EDSGN 100 ALCOA PROJECT

connor carr, connor maust, aditya kela, ahmed sherif
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Acronyms

SA- Surface Area
L- Length
W- Width
A- Base
B- Height
C- Leg of triangle
Al\textsubscript{2}O\textsubscript{3} - Aluminium Oxide
RSS Feed- Rich Site Summary Feed

Abstract

In this design project, we were challenged to improve sustainability here at Penn State using the powerful material aluminium. As a team we explored different options to achieve this, but we finally decided to invest our time in designing a micro-greenhouse. The greenhouse is of modest size, about 4 feet by 4 feet, but when many of these units are used they are capable of supplying significant amounts of food. The food grown in these greenhouses can be used to supply the dining hall with fresh fruits and vegetables. Also growing plants will help clean the air and contribute to Penn State’s green initiative. The micro-greenhouse is designed with the user in mind as we strived to reduce the amount of maintenance required to sustain the plants inside. Also the greenhouse is designed to be used on campus roofs. These areas are out of the way, largely unused, and receive plenty of sunlight. To achieve all of these design goals, we incorporated several design elements. These elements include a durable, enclosed structure capable of withstanding weather, wildlife, and years of use. Also we incorporated a smart irrigation system designed to make watering the greenhouse a fully automated process. We also strived to make our product profitable, and were able to achieve a projected 10 fold return on investment over the lifetime of the product. The greenhouse will also spread a sustainability
presence all over campus as the greenhouses will be distributed over roofs campus wide.
Overall, the micro-greenhouse is a product that makes use of the properties of aluminium to
greatly increase the sustainability of Penn State.

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**Introduction and Overview**

**Design:**
Our mission statement was to create a product to implement into the Penn State campus that
improves efficiency and sustainability through the use of aluminum. Our design goals are to
make a micro greenhouse that is modular, can be implemented on campus roofs, is near
maintenance free, and is profitable. We included several systems in the design to reach these
goals. First is our closed system design. The greenhouse is made of sheet aluminum and
plexiglass such that no animals can get in. Holes on the top of the greenhouse allow rain to
enter, but are covered in window screen to prevent anything from entering through them. A
single hose input allows the system to irrigate itself and a sloped aluminum base distributes
water to all of the plants.
Software
The other design element we created to reach our design goals was a smart irrigation system. Irrigation of the system is controlled through an automated computer irrigation system. Each unit is equipped with a small computer capable of processing weather data and comparing it to moisture sensors in the greenhouse to compute whether or not to allow water to flow into the greenhouse. The software works in three layers, data collection, data processing, and output and monitoring. Here is a breakdown of how the software works

Layer 1: Data collection
In this layer the software gathers inputs from two sources, a moisture sensor in the soil of the greenhouse and weather information from an online RSS feed. The software takes raw sensor data from the moisture sensor and scores it in a way the data processing software can understand. This software also interprets the weather information it receives and creates a score that can be compared to the moisture sensor data. Scoring the data in this way allows us to take both sources of information into account when deciding how to irrigate the greenhouse.
Layer 2: Data Processing

In this layer the software uses the data generated from layer 1 to decide whether or not to irrigate the system in real time. To do this, it compares the data from the weather feed and the moisture sensor. It will be able to compute how much water the greenhouse needs based on the moisture sensor data. Then it will decide if the weather will dry out the soil more (dry/hot weather) or if it will contribute water to the system (rain). To best interpret the weather information, the software will use modern weather optimization software. This type of software is used by major energy companies to anticipate energy usage based on weather. This type of software is also used by many large companies worldwide to reduce costs and optimize their work for the weather. However the software we use will be unique in that it will use error analysis equations to develop a software profile for our area that will enable us to more accurately anticipate how the weather will affect our system. This error analysis looks at what changes the software anticipated and compares it to what actually happened. Based on this difference it is able to establish a set of error correcting parameters based on several variables. Because each greenhouse is equipped with its own microcomputer, each greenhouse will create a unique set of parameters.
Layer 3: Output and Monitoring

This layer has two primary functions. The first is to send signals to the water shut off valve based on what is decided in layer 2. The second function is to relay information to external sources so the greenhouse can be monitored off site. The software will send a status report of whether the water is running or not, as well as all of the sensor information it received to an external database via the internet. The software will also use the weather feed to send pertinent information to the user such as frost warnings or extreme heat warnings. This information can then be viewed off site, making maintenance of the greenhouse even easier.
Software summary:

The software gathers and analyzes data to decide whether to irrigate the greenhouse or not.

The software makes use of weather optimization and error analysis, and it makes maintenance even easier by incorporating external monitoring functionality.

Uses of Aluminium

Sturdy, durable material for the base:

Cheap, durable material that’s easily malleable and serves it’s purpose effectively. The material is easily recyclable and reusable. Easily manipulated in case of advancements or modifications to the design of the structure.

Weather resistant or will not corrode:

In terms of prevention from corrosion, aluminium is naturally suited for the purpose due to
the pre-existing natural characteristic of forming aluminium oxide ($\text{Al}_2\text{O}_3$) layer on the surface that acts as an effective barrier to corrosion - even when the surface is subjected to mechanical damage it won’t affect the integrity of the structure in terms of subjecting it from corrosion. This characteristic increases its life span and maintains appearance of aluminium.

**Light weight and is easily malleable:**

Makes the greenhouses easier to get on the roof. Easy to work with sheet aluminium. In case of lifetime damage to the aluminium structure of the micro-greenhouse the structure is easily repairable or replaceable.

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**Economic Analysis**

The economics were determined through external research of the cost of materials needed and the profits of certain plants.

The surface area of the plexiglass and aluminium was calculated using simple mathematical area formulas:

(same colors represent same length)

The main dimension is 4ft x 4ft x 3ft(at its highest point)

**Aluminium** (silver color)

is 4ft x 4ft x 1ft, so..

Surface Area = LW + (4 x LH)
\[(4\text{ft} \times 4\text{ft}) + (4 \times (4\text{ft} \times 1\text{ft}))\]  
\[= 16\text{ft}^2 + 16\text{ft}^2\]  
\[= 32\text{ft}^2\] of aluminium. According to several external sources, 1\(\text{ft}^2\) of aluminium is approximately $6.73. The total price for aluminium for one unit is estimated at $215.36

**Plexiglass**

A more complicated version of the surface area was used. The plexiglass is represented by all of the colored pieces. Calculations are explained in the table below.

**Table 1**

<table>
<thead>
<tr>
<th>Red Shading</th>
<th>Green Shading</th>
<th>Blue Shading</th>
<th>Purple Shading</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA = ((L \times W) \times 3)</td>
<td>SA = (L \times W)</td>
<td>SA = (0.5 (A \times B) \times 2)</td>
<td>(A^2 + B^2 = C^2)</td>
</tr>
<tr>
<td>SA = ((4\text{ft} \times 1\text{ft}) \times 3)</td>
<td>SA = (4\text{ft} \times 2\text{ft})</td>
<td>SA = (0.5 (4\text{ft} \times 1\text{ft}) \times 2)</td>
<td>(4^2 + 1^2 = \sqrt{17}) or (C)</td>
</tr>
<tr>
<td>SA = (12\text{ft}^2)</td>
<td>SA = (8\text{ft}^2)</td>
<td>SA = (4\text{ft}^2)</td>
<td>(C = 4.123\text{ft})</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(C) is the length of the purple so.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SA = ((C \times W))</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SA = ((4.123\text{ft} \times 4\text{ft}))</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SA = (16.492\text{ft}^2)</td>
</tr>
</tbody>
</table>

By adding up all of the areas calculated for the plexiglass..  
\[12\text{ft}^2 + 8\text{ft}^2 + 4\text{ft}^2 + 16.492\text{ft}^2 = 40.492 \text{ ft}^2\]

The average cost of plexiglass per square foot, according to external sources, is about
$6.05.

So 40.492ft² x $6.05ft² = $244.98

If the prices of aluminum ($215.36) and plexiglass ($244.98) are added together, the total cost of the base unit is $460.34. However, as explained above, the software is run by a microcomputer that is priced at $25.00. A hose is also needed to distribute water to the system so that the plants can thrive. A typical garden hose is about $21.84. So the total cost with all the accessories for one unit is about $507.18.

This may seem relatively expensive but the micro-greenhouse offers potential for high return. By doing external research, the micro-greenhouse can produce about 16 square feet per harvest, which occurs about twice a year. The most profitable early fall plant is cilantro that sells at $21.20 per square foot. So 16 square feet can profit about $21.20 x 16ft² = $339.20. During the summer, the most profitable plant is blueberries that sell at $18.71 per square foot. Similarly, 16 square feet can profit about $18.71 x 16ft² = $299.36. During the course of one year, the micro-greenhouse can profit about $630.00. In the matter of one year, the micro-greenhouse will pay for itself and even profit about $130. Over the ten year lifespan, the micro-greenhouse can potentially produce $630 every year for ten years which amounts to $5,800 (including the cost of the unit), or about a ten-fold return.

<table>
<thead>
<tr>
<th>Early Summer Plant Options</th>
<th>Selling price per Square Foot</th>
<th>Early Fall Plant Options</th>
<th>Selling price per Square Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cherry Tomatoes</td>
<td>$15.57</td>
<td>Cilantro</td>
<td>$21.20</td>
</tr>
<tr>
<td>Strawberries</td>
<td>$8.13</td>
<td>Arugula</td>
<td>$20.92</td>
</tr>
</tbody>
</table>

Table 2
In order for us to abide by the outlines of our projects, we were to have a design that was deemed sustainable - and that’s what the team did. The basis of the idea is that of it being a biological system, and thus particular attention was given to the sustainability aspect of it since biological systems can be easily related to our partial sustainability mission statement. The project has implemented a design that allows for maximum nourishment and crop output of the plants being grown inside the greenhouse. This has two positive effects on our project.

Firstly, in focusing on the healthy output of the plants we’re guaranteeing maximum revenue which in turn can be used as a decent source of reinvestment in the university’s and our project’s green initiative. This can primarily go to the development aspect of the project as it will be this that shall prove of use to the sustainability and green factor of the project. The more development and investment goes into refining future designs of a similar principle, then subsequently the more efficient our system gets and thus the more environmentally friendly it becomes.

Secondly, the way we’re designing a system that harbours vegetative biological life only comes to strengthen the sustainability aspect of the project. Multiple systems and techniques have been designed and implemented in our project that promotes a maximum vegetative harvest. In doing this the plant inevitably takes in maximum carbon dioxide from the environment in order for it to photosynthesis. Thus, this project advertently acts as a carbon sink or a purifier to the surrounding air, which in turn contributes to the projects integrated sustainability.
measures.

The design face of the project calls for a versatile, durable base that will be subjected to the elements and the yearlong climate of State College, PA. Thus, in our search for the best material for that purpose, aluminium came to our aid. Not only is the material environmentally friendly in terms of it not reacting with the elements, but it's also a relatively cheap material to employ. Due to its versatility and durability as our material of choice, it significantly reduces our maintenance costs and substantially increases our anticipated design lifecycle, which also reduces replacements costs. This makes its use both environmentally and economically sustainable.

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**Design Process**

**Define the problem:**

The broad spectrum focus of the project was to design a system that was both environmentally sustainable and integrates aluminium in its design. The project was designed to be easily implementable around campus and partially contribute to the green initiative of the university. We tried to focus on both making a decent profit out of the project for two reasons. Firstly so that it can eventually pay off for itself over its operational lifetime and also to generate some sort of revenue for us to invest from later on - which will work hand in hand with the university's green initiative. Moreover, we tried to integrate a design to our project which mitigated the maintenance aspect. The landscape that we were to deal with was defined beforehand and thus including a solution to that was of paramount importance in our design phase of the project.
Gathering Pertinent Information:

Heavy research went into both finding suitable plants that were to successfully be planted in our greenhouse. This was of course part of the plant selection. In that process we researched both plants that are to survive and flourish in average State College, PA climate - data for that was acquired via national climate databases we accessed. All of such information proved pertinent in making our project a success. The plant selection process was based on two major criteria which were economics factors in terms of how much revenue that certain type of plant would generate under the conditions it’d be subjected to, and secondly, the likelihood of the plant to flourish based on biological factors. The team decided that to make use of the soil all year round and to generate maximum revenue we were to employ two planting cycles with different plants pertaining to their respected seasons of growth. This proved very efficient and economic since it substantially contributed to our impressive anticipated cash flow.

Moreover, the team went off and gathered information that was to prove detrimental as a point of early reference and an indicator to our project. This was information regarding other projects that were of a similar nature to our project in terms of objectives and technical challenges. In doing this we realised the benefits integrating a computerized system brings and thus decided to include that as part of our design for better efficiency and reduced maintenance cost, amongst other things.

The team gathered information pertaining to the likelihood of having a computerized system that not only is automated on predetermined functions such as opening and closing water valves connected to the greenhouse when certain climate variables are gathered via the RSS feed that’s also connected to it, but also on sending an error message to the control room whenever an error or failure in one of the components is met. This system design was decided upon due to the research done by the team in that field and on the unanimous decision made by
the team that this would only prove detrimental in improving and facilitating our design purpose.

With this we research various sources of viable information pertaining to the quantification of the amount of carbon dioxide absorption of plants as this would act as this can very well and effectively act as an enhanced carbon sink source which further strengthens the sustainability aspect of the project. Our finalized decision concerning which plants were to be used in the project was to an extent related to the level of carbon dioxide the subject plants were to absorb during their seasonal lifespan.

**Proposed Solutions:**

In order to try and overcome the problems that challenged us we devised several concepts that were later on refined further based on functionality, implementability and ease of modification later on during its operational lifetime. Firstly, we were working with a flat landscape since the greenhouse was to be located on top of buildings around campuses that predominantly have flat roofs. However, in order for the aqueous nutrient solution to reach every part of the soil equally there would have to be some sort of structural gradient in the design in order for the solution to practically drain down to all of the required parts and corners of the greenhouse. Thus several design options were brought up and several were considered and refined until the team settled for the design shown in the CAD images. Our final design in order to tackle this problem has the solution valve opening in the center of one side of the greenhouse's base’s sidewalls. We then decided to do the intuitive thing in this case and have the greenhouse’s base elevated from the centre side that had the solution valve and structurally descending till ground level from all other sides. This was proven the most efficient by an optimization problem the team performed. the height of the valve opening was a compromise between the cost of having to have more base material and between the efficiency of the design.
Secondly, in order to tackle the issue of maintenance that was addressed by the team earlier on during the project, we decided to employ an automated system that was both effective in doing preset tasks and also efficient in terms of implementability. Like was touched upon in the previous segment, this portion of the design is to be implemented in a way whereby a central computer hub will be based on top of each building with the sole responsibility of monitoring a continuously updated RSS feed and subsequently controlling various actuators - including the solution valves - for all the greenhouses on top of that particular building. There are to be moisture, pH and various other necessary sensors in each greenhouse that are to be connected to the main computer. If values aren’t within the predetermined range that’s imputed to the computer by specialists then the computer relays signals to actuators accordingly in order to make up for the unacceptable inconsistencies.

Conclusion

In conclusion we’ve designed a product that not only meets the mission statements of the ALCOA project glamorously but also goes up and beyond in utilizing an implementable state of the art simplistic yet effective amalgamation of technologies to maximize both environmental and economic sustainability. We’ve utilized the various steps of the design and development process relevant that we’ve come to learn about in the course and used the most effective ones pertaining to our project - as was mentioned earlier in the report. We settled for a design that has not only been deemed profitable at it’s current technical level but that has a great advantage in terms of it’s high implementability.

All in all this project has been a great success in terms of us getting to apply the engineering design aspects of the course to a hands-on project and getting to yet again work
collaboratively with team members for a final product that we’re proud to call our own. The ideological concept behind the project paves ground for future projects of similar nature that would only enhance the sustainability aspect of the initiative in the grand scheme of things. And that is inevitably what a project like this was initiated for. That is to enhance the university’s green initiative and develop implementable concepts that can be put to work which harness the green properties of aluminium we’ve grown to know very well. And that is precisely what this project does.
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