is prioritized. The test chamber must be completely air tight to prevent any leakage of CO_2 that might be harmful to those working around or with it. To prevent any leakage, a rubber gasket is used on the door opening to create an air-tight seal when the latches are hooked and the plexiglass door is pressed against it. All holes drilled into the box for the attaching of the latches and door were sealed with rubber gasket paired with nuts and bolts. Silicone was also used to ensure that there were no leaks through these holes, as well as the inlet and outlet holes for the volume flow of CO_2. With the box completely sealed as such, the pressure relief system ensures that the air will have somewhere to flow instead simply building up pressure. A manual check valve with a graduated nozzle was used for this pressure relief system. Whenever CO_2 is being implemented into the box, the nozzle should be help open to ensure that there is no build up of pressure. The graduated nozzle on the check valve allows tubing a many sizes to be attached, and then run outside or away from those working around the box. As high levels of CO_2 are toxic to humans, this is a necessary feature to keep all those using or around it safe.

B - Design For Ergonomics

The test box design implements features that provide easy use and setup for the user. The box was built to be a ready to test system. The door for the box was measured and screwed into place so that the user only needs to attach latches at the sides, top and bottom of the door. The latches are used to ensure that there is no leakage. Air leakage was tested and redesigned at the door frame; so when plants are ready to be tested, the tray of plants can easily be placed in the box without any other considerations when testing begins. The RAIN tubing is set at an optimal placement for homogenous air flow, the tubing is also attached to a T connector which connects to ¼" tubing that will connect to the CO_2 gas tank. All the user needs to do it attach the tubing to the gas tank and turn the valve to release the gas into the test box. To optimize homogeneous flow, a battery powered fan is set at an updraft formation and the fan has settings for different time lengths and speeds. The battery is rechargeable, so before every test, simply charging and attaching the fan back to its set position (which is indicated by a velcro attachment), will ensure successful homogenous air flow for any desired time. The pressure relief system is also a very easy tool to use as testing is occuring. When CO_2 gas is flowing in the test box, the user simply needs to press on the manual check valve which will release gas and pressure in the test box. This needs to be held until a desired concentration is reached which is at the discretion of the user. Testing showed that max concentration can be reached in 20 minutes at 10 SCFH.

C - Design For Reliability

The test box was tested multiple times to reach specific concentrations for specific time lengths. All parameters for the test box were preliminary reached, tested, redesigned, and tested again to ensure successful operation. Materials used were important factors to reach these parameters. Plexiglas was used so that when testing for the mitigation of pests, the user can easily look inside the box and see if successful mitigation has occurred. The dimensions of the test box are important as to fit a tray of plants in the box and also to make sure the there is room for the tallest leaves. The height of the box was a necessary factor so that there would be no damage to the leaves from the fan power. The door design was important so that the user does not need to attach and detach one of the Plexiglas frames completely. The design also ensures that there will be no leakage every single time testing occurs which can become a safety concern.

Project Specific Details & Analysis:

The project focuses on work directly related to CO_2 fumigation systems and pest mitigation within the JBE facility. Therefore, the project must follow all guidelines set forth by JBE Industries. JBE Industries must follow rules and regulations set by the United States Government, Rhode Island State Government, and Local Government. CO_2 fumigation is classified as high concentrations of CO_2 gas ranging from 100,000-500,000 ppm. JBE has been granted special permission and is authorized to use high levels of CO_2 gas within areas of their facility.

A CO_2 fumigation system is already installed in the flower room at JBE and a floor plan of the room was reviewed to understand the functionality of the room during fumigation. The fumigation process must follow a strict set of rules or else the process may terminate the plants, and all safety parameters must be met before fumigation can occur again. When testing plants, the design must comply with all safety rules instituted by JBE and the government. The project has little room for error because any gas leakage/neglect to the test box can be a potential hazard to any workers nearby.

It is the goal of the project to implement a test box for fumigation that has minimal to no gas leakage. Testing for pest mitigation requires the user to be able to observe the test box closely to ensure all pests have been successfully fumigated. If gas leakage occurs, the user can suffer from headaches, shortness of breath, dizziness and possible death. In order to safely and accurately monitor the CO_2 levels inside the box, a computer program called GasLab will be used. Sensors in the test box will be connected to GasLab via a USB connection. As CO_2 gas is being pumped into the test box, the CO_2 sensors will be able to read the concentrations every second for the duration of the test. Also handheld CO_2 sensors, supplied by JBE Industries will be used to determine if there is any gas leakage during testing.

Data collection was gathered using the GasLab program as well. Being able to determine CO_2 concentrations is essential for the success of the test box. During testing, as CO_2 gas is being pumped into the test box, the sensors can read concentrations every second for the duration of the test whether it be for 2 hours or 6 hours. JBE Industries need to know these concentrations to determine when Arthropod pests are mitigated and if there are any biological damages to the plants as testing occurs.

For JBE Industries if testing proves to be successful in that pests are mitigated and there are no biological damage to the plants, then they will invest in a $40,000 CO_2 fumigation system in their flower room as their new system to mitigate pests. The project given to the team had a total budget of $5,000 and the project’s purpose is to determine if CO_2 fumigation is a reliable and safe method for both the product and the consumer.

Detailed Product Design:

The team was tasked with the goal of reaching and sustaining high levels of CO_2 inside an enclosed homogenous environment in order to test the possible application of fumigation in order to mitigate pests. In order to achieve the goal set forth, a conceptual prototype with multiple features was designed. The enclosed volume was achieved using a plexiglass structure to create an airtight environment that can be modified for the needs of the team. A basic 3D autocad design is shown below:

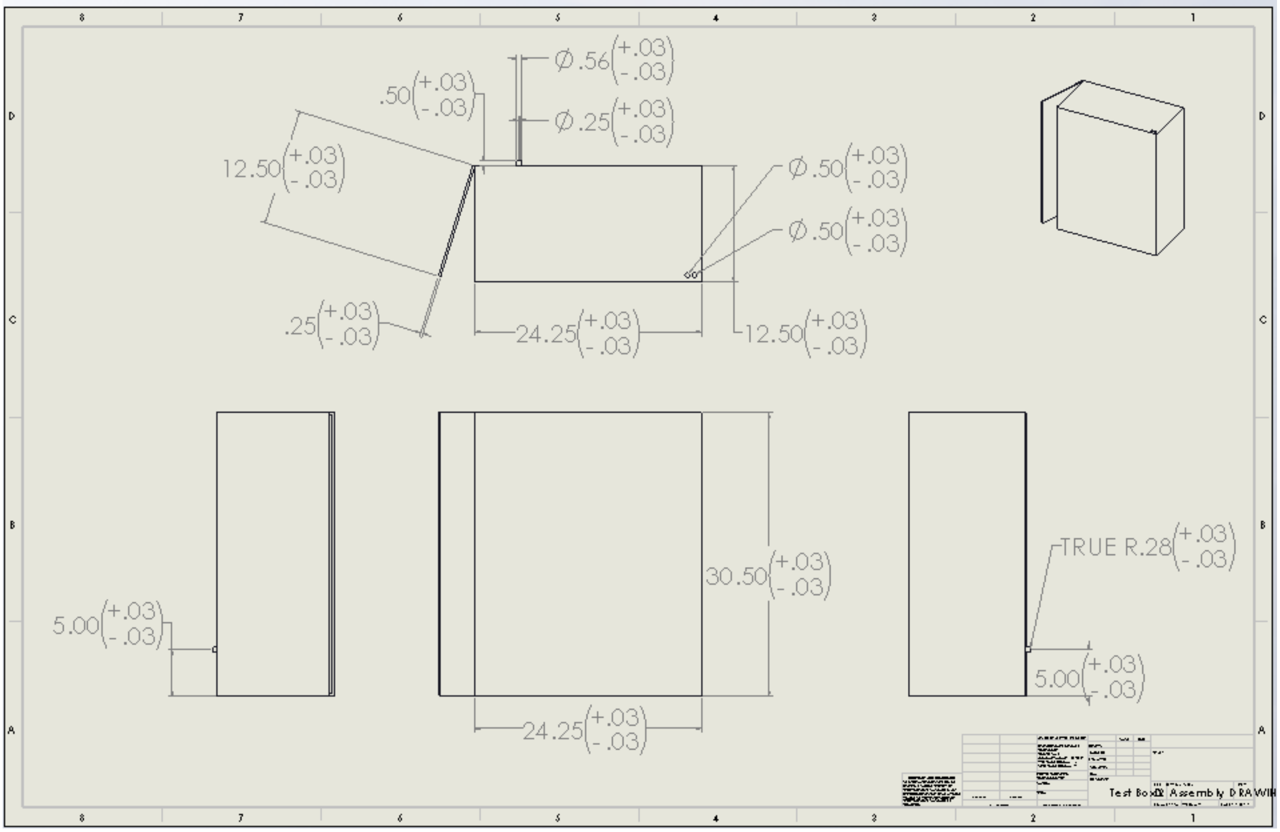


FIGURE 52: SOLIDWORKS DRAWING OF THE TEST BOX WITH TOLERANCE

TABLE 10: TEST BOX COMPONENT DIMENSIONS AND QUANTITY

Quantity	Component	Dimensions
2	Wall Plate (sides)	Width: 30.5” Length: 12.5” Thickness: 0.25”
2	Wall Plate (sides)	Width: 30” Length: 24” Thickness: 0.25”
2	Wall Plate (top and bottom)	Width: 12.5” Length: 24” Thickness: 0.25”
1	Rubber Gasket	Thickness: 0.25”
2	Acrylic Hinges	1.5” x 1.5” x 0.2”
4	Latch	Industrial grade

TABLE 11: GAS DELIVERY SYSTEM

Quantity	Component	Description/Specifications
1	CO_2 Tank	20lb tank ; to raise CO_2 levels
1	Rain Tubing (25 ft)	For dispersal of air within test box.
1	Tubing (10 ft)	For air flowing out of regulator and towards the test box. (0.25” diameter)
1	Gas Regulator	Highly Adjustable ; Easy shut-off
1	Manual Pressure Relief Check Valve	¼” diameter ; Graduated Nozzle
1	Pressure Gauge	Reads 0 - 5 psi

TABLE 12: CO_2 DISPLAY AND GAS DETECTION SYSTEM

Quantity	Component	Details
1	COZIR-WR CO_2 Sensor (GC-0016)	Measure Range: 0-100% CO_2 Dimensions: 40 x 25 x 19 mm; Power Input: 3.2-3.4V (3.3V recommended) Peak Current: 33 mA
1	MinIR Smart LED Sensor w/ MX board	Measure Range: 0-100% CO_2 Dimensions: 40 x 25 x 12.5 mm; Power Input: 3.25-5.5V (3.3V recommended) Peak Current: 33 mA MX board: Temperature, Humidity, Pressure Measurements
2	USB DAS Cable (aka. Development kit by CO2meter.com)	Description: 10 pin female connector to USB male connector Dimensions: 60 inches
1	GasLab 2.1	Software

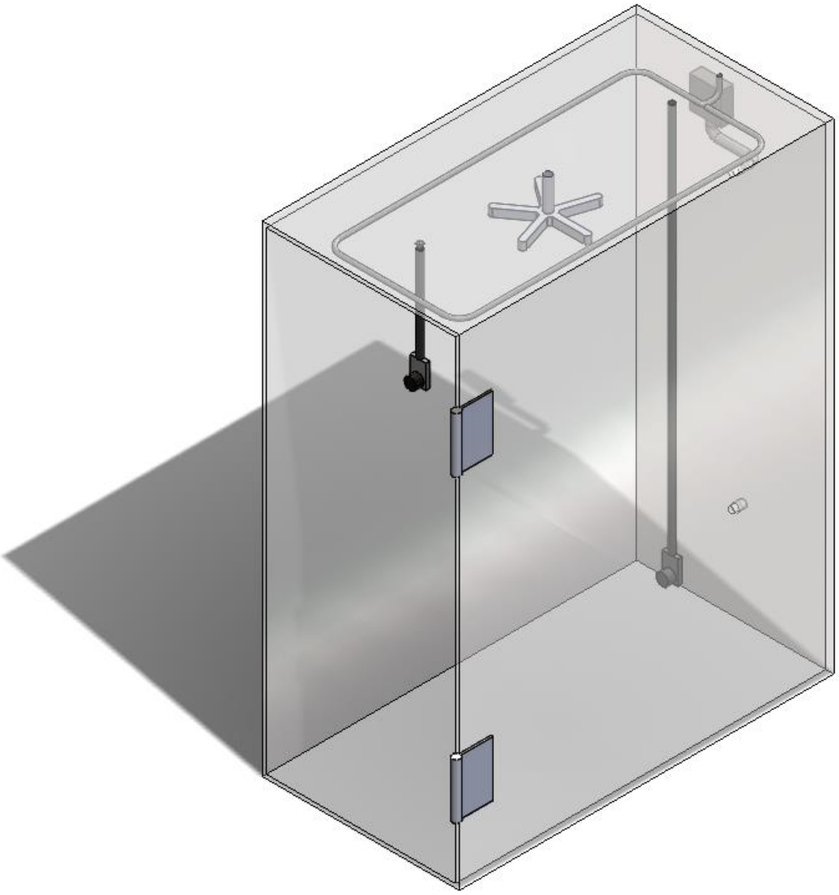


FIGURE 53: SOLIDWORKS DRAWING OF TEST BOX

Engineering Analysis:

Pressure Analysis:

When considering the amount of air needed to be added within this test box, a high resulting pressure can be easily predicted. To find the resulting pressure of the box after the desired level of CO_2 ppm is reached, the amount of CO_2 added must first be calculated. The dissipation of CO_2 due to photosynthesis of the plants is so small that it can be considered negligible (30 ppm per hour, per plant), meaning that the box may remain sealed and retain a near constant CO_2 level. Assuming that the test box will start at atmospheric pressure and room temperature (70°F), the Ideal Gas Equation could be used to determine the number of moles of air within the box.

$$PV = nRT$$

Using Avogadro's number as well as a ratio, the moles/molecules of CO_2 within the untouched test box can be found. More importantly, a ratio can be used to find the amount of CO_2 needed to be implemented to reach any sort of ppm concentration. In this ratio results may be obtained for any chosen CO_2 ppm concentration.

$$\frac{(Desired\ ppm)}{1{,}000{,}000} = \frac{(CO_2 within\ box)\ +(CO_2\ added)}{(Total\ air\ within\ box)\ +\ (CO_2\ added)}$$

Any amount of CO_2 can be converted to pounds using the molecules molar mass. The total resulting poundage of CO_2 added is essential to know so that is may be controlled by the regulator while coming out of a 20 pound tank. Since this calculation was derived for a box with no external leakage or release, the resulting pressure is critical to find.

Adding the total air within the box at the start to the amount of CO_2 added, the new total moles of the gaseous mixture can be found. Using the Ideal Gas Equation once more, a new resulting pressure can be found for the inside of the box. In order to make sure that this higher pressure does not crack the test box and leak, a pressure relief valve was be implemented in the design. This sort of one way pressure relief pipe is called a check valve. Using a Manual check valve, the box can be opened to prevent an increase of pressure and also be closed to a complete seal seamlessly. In this project, our aim is to keep plants at the ideal pressure of 1atm, and using this sort of release valve we were able to very easily. This eliminated the possibility of breaking or shattering the box due to abnormally high pressures. It should also be noted that the release valve should be held open for any air implementation, whether it be CO_2 to raise ppm or just outside air to lower the ppm of CO_2. For structural, functionality, and safety reasons, a pressure relief system must be included in this project design.

Implementation Analysis:

All of the CO_2 added to the text box must come from a 20lb tank and be controlled through a regulator. The same goes for regularly composed outside air, as it must be controlled through the use of a regulator too. Regulators are rated in ft^3/hr, not by the poundage of air to be input. To find the correct manner in which to operate the regulator, one must first take the amount of CO_2 inserted into the box and convert it to ft^3.

$$x\left(\frac{ft^3}{s}\right) \times Time(seconds) \ = \ (CO_2 \ inserted)$$

After selecting a value of time, solving for the cubic feet of CO_2 implemented per second with the equation above becomes quite easy. Converting this value to cubic feet of CO_2 implemented per hour gives the direct information needed to properly operate the regulator, including the time as well as air flow rate.

Sensors and Display System Analysis:

Due to the use of such high concentrations of CO_2 within a closed system, safety precautions are needed to ensure the safety of all those involved in the project. One measure taken was the selective search for the most accurate and highest measurement-range carbon dioxide sensor. From calculations obtained by the team, within such a small space, only a small amount of CO_2 is needed to increase the level of CO_2 from “safe to humans” to “deadly”. With this same reason, the levels within the test box changes rapidly with the insertion of only a small amount of CO_2. This raises a concern relating to the health of the plants. Currently, it is still unknown as to whether or not, what level or if any level of CO_2 concentration will possibly harm or cause leaf foliage. For these reasons, the highest measurement-range CO_2 sensors are needed (0-100%). The COZIR Wide-Range 100% CO_2 sensor and the MinIR 100% Smart LED Sensor were specifically selected for the task. In addition to the CO_2 measurements, the MinIR sensor is also capable of measuring temperature, relative humidity and barometric pressure, which are other parameters the team had to consider in this project.

For the operation of any gas detection sensor, it is important to note that all sensors must first be “burned” in (i.e. the sensor must be left on for at least 24 hours) then calibrated before use. CO_2 calibration can be done by either using specifically made gas tanks or by turning on and leaving the sensor outdoors in fresh air for at least 10 minutes. Outdoor air has a CO_2 level of approximately 400 ppm. Depending on the sensor, some simple calculations may have to be inputted into the software used to obtain the analog readings. For example, after calibration if outdoor air reads 600 ppm, approximately 200 ppm will have to be subtracted in the software to equate to and display 400 ppm. When using the GasLab software, in the calibration tab, 600 ppm can simply be inputted to calibrate the sensor. For further calibration details, the GasLab software manual can be referenced. All sensors purchased are calibrated prior to shipping. To double check that calibration was done, the sensors can be setup outdoors to compare to outdoor air.

To detect the level of CO_2, carbon dioxide sensors capable of measuring from 0-100% are to be used. The sensors will be connected to a computer via a USB cable where the software GasLab 2.1 is used to obtain the readings. Once setup, the desired reading per time span to obtain the values can be adjusted and set to obtain live data. Gaslab will display the exact value of the parameter measuring, the minimum value, the maximum value and the average value. A graphical representation of the live data is also provided. In the case of the MinIR sensor, along with CO_2 detection, temperature, relative humidity, and barometric pressure can also be measured and displayed.

Build/ Manufacturing:

A - Proof of Concept

<u>SolidWorks Design</u>

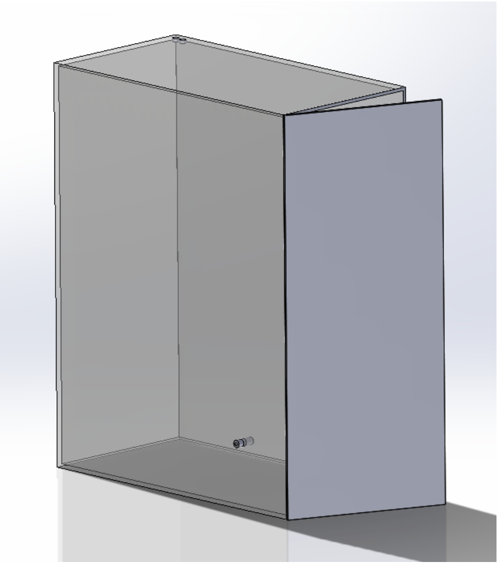


FIGURE 54: POC OF TEST BOX 1

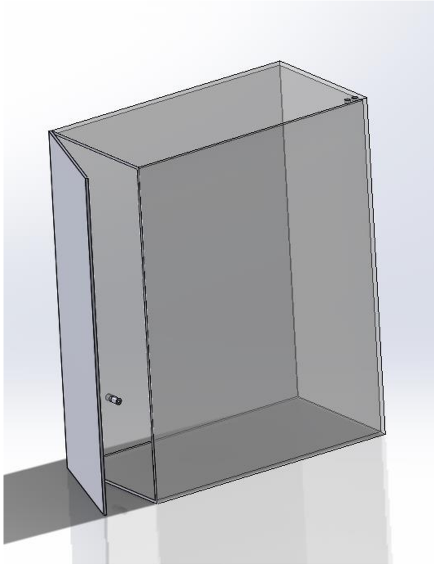


FIGURE 55: POC OF TEST BOX 2

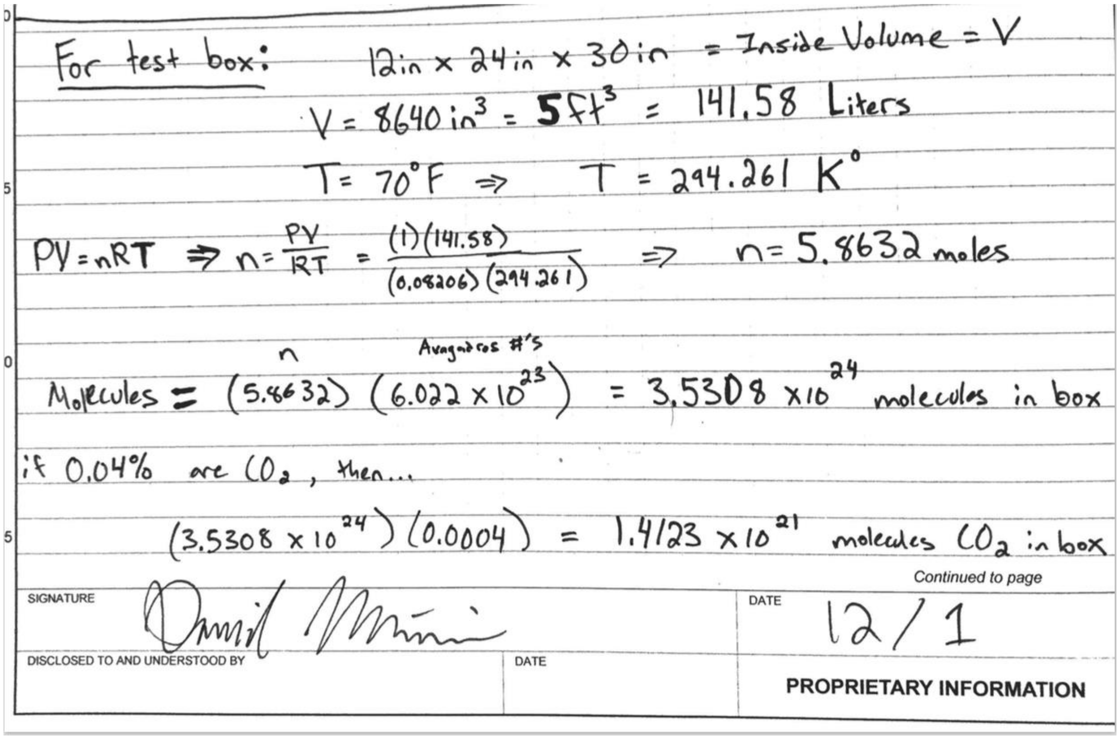
Represented by the 3D autocad model depicted above, our test box will have inside dimensions resulting in a height of 30”, a length of 24”, and width of 12”. The material used to construct the physical box with be ¼” plexiglass. The inside of the box will easily be able to hold a tray (or flat) of plants while leaving plenty of extra room inside to include any aspects we need for our internal systems. Two inlet holes should be drilled into the top of the box, as depicted, so that there my be tubes installed for the implementation of CO_2 and outside air. Another hole should be drilled near the bottom of one of the sides, and it should act as the position of the pressure relief valve. The extra space inside the box may be used to hold a dehumidifying unit. At JBE, the dehumidifying units are suspended from the ceiling so recreating this general layout may prove beneficial to the project. Solidworks has accurately modeled this layout, and it will be used throughout the second semester to finalize any changes made to the project design.

CFD/Fan Placement/Homogeneity

The theory and design feature behind achieving a homogenous environment inside the test box is having an inlet and outlet on opposing sides of the test box. This will allow CO_2 to be pumped through the inlet and flow in a near homogeneous manner with the center of flow being closest to full homogeneity. The testing plants will be placed in the center of the box, planned in order to deliver consistent homogenous airflow to the plants in order for the fumigation process to be successful. The corners of the test box will be most problematic in achieving homogeneity, the team planned to install fans in the corners adding additional airflow and hopefully alleviating any high/low concentrations of CO_2 inside the box. The tubing that will be used to transport the CO_2 gas throughout the test box will be RAIN tubing. RAIN tubing has multiple inlets in the tubing so the gas can enter the test box at different areas. This will increase homogeneity because gas has entered throughout all parts of the test box. Pressure theory suggests that gas will exit towards the path of least resistance. According to this, it would be beneficial to change the diameters of the inlets in the tubing so that gas will travel to locations furthest away from the source of the CO_2 being entered in the test box.

Pressure Relief

By including a 0 psi check valve in our design, it is certain that the box will not crack or explode due to pressure build up. This valve may even include the feature of being adjustable so that the ability to seal the box despite pressure increase is an option. Calculations supporting the determined rates and quantities relating to air implementation and pressure relief can be found following this excerpt. Maintaining atmospheric pressure inside the box was a valued requirement of this project, and through these various calculations and determinations of what products to use, pressure relief can be so well controlled that it might even be denounced as a more minor concern for the time being.



For test box: 12in × 24in × 30in = Inside Volume = V

$V = 8640\ in^3 = 5\ ft^3 = 141.58$ Liters

$T = 70°F \Rightarrow T = 294.261\ K°$

$PV = nRT \Rightarrow n = \frac{PV}{RT} = \frac{(1)(141.58)}{(0.08206)(294.261)} \Rightarrow n = 5.8632$ moles

Molecules $= \overset{n}{(5.8632)}\ \overset{\text{Avagadros \#'s}}{(6.022 \times 10^{23})} = 3.5308 \times 10^{24}$ molecules in box

if 0.04% are CO_2, then...

$(3.5308 \times 10^{24})(0.0004) = 1.4123 \times 10^{21}$ molecules CO_2 in box

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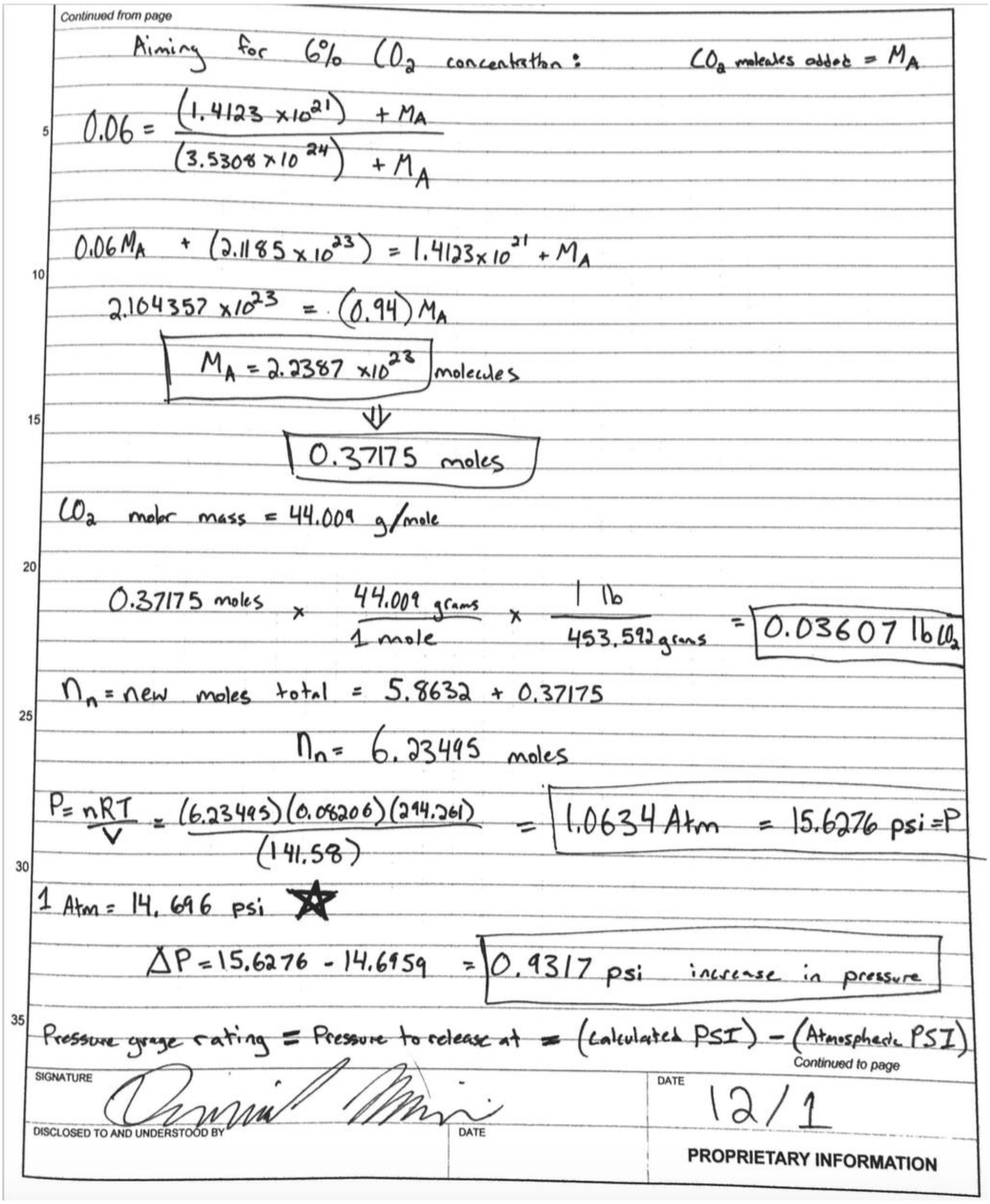
FIGURE 56: CO_2 CONCENTRATION CALCULATIONS



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Aiming for 6% CO_2 concentration: CO_2 molecules added = M_A

$$0.06 = \frac{(1.4123 \times 10^{21}) + M_A}{(3.5308 \times 10^{24}) + M_A}$$

$$0.06M_A + (2.1185 \times 10^{23}) = 1.4123 \times 10^{21} + M_A$$

$$2.104357 \times 10^{23} = (0.94) M_A$$

$$\boxed{M_A = 2.2387 \times 10^{23}} \text{ molecules}$$

$$\Downarrow$$

$$\boxed{0.37175 \text{ moles}}$$

CO_2 molar mass = 44.009 g/mole

$$0.37175 \text{ moles} \times \frac{44.009 \text{ grams}}{1 \text{ mole}} \times \frac{1 \text{ lb}}{453.592 \text{ grams}} = \boxed{0.03607 \text{ lb } CO_2}$$

n_n = new moles total = 5.8632 + 0.37175

n_n = 6.23495 moles

$$P = \frac{nRT}{V} = \frac{(6.23495)(0.08206)(294.261)}{(141.58)} = \boxed{1.0634 \text{ Atm} = 15.6276 \text{ psi} = P}$$

1 Atm = 14.696 psi ★

$$\Delta P = 15.6276 - 14.6959 = \boxed{0.9317 \text{ psi increase in pressure}}$$

Pressure gauge rating = Pressure to release at = (calculated PSI) − (Atmospheric PSI)

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FIGURE 57: PRESSURE CALCULATIONS

B - Building:

The engineering team built the fumigation chamber with some main goals in mind. First and foremost, to maintain an airtight chamber so possible leakage of CO_2 would not occur which could be dangerous to any testing personnel. Plexiglass was chosen for the walls of the chamber with an acrylic bonding agent used to fuse the walls together to ensure the airtight seal, additionally silicon was used around all seams of the box and seams of the holes that were drilled into the box. The chamber also needed to complete the tasks JBE put forth which was to properly regulate CO_2 levels for a set duration, in order to do this the chamber needed to be as homogenous as possible. The battery powered fan in the updraft position was the component that allowed a homogenous environment inside the box. The walls of the chamber were fused together in the first steps of this project, then the drilling of holes for bolts/nuts, inlet and outlet air supply, pressure gauge and CO_2 sensors was completed prior to implementing the components. A gasket was cut and configured around the opening of the box where a door would latch against the gasket to ensure an airtight seal on the door of the chamber. After holes were drilled the team secured the door with hinges, latches, nuts, bolts and rubber washers for an airtight seal. The CO_2 sensors were designed to be adjustable by using a plastic tube and rubber gasket which allowed the tubes to go up and down while maintaining a seal, the wire themselves were siliconed inside the tube to ensure no leakage through the tubes. Figure ## shows how the sensors were configured. The battery powered fan was secured to the ceiling using a strip of velcro to allow for easy removal of the fan to allow recharging of the battery. The inlet CO_2 tubing was connected to rain tubing on the inside of the box using a bulkhead to feed the inlet tubing into the box and maintaining an airtight seal. The outlet tubing was connected to a check valve which allowed controllable release of the air/gas mixture inside the chamber, the tubing was secured using epoxy. The pressure gauge was adhered to the box using epoxy and two strips of velcro. Finally an additional sheet of plexiglass was adhered to the bottom of the box to increase the structural strength, leg stands were than added to the bottom of the box, JB weld was used to adhere the plexiglass and leg stands. Figure ## shows the completed fumigation chamber. This will be the only fumigation chamber created to test the hypothesis that CO_2 will fumigate the pests while not harming the marijuana plants. If the hypothesis proves correct than this fumigation concept will be scaled up to allow fumigation of flower rooms in medicinal marijuana facilities.

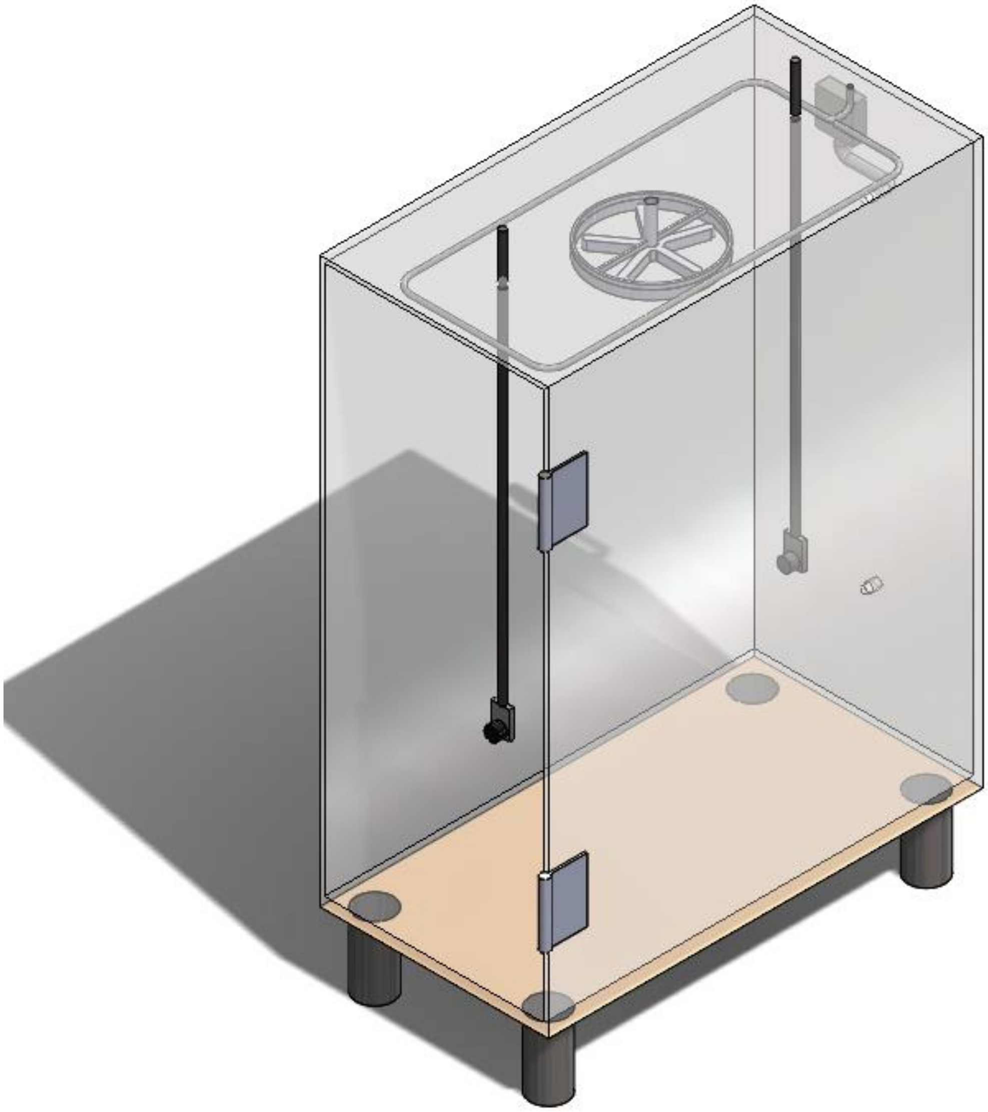


FIGURE 58: SOLIDWORKS OF REDESIGNED TEST BOX

Testing:

To ensure the fumigation chamber can reach and maintain CO_2 levels, CO_2 testing was performed multiple times throughout the semester. An initial problem faced by the engineering team was leakage from the box, specifically around the door/gasket. Therefore smoke tests were performed to check for any possible leakage coming out of the box. Testing matrices for both CO_2 and smoke tests can be found below.

TABLE 13: TESTING MATRICES

Test Name	**What to Test?**	**Test Parameters**	**Results**	**Planned Resolution**
Smoke Test 1	Door Gasket	Must be completely sealed	Small leaks found in top and bottom of door	Add silicone to top and bottom of the door to increase seal
Smoke Test 2	Pressure Release Hole seal	Must be completely sealed	NO leakage	N/A
Smoke Test 2	Pressure gauge hole seal	Must be completely sealed	NO leakage	N/A
Smoke Test 2	CO_2 Inlet Hole seal	Must be completely sealed	Small leakage	Add silicone to the bulkhead fitting to seal
Smoke Test 2	Door Gasket	Must be completely sealed	Small leaks on top and bottom of the door at previous locations	Add latches to the top and bottom of door to increase seal
CO_2 Test 1	Reaching 500,000 ppm of CO_2	Must stay sealed well enough to be able to reach 500,000 ppm of CO_2	Reached desired level in 15 mins	N/A
CO_2 Test 1	Maintaining CO_2 levels for 30 mins	Must maintain at 500,000 ppm (+/- 10,000 ppm) of CO_2 for 30 mins	Maintained desired level within tolerance	N/A

Test Name	**What to Test?**	**Test Parameters**	**Results**	**Planned Resolution**
CO_2 Test 2	Reaching 500,000 ppm of CO_2 and possible leakage	-Must reach 500,000 ppm -CO_2 Flow Rate: 10 scfh -Maintain pressure: 1 atm	Reached desired level after 20 min	N/A
CO_2 Test 2	Maintaining Co_2 level for 1-2 hours	-Maintain at 500,000 ppm (+/- 10,000 ppm)	Maintained within tolerance (+/- 5,000 ppm)	N/A
CO_2 Test 2	Homogeneity of Concentration within box	-Maintain at 500,000 ppm (+/- 10,000 ppm) -Measured concentration at different heights	Maintained within tolerance (+/- 5,000 ppm)	N/A
Smoke Test 3	Complete seal of box	-Must be completely sealed and not let out any smoke	Box was completely sealed	N/A

From the tests that the team conducted, it was concluded that the test box successfully reached desired parameters. Although the team did not test to maintain a desired concentration for 6 hours, based off of the results, it can be inferred that the box can hold desired concentrations for a long period of time.

Redesign:

One major redesign made prior to Smoke Testing and CO_2 implementation testing involved the Sensor Display System. Originally, to detect the level of CO2, the carbon dioxide sensors were to be connected to an arduino board, a programmable microcontroller, which then connected to an LCD to display concentration values. Using the arduino board in conjunction with the Arduino software, inputs can be read from one device (i.e. the sensors) and displayed as an output (i.e. the LCD). In the case of the MinIR sensor, along with CO2 detection, temperature, relative humidity, and barometric pressure were also be measured and displayed. The system involved extensive research and calibration coding however would have provided a more conventional method of displaying CO_2 concentration, temperature, humidity, and pressure values since a computer would not be needed. The system was nearly complete, however the major mishap the team encountered involved the arduino calibration coding for the Minir sensor to measure temperature, pressure, and humidity. Due to lack of time, an executive decision was made to move on to the second alternative, which was using a computer software called GasLab to obtain the values for testing.

From initial testing, there were a few issues that had to be addressed. Smoke Test 1 and 2 both showed that there were minor leakages within the test box. In Smoke Test 1, results concluded that there was leakage at the center of the gasket at the top and bottom of the door. As a resolution, silicone was added to the top and a strand of rubber tape was added along the bottom. From Smoke Test 2, there was first a minor leak at the CO_2 inlet hole located on the back wall at the top of the box. To fix this issue, an additional layer of silicone was added around the hole for a more complete seal. The second leakage found was the same leakage at the center of the top and bottom of the door. To remedy the leak, this time two additional latches were added to the top and bottom of the door. The two latches provide additional compressive forces to the top and bottom of the door so that there is a better closure against the gasket.

An additional redesign that was added to the test box were adjustable sensor heights. This redesign was added to provided the ability of measuring CO_2 concentration levels at different heights within the test box. The USB wires that connects the sensors to the computer are siliconed into a quarter inch PVC pipe. This pipe is lubricated and runs up and downward through a rubber washer that is attached to the ceiling wall. Figure # and # provide a visual representation of this system.

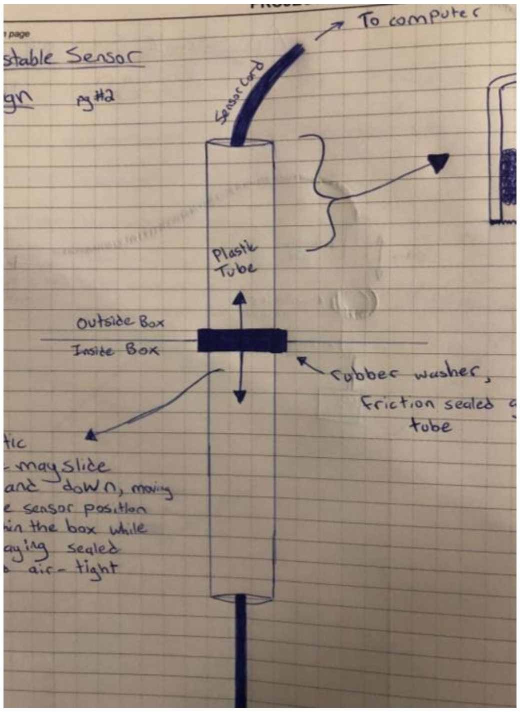


FIGURE 59: DRAWING OF CO_2 ADJUSTABLE SENSOR SYSTEM

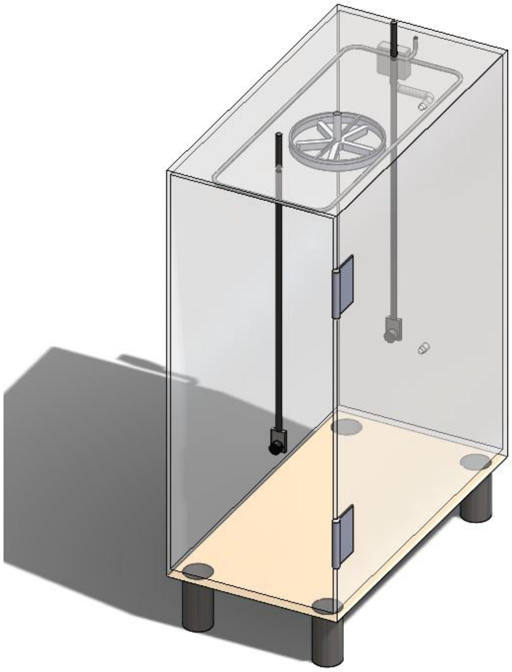


FIGURE 60: MODEL OF REDESIGNED TEST BOX

FIGURE 61: PICTURE OF REDESIGNED TEST BOX

Project Plan:

In order to have a successful engineering project, a project plan must be implemented to keep all team members on task with due dates on quality of assignments. Microsoft Project is a useful tool that the engineering team utilized to stay on task. Important dates (including presentation and assignments), meeting days/times were used in the software. The Gantt Chart was created in the software and contains all important tasks, dates and deadlines throughout the fall semester. The Gantt Chart can be viewed in the appendix. The team had weekly meetings with JBE Industries. Those who attended the meetings in the first semester of this project were the entire engineering team, Diana Coates, Jordan Salem (Plant Science student), and sometimes Dr. W Michael Sullivan. All meetings during the second semester were attended by the same group of people with the exception of Jordan Salem.

In the beginning of the semester, the project mainly consisted of research to help the team understand the problem presented by JBE and any current solutions. The research consisted mainly of the patent searches and literature searches. Each team member was required to conduct their own patent and literature search and come together to share and discuss their individual findings. Once this research was conducted and the team had a strong understanding of the project definition, the concept generation was the next big assignment required by all members of the engineering team. Each team member was required to develop 30 concept designs which related to problem that JBE presented to the team. The team met and discussed each concept and analyzed value of each one in a QFD analysis. Some ideas were scrapped and some ideas were further studied as a potential POC. All deadlines were met on time with 100% completion.

A CDR presentation was next in the project plan. The team presented their findings to the class and provided future plans on how to finalize a concept. Diana Coates from JBE Industries was present and gave good feedback and created a timeline on how to move forward with the initial design. It should be noted that for a short time, the engineering team was tasked by JBE to purchase materials for a “Bug Box” to test CO_2 concentrations specifically on pests and not plants. After a discussion with Dr. Nassersharif, it was established that the engineering team no longer had to work on that aspect of the project and instead focused all efforts on the test box. The final aspect of the project for the fall semester was to develop a final proof of concept that would be pursued the following semester. SolidWorks and OpenFoam software were used in order to demonstrate and develop clear designs that fulfilled design specifications and proved that the design would work. The team received good feedback from the presentation and from Diana Coates. From here, the team stopped working on any design aspects and strictly focused on completing the Preliminary Design Report. As of the date of submission, all deadlines were met on time with 100% completion.

The second semester of this capstone project focussed on the actual construction of the CO_2 fumigation chamber. Dates and deadlines were made in the project plan to keep our team focused and on task as the semester went on. Since there were no other assignments tasked to our capstone class by Professor Nassersharif, our group's focus was entirely on the building and testing of our test box. Some examples of tasks that were put into our project plan for second semester include; Order all necessary materials for design build, Finish design build, Order all necessary parts for redesign, Build-Test review presentation, etc… More examples of what our group included in our project plan for second semester are shown below. The corresponding Gantt chart can be found in the appendix along with all categories of material included in this capstone’s Project Plan.

Goals For The Past/Upcoming Weeks	**74 days**	**Wed 1/23/19**	**Mon 5/6/19**				**100%**
Order Parts and supplies to build test box	7 days	Fri 1/25/19	Mon 2/4/19				100%
Finalize plans with JBE	7 days	Fri 1/25/19	Mon 2/4/19				100%
Build Test Box	11 days	Mon 2/11/19	Mon 2/25/19				100%
Meet as a team to go over build of box again	3 days	Wed 2/13/19	Fri 2/15/19				100%
Finalize sensor placement within box	20 days	Mon 2/11/19	Fri 3/8/19				100%
Build frame of plexiglass test box	3 days	Wed 2/13/19	Fri 2/15/19				100%
Drill all necessary holes into test box	6 days	Fri 3/1/19	Fri 3/8/19				100%
Attatch air-tight gasket to the test box and test for	6 days	Mon 2/18/19	Mon 2/25/19				100%
Re-Order any additional parts required in building the test box	10 days	Mon 2/18/19	Fri 3/1/19				100%

FIGURE 62: EXAMPLE OF MATERIAL WITHIN PROJECT PLAN

Financial Analysis:

Over the course of the semester, the engineering team has researched the materials and equipment that will be needed to successfully build the test box. Materials and equipment costs are laid out in the table below.

Materials Cost:

TABLE 14: PRODUCTS USED IN FINAL BUILD

Product to buy	Quantity	Total Cost
Plexiglas (sheets)	6	$152.90
Rubber Gasket	1	$36.32
Door Hinges	2	$9.98
Latch (4pk)	1	$21.99
Black Shock Latches (4pk)	1	$22.98
Rain Tubing (25 ft)	1	$17.70
⅜” Plastic Tubing (1 ft)	1	$3.95
Fan	1	$26.99
Acrylic Plastic Cement	1	$15.98
Silicone Waterproof Seal	1	$4.48
Plastic Bonder Epoxy	3	$13.44
Pressure Relief Valve	1	$40.00
Pressure Gauge	1	$14.99
½” Plastic Tubing (1 ft)	1	$4.50
½” x ½” Acrylic Hose Connector 90°	2	$7.98
COZIR-WR CO_2 Sensor (GC-0016) with dev kit	1	$159.00
MinIR Smart LED Sensor w/ MX board	1	$179.00

USB DAS cable	1	$49.00
Adjustable Cabinet Legs (4 pk)	1	$13.50
Rubber Cone Washer (4 pack)	1	$6.53
Bee Smokers	1	$19.91
Misc Nuts/Bolts/Metal & Rubber Washers	1	$7.61
¼ “ PVC Pipe (5 ft)	1	$2.00
Total Cost		**$830.73**

TABLE 15: PRODUCTS BOUGHT BUT NOT USED IN FINAL BUILD

Product Bought but Not Used in Final Build	**Quantity**	**Cost ($)**
0-20 psi Check Valve	2	$39.90
Arduino nano v2.3	1	$20.00
20x4 Liquid Crystal Display w/ I2C interface module	1	$12.99
Circuit Board Spacers	1	$7.89
Large Piezo Alarm Buzzer	1	$2.95
Piano Hinge	1	$11.99
9V AC/DC Power Cord	1	$8.99
Total Cost		**$104.71**

Over the course of the academic school year, each team member spent numerous hours working on the project. Members of the team worked on research, calculations, patent searches, literature searches, design, proof of concept, engineering analysis, and SolidWorks modeling. The tables below show a breakdown of where hours were allocated to each aspect of the project.

TABLE 16: TIME SPENT ON THE PROJECT BY IAN HALLAM(FALL)

Task	**Fall Semester Hours**
Research	30
Calculations	2
Patent Searches	3
Literature Searches	2
Design	14
Proof of Concept	10
Engineering Analysis	7
SolidWorks Modeling	4
Total	**72**

TABLE 17: TIME SPENT ON PROJECT BY IAN HALLAM(SPRING)

Task	**Spring Semester Hours**
Research	12
Calculations	2
Design	30
Testing	10
Solidworks Modeling	3
Building	30
Total	**87**

TABLE 18: TOTAL TIME SPENT ON PROJECT BY IAN HALLAM

Task	**Total Hours (Both Semesters)**
Research	42
Calculations	4
Design	44
Testing	10
Solidworks Modeling	7
Building	30
Patent Searches	3
Literature Searches	2
Engineering analysis	7
Proof of Concept	10
Total	**149**

TABLE 19: TIME SPENT ON THE PROJECT BY EMILY YANG(FALL)

Task	**Fall Semester Hours**
Research	41
Calculations	3
Patent Searches	3
Literature Searches	2
Design	8
Proof of Concept	10
Engineering Analysis	11
SolidWorks Modeling	2
Total	**80**

TABLE 20: TIME SPENT ON PROJECT BY EMILY YANG(SPRING)

Task	**Spring Semester Hours**
Research	26
Calculations	2
Design	15
Testing	21
Solidworks Modeling	6
Building	21
Total	93

TABLE 21: TOTAL TIME SPENT ON PROJECT BY EMILY YANG

Task	**Total Hours (Both Semesters)**
Research	67
Calculations	5
Design	23
Testing	21
Solidworks Modeling	8
Building	21
Patent Searches	3
Literature Searches	2
Engineering analysis	11
Proof of Concept	10
Total	171

TABLE 22: TIME SPENT ON THE PROJECT BY DAVID NICOSIA(FALL)

Task	**Fall Semester Hours**
Research	23
Calculations	12
Patent Searches	3
Literature Searches	2
Design	14
Proof of Concept	9
Engineering Analysis	10
SolidWorks Modeling	7
Total	**80**

TABLE 23: TIME SPENT ON PROJECT BY DAVID NICOSIA(SPRING)

Task	**Spring Semester Hours**
Research	12
Calculations	12
Design	15
Testing	23
Solidworks Modeling	10
Building	25
Total	**97**

TABLE 24: TOTAL TIME SPENT ON PROJECT BY DAVID NICOSIA

Task	**Total Hours (Both Semesters)**
Research	35
Calculations	24
Design	29
Testing	23
Solidworks Modeling	17
Building	25
Patent Searches	3
Literature Searches	2
Engineering analysis	10
Proof of Concept	9
Total	177

TABLE 25: TIME SPENT ON THE PROJECT BY CHRIS DUFFY(FALL)

Task	**Fall Semester Hours**
Research	33
Calculations	4
Patent Searches	4
Literature Searches	3
Design	15
Proof of Concept	5
Engineering Analysis	5
SolidWorks Modeling	1
Total	**70**

TABLE 26: TIME SPENT ON PROJECT BY CHRIS DUFFY(SPRING)

Task	**Spring Semester Hours**
Research	24
Calculations	4
Design	25
Testing	22
Solidworks Modeling	1
Building	21
Total	**97**

TABLE 27: TOTAL TIME SPENT ON PROJECT BY CHRIS DUFFY

Task	**Total Hours (Both Semesters)**
Research	57
Calculations	8
Design	40
Testing	22
Solidworks Modeling	2
Building	21
Patent Searches	4
Literature Searches	3
Engineering analysis	5
Proof of Concept	5
Total	**167**

TABLE 28: TEAM LABOR COST

Person	Occupation	# of Hours	Cost per hour	Total Cost ($)
Ian Hallam	**Team/ Undergrad**	**149**	**20**	**2,980.00**
Emily Yang	**Team/ Undergrad**	**171**	**20**	**3420.00**
David Nicosia	**Team/ Undergrad**	**177**	**20**	**3540.00**
Chris Duffy	**Team/ Undergrad**	**167**	**20**	**3340.00**
Total Team Labor Cost				**$13280.00**

TABLE 29: ADDITIONAL LABOR COST

Person	Occupation	# of Hours	Cost per hour	Total Cost ($)
Diana Coats	**Sponsor**	**21**	**60**	**1260.00**
Blake	**Sponsor/Tech**	**1**	**35**	**35.00**
Michael Sullivan	**Sponsor/Partner**	**1**	**60**	**6.00**
Jordan Salem	**Undergrad/ Partner**	**4**	**20**	**80.00**
Anthony Marshall	**Laird PLastics Tech**	**1**	**35**	**35.00**
Elio Manzi	**Grad student**	**4**	**30**	**120.00**
Nassersharif	**Faculty**	**2**	**100**	**200.00**
Total Additional Labor Cost				**$1790.00**

TABLE 30: FACILITIES/EQUIPMENT COST

Equip/Facility	# of Hours	Cost per hour	Total Cost ($)
Schneider Machine Shop	56	40	2240.00
Schneider Electric Computer, Software, printers	7.5	5	37.50

Operation:

To operate the fumigation device the following steps must be followed:

1. Ensure a safe testing environment (well-ventilated room or outside in non-confined area).
2. Attach CO_2 tubing from box to regulator on CO_2 tank, with regulator set to 0 SCFH.
3. Unlatch chamber door, set fan to medium in updraft position, insert flat containing pest infested plants and re-latch door.
4. Attach chamber's check valve to additional tubing to vent outgoing gas/air mixture to a seperate safe environment that will remain clear of people.
5. Plug in CO_2 sensors USB cords to laptop, Open Gas Lab 2.1 software and connect the sensors.
    a. To connect the Cozir Sensor: Port ⇒Select *COM #* (that sensor is connected to); Product ⇒*CM-0121*; Ensure that Series/Model ⇒*Cozir* and *GSS 100%*; Select *Connect*.
    b. To connect the Minir Sensor: Port ⇒Select COM # (that sensor is connected to); Product ⇒*CM-4XXXX*; Ensure that Series/Model ⇒*EC/MX-Series* and *Auto*; Select *Connect.*

   Set Auto-Logging to desired time span and select *Start Logging* when ready.
6. Set regulator to 10 SCFH and allow CO_2 gas to flow in while opening the check valve simultaneously.
7. Observe the graph on Gas Lab which shows CO_2 PPM level inside the chamber.
8. Set regulator to 0 SCFH when desired CO_2 levels are reached, close check valve.
9. Observe Gas Lab graph to ensure CO_2 levels are maintained for desired time period
10. Once fumigation duration is reached, unlatch/open door and allow 3-5 minutes for air to dissipate before testing personnel reaches inside the box to remove the flat.

Maintenance:

To maintain the interior quality of the test box, it is necessary to use windex cleaner to clean the Plexiglas. Also it is necessary to recharge the battery for the fan after every test to ensure that there is constant air flow to keep the test box homogenous. Battery life may drain after continued and prolonged use so JBE Industries may need to purchase extra fans and/or batteries in case the fan does not reach desired speeds or time lengths. Extra ¼” tubing may need to be purchased because after every test, the tubing needs to be cut so it can be detached from the CO_2 tank. When JBE Industries is finished using the test box and if they wish to dispose of the test box, they can simply throw out the box at any garbage disposal or JBE Industries or Dr. Mike Sullivan can keep the box as memorabilia.

Additional Considerations:

The design is meant to conduct preliminary tests in order to test the functionality of CO_2 fumigation. The investment from JBE Industries will give them an assessment if they should incorporate a fumigation system in their flower room at the facility. The cost to operate this system in the flower room will be a bigger investment and it is necessary for JBE Industries to know if fumigation will prove successful in the mitigation of Arthropod pests. Fumigation has the potential to be a major aspect in medicinal plant cultivation because the use of pesticides on plants is a heavily regulated procedure. These regulations are run by federal, state and local governments in Rhode Island. The reason for these regulations is for the safety and health concerns for the consumer because these plants are mainly ingested through combustion, sublimation, and inhalation (smoking). Fumigation has the potential to be a dangerous procedure. At around 1500 PPM of CO_2, humans can start to feel the negative effects of CO_2 concentrations. It is necessary to check all safety parameters while fumigation is taking place. Because of its dangerous practice, it is important that all steps going into fumigation are easily understood by the staff. The test box is an easy to use and ready to start system where the staff needs to turn on the fan, close the door, and connect the tubing to the CO_2 tank. It is necessary to mimic the same steps when operating fumigation in the flower room at the facility. There is no need to be concerned with environmental impact and sustainability.

Conclusions:

JBE tasked the team with designing an environment with an enclosed volume where CO_2 levels can be controlled in order to fumigate their desired plants. The conceptual design of our product satisfies the testing applications JBE has put forth. At the JBE facility, the team witnessed successful testing using a small scale box with the same functionality features that our large scale testing box will include. After observing the testing, flawed design features were identified and taken note in order to not repeat the same mistakes. The main design problems were leakage from the inlets/outlets of the box and difficulty keeping a steady level of CO_2 inside the box. To alleviate leakage from the box silicon seals will be used around any inlets/outlets of the box in order to provide an airtight seal. To maintain a steady CO_2 level, the team is using a computer software called GasLab.

After correcting the flawed design features witnessed during JBE initial testing, the team is confident in completing the fumigation goals JBE has put forth. The design is scalable which will allow JBE to easily implement the process in order to achieve the larger scale fumigation goals at hand. After submitting proof of concept and bill of materials, the team is ready to start the build. The physical building of the box was to be accomplished in the spring semester.

The spring semester incorporated a build, testing, and redesign to satisfy all parameters specified in the design specifications. After initial testing, it was determined that there was a need to seal the door gasket more with a silicone seals and extra latches. The redesign phase focused on confirming a homogenous air flow within the test box. This was completed using a PVC piping that was adjustable using rubber gaskets at the top of the test box. Testing was performed again to determine if there was any leakage and if in fact the concentration of CO_2 was homogenous in the test box. Redesign testing proved to be successful and concluded that the project was complete for live plant testing.

The future of the project now starts with JBE Industries. They will start testing on live plants with bugs and determine appropriate concentrations and time lengths for successful fumigation and mitigation of Arthropod pests. If CO_2 fumigation proves to be successful to mitigate pests, JBE Industries will invest in a larger fumigation system in their flower room as a new method of raising the quality of their product.

References:

1. Bond, E.J. *Manual of Fumigation for Insect Control*. Research Centre Agriculture, 1989, ftp://ftp3.us.freebsd.org/pub/misc/cd3wd/1004/_ag_fumigation_insect_unfao_en_lp_108020_.pdf.

2. Jimenez, Jorge I.; Margolis, Jonathan S.; Baird, John K.; Lego, Sarah F. US Patent 8728442, United States Patent and Trademark Office, 20 May 2014

3. Nielson, Peter V. *Fifty Years of CFD for Room Air Distribution.* Department of Civil Engineering, Aalborg University. https://sakai.uri.edu/access/content/group/8ab02694-143d-45d5-9dac-1bd143999eee/Team%2005/References/Fifty%20years%20of%20CDF%20for%20room%20air%20distribution.pdf

4. Carmen Marza. *Methods for Representing the Tubing of Ventilation/Air-Conditioning Plants*. Anagabielan DEAC, Georgiana CORSIUC. https://sakai.uri.edu/access/content/group/8ab02694-143d-45d5-9dac-1bd143999eee/Team%2005/References/Methods%20for%20Representing%20the%20Tubing%20of%20Ventilation%3AAir-Conditioning%20Plants.pdf

5. Edman, Lenore. "Basics: Picking Resistors for LEDs." Evil Mad Scientist Laboratories. August 29, 2012. Accessed December 17, 2018. https://www.evilmadscientist.com/2012/resistors-for-leds/.

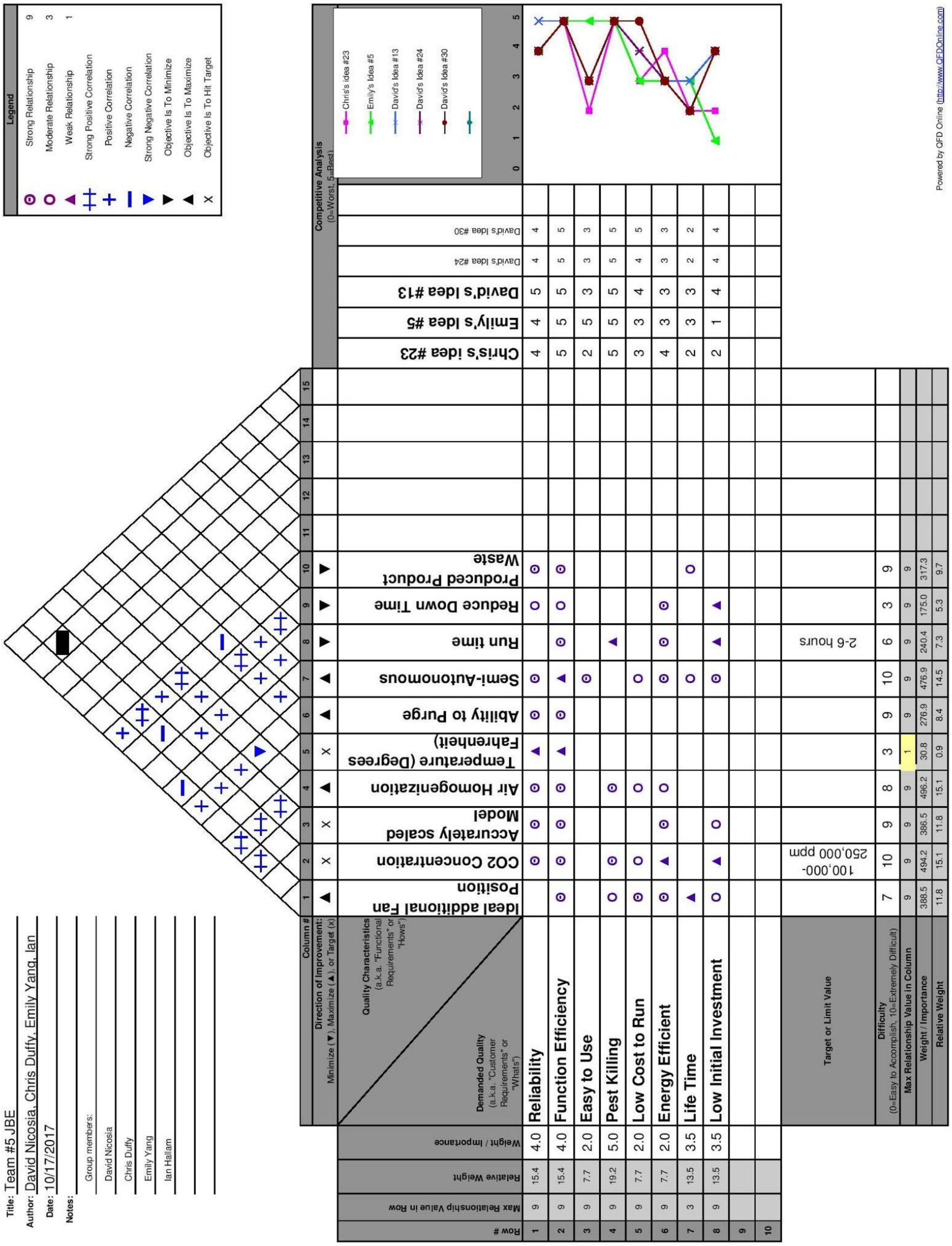
6. "Language Reference." Arduino - Introduction. Accessed December 17, 2018. https://www.arduino.cc/reference/en/.

7. McQuiston, Faye C., Jerald D. Parker, and Jeffrey D. Spitler. *Heating, Ventilating, and Air Conditioning: Analysis and Design*. Hoboken, NJ: John Wiley & Sons, 2005.

8. Svoboda, James A. *Introduction to Electric Circuits*. 2013.

Appendices:

1.) QFD



Title: Team #5 JBE
Author: David Nicosia, Chris Duffy, Emily Yang, Ian
Date: 10/17/2017
Notes:
Group members:
David Nicosia
Chris Duffy
Emily Yang
Ian Hallam

Legend		
⊙	Strong Relationship	9
○	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") \ Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	1 Ideal additional Fan Position	2 CO2 Concentration	3 Accurately scaled Model	4 Air Homogenization	5 Temperature (Degrees Fahrenheit)	6 Ability to Purge	7 Semi-Autonomous	8 Run time	9 Reduce Down Time	10 Produced Product Waste	11	12	13	14	15	Chris's idea #23	Emily's Idea #5	David's Idea #13	David's Idea #24	David's Idea #30
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	x	x	▲	x	▲	▲	▼	▼	▼										
1	9	15.4	4.0	Reliability		⊙	⊙	⊙	▲	⊙	⊙		○	⊙						4	4	5	4	4
2	9	15.4	4.0	Function Efficiency	⊙	⊙	⊙	⊙	▲	⊙	▲	⊙	○	⊙						5	5	5	5	5
3	9	7.7	2.0	Easy to Use							⊙									2	5	3	3	3
4	9	19.2	5.0	Pest Killing	○	⊙		⊙				▲								5	5	5	5	5
5	9	7.7	2.0	Low Cost to Run	⊙	○		○			○									3	3	4	4	5
6	9	7.7	2.0	Energy Efficient	⊙	▲	⊙	○			⊙	⊙	⊙							4	3	3	3	3
7	3	13.5	3.5	Life Time	▲						○			○						2	3	3	2	2
8	9	13.5	3.5	Low Initial Investment	○	▲	○				⊙	▲	▲							2	1	4	4	4
9																								
10																								
				Target or Limit Value		100,000-250,000 ppm						2-6 hours												
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	7	10	9	8	3	9	10	6	3	9										
				Max Relationship Value in Column	9	9	9	9	1	9	9	9	9	9										
				Weight / Importance	388.5	494.2	386.5	496.2	30.8	276.9	476.9	240.4	175.0	317.3										
				Relative Weight	11.8	15.1	11.8	15.1	0.9	8.4	14.5	7.3	5.3	9.7										

Competitive Analysis (0=Worst, 5=Best)

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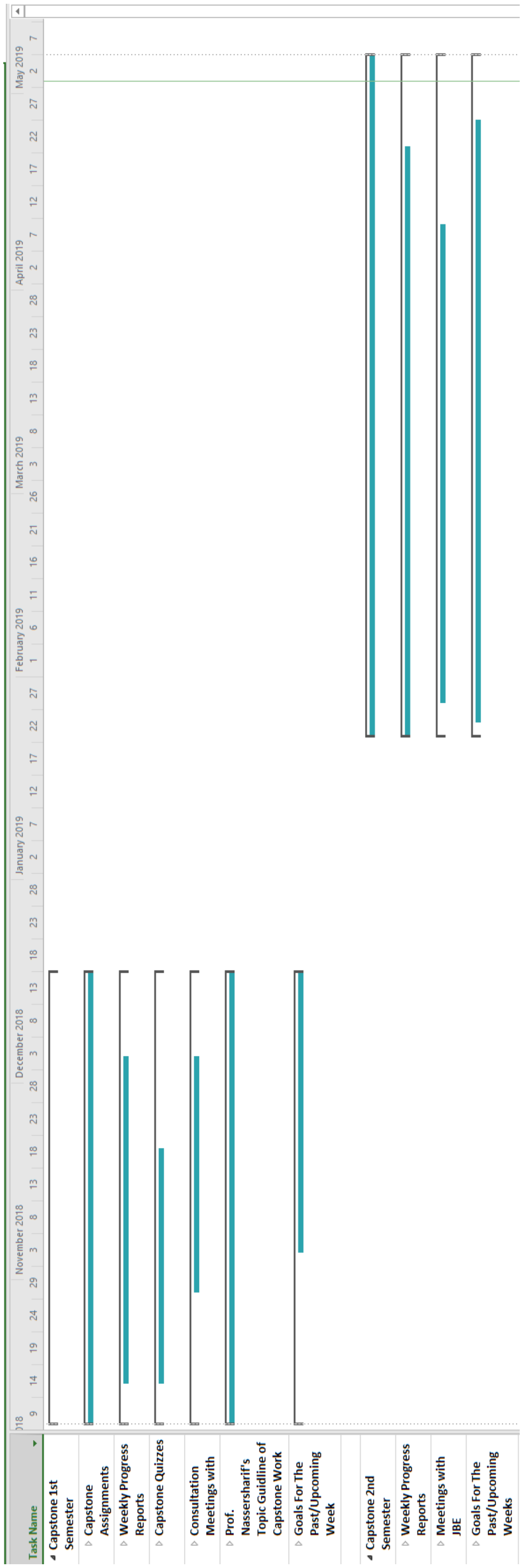
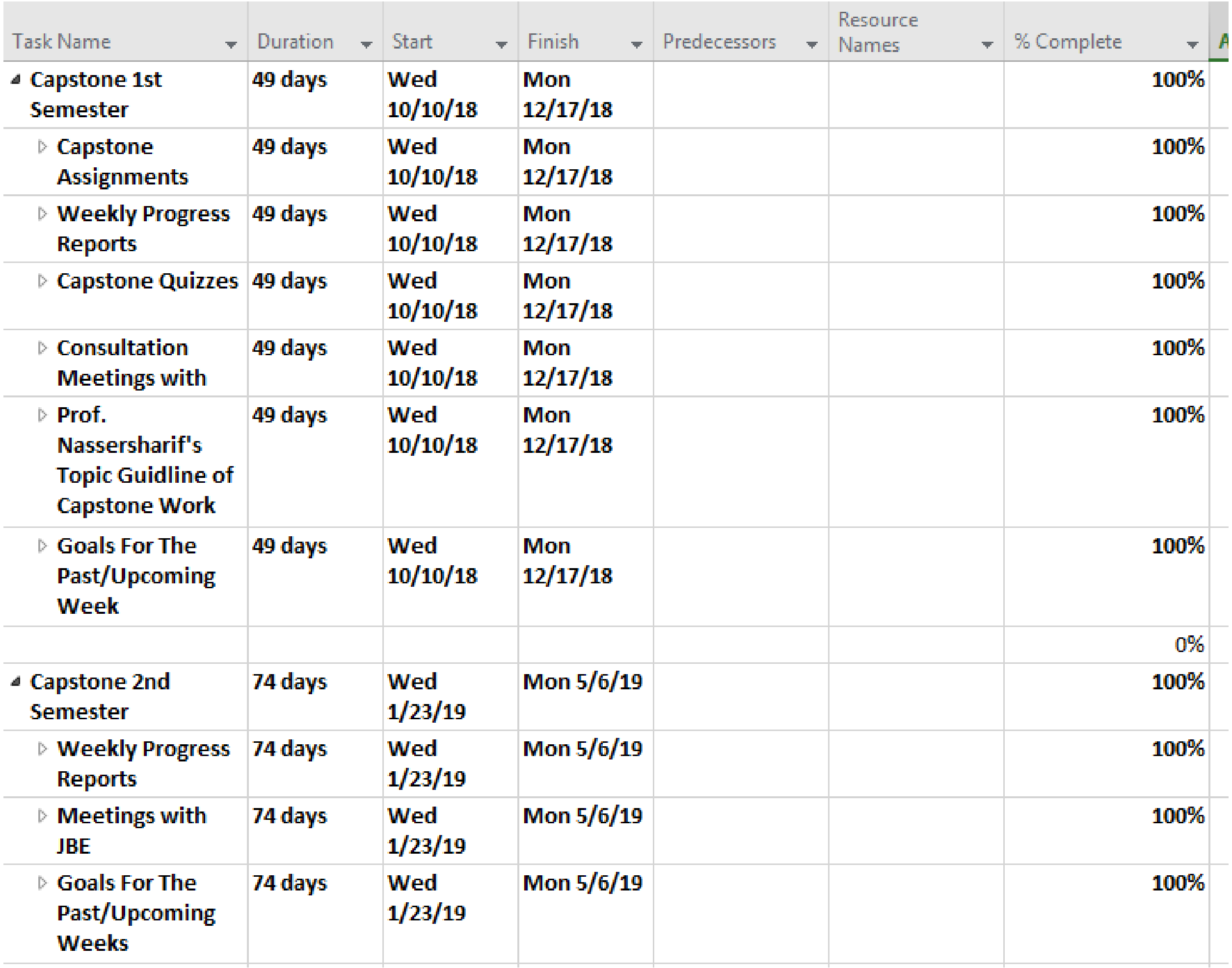
2.) Project Plan



Task Name
Capstone 1st Semester
Capstone Assignments
Weekly Progress Reports
Capstone Quizzes
Consultation Meetings with
Prof. Nassersharif's Topic Guildline of Capstone Work
Goals For The Past/Upcoming Week
Capstone 2nd Semester
Weekly Progress Reports
Meetings with JBE
Goals For The Past/Upcoming Weeks



Task Name	Duration	Start	Finish	Predecessors	Resource Names	% Complete
Capstone 1st Semester	49 days	Wed 10/10/18	Mon 12/17/18			100%
Capstone Assignments	49 days	Wed 10/10/18	Mon 12/17/18			100%
Weekly Progress Reports	49 days	Wed 10/10/18	Mon 12/17/18			100%
Capstone Quizzes	49 days	Wed 10/10/18	Mon 12/17/18			100%
Consultation Meetings with	49 days	Wed 10/10/18	Mon 12/17/18			100%
Prof. Nassersharif's Topic Guidline of Capstone Work	49 days	Wed 10/10/18	Mon 12/17/18			100%
Goals For The Past/Upcoming Week	49 days	Wed 10/10/18	Mon 12/17/18			100%
						0%
Capstone 2nd Semester	74 days	Wed 1/23/19	Mon 5/6/19			100%
Weekly Progress Reports	74 days	Wed 1/23/19	Mon 5/6/19			100%
Meetings with JBE	74 days	Wed 1/23/19	Mon 5/6/19			100%
Goals For The Past/Upcoming Weeks	74 days	Wed 1/23/19	Mon 5/6/19			100%

3.) Final Box