

To whom it may concern at the University of Idaho Extension:

This document is a final report for the High Tunnel Greenhouse Project. This report encompasses all of the project learning, research, and design specifications.

High Tunnel Greenhouse

Design Report

Team Stand Your Ground



Members: Faisal Alahmadi Christopher Kreps
 Kyle MacLean Stephen Van Patten

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Executive Summary

This project's goal is to design the ideal high tunnel greenhouse to survive the high wind speeds and snow loads in the Buhl, Idaho area. The University of Idaho extension's high tunnel greenhouses have been failing due to these conditions. The primary design needs for the greenhouse are the ability to withstand wind speeds of 65 mph or higher and to withstand snow loads of 20 psf or more. Secondary needs for our design include the incorporation of passive ventilation in the greenhouse sides and a door large enough to permit access for a small skid-steer loader. Our final design meets all of the primary and secondary goals for the project. The main feature for our solution is the windbreak structure. We designed this feature to minimize the wind forces on the leading edge of the greenhouse by deflecting the wind. Other features of our solution include a NRCS approved steel frame kit for the main greenhouse structure with side ventilation, a sufficiently large door, and double layered 6 mil plastic sheeting. Our design effectiveness will be determined in a ten-year study comparing the structural integrity of a traditional greenhouse design with our modified design. This will contribute to improving greenhouse designs thereby minimizing costs for our client incurred through damaged crops and greenhouses.

Background

Given the high wind speeds and average snow loads in the Buhl, Idaho area, the University of Idaho extension's high tunnel greenhouses have been failing. This has resulted in costly repairs and project setbacks for research. Our project is to design the ideal high tunnel greenhouse to survive the area's environmental conditions. This will contribute to improving greenhouse designs thereby minimizing costs for our client incurred through damaged crops and high tunnels. Long-term benefits include utilizing our high tunnel windbreak design throughout the industry to improve the integrity and longevity of high tunnels.

Problem Definition

The primary design goals for the high tunnel are to have the ability to withstand the area's high wind speeds and snow loads. Secondary goals for our design include the incorporation of passive ventilation in the greenhouse sides and a door large enough to permit access for a small skid-steer loader. The deliverables for our project are a final high tunnel design and an assembly manual for the client. Other deliverables include our research data and our suggestions for a testing regimen for the 10 year study comparing the structural integrity of a traditional greenhouse design with our modified design.

The critical specifications for our design are the ability to withstand a sustained wind speed of 65 mph with an extreme goal of withstanding 105 mph gusts. Another specification is the ability to support a snow load of up to 20 psf. Secondary specifications include the greenhouse dimensions, features, and lifespan. All of these specifications must be met with the high tunnel facing into the most common wind direction. Our budget to complete the project is \$16,000. A detailed summary of our design specifications are located in Table 1 below.

High Tunnel Greenhouse		
Desired Specifications		
Variable	Design Goals	
Wind Speed	Customer: 65 mph	Worst Case: 105 mph
Snow Load	Avg. Snowfall=31.3"	Loading up to 20 lb/ft ²
Foundation Dimensions	Length=40ft	Width=24ft
Door Dimensions	Height=8ft (min)	Width=6ft (min)
Ventilation	Passive Roll-up Sides	
Orientation	Facing Wind	
Life Expectancy	10+ Years	
Cost	Budget=\$16,000	

Table 1: This table defines our design specifications.

Project Plan

The design schedule is located in Appendix E. The project was organized into four different sections that each encompassed a portion of the project's development. These were completed according to deadlines that were previously established at the beginning of the project. Within each of these project sections were general tasks that were due periodically. The top section listed deadlines for the capstone class, as well as vacations to help with the overarching timeline structure. The timeline was left in a general format to allow for flexibility in changing the dates of specific project phases.

Team responsibilities are divided equally between our four members. Faisal is responsible for team documentation and meeting minutes. Chris is the team manager and is in responsible for maintaining the project schedule. Chris is also responsible for the team Wiki page. Kyle is responsible for organizing team meetings and shares responsibility for up keeping the team budget with Stephen. Stephen is responsible for maintain client communication in addition to his responsibilities with the budget.

Concepts Considered

Our team considered many different designs to accommodate our client's needs. The highest priority for this project was to reduce the problematic wind force on the end walls. To accomplish this we considered natural windbreaks, different geometry end-shapes, extra interior support, manmade external windbreak, and portable windbreaks.

Our first option was a natural windbreak, which is a screening mass of trees or shrubs located in front of the high tunnel in the direction of the primary wind source. This method would be expensive, space consuming, and would take extensive time for foliage to reach maturity. In addition, it could block sunlight, which would be detrimental to the crops. However, this method would take little technical experience to assemble and would be effective at diffusing wind.

Our next consideration was the end shape geometry. We considered modifying the end to be aerodynamic to deflect the wind. This method would be very effective at reducing the forces on the high tunnel. It also would be more cost effective. In order for this design to be effective, we needed to carefully consider the means of entry, ease of construction, as well as the footprint of the design. The extra support and detached windbreak would take up valuable space and be less effective than some of the other methods.

The next main consideration was the high tunnel's body style. There are two traditional frame types for high tunnels: gothic/gable and quonset. The gothic/gable style is generally taller than the quonset and has flat sidewalls with a pointed roof. This design is more effective at shedding snow because of its steep peak. It also has more

space on the inside to maneuver around. The quonset style is traditionally easier to construct and a bit cheaper than the gothic/gable style. The two styles are shown below in Figure 1.



Figure 1: The left picture shows a gable style and the right shows a quonset style

Another key consideration was the frame material. We researched different materials such as wood, steel, aluminum, and plastic piping. A wood frame would be cheap and easy to work with; however, it is susceptible to weather. Steel and aluminum are strong and long-lasting options. Aluminum is a very expensive option. We found that different types of plastic piping can be used for easily installed quonset framing; although, it isn't as strong and durable as the other frame options.

We also needed to consider different coverings, covering attachment methods, and mechanisms for passive ventilation. Our client suggested the use of an 11 mil woven plastic covering over the traditional 4-6 mil covering. We found that the 11 mil is very expensive and the expected life was minimally larger than the traditional covering. The 4-6 mil covering was comparably very cheap and doubling it up could provide more strength. We found that the most common method to attach the plastic sheeting was to use wiggle wire attachments. They are very easy to use and provide a great amount of strength to hold the plastic sheeting taut. In order to accommodate the client's passive ventilation needs we considered different designs of rolling plastic sides. The sides can

be installed to either roll up or down and can be activated manually or by motor. There are minor differences in the roll up or down sides and we found that the roll-up sides have proved effective. We also found that the manual rolling sides are not difficult to use and that the cost of a motor for our project is unnecessary.

The next consideration was the anchoring method. There are two main anchoring types: earth anchors and concrete anchors. Earth anchors would be cheaper options but do not provide as much strength as concrete anchors. We found that the earth anchors we would be using are rated from 1500 – 2500 lbs of vertical pullout force. A picture of an earth anchor setup is shown below in Figure 2.



Figure 2: This figure displays an earth anchor setup.

As you can see from the figure above, the installation for earth anchors would be fairly quick whereas concrete anchors would be more time consuming. Each method requires that the anchoring method reaches beyond the frost depth to be effective. We found that the Buhl, Idaho area's frost depth is around 24 inches.

Finally, we considered different door types. This depended on the type of windbreak mechanism that we used. Some of the designs we considered were a barn door type, rolling type, roll-up type, and a pulley-type. A major task would be implementing a door into a windbreak that would be large enough to accommodate a skid-steer. Each of these design ideas were focused on this concept to not sacrifice stability while still creating a large enough door. Figure 3 below shows a few sketches of our designs ideas for an attached windbreak to a gable style high tunnel.

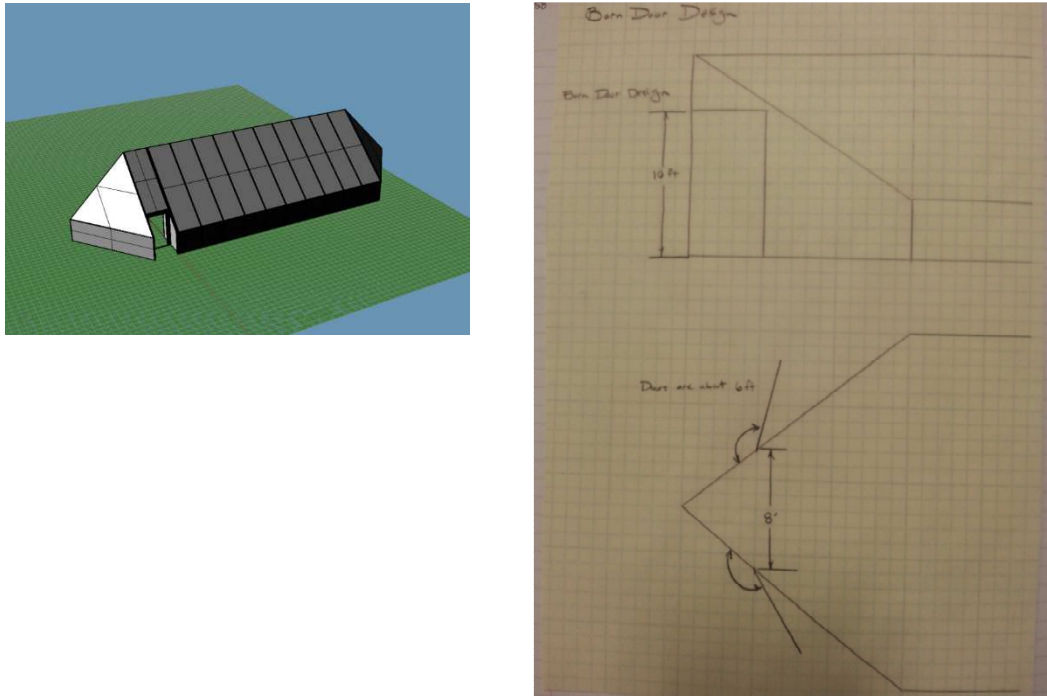


Figure 3: This figure shows different ideas for door implementation.

Concept Selection

We selected the Gothic style to be our fundamental frame base. This was mainly justified by the gothic frame's superior ability to shed snow versus the quonset frame and the ability to easily add a windbreak to its geometry. We also determined that a windbreak would be an effective means of reducing wind forces on the greenhouse face through our first round of wind tunnel testing. We tested the two different high tunnel styles with and without our general windbreak ideas. With our test results we conducted a statistical analysis to determine if the forces on the designs were significantly different. We found that windbreaks provided a significant amount of force reduction on the high tunnels. This data and information can be seen in the attached Appendix A.

After this, we developed a wind break frame design and modelled it for additional wind tunnel testing. This testing established the effectiveness of our specific design and justified its finalization. These test results can be seen in Appendix A. The structure geometry decision matrix that outlines our choice is displayed in Table 2 below.

Decision Matrix of Design Options					
	Weight	Option One	Option Two	Option Three	Option Four
Criteria		Gothic Plain	Quonset Plain	Gothic Windbreak	Quonset Windbreak
Snow Load	4	5	3	5	3
Wind Load	5	3	3	5	5
Ease of Construction	2	4	5	3	2
Space Required	1	5	4	4	3
Cost	3	4	5	3	4
	Total:	60	56	64	56

Table 2: This is a table showing a key decision matrix in our design process.

Next, we chose the frame material to be galvanized steel because of its superior strength and longevity in outdoor environments. We found that there was an ideal high tunnel kit that exists that incorporated many of our design needs. We discovered that

this NRCS approved high tunnel kit could be purchased and we would be able to focus on the design of the windbreak attachment. The main body of the kit includes manual roll-up sides, galvanized steel frame, wiggle wire attachments, and strong, treated 6 mil plastic covering with a four year limited warranty. The kit characteristics for the main body met the exact needs of our client.

System Architecture

The conceptual design for our solution utilizes a windbreak which is designed to improve the aerodynamics of standard high tunnel greenhouse geometries. This works by building a structure off of the front face of the greenhouse that provides a sloping surface on the face that is directly in the wind. This concept is effective because it is a cost effective means of adapting existing greenhouse designs to withstand wind gusts by directly reducing the amount of loading experienced by the greenhouse end wall. This could be developed further by providing designs which are compatible with other standard greenhouse frames. In addition, the design can be adapted for use on both ends of a greenhouse, however this would require designing a windbreak that can serve as a door as well. However, the concept of utilizing a windbreak on the single face of a high tunnel greenhouse is ideal in our particular situation due to a singular wind direction resulting from a fixed orientation with respect to the wind.

The most basic component of our solution is the recommended kit for constructing the greenhouse body. This frame was selected for several reasons. Then gothic geometry of the frame was selected for its snow shedding capabilities and the ease of construction and adaptation with a windbreak. The material selection of galvanized steel was determined due to its superior strength, durability and affordability. This allows our design to meet the ten year durability requirement. The kit also includes the desired passive side ventilation as well as a suitably large door on the back face. The dimensions for our frame are 24 by 40 feet, which meets our requirements as well. The high tunnel will be anchored using a combination of ground stands and concrete anchors. The ground stands were selected for their superior

strength as compared to the more common ground screws. Using studies done by the University of Kentucky we were able to estimate the amount of pullout force that each anchor point of our high tunnel has to resist. We found that with 4 foot frame spacing, our high tunnel shouldn't have to resist more than 565 lbs of pullout per contact point. With the use of ground stands and concrete anchors our high tunnel will have no problem resisting this force. The calculation can be seen in the appendix. The plastic covering provided in the kit will be the covering utilized in our solution. It is a 6 mil poly covering that is reasonably durable and much more cost efficient than alternative coverings. The covering comes with a 4 year warranty and is UV-treated for improved durability. The covering will be attached using the wiggle wire system that is also provided in the kit. The covering will extend over the body and cover the entire windbreak as well. This will be composed of several sheets of covering that will be joined into a continuous covering between the two sections of the greenhouse using the wiggle wire.

The unique portion of our solution is the windbreak assembly that attaches to the front of the recommended kit. The windbreak is designed to gain its shape from half of a frame cross section. This results in a footprint that extends twelve feet from the original face of our greenhouse. The use of the half cross section allows for easier construction and easier integration into the existing structure. The geometry that this yields provides significant wind breaking capability as well. The cross section is welded to the top of the original greenhouse face. Horizontal purlins then provide the structure for the faces of the windbreak. The bottom section of the windbreak is built with the same piping, however it utilizes diagonal cross bracing to transfer the majority of the loading into the

concrete anchors. These are connected using galvanized steel pipe fittings, rather than welds, in order to make the windbreak easier to construct. These fittings also have a strength that exceeds our requirements. The specifics of the windbreak design can be seen in the image below.



Figure 4: Wind break frame.

Using a computational fluid dynamics simulation the pressure distributions on the windbreak were determined for 105 mile per hour wind gusts. This wind speed meets the ASCE 7-10 building requirements. We found that the maximum pressure at this speed on the windbreak was significantly smaller than the maximum pressure on the normal end geometry. The range of the high pressure distribution is also much larger on the normal end type. Graphics of the simulation can be seen in the figure below. Additional result outputs can be seen in Appendix B.

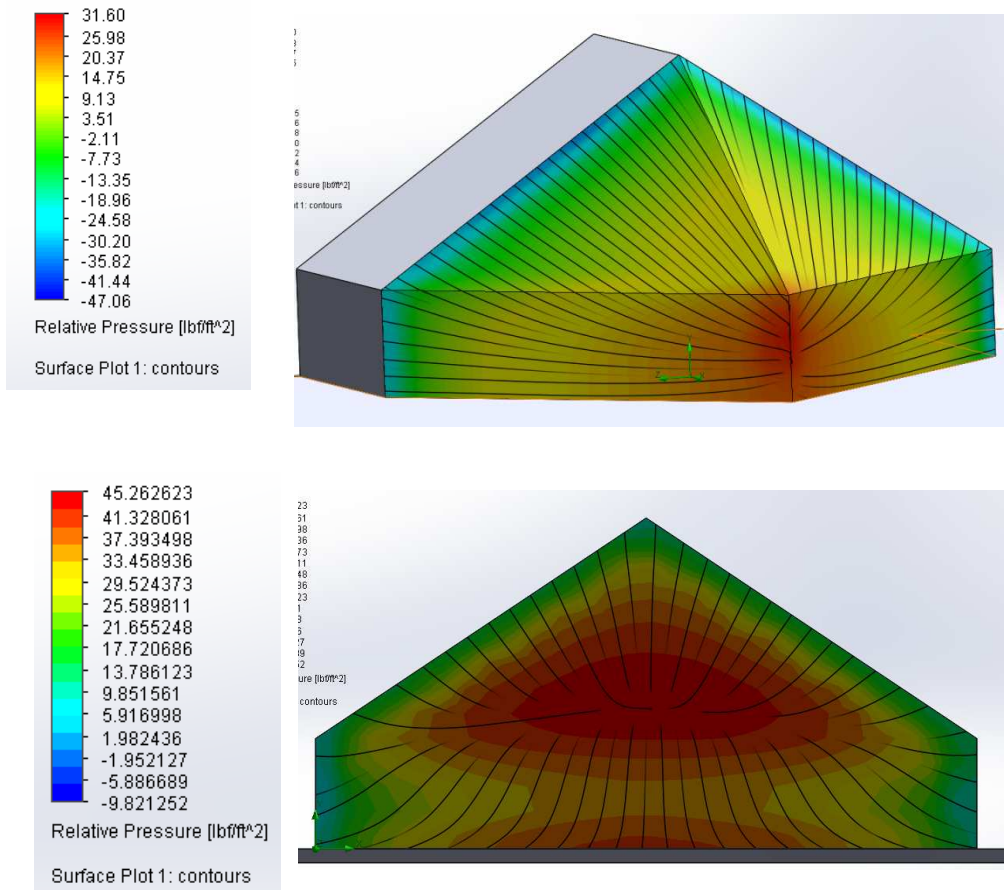


Figure 5: CFD results of windbreak and standard greenhouse end-walls

Using a worst case wind orientation analysis on our windbreak, the loading in the members of the windbreak were approximated and the design was shown to withstand the loading with a safety factor of about 1.02. This analysis included using the 105 mph wind directed 45 degrees from the point of the windbreak. We disregarded the snow loading because with the high winds the scenario of any heavy snow load staying on the high tunnel is negligible. The details for this calculation can be seen in the table below.

Indirect Wind Stress Calculation	
Wind Speed = 105 mph	
Load Status	Pipe Characteristics
Total Wind Load [lb]	Outer Diameter [in]
1135.5	1.66
Moment Acting on Each Support [lb*ft]	Moment of Inertia [in⁴]
763.75	0.121508922
Stress [psi]	Ultimate Strength [psi]
62604.0447	63800
Safety Factor	
1.019103483	

Figure 6: Wind Load Calculation.

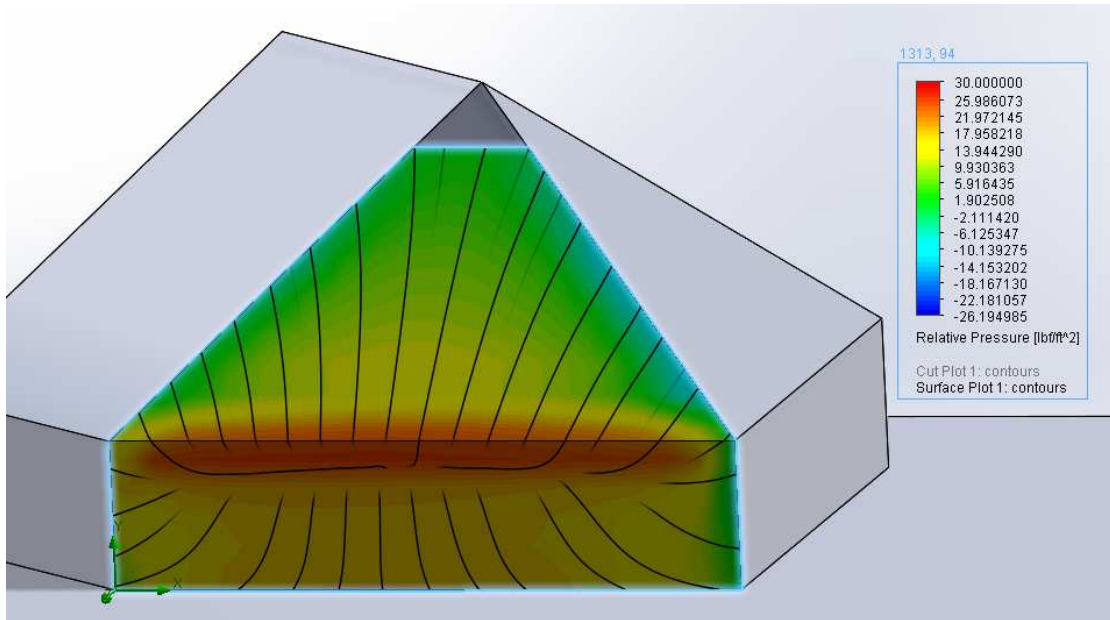
Overall, our design fits the needs of our customer. The high tunnel will be able to be built using our provided instruction manual in Appendix D. All of the components will be able to be bought and shipped well within our designated budget. Our calculated cost estimate is about \$5800 for the kit and windbreak materials needed. The cost breakdown can be seen in Appendix A.

Future Work

After completing our design work there are a few things to be done. First, our client will build our specified kit and our designed windbreak. The client will also build another high tunnel without our windbreak right next to it. Then the client will be able to test and make comparisons between the two designs. Frequently throughout the ten years the client should test characteristics such as plastic strength, sagging, tearing and necessary replacement periods. The client should also test and compare structure stability. This includes comparing the rigidity of the frame and anchoring between the two structures. The testing will help provide data for a more in-depth economic analysis to determine if the windbreak is worth the cost in the long run. Through these tests and comparisons the client will be able to identify more pros and cons of having the attached windbreak. This could lead to future projects for University of Idaho students to improve other areas in the windbreak such as plastic attachment and windbreak frame construction.

Appendix A – Calculations

CFD worst case scenario, 105 mph wind.



Calculation on Member Receiving most Stress

Upper area loading

Lower area loading

Indirect Wind Stress Calculation	
Load Status	Pipe Characteristics
Area of Loading [ft^2]	Outer Diameter [in]
49.5	1.66
Pressure [psf]	Thickness [in]
17	0.078
Wind Load [lb]	Area [in^2]
841.5	0.38746344
Moment Acting on Each Support [lb*ft]	Moment of Inertia [in^4]
420.75	0.121508922
Stress [psi]	Strength [psi]
34488.57847	63800
Safety Factor	
1.849887784	

Indirect Wind Stress Calculation	
Load Status	Pipe Characteristics
Area of Loading [ft^2]	Outer Diameter [in]
14	1.66
Pressure [psf]	Thickness [in]
21	0.078
Wind Load [lb]	Area [in^2]
294	0.38746344
Moment Acting on Each Support [lb*ft]	Moment of Inertia [in^4]
343	0.121508922
Stress [psi]	Strength [psi]
28115.46623	63800
Safety Factor	
2.269213659	

Combined loading on member

Indirect Wind Stress Calculation	
Wind Speed = 105 mph	
Load Status	Pipe Characteristics
Total Wind Load [lb]	Outer Diameter [in]
1135.5	1.66
Moment Acting on Each Support [lb*ft]	Moment of Inertia [in^4]
763.75	0.121508922
Stress [psi]	Ultimate Strength [psi]
62604.0447	63800
Safety Factor	
1.019103483	

Anchor Analysis

High Tunnel	Size	Wind	Lift force	Structure Weight	Contact Points	lbs/Contact	Earth Anchors Contact
UK	22' x 100'	80 mph	22000 lbs	--	--	--	--
UK	30' x 72'	80 mph	16000 lbs	3000 lbs	36	360	--
UI	24' x 52'	80 mph	13000 lbs	--	23	565	1500 lbs

Cost Analysis

Cost Analysis Overview	
Kit Cost	\$4500
Windbreak Poly	\$125
Windbreak steel	\$220
Windbreak Extras	\$95
Windbreak frame fittings	\$500
Lumber	\$205
Concrete	\$115
Total Cost	\$5760

Appendix B – Test Results

Wind Tunnel Experiment #1

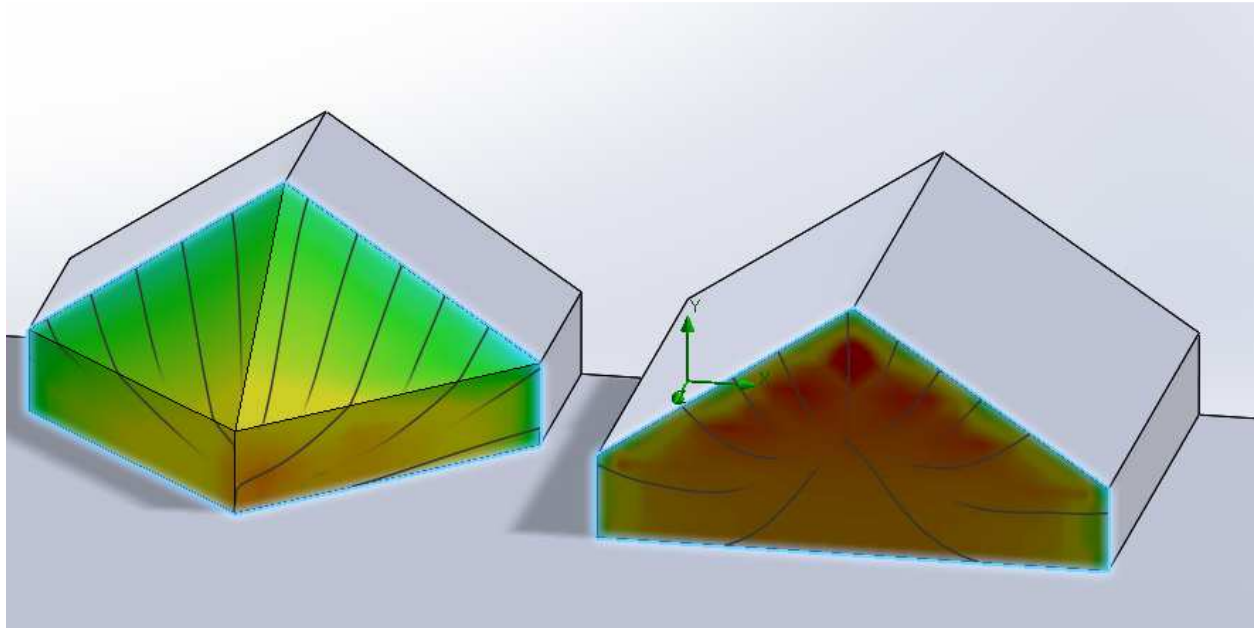
Run	Windspeed (mph)	End type	Drag Force (N)
1	35	GP	3.345
2	35	GP	3.362
3	35	GP	3.358
4	35	GP	3.355
5	60	GP	9.001
6	60	GP	8.919
7	60	GP	8.905
8	60	GP	8.942
9	35	GW	2.119
10	35	GW	2.16
11	35	GW	2.149
12	35	GW	2.143
13	60	GW	5.937
14	60	GW	5.893
15	60	GW	5.84
16	60	GW	5.89
17	35	QP	3.704
18	35	QP	3.652
19	35	QP	3.67
20	35	QP	3.675
21	60	QP	10.38
22	60	QP	10.305
23	60	QP	10.35
24	60	QP	10.345
25	35	QW	1.526
26	35	QW	1.528
27	35	QW	1.525
28	35	QW	1.526
29	60	QW	4.417
30	60	QW	4.414
31	60	QW	4.35
32	60	QW	4.394

Wind Tunnel Experiment #2

Direction	Windspeed (mph)	Percent Reduction of Force
Head-On	35	27.4%
	60	27.7%
	103	31.5%
45 Degrees	35	33.0%
	60	25.5%

Additional CFD Simulation Results

CFD Summary		
	Average Abs. Pressure [lbf/ft ²]	Maximum Abs. Pressure [lbf/ft ²]
Normal End	2149.538154	2161.545897
Windbreak Head-On	2127.003885	2147.833279
Windbreak Sidewind	2128.052412	2145.501518



Appendix C – Order Specifications



REVISED

Poly-Tex, Inc.
 27725 Danville Avenue
 Castle Rock, MN 55010
 800-852-3443
 Phone: 651-463-7009
 Fax: 651-463-2479

24' Field-Pro Gable High Tunnel

Date: 5/1/2014

Quotation valid until: 5/31/2014
Prepared by: Liz Crombie

Quote: 1547-LC

Bill to: Tony McCannon
630 Addison Avenue West Suite 1600
Twinfalls, ID 83301Ship to: Tony McCannon
630 Addison Avenue West Suite 1600
Twinfalls, ID 83301

Phone: 208-734-9590

Phone:

Fax:

Fax:

Email: tonym@uidaho.edu

Email:

Structure:	24' FieldPro Gable High Tunnel
Width (ft):	24
Length (ft):	40
Total Sq/Ft:	960
Frame Spacing (ft):	4
Side Wall Height (ft):	4
# of Purlins:	3
Anchoring Type:	Ground Stands

The Field-Pro™ High Tunnel is designed with the small fruit and specialty crop grower in mind. The frame goes up quickly and easily so you can get an earlier jump on the growing season. Durable roof poly and roll-up sides will provide an environment that will extend your growing season, protect your crop, and increase your yield and profits.

The Field-Pro™ High Tunnel will include the following equipment.

FIELDPRO GABLE HIGH TUNNEL FRAME \$2,151.92

The structure will have 4ft high straight side walls and will be constructed from 14 gauge x 1.66" diameter galvanized tube. 24'0" wide frame sections include 3'0" ground stands, diagonal end bracing, and miscellaneous fittings and hardware for construction. Frames will be placed 4'0" on center.

SIDE WALL HARDWARE PACKAGE \$129.02

Includes "U" clamps, "L" brackets, and screws attaching hardware to mount lumber supplied by customer.

END FRAME HARDWARE PACKAGE \$82.30

Includes "L" brackets, spike mount, and spike attaching hardware to mount lumber supplied by customer.

SIDE ROLL UP PACKAGE \$559.94

Includes gearbox, 17gauge shaft running the length of the greenhouse, 60" 6mil clear poly roll-up curtain, and attaching hardware.

ROOF POLY PACKAGE **\$378.44**

(1) 32 ft x 42 ft single layer 6mil clear poly - sheet - roof
Includes clear 6mil 4yr film with mounting base and securing wire.

END WALL POLY PACKAGE **\$230.22**

(2) 14 ft x 26 ft single layer 6mil clear poly - sheet - end
Includes clear 6mil 4yr film with mounting base and securing wire.

ROLL-UP END DOOR KIT 8' X 8' opening **\$268.00**

(1) Door kit includes reinforced clear poly door material, roll-up tube, crank, door jambs, header, and mounting hardware.

TRUSS KITS **\$306.00**

Includes chords, struts, and mounting hardware for 9 Truss Kits

EXTRAS

(1)	Hoop section plus (1) HP3500	\$	145.92
(3)	Ground Stands	\$	36.00
(5)	pieces of base	\$	39.75
(10)	wiggle wire	\$	19.60
(1)	28' x 32' Clear Sheet poly	\$	125.44
(10)	1.66 14ga x 9'	\$	215.75
(3)	1.66 14ga x 13'-6"		
(1)	1.66 14ga x 13'-3"		
TOTAL			\$4,688.30

F.O.B. POINT

F.O.B. our dock, Castle Rock, MN. Freight not included.

Estimated weight 1,240 lbs

Freight Estimate **CALL**

Customer is responsible for unloading freight.

TERMS OF SALE

To be determined.

PRICES

Prices in this quotation are firm for 30 days from above date of quote.

We hope this quotation meets with your approval, but should you have any questions or comments please feel free to contact our office.

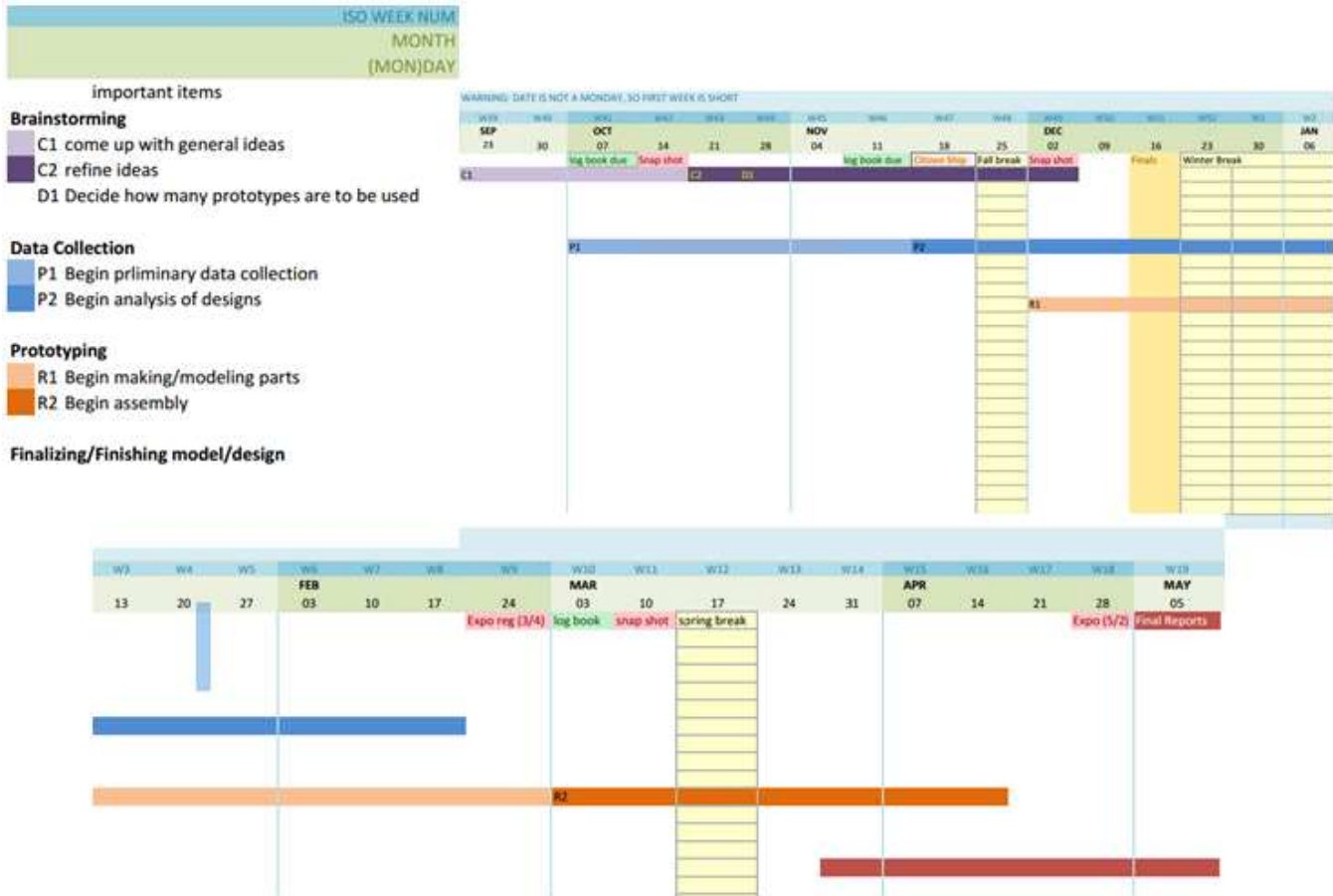
Best Regards,

Poly-Tex, Inc.

Liz Crombie
Account Representative

Simplified Building Order Sheet				
http://www.simplifiedbuilding.com/store/components/kee-klamp.html?fits_pipe=645				
Kee Klamp Fittings				
	Model	Qty	Price	Total Price
Single Socket Tee	10-7	4	11.59	46.36
Adjustable Side Outlet Tee	19-7	2	31.96	63.92
Single Swivel Socket	C50B-77	14	20.02	280.28
Two Socket Cross	26-7	4	15.87	63.48
Corner Swivel Socket	C52-777	1	39.22	39.22
Totals		25		493.26

Appendix D – Design Schedule



For a better view of the schedule go to http://www.shoutwiki.com/w/images/mindworks/8/84/2014_GreenHouse_Capstone_design_management_timeline.pdf