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Hydro-Aeroponic Design

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Department of Mechanical Engineering

Honors Research Project

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Hydro-Aeroponic Design

Honors Project

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Abstract:

With the intention of combining the efficiency of aeroponics and the compactness of hydroponics, a hydro-aeroponic system was created to grow spinach and lettuce. This design utilized a misting box and recirculating fan to drive humid, nutrient-laden mist through a series of channels. Several setbacks resulted in many iterations of misting boxes, fans, and component arrangements which ultimately lead to a proof of concept design. The proof of concept design was implemented and tested for several weeks with a variety of plants and showed a varying degrees of success. Several design improvements were proposed to enhance the system however, due to the restrictions with time and budget, the decision was made to continue with the current design. Reflections and recommendations for future iterations of the design are also considered in hopes to improve system reliability and efficiency.

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Background

Hydroponic and aeroponic systems are currently being used around the world. They are popular because of their ability to grow plants more quickly and efficiently than traditional ground planting. The advantages and disadvantages of hydroponic and aeroponic systems will be explained in further detail, developing the desire to create a hydro-aeroponic system to combine the best of both systems.

Hydroponic systems consist of plants planted in trays with some type of support such as rockwool or net pots, and having a small stream of water running around the roots. This type of system is efficient because it requires less water to grow the plants and they grow much faster because the roots have direct access to the nutrients they need. Hydroponic channels are also desirable because they are able to be stacked and require less space for mass production. Because the plants are not being planted in ground, a nutrient mixture is added to the water that runs through the channel. The downside of hydroponic planting is that it is very expensive. The plants also require constant attention to ensure that they are growing well, no system malfunctions occur, and no illnesses spread through the water. Additionally, because the plant roots are submerged in water, plant growth is slowed as oxygen absorption through the roots is limited. In the aeroponic system some of these issues can be resolved, while new issues are created.

Aeroponic systems use mist instead of a water stream to make the plants grow. Nozzles periodically spray the roots of the plants, allowing them to absorb the nutrients they need. In an aeroponic system, the roots of the plants are completely suspended in the air, allowing them to get a lot of oxygen which accelerates their growth. The aeroponic system uses mechanical energy and nutrients more efficiently than the hydroponic system. However, because the roots of the plants are suspended in the air, they are completely dependent on the misting system to keep to roots moist. Because the spray nozzles often clog, continued maintenance is required for this system. Some other disadvantages of aeroponics is the cost and the space required. They are very expensive and require a certain amount of technical knowledge to maintain, and the aeroponic setup does not allow plants to be stacked, which is not desirable for mass production.

With both the advantages and disadvantages of the hydroponic and aeroponic systems considered above, thoughts turned to a system that could combine the best of both designs: a hydro-aeroponic system. The design intends to use the channels of the hydroponic system and the mist of the aeroponic system. This combination would allow the plants to have the abundance of oxygen they need to thrive, and allow the system to be stacked like other hydroponic systems. Throughout the design process, several iterations of this system were developed.

Requirements

A system combining the efficiency of aeroponics and the compactness of hydroponics is to be designed. The system should incorporate a forced-airflow misting box. Measurements of system humidity, temperature, pH, and conductivity shall be collected. This project shall be completed with budget considerations, and in time to grow a crop of spinach or lettuce in April, 2019.

Existing Design

Most existing designs, as mentioned above, are either aeroponic or hydroponic. The hydroponic systems usually consist of some type of channel array where the plants are grown, and a pump that delivers a small stream of water through each channel. This stream is drained through the tray and recycled back into the system in a continuous loop.

Aeroponic systems can vary by orientation and size more than hydroponic systems. They can be horizontal or vertical, but they all tend to have the same type of mist delivery system. There are usually nozzles of some sort spraying up at the plant from the bottom as in a horizontal system or down from the top in a vertical system. Figure 1, shown below, depicts the major differences between the hydroponic and aeroponic systems.

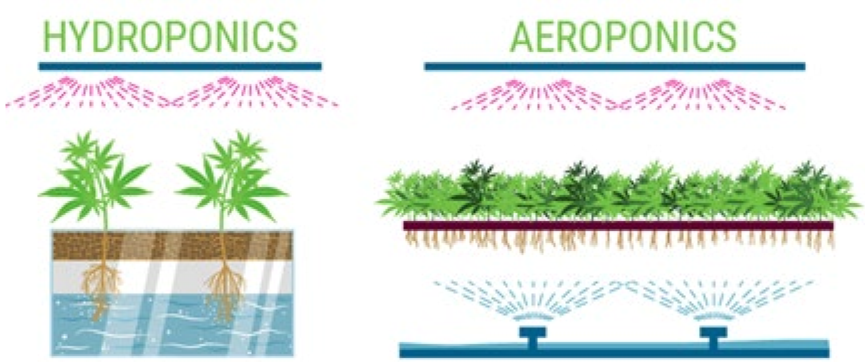

Figure 1: Hydroponic and Aeroponic Systems

Considered Designs

The design selection process involved many steps and considerations. First, a design tree was created to identify the main objectives and standards of the design as shown in Figure 2.

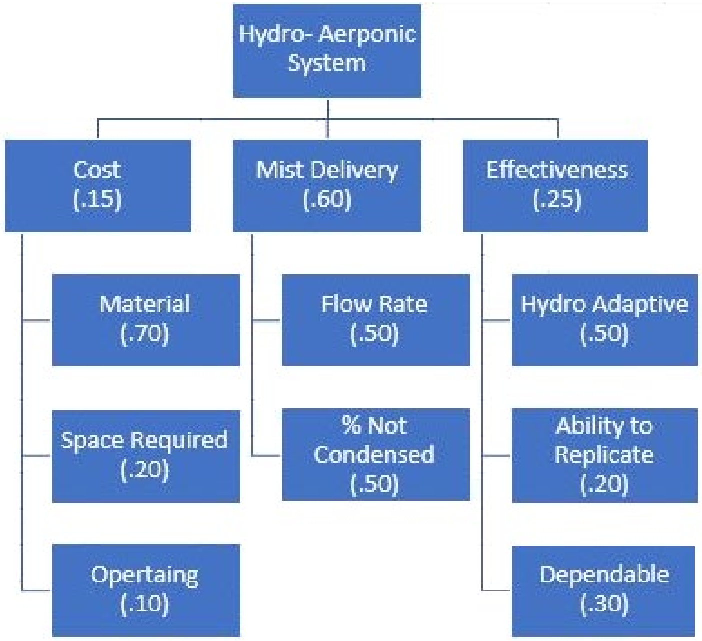

Figure 2: Design Tree

With these considerations, a morphological chart was used to create possible designs. Such ideas are conveyed in Figure 3. The design concepts that are mentioned in the morphological chart have depicted sketches in the appendix.

						Design 1	Design 2	Design 3	Deisgn 4	Design 5	Design 6	Design 7	Design 8
Sub Function	Solutions												
Misting Box Orientation	Horizontal	Below	Above			Horizontal	Below	Horizontal	Horizontal	Horizontal	Below	Above	Above
Misting Box Shape	Box	Barrel				Box	Box	Box	Box	Box	Box	Box	Box
Supply Manifold	Yes	No				Yes	Yes	No	Yes	Yes	No	No	Yes
Supply Fan	Below	Beside	None			Beside	Below	None	None	Beside	No	No	No
Return Manifold	Yes	No				Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Return Fan	Tee Below	Tee Beside	Parallel Beside	None		Parallel	Below	Below	Below	Below	Below	Tee Beside	Tee Beside

Figure 3: Morphological Chart

Using these designs and decision criteria, a weighted decision matrix was created, as shown in Figure 4.

11 point scale		Design 1		Design 2		Design 3		Design 4		Design 5		Design 6		Design 7		Design 8	
	Weight Factor	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating
Material Cost	0.105	4	0.42	3	0.315	6	0.63	5	0.525	4	0.42	6	0.63	5	0.525	4	0.42
Space Required	0.03	5	0.15	5	0.15	5	0.15	5	0.15	5	0.15	5	0.15	5	0.15	5	0.15
Operating Cost	0.015	5	0.075	5	0.075	6	0.09	6	0.09	5	0.075	6	0.09	6	0.09	6	0.09
Mist Not Obstructed	0.3	7	2.1	5	1.5	8	2.4	7	2.1	7	2.1	4	1.2	5	1.5	6	1.8
Mist Flow (Speed)	0.3	7	2.1	7	2.1	6	1.8	5	1.5	7	2.1	4	1.2	7	2.1	7	2.1
Hydro-Adaptivity	0.125	5	0.625	5	0.625	5	0.625	5	0.625	5	0.625	5	0.625	5	0.625	5	0.625
Construction Complexity	0.05	6	0.3	4	0.2	7	0.35	6	0.3	6	0.3	4	0.2	6	0.3	7	0.35
Dependable	0.075	6	0.45	5	0.375	6	0.45	6	0.45	6	0.45	5	0.375	6	0.45	6	0.45
Totals			6.22		5.34		6.495		5.74		6.22		4.47		5.74		5.985

Figure 4: Weighted Decision Matrix

Selected Designs

From these highlighted designs, an optimal design was conceived which involved a horizontal misting box supply (for ease of support), a supply manifold and fan (to drive mist in central location), and a return manifold and fan (to draw the moist air through channels and out one central location). This is represented in Figure 5, below.

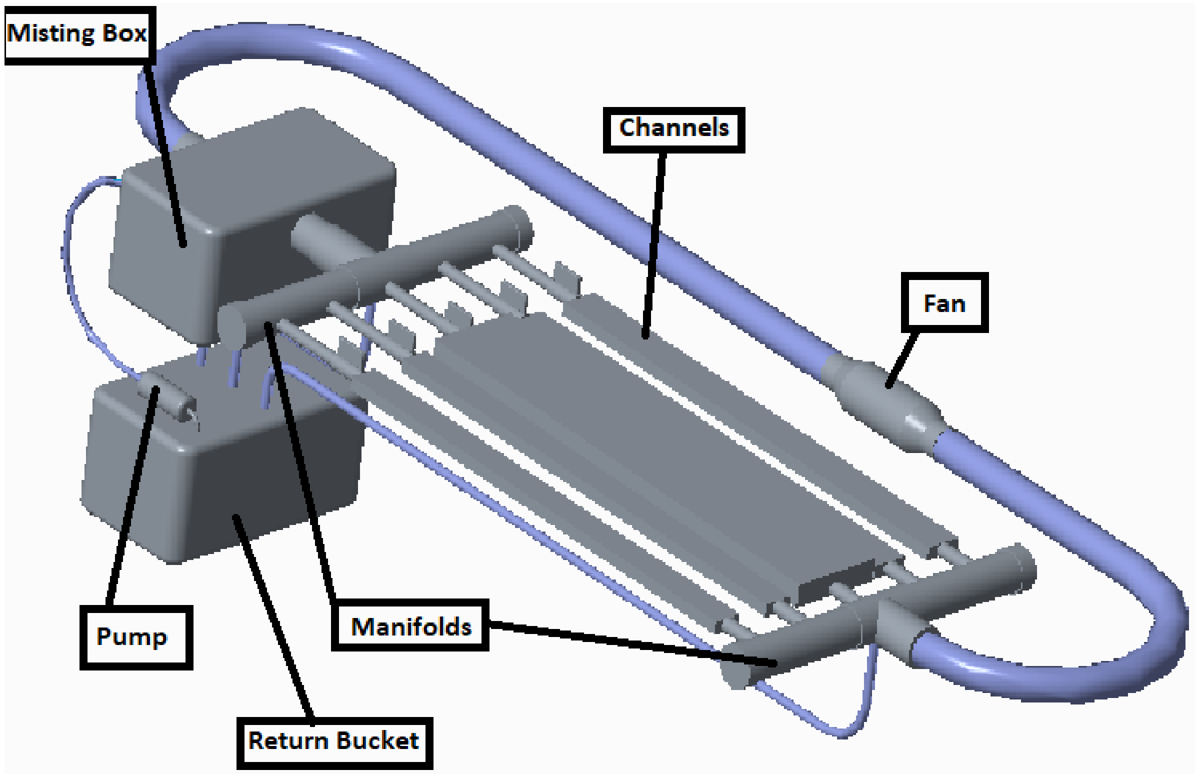

Figure 5: Selected Design Model

Testing

The success of the project and its different stages was considered by several measurable standards.

1. The primary objective of the project is the final system's ability to grow plants. Once the system was assembled, this was tested by introducing seedlings into the channels. True success of the project would be to compare the rate at which the system grows plants to that of a similar hydroponic and aeroponic system. However, the controlled test was not available at the time of this project.
2. Before introducing plants into the system, a humidity test had to be satisfied. The system was considered acceptable if it could produce at least 95% RH, with 98% RH (at both channel inlets and outlets) being more desirable. It took several misting box iterations to reach this criteria, but eventually the system met these testing standards. The project has the ability to control misting through a timer or humidity levels. If the humidity controller is used, the system's humidity is always known. In the cases when the timer is used, the system's humidity could be determined by a hand-held humidity sensor.
3. Other variables of concern in the system would be the pH, temperature, and nutrient levels. However, these considerations were not tested for in this project.

Redesigns

The most frequently altered component of the design was the misting box. The purpose of the box is to accommodate the creation of mist and feed fine mist into the rest of the system. Thoughts and physical representations of this evolved over the course of the project.

1. The original idea for the misting box was a simple container with misting nozzles at the top or bottom. A pump would feed the nozzles and send mist into the air, allowing large particles to fall to the box's bottom and fine mist to be sucked into the system. Placement of the nozzles on the box's top had the advantage of being easy to install and run condensate lines from. Placement of the nozzles on the box's bottom seemed to have the advantage of allowing only the finest of mist into the system, but introduced challenges for installing nozzles and running drains.
2. Consideration of this design lead to the concern that the misting box would become negatively pressurized as moist air was sucked out of it, revealing that a fresh air source would become necessary. In order to avoid this open loop problem, it was decided to return air from the return manifold back to the misting box. This allows the box to avoid a negative pressure and allows for the recycling of moist air. With the return air being pre-conditioned, the misting box's efficiency and achievable-humidity levels increase.
3. With the evolution of the concept came prototypes. The first misting box was a round five-gallon bucket with holes drilled in its top for the nozzle heads. This box served its purpose as a proof of concept, but its curvature made it difficult to work with.
4. A cat litter box served as the next misting box iteration. This box had the leak-resistant advantages of the five-gallon bucket, and its flat surfaces made it possible to drill large concentric holes. This design was completed and installed with supply and return attachments.
5. Upon testing the system with this misting box, it was determined that enough mist was not being produced. In an attempt to correct this, a 3-D printed lid was designed to replace the cat litter box's original lid. This new lid allowed for the placement of additional nozzles and the generation of more mist. However, the increase in mist was not sufficient, and a serious re-design of the box was necessary.
6. Alternative misting sources were researched, and it was decided to remove the misting nozzles from the system and utilize an ultrasonic fogger. Once implemented, this fogger produced a large amount of mist and met expectations.
7. To better accommodate the size and power of this new fogger, the cat litter misting box was retired and replaced with a thirty gallon tub. This tub was modelled similarly to the previous misting box, with concentric supply and return air holes and condensate lines. However, the needs of the fogger required the pump to serve directly into the tub and fill it to a certain water level, at which level two condensate lines (on the misting box's sides) returned excess water to the water source. This system allows constant circulation of water, provides ample space for fog/mist development, and observes the return of moist air which demonstrates its ability to meet design requirements.
8. Minor adjustments were made to this misting box in attempts to reduce mist leakage due to the box's lack of a lid seal.
9. Originally, the intention was to incorporate an Arduino board into the system to measure the temperature and humidity in each of the channels. After researching and programming a board, it was decided to move forward without the board because of its sensitivity to

water and salt; both of which the board may have come in contact with. Instead, a variety of handheld sensors were purchased to monitor the system.

Another re-designed piece of the system was the supply-side channel attachment. The original intent was to connect the supply manifold to the channel with a simple piece of tube (one tube per channel attachment). However, it became desirable to have the ability to isolate channels and manage their relative flow rate. To accommodate this, ball valves were introduced in the channel connection. This allowed for channel isolation (which was used in the system's testing) but introduced more junctions and lead to a significant amount of leaking.

The system saw a small redesign with its fan. The original fan did not have the desired power, so a more powerful fan was borrowed for the project and allowed for the flow of more air.

Discussion

Throughout the project, a number of improvements came to light which would make the next iteration of the system more functional and productive.

1. One of the most significant need in the system is better sealant. Any future re-creation of the system ought to use better sealant techniques at all junctions (hoses, ducts, screws, etc.). If this was done on a large scale, one might hope to see threaded hoses used in place of plastic tubes and single-piece manifolds in place of loose, drilled attachments.
2. Considering the final layout of the system, it would be desirable to alter the configuration of the return manifold. Presently, the channels have tubes connecting to the manifold which has a central duct return and condensate lines at the bottom. A better design would be to have the return duct have an upward connection. This would allow for the same function, but would help keep more condensate out of the duct.
3. A significant problem the system encountered is water in the ducts and fan. There are several obvious solutions to this, each having drawbacks. An obvious fix would be to exhaust the air to the atmosphere after the return manifold. However, the closed-loop cycle benefits would be forfeited, chiefly that the air would not enter the misting box pre-conditioned. Alternatively, the moisture could be removed from the air before entering the duct, but again, pre-conditioned benefits are lost. A more practical solution might be to arrange the duct in such a way that it has a certain pitch throughout its whole length. This way water that does condense can at least run down to either the misting box or return manifold, rather than sitting in the duct.
4. On a similar thread, the selection of the fan requires significant consideration. The system first utilized a small, six inch diameter fan from a local hardware store. This fan's flow was not sufficient, so a more powerful six inch fan was donated for the project. This fan worked well, but eventually clogged and burned out due to the collection of water and nutrients within it. The need for a corrosion-resistant fan intended to move moist air became prevalent after this. The less powerful fan was installed while the broken fan was fixed, and this fan shorted out in a matter of hours, further demonstrating the need for a specific fan. A fan that had a waterproof connection box was found. It also had the benefit of being made from high grade plastic so it is more corrosion resistant to the nutrients. The decision was made to save this for further iterations of the system due to time and budget constraints.
5. With the final design of the misting box, two condensate lines were used to maintain the water line. A single line would not do because it could not evacuate as much water as was

being pumped in (with the tube sizes available). This could be addressed if desired, but more pressing might be the relocation of the constantly-used return tube. One tube is constantly submerged, draining a constant flow of water while the other drains only when the water line is too high. It would be desired to relocate the constantly draining tube to the tub's bottom (as opposed to its side) in hopes to reduce the amount of nutrient sedimentation in the bottom of the misting box.

6. As the system was tested by growing plants, a concern was developed that the mist generated by the fogger may be too fine. It appeared the roots were not wet enough to facilitate rapid growth, but it was evident that significant moisture was in the air because of the condensate leaking through the fan. From this, it was postulated that the dwell-time of the mist was too large, and it was falling out of the air stream after passing through the channels (perhaps influenced by temperature changes or increased roughness experienced in the flex duct). Future iterations for mist generation may consider a source which creates mist droplets larger than the fogger, but smaller than the original nozzle assembly.
7. It was also observed that the mist produced by the fogger declined through the span of the project. Upon investigation, this appeared to be due to cracked and clogged plates on the fogger. Part of this failure is likely due to the chemical composition of the water, and future designs should consider a chemically resistant fogger (if the fogger is still desirable).

Conclusion

Many lessons were learned during the course of this project. This project provided the opportunity to design, build and test a design of the students own creation. This allowed students to utilize the engineering processes of conceptual, embodiment, and detail design that were learned in the Concepts of Design course. From the beginning, there were flaws and setbacks that had to be fought through or gone around. Such setbacks included leakage, fan and water problems. Students learned to think creatively and come up with solutions out of their comfort zone to solve these issues. This led to the students becoming more well-rounded engineers as they learned about different ways to help plants grow while also experimenting with engineering aspects of design.

References

Guenther, J. (2018, September 14). Cropking. (N. Boring, M. Doll, C. Sunkle, & M. Taylor, Interviewers)

Appendix A

Original Concept Sketches

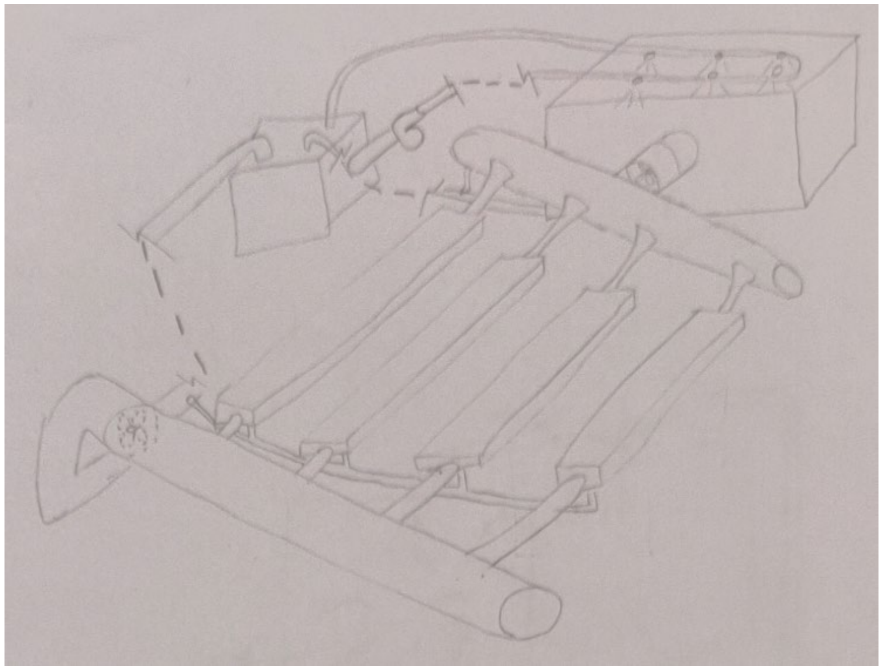

Figure 1A

The concept sketch in Figure 1A utilizes a horizontal misting box with a supply and return manifold. In this orientation there is a supply fan and a return fan in the system. This concept design received the second highest weighted decision matrix score. The main difference between this design and the chosen design is that only one fan was utilized in the chosen design.

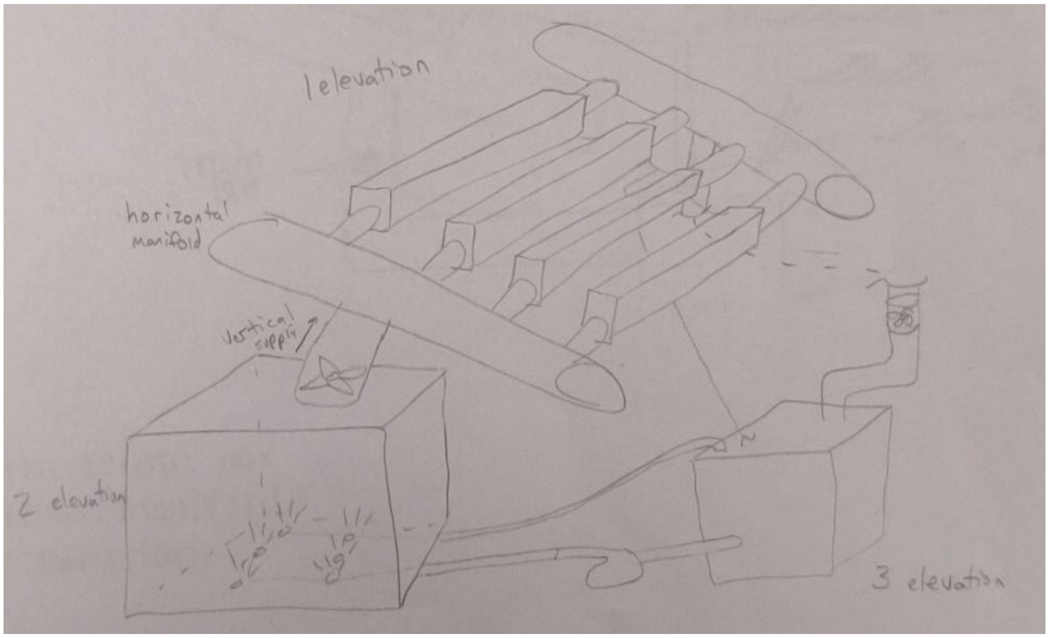

Figure 2A

Figure 2A depicted Design 2 from the weighted decision matrix. This design had one of the lowest overall weighted decision matrix scores. This design consisted of the misting boxes and supply and return fans being below the channels which was determined to not be an optimal design. This design also had supply and return manifolds.

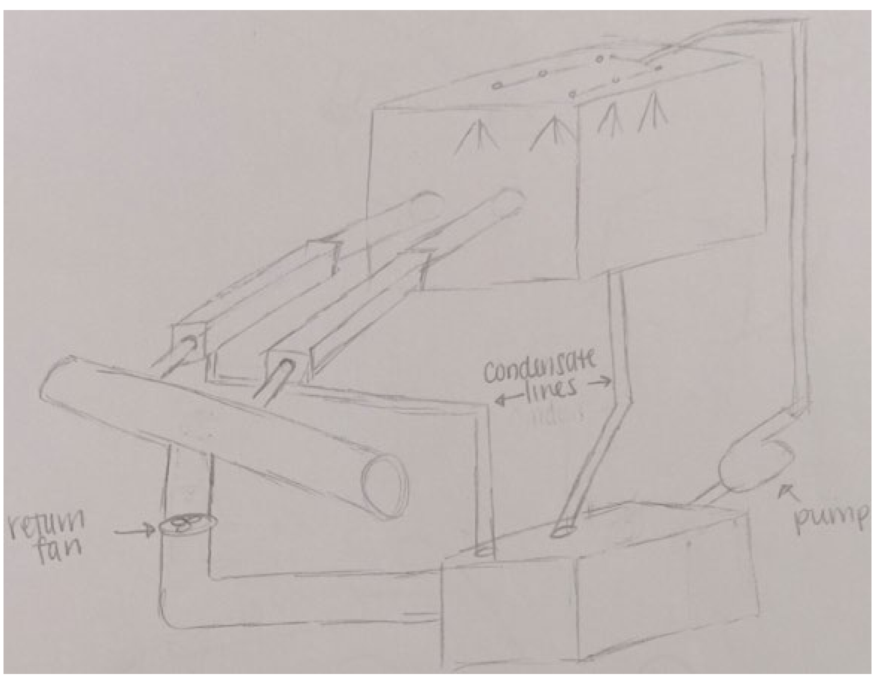

Figure 3A

Figure 3A represents the design that the team scored the highest. This design had a return fan and return manifold as well as a horizontal misting box. Although this design was the highest score the team ultimately did not go with this design due to the lack of a supply manifold. The team felt the supply manifold would aid getting mist into the channels.

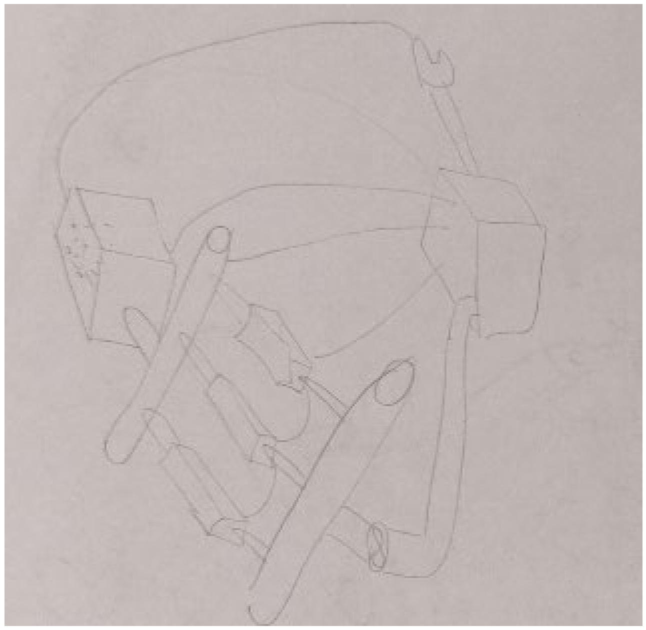

Figure 4A

Figure 4A represents the design that was ultimately chosen to build. Although it did not have the highest score in the weighted decision matrix, it ultimately met all of our needs. This design consists of a horizontal misting box and has a return fan. It also utilizes a supply and return manifold.

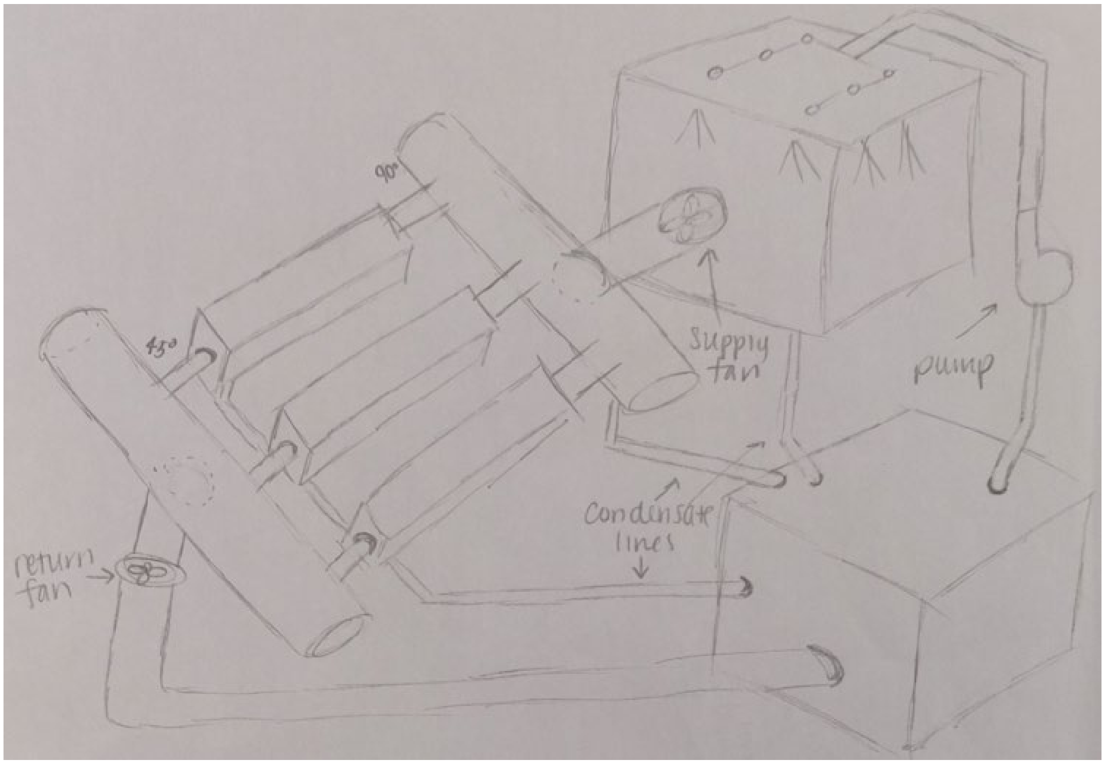

Figure 5A

Figure 5A represents Design 5. This design uses a horizontal misting box. It consists of a supply fan, return fan, supply manifold, and return manifold.

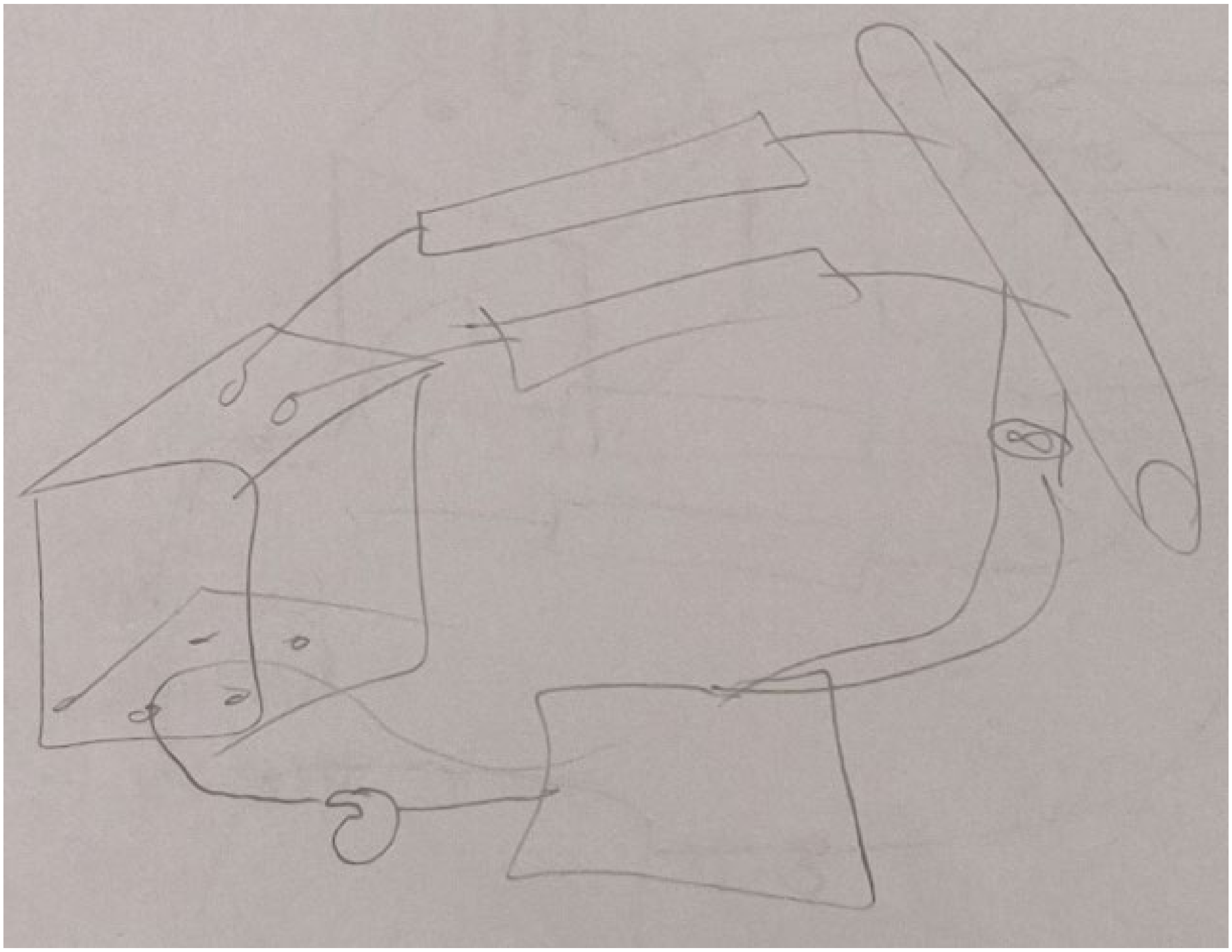

Figure 6A

Figure 6A showcases Design 6 in the morphological chart. This design uses a misting box below the channel. This design does not have a supply fan or manifold, but does consist of a return fan and manifold. This design ultimately received the lowest score.

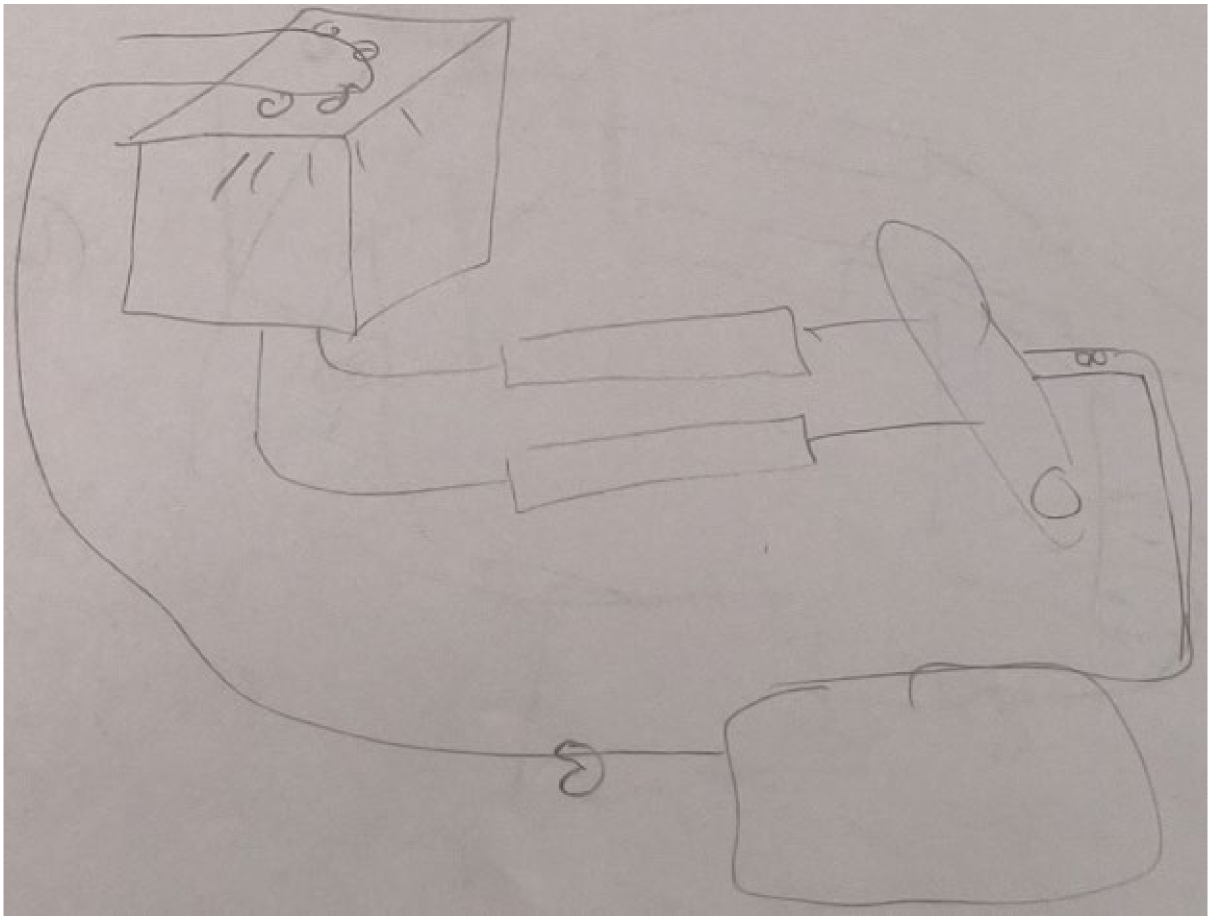

Figure 7A

Figure 7A represents Design 7 from the morphological chart. This design utilized an above misting box orientation and did not have a supply fan or supply manifold. This design did use a return fan and a return manifold.

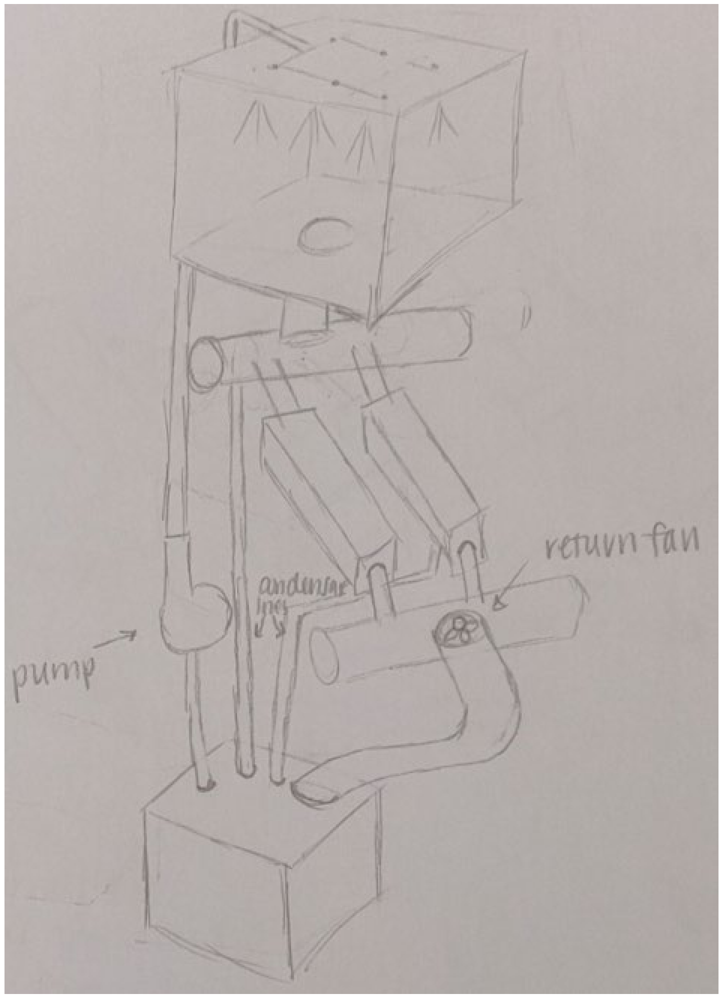

Figure 8A

Figure 8A represents an above misting box orientation. This design still utilized a supply and return manifold. There was a return fan in this design as well. One of the issues with this design is it would have to be designed to be located on shelves.