"Green" Greenhouse: An Affordable, Energy Efficient Greenhouse for Cold Climates

FNE99-234

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Project Goals

The goal of this project is to design and build a small commercial greenhouse (1000 sq. ft.) consistent with some "green" design goals of energy efficiency, longevity, affordability, and minimally polluting systems and materials. We will use technologies that show promise, but are not well established in the greenhouse industry.

The innovations we are testing include:

- new frame design
- airtight and affordable glazing system
- heat recovery ventilation in heating season (passive ventilation in cooling season)
- ventilation preheating using "earthtubes"
- temperature moderation and heat storage with subsurface rock bed.
- insulated, airtight shell

Our original plan for the greenhouse was to grow flowers for the fresh market. We have changed our plans, and are now concentrating on growing heaths and heathers and own-root hardy roses to sell both wholesale and at farmers' markets. To date, we have started with rooting heath/heather cuttings in the fall of 2003, and will be experimenting with rose cuttings in spring/summer 2004. Our farm consists of about 55 acres, with 30 acres in hay and the rest wooded.

Cooperators

Many wonderful people and organizations contributed to this project. It is not hyperbole to state that this project would not have been possible without them.

- Sustainable Agriculture Research & Education Program, Northeast Region provided funding for some of the design work and testing.
- Massachusetts Department of Food and Agriculture Agro-Environmental Technology Grant Program provided funding for some of the untried aspects of our greenhouse.

- Mark Rosenbaum of Energysmiths provided engineering and design consultation, and helped us to understand how to think about our project
- Dave Vreeland of Spectrum Design Collaborative engineered the greenhouse frame.
- Allen Barker of the Department of Plant and Soil Sciences at the Univ. of Massachusetts was generous with his time and expertise in hydroponics.
- David Hansen of Memphremagog Heat Exchangers provided the materials for the HRV core. He also recommended the amount of HRV core that would be needed for our 500 CFM exchange rate, and generously took the time to sketch and describe how the HRV should be constructed.
- Dick and Rob Hillman of W.R. Hillman and Sons of Shelburne Falls, MA did all the site work for the project including installing the earthtubes and the stone in the rock bed.
- Franklin County Fabricators of Greenfield, Massachusetts fabricated the frame.
- Rugg Lumber in Greenfield, Massachusetts supplied all of the standard construction materials, and was consistently helpful in brainstorming untraditional applications of traditional materials.
- John Bartok, professor emeritus of greenhouse engineering at the University of Connecticut, reviewed our plans and made many useful comments.
- The NESEA (Northeast Sustainable Energy Association) library was a helpful source for some out-of-print reference material.
- Ellen Shukis, Director of the Mt. Holyoke College Botanic Garden, was generous with her time and her expertise on greenhouse cultural requirements of subtropical plants.
- Ed and Eddie Diemand worked with Glenn on the construction of the greenhouse.
- Steven Breyer of Tripplebrook Nursery (Easthampton, MA), Phil Maddern of the Gill Greenery (Gill, MA), and the folks at Natick Community Organic Farm (Natick, MA) generously allowed us to tour their greenhouses, and shared their experiences.
- Celluspray Insulation of Shelburne Falls, MA did a careful job packing in as much cellulose as the walls would bear.
- Lee Edelberg (and Tristan), electricians, did a thoughtful job wiring the greenhouse.

Project Description

The following describes the design, cost information, and construction details for each component of the greenhouse. Components include the greenhouse frame, glazing system, heat storage system, ventilation, greenhouse shell, and earthtubes.

The Greenhouse Frame

Design Goals: The greenhouse frame had to be strong, withstand high winds, and shed snow well. It also should be optimized to capture the low winter light. We sought a design that was affordable and durable, and one that would require minimal maintenance. The frame should permit flexible use of the greenhouse space underneath. Finally, the frame should be compatible with the glazing system (i.e., it must have a flat outer surface at least 2 inches in width).

Design Loads:

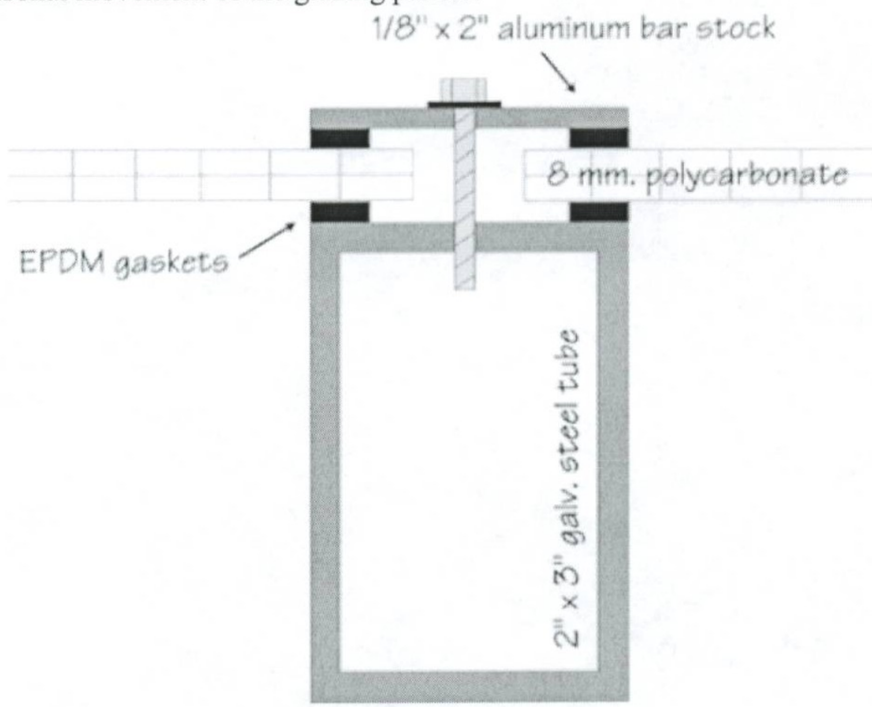
Snow Load (north roof)	40.0 psf	
Snow Load (south roof)	15.0 psf	based on 12/12 roof pitch, the reduced friction of the polycarbonate glazing, the heat loss through the glazing, and data from the Standards for Design Loads in Greenhouse Structures published by the National Greenhouse Manufacturers Association.
Wind Load (windward)	6.6 psf	Load on 12/12 pitch roof. Assumed 80 mph. Exposure B. Reference Wind Pressure at 20' = 16.4 psf (0.4) = 6.6 psf
Wind Load (leeward)	8.2 psf	Load on 12/12 pitch roof. Assumed 80 mph. Exposure B. Reference Wind Pressure at 20' = 16.4 psf (0.5) = 8.2 psf
Dead Load (north roof)	12.0 psf	
Dead Load (south roof)	2.0 psf	

Structure: Our frame sections were welded locally from 2x3 inch tubular steel and 2 inch angle steel. The frame was then sent off to be galvanized in the Boston area. The frame sections are bolted together 6 feet on center with 2 inch angle purlins spaced 43 inches on center.
Plans: The **plans** (3 pages) used by the fabricators are included as Appendix A [Frame.pdf]. The frame drawings might make more sense if you looked first at a drawing of the whole greenhouse **cross section** (Appendix B) [eastelevationframe.pdf], viewed from the east.
Costs:
Our frame consisted of 8 frame sections and 63 purlins, all predrilled, mounted with connector tabs, and galvanized. Total frame costs including materials, welding, shipping, and galvanization was $3,557. A large part of the cost was shipping the welded frame members to Boston (2.5 hours away) and back for galvanizing.

Glazing System

Design Goals: For the greenhouse to conserve heat, it needs to be airtight with controlled heat-recovery ventilation. Air infiltration around the glazing panels must be minimized. The two common alternatives for multi-wall polycarbonate glazing systems were problematic. The inexpensive aluminum extrusions that slip over the glazing panels are not truly airtight. Gasketed glazing systems that clamp the panels between beefier extrusions fitted with EPDM gaskets are airtight, but are exceedingly expensive. Our design seeks to provide a durable barrier to air infiltration without breaking the bank.

The Design: Our system uses 1/8" by 2" aluminum bar stock as a cap to bolt the glazing panels to the frame below. Both the bar stock and the frame have 3/8" by 1/8" EPDM self-adhesive gaskets mounted to the outside edges. This gasketing is intended to seal out air infiltration without restricting seasonal movement of the glazing panels.



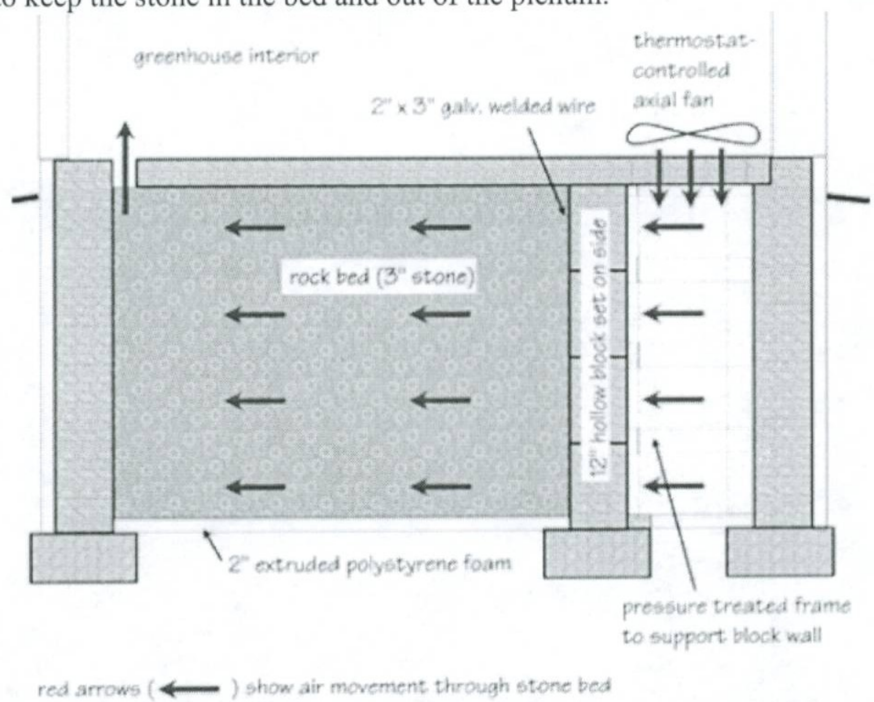
Suppliers:

gaskets	Resource Conservation Technology (410-366-1146) part# GG05	$37 for a 328' roll
glazing	(9) 18' x 71.25" SPS Thermoglas polycarbonate panels (ordered through Griffin Greenhouse Supply), 500 screws, 500 washers, 500 spacers, 160′ 1″ sealing tape, 110′ 1″ permeable tape	$2651
bar stock	1/8" x 2" x 12' aluminum bar stock from The Steel Shed (a local metal supplier)	288′ for $296

The Heat Storage System

Design Goals: For plants to thrive, temperatures during the heating season cannot be left to swing wildly. This temperature moderation should be separated from fresh air ventilation. Excess heat during the heating season should not be vented to the outside. It should be stored for later use. The heat storage system should not reduce or restrict greenhouse floor space. It should be sized to handle the expected excess heat that might be produced on a sunny day during the heating season. Ideally, the heat should be stored below the root zone of the plants. This is to protect plants from shock that might occur when the greenhouse air temperature rises suddenly on a sunny morning, but the roots are still cold.

The Design: A 4′ deep bed of 3″ stone lies below the greenhouse floor with a plenum running the length of the greenhouse on one side. The plenum is constructed with pressure treated wood and welded wire to keep the stone in the bed and out of the plenum.



Costs and Materials:

Fan	Dayton 24" Venturi Exhaust Fan 6.6A Model #9K955A 1/2 HP 1725 rpm from Grainger	$458
3" stone	W.R. Hillman & Sons	$1655 (time & materials)
welded wire	Amherst Farmers Supply	100′ for $120
12" hollow block	Amherst Farmers Supply	166 blocks for $354 (delivered)
Lumber	Rugg Lumber Company	$201

Pictures:
Stones partially loaded. (Appendix C Figures 1 & 2) [Stones.jpg. Stones2.jpg]
View of plenum. (Appendix C Figure 3) [Plenum.jpg]
Resources: Tables for pressure drop through the rock bed came from Passive Solar Design Handbook Volume Two: Passive Solar Design Analysis by D. Balcomb for the Department of Energy, 1980.

Ventilation

Design Goals: The heat storage system does all the work to moderate the temperature on sunny winter days. The role of the ventilation system is simply to exchange stale air with fresh according to the needs of the plants. In the process, we want to recover as much of the heat in the air and embodied in the water vapor as possible.
Our Design: We will use a heat recovery ventilation system (HRV) running at approximately 500 CFM to ventilate our greenhouse. This was sized to handle the expected ventilation requirements of our 1000 sq. ft. greenhouse. The HRV will be turned on automatically by a humidistat. Fresh air from outside will be preheated in earthtubes. In the warmer weather, we will use manual ventilation, consisting of hopper windows installed along the bottom of the south facing wall and exterior doors installed sideways at the top of the north wall.
Costs:

Fans	2 Fan-tech fans from EFI	$504
Heat exchanger	Coroplast sheets and double stick tape from Memphremagog	$185
Ducts		Not yet purchased
Humidistat	EFI	$22
Vent doors	4 exterior doors from Rugg Lumber	$887
Windows	18 35″x24″ insulated hopper windows with screens from Rugg Lumber	$2050

The construction of the heat recovery ventilation system is still in progress.

The Greenhouse Insulated Shell

Design Goals: The greenhouse shell should be long lasting and be able to withstand the high moisture levels of the greenhouse with little maintenance. The shell should be designed to conserve heat in the winter and ventilate passively in the summer. The appearance should be attractive. There should be storage for greenhouse supplies outside but adjacent to the greenhouse.
The Design:

Walls – 2″x6″, insulated with dense pack cellulose
Exterior – plywood, covered with Tyvek, and finished with white cedar shingles
Interior – vapor barrier (6 mil poly), plywood, covered with 2-part epoxy paint

Roof – 2'x12', insulated with dense pack cellulose, plywood covered with 30 lb. felt and metal roofing.

Costs:

Insulation	Dense pack cellulose from Cellu-spray Insulation	$944
Vapor barrier	16x100 6 mil poly from Rugg Lumber	$58
Roof	Metal roofing from Rugg Lumber	$1012
Shingles	Cedar shingles from Leader Home Centers – 36 bundles	$904
Lumber & other supplies	Rugg Lumber & Leader Home Centers	Approx. $4000
Doors	2 exterior doors from Rugg	$488

Earthtubes

Design Goals: The role of the earthtubes is to preheat the fresh air supply to the ventilation system during the cold season. Two benefits are expected: the obvious benefit of replacing exhausted air with air that is warmer that ambient winter air, and the hope that incoming air will always be above freezing temperatures so that the heat recovery ventilator does not need a defrost cycle. Mold problems and questionable effectiveness are a common theme of Internet discussions of earthtubes. Our system only uses earthtubes for heating air, not cooling, so condensation should not be an issue. Secondly, our tubes are smooth-walled and run continuously downhill, so any moisture that gets into the system should drain out. Thirdly, our tubes are not replacing a heat recovery ventilation system, but supplementing it. The function of the earthtubes is narrow, and specific to what they should do well.

Our Design: Air will be pulled through the earthtubes into our ventilation system at approximately 500 CFM. We used 351 feet of 6" gasketed sewer pipe for the earthtubes. The piping was divided into three 117 foot runs starting from one point at the greenhouse about 3.5 feet below grade. The runs diverge to about 10 feet apart and dive to approximately 7 feet below grade. The pipes emerge above grade at the end of their runs. The whole run is pitched downhill; our sloped site made this easy.

Costs:

351' of 6" gasketed SDR35 sewer pipe	$598
approximately 3 hours excavator time	$255

There certainly are cheaper pipe options. For example, corrugated drainpipe would be a small fraction of the cost, and should be considered. We chose the SDR35 pipe because it was the safest option (i.e., no water accumulation in the pipes and can withstand 7' of earth above) and because of the virtual impossibility of correcting any problems in the piping that might arise. We expect the earthtubes to be in service for a long time. Our focus is on the effectiveness of earthtubes in meeting our objectives. If they prove effective, future effort could be directed toward reducing costs and optimizing design.

Construction Notes

Frame:

- The tabs on the frame members used to attach the purlins were, in some cases, welded so that the purlins would be slightly above the face of the frame. This would compromise the air sealing of the glazing system. To compensate, I affixed a 2" wide strip of cured EPDM repair tape (Resource Conservation Technology sells a 6" wide roll that is a EPDM and butyl sandwich with one adhesive side). The tape was thick enough for one layer to build up the frame so that the gaskets would make good contact with the glazing. Additionally, the tape will cover the steel frame and slow heat loss.
- The cavity in the 2"x3" steel frame was filled with extruded polystyrene foam by cutting strips of the approximate size and ramming them up into the tube from the bottom with a hand sledge and an appropriately sized 2x4. I used two brands of foam that I had. One was stiffer, and consequently was easier to ram 18 feet worth in each frame.

Air Sealing:

- **sills:** on top of the foundation wall, I put down a bead of Tremco acoustical sealant (available from EFI), a layer of the pink foam sill seal, and another bead of Tremco, before putting down the sills.
- **glazing system:** the EPDM gaskets and glazing system made achieving an air seal easy, with one major exception. We used "self-tapping" screws to fasten the sandwich (consisting of 1/8" aluminum bar stock, 1/8" EPDM gasket, 8 mm polycarbonate glazing, 1/4" EPDM gasket, EPDM/Butyl repair tape, 3/16" thick wall of steel frame) together. The steel frame was too tough for the self-tapping screws, so we had to pre-drill the holes. All drill bits used except cobalt were useless after a couple holes. The cobalt drills lasted through the hundreds of holes but drilling was challenging, requiring about 20 seconds of pressure, usually in an awkward position. Perhaps pre-drilling the holes before the frame is erected will make this job much easier. Also, be sure there is enough grab in the screw to go through all the layers. Our screws, which were considered 1-1/2", had just enough grab when you subtract out the self-tapping end to hold everything together. Longer screws would be safer.
- **glazing:** The glazing I used (Thermaglas from SPS) was perfect for my glazing system. My system squeezed the panel edges between a 2" wide frame and 2" aluminum bar stock using 3/8" wide EPDM gaskets. Additionally, the steel greenhouse frame had rounded corners, further reducing the clamping surface area. Because the panels expand and contract, allowances for changing panel width must be accommodated by the glazing system. The integrity of the panel edges is vital to the success of this clamping system. The Thermaglas panels came sealed at the panel edges with a vertical rib. If the panels needed to be trimmed to width, it would have been impossible to get a good seal (unless it was trimmed to another vertical rib). Moreover, the vertical ribs in the Thermaglas panels were closer together at the panel edges, adding to the panel strength when clamped. If the panels did not have a clampable outer edge, a wider clamping system would be needed.
- **insulated walls:** The steps we took to protect the walls from moisture, will be more than adequate to handle our air sealing requirements. From the inside out, our walls had 2 coats

of epoxy paint, a sealing primer, plywood, 6 mil poly, 2x6 cavity with dense-packed cellulose, plywood, Tyvek, white cedar shingles.

Moisture proofing:

- After flip-flopping through many options for interior wall surface, we settled on plywood walls painted with an industrial quality paint. While we wanted to avoid wood inside when possible, the other options seemed too expensive or cumbersome. We used a 2-component water-based catalyzed epoxy paint (Sherwin Williams) over a high quality sealing primer. The literature described the epoxy in such a way that I was intimidated by the thought of applying it. It turned out to be very easy to work with. One coat of primer and two coats of epoxy provided a surface that seems like it will be up for the task. Time will tell.

Rock Heat Storage Bed:

- We decided on 3 inch stone for the rock bed, based on tables for pressure drop and heat transfer. It was challenging to find consistently sized 3" stone in our area. All the quarries had smaller stone in consistent sizes, but the larger stone had excessive variability in size. Even stone called 3" stone might vary from 2" - 9" in size. We were able to get some stone re-screened to eliminate 2-1/4" stone and less, but the screening process does not seem precise, and there is still some variability to our stone. While I don't know how "perfect" stone would behave, ours seems good enough, in that the fan we have does manage to blow air through the bed.
- Do to a miscommunication (which means I blew it) we constructed our rock bed with only one plenum on the fan side of the rock bed. We should have had another block wall on the down-wind side so that the air would flow equally through the entire depth of the rock bed. In our system, the air will tend to flow more toward the top of the bed, compromising the efficiency of the rock bed. Our air returns on the south side of the greenhouse where the concrete slab was held back from the wall by 18". We will pull out as many of the stones in that strip as we can to improve the air flow at lower depths. The data in the performance chart is based on the system as is. Based on the temperature fluctuations in the bed, it looks like we would have been better off if we constructed the rock bed as the engineer intended. However, we haven't yet pulled out the 18" of stone from the return, and the greenhouse was not fully loaded with plants (and their resulting ventilations requirements and transpirational cooling), so next winter will be a better indication.
- The fan is thermostatically controlled by a Dramm T42 2-stage thermostat to blow when the temperature exceeds a threshold (currently ~90 degrees) or falls below a threshold (currently ~45 degrees). This system seems to work perfectly.

Insulation:

- The foundation and rock bed were insulated with 2" of extruded polystyrene. Above grade, the foundation was covered by 24 inch brown "aluminum" flashing. The flashing was tucked under the sill and extends quite a ways below grade. On the east, west, and north sides, the sills extend out past the foundation wall to cover the foam. On the south side the frames cannot extend beyond the sill, so the foam was cut to taper to the sill, and the flashing was prebent to follow the foam's profile. So far, this system was easy to install and seems to work well.
- The decision to use cellulose in a greenhouse environment was slightly scary for me. We are big fans of cellulose insulation, however, so we decided to try it. We worked hard to

keep moisture out of the walls, and to allow any moisture that gets in the walls to get out more easily than it got in. To get into the wall from the inside of the greenhouse, moisture would have to get through 2 coats of epoxy paint, a coat of primer, 1/2 inch plywood with joints sealed with silicone, and a 6 mil poly vapor barrier. Having constructed the greenhouse, it seems a safer bet now.

Results

The performance data that follows provides the details of the outcome of our project. We collected data for two winters: 2001-2002 and 2002-2003. The first winter was fairly mild; the second was severe. In both cases, the circulating fan/rock bed heat sink system kept the greenhouse from freezing. We believe that the coming winter will show better temperature moderation, because of a 6′ x 26′ permanent soil bed built this summer which will provide additional thermal mass. The greenhouse was largely empty for most of the previous two winters with the exception of a small quantity of potted plants. We experimented with a variety of plants over the winter of 2002-2003, all of which survived, including tomatoes, broccoli, nasturtiums, new cuttings of heaths and heathers (taken in late October—they rooted in 60-90 days), and a few other tender perennials. The tomatoes produced flowers and fruit throughout the winter, but the fruit was small and did not ripen well. However, in the spring the quality of the fruit improved, so that each trip to the greenhouse included snacking on ripe cherry tomatoes.

The cost of building the greenhouse was more than we had anticipated, partly because of the cost of hiring labor to do work we had intended to do ourselves. We estimate that the total materials cost for this greenhouse ran about $29,000

Performance Log

Date	max. temp.	min. temp.	time	curr. temp.
11/18/2001	93	52	2:07 pm	90
11/19/2001	94	58	4:25 pm	79
11/20/2001	94	58	4:00 pm	68
11/21/2001	93	50	8:35 pm	64
11/22/2001	94	56	10:51 am	92
11/23/2001	away			
11/24/2001	away			
11/25/2001	away (next line is 4-day max. and min. values)			
11/26/2001	98	55	2:40 pm	88

11/27/2001	max./min. thermostat not reset		4:39 pm	61
11/28/2001	97	55	2:25 pm	88
11/29/2001	90	51	5:50 pm	51
11/30/2001	97	57	4:00 pm	79
12/1/2001	97	57	4:00 pm	79
12/2/2001	79	58	5:04 pm	59
12/3/2001	99	49	2:30 pm	87
12/4/2001	101	52	4:19 pm	76
12/5/2001	100	59	11:36 am	97
12/6/2001	97	59	4:20 pm	78
12/7/2001	away			
12/8/2001	98	52	5:36 pm	55
12/9/2001	away			
12/10/2001	98	47	2:45 pm	85
12/11/2001	97	49	12:39 pm	94
12/12/2001	94	48	9:10 am	69
12/13/2001	94	48	10:26 am	49
12/14/2001	away			
12/15/2001	97	46	8:46 pm	51
12/16/2001	98	44	2:00 pm	90
12/17/2001	89	46	2:52 pm	46
12/18/2001	61	44	2:44 pm	61
12/19/2001	79	44	12:37 pm	62
12/20/2001	79	44	10:09 pm	44

Lowered thermostat maximum setting for fan from 90 - 80 deg. F.
Because the thermostat is on an outside wall and the thermometer is in the center of the greenhouse, the thermostat temperature fluctuates more than the thermometer in both directions.

12/21/2001	74	44	2:15 pm	73
12/22/2001	82	44	12:30 pm	82
12/23/2001	84	44	3:30 pm	69

12/24/2001	69	44	9:02 pm	45
12/25/2001	83	44	12:30 pm	83
12/26/2001	away			
12/27/2001	away			
12/28/2001	85	44	5:00 pm	47
12/29/2001	81	44	2::27 pm	76
12/30/2001	80	46	4:01 pm	69
12/31/2001	79	46	1:55 pm	72
1/1/2002	78	46	5:30 pm	57
1/2/2002	86	45	12:30 pm	83
1/3/2002	86	46	1:42 pm	77
1/4/2002	86	46	2:58 pm	71
1/5/2002	71	46	5:50 pm	47
1/6/2002	away			
1/7/2002	69	45	2:11 pm	45
1/8/2002	49	43	9:15 am	49
1/9/2002	47	45	2:42 pm	47
1/10/2002	73	45	2:45 pm	73
1/11/2002	away			
1/12/2002	58	45	4:15 pm	58
1/13/2002	70	45	4:15 pm	58
1/14/2002	78	42	2:32 pm	71
1/15/2002	71	45	6:33 pm	45
1/16/2002	78	42	4:37 pm	64
1/17/2002	71	45	5:11 pm	50
1/18/2002				
1/19/2002	75	41	1:13 pm	52
1/20/2002	76	39	4:10 pm	62
1/21/2002	62	41	12:15 pm	44
1/22/2002	76	39	2:10 pm	76
1/23/2002	80	43	4:07 pm	72
1/24/2002				

1/25/2002	77	45	3:26 pm	70
1/26/2002	80	46	4:42 pm	70
1/27/2002	85	48	3:52 pm	77
1/28/2002	90	52	9:30 pm	61
1/29/2002	69	55	2:30 pm	68
1/30/2002	70	52	6:06 pm	52
1/31/2002	52	45	9:15 pm	46
2/1/2002				
2/2/2002	85	43	2:12 pm	83
2/3/2002	88	45	5:06 pm	67
2/4/2002	89	46	4:46 pm	70
2/5/2002	92	47	6:16 pm	63
2/6/2002	91	48	7:20 pm	62
2/7/2002	75	47	5:52 pm	61
2/8/2002	95	49	5:52 pm	71
2/9/2002	99		1:30 pm	99
2/10/2002				
2/11/2002	100	49	5:56 pm	60
2/12/2002	92	46	2:42 pm	79
2/13/2002	99	48	5:05 pm	75
2/14/2002	100	47	5:57 pm	71
2/15/2002	70	49	8:35 am	54
2/16/2002				
2/17/2002	89	54	1:52 pm	56
2/18/2002	101	46	2:03 pm	101
2/19/2002	102	49	12:25 pm	98
2/20/2002	99	61	5:28 pm	73
2/21/2002	73	61	5:28 pm	68
2/22/2002	85	55	5:50 pm	71
2/23/2002	99	50	1:27 pm	99
2/24/2002				
2/25/2002	103	53	4:09 pm	81

2/26/2002	99	60	9:25 pm	71
2/27/2002	71	61	3:30 pm	62
2/28/2002				
3/1/2002	102	47	7:10 pm	71
3/2/2002	83	55	4:56 pm	74
3/3/2002	73	58	4:20 pm	65
3/4/2002	93	48	6:11 pm	71
3/5/2002	71	48	8:58 am	61
3/6/2002	95	52	3:15 pm	82
3/7/2002	84	52	4:16 pm	74
3/8/2002				
3/9/2002	86	55	2:20 pm	72
3/10/2002	88	57	4:04 pm	76
3/11/2002				
3/12/2002	99	49	6:23 pm	60
3/13/2002				
3/14/2002	99	49	4:16 pm	91
3/15/2002				
3/16/2002	91	56	5:44 pm	63
3/17/2002	90	47	6:20 pm	70
3/18/2002				
3/19/2002				
3/20/2002				
3/21/2002	89	45	1:28 pm	89
3/22/2002	94	47	5:15 pm	74
3/23/2002	78	48	3:22 pm	78
3/24/2002				
3/25/2002	96	49	4:23 pm	79
3/26/2002				
3/27/2002	89	52	4:58 pm	74
3/28/2002	99	53	5:51 pm	79
3/29/2002	105	60	7:58 pm	78
3/30/2002	101	65	5:22 pm	85
3/31/2002				
4/1/2002	107	66	6:23 pm	75
4/2/2002	106	58	6:54 pm	77
4/3/2002	86	64	8:17 pm	64
4/4/2002				
4/5/2002	89	53	11:34 pm	60

4/6/2002	94	54	3:20 pm	72
4/7/2002	98	51	7:00 pm	79
4/8/2002	80	62	7:32 pm	71
4/9/2002	91	62	3:15 pm	79
4/10/2002				
4/11/2002	89	43	7:37 pm	67
4/12/2002	88	59	7:03 pm	66
4/13/2002	85	66	5:32 pm	69
4/14/2002	87	65	11:07 AM	83
4/15/2002	94	57	7:08 pm	73
4/16/2002				
4/17/2002	103	60	8:12 AM	75
4/18/2002				
4/19/2002	133	63	8:10 AM	64
4/20/2002	109	64	6:16 AM	69
4/21/2002	80	55	7:12 pm	61
4/22/2002	69	56	7:33 pm	56
4/23/2002				
4/24/2002	102	52	3:40 pm	88
4/25/2002				
4/26/2002	89	52	3:32 pm	88
4/27/2002	124	52	7:46 pm	61
4/28/2002				
4/29/2002	69	53	6:10 pm	58
4/30/2002				
5/1/2002	88	48	5:49 pm	83
5/2/2002				
5/3/2002	88	48	6:34 pm	77
5/4/2002				
5/5/2002				
5/6/2002	98	51	3:32 pm	97
5/7/2002	98	56	10:18 pm	70
5/8/2002	89	55	6:47 pm	74
5/9/2002	76	57	4:13 pm	62
5/10/2002	90	59	7:57 pm	71
5/11/2002	86	63	10:33 pm	74
5/12/2002	74	65	8:08 pm	65
5/13/2002	64	58	6:00 pm	58
5/14/2002	84	53	6:35 pm	76
5/15/2002				
5/16/2002				
5/17/2002	96	56	9:05 pm	71

5/18/2002	82	54	6:53 pm	59
5/19/2002				
5/20/2002				
5/21/2002	71	53	7:15 pm	58
5/22/2002	89	54	7:05 pm	70
5/23/2002				
5/24/2002	97	62	6:58 pm	75
5/25/2002	86	67	10:29 AM	85
5/26/2002	92	52	8:28 pm	64
5/27/2002				
5/28/2002				
5/29/2002	87	54	7:54 pm	72
5/30/2002	86	61	7:25 pm	70
5/31/2002	88	64	9:10 pm	64
12/1/2002				
12/2/2002				
12/3/2002	108	32	?	
12/4/2002			?	77
12/5/2002				
12/6/2002	80	40	3:58 pm	63
12/7/2002	79	44	3:30 pm	71
12/8/2002	77	43	1:45 pm	72
12/9/2002	77	43	2:01 pm	74
12/10/2002	79	44	4:48 pm	63
12/11/2002				
12/12/2002	62	43	7:40 pm	45
12/13/2002				
12/14/2002	76	44	7:38 pm	45
12/15/2002				
12/16/2002				
12/17/2002	76	41	1:50 pm	74
12/18/2002	77	44	12:43 pm	77
12/19/2002	80	47	1:10 pm	77
12/20/2002	79	47	2:24 pm	51
12/21/2002				
12/22/2002				
12/23/2002	77	44	6:52 pm	48
12/24/2002	76	44	9:45 pm	49
12/25/2002	49	47	3:30 pm	47
12/26/2002				
12/27/2002	78	44	2:52 pm	73
12/28/2002	78	46	5:07 pm	61

12/29/2002	79	46	2:56 pm	73
12/30/2002	73	46	9:50 AM	63
12/31/2002	78	46	1:42 pm	54
1/1/2003				
1/2/2003	73	43	4:25 pm	58
1/3/2003	57	42	12:22 pm	42
1/4/2003	57	40	7:11 pm	40
1/5/2003	40	38	2:45 pm	39
1/6/2003	39	37	6:55 pm	37
1/7/2003	72	37	6:30 pm	45
1/8/2003	46	38	2:54 pm	42
1/9/2003	59	38	4:09 pm	49
1/10/2003				
1/11/2003	71	38	1:04 pm	60
1/12/2003				
1/13/2003	72	38	1:30 pm	65
1/14/2003	73	37	1:51 pm	73
1/15/2003	74	40	2:58 pm	58
1/16/2003	72	38	3:21 pm	69
1/17/2003	77	42	5:01 pm	58
1/18/2003	76	38	4:50 pm	62
1/19/2003	71	41	3:44 pm	61
1/20/2003				
1/21/2003	74	35	2:40 pm	73
1/22/2003	76	37	2:45 pm	75
1/23/2003	78	37	5:13 pm	57
1/24/2003				
1/25/2003	77	38	4:58 pm	62
1/26/2003	62	43	2:10 pm	46
1/27/2003	75	39	6:16 pm	50
1/28/2003				
1/29/2003	68	38	2:25 pm	44
1/30/2003	73	35	4:25 pm	60
1/31/2003				
2/1/2003				
2/2/2003	60	38	10:00 AM	42
2/3/2003	77	38	4:14 pm	69
2/4/2003				
2/5/2003	76	41	3:56 pm	62
2/6/2003				
2/7/2003				
2/8/2003	72	38	10:00 pm	47

2/9/2003	76	44	11:56 AM	76
2/10/2003				
2/11/2003				
2/12/2003				
2/13/2003				
2/14/2003				
2/15/2003	79	36	10:23 AM	73
2/16/2003	79	40	11:52 AM	56
2/17/2003				
2/18/2003				
2/19/2003	67	35	5:30 pm	55
2/20/2003	72	38	4:48 pm	67
2/21/2003				
2/22/2003				
2/23/2003				
2/24/2003	78	42	5:25 pm	51
2/25/2003	77	40	3:01 pm	55
2/26/2003				
2/27/2003	84	43	12:30 pm	84
2/28/2003				
3/1/2003				
3/2/2003				
3/3/2003	88	44	4:42 pm	76
3/4/2003				
3/5/2003	90	45	5:15 pm	52
3/6/2003				
3/7/2003	81	44	5:50 pm	67
3/8/2003	83	45	3:35 pm	80
3/9/2003				
3/10/2003				
3/11/2003	89	43	4:24 pm	81
3/12/2003	81	47	12:21 pm	79
3/13/2003				
3/14/2003	89	44	2:21 pm	88
3/15/2003				
3/16/2003				
3/17/2003				
3/18/2003				
3/19/2003				
3/20/2003				
3/21/2003				
3/22/2003				

3/23/2003				
3/24/2003	116	48	6:02 pm	86
3/25/2003				
3/26/2003	113	67	4:56 pm	80
3/27/2003	97	62	10:06 AM	95
3/28/2003				
3/29/2003	123	41	2:50 pm	63
3/30/2003				
3/31/2003	96	45	3:50 pm	84
4/1/2003				
4/2/2003	92	49	6:35 pm	57
4/3/2003				
4/4/2003				
4/5/2003				
4/6/2003	90	44	3:43 pm	83
4/7/2003				
4/8/2003				
4/9/2003	84	49	8:04 pm	52
4/10/2003				
4/11/2003				
4/12/2003	90	44	1:56 pm	79
4/13/2003				
4/14/2003				
4/15/2003	96	43	6:23 AM	62

Outreach

Our outreach to date has included creating a website (www-unix.oit.umass.edu/~caffery/greenhouse/) that describes our project in detail, including plans and photographs. We have also received quite a few inquiries regarding our greenhouse and have responded to interested parties both by phone and via email. We hope to establish a link to our website from the Massachusetts Cooperative Extension website.

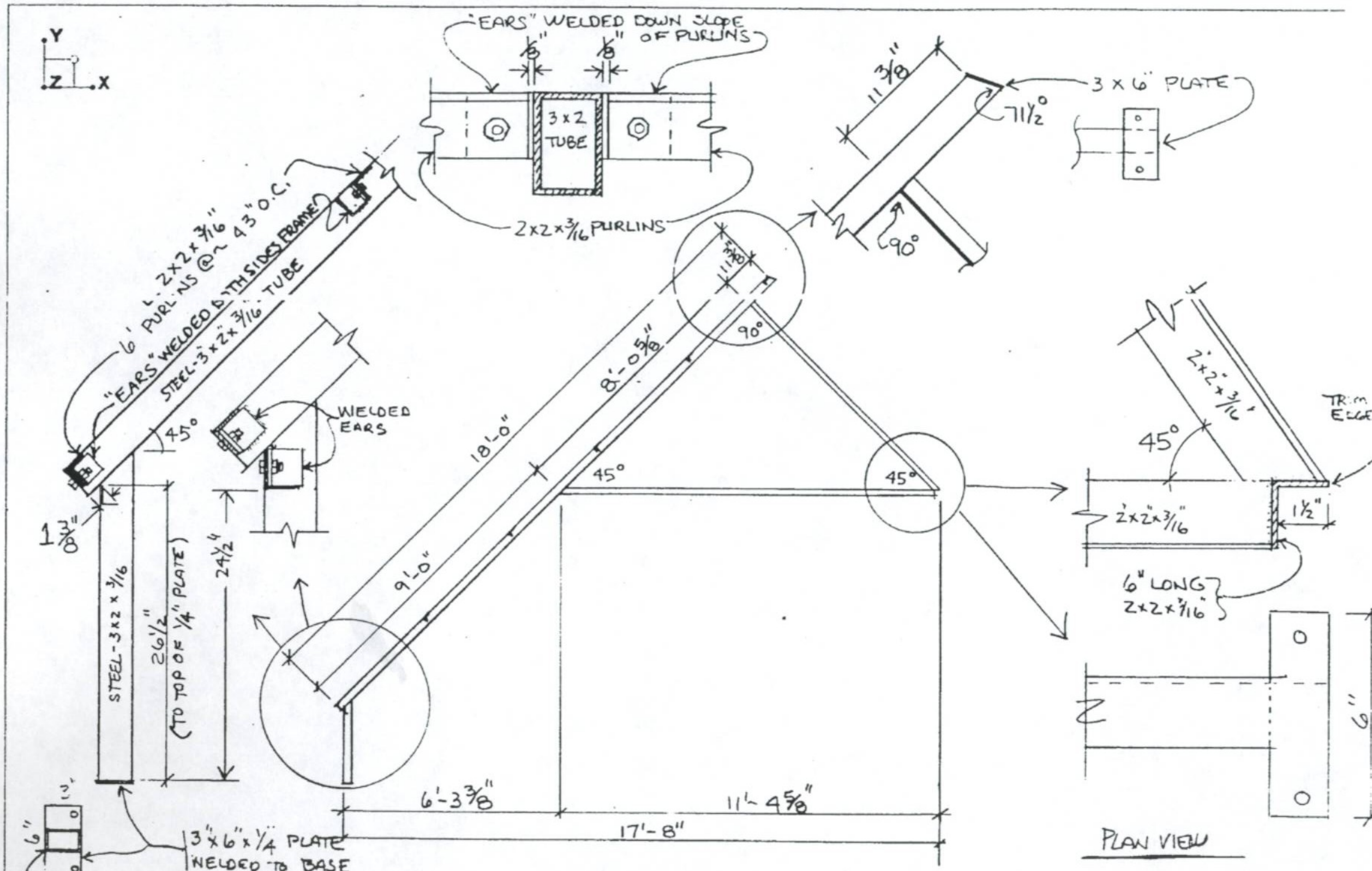
Appendix A

Plans for greenhouse frame [Frame.pdf]

Appendix B

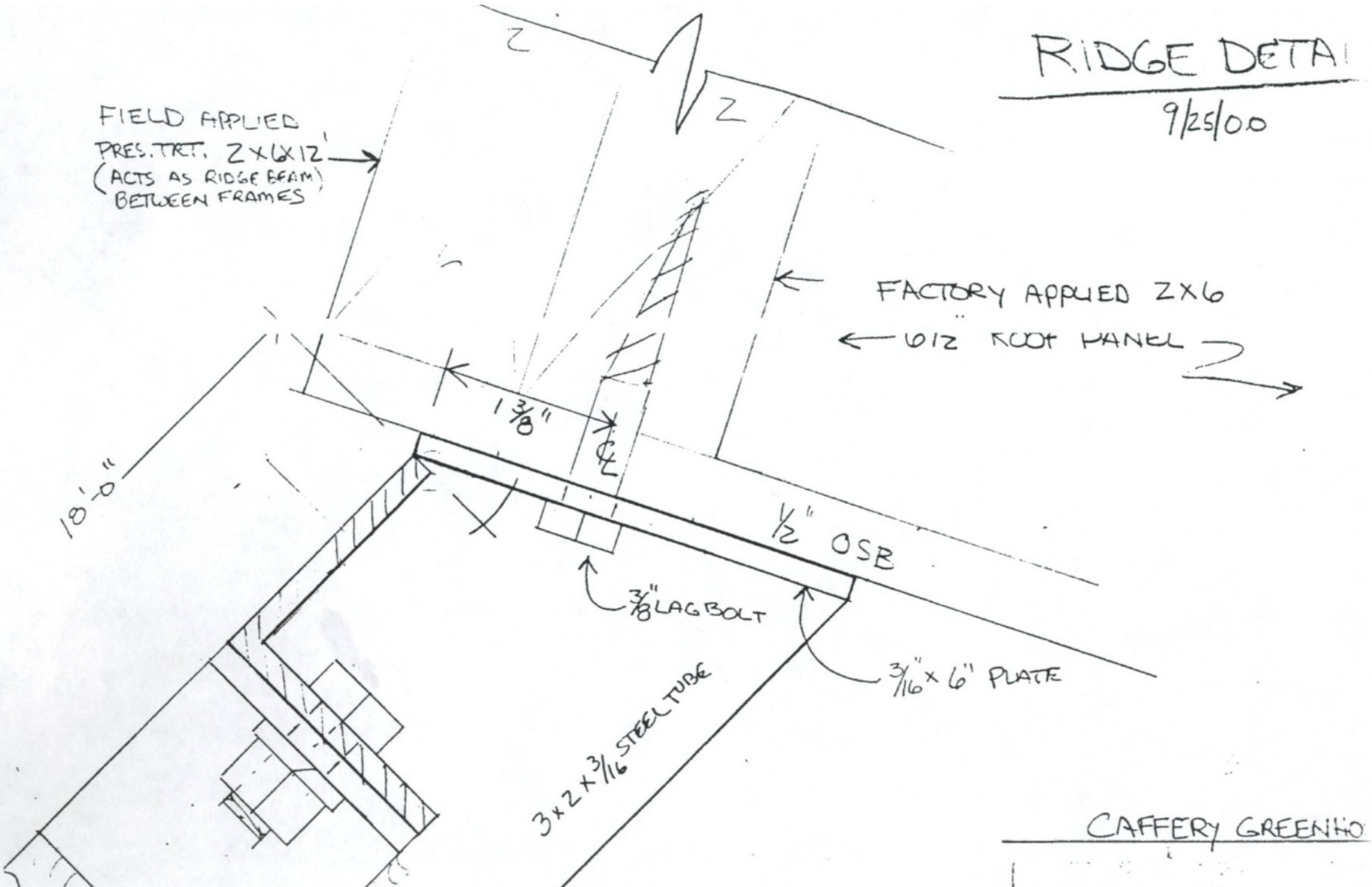
Cross section of greenhouse frame, east view [eastelevationframe.pdf]

Appendix C



NOTE: ASSUME ALL HOLES FOR 3/8" BOLTS.

Spectrum Design	CAFFERY GREENHOUSE 54' LONG.	September 25, 2000
David Vreeland	STEEL FRAME DETAILS	
		CAFFERY GREENHOUSE2STEEL.r2d



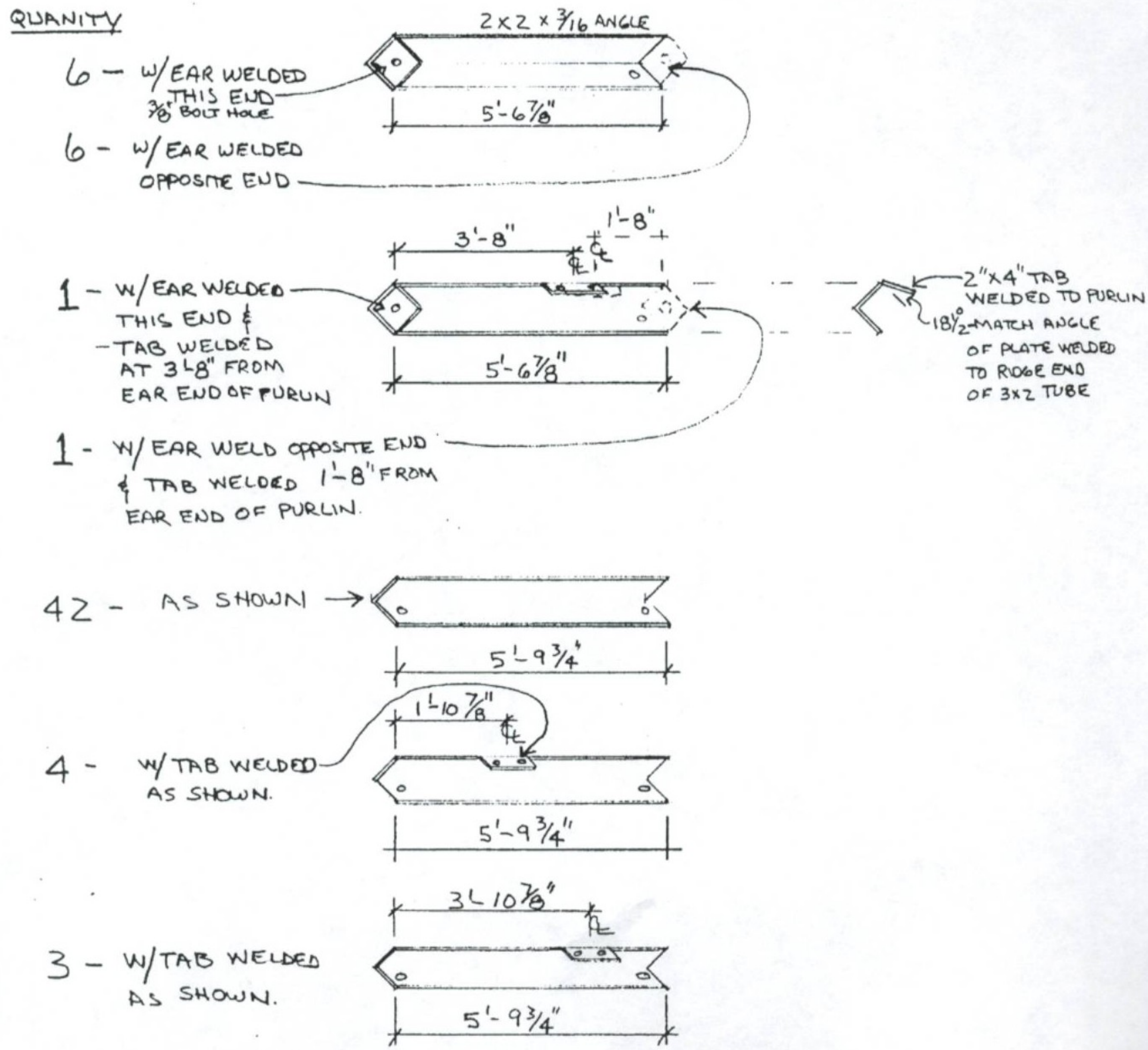
Spectrum Design Collabo

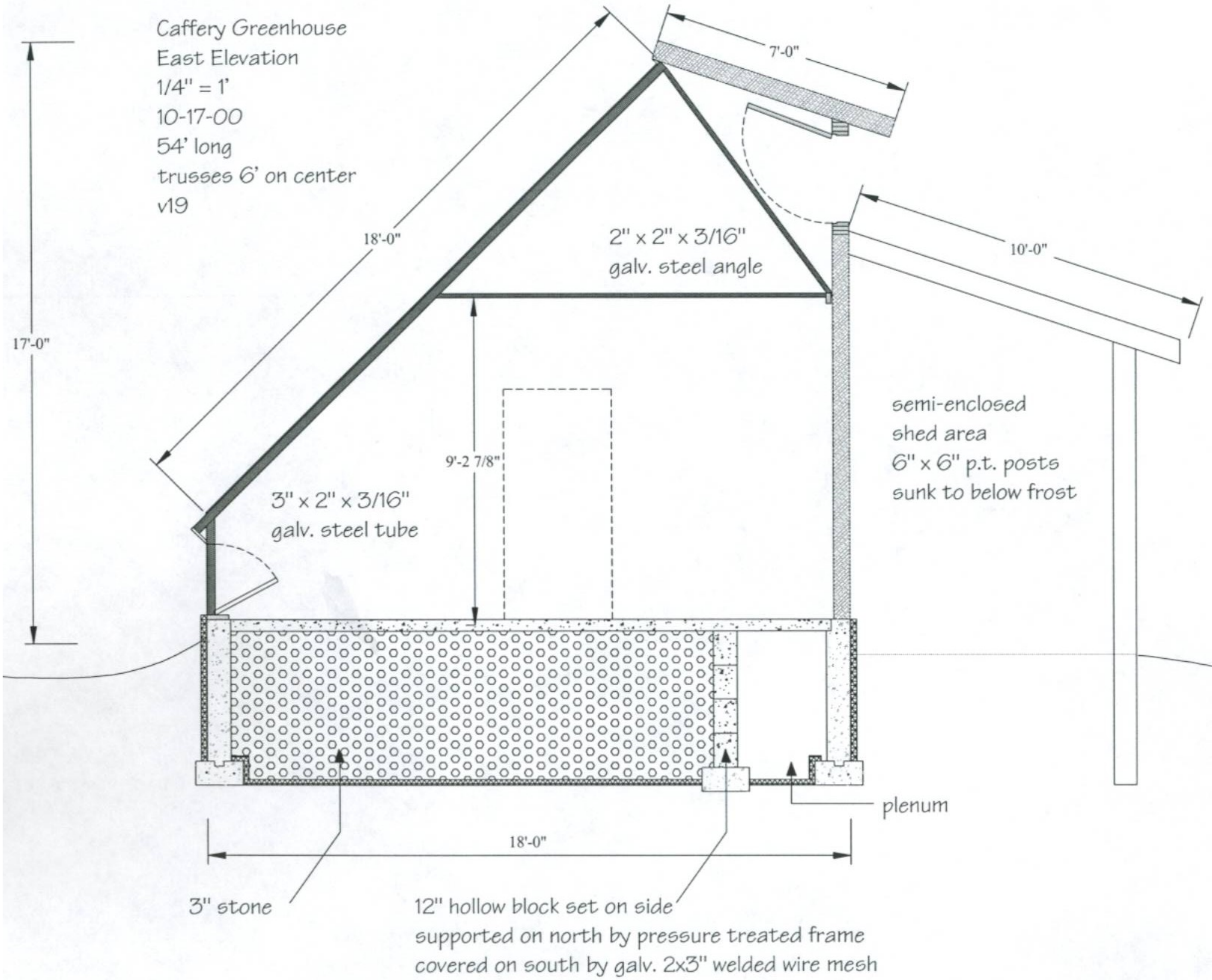
An integrative approach to planning, c
and construction management

DAVID VREELAND
116 RIVER ROAD, LEYDEN, MA 01337
PHONE (413) 624-0126 • FAX (413) 624-(

CAFFERY GREENHOUSE
9/25/00

PURLINS





Caffery Greenhouse
East Elevation
1/4" = 1'
10-17-00
54' long
trusses 6' on center
v19
7'-0"
18'-0"
2" x 2" x 3/16"
galv. steel angle
10'-0"
17'-0"
9'-2 7/8"
3" x 2" x 3/16"
galv. steel tube
semi-enclosed
shed area
6" x 6" p.t. posts
sunk to below frost
plenum
18'-0"
3" stone
12" hollow block set on side
supported on north by pressure treated frame
covered on south by galv. 2x3" welded wire mesh