T14 Greenhouse Proposal

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Abstract

§ The recent discoveries involving carbon emissions and global warming have led to worldwide concern for more "green" ways of producing goods and energy; our team has been researching and conceptually designing a "green" greenhouse, to produce crops in an energy efficient and environmentally friendly manner. In a modern world, where capitalist democratic policies reign in most civilized countries, it is important to understand global concerns and to adapt business and production methods to what the world needs, collectively. In this, pursuing this "green" greenhouse was a legitimate business endeavor as well as an attempt to meet the world's desires. ¶ Since different geographical locations all have their respective crops, prices, and growing seasons, it was important to understand what the people wanted and where that product could be grown cheaply. Our team researched the prices of crops in different places, the prices of land in different countries, the efficiency of each location's growing seasons, and many other factors of the business end of things. As a result of the geographical information that we reviewed, we decided that the best location for a greenhouse would be the Dominican Republic for its cheap land and climate stability. Our economic research into the construction and energy costs of a greenhouse yielded a very efficient rectangular model, designed to maximize sun time and climate stability on minimal energy usage and pollution. Our crop research showed that the most economically feasible crops were Garlic Chives, Cilantro, Spinach, Poinsetta, and Orchid. Given all of this information and the calculated results that constituted them, the `T14` group has constructed a very comprehensive array of graphs and statistics, a physical scale-model of their future greenhouse, a detailed and very accurate computer aided design of the model to portray it for the public in a reasonable fashion. ¶ The implications of this very well thought out design are that these ideas are completely feasible. It has overarching energy, economic, and environmental implications for the future that are relatively astounding. With the proper research, motivation, funding and willpower this new greenhouse just may be the future of crops and the water to douse the fire of global energy demands.

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1 Introduction

In a world where supply and demand changes daily, where the slightest fluctuation in stock numbers cause a shift of millions of dollars, where global environmental concerns and energy efficiency goals approach substantially higher concern, where food is scarce and attention for crop growing is high on the global agenda, an almost infinite amount of factors apply in creating and developing ideas that meet all of the global needs. Because our team is engineering-oriented and has entered a “contract” of sorts to create an economically sound and environmentally friendly greenhouse, we have set out to do the proper research and information collecting required to model and project the successfulness of the greenhouse itself. Everything from the geographical location to the cost of materials was factored into the decision-making process. An array of economic factors was considered as well, including the demand of a certain crop in a certain area, or the price of heating or cooling the greenhouse in a climate that a specific crop didn’t grow in. Hundreds of other factors were considered in the design, layout, and modeling of this specific greenhouse. An analysis of the statistics and the graphs that were pertinent to our research is presented and a conclusive decision is made on each aspect of the greenhouse’s theoretical construction in order to most efficiently satisfy global needs. Not only were some results surprising as they contrasted what our initial pre-research perceptions had been, but some were outright astounding. Our report ends with a beautifully organized assortment of facts, statistic and of course a computer aided design that will help readers visualize the probably future in greenhouse establishment.

2 Primary Greenhouse Characteristics

2.1 Location of Greenhouse

2.1.1 Cost of Land

The first criteria considered in the placement of our greenhouse was the relative cost of land in each of the four locations offered. The design team was presented with four possible locations for the construction of the greenhouse: *a*) NYC, NY, *b*) Ithaca, NY, *c*) Topeka, KS, and *d*) the Dominican Republic.

It should be noted that the design team was also offered a rooftop location in NYC for a substantial 90% discount over average NYC prices. These prices are depicted in **Table 1** and **Figure 1**.

From the above analysis, it is clear that the New York City locations (both rooftop and ground level) are not economically feasible. The cost of an acre of ground-level land in New York City, in US dollars, is approximately 400,752.00% more expensive than land in the Ithaca, NY location. Even the rooftop location - which costs only $1/10^{\text{th}}$ of the ground level location - is 400 times as expensive as the Topeka location. This analysis strongly advocates selecting either the Ithaca, Topeka, or Dominican Republic locations.

2.1.2 Market Viability

Market viability is mostly contingent upon the population in that market; the larger the market, the higher the probability that there will be no crop surplus. This critera can be analyzed by comparing the relative population densities. All data in **Table 2** was obtained from the CIA World FactBook.

Table 1: Cost of Land by Location

Location	Cost ($ / Acre)
NYC	$100,188,005.00
NYC Rooftop	$10,018,800.50
Ithaca	$25,000.00
Topeka	$11,240.00
Dom. Repub.	$920.00

Figure 1: Cost of Land by Location

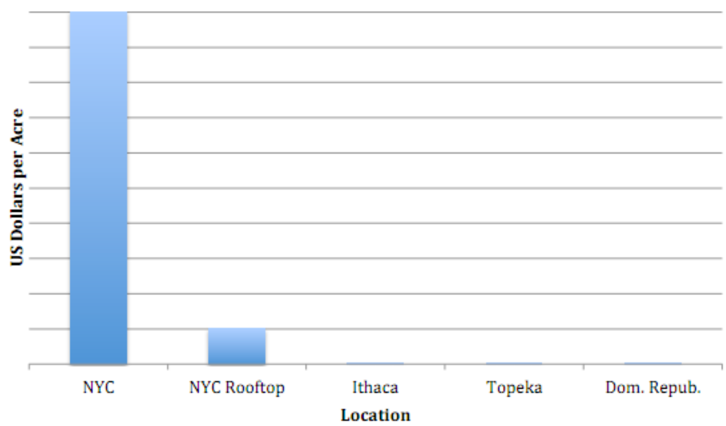


Table 2: Population Density by Location

Location	People/Sq. Mile
NYC	70951
Ithaca	5363
Topeka	2236
Dom. Repub.	539

Figure 2: Population Density by Location

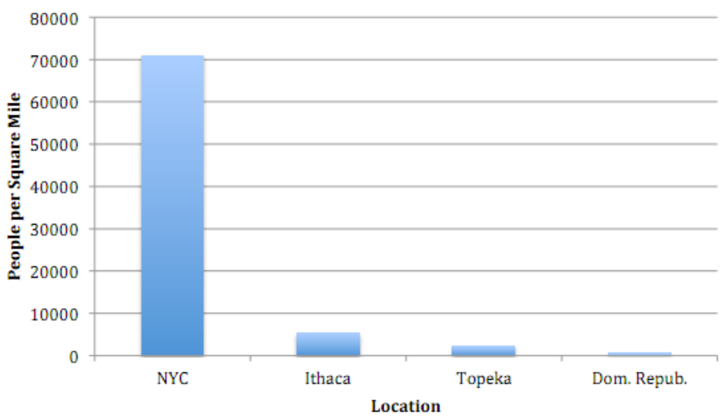


Table 2 suggests that New York is the best location for selling the crops produced in the greenhouse, based on the fact that it has the highest population per unit area, as clearly demonstrated in **Figure 2**.

2.1.3 Competitivity

The next factor that must be considered are the crops that are grown locally in each location. A greenhouse will not be able to sell its product if the local market is already flooded with competitors. **Table 3** shows the different crops that are already abundant in each location.

Growing large-scale field crops in greenhouses (like wheat, potatoes, and sugar) is not economically feasible. These crops sell for extremely low prices per unit weight, and therefore, massive fields of the crop must be grown to reach any appreciable profit margin. Therefore, fruit/vegetable type plants must be grown in the greenhouse.

The NYC and Ithaca markets are already saturated with greenhouse-grown fruits, vegetables, and herbs. Therefore, the Topeka and Dominican Republic locations seem best suited for greenhouse-type products; there will be minimal competition when it comes time to sell.

2.1.4 Competitive Pricing

It is important to analyze the selling price of crops in each of the four possible locations. To evaluate the relative retail values of the crops, a spreadsheet **(Appendix D)** was created. The price of a particular crop in each of the four locations was averaged, to create the average price of the particular crop. The price of that particular crop in each location was then subtracted from the average, giving a price differential between the local price and the average. This price differential was then converted into a percentage of the average price. The percentage difference for each crop was then averaged for each of the four locations. The most positive average percentage has the highest relative sale prices, and the most negative percentage has the lowest relative sale prices.

2.2 Plant Selection

The primary goal for the greenhouse is profit. Therefore, it is in the owner's interest to grow the most profitable crops.

Plant densities were used to calculate how many plants could be fit into the greenhouse. The total number of plants that could be fit into the greenhouse was multiplied by the particular plant's harvest percentage, and then multiplied by the price per weight of the individual crop and the weight of a crop in pounds (assuming Dominican Republic prices). This returned a theoretical profit (assuming that the entire greenhouse was just one crop). This plant profitability analysis is demonstrated in **Appendix E**.

The above process was carried out for the un-scaled greenhouse $\mathbf{A} = 2\text{ft}^2$ and the scaled up greenhouse $\mathbf{A} = 3100\text{ft}^2$. The top five most profitable crops are presented in **Table 4**, in order from most profitable to least profitable.

2.2.1 Growing Season Selection/Determination

The crops were grouped together into three separate growing seasons, displayed in **Table 5** The following considerations were made:

Table 3: Crops Grown per Location

Location	Crops Grown
Topeka	Wheat, Potatoes
NYC	Vegetables (Organic Niche)
Dom. Repub.	Sugar
Ithaca	Vegetables (Organic Niche)

Table 4: Top Five Most Profitable Crops

Crop	Potential Full-Scale Profit
Garlic	$1,309,069.27
Orchids	$222,912.22
Cilantro	$94,860.09
Poinsettia	$63,244.86
Spinach	$47,138.73

Table 5: Growing Season Statistics

Crop	Temp. (F)	Humidity	Area (m^2)	No. of Plants
	Growing Season #1: Jan - Feb			
Garlic Chive	68	70%	3100	446,400
	Growing Season #2: Mar - Apr, Nov - Dec			
Cilantro	68.5	62.50%	1550	111,600
Spinach			1550	23904
	Growing Season #3: May - Jul, Aug - Oct			
Poinsetta	76	65%	1550	2880
Orchid			1550	6192

The most profitable crop - Garlic Chive - was given a growing season to itself. This serves to maximize profit. The remaining four crops were grouped together into two additional growing seasons according to their optimal growing temperature and humidity. Optimal growing temperature was obtained by averaging the maximum and minimum growing temperatures of the individual crop. Exactly half of the area of the greenhouse is dedicated to growing each of the four remaining crops. This is to maximize sale numbers - if too many crops are grown, they will not all be sold. Growing only half of the greenhouse full of a crop ensures that this does not happen.

The five growing cycles (comprised of the three growing seasons) were arranged in such a way as to minimize the temperature differential between the inside temperature of the greenhouse and the outside temperature (e.g. the growing seasons requiring higher growing temperatures occur during the hot months, and the cooler growing seasons occur in the winter).

The calculations in **Table 6** show that there is only an average 8% temperature difference between the inside and outside temperatures. This minimizes cooling costs dramatically, as shown in **Figure 3**.

2.2.2 Climate Stability

The design team wanted to select the location that would have the most stable climate. Extreme variances in temperatures from month to month require high amounts of heating and cooling, which is often expensive. The more stable the climate, the less artificial temperature regulation is needed.
The relative monthly stabilities of the climates can be examined visually by plotting the average monthly temperature as a function of the month.

Mathematics can also be used to examine the relative constancy of the temperature from month to month. A linear regression was preformed on all the data sets, as depicted in **Figure 4** The R^2 value indicates how well the computed line of best fit matches the data. If $R^2 = 0$, the line is not a good fit; if $R^2 = 1$, the line is a perfect fit. Non-linear temperature plots will have low R^2 values. **Table 7** displays the Linear Regression Analysis values for each location.

The Dominican Republic, therefore, has the most constant climate. Because the average temperature in the Dominican Republic is high, there is essentially no need for a heating system - the temperature in each month is consistently higher than the temperature of the greenhouse. This will eliminate heating costs and result in a higher net profit. All the other locations have cold winters, requiring heating systems and additional costs.

2.2.3 Soil Considerations

The vast majority of Kansas' soil has a significant problem - high clay content. Clay in soil holds water and prevents plants form being able to absorb it. Kansas State University research confirms that high clay content in Kansas soil can be detrimental to plant growth. For this reason, a greenhouse in Kansas would have to purchase planting soil. Estimates for soil suitable for growing in the Topeka area are approximately \$43 per cubic yard. [1]

There are no such problems in the Dominican Republic. The soil in the Chibao Valley is clay free and is extremely fertile. Scientists have determined one potential

[1] *American Topsoil, Buy Rich Black Topsoil at a Good Price. Locations in Kansas & Missouri.* Web. 04 Aug. 2011. `http://americantopsoil.com`.

Table 6: Growing Season Temperature Statistics

Month	Min	Avg	Max	Growing Temperature	Season #	Difference	Percentage
Jan	67	75.5	84	68	1	7.5	10%
Feb	67	75.5	84	68	1	7.5	10%
Mar	68	76.5	85	68.5	2	8	10%
Apr	70	79	86	68.5	2	9.5	12%
May	72	79	86	76	3	3	4%
Jun	73	80	87	76	3	4	5%
Jul	73	80.5	88	76	3	4.5	6%
Aug	72	80	88	76	3	4	5%
Sep	72	80	88	76	3	4	5%
Oct	72	80	88	76	3	4	5%
Nov	70	78.5	87	68.5	2	10	13%
Dec	68	76.5	85	68.5	2	8	10%
					Average Difference	**6.167**	⋮
						Average Percentage	**8%**

Figure 3: Annual Temperature Variance vs. Greenhouse Variance

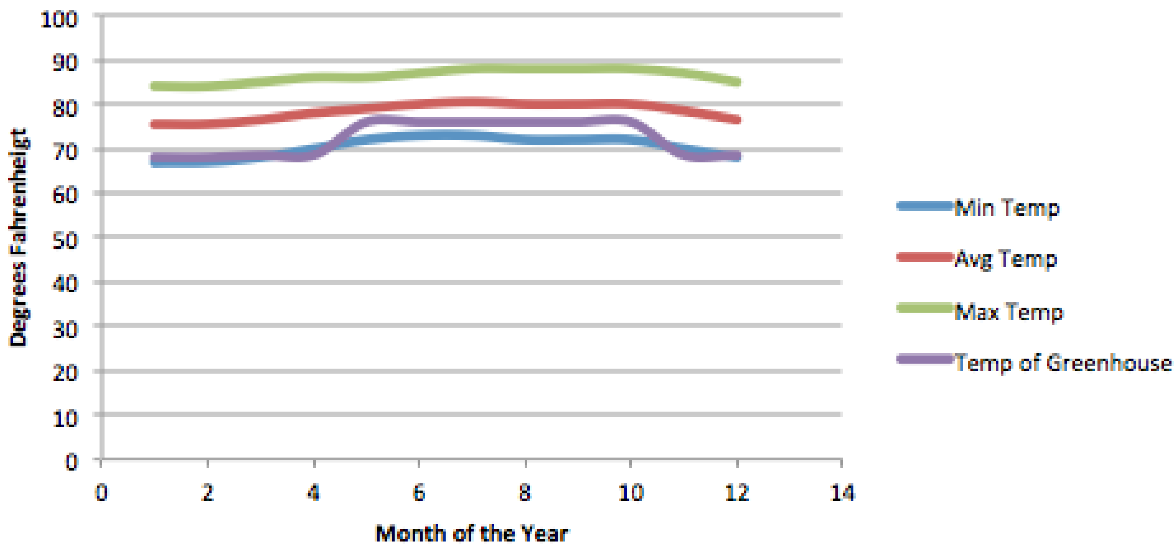


Table 7: Linear Regression Analysis

Location	R^2
Dom. Rep.	0.25782
Ithaca	0.10119
NYC	0.09615
Topeka	0.05318

problem however - heavy metal content. According to Hernandez, Alexis, and Pastor [2], human civilization of the area has increased heavy metal content in the soil, which can be detrimental to plant growth. The metals in the study included Zinc, Copper, Lead, and Chromium. The study determined, however, that certain field crops use up the metals and leave the soil safe for growing. Therefore, there is an abundance of suitable growing soil in the Dominican Republic, and minimal soil (if any) needs to be shipped to our location. This saves incredible amounts of capital.

Choosing to build the greenhouse in the Dominican Republic carries along with it several cost saving advantages - mostly in the way of soil purchasing. The soil in the Dominican Republic (the Chibao Valley, specifically) is extremely fertile. All the crops we chose to grow in the greenhouse require a soil pH of 6.5 - a characteristic that the natural soil in the Dominican Republic possesses. Additional land can be purchased; the soil can be harvested for use in the greenhouse. This is significantly cheaper than purchasing soil form a third party producer. Further, the area left behind by the soil harvesting can be used for composting plant dead loss, creating an ample supply of organic fertilizer (that is also free).

2.2.4 Weather

A potential drawback to the Dominican Republic (pictured in **Figure 5**) is the potential for hurricanes.[3] A major hurricane has not struck the Dominican Republic since 1979 and 1980. Hurricane David (1979) brought 125 MPH winds and extensive flooding. Hurricane Allen (1980) only consisted of strong winds, and caused minimal damage. Both hurricanes struck the southwestern and western coasts of the DR - and historically, hurricanes most often fall in that location. The National Weather Service (NWS) predicts that there is a 61% chance of a major tropical storm or hurricane hitting the Dominican Republic in the year 2011.

Our greenhouse was out of the path of destruction of both the 1979 and 1980 hurricanes; our greenhouse will be located in the Chibao Valley. The Chibao valley is located in the north of the Dominican Republic, and is therefore out of the path of the vast majority of hurricanes. 30% of the Dominican Republic is suitable for farming, and vast majority of the fertile land lies in the Chibao area.

The Topeka, Kansas location is extremely prone to tornados, which could easily destroy the entirety of the greenhouse. Kansas has, on average, 47 tornados per year - making Kansas the third most susceptible state in the nation. As recently as the 21st of May, 2011, "baseball sized hail" and "massive tornadoes" destroyed 20 homes and damaged 200 more [4].

The high possibility of tornadoes makes the Topeka Kansas location a less attractive option. Although hurricanes are a potential risk in the Dominican Republic, the likelihood of them occurring is low; further, the likelihood of them striking the Chibao Valley is even lower.

[2] Hernandez, Alexis, and Pastor. *"Soil Degradation in the Tropical Forests of the Dominican Republic's Pedernales Province in Relation to Heavy Metal Contents."* (2007). Web. http://www.ncbi.nlm.nih.gov/pubmed/17307235.

[3] *Wikipedia.* Wikipedia. Web. 3 Aug. 2011. http://upload.wikimedia.org/wikipedia/commons/3/30/Map_of_Geographic_Regions_of_the_Dominican_Republic.PNG.

[4] *"Tornadoes Slam Northeast Kansas; 1 Killed."* MSNBC.COM U.S. & World News. Web. 5 Aug. 2011. http://world-news.newsvine.com/_news/2011/05/21/6693166-tornadoes-slam-northeast-kansas-1-killed.

Table 8: Monthly Solar Irradiance in the Dominican Republic

(Sunlight is measured in $\frac{\text{kWh}}{\text{m}^2 \cdot \text{day}}$)			
Month	Sunlight	Month	Sunlight
Jan	4.17	Jul	5.59
Feb	4.76	Aug	5.31
Mar	5.41	Sep	5.03
Apr	5.7	Oct	4.75
May	5.55	Nov	4.24
Jun	5.64	Dec	3.98

2.2.5 Insolation

To calculate the magnitude of the solar irradiance received by the floor of the greenhouse, we first needed to determine the path of the sun's rays inside the greenhouse.[5] **Table 8** gives a monthly list of solar irradiance values, which were then applied to the flat surfaces in our building.

Given the dimensions of our building and assuming optimal alignment with the solar arc on an average day, we found the base angle θ of the right triangle formed by the length and height of the greenhouse. This angle, θ, can be divided by 180 (the arc the sun travels in the sky) and multiplied by 12 (the rough number of hours of sunlight in a day) to provide the equation $(\theta/180) \times 12 =$ hours of sunlight which supplied us with the number of hours of sunlight a far edge of the greenhouse floor would receive. Because the sun travels a complete arc, both edges of the greenhouse receive approximately the same amount of sunlight; the overall minimum number of hours of sunlight received by any point on the greenhouse floor.

To calculate the maximum, we draw a triangle from the height of the greenhouse to the midpoint of the length of the base; that angle, when plugged into the earlier equation, supplies us with the maximum number of hours of sunlight any point on the greenhouse floor receives. For a height of 8.5" and a length of 24", we receive the values of 4.7 and 7.29 hours for the minimum and maximum number of hours of sunlight received by any point on the greenhouse floor per day.

However, the previous calculations were all assuming the complete opacity of the walls of the sunlight facing along the east-west axis. The plants we need to grow, however, all require between 6 and 10.6 hours of sunlight a day. As such, we chose a novel approach to construction: the floor of the greenhouse is built in steps approximating an inverse parabola, rising towards the east-west walls and sinking towards the center. This serves two purposes: to prevent shadows from being cast on any plants near the edges, and to allow for placement of the control circuit. As a result, the previous solar irradiance calculations retain only their maximum sunlight values; the angle calculation proves that the parabola method is necessary to provide adequate sunlight for all crops regardless of physical placement inside the greenhouse.

[5] Data from *"Solar Irradiance - Calculate the Solar Energy Available on Your Site."* The Solar Electricity Handbook - the Solar Photovoltaic Book. Web. 2 Aug. 2011. `http://solarelectricityhandbook.com/solar-irradiance.html`, assuming that the greenhouse is located facing on the east-west axis roughly around Santo Domingo in the Dominican Republic.

2.3 Final Location Decision

The New York City location is not feasible for the following reasons:

- The cost of land is too expensive - even the alternative option: a rooftop location that costs a tenth as much as a ground-level location.
- The climate varies too much from month to month - extensive heating would be required.
- The fruit/vegetable market is already saturated

The Ithaca location is not feasible for the following reasons:

- The temperature varies too much from month to month - extensive heating would be required.
- The market is already saturated with greenhouse-type plants.

The Topeka, Kansas location is not feasible for the following reasons:

- The temperature is too varied from month to month - extensive heating would be required.
- Good growing soil is not available; clay in the native soil means that the owners will have to purchase growing soil at great cost.
- Crops sell for largely below-average prices.

The Dominican Republic is the best choice for the following reasons:

- The Dominican Republic has the most inexpensive land (by far)
- The climate is very stable - no heating will be required. The climate is warm year-round.
- Good growing soil is available and abundant - no added cost here.
- The risk of natural disasters (i.e. hurricanes) is very low.
- The market is currently unsaturated - there is a market for the products of the greenhouse.

The below average selling prices of the crops is a potential problem, but the money saved by purchasing cheaper land, not heating the greenhouse (its not needed), the unsaturated market, and maximizing the growing area of the greenhouse will prevent any negative impacts of the low selling prices.

3 Secondary Greenhouse Characteristics

3.1 Structure and Materials Analysis

3.1.1 Physical Structure

Our greenhouse is 24" × 12" × 8.5" high, containing 288 square inches of arable land. On one far end of the rectangular greenhouse will be a 4" × 6" × 6" space left for placement of the control circuit. That side will have a 6" × 8" panel for circuit maintenance. In addition, our greenhouse contains a novel parabolic plant shelving mechanic with a threefold purpose; *a*) to maximize sunlight to all parts of the greenhouse; *b*) to fulfill the 150 in^2 shelving requirement; and *c*) to avoid the unnecessary cost of artificial lighting. We used a Reimann approximation to place efficient shelving on either side of the greenhouse, approximating a parabola, the most efficient surface. Details are provided in the structural drawing, **Appendix F**.

3.1.2 Optimal Greenhouse Dimensions

Because a lower volume means a lower energy requirement for temperature regulation, we aimed for an optimal growing surface-to-volume ratio. Given the minimum height requirement of 8.5", we decided to maximize growing surface in order to achieve the most plants for the least heating costs. As a result, we used the maximum area our board would allow, 12" wide and 24" long.

3.2 Construction Methods

Prior to actual construction of the model, the group calculated which materials would be used based on location, cost, and efficiency. The construction began with a foundation of bamboo sticks. Next the insulator for the ground (cork) was placed within the foundation. Popsicle sticks were oriented in a vertical position around the outside of the greenhouse and then wooden dowel rods reinforced the popsicle sticks in an X pattern. From here, a door was assembled using popsicle sticks and a dowel rod. This door is large enough for the control circuit and fuel cell to be placed inside the greenhouse. A second door, 4" tall, was constructed on the longer side of the model in order for workers to enter and exit the greenhouse. The stairs follow a parabola, which was determined based on the fact that plants need to receive an equal and adequate amount of sunlight, and shelving was required by the proposal.

The group decided against artificial light, and devised a set of stairs that would satisfy the proposal and increase efficiency of the greenhouse. Four supports for "stairs" were designed using different sizes of popsicle sticks that were hot glued together. Wooden dowel rods 12" long were placed at the back of each step to give the aluminum foil support, which covers the steps. Foam was added under the bottom step on each side of the greenhouse for additional support. Insulation on the outside of the greenhouse was added next. In the model, it is represented by brown craft paper but actually represents cork (there was a limited supply of cork). Similar to the way a canvas for painting is prepared, one corner of the craft paper was glued to the bamboo on the outside of the greenhouse and then this process was repeated until each side was pulled tightly and the paper was smooth. The roof was constructed by placing three dowel rods across the top of the greenhouse.

Meanwhile, longer curved dowel rods were glued to the horizontal dowels. For extra support, small dowels were placed in between each horizontal and curved dowel. Two rods connect the three support beams to the middle of the width sides of the greenhouse. Finally, plastic wrap was placed over the roof to allow the sun to strike the plants and to allow the plants inside the greenhouse to be observed, which was another requirement. Inside the greenhouse, the infrared heater and fans will be suspended from the ceiling. Small fans with a cubic-foot-per-minute ($\text{ft}^3\text{min}^{-1}$) air-moving capacity equal to one quarter of the air volume of the greenhouse are sufficient. For small greenhouses (less than 60 feet long), place the fans in diagonally opposite corners but out from the ends and sides. The goal is to develop a circular (oval) pattern of air movement. Operate the fans continuously during the winter. Turn these fans off during the summer when the greenhouse will need to be ventilated.[6] Evaporative cooling will be used to cool the greenhouse when the temperature is too high and the heater will turn on when the temperature is too cool.

3.3 CAD Renders

The computer aided design (**Appendix F**) was created in Valve's *Hammer Editor*[7], part of the *Source Developer's Kit*.[8] The design (in `.vmf` format) was compiled into a `.bsp` using Hammer's configuration for *Counter-Strike: Source*, allowing for high definition brush surface rendering of both light entities and a sky. The `.png` files shown in the report are compressed and edited from their original format as `.jpeg`s, taken directly through the *Counter-Strike: Source* engine.

4 Energy and Heat Analysis

4.1 Thermal Conductivity Analysis

The amount of heat flow $\Delta J/\Delta t$ through the greenhouse was calculated for each growing season based upon the properties of the materials used and the temperature inside and outside the greenhouse during the respective season. While many of the materials were standard issue and had thermal conductivities which could be easily researched, there was one substance which had a much more difficult k value. As a result, **Appendix B** exists to show our calculations for the thermal conductivity of bubble wrap.

First, the surface area A was calculated for each side of the greenhouse. Next, the constant values for thermal conductivity k and thickness ℓ of each material were added to the spreadsheet. Then, the temperature difference Δt for each growing season was determined. Finally, using the thermal conductivity equation,

$$\frac{\Delta J}{\Delta t} = kA\frac{\Delta t}{\ell}$$

the heat flow through each side of the greenhouse was calculated in J/sec. Lastly, the heat flow values were summed in Table 9 in order to determine the net heat flow through the greenhouse during each growing season.

[6] `http://www.wvu.edu/~agexten/hortcult/greenhou/building.htm`

[7] `http://developer.valvesoftware.com`

[8] `http://developer.valvesoftware.com/wiki/Main_Page`

Table 9: Heat Loss by Season

Surface (m^2)	ℓ (m)	k	Material	$\left(\frac{\Delta J}{\Delta t}\right)_{S1}$	$\left(\frac{\Delta J}{\Delta t}\right)_{S2}$	$\left(\frac{\Delta J}{\Delta t}\right)_{S3}$	$\left(\frac{\Delta J}{\Delta t}\right)_{S4}$	$\left(\frac{\Delta J}{\Delta t}\right)_{S5}$
12×8.5	8×10^{-3}	0.043	Cork	4,112	5,483	1,919	2,193	9,594
24×8.5	8×10^{-3}	0.043	Cork	8,224	10,965	3,838	4,386	19,189
Floor (12×24)	8×10^{-3}	0.043	Cork	11,610	15,480	5,418	6,192	27,090
Roof (523)	4×10^{-3}	0.03	Plastic Wrap	29,419	39,225	13,729	15,690	68,644
			Total (J/sec)	65,700	87,600	30,660	35,040	153,300

Average Heat Loss: 74,460 J/s

Worst Case Scenario Heat Loss: 153,300 J/s

4.2 Energy Calculations

4.2.1 Cooling

To determine the number of joules it takes to cool the greenhouse, we use

$$q = mC\Delta t$$

where m is the number of grams of plants we need to cool, C is the specific heat of water (which plants are mostly composed of), and Δt is the minimum temperature difference our least stable plant can endure. Thus:

$$q = (1.140 \times 10^6 \text{ g})(1 \text{ J/gC})(3^\circ \text{ C})$$

$$q = 3.92 \times 10^6 \text{J}$$

H_2O absorbs 540 calories/g when evaporating, so

$$\frac{540 \text{ calories}}{\text{g}} \times \frac{4.2 \text{ J}}{1 \text{ calorie}} = 2268 \text{ J/g}$$

The amount of energy needed to cool the plants is the same amount of energy the H_2O needs to absorb.

4.2.2 Sprinkler Cycle Length

$$3.82 \times 10^6 \text{ J} \times \frac{1 \text{ g}}{2268 \text{ J}} = 1508\text{g H}_2\text{O}$$

$$1508 \text{ g H}_2\text{O} \times \frac{1 \text{ hg}}{1000 \text{ g}} \times \frac{1 \text{ m}^3}{1000 \text{ hg}} \times \frac{1 \text{ mL}}{1 \times 10^6 \text{ m}^3} \times \frac{1\text{sec}}{48 \text{ mL}} = 31 \text{ sec}$$

Thus 31 sec is the amount of time one sprinkler would have to be on for the plants in the greenhouse to be cooled by 3° C assuming all the water has evaporated and been vented out. Thus there will be three sprinklers which all have to run for about 10 seconds each in a continuous cycle.

4.2.3 Hydraulc Pump Power

$$P = \frac{qpgh}{3.6 \times 10^6}$$

where P = power (kW), q = flow capacity (m^3/h), p = density of fluid (kg/m^3), g = gravitational constant (9.81 m/s^2), and h = differential head (m);

$$q = \frac{48 \text{ ml}}{\text{s}} = \frac{0.173 \text{ m}^3}{h} \times 3 \text{ sprinklers} = \frac{0.519 \text{ m}^3}{h}$$

$$p = \frac{1000 \text{ kg}}{\text{m}^3}$$

$$g = 9.8 \text{ m/s}^2$$

$$h = 3 \text{ m}$$

$$P = \frac{0.519 \times 1000 \times 9.8 \times 3}{3.6 \times 10^6} = .006\text{kW}$$

thus the efficiency of the pump is $\approx 70\%$. [9]
Therefore the hydraulic power required to raise the water 3 m is:

$$P_S = \frac{P}{\% \text{ efficiency}} = \frac{.006}{.7} = .009\text{kW}$$

Now we will calculate hydraulic power to pressurize the water.

4.2.4 Pressurization Energy

Using the same formula, we can calculate the amount of power necessary to pressurize the water in order to deliver it as a spray: in this way, the water will evaporate more quickly. A sprinkler needs 15 psi (pounds/in^2).

$$15 \text{ psi} \times \frac{2.31 \text{ feet of water head}}{1 \text{ psi}} = 34.65 \text{ ft of water head}$$

$$P = .02 \text{ W}$$

so .02 kW + .008 kW $\approx$ .03 kW of total energy used per pump per cycle.

4.2.5 Sprinkler and Fan Energy

The purpose of the fan is to enduce evaporation. According to a study conducted by the University of Florida, the cfm (cubic feet/minute) of a fan needs to be greater than or equal to the total volume of the space which requires air flow in order for a worthwhile amount of evaporation to take place, as a result of the air current.

Our greenhouse has an area of 3000ft^3, which requires two 1600 cfm fans.

$$3000 \text{ ft}^3 \approx 2(1600\text{cfm}) \text{ fans}$$

The total wattage of the fans is 800W.

The evaporation of the water will only lower the temperature of the plants to a certain extent. When the temperature of the plants exceeds a certain amount of degrees below

[9] `igcusa.com/CatalogsGreenhouse_Sprinler_AUG2000.pdf`

the temperature of the water, the droplets which are evaporating will absorb most of their energy from the air. Hence the plants will not become too cold as a result of excessively using the sprinkler cooling method. Since the plants will never get too cold, we can reasonably say that the time between each sprinkler cycle should be the amount of time that the water from one sprinkler takes to evaporate.

From experimentation, our group figured out that when water is sprayed over a surface and exposed to a relatively indirect air flow, the water takes about 6 minutes to evaporate. Unfortunately this experiment was different from a realistic scenario, as the air flow in the actual greenhouse is almost impossible to duplicate. At any rate, the value, 6 minutes, gives us the ballpark time which the sprinkler cooling cycles should be spaced.

The 6 minute spaces between cooling cycles tell us how often to run the sprinklers per day. Assuming the time that the sprinklers take to actually spray water is negligible, so the sprinklers will run around 250 times each for 10 seconds, as we calculated before.

If the cooling sprinklers were to run 250 times day,

$$250 \times 10 \text{ sec} \times 30 \text{ J/s} = 75,000 \text{ J/day used by cooling sprinklers}$$

The fans need to run constantly so that the evaporation will be able to take place and that oxygen as well as excess moisture can be filtered out. As photosynthesis takes place inside the greenhouse, the ratio of oxygen over the rest of the elements in the air increases from that of normal sea level. Plants don't need oxygen, so we need to get it out. The fresh air carries with it a fresh supply of CO_2.

When the sprinklers switch from cooling mode to watering mode, things change. Firstly, the psi is increased to 30, so that it sprays in an increased radius of 6 ft. Secondly, water flow is increased to .5L per second. This makes it so that the sprinklers don't have to be on for a ridiculous amount of time in order to properly water the plants. This specific water flow also ensures that it is possible to distribute the water evenly to all the plants under high pressure. Using these new values, the new energy calculation comes to .62 kW. Since the fans are running approximately all day,

$$\frac{800 \text{ J}}{\text{s}} \times \frac{86400 \text{ sec}}{\text{day}} \times \frac{1 \text{ J}}{1000 \text{ kJ}} = \frac{69120 \text{ kJ}}{\text{day}}$$

The most energy the pump would use to water the plants would be during the garlic growing season. This crop needs a total of 41L of water every day, so the amount of energy the pump uses is:

$$27 \text{ sec} \times \frac{620 \text{ J}}{\text{s}} \times \frac{1 \text{ cycle}}{\text{day}} = 16740 \text{ J/day}$$

4.2.6 Energy Usage of Heater

The advantages of infared heaters are as follows: Infared heaters can run entirely off electric power, which can be provided through solar cells. They also radiate 86% of their input energy. In addition, as opposed to pumping hot air into the greenhouse as a conventional heater would do, the infared heater will heat the air that is already in the greenhouse. In addition, the infared heaters will directly heat the plants below them.

4.2.7 Heat output of Infared heaters

$$1500 \text{ J/s} \times .86\% \text{ efficiency} = 1290 \text{ J/s}$$

Table 10: Energy Consumption Analysis

Requirement	Consumption
Cooling Energy Consumption	75000 J/day
Watering Energy	16740 J/day
Fan Power Consumption	1.7×10^4 J/day
Infared Heater Consumption	7.8×10^8 J/day
Total Energy Consumption	7.8×10^8 J/day 9.111 kW

If the volume of the greenhouse is 83.1m^3 and the density of air is 1275 g/m^3, the number of Joules required to heat the full volume of the greenhouse by three degrees is

$$83.1 \text{ m}^3 \times 1275 \text{ g/m}^3 = 105952.5 \text{ g of air}$$

$$q = (105952.5 \text{ g})(1 \text{ J/gC})(3°C) = 317857.5 \text{ J}$$

$$317857.5 \text{ J} \times \frac{1 \text{ sec}}{1290 \text{ J}} = 246 \text{ sec}$$

which, distributed among six heaters comes to a 41 second **heater cycle time**.

$$1500 \text{ J/s} \times 6 \text{ heaters} = 396 \text{ kJ/cycle}$$

The amount of time it takes for the greenhouse to cool 3° when the outside temperature is 5° hotter in the worst case scenario is:

$$153300 \text{ J/s} \times 3 \text{ seconds} = (105852.5 \text{ g})(1 \text{ J/gC})(3°)$$

and since the number is less than three seconds, we can safely say that the heaters would be on all day in the worst case scenario. Therefore:

$$1500 \text{ J/s} \times 6 \text{ heaters} \times 86400 \frac{\text{sec}}{1 \text{ day}} = 7.8 \times 10^8 \text{ J/day}$$

4.2.8 Final Energy Calculation

Thus if the heaters run all day, we use 7.8×10^8 J/day. The fans run for one minute each to refresh the air, which consumes 1152000 J. The energy required to water the plants is negligible in comparison.

The **grand total of energy** required to run the greenhouse is 7.79×10^8 J/day.

For energy calculation statistics and citations, see **Appendix C**.

4.3 Solar Energy Differential

To calculate the net power a solar panel can produce, we assumed that the sun puts out a solid 1000W, and that the solar panel is relatievely inexpensive and has a low efficiency of $\tilde{1}3\%$.

$$(1000 \text{ W})(13\%) = 130 \frac{\text{watts}}{\text{m}^2}$$

Table 11: Solar Energy Required by Season

Growing Season	Months	Solar Watts	Necessary Energy (W/m^2)	Hours of Daylight
1	Jan-Feb	56.5-64.5	41	8.1
2	Mar-Apr	73.3-77.2	49	7.8
3	May-Jul	75.2-76.4	38	6.0
4	Aug-Oct	64.4-72.0	38	6.7
5	Nov-Dec	53.9-57.5	49	10.6

We can divide up the solar arc into sixths; the first and last sixths of daylight have a lower solar energy efficiency than, say, mid-noon, due simply to the angle of sunlight. As such, we can assume that the solar panel operates at nearly 100% efficiency for a third of the day, at $\tilde{9}0\%$ efficiency for a third of the day, and at 47% efficiency for a third of the day. As a result, the total energy the solar panel produces on an average day from dawn till dusk is:

$$\Big((100\%)(130)(1/6) + (90\%)(130)(1/3) + (47\%)(130)(1/3)\Big) = 81.0 \text{ J/s}$$

If the average amount of sunlight in December is 10.8 hours, then

$$81.0 \text{ J/s} \times 10.8 \text{ hours} = 3.1 \times 10^6 \text{ J/m}^2$$

$$\frac{\text{Total Energy Consumption}}{\text{Energy Output per m}^2} = \frac{7.79 \times 10^8 \text{ J/day}}{3.1 \times 10^6 \text{ J/m}^2} = 247 \text{ m}^2$$

which means 247 m^2 of solar paneling required to power the greenhouse every day.

4.4 Fuel Cell Output

The amount of energy the fuel cell should theoretically be able to store should primarily depend on the amount of days in a row that the solar panels output an insufficient amount of energy. When the skies are overcast the solar panels output drops as low as zero to 25% of the energy they normally output. Therefore in a worst-case scenario situation, we will assume that the solar panels output zero percent of the energy they normally do. The total amount of days in a row that the solar panels could theoretically output insufficient energy is during hurricanes which occur quite frequently. Such events last usually 4-5 days on shore; however can last as long as 12 days off shore. To decrease the odds of an energy deficiency, along with a crop failure, we will safely assume that the hurricane even before it comes into contact with land produces mildly overcast skies for 10 days all of which cause a significant drop in solar power output. The green house needs 7.9×10^6 J per day; multiply this by ten days and we get 7.9×10^7; the total amount of energy in joules the fuel cell needs to store.

5 Circuitry System

5.1 Arduino Psuedocode

For the required plants in any given growing season, there is an absolute maximum temperature the plants can bear and there is an absolute minimum. The average of these two is defined as ‘ideal’. Thus, ‘max’ is defined as halfway between ‘ideal’ and ‘absolute max’, and ‘min’ is halfway between ‘ideal’ and ‘absolute min’. Our pseudocode is as follows:

```
if temp > max:
    turn on fan
if (temp < ideal) and (fan == ‘on’):
    turn off fan
if temp < min
    turn on heater
if (temp > ideal) and (heater == ‘on’):
    turn off heater
```

This ensures a safe and efficient heating procedure for all temperature fluctuations.

5.2 Arduino Explanation

The coding for the microprocessor is rather simple in its actions. If the temperature is higher than a certain threshold, the cooler turns on and if the temperature is lower than a certain threshold, the heater turns on. However, if the cooler turned off the instant the temperature went below that value, the the greenhouse would heat up again above that value and the cooler would turn back on and so on and so forth. In order to prevent the heater and cooler from rapidly cycling through the on and off states, the code waits for the temperature to reach a certain ideal temperature before changing the heater/cooler state back to off. By decreasing the amount of times that the state is changed, the heating and cooling systems will fail less frequently allowing for increased efficiency.

6 Economic Analysis

6.1 Transporation Costs

Notes on Table 12: Because the owners of the greenhouse will be selling the products in a local market, shipping or extensive transportation services are not required. The team opted instead to buy a used delivery truck to shuttle the goods to the market. Less than 200 miles will be driven each year, so the truck is very economical.

6.2 Greenhouse Analysis

Notes on Table 14: Extensive research into ideal garden conditions for our plants indicates that a soil with a pH of 6.5 is ideal. The Dominican Republic offers us this soil naturally in the ground. For this reason, no soil needs to be purchased from a third party - land can be purchased and the soil can be harvested. This process is cheaper than buying soil form a third party. ¶ To calculate how much additional land needs to be

Table 12: Gas and Transportation Costs

Truck Cost	$20,000.00			
Gas Cost	Miles/Year	MPG	Gallons	Cost of Gas
$ 3.94	200	18	11.11	$43.78
Total Cost:	$20,043.78			

purchased, one must find the volume of soil needed. The first growing season requires six inches of soil. The second and third growing season require half of the greenhouse to be filled with 6 inches of soil, and the second half to be filled 7 inches of soil. Therefore, in Season #2, 0.0417 inches of soil must be added. The planting area multiplied the depth of soil needed, and the volume of soil needed was calculated.

Notes on Table 15: The number of seeds planted was multiplied by the price per seed to obtain the total cost of seeds annually for the greenhouse. The price data was obtained from a large northeast bulk seed supplier - Burpee Gardening.

Notes on Table 16: Energy calculations (see the specific calculation in Section 4.3) were preformed to determine the area of solar panels needed for the greenhouse. Because the panels cannot be placed on the roof, they must be placed on the ground. Additional land was purchased. ¶ The Dominican Republic soil is only fertile to a depth of six inches in some areas. The volume of soil needed annually was divided by this depth to obtain an area - the area of land that must be purchased for soil harvesting.

Notes on Table 17: Energy calculations indicate that a 1kW fuel cell system was needed to run the greenhouse. Two 500W systems (from Arcola Energy) were purchased and connected in tandem. ¶ Water pumps are needed to run the sprinkler system, evaporative cooling pads, and water supply to the fuel cell. The "gallon per hour" requirements of these pumps are low, so a significant investment is not necessary. ¶ Compressed gas tanks are needed to store excess hydrogen gad from the fuel cell. A used gas storage tank was sourced from eBay for $1500, which met or exceeded all needs. A water tnak sourced from eBay also serves the fuel cell system by storing excess water. The fans and evaporative cooling systems were sourced from `greenhousesupply.com`. Department of Energy (DOE) estimates were used to compute the cost of the solar panel system, given the area of solar panels needed.

Notes on Table 18: Wood Beams are *Georgia Specific Composite I-Beams*, Steel Cable is *1/2 Steel Cable* from `riggingsupply.com`, Steel Bars are *1/2 round hot rolled* from `metalsdepot.com`, Studs are from *ACE Hardware*, Aluminum is *1/8 corrosion resistant* from `onlinemetals.com`.

Notes on Table 19: The sum of the total construction costs and first year operating costs are summarized below. Second year losses are only about 3% of the first year losses. Thus the greenhouse is extremely profitable. **Labor**: Electricians are needed to install the control circuits and fuel cells, and tos upervise the connection of the solar panels to one another. Plumbers are needed to construct the evaporative cooling system and sprayers. The rest of the labor can be done by unskilled laborers. **Water**: The local price for water in the Chibao Valley was sourced from the CIA world fact book.

Table 13: Economic Seasonal Analysis

Density (# / ft^2)	Seeds #	Harvest %	Produced #	Weight $\left(\frac{lbs}{plant}\right)$	Mass (lbs)	Price ($ / lbs)	Profit ($)
			Growing Season # 1: Garlic Chive				
Garlic Chive							
143.9	446,400	85%	379,440	1.5	569,159	$2.30	$ 1,309,066.65
						Total Profit for One Cycle:	$ 1,309,066.65
			Growing Season # 2: Cilantro, Spinach				
Cilantro							
71.9	111,600	85%	94,860	0.315	29,644	$1.60	$47,429.95
Spinach							
15.4	23,904	85%	20,318	0.3625	7,365	$3.20	$23,569.32
						Total Profit for One Cycle:	$ 70,999.27
						Total Profit for Both Cycles:	$ 141,998.54
			Growing Season # 2: Cilantro, Spinach				
Poinsetta							
1.85	2,880	90%	2592			$12.20	$31,662.37
Orchid							
3.9	6,192	90%	5,573			$20.00	$111,455,88
						Total Profit for One Cycle:	$ 143,078.25
						Total Profit for Both Cycles:	$ 286,156.50
						Total Annual Profit:	$ 1,737,221.70

Table 14: Soil Depths per Season

	Average Soil Depth (ft)	Soil Depth Added (ft)	Volume (ft^3)
Season # 1	0.4167	0	1292
Season # 2	0.4583	0.0417	129
Season # 3	0.4583	0	
Total Volume Required		1421 ft^3	
		40.2382 m^3	

Table 15: Seed Cost per Plant

Plant	# of Seeds Needed	Cost per Seed	Total Cost
Garlic Chive	446,400	0.00019	$ 84.55
Cilantro	223,200	0.00132	$ 293.88
Spinach	47808	0.00250	$ 119.52
Poinsetta	5,760	0.01975	$ 113.76
Orchid	12,384	0.24400	$ 3,021.69
		Total Annual Seed Cost	$ 3,633.40

Table 16: Cost of Land

	Area of Greenhouse	288 m^2
	Area of Solar Panel	247 m^2
	Soil Harvesting	16 m^2
	Total Area Needed:	551 m^2
Area	Price	Total Land Cost
551.25 m^2	0.23 $\$/m^2$	$ 125.32

Table 17: Infrastructure Costs

Item	Price
Fuel Cell	$7,500.00
Water Pump	$ 300.00
Gas Tanks	$ 1,500.00
Water Tank	$ 800.00
Solar Panel	$ 148,200.00
Fans	$ 200.00
Evap. Cool. Sys	$1,800.00
Total Infrastructure Cost:	$160,300.00

Table 18: Materials

Material	Size	Price	Cost
Wood Beams	461.2m	$6.76 / m	$3,117.03
Steel Cable	222.4m	$5.09 / m	$1,130.97
Cork	900m^2	$50.88 / m^2	$45,792.00
Plastic	236m^2	$15.50 / m^2	$3,658.00
Steel Bar	245.7m	$2.17 / m	$532.03
Studs	162.5m	$2.49 / m	$405.18
Aluminum	360m^2	$79.74 / m^2	$28,707.35
Total Building Materials Cost:			$ 83,341.57

Table 19: Profit Analysis

Startup Costs (First Year)		Annual Profits (Subsequent Years)	
Plant Revenue	$1,737,221.70	Plant Revenue	$1,737.221.70
Seed Costs	-$3,633.40	Seed Costs	-$3,633.40
Land Costs	-$125.32		
Labor Costs (startup)	-$682.50		
Labor Costs (normal)	-$4,555.20	Labor Costs (normal)	-$4,555.20
Water	-$1,339.28	Water	-$1,339.28
Infrastructure	-$160,300.00		
Building Materials	-$83,342.57		
Transportation	-$20,043.78	Transportation	-$43.78
Losses	$274,022.05	Losses	$9,571.66
Net Profit	$1,463,199.65	**Net Profit**	$1,727,650.03

Table 20: Water Usage

Use	Amount	Price	Cost
Watering Plants	6,333,747 L	0.00021 $/L	$ 1,330.09
Evaporative Cooling	43,800 L	0.00021 $/L	$9.20
		Total Water Cost:	$ 1,339.28

Table 21: Greenhouse Construction Costs

Job	Man-Hours	Wage/Hour	Cost
Electrician	25	$1.95	$48.75
Construction	750	$0.39	$292.50
Contractor	100	$1.95	$195.00
Plumbing	25	$1.95	$48.75
Planter	250	$0.39	$97.50
		Total Building Labor:	$682.50
		Minimum Wage:	$0.39 /hour

Table 22: Greenhouse Maintanence Costs

Job	Hours/Day	Wage/Hour	Work Days	Cost
Gardener (×3)	4	$0.39	365	$1,708.20
Supervisor	4	$1.95	365	$2,847.00
			Total Annual Upkeep Labor:	$4,555.20

7 Conclusion

Because our team decided to grow in the Dominican Republic, both labor and land costs were lowered and that put us at a distinct economic advantage for the future. Choosing to grow Garlic Chives also brought us a huge profit every year, especially because the Dominican Republic has two growing seasons for that crop. After factoring in the money geared towards climate control systems, materials for the greenhouse itself, labor, maintenance, and shipping, the profitability of this particular greenhouse is significantly higher than a comparable one located in the United States. This "green" greenhouse is environmentally friendly and economically sound in our modern world, something that most greenhouses today cannot boast about. The determining factors in this greenhouse's profitability are the location, the double growing season, and the crop type. In conclusion, this is a new and environmentally friendly way to create the future of greenhouses; it's a step up towards solving the energy crisis, global warming, and starvation all at the same time.

A Arduino Code

```
boolean heaterOn = false;
boolean coolerOn = false;
float minimum;
float ideal;
float maximum;

void setup()
{
   pinMode(2,INPUT);
   pinMode(3,INPUT);
   pinMode(4,INPUT);
   //set the season determiner
   //pins as inputs

   pinMode(11,OUTPUT);
   //sets the "too cold" pin
   pinMode(12,OUTPUT);
   //sets the "too hot" pin
}

void loop()
{
   float tempData = analogRead(A3);
   //gets the temperature voltage
   //reading from the temp. sensor
   float temperature=500*tempData/1023-275;
   //converts the raw data into
   //the actual temperature in celsius
   if (digitalRead(2))
   {
       //season 1 data
       minimum = 18;
       ideal = 20;
       maximum = 22;
   }
   if (digitalRead(3))
   {
       //season 2 data
       minimum = 19.44;
       deal = 20.28;
       maximum = 21.78;
   }
   if (digitalRead(4))
   {
       //season 3 data
       minimum = 22.83;
       ideal = 24.44;
       maximum = 27.5;
   }
   if (temperature < minimum)
   {
       //if the temperature is less
       //than the minimum tolerable
       //temperature, the heater turns on
       digitalWrite (11,HIGH);
       heaterOn = true;
   }
   if (temperature > ideal && heaterOn)
   {
       //if the heater is on
       //and the temperature is above
       //the ideal temperature, the
       //heater is turned off
       digitalWrite (11,LOW);
       heaterOn = false;
   }
   if (temperature > maximum)
   {
       //if the temperature is greater
       //than the maximum tolerable
       //temperature, the cooler turns on
       digitalWrite (12,HIGH);
       coolerOn = true;
   }
   if (temperature < ideal && coolerOn)
   {
       //if the heater is on
       //and the temperature is below
       //the ideal temperature, the
       //cooler is turned off
       digitalWrite (12,LOW);
       coolerOn = false;
   }
}
```

B Thermal Conductivity of Bubble Wrap

The thermal conductivity of bubble wrap is not immediately evident due to its complex shape; to find a reasonable approximation, we estimated the shapes and volumes. The thermal conductivities T_C for air and low density polyethylene are 0.023J/s m C and 0.32 J/s m C, respectively. Although bubble wrap is made of cells arranged in a hexagonal pattern, the ratio of air pocket-to-plastic remains constant with regard to a single cell or a whole sheet.

Because of the compressible nature of each bubble cell, the normally dome-shaped air pockets can be reasonably approximated by cylinders with radius 1/2 inch and height 1/4 inch. Therefore the area of each cell not occupied by bubble is $(11/8)^2 - \pi/4 = 0.48$ in^2, and the base of each cylindrical bubble is $\pi/4$ in^2. The plastic used to form the curved side of each cylinder has an area $A = 2\pi rh = \pi/4$, so the total amount of plastic used in a bubble is $3/4\pi$ in^2, and the total air used in each bubble is simply the volume of each cylinder, $\pi/18$ in^2. The thickness of each bubble is 1/4 in, but the thickness of the plastic itself is 0.01 in or less (rounded up). As such, the original thermal conductivites can be redistributed as a function of the ratio of plastic-to-air; 95%-to-5% respectively. This is represented in the equation by the mass fractions of air and LDPE to the total mass. Thus the heat flow through bubble wrap of area A with temperature difference Δt is

$$\begin{aligned}\frac{\Delta Q}{\Delta t} &= \left(kA\frac{\Delta t}{\ell}\right)_{\text{air, LDPE}} = \frac{m_{\text{air}}}{m_{\text{total}}}\left(k_{\text{air}}A\frac{\Delta t}{\ell_{\text{air}}}\right) + \frac{m_{\text{LDPE}}}{m_{\text{total}}}\left(k_{\text{LDPE}}A\frac{\Delta t}{\ell_{\text{LDPE}}}\right)\\ &= (.95)\left(0.32\frac{\text{J}}{\text{s}\cdot\text{m}\cdot\text{C}}\right)(A)\left(\frac{\Delta t}{0.01\text{ in}}\right) + (0.05)\left(0.023\frac{\text{J}}{\text{s}\cdot\text{m}\cdot\text{C}}\right)(A)\left(\frac{\Delta t}{1/4\text{ in}}\right)\end{aligned}$$

C Energy Calculation Sources

Latitude/Longitude of Dominican Republic `http://www.gorissen.info/Pierre/maps/googleMapLocationv3.php`,
Hours of Daylight in the Dominican Republic `http://astro.unl.edu/classaction/animations/coordsmotion/daylighthoursexplorer.html`,
Frequency of Cloudy Days in the Dominican Republic `http://dominicanrepublic-guide.info/weather/cloudiness/`,
Power Output vs. Angle of Incidence `http://userwww.sfsu.edu/~ozer/engr300-solar1N.pdf`,
Greenhouse PSI Efficiency `http://cetulare.ucdavis.edu/files/82040.pdf`,
Hydraulic Pump Power Forumla `http://www.engineeringtoolbox.com/pumps-power-d_505.html`,
Max/min temperatures in the Dominican Republic `http://qwikcast.weatherbase.com/weather/weather.php3?s=68487&refer=`,
Infared Heater `http://www.theinfraredheatsource.com/Infrared_Heater_Information`,
Fan Power Usage / Cost / Cfm `http://www.4hydro.com/growroom/exhaust-fans.asp`,
Florida University Paper `http://edis.ifas.ufl.edu/cv256`,
Infared Heat Infro `http://www.ceramicx.com/en/`

D Crop Analysis

	Spinach	Soy	Tomato	Wheat	Bell Pep.	Poinsetta	Eggplant	Orchids	Strawberry	Garlic	Cilantro	Lettuce
Dom. Rpb.	$ 3.20	$ 0.09	$ 0.40	$ 0.04	$ 0.08	$ 12.20	$ 0.20	$ 20.00	$ 6.80	$ 2.30	$ 1.60	$ 1.10
Ithaca	$ 5.99	$ 2.49	$ 2.49	$ 0.11	$ 1.99	$ 14.90	$ 1.99	$ 15.00	$ 2.49	$ 3.99	$ 0.82	$ 1.99
NYC	$ 2.49	$ 2.99	$ 2.49	$ 0.11	$ 1.99	$ 20.00	$ 1.49	$ 17.90	$ 3.99	$ 4.99	$ 1.49	$ 2.99
Topeka	$ 1.99	$ 1.99	$ 2.49	$ 0.11	$ 1.99	$ 9.99	$ 1.99	$ 7.99	$ 3.99	$ 1.60	$ 0.99	$ 1.59
Average	$ 3.42	$ 1.89	$ 1.97	$ 0.09	$ 1.51	$ 14.27	$ 1.42	$ 15.22	$ 4.32	$ 3.22	$ 1.23	$ 1.92
Deviation From Average:												
Dom. Rpb.	$ (0.22)	$ (1.80)	$ (1.57)	$ (0.05)	$ (1.43)	$ (2.07)	$ (1.22)	$ 4.78	$ 2.48	$ (0.92)	$ 0.38	$ (0.82)
Ithaca	$ 2.57	$ 0.60	$ 0.52	$ 0.02	$ 0.48	$ 0.63	$ 0.57	$ (0.22)	$ (1.83)	$ 0.77	$ (0.41)	$ 0.07
NYC	$ (0.93)	$ 1.10	$ 0.52	$ 0.02	$ 0.48	$ 5.73	$ 0.07	$ 2.68	$ (0.33)	$ 1.77	$ 0.27	$ 1.07
Topeka	$ (1.43)	$ 0.10	$ 0.52	$ 0.02	$ 0.48	$ (4.28)	$ 0.57	$ (7.23)	$ (0.33)	$ (1.62)	$ (0.24)	$ (0.33)
Percentage Deviation From Average:		[Deviation/Average]*100										
Dom. Rpb.	-6%	-95%	-80%	-57%	-95%	-15%	-86%	31%	57%	-29%	31%	-43%
Ithaca	75%	32%	27%	19%	32%	4%	40%	-1%	-42%	24%	-33%	4%
NYC	-27%	58%	27%	19%	32%	40%	5%	18%	-8%	55%	22%	56%
Topeka	-42%	5%	27%	19%	32%	-30%	40%	-48%	-8%	-50%	-19%	-17%
	NOTE: Dark green corresponds to the most positive deviations from average, dark red correponds to the most negative.											
Average Deviation:												
Dom. Rpb.	-32%											
Ithaca	15%											
NYC	25%											
Topeka	-8%											

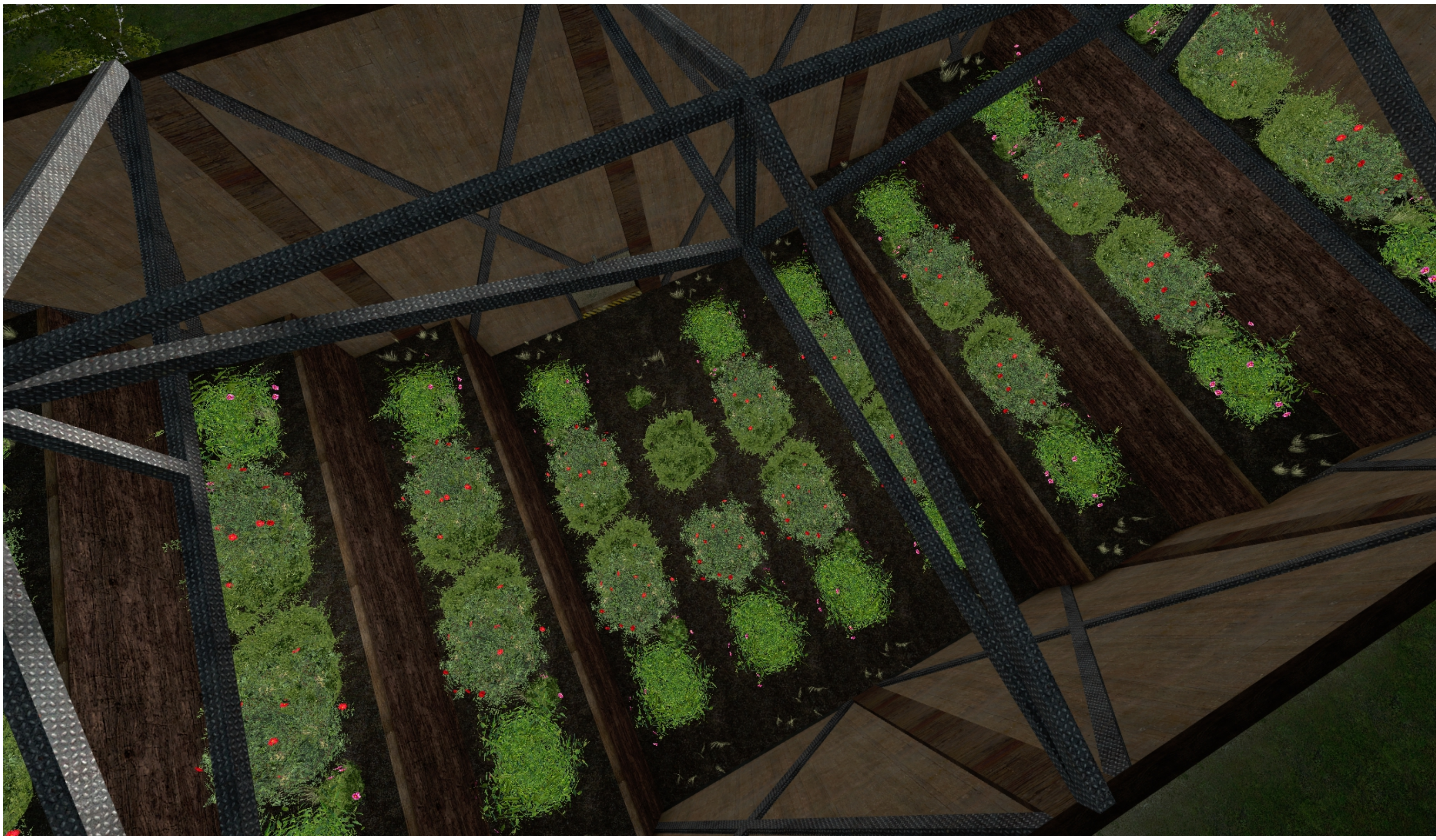
E Plant Profitability Analysis

	Temp MIN	Temp MAX	MIN	MAX	AVG
Spinach	19	22.5	66.2	72.5	69.35
Soy Beans	20	26	68	78.8	73.4
Tomato	21	26	69.8	78.8	74.3
Wheat	21	23	69.8	73.4	71.6
Bell Peppers	18	26	64.4	78.8	71.6
Poinsetta	22	29	71.6	84.2	77.9
Eggplant	20	26	68	78.8	73.4
Orchids	15	32	59	89.6	74.3
Strawberries	12	21	53.6	69.8	61.7
Garlic Chive	17	23	62.6	73.4	68
Cilantro	17	23	62.6	73.4	68
Lettuce	15	19	59	66.2	62.6
	*C	*C	*F	*F	*F

Humidity	Weight	Lb/Plant	Selling Price	Plants/m2	Plants/ft2	Scale Area
50%	5.8	0.3625	$ 3.20	166	15.4219196	2
67%	8	0.5	$ 0.90	20	1.8580626	2
67%	20	1.25	$ 0.40	6.7	0.62245097	2
65%	6	0.375	$ 0.04	687	63.8244502	2
75%	10	0.625	$ 0.08	30	2.7870939	2
70%		0	$ 12.20	20	1.8580626	2
75%	12	0.75	$ 0.20	66	6.13160657	2
60%		0	$ 20.00	43	3.99483459	2
70%	16	1	$ 6.80	30	2.7870939	2
70%	24	1.5	$ 2.30	1550	143.999851	2
75%	5	0.3125	$ 1.60	775	71.9999257	2
75%	6	0.375	$ 1.10	200	18.580626	2
	(ounces)	(pounds)				(Small Scale)
						Sq. Feet

Actual Area	Total Plntd	% Harvstd	Ttl. Hvstd	Scale Profit	Real Profit
3100.0062	30.8438391	85%	26.2172633	$ 30.41	$ 47,138.73
3100.0062	3.7161252	24%	0.89187005	$ 0.40	$ 622.08
3100.0062	1.24490194	51%	0.63489999	$ 0.32	$ 492.05
3100.0062	127.6489	32%	40.8476482	$ 0.61	$ 949.71
3100.0062	5.57418779	80%	4.45935024	$ 0.22	$ 345.60
3100.0062	3.7161252	90%	3.34451268	$ 40.80	$ 63,244.86
3100.0062	12.2632131	90%	11.0368918	$ 1.66	$ 2,566.08
3100.0062	7.98966917	90%	7.19070225	$ 143.81	$ 222,912.22
3100.0062	5.57418779	60%	3.34451268	$ 22.74	$ 35,251.23
3100.0062	287.999703	85%	244.799747	$ 844.56	$ 1,309,069.27
3100.0062	143.999851	85%	122.399874	$ 61.20	$ 94,860.09
3100.0062	37.161252	85%	31.5870642	$ 13.03	$ 20,196.02
(Lg. Scale)					
Sq. Feet					

F CAD Renders

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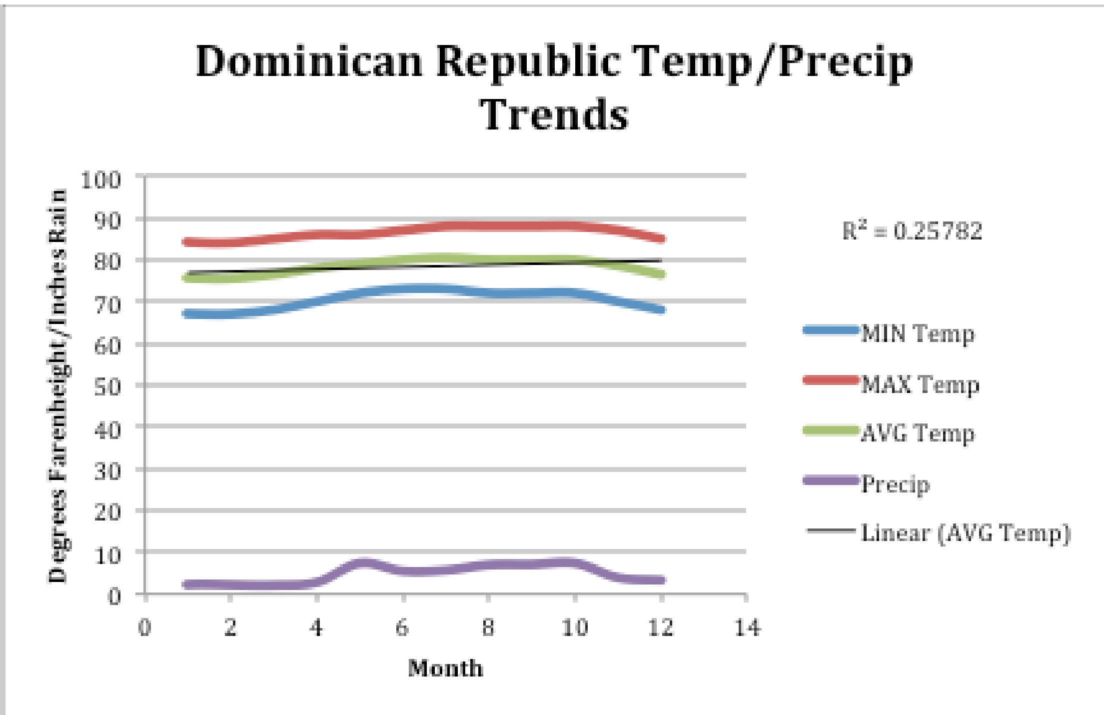
G Temperature Statistics by Location

Table 23: Temperature Statistics by Location

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature Statistics in the Dominican Republic												
Min	67	67	68	70	72	73	73	72	72	72	70	68
Max	84	84	85	86	86	87	88	88	88	88	87	85
Avg	75.5	75.5	76.5	78	79	80	80.5	80	80	80	78.5	76.5
Prec.	2.5	2.2	2.1	2.8	7.4	5.5	5.7	7	7.1	7.4	3.9	3.3
Yearly Average Temperature							78.3					
Yearly Average Precipitation							4.7					
Temperature Statistics in Ithaca, NY												
Min	14	14	22	33	43	53	57	56	48	37	31	20
Max	31	33	42	55	67	76	80	79	71	59	47	36
Avg	22.5	23.5	32	44	55	64.5	68.5	67.5	59.5	48	39	28
Prec.	2.1	2.1	2.6	3.3	3.2	3.9	3.5	3.4	3.8	3.2	3.1	2.5
Yearly Average Temperature							46.0					
Yearly Average Precipitation							3.1					
Temperature Statistics in New York City												
Min	23	24	32	42	53	63	68	66	58	47	38	28
Max	36	40	48	58	68	77	83	81	74	63	52	42
Avg	29.5	32	40	50	60.5	70	75.5	73.5	66	55	45	35
Prec.	3.9	2.9	4.1	4.1	4.5	3.5	4.2	4.1	4.1	3.5	4	3.9
Yearly Average Temperature							52.7					
Yearly Average Precipitation							3.9					
Temperature Statistics in Topeka, Kansas												
Min	16	21	32	42	54	62	67	64	55	44	32	21
Max	37	42	55	66	75	84	88	87	78	68	54	40
Avg	26.5	31.5	43.5	54	64.5	73	77.5	75.5	66.5	56	43	30.5
Prec.	1	1	2.5	3.1	4.5	5.5	3.6	3.9	3.8	3.1	1.9	1.4
Yearly Average Temperature							53.5					
Yearly Average Precipitation							2.9					

Figure 4: Regional Weather Trends



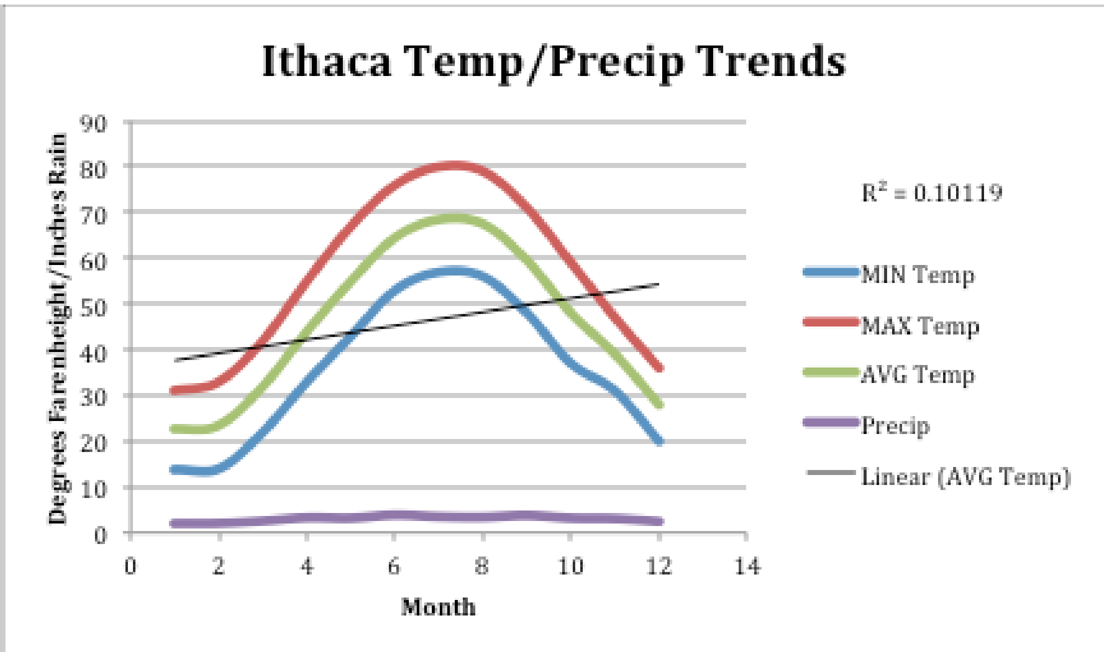


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Figure 5: Map of the Dominican Republic