EDSGN 100

Section 20, Spring 2013
Liz Kisenwether

I³ Greenhouse Glazing

Katie Raudenbush, Max Webb, Lauren Thompson, Darren Slotnick

Darren Slotnick – Front Page Info, Problem Statement, Final Editor
Responsibilities: Tester, Writer

Lauren Thompson – Concept Development, Testing
Responsibilities: Tester, Researcher

Max Webb – Design Refinement and Testing
Responsibilities: Tester, Built Frames

Katie Raudenbush – Costing, Lessons Learned
Responsibilities: Researcher, Created handout

Problem Statement

At Team I^3, our goal is to develop Innovative Ideas for Improvement. We focused on creating an inexpensive glazing for low-cost greenhouses that could last one year in a typical Kenyan environment. Glazing is the term used for the cover material that is placed over a frame, forming a greenhouse. Kenyan farmers could buy our glazing and use their increased profits to purchase a more permanent glazing solution. It was important that our design was durable in both rain and UV light, affordable for poor Kenyan farmers, and was made of a material that was either available locally or could be cheaply imported from China. Our goal was to create or find a glazing that can be produced for under $30 per 1500 square feet, the amount of material needed to cover the greenhouses in Kenya, while at the same time meeting all of the other stated requirements.

Concept Development

Our team conducted extensive research from several sources to further our understanding about the economic conditions in Kenya, as well as the country's history and its societal structure. One of the key facts that influenced our design was the high range of temperatures that can be seen on a given day. Kenya can get cold at night and very hot during the day. Our greenhouse glazing needed to be able to insulate the plants when it was cold, but not suffocate them when it was very hot. We also found that most farmers in Kenya were relatively poor and did not have much money to spend. As a result, we needed to keep the glazing as cheap as possible. We also found that there was extreme weather in Kenya, including heavy rains and a scorching sun. Our glazing had to be durable enough to handle this environment. We used the Internet to write an initial comprehensive report on the history of Kenya, as well as its societal and economic conditions. We also took advantage of the time that Kanjan Mehta, the head of the Greenhouse project, spent talking to our class by asking him multiple questions regarding various conditions in Kenya.

Using our research, we determined several critical features that our glazing would need to have. The glazing had to be durable in the rain and wind, and easy and cheap to repair if it ripped. Our material needed to keep pests out of the greenhouse, and at the same time let in visible light so the plants can grow. It needed to be able to fit the existing greenhouse structure the Penn State team had designed, and farmers needed to be able to roll up the glazing and attach it to the structure on especially hot days. Finally, our glazing needed to be made of a locally available material, and be aesthetically pleasing to farmers in Kenya.

Figure 1 shows a scanned photo of our earliest design concept. Figures 2 and 3 below show our first four prototypes, and the structure they were held together with. We tested these prototypes to see if they had the features that our glazing needed. Figure 4 shows the first paint coating we tested, hoping that it would help our materials become more durable and water-resistant. Finally, Figure 5 shows the coated nylon material being put through a test to see if its coating would flake off if the material was stressed or folded.

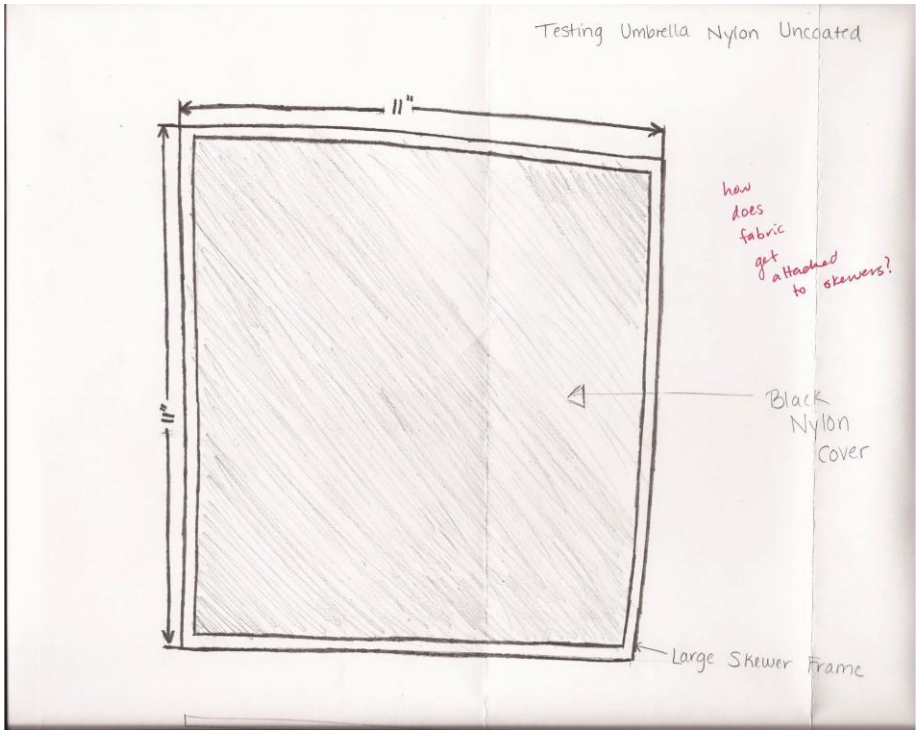

Figure 1: Shown above is a scanned version of an early concept design for a frame made from wooden skewers that can be used to hold a material being tested.

Figure 2: This photo shows our first four prototypes. Coated and uncoated rice bags are displayed on the right, and coated and uncoated nylon is displayed on the right.

Figure 3: In this photo, the backs of our first four prototypes are displayed. You can see the skewer frames that hold the material taught.

Figure 4: Shown is a close-up of the BEHR paint coating on the nylon fabric.

Figure 5: This photo demonstrates the lack of stiffness of the coated nylon material.

Table 1: AHP Matrix

	Rain/Wind Durability	Attachable	Keeps Bugs Out	Easy/Cheap to Repair	Fit Existing Structure	Aesthetic Appeal	Local Material	Scatter Light	
Rain/Wind Durability	1	0.25	0.5	0.5	0.5	0.333	3	0.165	
Attachable	4	1	4	3	1	2	6	0.5	
Keeps Bugs Out	2	0.25	1	0.5	0.25	0.333	2	0.165	
Easy/Cheap to Repair	2	0.333	2	1	1	0.333	2	0.165	
Fit Existing Structure	2	1	4	1	1	2	4	0.5	
Aesthetic Appeal	3	0.5	3	3	0.5	1	3	0.25	
Local Material	0.333	0.165	0.5	0.5	0.25	0.333	1	0.165	
Scatter Light	6	2	6	6	2	4	6	1	
Total	20.333	5.498	21	15.5	6.5	10.332	27	2.91	109.073
Weight	0.19	0.05	0.19	0.14	0.06	0.09	0.25	0.03	

Our AHP Matrix, shown in table 1, provides the various features we decided to be most and least important when designing an ideal glazing material. As can be seen, we found it most important that our glazing was made of local material, although we later realized that criteria was next to impossible to meet if our other features are to be considered. On the other hand, we saw "scattering light" as least important based on our weight of .03 on our AHP. We felt there were far more important things than something as sophisticated and technologically advanced as a greenhouse that scatters light for optimum growing. We just needed a basic greenhouse to get these poor farmers through a year of crops.

The name for our final product is I^3 Greenhouse Glazing, as our team name is I^3, and the name "Greenhouse Glazing" will help a Kenyan farmer know exactly what our product is with little to no description. A product that has a name that is irrelevant to its use may unintentionally confuse uneducated farmers. By being as direct as possible in our product's name, we hope to break through any language barriers and make it crystal clear what we are selling.

Testing – Prototype 1

Our test results from prototype 1 helped us determine which material was working the best, and helped us identify things that weren't working. The rice bag was the only local material we tested, but it did not hold up well on other tests, such as the rain durability test and the visible light test. The nylon performed well on the rain durability test, although coating it with paint did not improve its performance. The rice bags were not waterproof, and according to our test results, would absorb large amounts of water after rainfall. More specifically, Table 2 shows the initial mass of the tested materials from prototype one and then the final mass after we poured one gallon of water over each of the materials. The column for time represents the amount of time in minutes that we took to pour the one gallon of water on the material.

Table 2: Rain Durability Test

	Initial Mass	Final Mass	Time (minutes)
Rice bag	20.0 g	28.2 g	2:07
Coated Rice Bag	22.0 g	30.8 g	1:50
Nylon	19.5 g	20.6 g	1:10
Coated Nylon	22.1 g	24.5 g	2:40

This data shows how much water, in grams, each material absorbed after being subjected to heavy rain, calculated to be approximately equivalent to 45 inches of rain per hour**.** This extreme simulation is much more intense than any rainfall in Kenya, but will test the limits of our glazing prototypes. The data shows that the nylon material did not absorb much water at all, while the rice bag absorbed nearly 50% of its weight in water. This indicates that a rice bag material would likely sag or even collapse due to the additional weight in heavy rains.

We needed our material to be durable enough to last a year in Kenya's expected weather conditions. Neither the rice bag or the nylon seemed to be durable to the degree we needed, but the rice bag especially flimsy, as it was falling apart after two weeks of testing. Bugs could likely pass through split cross-hatchings on the rice bags. Finally, according to a survey of classmates, the coating made both the nylon and the rice bags less aesthetically pleasing.

Based on these test results for prototype #1, we determined that uncoated nylon was our best choice out of the four options. Due to the poor performances of the materials after being coated with paint, we decided to focus more on the material instead of the coating for our second round of prototypes. We worried that there were too many variables that a coating needed to satisfy at the same time, such as being UV repellent as well as water resistant. In addition, a coating would have driven up the cost of the material significantly. We also determined that we needed more durable materials to test. The rice bag in particular was simply too flimsy to hold up under the elements for a year.

Spending time in class talking to Shayne Bement, a member of the Penn State greenhouse team, was also beneficial in our second round of prototype developments. Shayne provided us with much needed insight on the conditions in Kenya and offered an educated opinion on the ideas we had come up with so far. Shayne emphasized that we should focus our designs on being simple and inexpensive. As a result of both experimentation and talking to Shayne, we decided to create our second prototypes with two new materials, and to eliminate an expensive and minimally effective coating from our design.

Design Refinement and Testing

After the first round of prototype testing, we used the selection matrices and the AHP to adjust what we would do for the second prototype. After prototype 1 testing, we quickly saw that the rice bags were failing several of our tests, including its durability in the rain and its ability to keep out bugs. Both rain durability and a material's ability to keep bugs out were important factors as determined by the AHP

matrix and selection matrices. As a result, we decided to stop testing the rice bags and focus our efforts on two new materials for prototype 2, specifically Polyvinyl chloride plastic, also known as PVC plastic, and shower curtain. These prototypes are shown in Figure 7 below: nylon is the black square on the right, PVC is the clear plastic square in the center, and the shower curtain is the hazy square to the right.

We also made the decision to stop using a paint coating on our materials when constructing our second round of prototypes. When applying our paint coating to the nylon and rice bags, we found that they had little to no positive impact on the materials durability, and actually had a negative impact on the rice bag and nylon's rain durability. As a result, we decided to try a different type of coating for the second prototypes. Figure 6 shows our updated design for the layout of our glazing. By only covering the upper 75% of the greenhouse in glazing, we can save money and instead use a slightly more expensive and higher qualtiy material.

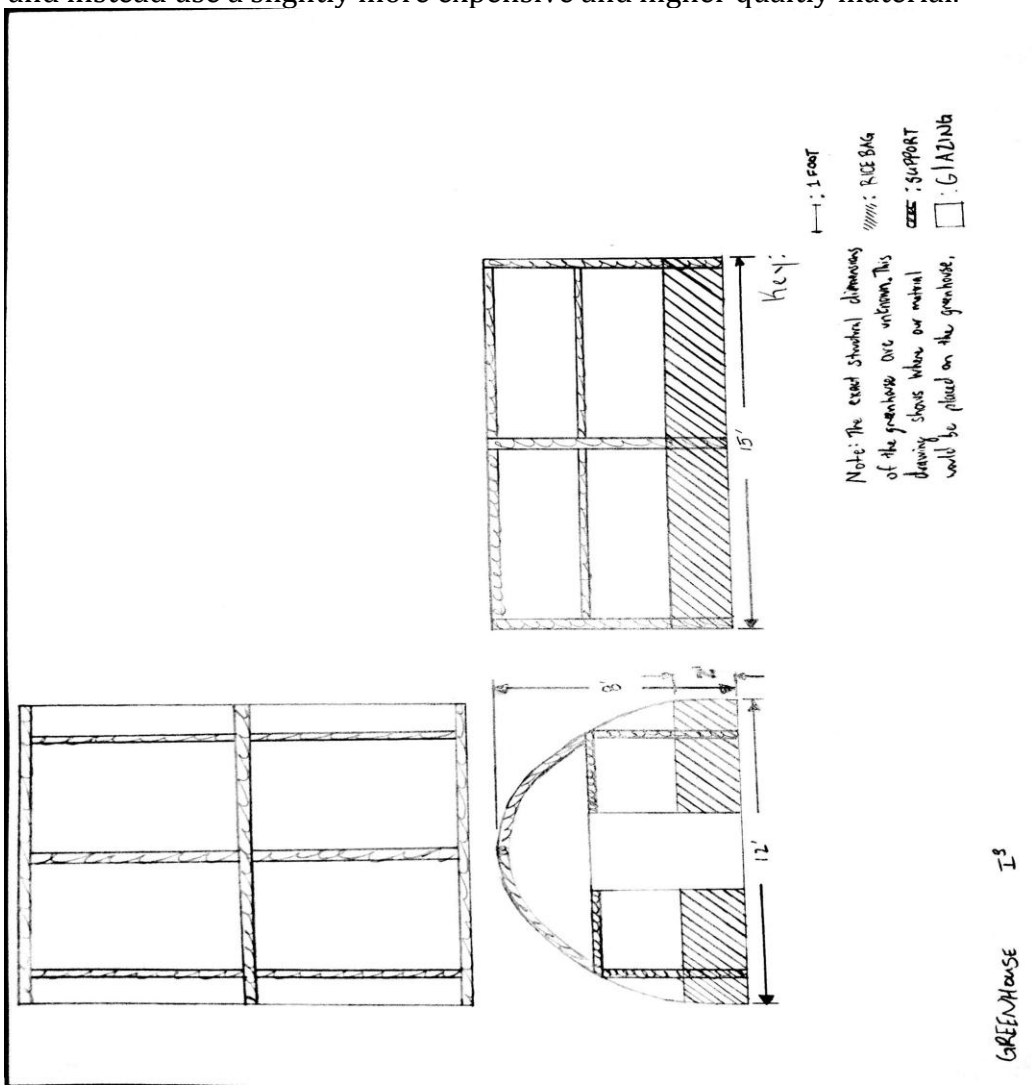

Figure 6: Shown is a scanned copy of our design that ensures our material provides optimal glazing covering.

Figure 7: This photo shows our three final prototypes: nylon, PVC plastic, and shower curtain.

Table 3: Selection Matrix

DEM Project	Feb. 15, 2013		Prototype #2		Concept Selection Matrix		
	Design Failure needing work: _____						
		*Score 1-5		*Score 1-5		*Score 1-5	
Design Constaint [C] or Feature [F]	AHP weight	Design Concept #1: Nylon	Weighted Score	Design Concept #2: PVC	Weighted Score	Design Concept #3: Shower Curtain	Weighted Score
Rain Durability [C]	0.19	5	0.95	5	0.95	5	0.95
Keeps Bugs Out [F]	0.19	2	0.38	5	0.95	5	0.95
Easy/Cheap to Repair [C]	0.14	2	0.28	1	0.14	1	0.14
Aesthetic Appeal [F]	0.09	3	0.27	5	0.45	4	0.36
Fit Existing Structure [F]	0.05	5	0.25	5	0.25	5	0.25
Scatter Light [C]	0.03	1	0.03	5	0.15	5	0.15
Local Material [F]	0.25	1	0.25	1	0.25	1	0.25
		Total:	2.41	Total:	3.14	Total:	3.05
		* Score = 1: design concept fails to meet this feature or contraint					
		Score = 5: design concept meets this feature or constraint very well					

The ability of a material to let through visible light was one of the most important tests we ran on the second prototypes. We used a visible light meter, which measures how much visible light was reaching the sensor, and determined a base reading of 1300 lux without any obstruction between the sensor and a fluorescent light bulb. A lux is the standard unit used for measuring luminance.

Next, we placed each material between the light source and the sensor. Unfortunately, the black nylon performed very poorly on this test, letting through only 120 lux, or 9% of visible light. Since plants need visible light to grow, we determined that we wouldn't be able to use black nylon as the greenhouse glazing. We do expect that a clear nylon would perform better on the visible light test. On the other hand, the PVC plastic and shower curtain both performed very well, as the PVC plastic let through 1190 lux and the shower curtain let through 1060 lux, or 86% and 80% of visible light, respectively. After we finished experimenting, we determined that this is one of the biggest advantages that the PVC plastic and shower curtain materials have over the nylon.

Another important feature that we tested our materials for was their durability in rain. To conduct this experiment, we first weighed our material to determine its weight while dry. Next, we poured a gallon of water on the material over a period of about two minutes. This is equivalent 45 inches of rain per hour, well beyond any heavy rainstorm that will occur Kenya. By simulating an extreme rainfall, we tested the limits of our materials. Afterwards, we briefly shook out the material, and then weighed it again to see if it absorbed any water. All prototype 2 materials tested performed very well on this test, as they retained only about .5 grams each, which can be attributed to water droplets left on the surface. If there is .5 grams of water left on one square foot of material over 1500 square feet, then that would translate to approximately 1.65 pounds of absorbed water over the entire greenhouse. This leftover water is insignificant and alleviates any fears of a collapsed greenhouse due to too much extra weight after a rainstorm**.** Our results indicate that all three materials are essentially waterproof.

Since it wasn't practical to determine if the materials met the rest of the requirements through testing, we instead conducted research and observed the materials' physical properties. After a week of testing, it was evident that the nylon was beginning to tear, while the PVC plastic and shower curtain showed no signs of wearing down. The PVC plastic and shower curtain's durability was another advantage the two materials had over nylon.

We used the selection matrix shown in Table 3 to help evaluate our best material in our second round of prototypes. You can see that The PVC Plastic was the top performer, scoring a perfect 5 in all but two categories. The shower curtain was close behind, scoring lower than PVC plastic in just its aesthetic appeal. While initially promising, nylon is relatively unable to keep bugs out and scatter light. Based just on material properties, the PVC plastic was our best prototype 2 option.

Costing

We made many assumptions when determining the total cost of our greenhouse glazing. One assumption we made was that there is an existing greenhouse structure onto which a 1500 square foot sheet of our glazing choice may be laid. We assume there will be no additional installation cost, as the assembly is simply tossing the glazing over the structure and securing both sides with rocks or other heavy objects. No attachment hardware will be necessary. We also assume

that each different material will have identical transportation costs per square foot, as each will be imported from China directly to a local market in Kenya. Transportation costs will be included in final estimation of the project cost.

After testing, rice bags, solar protectant paint and spray were all eliminated from our final prototypes. Therefore, their costs will not be included because of their testing failures that proved them to be of little use to our final goal. The three materials that will be analyzed for cost effectiveness will be the shower curtain, nylon, and PVC plastic sheet.

Shower Curtain:

Source used:
http://www.alibaba.com/product-gs/569042156/white_shower_curtain_hotel_polyester_shower.html?s=p

According to alibaba.com, a white shower curtain from Shanghai in China costs $2.00-3.50 per curtain. According to ehow.com, a typical shower curtain is 6 by 6 feet. Because the size of the curtain is not specified, we will assume that the Shanghai curtain is of average size. . We also assume that we may order the shower curtain material in large pieces, not cut in the traditional shower curtain sizing. From this, we can deduce that enough glazing material to cover 1500 square feet on a greenhouse will cost somewhere between $83.33 and $145.83. This is beyond our $30 goal.

PVC Plastic:

Source used:
http://www.alibaba.com/product-gs/510955110/pvc_plastic_sheet.html

According to alibaba.com, a 1-millimeter thick PVC plastic sheet costs $1.00-2.00 per square meter. However, our PVC sheet was noticeable less than 1 millimeter thickness, so we will assume that our material will cost only 50% of the 1 millimeter sheet of PVC plastic. 1500 square feet is equivalent to 139.35 square meters, so enough glazing to cover a 1500 square foot greenhouse at the adjusted rate will cost $69.67-139.35. This is slightly closer to our $30 goal.

Nylon Material:

Source used:
http://xinsiwei.en.made-in-china.com/product/gKxmCnQJBGVu/China-290t-Nylon-Taffeta.html

According to made-in-china.com, a 1 meter by 1.5 meter square of nylon costs between $.98-1.06. As stated before, 1500 square feet is equivalent to 139.35 square meters, so enough glazing to cover a 1500 square foot greenhouse will cost $91.04-98.47. This is the most expensive material and is the farthest from our $30 goal.

However, as a bonus, the supplier also conveniently supplies add-ons such as UV protection, in case the nylon alone is not enough to keep the material from disintegrating. This could prove to be an important advantage over other materials if determined through further testing that none of the other glazing materials withstand UV deterioration.

Transportation Costs:

Since it is assumed that transportation costs will be equal for each material, we already have determined that PVC plastic is the most affordable, followed by shower curtain and finally nylon material. However, for the sake of finding a more accurate estimation of cost, transportation will be included. It is assumed that the lowest price will be applicable for both materials and transportation, as all materials will be bought and transported in bulk.

Source used:
http://www.alibaba.com/product-gs/674659520/cheap_china_air_freight_to_Kenya.html

According to alibaba.com, cargo shipping by air is $1.00-50.00 per kilogram. (It is assumed that materials bought in bulk will have a lower cost.) Nylon is estimated to be 60-62 grams per square meter. It is assumed that the other two materials will have a similar weight as they look and feel equal in density and thickness. In this case, a 1500 square foot greenhouse will require 8.36-8.64 kg of material. With the bulk shipping, this will mean about $8.36-8.64 for shipping per greenhouse. We will use the lower end of the transportation cost estimate as well due to the materials being bought in bulk.

With transportation costs accounted for, shower curtain will cost an estimated $91.69, PVC plastic will cost an estimated $78.03, and nylon will cost an estimated $99.40 per greenhouse. These prices are all beyond the $30 goal, but the most economical choice of our prototype 2 materials is PVC plastic at $78.03 per greenhouse. Although this may seem high compared to our goal, it is significantly lower than the $120 currently spent on glazing for each greenhouse by the Penn State Greenhouse Team.

Lessons Learned

If there were a third round of prototype design and testing, our group would most likely test a few local materials. Our access to information about readily available materials in Kenya was limited, and because we had to order our materials and begin testing soon after we began research, we were unable to find a local material that had any good attributes for the greenhouse glazing's necessities. After walking around at the DEM Showcase, we were able to see many other ideas for

locally available greenhouse glazing. Our team was particularly interested in the glazing done with vines or other living plants, and the glazing done with discarded plastic bottles. If we were given sufficient time to build and test another prototype, our team would test both a vine type of plant and a material made from cut up plastic water bottles for all of our previous tests. With more time, our team could also obtain an operational UV light detector and test all of our prototypes for UV durability. This is a very important aspect of our glazing and it is necessary to see if a material can withstand solar radiation, unlike the rice bags.

Our team worked very well together. Our personalities provided our team with unique qualities and where one teammate lacked skill, another excelled in it, making us well rounded as a unit. When we came to roadblocks or disagreements, we had positive and open-minded discussions about how to solve the problem. This happened several times when our materials failed tests. Instead of blaming one another and becoming discouraged, we came up with many new materials to test that would correct whatever the previous material had lacked. This required some extra prototypes to be made, but in doing so we came up with several reasonable solutions. Another disagreement our group overcame was whether or not to do the Greenhouse Glazing project or the Gutter system project. Our group was split on the issue, but after an open discussion where we weighed the pros and cons of doing each project, our team collectively decided to do the glazing project.

Our biggest problem our team experienced was not so much the way in which we split up our work or the dynamics of our group, but instead the lack of knowledge about the technology we had at our disposal. We were unable to use the UV radiation detector because of our lack of experience with the technology as well as faulty equipment, so we were unable to test a big factor of our design. As a whole, we did not have much prior knowledge of local materials in Kenya, nor did we know much about the details of trade between China and Kenya. These attributes could have greatly helped our prototype development if we had more prior knowledge provided by the PSU Greenhouse Team on these issues.

As we were the only greenhouse glazing team, we ran into many unique problems, specifically because of the timeline and due dates for our prototypes and testing. For example, the greenhouse glazing required more extensive research and relatively less time constructing the prototypes. In addition, the greenhouse glazing took a lot longer to test. In fact, to test it properly for decay due to UV radiation, a few months would be needed. We were given leeway because of these roadblocks, but an improvement for the DEM activity would be coming up with a separate, detailed timeline so that both the gutter groups and the greenhouse glazing groups can make the most of their class time.

The Greenhouse Glazing project was a unique and challenging experience for our team. Coming up with an affordable material that had all the features required by a real greenhouse was a difficult task, yet our team approached the challenge with determination, persistence, and an open mind. We believe our final prototypes all have qualities that would make them a great greenhouse glazing. Although they do not meet our initial cost goal, they are a significant improvement on the existing cost of glazing, and each is a viable and more independent alternative to the glazing in place.