Design Proposal Report

GreenLine

BAE 4012: Senior Design

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Submitted to: Dr. Paul Weckler

21 November 2014

Problem Statement

The client, Steve Hill of Phocas Farms in Edmond, OK, is interested in lengthening the growing season of his carrots in order to increase revenue. Currently, carrot growing is limited to the early months of spring and fall. The client would like to extend these growing seasons by cooling his raised greenhouse beds in the summer and heating them in the winter. It is clear that this two part design needs to provide ideal carrot growing conditions while being economically feasible enough to build, operate and maintain for years to come.

Statement of Work

Objectives

Our goal is to design a system that will both heat and cool raised greenhouse beds in order to maintain ideal growing conditions for crops. Carrots, the cash crop currently being implemented, grows best when the soil is 60^0F to 65^0F. During the hot summer months, the soil must be cooled to avoid overheating and the soil must be heated to avoid freezing in the colder winter months. The system needs to be able to adjust easily between heating and cooling to suit the changing climate at any given moment. It must be able to maintain multiple hoop houses each containing 5 raised beds that are twenty feet long and forty-three inches across. Heating and cooling must reach an effective depth as deep as twelve inches. Carrots need only one inch of water a week. Too much water can cause the carrots to crack and become susceptible to disease, and not enough will hinder growth.

Tasks

To determine the best design for this system, we must understand how energy travels through different types of material such as the soil and insulation used to construct the beds. This can be determined by finding the materials' thermal conductivities. Thermal conductivity is the measurement of energy (heat) that travels through a thickness of a material. A high thermal conductivity is most desired as the material will more readily transfer heat. The thermal conductivity for soils can vary greatly with differing moisture content and organic material. Increasing moisture and organic material increases the thermal conductivity. Since carrots grow best with one inch of water a week, adjusting the water content of the soil is limited. A COMSOL model has been created as a rough estimate of how the heat will flow through the water circulation pipes buried within the beds and the ground, but more data needs to be collected to get a more accurate model. Pipes and a pool heater are already in place to heat the soil underground. The pool heater is a Digital and Millivolt pool/spa heater model P-M 336 that runs at 332,500 BTU/hr with two inch water connections.

Data will be collected to determine the best fit for the design. Evaporative cooling has been considered in combination with underground cooling pipes for the hot season. It is imperative that most of the water evaporates so that moisture content does not surpass the maximum allowable growing conditions. A thermal data logger is being used to measure how heat will move through the clay portion of the soil at the client's location, which underlies the top soil of the beds. The best way to collect data is to replicate the beds and the conditions the crops will experience. Location has not yet been established for where the testing is going to take place, but the goal is to be able to test both hot and cold conditions at the same time.

By the fall, we will be able to present a few design alternatives. We will determine the total cost to set up such designs as well as maintenance cost. Cost is a major concern when considering different designs. The client would like to avoid spending a significant amount of money. However, if a design is able to save more money in the long run while investing more at the start, then it may be beneficial to pursue that design. By the end of fall, we hope to have a well-defined design with cost benefits and maybe a few other alternatives that could be considered along with those cost benefits. We hope to also be able to adjust the COMSOL model to display how some different alterations might be more beneficial than others.

By spring we will have developed and implemented the design that has been determined as the best choice. We will have data demonstrating the effectiveness of the proposed design. We would also like to have data showing an increase of revenue for what was previously months void of profit.

Work Breakdown Structure

Project Name: GreenLine
Department: Biosystems and Agriculture Engineering
Focus Area: Greenhouse Environmental Control
Product/Process: Heating and Cooling Raised Greenhouse Beds

Prepared By

Document Owner(s)	Project/Organization Role
Breanna Bergdall	Modeler, Documentation
Robert Honeyman	Leader, Soil Testing
Audrey Plunkett	Webmaster, Presentation Design

Project Closure Report Version Control

Version	Date	Author	Change Description
1.0.0	11/12/14	Breanna Bergdall	Created document.

Work Breakdown Structure Purpose and Limitations

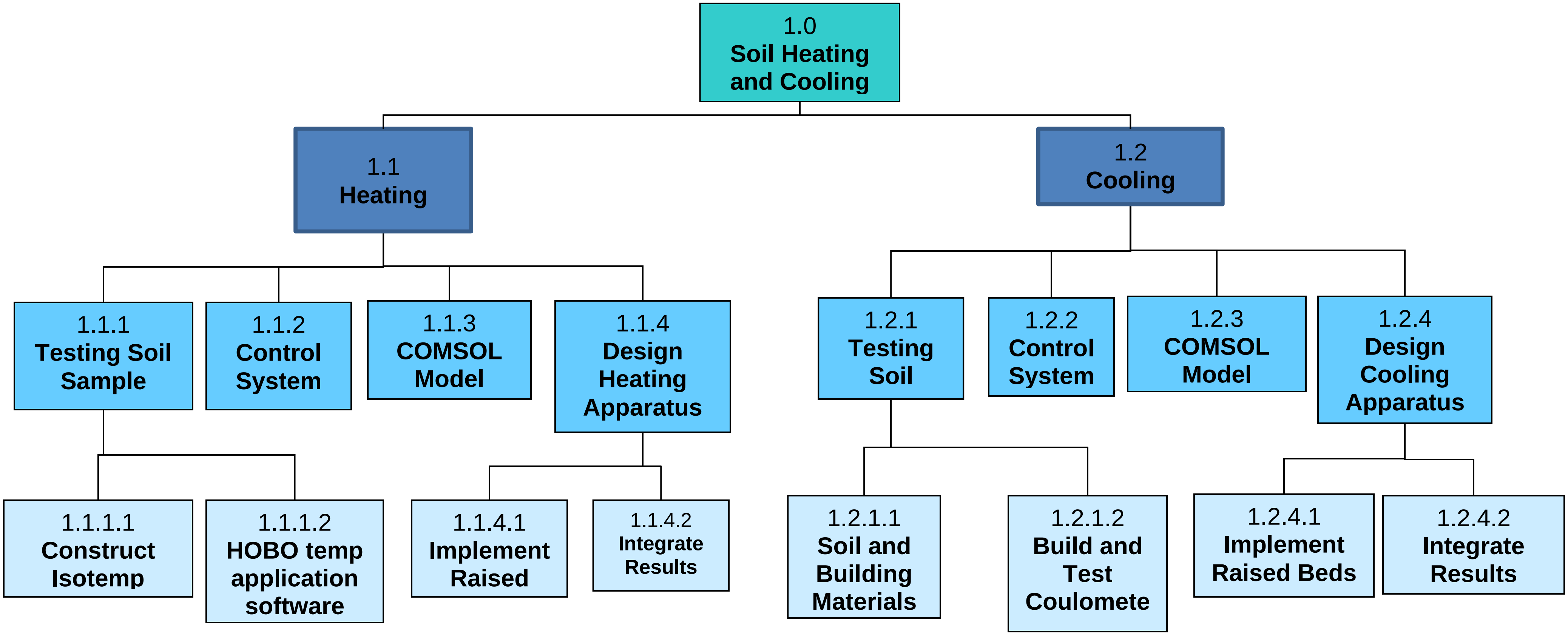
The purpose of this worksheet is to:

- Identify the work to be done.
- Identify the types of resources required for the work.
- Develop estimates for each work element.
- Identify storage locations.

This worksheet does not address:

- Who will perform the work.
- When the work will be completed.

Work Breakdown Structure Organization Chart



Work Breakdown Structure Worksheet

Work ID	Work Name	Description	Include (Completion Criteria)	Complexity	Estimated Effort	Dependency	Hand Off To	Storage/Location
1.0	Soil Heating and Cooling System	An overall system used to control the preferred conditions of crops.	Passing grade received.	8	100	Heating and Cooling	Client	Multiple Locations
1.1	Heating	Heat soil.	Soil is hot.	7	34	Design and Control system	Client	Multiple Locations
1.1.1	Testing Soil Sample	Determine equilibrium thermal profile of ground.	Data collected.	5	4	---	COMSOL model	Phocas Farms
1.1.2	Control System	Design a system that regulates heater and pump flow.	Works.	8	10	Model and Design	Heating	BAE Lab
1.1.3	COMSOL model	Calculate losses in surrounding area.	Verified by experiment.	9	8	Soil Testing	Design and control system	Computer.
1.1.4	Design Heating Apparatus	Improve the existing heating recirculation system.	Approved by customer.	4	12	Model	Control system	BAE Lab
1.2	Cooling	Cool soil.	Soil is cold.	8	66	Design and Control system	Client	Multiple Locations
1.2.1	Testing Soil Sample	Determine specific heat and thermal conductivity of clay and soil.	Values calculated.	6	6	---	COMSOL model	BAE Lab
1.2.2	Control System	Design a system that regulates cooler, mister, and pump flow.	Works.	9	25	Model and Desgin	Cooling	BAE Lab
1.2.3	COMSOL Model	Calculate losses in surrounding area.	Verified by experiment.	9	--	Soil Testing	Design and Control System	Computer.
1.2.4	Design Cooling Apparatus	Create evaporative recirculated and misting system.	Approved by customer.	10	35	Model	Control System	BAE Lab

Literature Review

The prevalent method of greenhouse cooling is using fan blown evaporative cooling or fan-less misting above plants. The fan-less systems simply spray a fine mist of water into the air, usually over the plants, to cool the air and plants through the evaporation of water (Alam, 2012). This works because water requires energy to become water vapor, which is provided by the heat in the air it is sprayed into. The effectiveness of this method is dependent on how fine a mist can be generated because a finer mist has greater surface area, which increases the rate of the conversion from mist to vapor. If the mist is not fine enough, excess water will fall out of the air prior to evaporating. If uncontrolled, this excess can result in oversaturation of the soil, which promotes mold growth and can cause root rot. In the event the air becomes saturated with water vapor, it will no longer matter how fine the mist is, all water sprayed will fall out of suspension. This can be beneficial, though, as the abundance of misted water discourages some types of insects.

Blown evaporative cooling systems are less prone to oversaturating the soil because most designs use passive evaporation off a mesh pad instead of misting, so at air saturation no more water is added to the air. Additionally, the turbulence of the air encourages full evaporation of the water in misted designs, so it is more likely to have a higher cooling efficiency per unit of water used. Operating these fans can be costly due to the amount of electricity required to run them. A fan system is also unable to isolate the cooling effect to the localized area directly above the plants and instead cools the entire greenhouse.

Both systems rely on a water source that is mostly free of dissolved solids and salts as these will foul the nozzles of the mister systems and accumulate in the evaporative mesh pads of the blown systems. Adequate control of both systems relies on air and soil measurements of temperature and moisture content. This will prevent oversaturation of the soil and will also prevent needless cooling effort when the plants are at a desired temperature. The sensors can perform automatic irrigation control, which frees up labor. Additionally, the sensors will provide a means of data logging, which allows easy comparison of plant conditions to yield.

Dual stage evaporative cooling, heat pumps, and spraying chilled water are options that seem to not yet be implemented in greenhouses. This makes sense because these methods add complexity and increase base cost while also increasing operating costs. The main advantage provided by these systems is that they offer extra headroom to cool past the dew point temperature. Because the dew point is only occasionally above the preferred temperature to grow carrots, these more complex methods should be considered as a last resort. Cooling of soil through pumping a cooled fluid has been researched and demonstrates a noticeable improvement in growth rate.

Several publicized patents have applied misting and fanning in their inventions with different methods. One invention uses a single, portable device in combination with both misting and fanning. This single device can be stationary to cover one large area at a time then moved to the next site. This concept is advantageous because it uses little material to cover many large areas. However, it requires some manpower to move the device to each site throughout the day.

The current trends in greenhouse heating focus on electric heating wire or recirculated hot water. Electric heating has the benefit of having a constant heat per unit of length and can be scaled easily to any size of greenhouse. It requires the least above ground equipment and is very intuitive. Unfortunately, electrical heating is highly susceptible to damage by rodents, and is not easily repaired. Since it is completely dependent on an electrical supply, it has no alternative sources for energy input. This is partially made up for by the fact that electrical heat cables provide nearly ideal efficiency, with the only losses being from the current regulator in the thermostat.

Recirculated water has the advantage of being able to be ignored in the event of minor leaks, and is much more inexpensive to repair and expand. Additionally, the heat can be sourced from anywhere, which allows vacuum insulated solar water heater tubes to be utilized as a source of free energy. Unlike the purely electrical method, a water recirculated system is able to store heat accumulated during the day and release it at night, providing another source of free energy. The only drawback is that there is a lineal deposition of heat along the flow of the water. This cooling of the water within the soil results in potentially substantial uneven heating of the soil as the difference in temperature between the outside air and the target temperature becomes large.

Because recirculated water is common to both systems, it may be possible to create a system that performs both heating and cooling with the same recirculation lines. Although this would increase control complexity, it has the potential of decreasing the overall cost of the base system and any expansion.

Testing

A sample of the soil used in the greenhouse beds was collected on Friday, October 10. This was performed using a soil sampling rod from Dr. Abit to collect the sample from the beds that were already in place. The sample will give us the percentage of silt, clay, and sand so that we could get an idea specific heat capacity and thermal conductivity for the type of soil.

A simulation was created in COMSOL to represent the heat transfers of the materials involved. The individual heat transferring media are the soil, the ground clay, the ambient air, and the garage door barriers, as shown in Figure 1. The information gathered from published data will be used to help create the model by specifying the specific heat and thermal conductivity of the materials. The model in Figure 2 shows the thermal profile of the cross section of the beds. The initial model calculates simple heat transfer of a cube of mostly homogenous clay. To validate this model, a test setup will be built from a cube of clay and a heating element. The thermal profile will be imaged with a Flir One and with simple temperature probes.

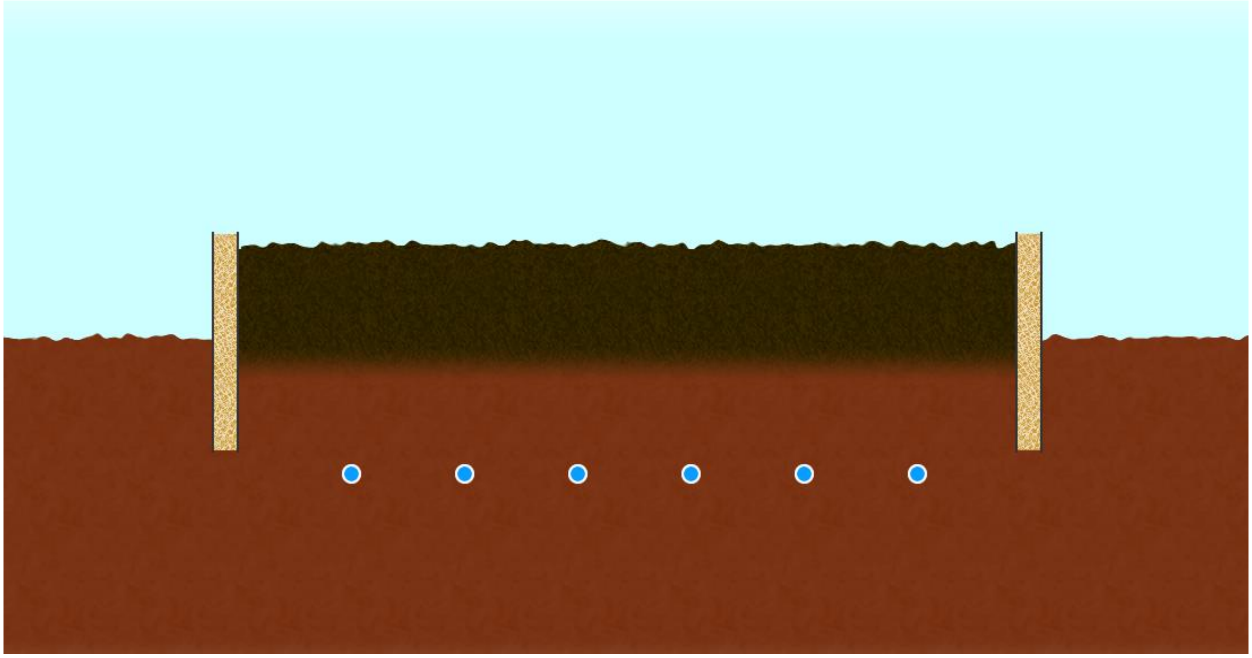


Figure 1: Cross section of the raised beds currently being used and the existing heating tubes.

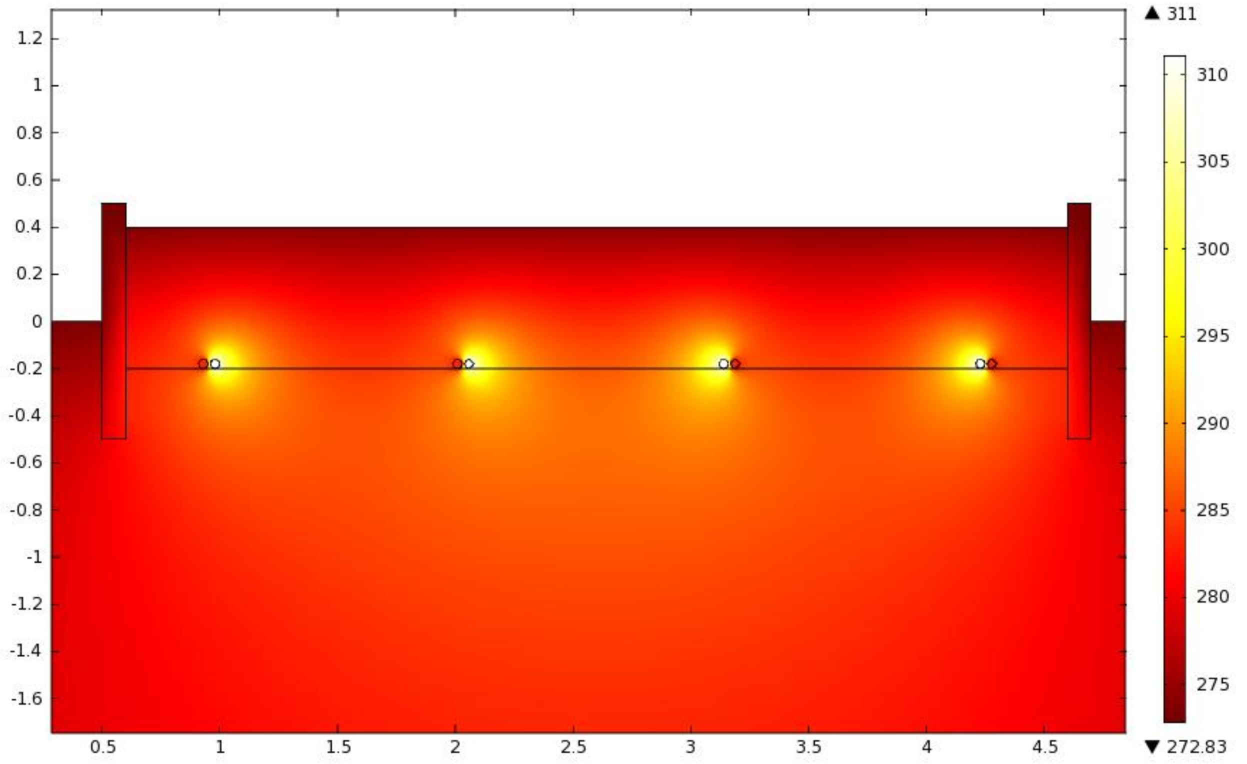


Figure 2: COMSOL model of thermal profile with convective cooling on top layer.

To improve accuracy of the model, testing of the thermal parameters may be performed and the model then updated with the corrected information. These tests can be performed with a vacuum chamber, electric heating element, and a calibrated temperature sensor, which are all readily available.

The material used to make the beds will be collected once there is a better understanding of the location as to where the testing will be taken place. Enough material will be needed to make the two beds 43 inches wide, 5 feet long, and 11 inches tall. Information collected from the soil sample could be used to best replicate an accurate model of the beds. Two models would be best so that both atmospheres of a hot day and a cold day may be replicated. One bed could be placed in a freezer room to simulate a cold winter and the other could be placed in a hot box to simulate a hot summer. We could get permission from one of the science labs to use a small space of one of their freezers to test the heated bed. We would like the beds to be at least five feet long if that much space is available to us. Since carrots seem to be the main crop that is going to be planted in these particular beds, some information on the optimal growing conditions for carrots will be needed.

Materials and tools that are needed:

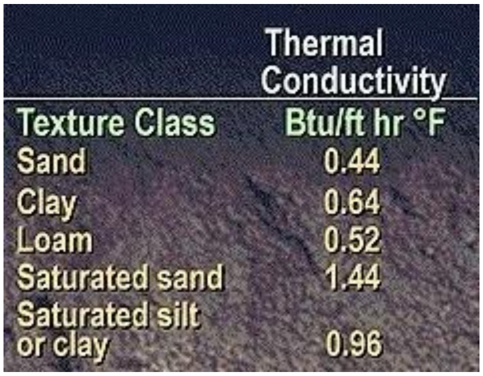
- 1yd Clay from client - $0
- 1yd Soil from client - $0
- 8 garage door panels from client - $0
- Water Heater Electric Element
- Cpvc pipe of various sizes - $0

- Electronic Flowmeter
- 1’x1’ and 1’x4’ sheet 1/8” glass
- 4’x8’ sheet foam insulation board
- 4’x8’ sheet ¾” plywood
- 20A Variac
- Watt*hr meter
- Calibrated temperature probes
- Datalogger
- Flir One Thermal Camera
- Soil moisture probes
- Water pump
- Inline water heater

Specifications

- Raised bed specifications:
    - Length: 90 ft. (inside length)
    - Width: 43 in. (inside length)
    - Height:11 in
    - Panels: 1.25 in thick
    - 4 beds per hoop house
- Ideal temperature: 60 - 65 F
- pH range: 6.5 - 7.5
- 1 inch of water per week
- Digital and Millivolt Pool/Spa Heater

  - Model: P-M336
  - 332,500 BTU/hr
  - 2” water connections
- Intellifo VS+SVRS Variable Speed Pump
- Norwesco 300 gallon water tank



Texture Class	Thermal Conductivity Btu/ft hr °F
Sand	0.44
Clay	0.64
Loam	0.52
Saturated sand	1.44
Saturated silt or clay	0.96

Figure 3: Thermal conductivity of the different textures of soil.

Thermal conductivity will be used to determine how heat flows through the soil. Moisture content also greatly influences thermal conductivity. Moisture content will be estimated by the 1 inch of water that the carrots need to grow properly.

Heat diffusion equation: q”=-k(∆T/∆x) ≐ Wm2 where ∆x≈12 in

The heat from the pipes to warm the soil can be calculated as: $T = Ti - \frac{T_i - T_o}{\ln\frac{r_o}{r_i}}\ln\frac{r}{r_i}$

To determine an accurate for the soil, the heat capacity for all the contents of soil should be calculated such as the minerals, water, air and organic matter. This can be determined using the following equation and info in the table below: $c_v = \rho_m\theta_m c_m + \rho_w\theta_w c_w + \rho_a\theta_a c_a + \rho_{om}\theta_{om} c_{om}$

Table 1. Values for calculating heat capacity. (Or, D., 2004)

Constituent	**Specific Heat, c_i** [J kg^{-1} $^{O}C^{-1}$]	**Density** [kg m^{-3}]	**c_v** [MJ m^{-3} $^{o}C^{-1}$]
Soil minerals (m)	733	265	1.94
Soil organic matter (om)	1926	1300	2.5
Water (w)	4182	1000	4.18
Air (a)	1005	1.2	0.0012

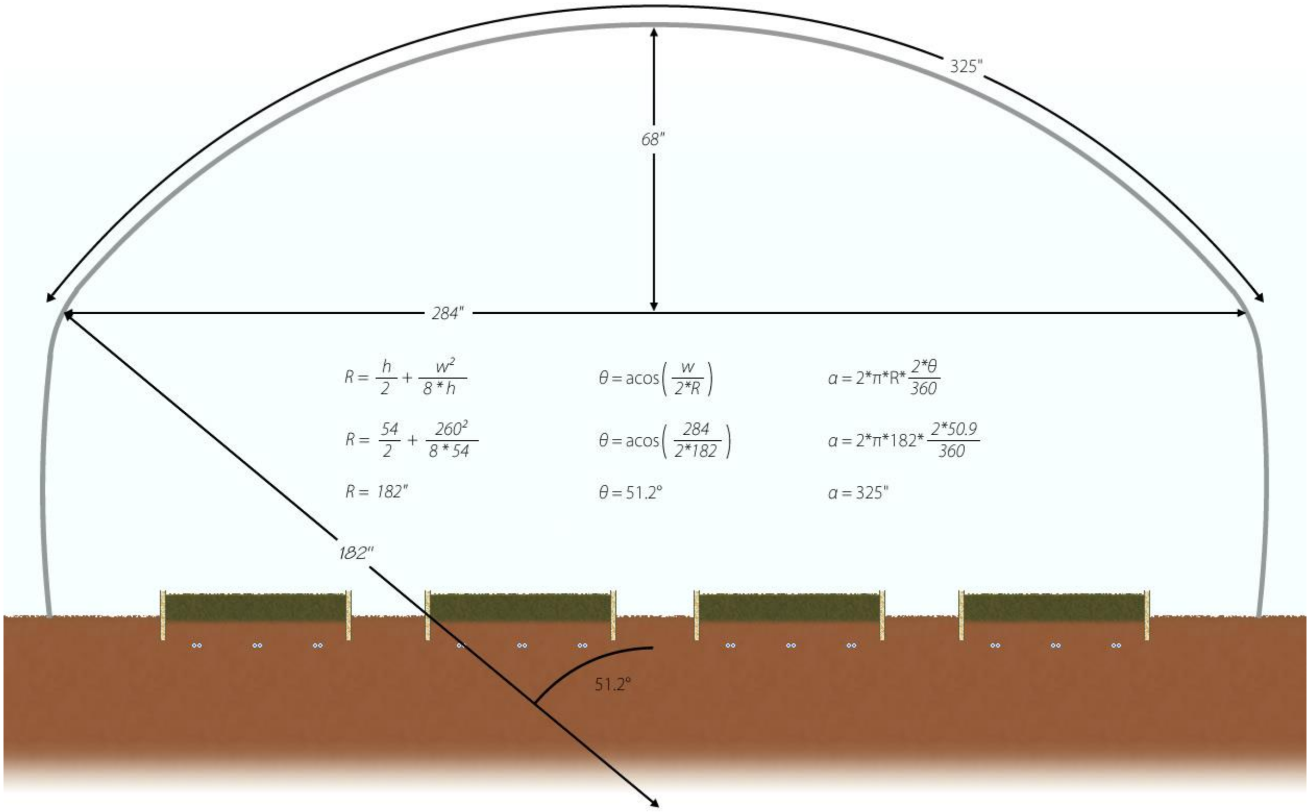
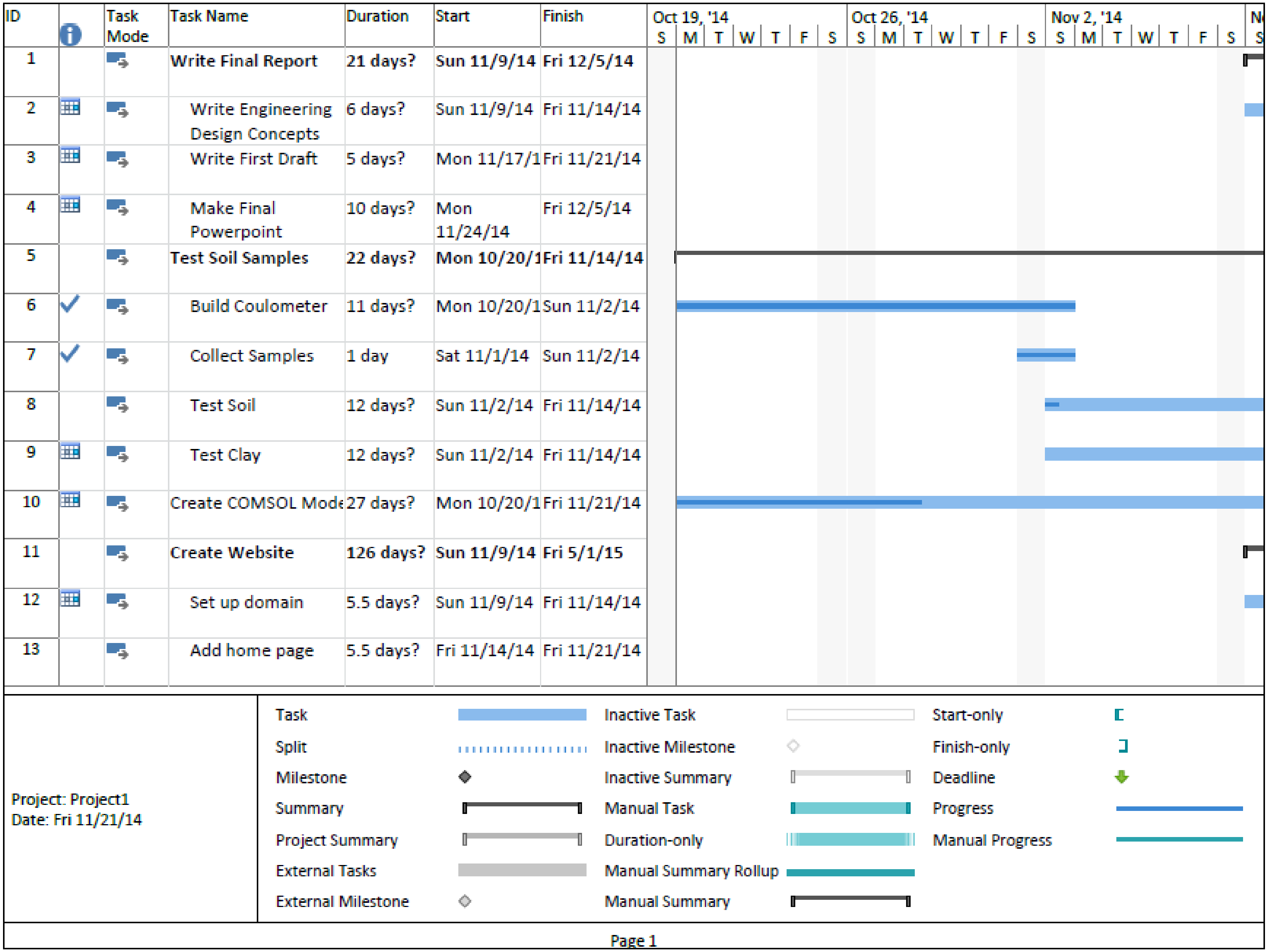


Figure 4: Diagram of the dimensions for the hoop house.

Diagram above is use to determine the amount of material needed to build the hoop houses by knowing the desired height.



ID		Task Mode	Task Name	Duration	Start	Finish
1		➡	**Write Final Report**	**21 days?**	**Sun 11/9/14**	**Fri 12/5/14**
2	▦	➡	Write Engineering Design Concepts	6 days?	Sun 11/9/14	Fri 11/14/14
3	▦	➡	Write First Draft	5 days?	Mon 11/17/1	Fri 11/21/14
4	▦	➡	Make Final Powerpoint	10 days?	Mon 11/24/14	Fri 12/5/14
5		➡	**Test Soil Samples**	**22 days?**	**Mon 10/20/1**	**Fri 11/14/14**
6	✓	➡	Build Coulometer	11 days?	Mon 10/20/1	Sun 11/2/14
7	✓	➡	Collect Samples	1 day	Sat 11/1/14	Sun 11/2/14
8		➡	Test Soil	12 days?	Sun 11/2/14	Fri 11/14/14
9	▦	➡	Test Clay	12 days?	Sun 11/2/14	Fri 11/14/14
10	▦	➡	Create COMSOL Mode	27 days?	Mon 10/20/1	Fri 11/21/14
11		➡	**Create Website**	**126 days?**	**Sun 11/9/14**	**Fri 5/1/15**
12	▦	➡	Set up domain	5.5 days?	Sun 11/9/14	Fri 11/14/14
13		➡	Add home page	5.5 days?	Fri 11/14/14	Fri 11/21/14

Project: Project1
Date: Fri 11/21/14

Task		Inactive Task		Start-only	[
Split		Inactive Milestone	◇	Finish-only	]
Milestone	◆	Inactive Summary		Deadline	⬇
Summary		Manual Task		Progress	
Project Summary		Duration-only		Manual Progress	
External Tasks		Manual Summary Rollup			
External Milestone	◇	Manual Summary			

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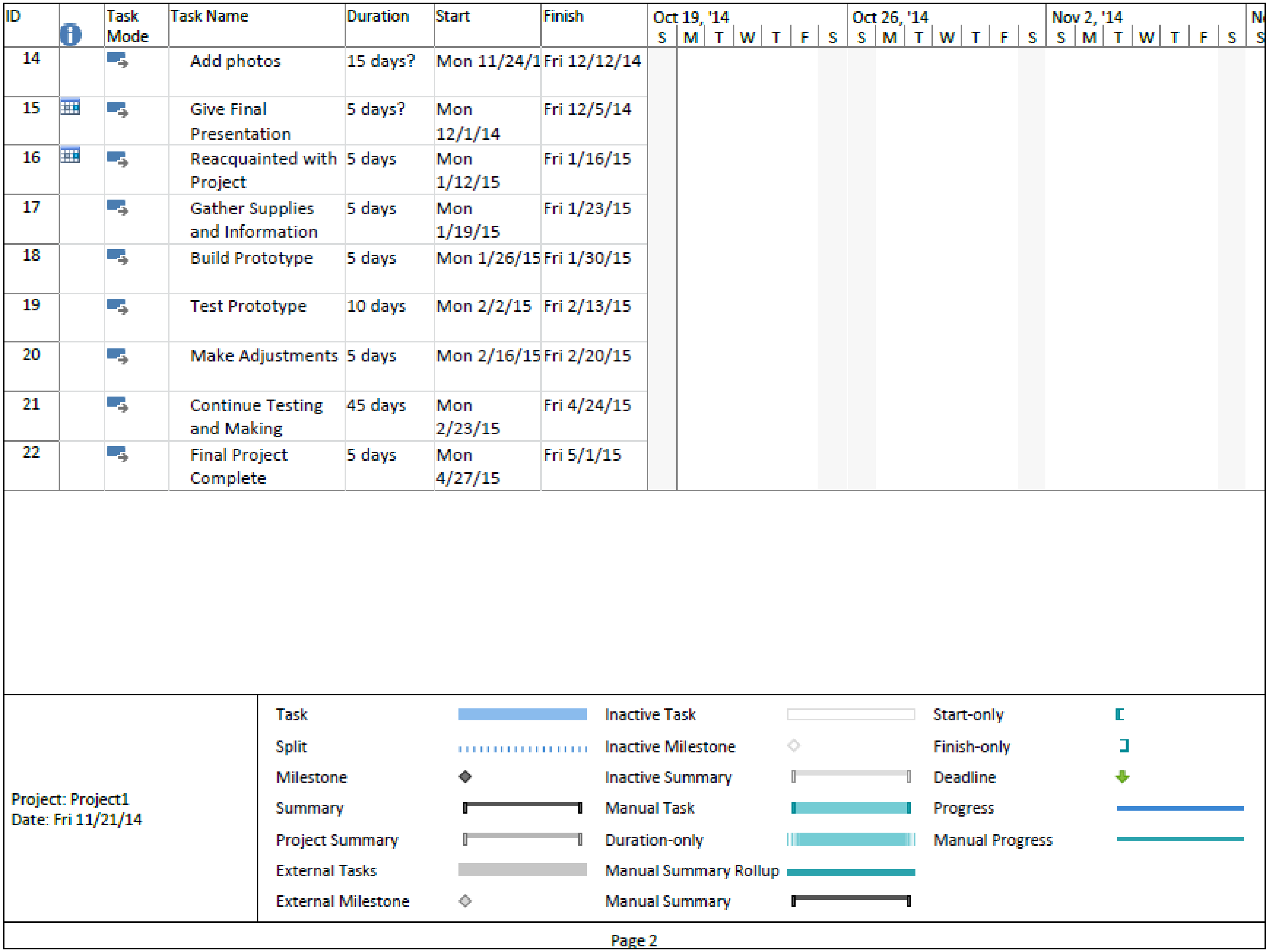

ID	ⓘ	Task Mode	Task Name	Duration	Start	Finish
14		⇨	Add photos	15 days?	Mon 11/24/1	Fri 12/12/14
15	▦	⇨	Give Final Presentation	5 days?	Mon 12/1/14	Fri 12/5/14
16	▦	⇨	Reacquainted with Project	5 days	Mon 1/12/15	Fri 1/16/15
17		⇨	Gather Supplies and Information	5 days	Mon 1/19/15	Fri 1/23/15
18		⇨	Build Prototype	5 days	Mon 1/26/15	Fri 1/30/15
19		⇨	Test Prototype	10 days	Mon 2/2/15	Fri 2/13/15
20		⇨	Make Adjustments	5 days	Mon 2/16/15	Fri 2/20/15
21		⇨	Continue Testing and Making	45 days	Mon 2/23/15	Fri 4/24/15
22		⇨	Final Project Complete	5 days	Mon 4/27/15	Fri 5/1/15

Project: Project1
Date: Fri 11/21/14

Task	▬	Inactive Task	▭	Start-only	[
Split	┈	Inactive Milestone	◇	Finish-only	]
Milestone	◆	Inactive Summary	┏━┓	Deadline	⬇
Summary	┏━┓	Manual Task	▬	Progress	━
Project Summary	┏━┓	Duration-only	▬	Manual Progress	━
External Tasks	▬	Manual Summary Rollup	▬		
External Milestone	◇	Manual Summary	┏━┓		

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GreenLine

Heating and Cooling of Raised Greenhouse Beds

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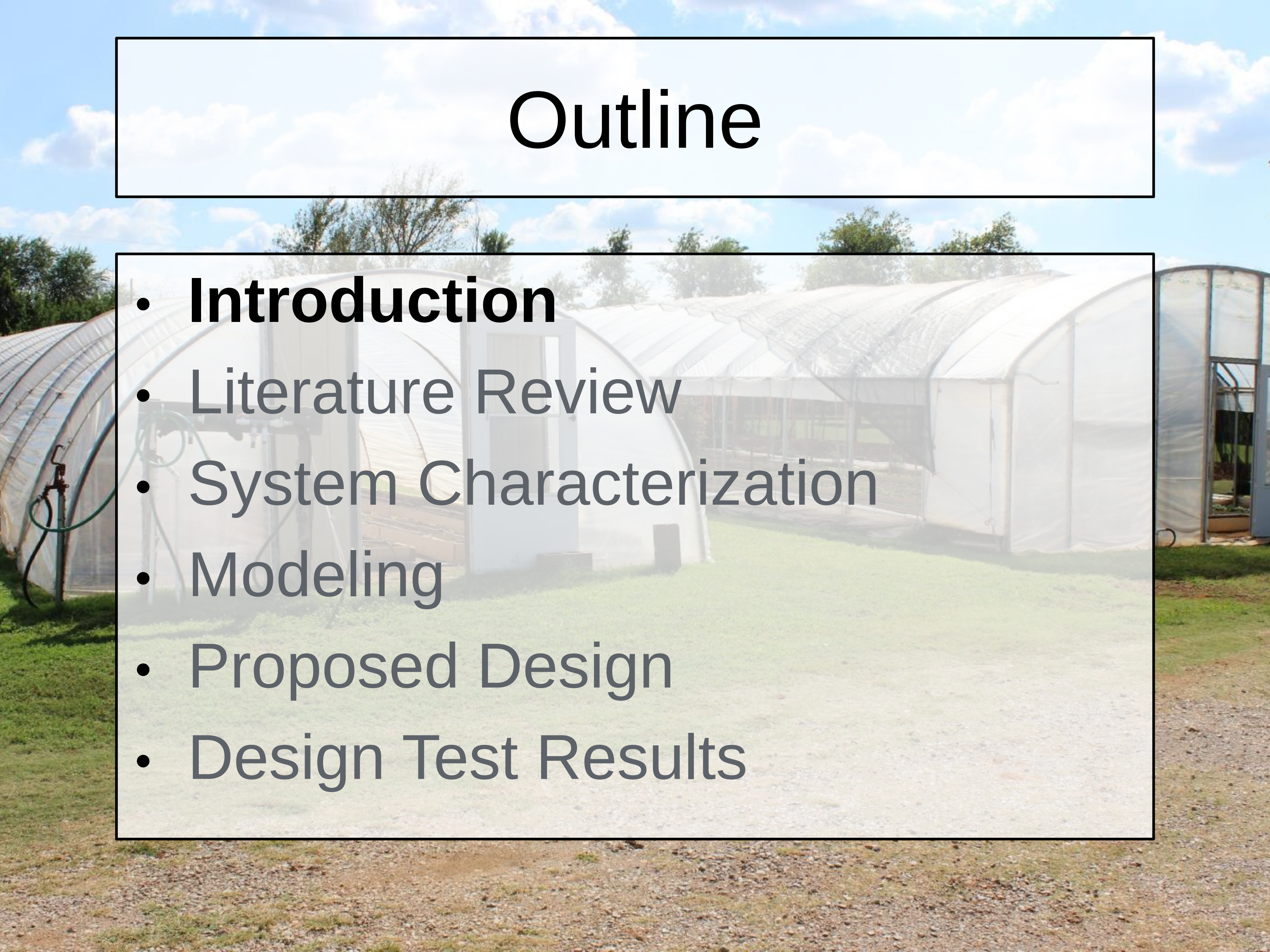


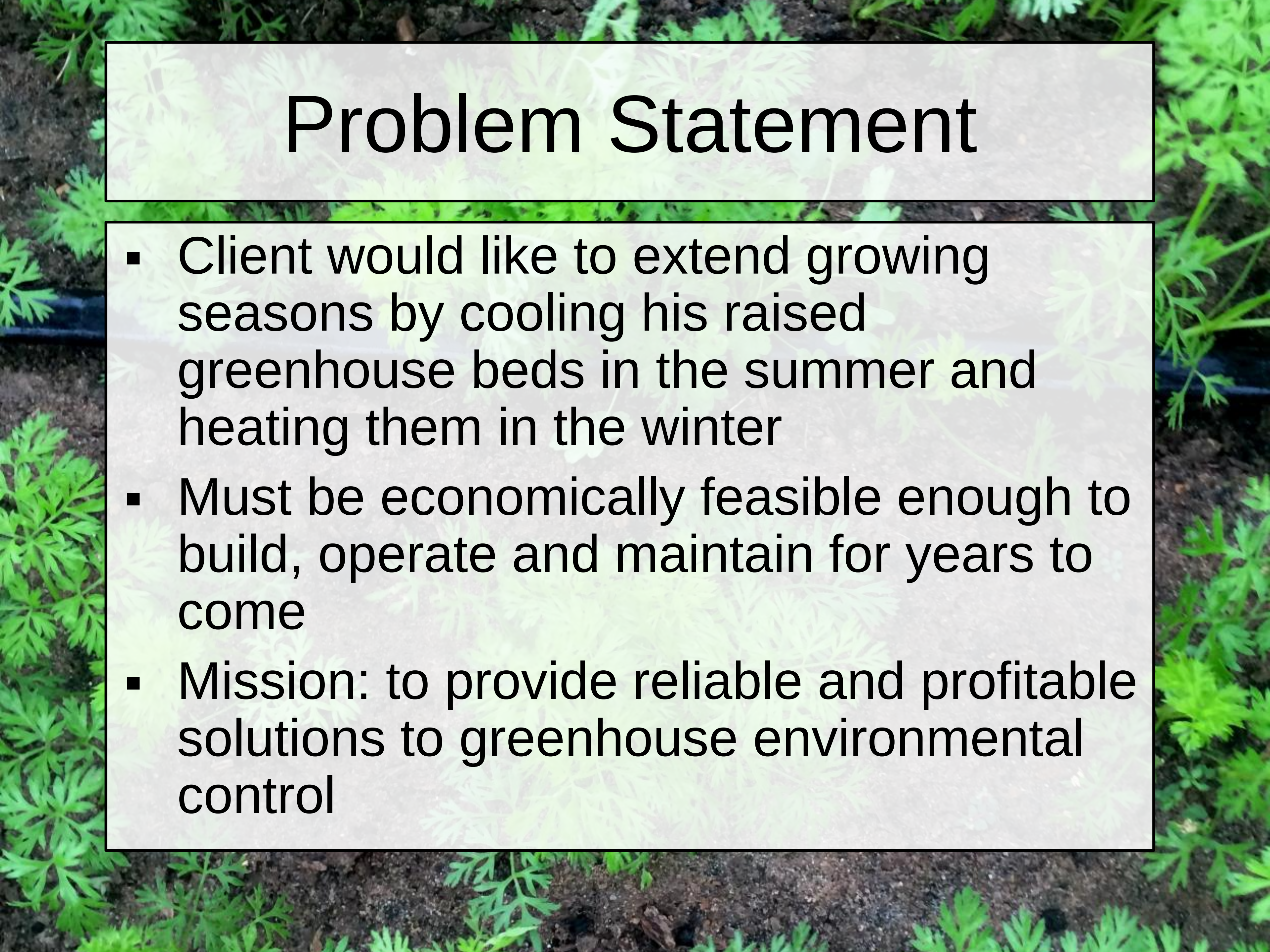
Outline

- **Introduction**
- Literature Review
- System Characterization
- Modeling
- Proposed Design
- Design Test Results

Introduction

Client:

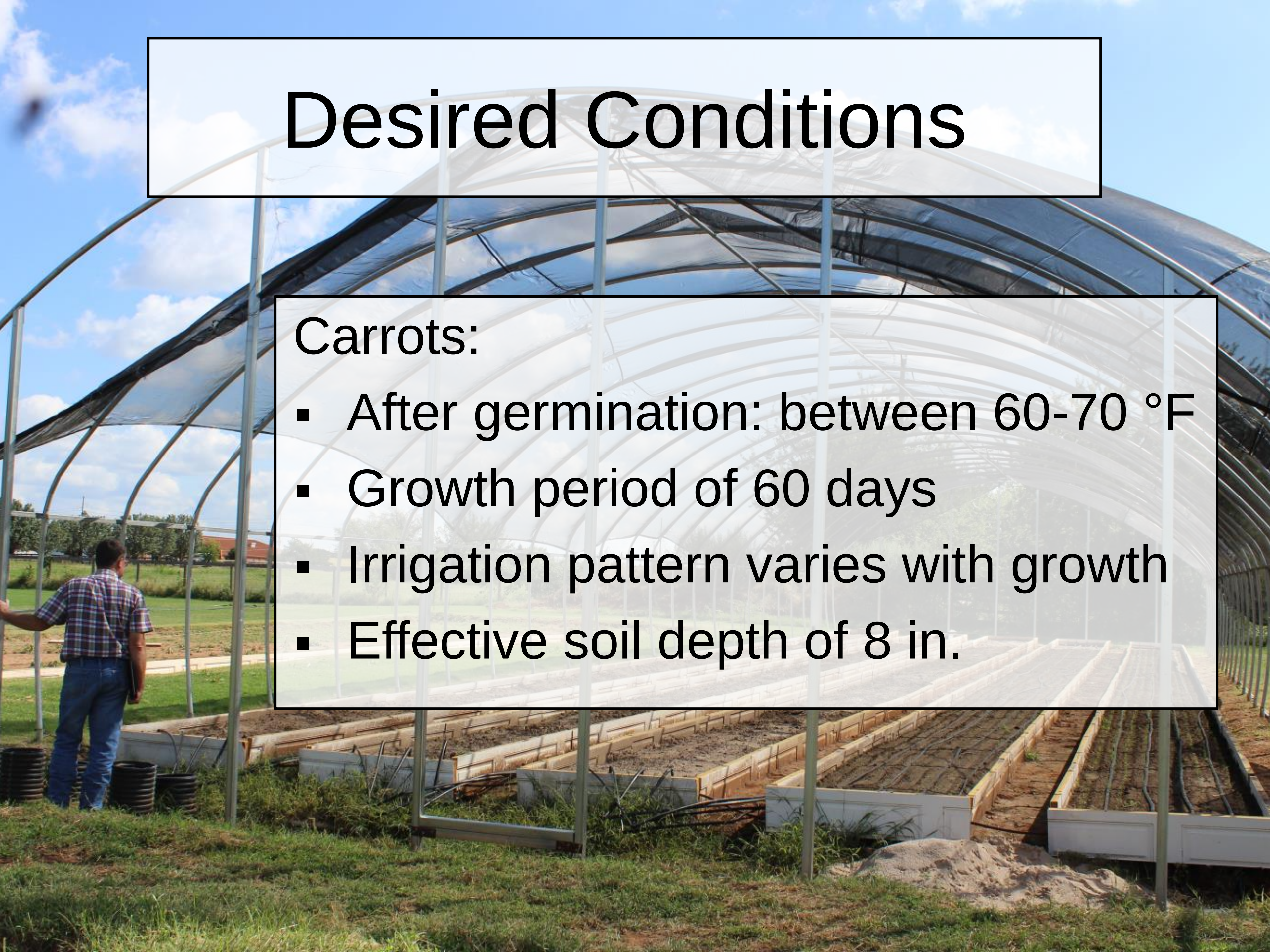
- Steve Hill
- Phocas Farms, Edmond, OK
- Provides produce for Edmond schools



Problem Statement

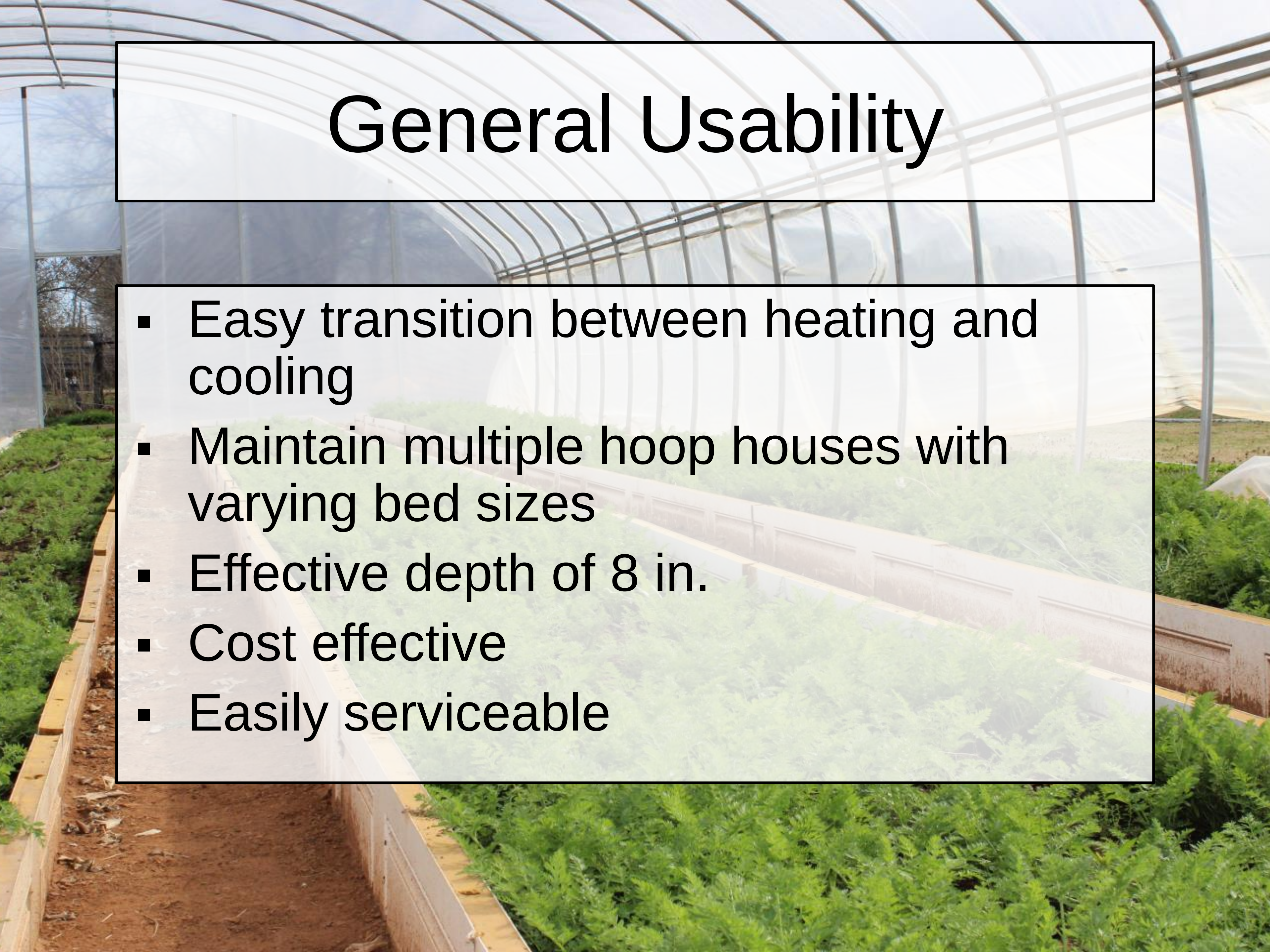
- Client would like to extend growing seasons by cooling his raised greenhouse beds in the summer and heating them in the winter
- Must be economically feasible enough to build, operate and maintain for years to come
- Mission: to provide reliable and profitable solutions to greenhouse environmental control

Desired Conditions



Carrots:

- After germination: between 60-70 °F
- Growth period of 60 days
- Irrigation pattern varies with growth
- Effective soil depth of 8 in.



General Usability

- Easy transition between heating and cooling
- Maintain multiple hoop houses with varying bed sizes
- Effective depth of 8 in.
- Cost effective
- Easily serviceable

Prior Equipment Integration

- Rheem Digital Gas Heater
- Pentair IntelliFlo Pump
- Norwesco Storage Tank
- 0.62 in. irrigation tubing

Prior Equipment Integration

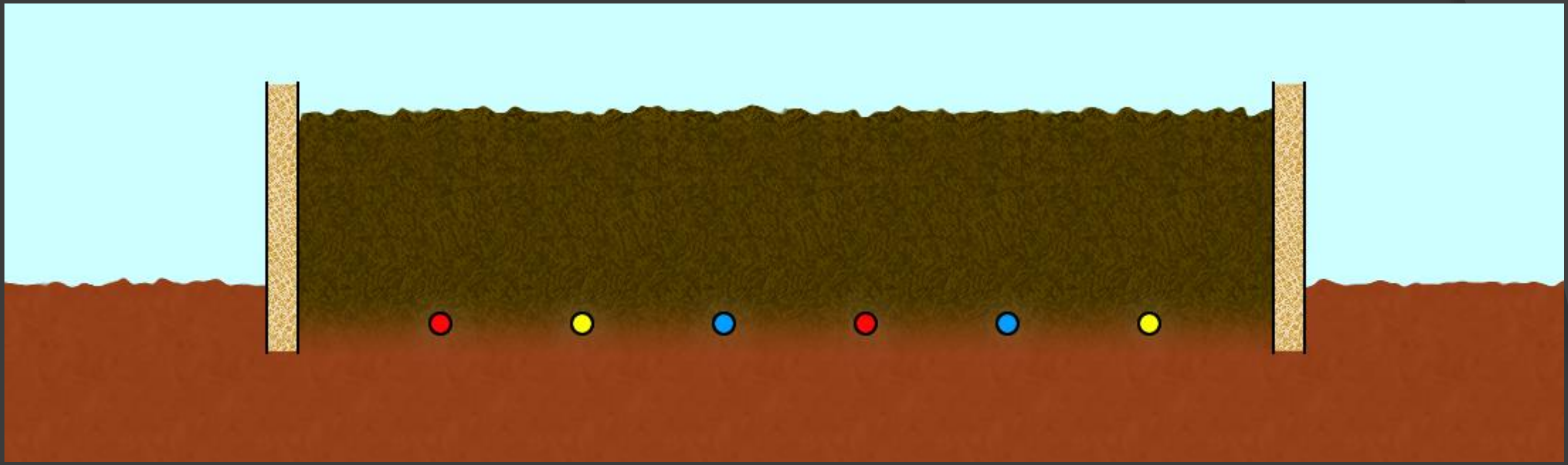


Figure 1. Vertical cross section of existing raised beds

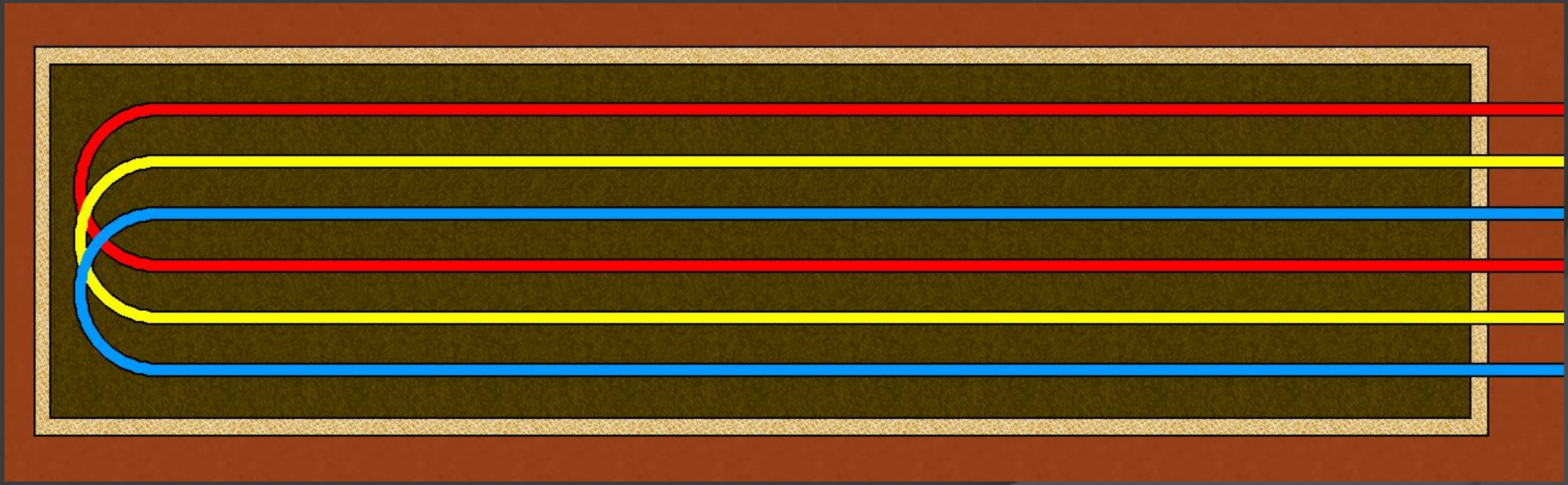
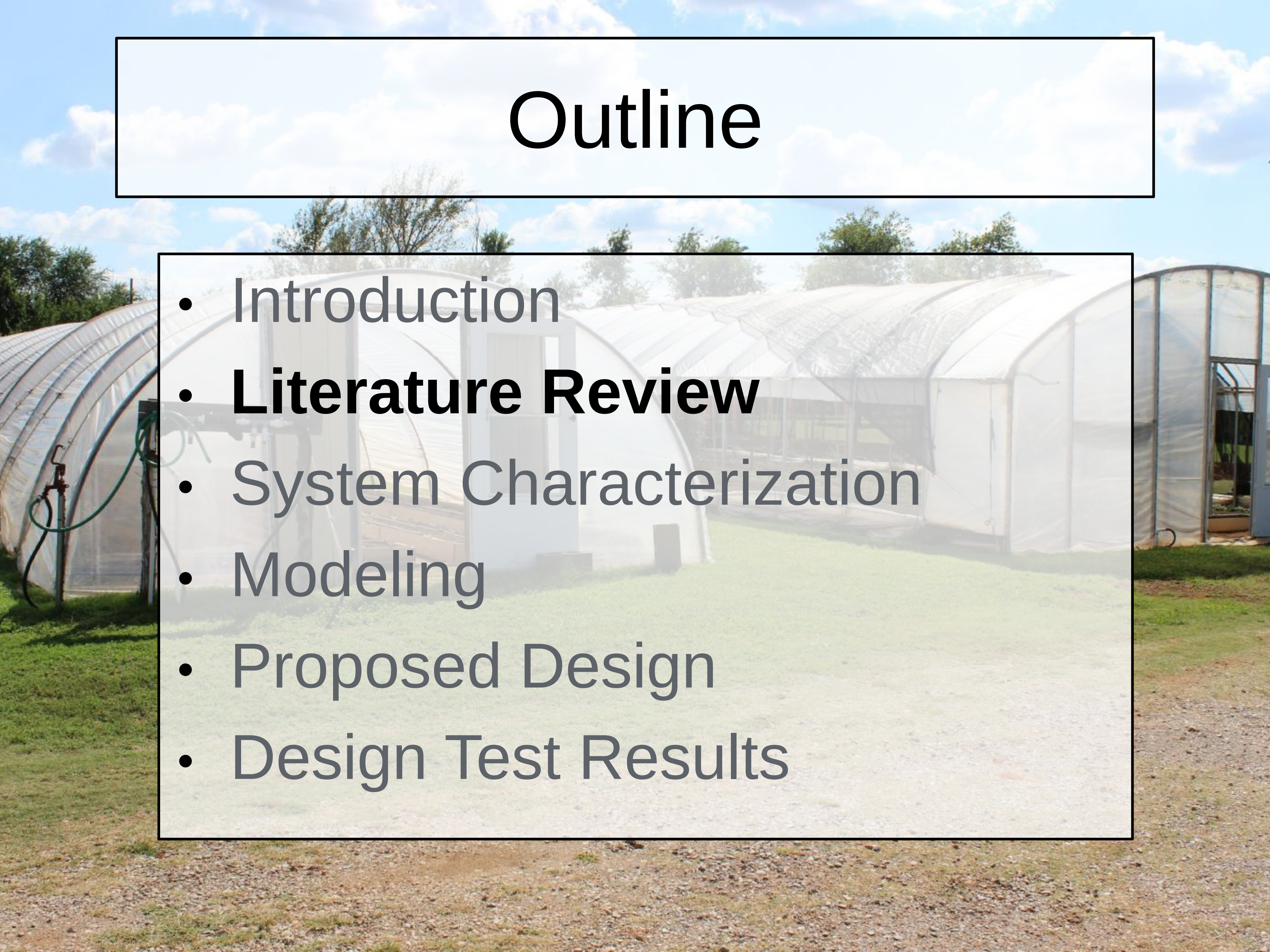


Figure 2. Horizontal cross section of existing raised beds

Outline



- Introduction
- **Literature Review**
- System Characterization
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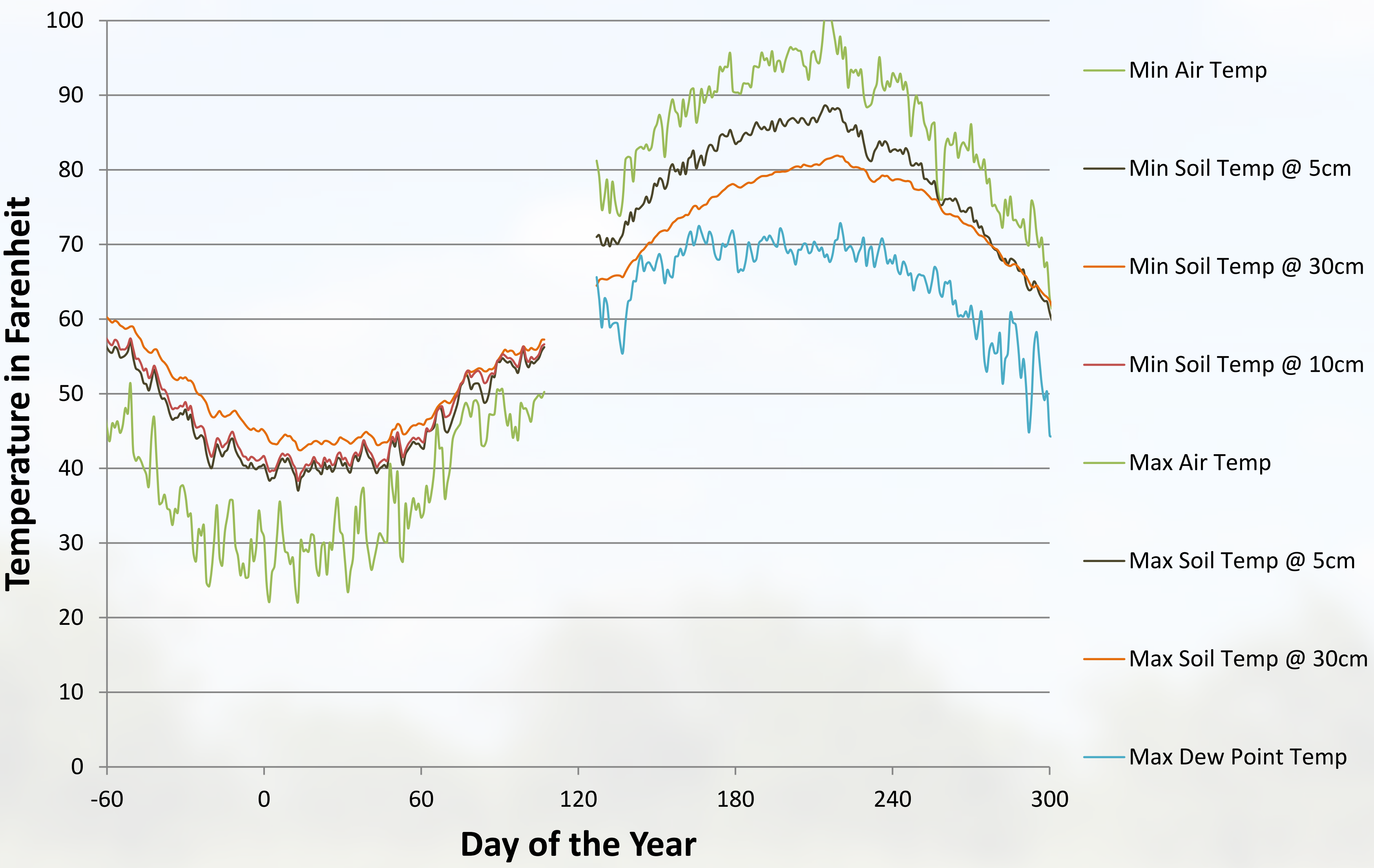
Conditions at Mesonet Station near Phocas Farms

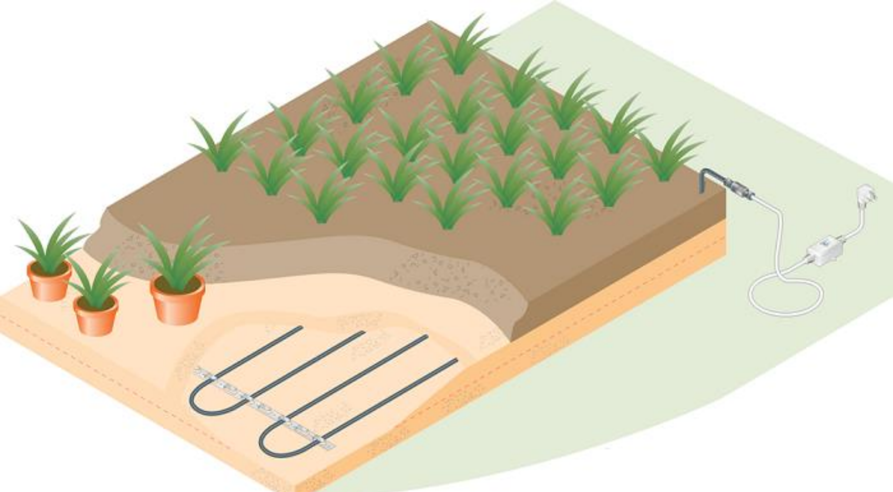


Effect of Climate on Energy Transfer

- When the ambient temperature is much higher or lower than the goal temperature, more energy is required.
- Evaporative cooling is not effective below the dew point.
- Irrigation water is supplied at a temperature near the average yearly temperature.
- System should be designed to function in the most demanding conditions.

Current Heating Methods

http://www.heat-safe.com/en/t/faq-soil



http://www.growhome.net/Bio-Green-Heating-mat-and-thermostat-and-soil-sensor.html

Electric Heating Wire

- Constant heat per unit of length
- Easily scaled to greenhouse dimensions
- Requires least amount of above ground equipment
- Heat cables highly efficient
- Highly susceptible to damage by rodents
- Not easily repaired
- Completely dependent on electrical supply

Current Heating Methods

http://aesop.rutgers.edu/~horteng/openroof1.htm

Recirculated Hot Water

- Inexpensive to repair and expand
- Multiple potential heat sources
- Can store heat during the day
- Can result in uneven heating

Current Cooling Methods

Fan-less misting above plants:

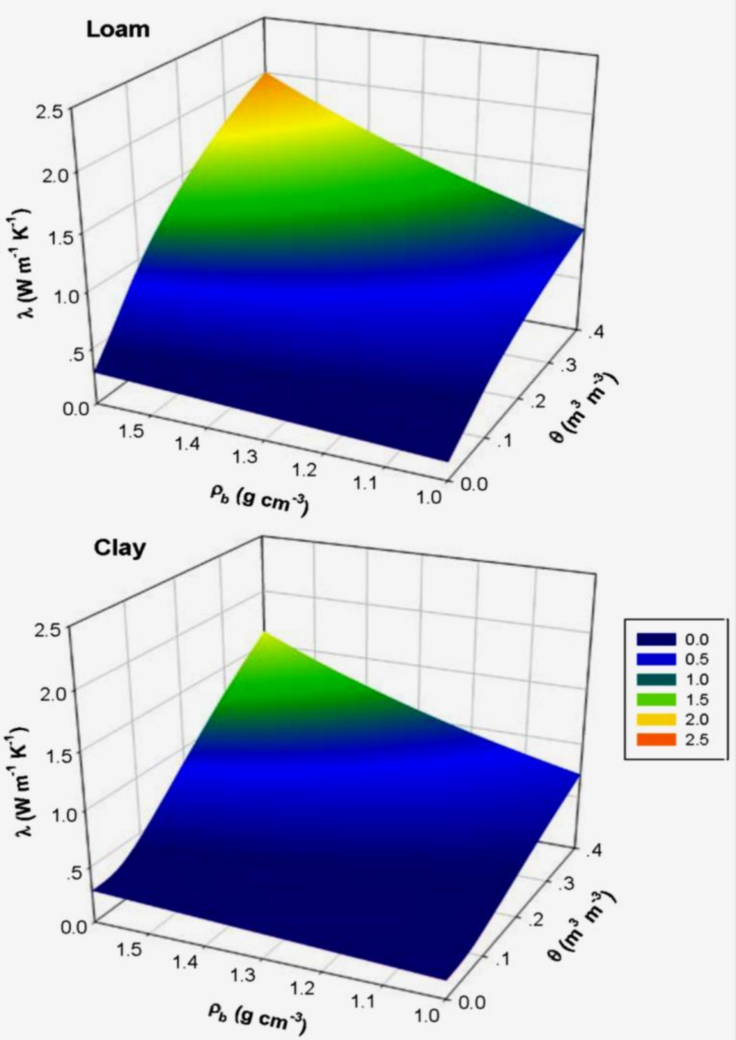
- Oversaturation can cause mold and root rot

Blown evaporative cooling:

- Less prone to oversaturation
- Air turbulence encourages full evaporation of mist
- Higher cooling efficiency per unit water used
- Fan operation costly

http://www.certhon.com/products/heating-and-cooling/greenhouse-cooling/air-and-water-cooling/jsk

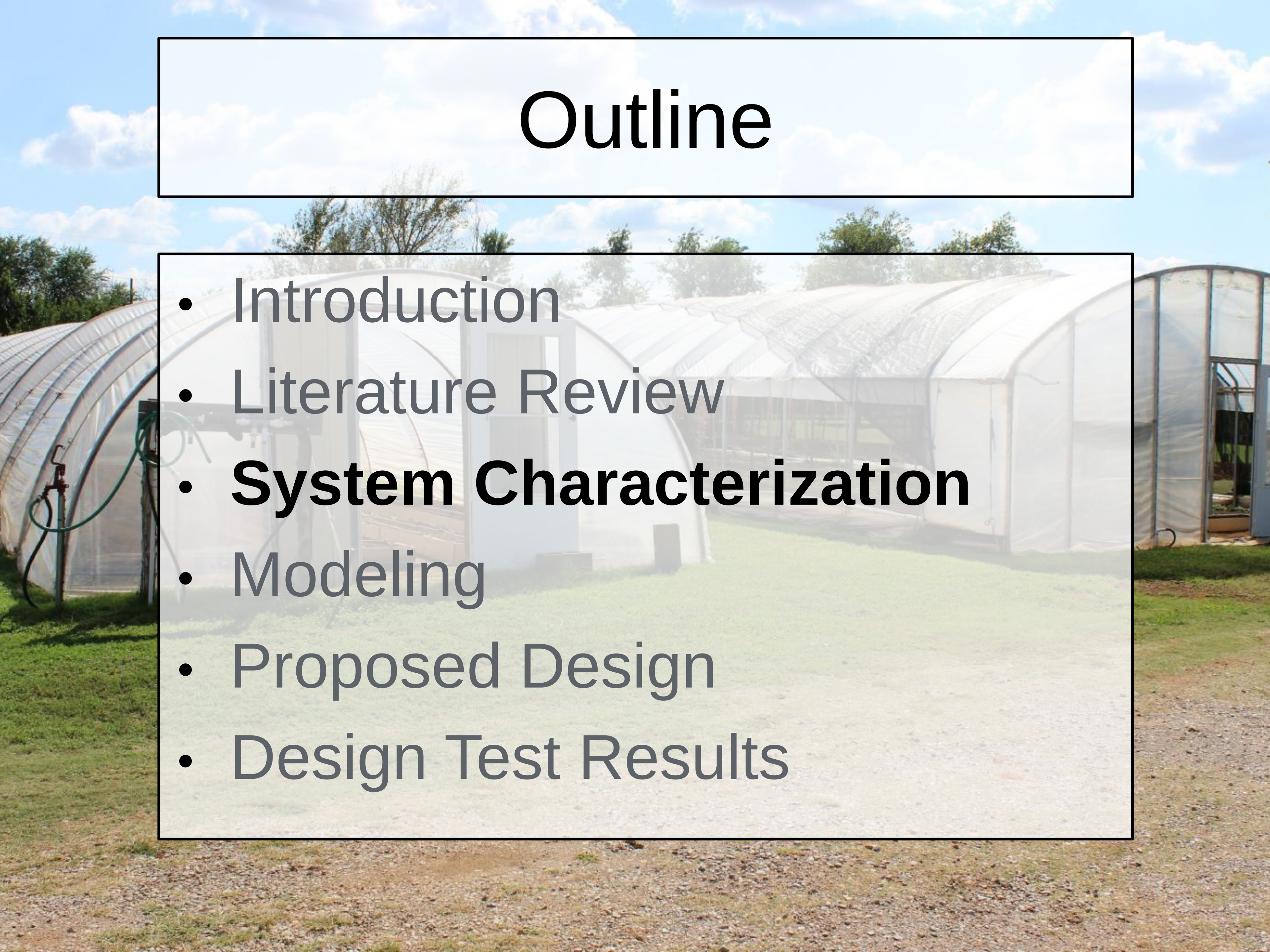
Energy Transfer in Soil



http://www.builditsolar.com/Projects/Cooling/EarthTemperatures.htm

- Thermal conductivity affects conduction through soil
- Varies by soil type and moisture content
- Thermal conductivity increases with moisture and organic material
- Heat capacity increases as moisture increases
- $q = -k\frac{\Delta T}{\Delta x}$ where Δx is about 8 in.

Outline



- Introduction
- Literature Review
- **System Characterization**
- Modeling
- Proposed Design
- Design Test Results

Soil Characterization

- 15 soil samples were collected
- Three samples were collected per location at approximately 2, 4, and 6 in depths

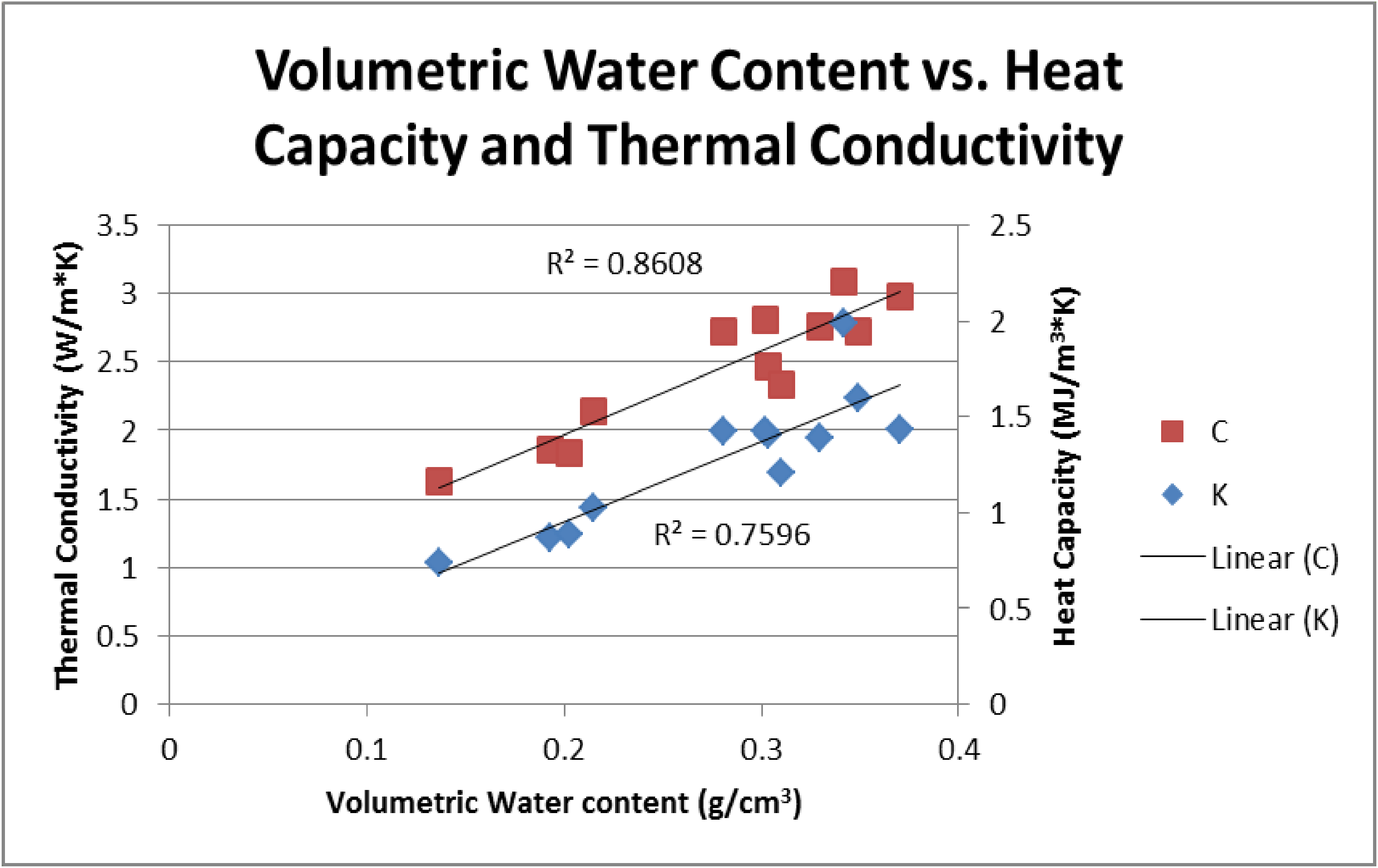
KD2 Pro Thermal Properties Sensor:

- Volumetric heat capacity
- Thermal conductivity

Calculations:

- Bulk density
- Volumetric water content

Soil Physical Properties

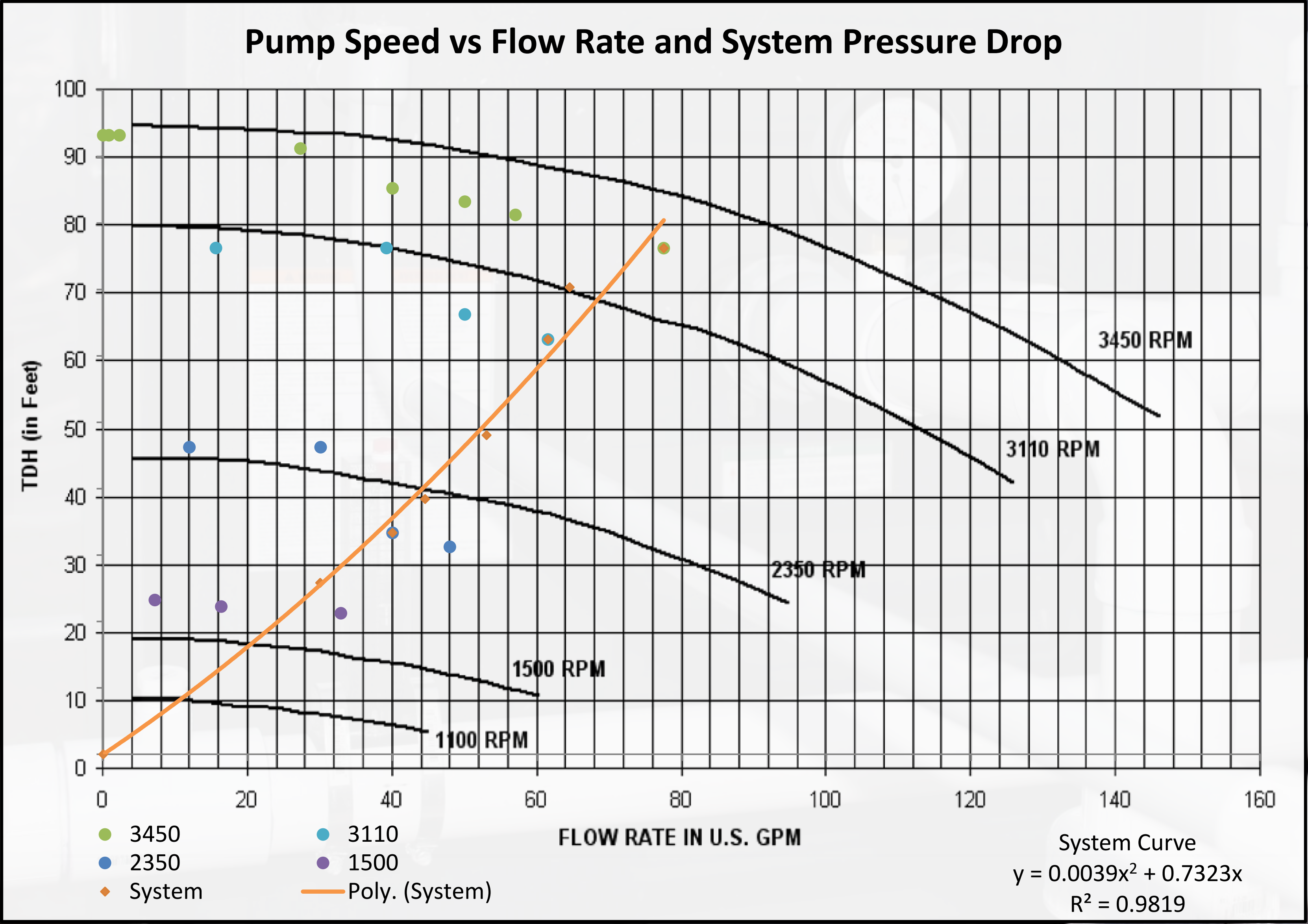


Pump Test Setup

System Test Setup

- Both tests use same pressure gauge and flow meter
- Flow meter was tested for accuracy and installed 10 hydraulic diameters downstream from last bend of flow

Fluid Power Loss



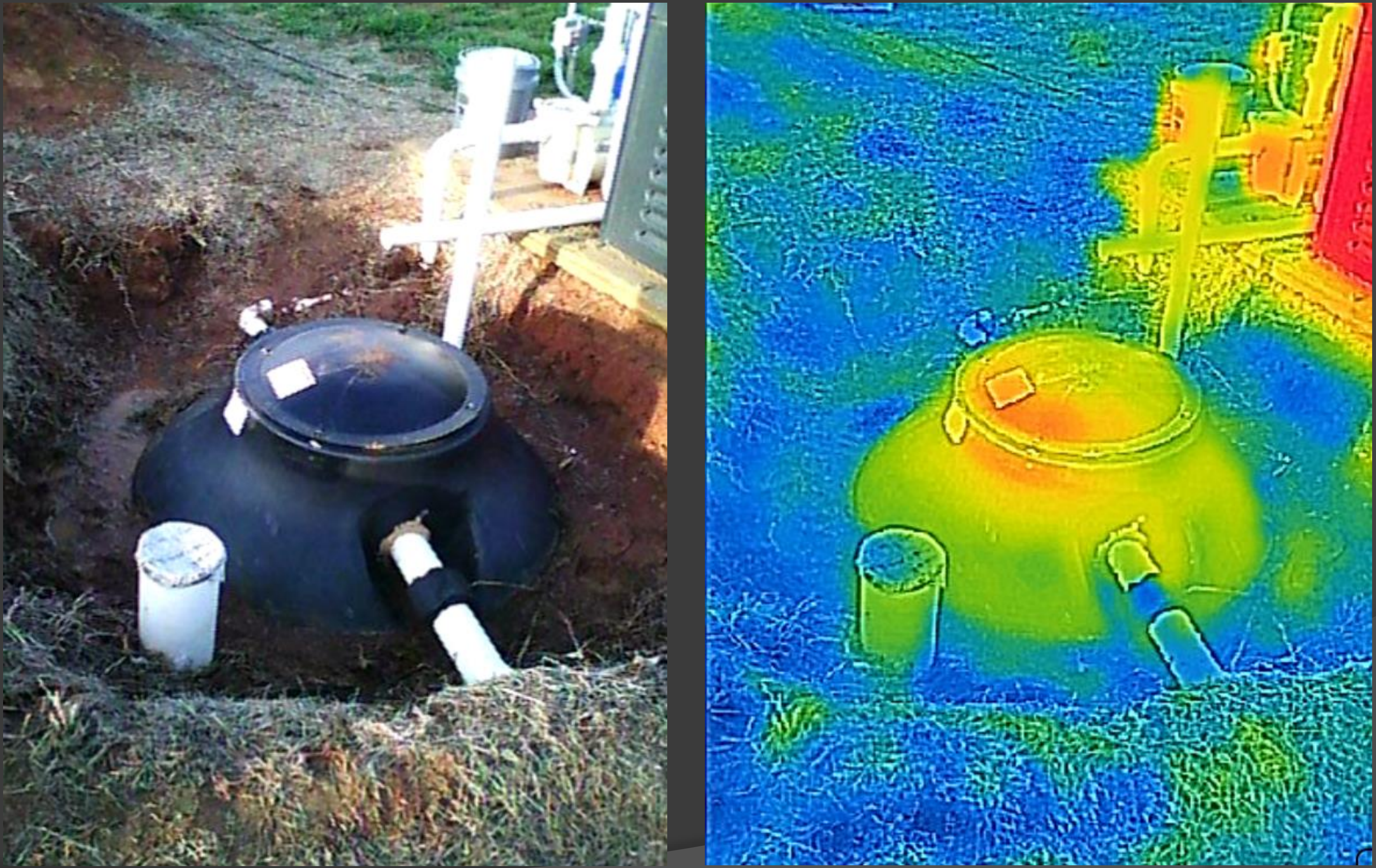
Pump Speed vs Flow Rate and System Pressure Drop

System Curve

$y = 0.0039x^2 + 0.7323x$

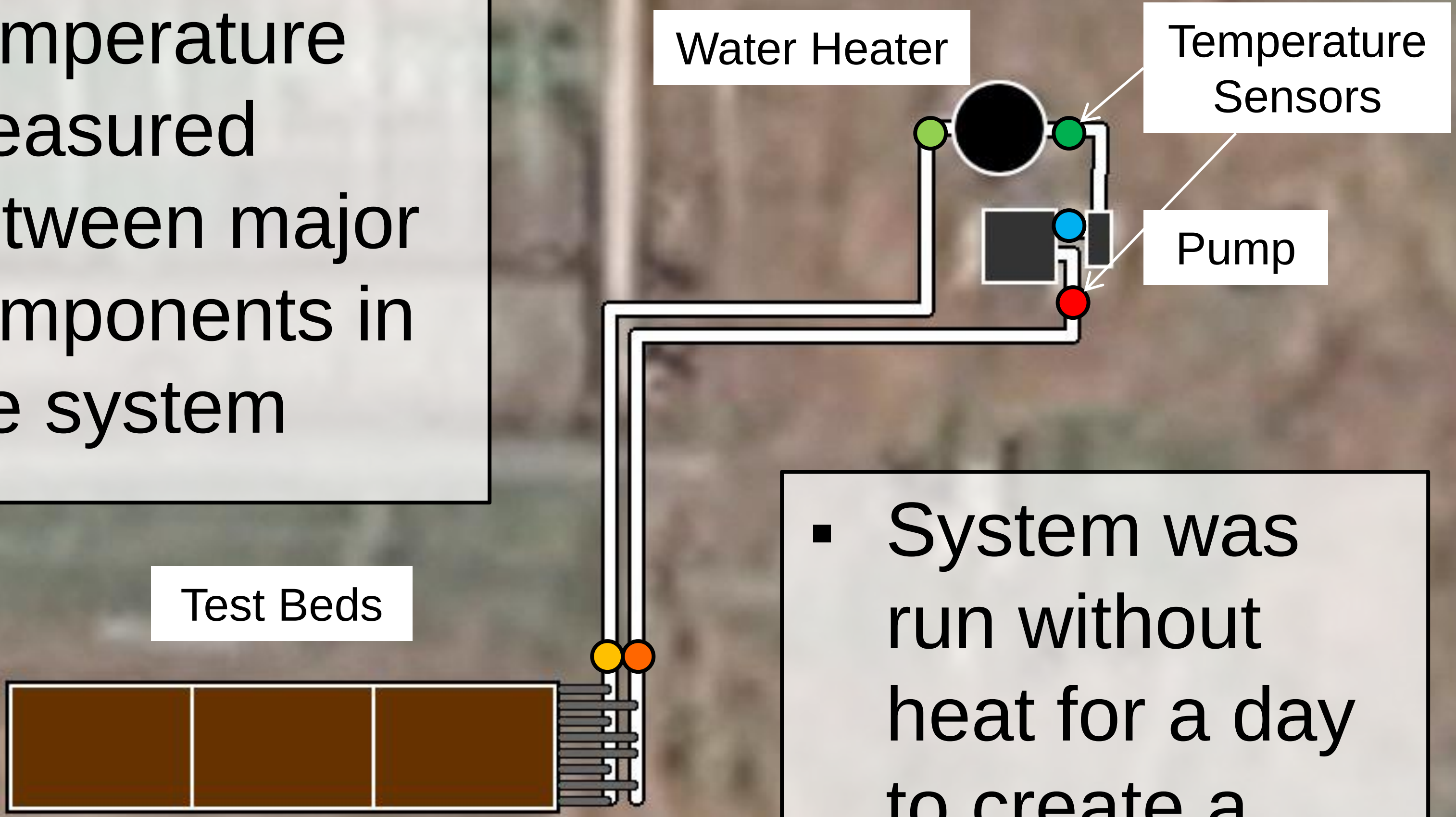
$R^2 = 0.9819$

Plumbing Test Setup



Plumbing Test Setup

- Temperature measured between major components in the system



Water Heater

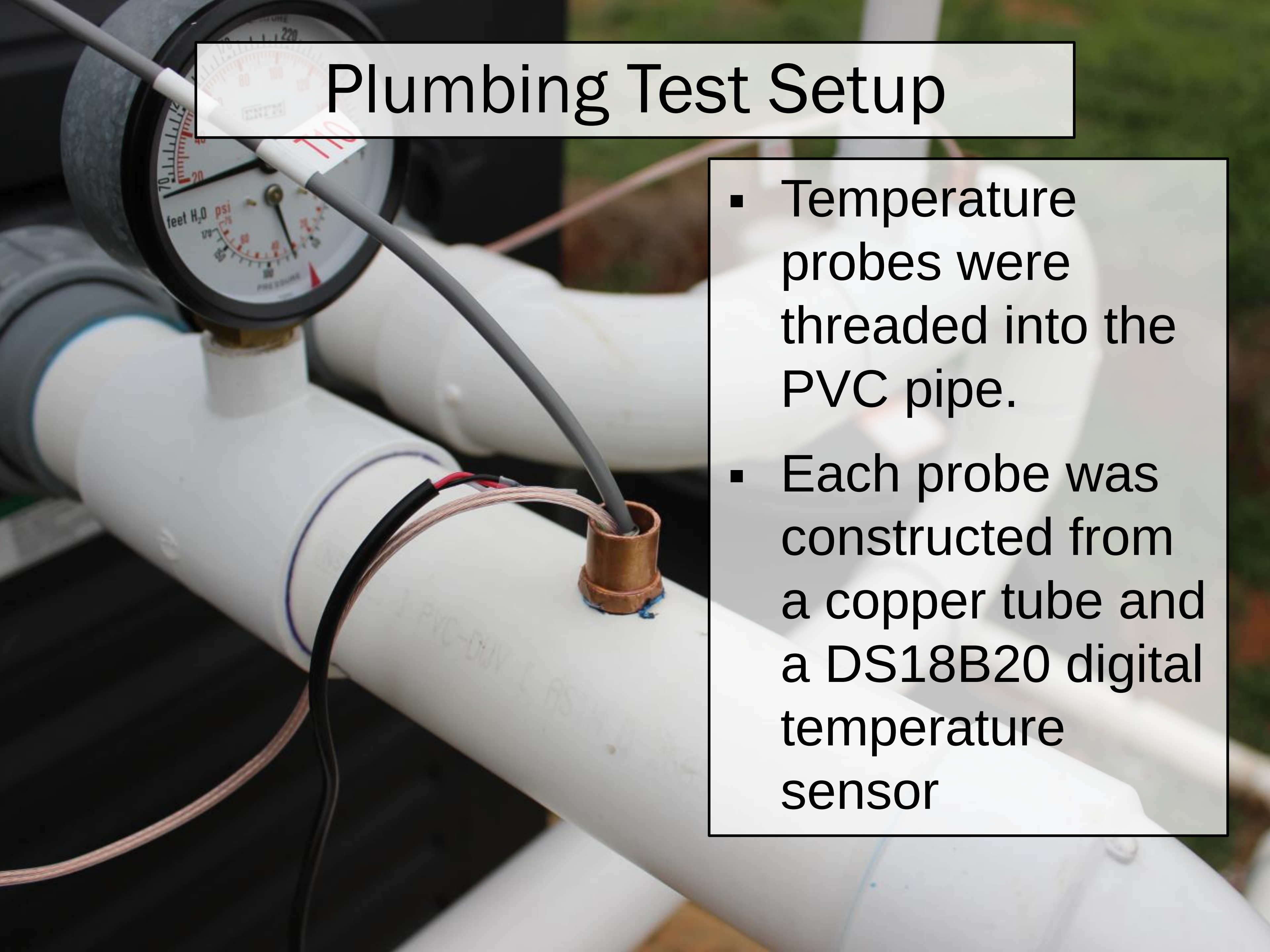
Temperature Sensors

Pump

Test Beds

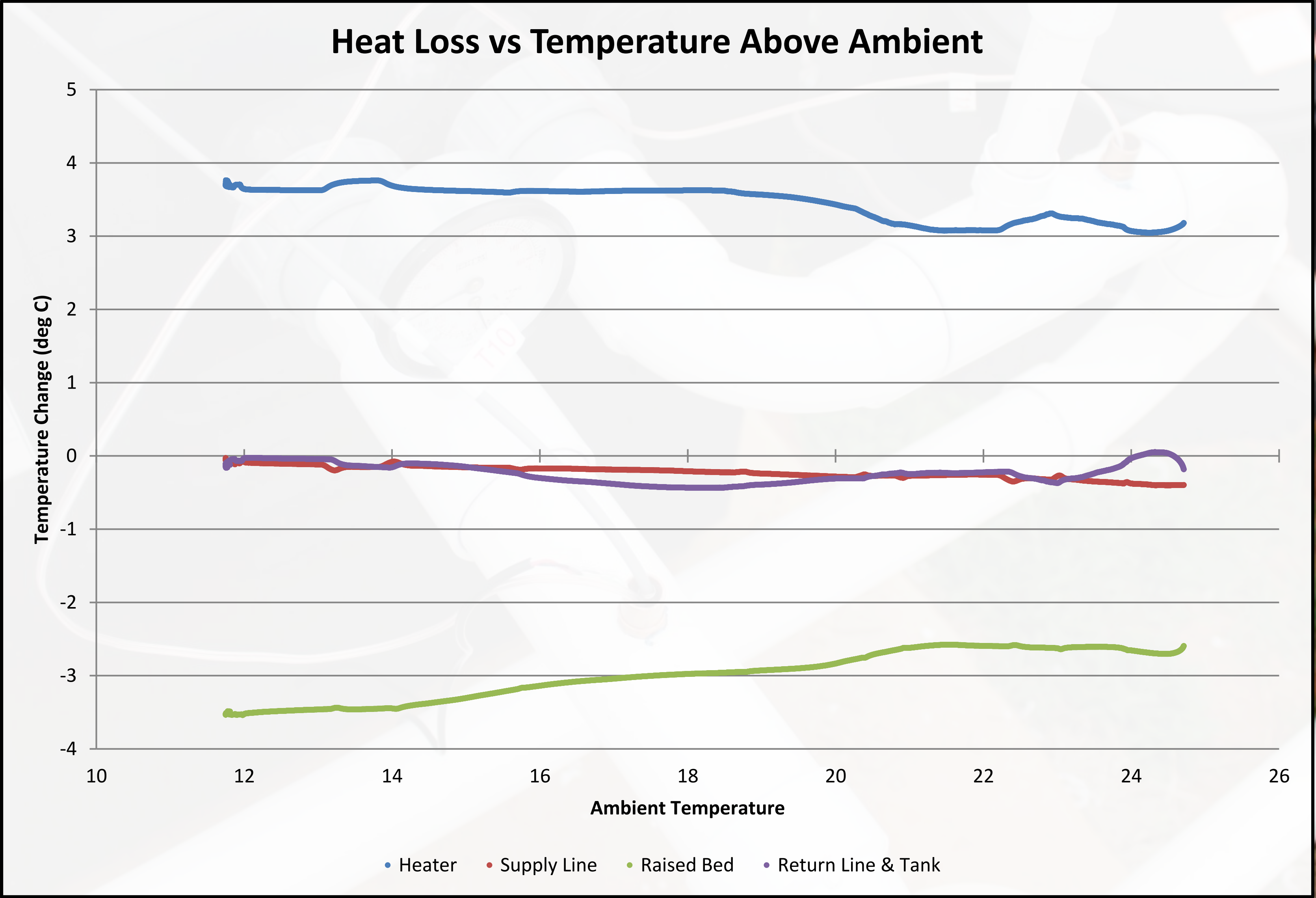
- System was run without heat for a day to create a calibration

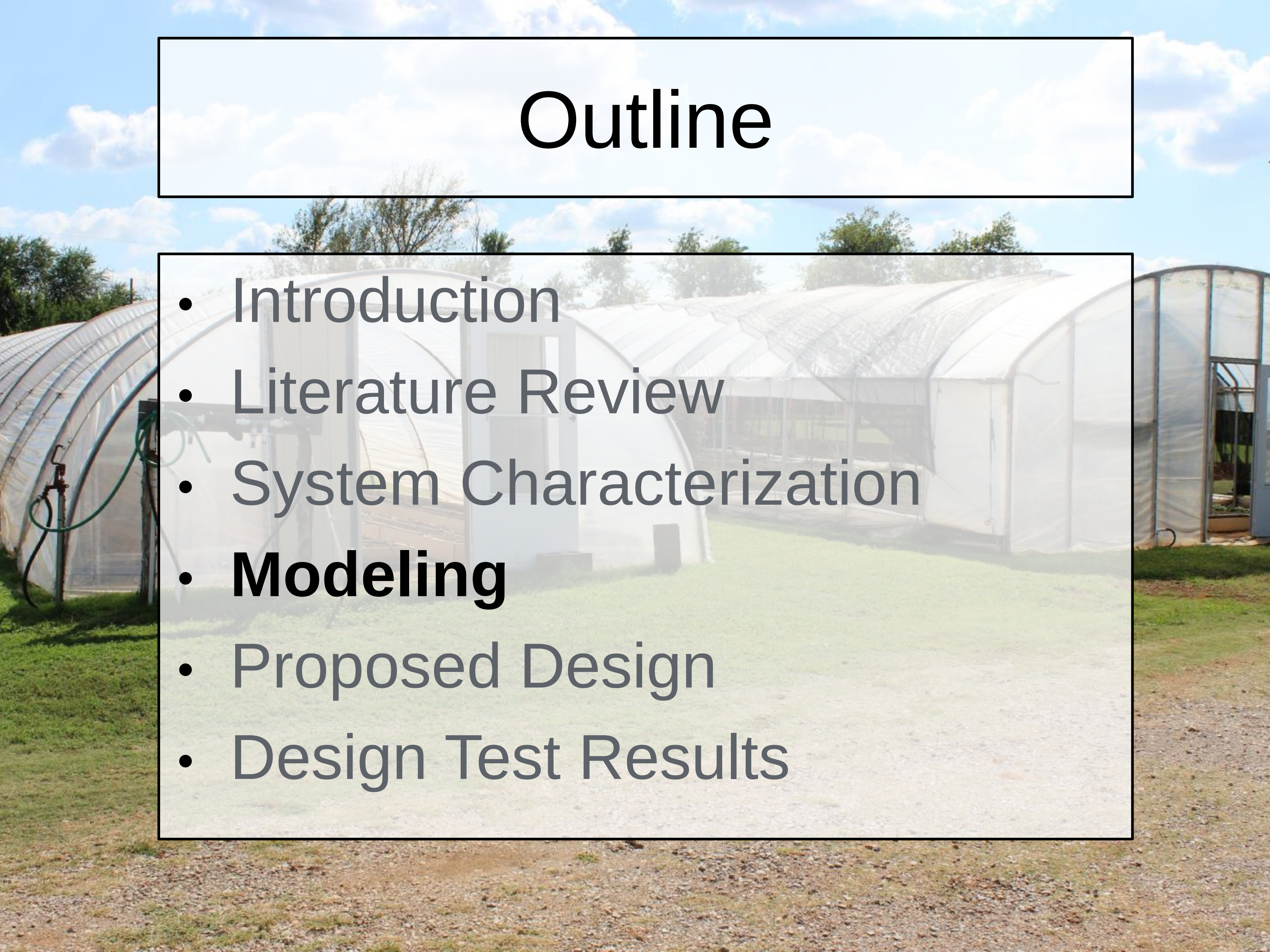
Plumbing Test Setup



- Temperature probes were threaded into the PVC pipe.
- Each probe was constructed from a copper tube and a DS18B20 digital temperature sensor

Plumbing Heat Loss





Outline

- Introduction
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- **Modeling**
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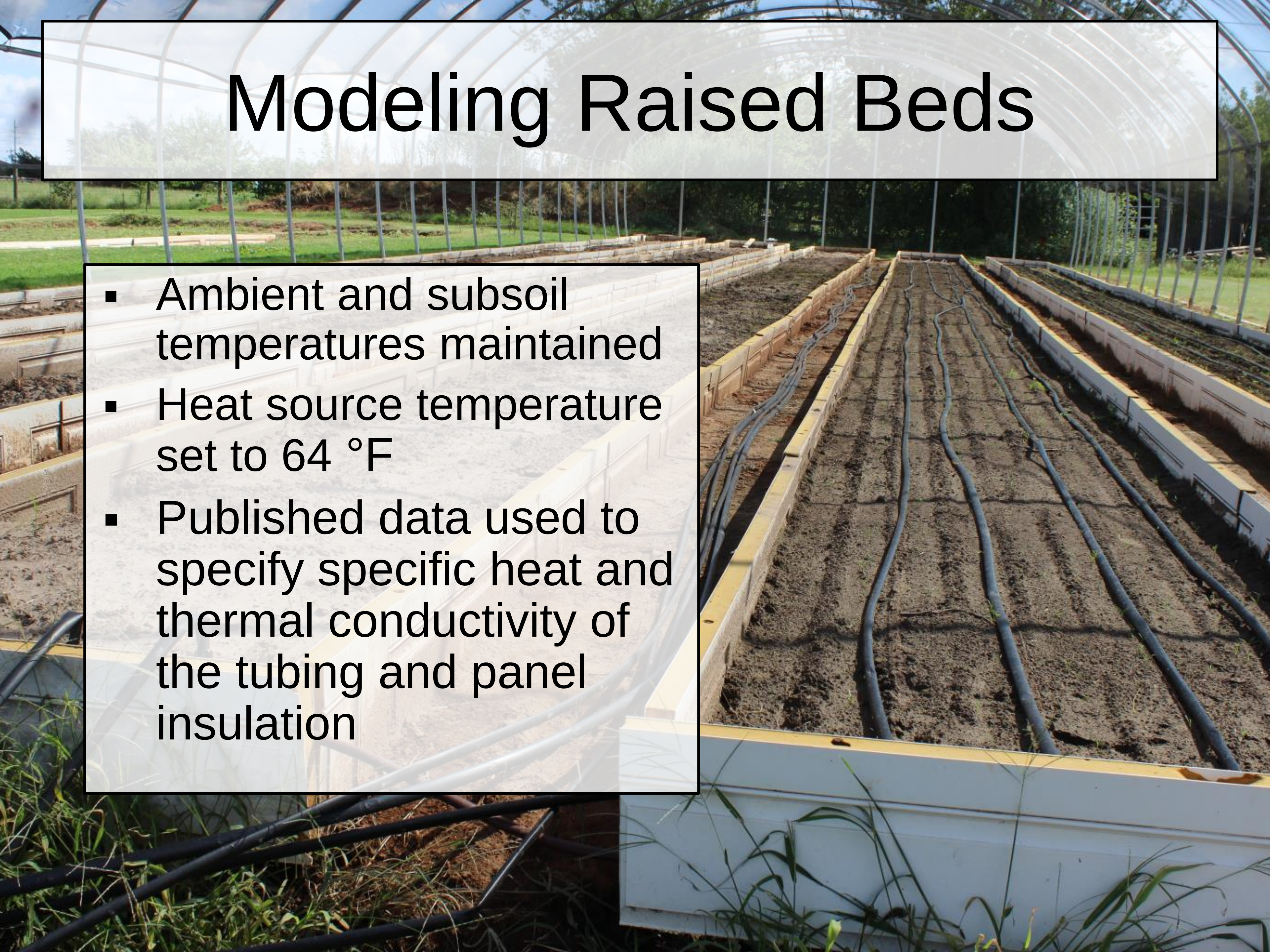
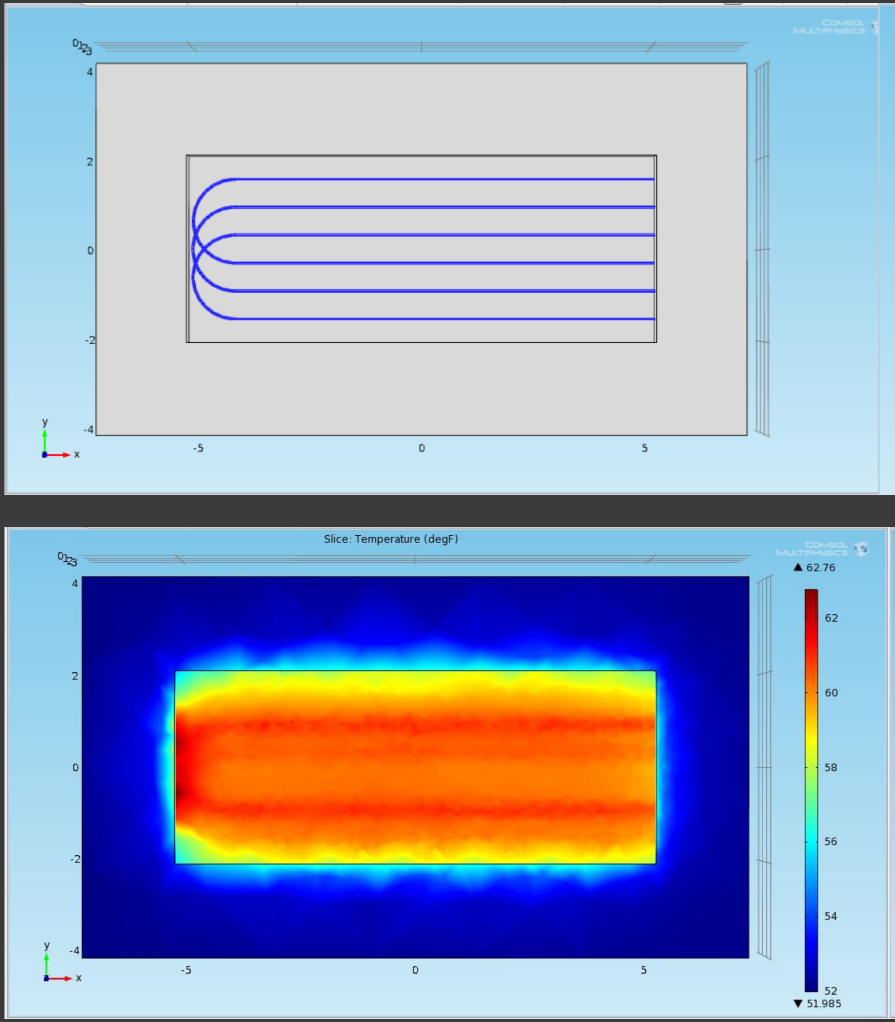
Modeling Raised Beds



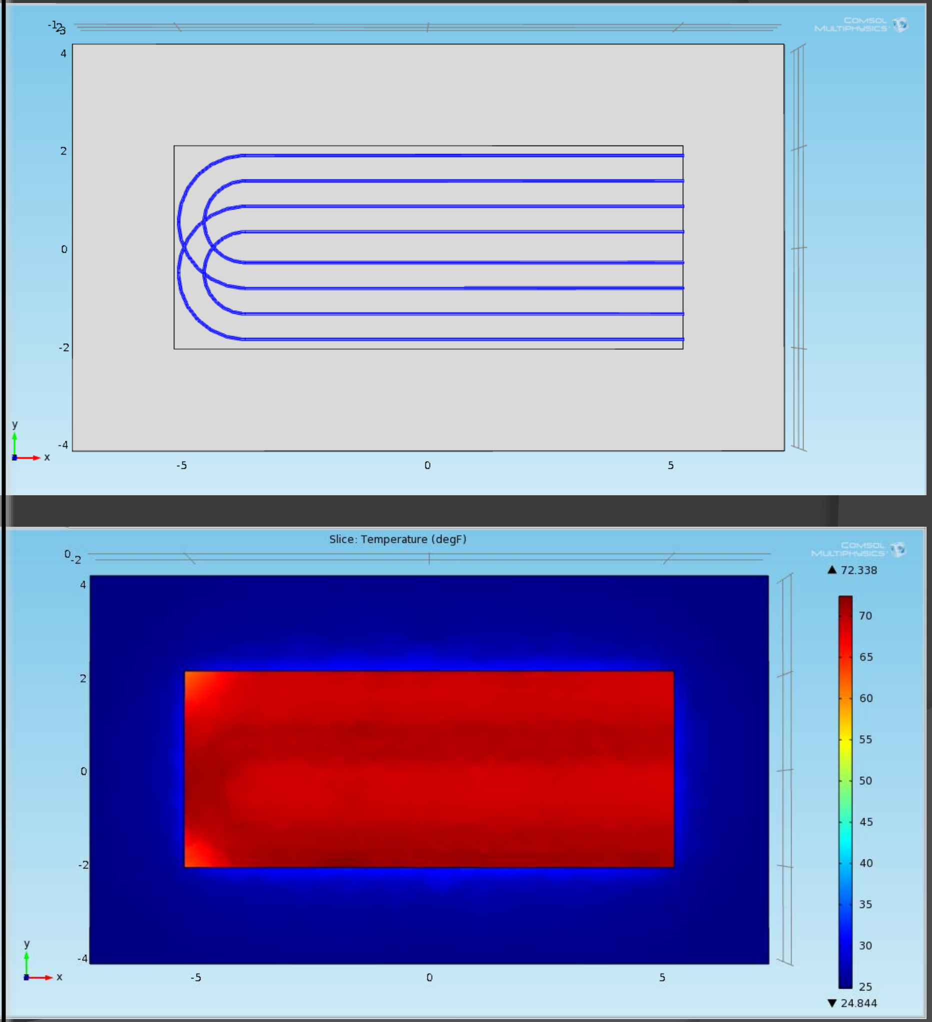
- Ambient and subsoil temperatures maintained
- Heat source temperature set to 64 °F
- Published data used to specify specific heat and thermal conductivity of the tubing and panel insulation

Heating Design Considerations

Current Recirculation Pattern

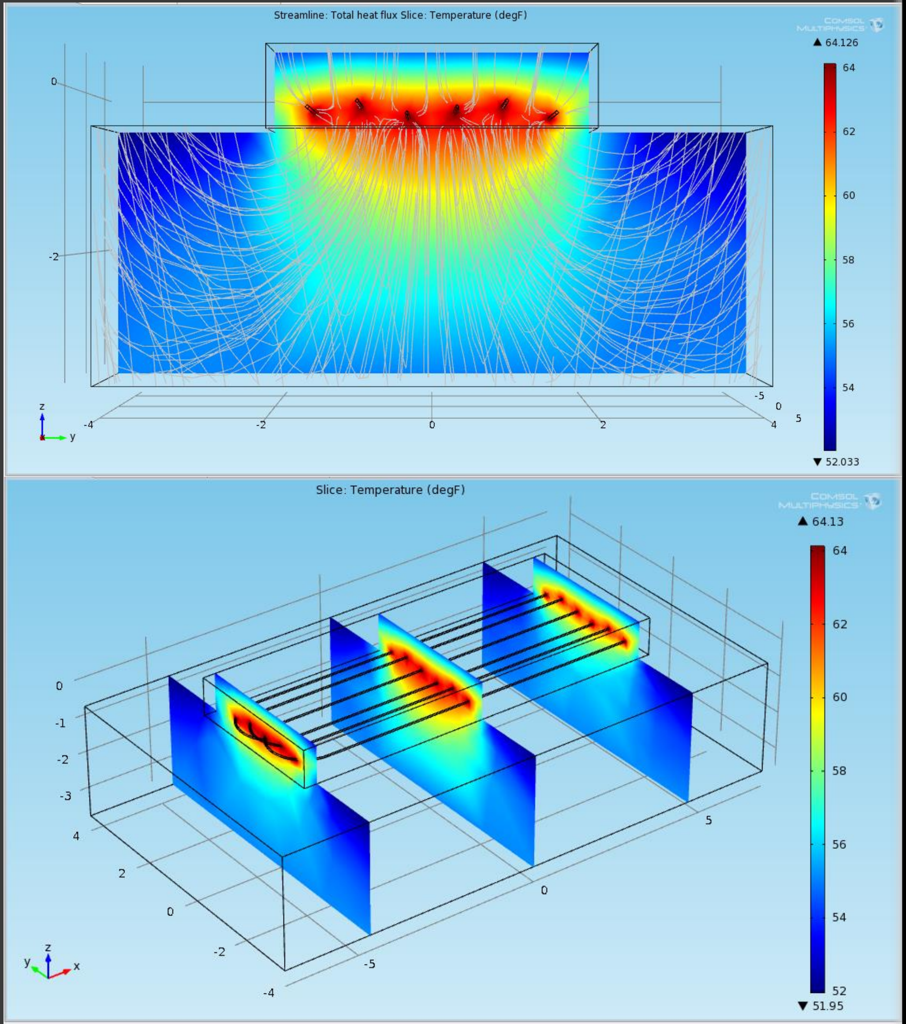


Improved Recirculation Pattern

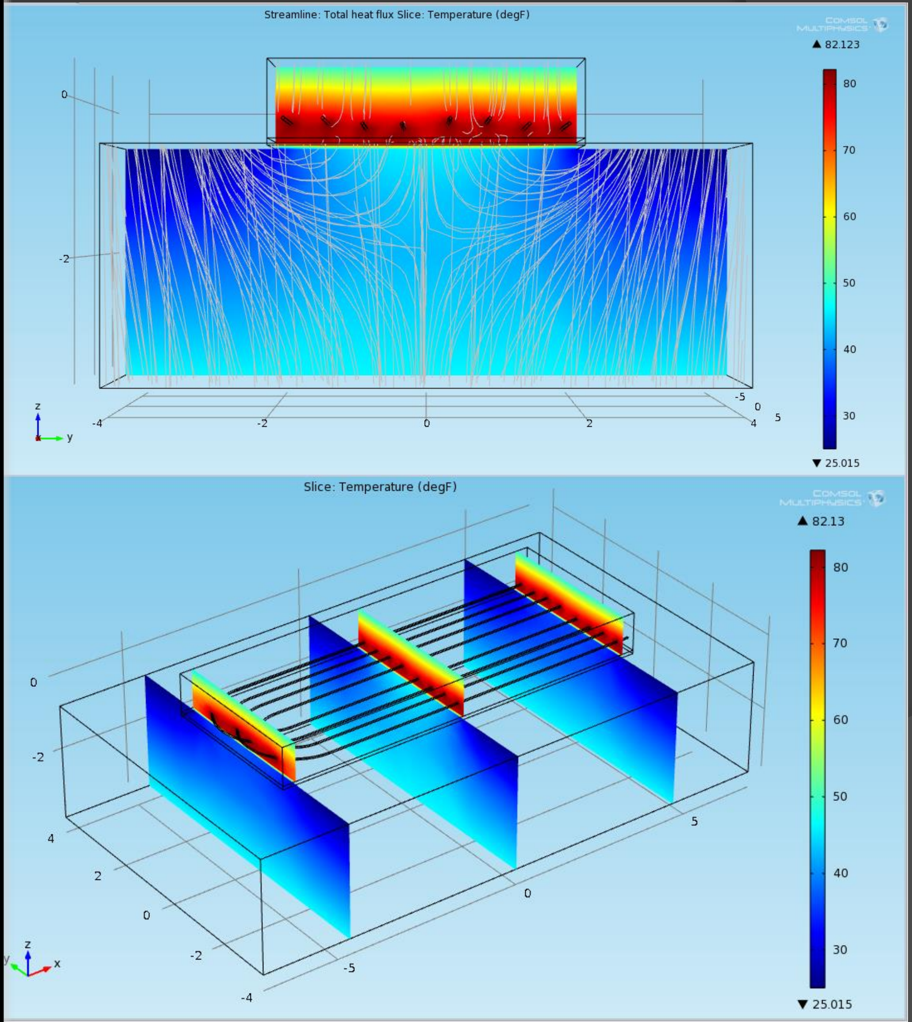


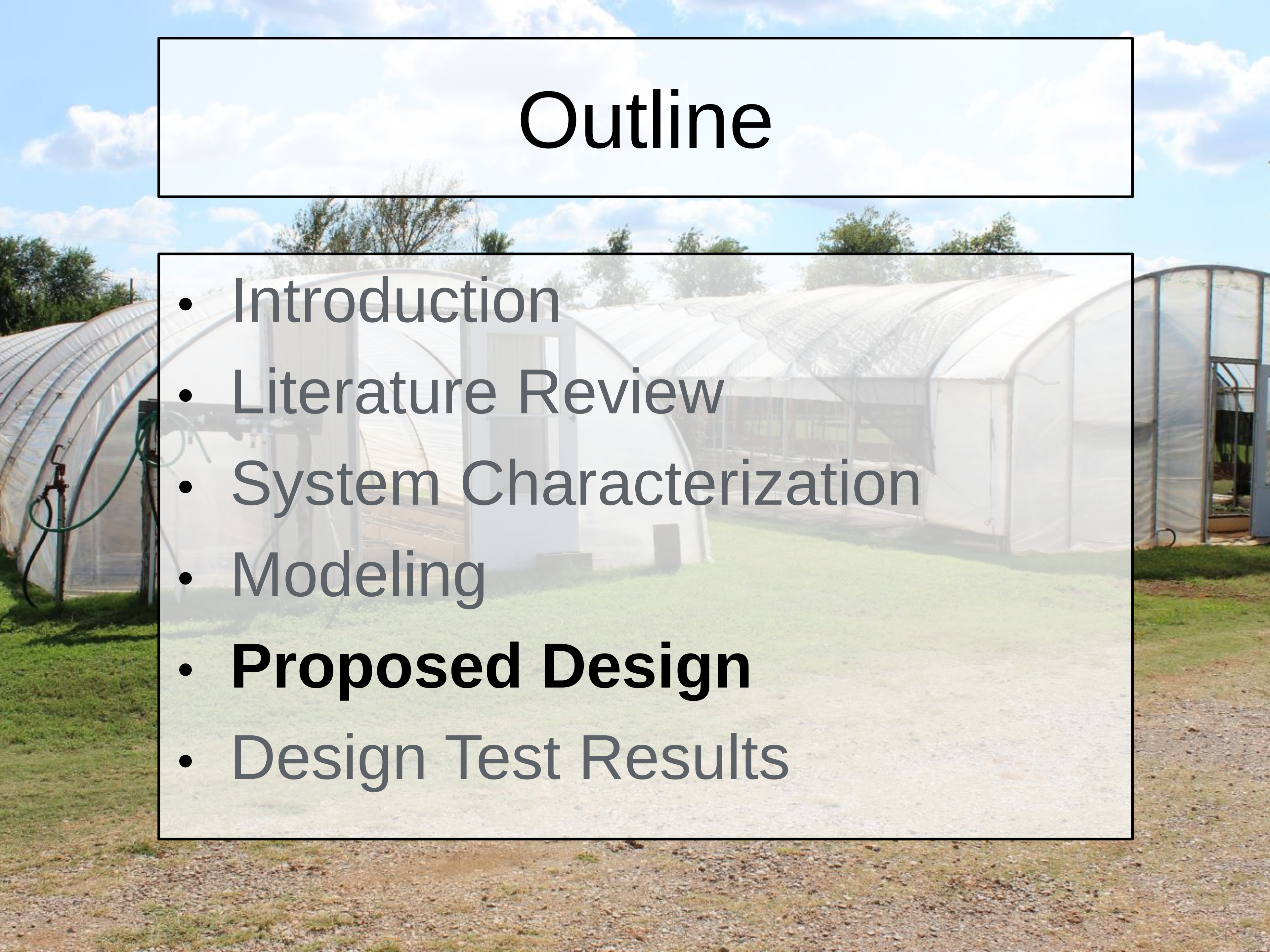
Heating Design Considerations

Current Heat Flow



Heat Flow with Insulation





Outline

- Introduction
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- Design Test Results

Heating Design Proposal

- Add a layer of Encapsulated Polystyrene (EPS) foam board beneath the recirculation tubes
- Increase number of recirculation tubes to improve uniformity of heat distribution at low flow rates

Cooling Design Proposal

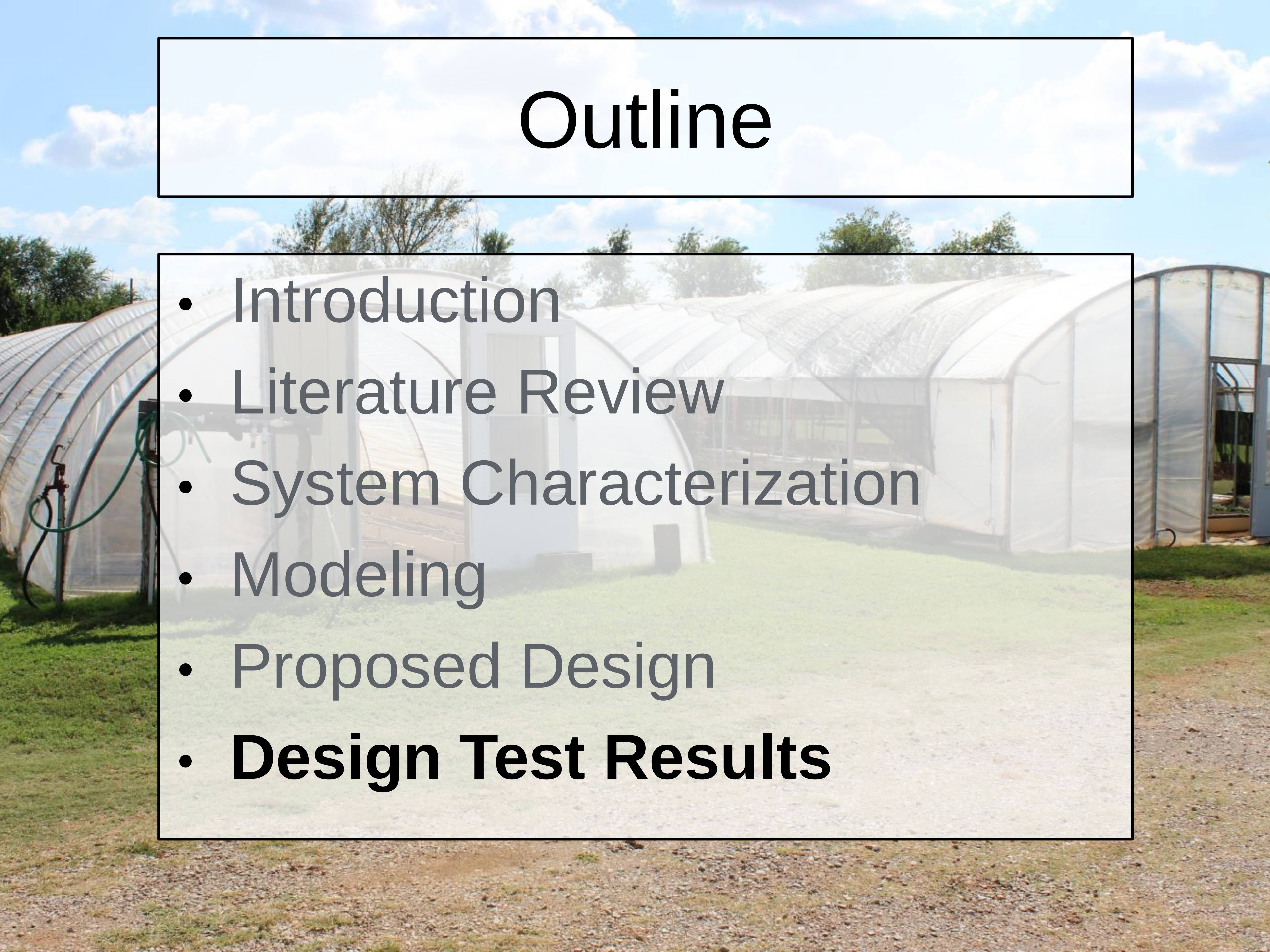
- Install a single misting tube above each raised bed to spray downward
- Supply misting water from the well
- Reduce solar heating by covering house with shade cloth

http://www.certhon.com/products/heating-and-cooling/greenhouse-cooling/air-and-water-cooling/jsk

Actual Expenditures

Date	Supplier	Unit Price	Total
11/4/2015	Motor Pool	-61.46	-61.46
12/12/2014	Ag Duplicating	-7.02	-68.48
2/11/2015	McMaster-Carr	-142.82	-211.3
2/13/2015	Lowe's	-67.56	-278.86
3/3/2015	Digi-Key	-422.12	-700.98
3/3/2015	Lowe's	-74.26	-775.24
4/2/2015	Spark Fun	-51.87	-827.02
4/4/2015	Amazon	-69.91	-897.02
4/4/2015	Digi-Key	-350.2	-1,247.22
4/13/2015	Napa Auto Parts	-707.25	-1,954.47
		Total Expenses	**-1,954.47**

Outline



- Introduction
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- Proposed Design
- **Design Test Results**

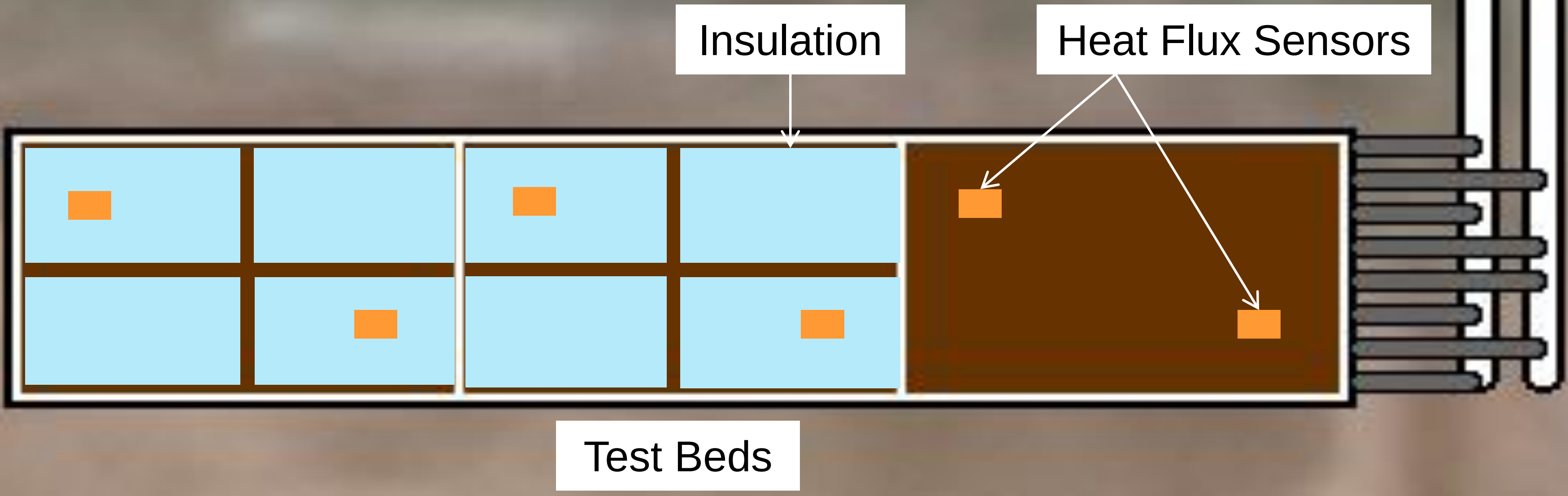
Proposed Design Test Setup

- 3 Test beds of equal size: 4’ x 6’
  - Control
  - ¾ in. EPS foam board
  - 2 in. EPS foam board
- Additional insulation added to 1’ below recirculation tubes to prevent heat flux interference from neighboring beds

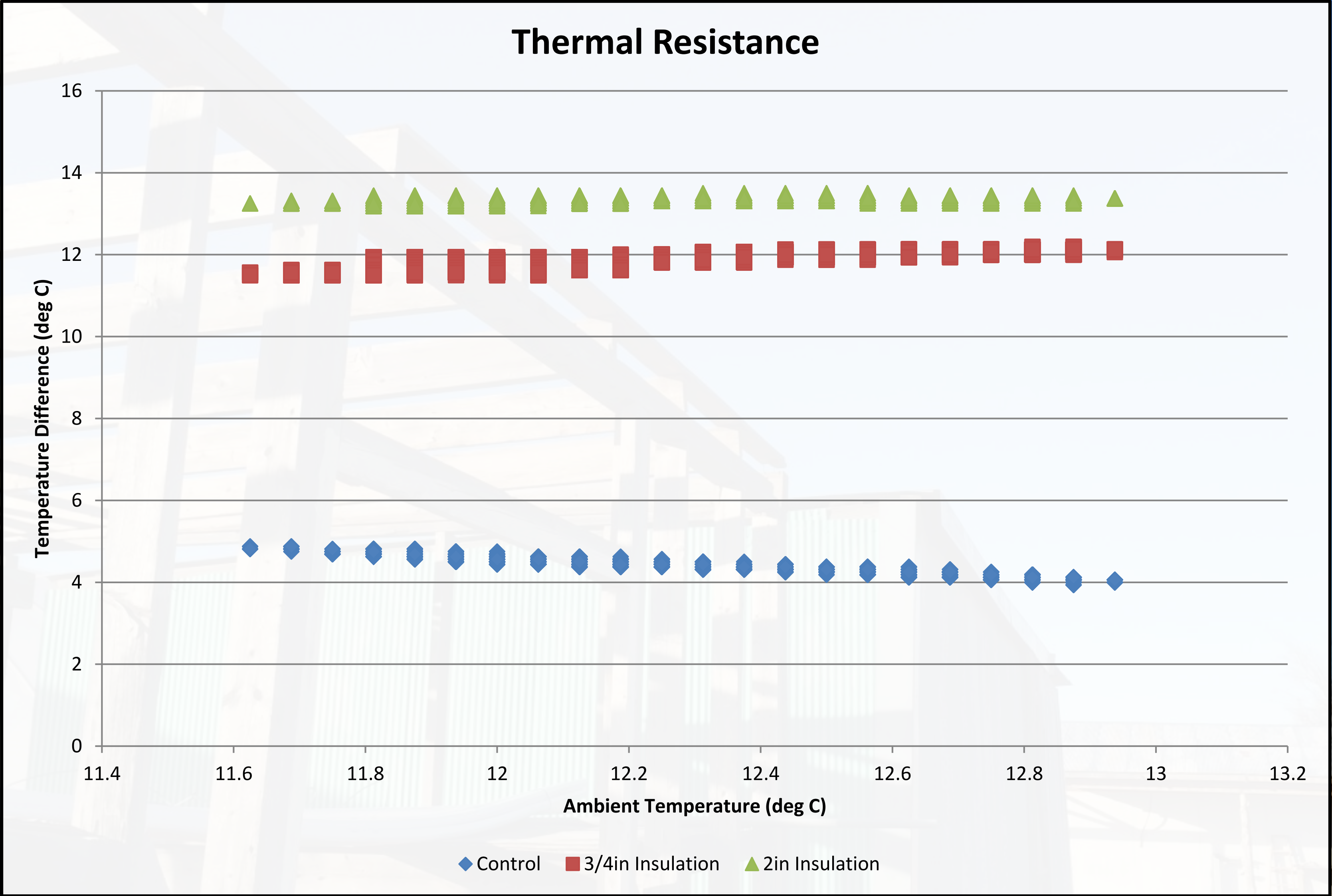
- Insulating foam board was cut into quarters to allow drainage
- Sand added between gaps in sections of foam board to improve porosity

Proposed Design Test Setup

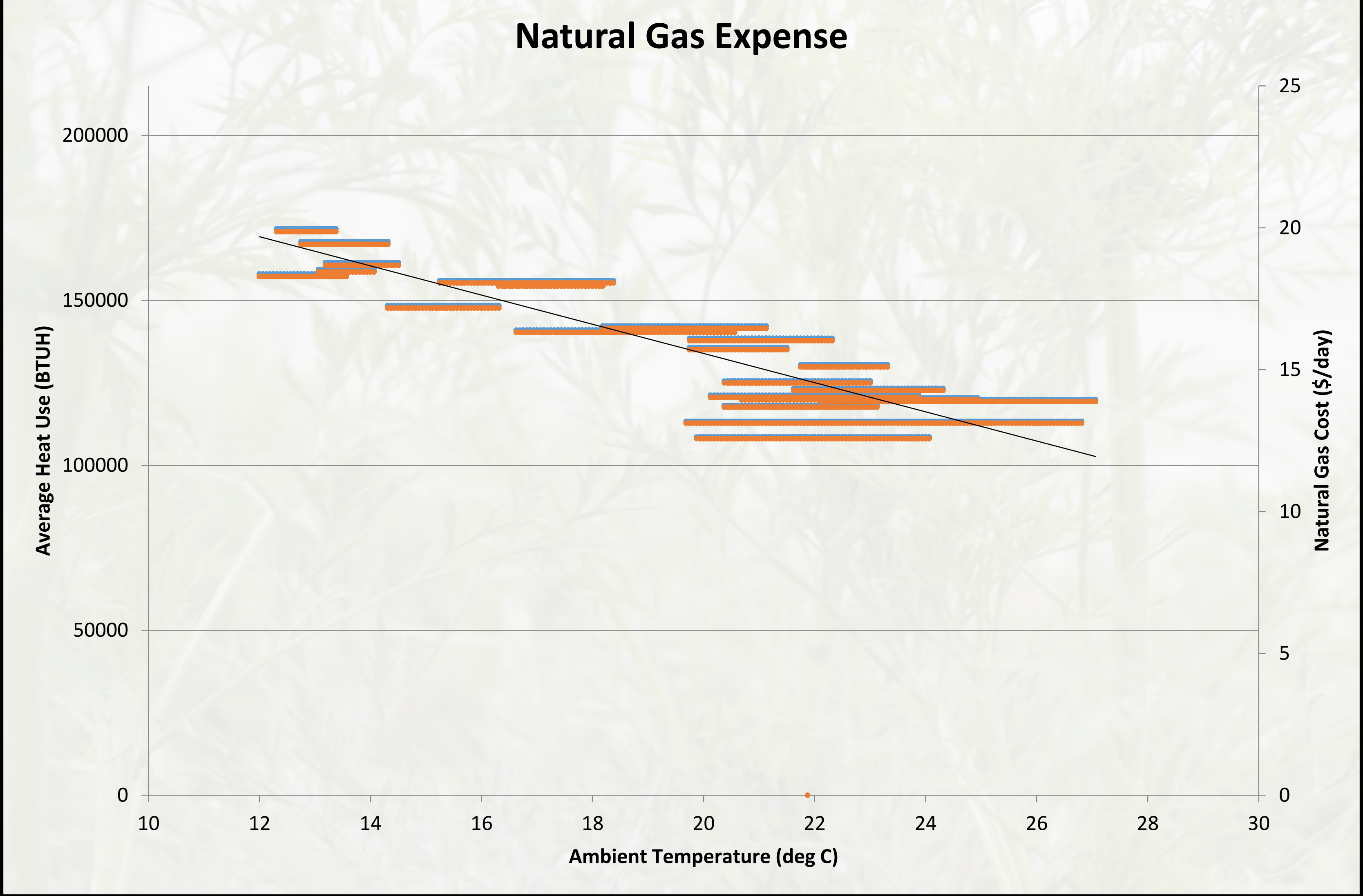
- 5TE VWC/EC/Temp sensors installed above and beneath foam and between pieces
- Temperature sensors placed on top and bottom of each foam panel



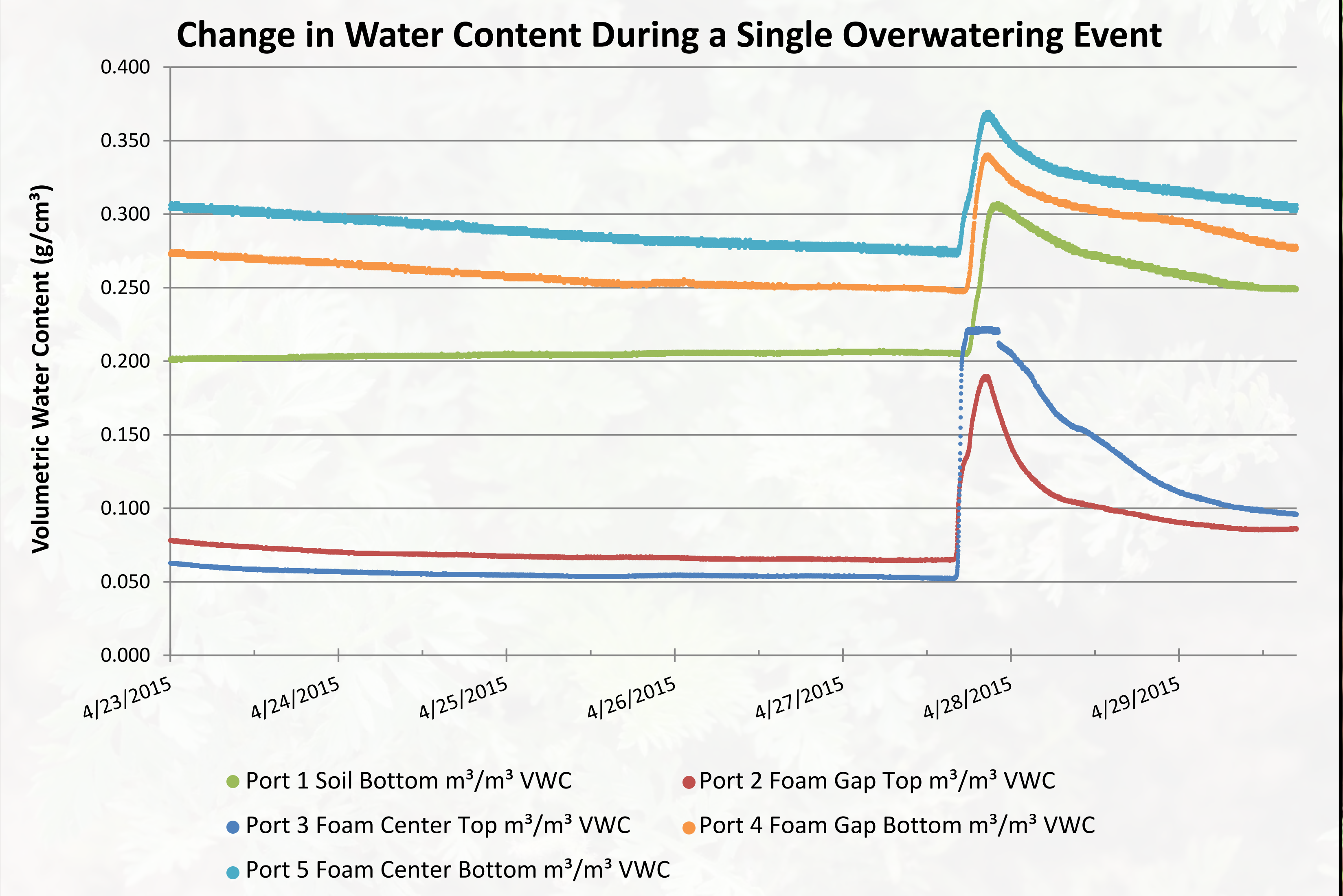
Heat Loss Results



Heat Loss Results



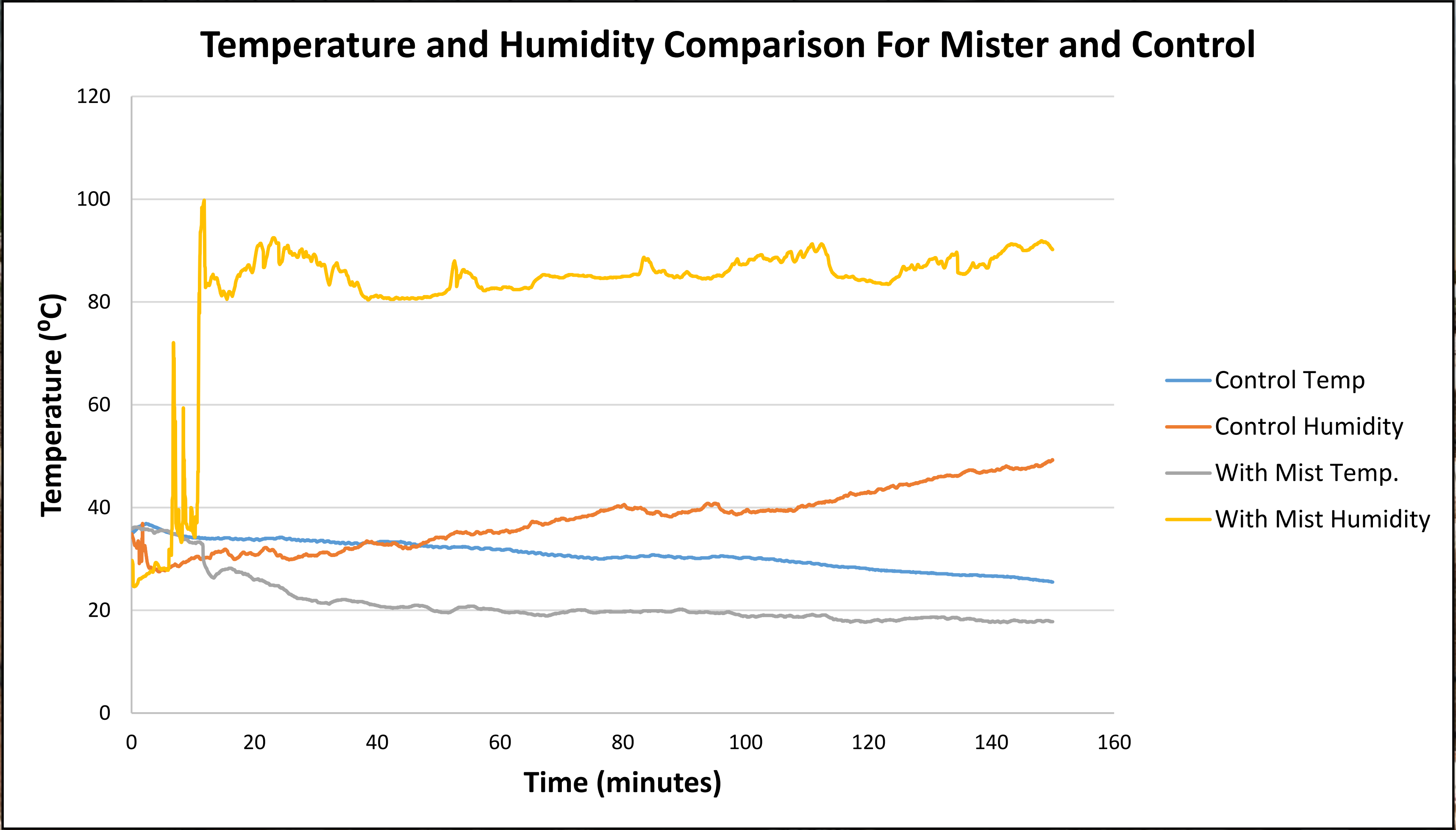
Drainage Results



Misting Design Setup

- Temperature and relative humidity were recorded as misters were running
- A control was used to compare effectiveness

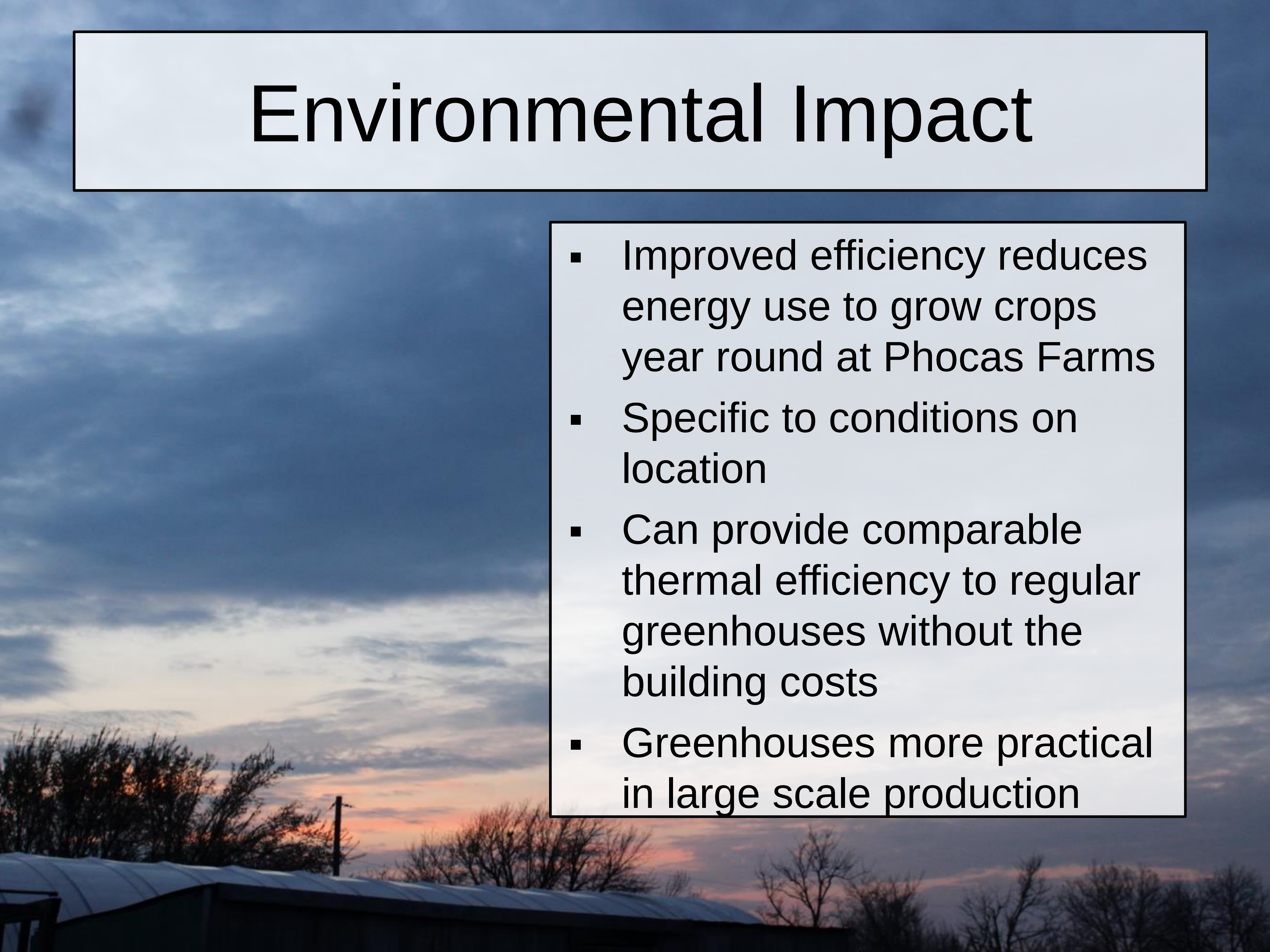
Misting Results



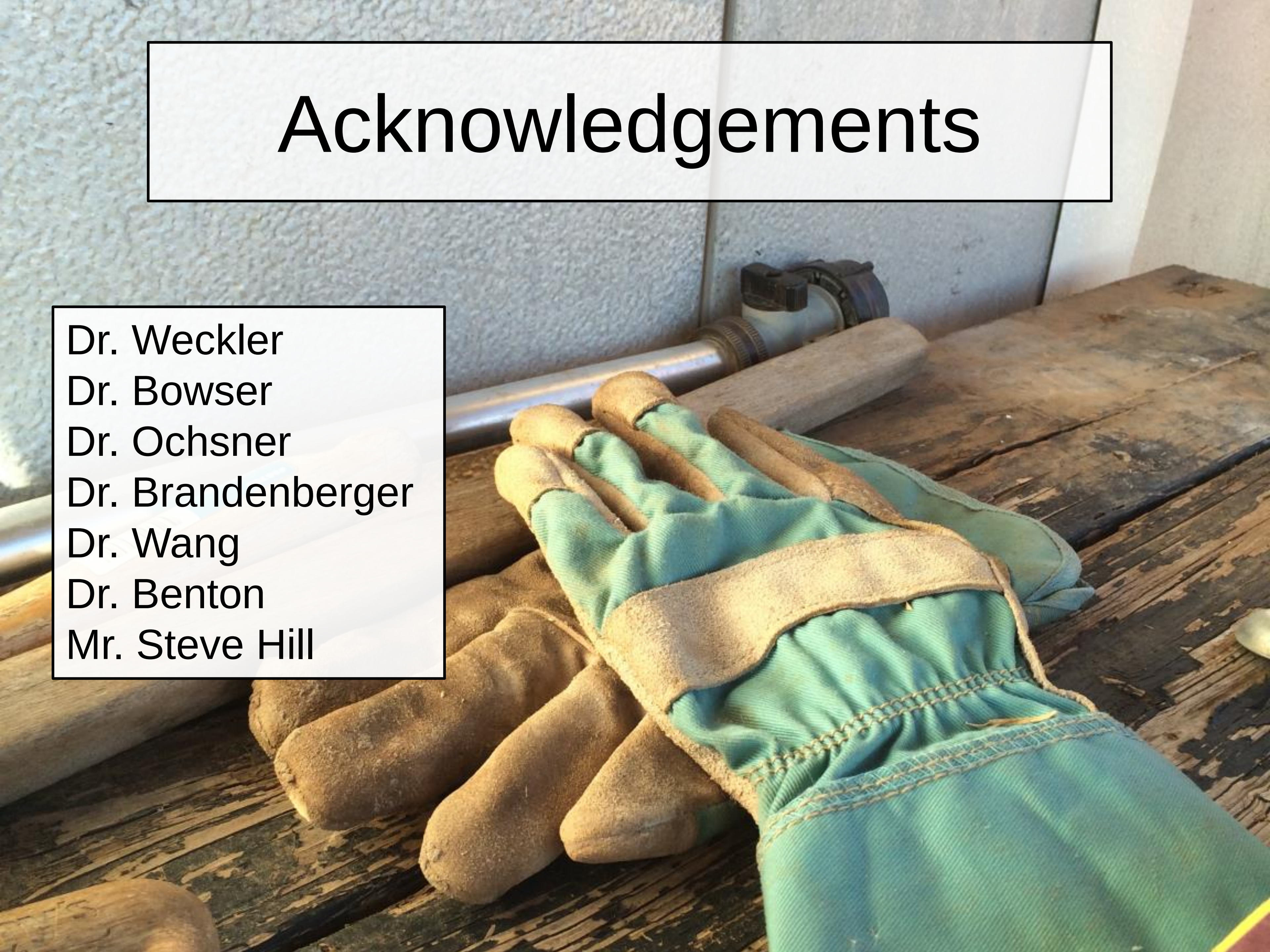
Relative Cost Effectiveness

	kW	Labor	Gas Usage	Cost Seeds	Crop Sales	Profit
January	124.72	543.34	610	14.58	1291.67	-0.97
Febuary	116.04	527.92	230	29.16	1166.67	263.55
March	16.32	543.34	230	14.58	1291.67	487.43
April	13.00	538.2		29.16	1250.00	669.64
May	21.80	543.34		14.58	1291.67	711.95
June	31.77	630.72		14.58	1250.00	572.93
July	32.83	543.34		29.16	1291.67	686.33
August	32.83	543.34		14.58	1291.67	700.91
September	16.42	538.2		29.16	1250.00	666.22
October	8.21	543.34	120	29.16	1291.67	590.96
November	121.48	538.2	520	14.58	1250.00	55.74
December	124.20	543.34	540	29.16	1291.67	54.97

Environmental Impact



- Improved efficiency reduces energy use to grow crops year round at Phocas Farms
- Specific to conditions on location
- Can provide comparable thermal efficiency to regular greenhouses without the building costs
- Greenhouses more practical in large scale production



Acknowledgements

Dr. Weckler
Dr. Bowser
Dr. Ochsner
Dr. Brandenberger
Dr. Wang
Dr. Benton
Mr. Steve Hill

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Boland, C.M. 1934. Combined heating and irrigating system. U.S. Patent No. 1,967,803

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Givoni, B. 2007. Cooled soil as a cooling source for buildings. *Solar Energy*. 81: 316-328.

Hunt, E.R., Running, S.W., Daolan. 1993. A daily soil temperature model based on air temperature and precipitation for continental applications. School of Forestry, University of Montana, Missoula, Montana.

Pierre, H., Lachal, B. 2000. Cooling and preheating with buried pipe systems: monitoring, simulation and economic aspects. *Energy and Buildings*. 1295: 1-10.

Marsden, A.R., Otermat, A.L., Weingaertner, D.A., Johnson, P.C., Dicks, L.W.R., Wilde, H.B. 1993. Heater blanket for in-situ soil heating. U.S. Patent No. 5,221,827

Nennich, T.T., Using Solar Energy to Heat the Soil and Extend the Growing Season in High Tunnel Vegetable Production.

Thuries, E. 1998. Burid electrical transmission line equipped with a cooling device. U.S. Patent No. 5,742,001.

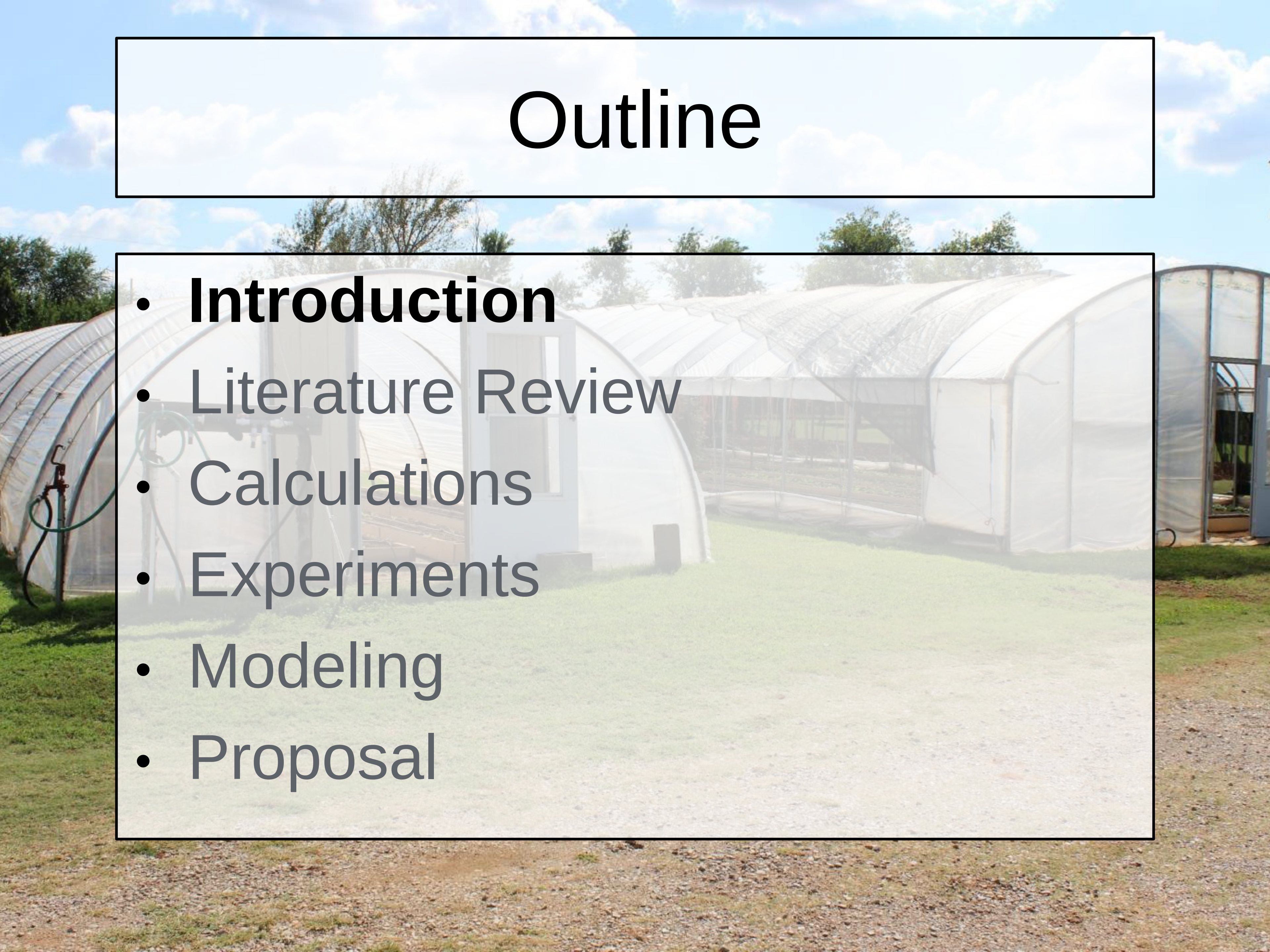
Questions?

GreenLine

Heating and Cooling of Raised Greenhouse Beds

Robert Honeyman
Breanna Bergdall
Audrey Plunkett

Outline



- **Introduction**
- Literature Review
- Calculations
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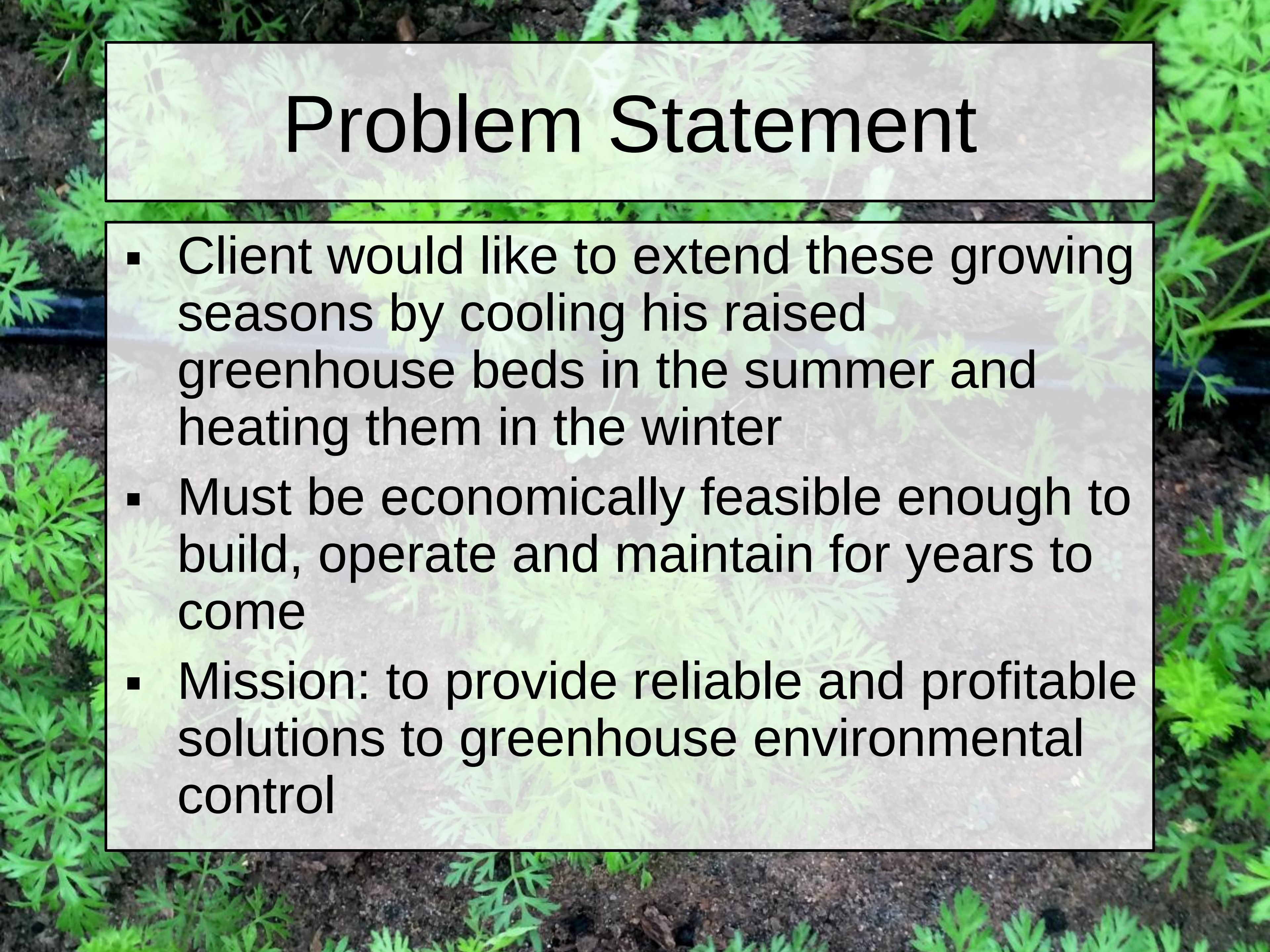
Introduction

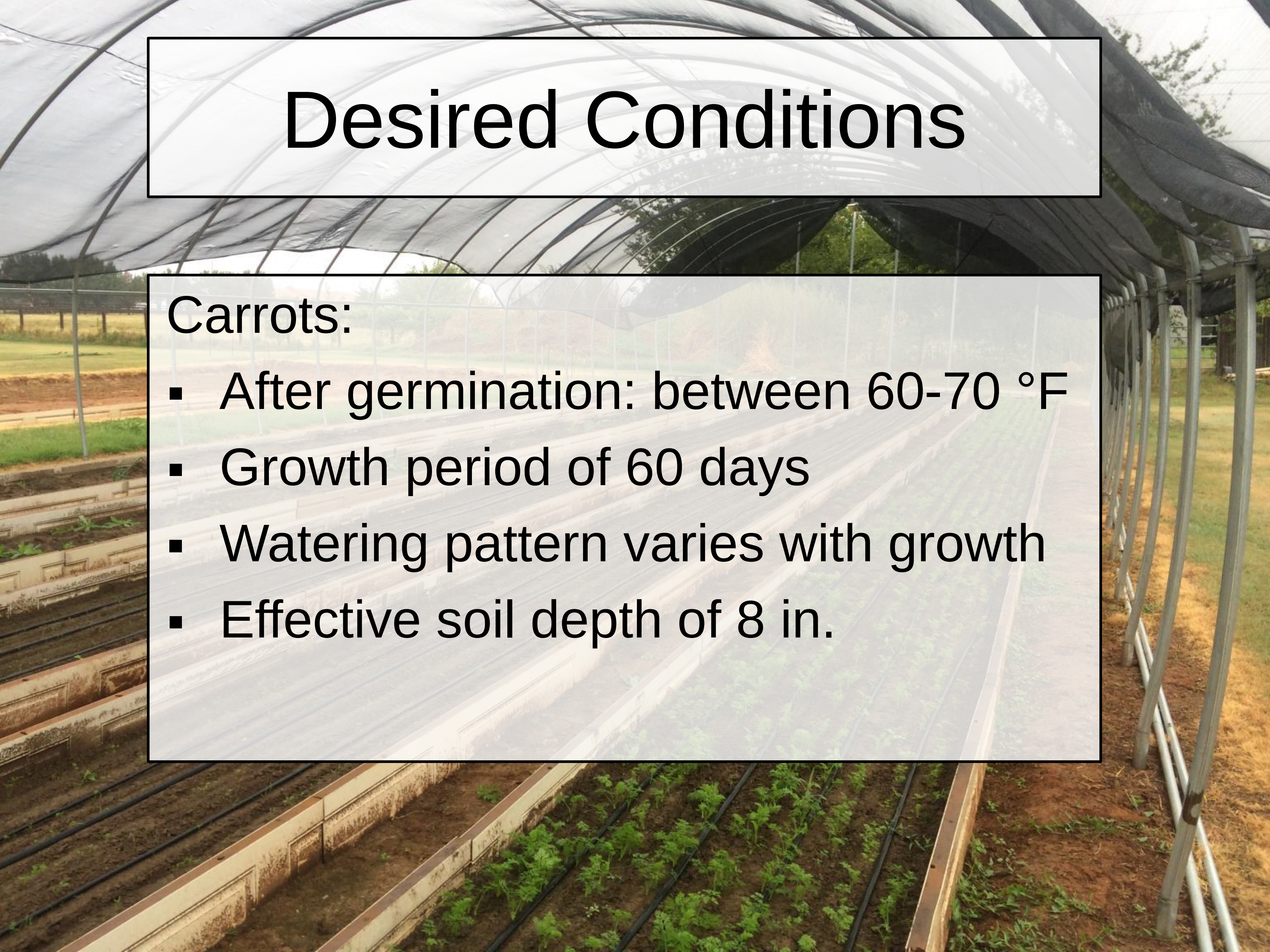
Client:

- Steve Hill
- Phocas Farms, Edmond, OK
- Provides produce for Edmond schools
- Interested in increasing growing season



Problem Statement

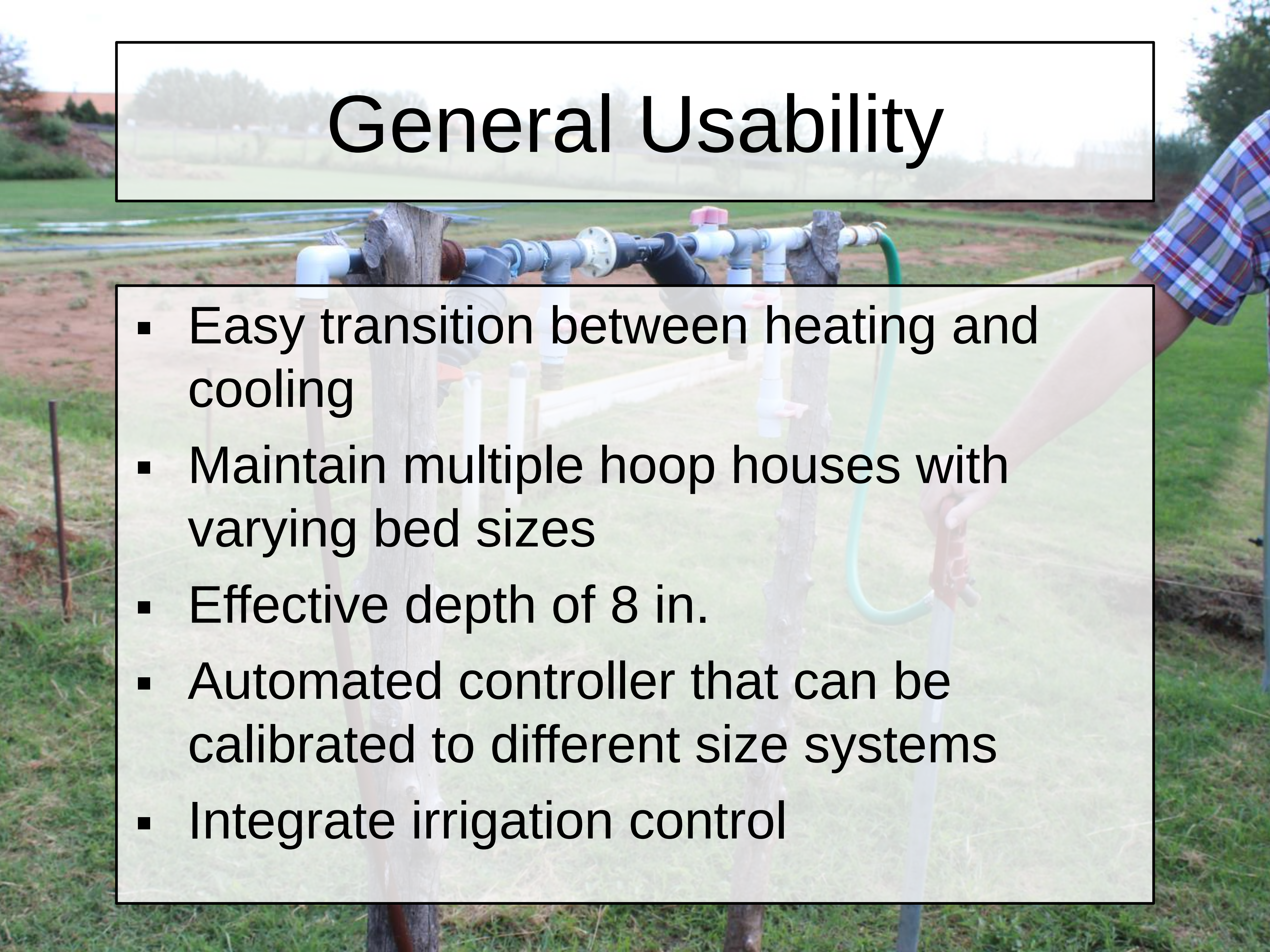
- Client would like to extend these growing seasons by cooling his raised greenhouse beds in the summer and heating them in the winter
- Must be economically feasible enough to build, operate and maintain for years to come
- Mission: to provide reliable and profitable solutions to greenhouse environmental control



Desired Conditions

Carrots:

- After germination: between 60-70 °F
- Growth period of 60 days
- Watering pattern varies with growth
- Effective soil depth of 8 in.



General Usability

- Easy transition between heating and cooling
- Maintain multiple hoop houses with varying bed sizes
- Effective depth of 8 in.
- Automated controller that can be calibrated to different size systems
- Integrate irrigation control

Prior Equipment Integration

- Rheem Digital Gas Heater
- Pentair IntelliFlo Pump
- Norwesco Storage Tank
- 0.62 in. irrigation tubing

Prior Equipment Integration

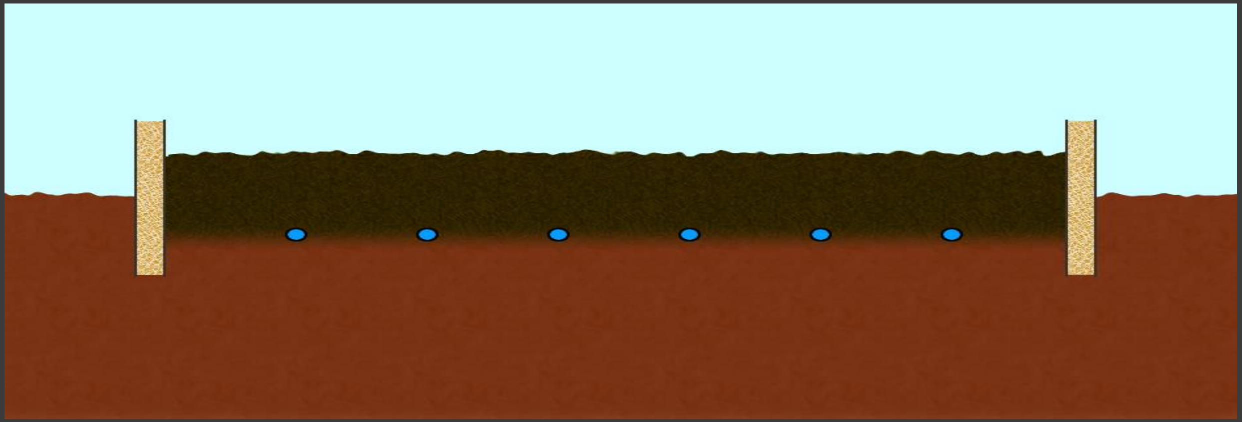
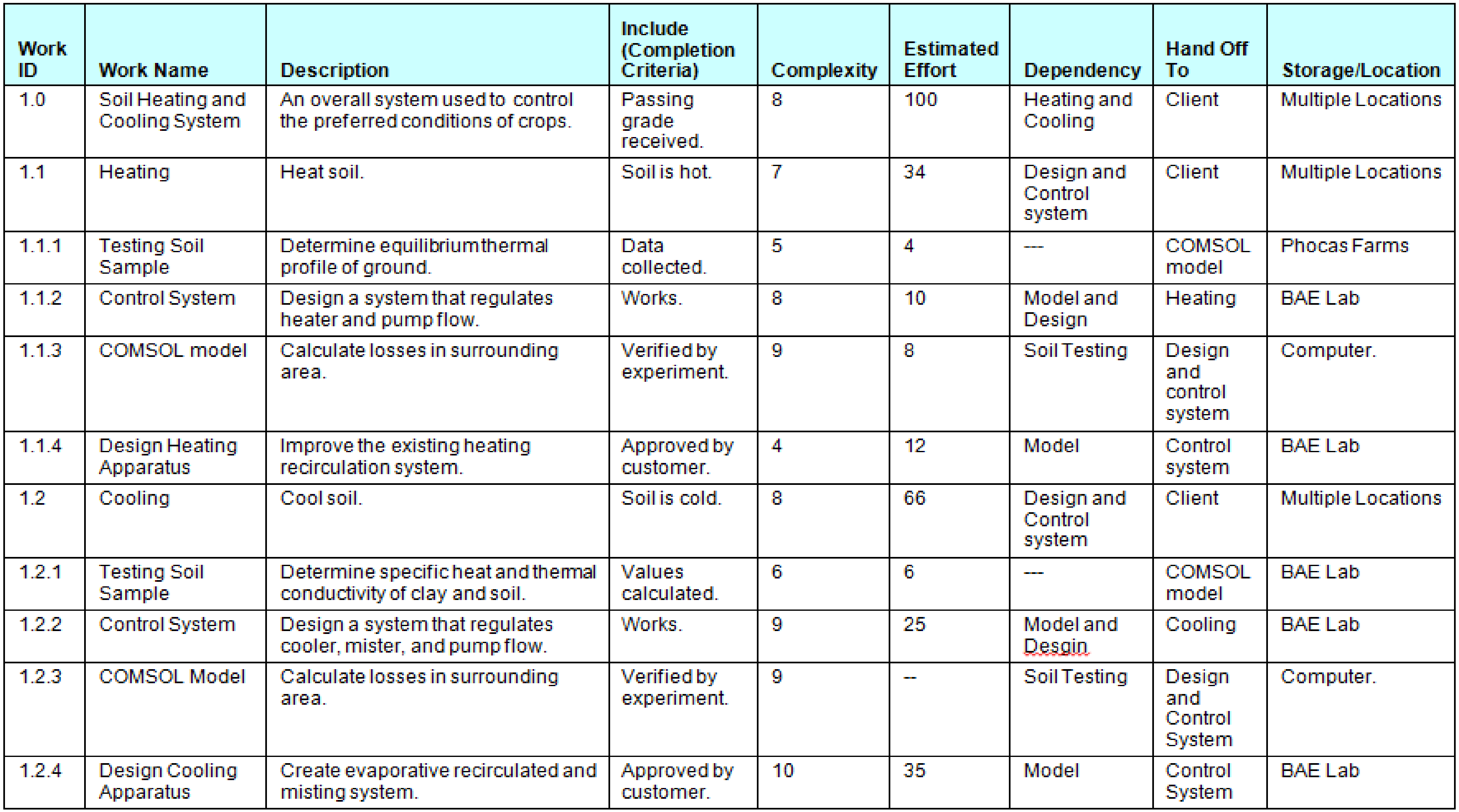


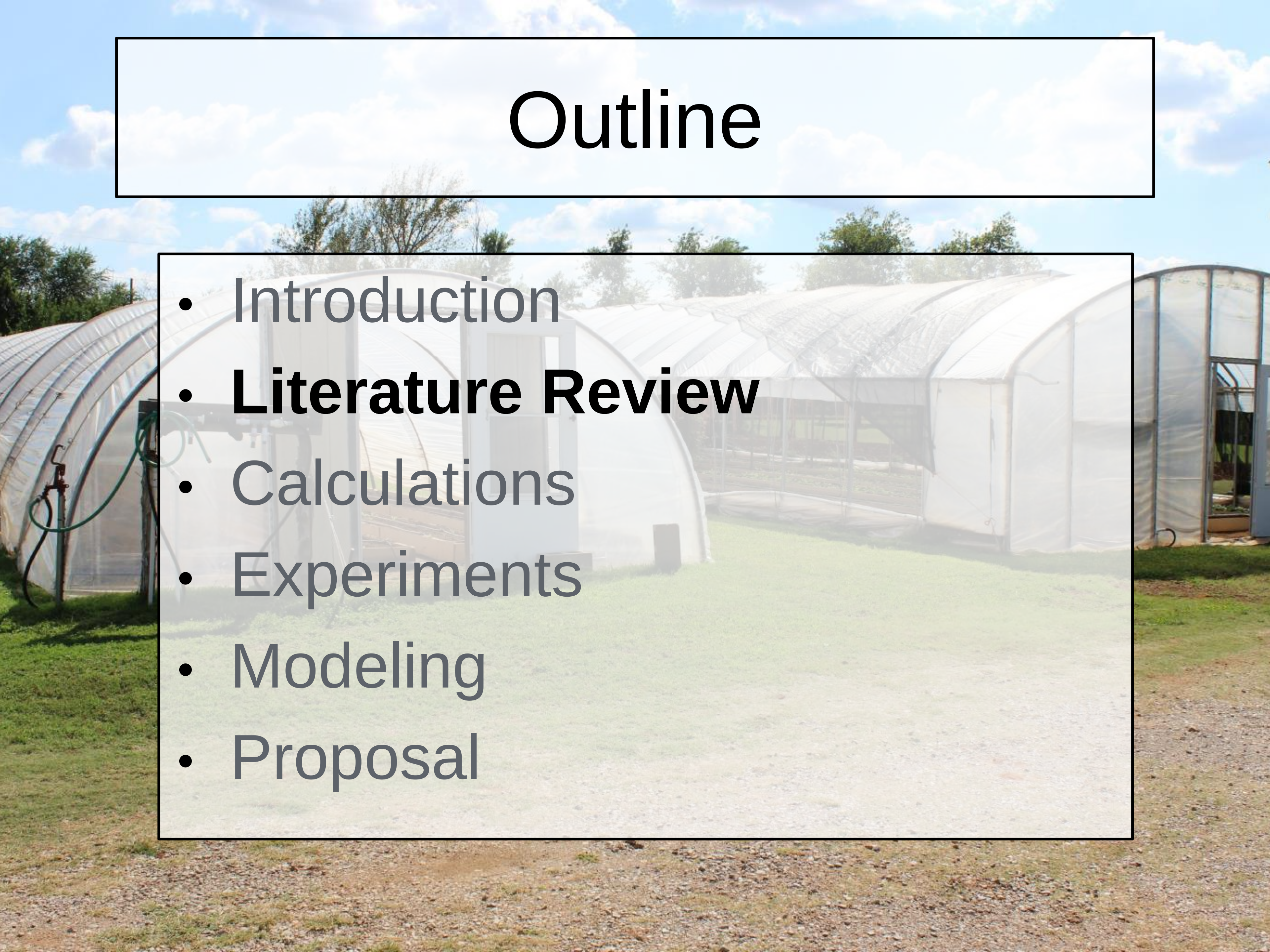
Figure 1. Vertical cross section of existing raised beds

Figure 2. Horizontal cross section of existing raised beds

Work Breakdown Structure



Work ID	Work Name	Description	Include (Completion Criteria)	Complexity	Estimated Effort	Dependency	Hand Off To	Storage/Location
1.0	Soil Heating and Cooling System	An overall system used to control the preferred conditions of crops.	Passing grade received.	8	100	Heating and Cooling	Client	Multiple Locations
1.1	Heating	Heat soil.	Soil is hot.	7	34	Design and Control system	Client	Multiple Locations
1.1.1	Testing Soil Sample	Determine equilibrium thermal profile of ground.	Data collected.	5	4	---	COMSOL model	Phocas Farms
1.1.2	Control System	Design a system that regulates heater and pump flow.	Works.	8	10	Model and Design	Heating	BAE Lab
1.1.3	COMSOL model	Calculate losses in surrounding area.	Verified by experiment.	9	8	Soil Testing	Design and control system	Computer.
1.1.4	Design Heating Apparatus	Improve the existing heating recirculation system.	Approved by customer.	4	12	Model	Control system	BAE Lab
1.2	Cooling	Cool soil.	Soil is cold.	8	66	Design and Control system	Client	Multiple Locations
1.2.1	Testing Soil Sample	Determine specific heat and thermal conductivity of clay and soil.	Values calculated.	6	6	---	COMSOL model	BAE Lab
1.2.2	Control System	Design a system that regulates cooler, mister, and pump flow.	Works.	9	25	Model and Desgin	Cooling	BAE Lab
1.2.3	COMSOL Model	Calculate losses in surrounding area.	Verified by experiment.	9	--	Soil Testing	Design and Control System	Computer.
1.2.4	Design Cooling Apparatus	Create evaporative recirculated and misting system.	Approved by customer.	10	35	Model	Control System	BAE Lab



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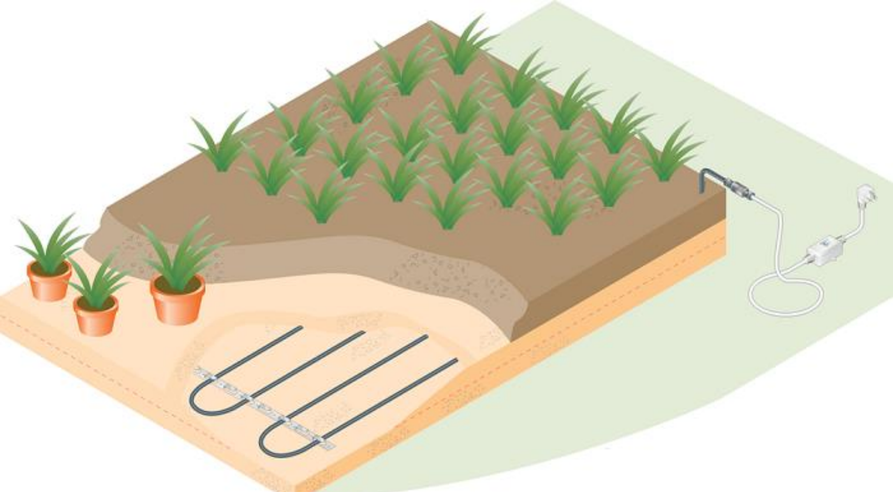
Patent Results: Heating Methods

http://www.heat-safe.com/en/t/faq-soil



http://www.growhome.net/Bio-Green-Heating-mat-and-thermostat-and-soil-sensor.html

Electric Heating Wire

- Constant heat per unit of length
- Easily scaled to greenhouse dimensions
- Requires least amount of above ground equipment
- Heat cables highly efficient
- Highly susceptible to damage by rodents
- Not easily repaired
- Completely dependent on electrical supply

Patent Results: Heating Methods

Recirculated Hot Water

- Inexpensive to repair and expand
- Multiple potential heat sources
- Can store heat during the day
- Can result in uneven heating

Patent Results: Cooling Methods

Fan-less misting above plants:

- Oversaturation can cause mold and root rot

Blown evaporative cooling:

- Less prone to oversaturation
- Air turbulence encourages full evaporation of mist
- Higher cooling efficiency per unit water used
- Fan operation costly

http://www.certhon.com/products/heating-and-cooling/greenhouse-cooling/air-and-water-cooling/jsk

Energy Transfer in Soil

Texture Class	Thermal Conductivity Btu/ft hr °F
Sand	0.44
Clay	0.64
Loam	0.52
Saturated sand	1.44
Saturated silt or clay	0.96

Figure 3. Heat capacity as water content increases.

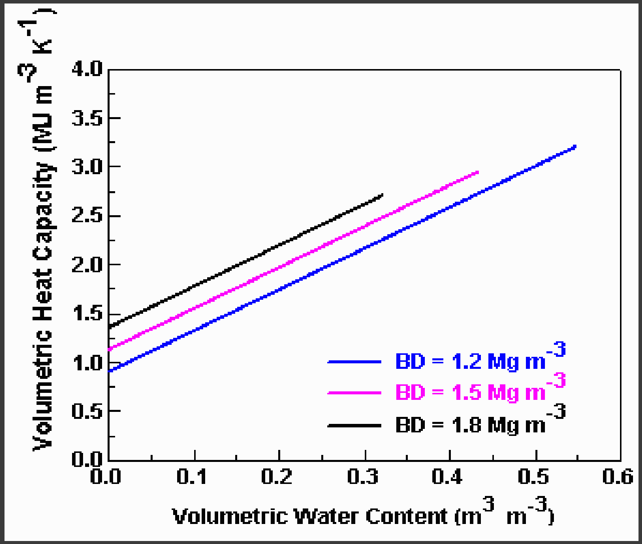
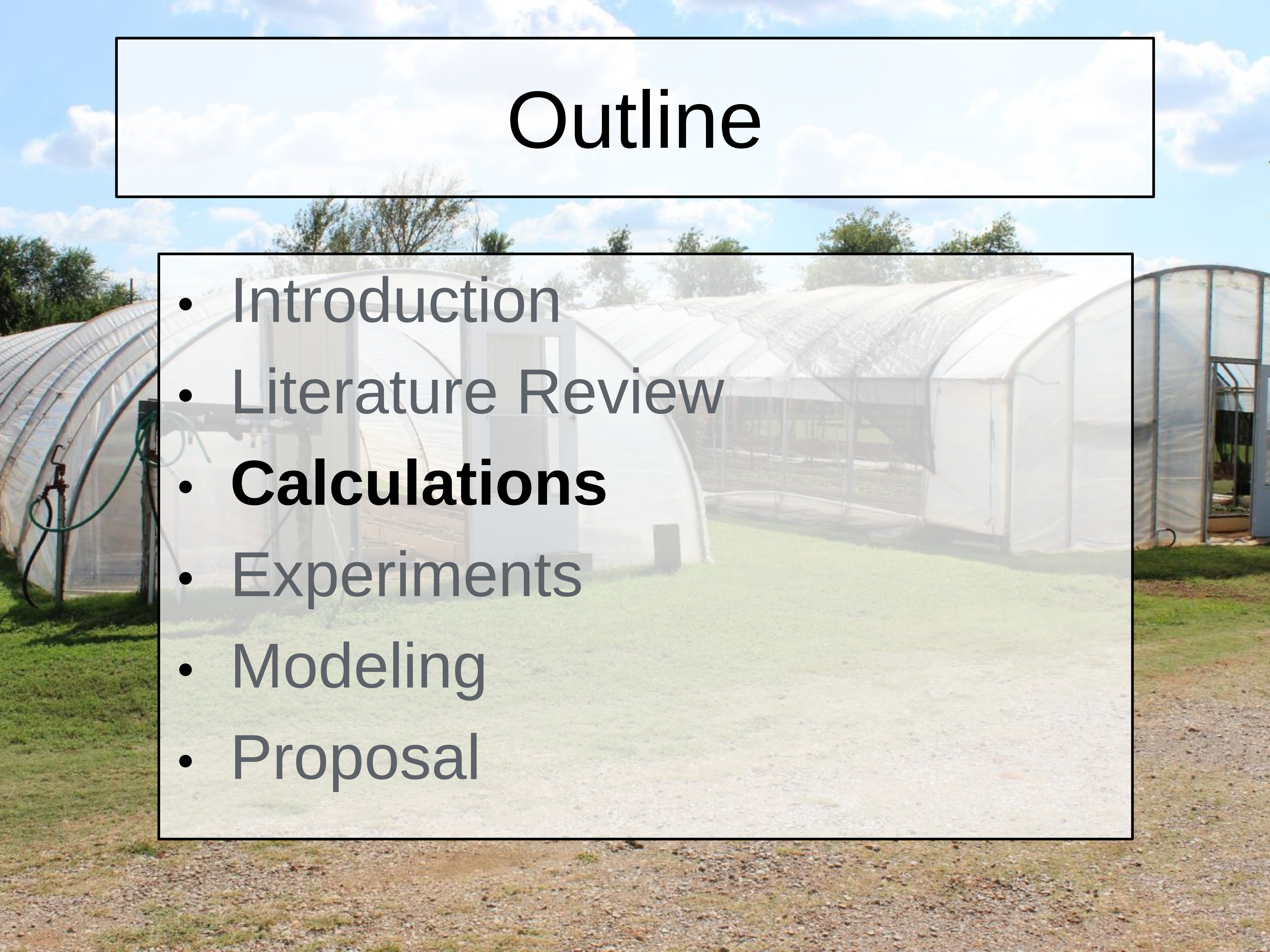


Figure 4. Normal thermal conductivity of biological materials.

- Thermal conductivity affects conduction through soil
- Varies by soil type and moisture content
- Thermal conductivity increases with moisture and organic material
- Heat capacity increases as moisture increases
- $q = -k\frac{\Delta T}{\Delta x}$ where Δx is about 8 in.



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Calculations

- Eqn 1: Heat and mass transfer to determine temperature of water in tube
- Eqn 2: Mass flow rate of water
- Eqn 3: Combining eqn 1 and 2
- From Eqn 3: temperature delta = 3.2 °F
- Eqn 4: determining laminar or **turbulent** flow in tubes

$$\dot{E} = \dot{m} c_p \Delta T \qquad \text{Equation 1}$$

$$\dot{m} = \rho \dot{\forall} \qquad \text{Equation 2}$$

$$\Delta T = \frac{\dot{E}}{\rho \dot{\forall} c_p} \qquad \text{Equation 3}$$

$$Re = \frac{\rho \dot{\forall} D_H}{\mu A} \qquad \text{Equation 4}$$

Calculations

- Eqn 5: Mass flow rate of applied mist
- Eqn 6: Find enthalpy to determine temperature of water

$$\dot{m}_w = \dot{m}_a(H_2 - H_1)$$

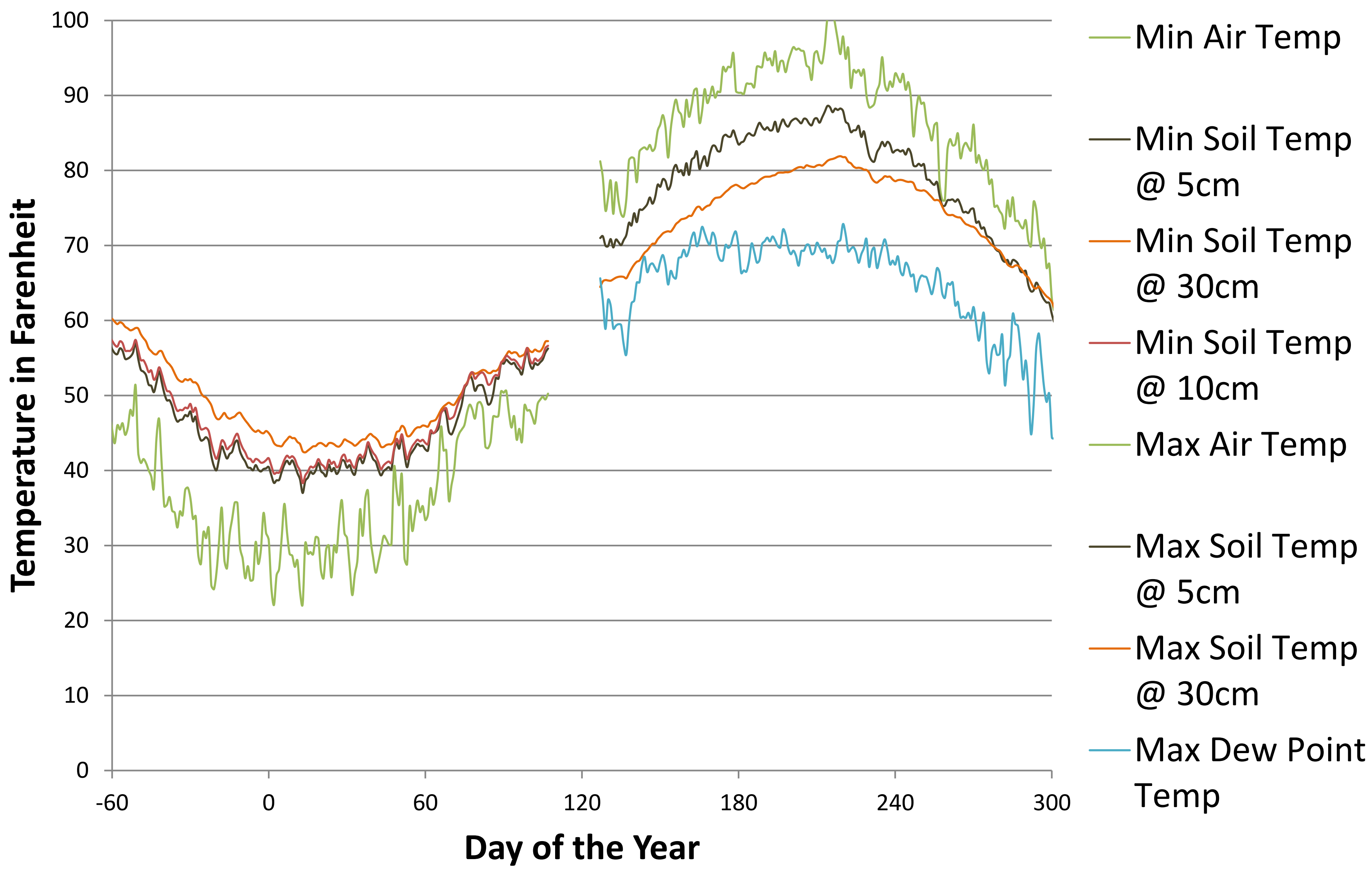
Equation 5

$$h_w = \frac{\dot{m}_a}{\dot{m}_w}(h_2 - h_1)$$

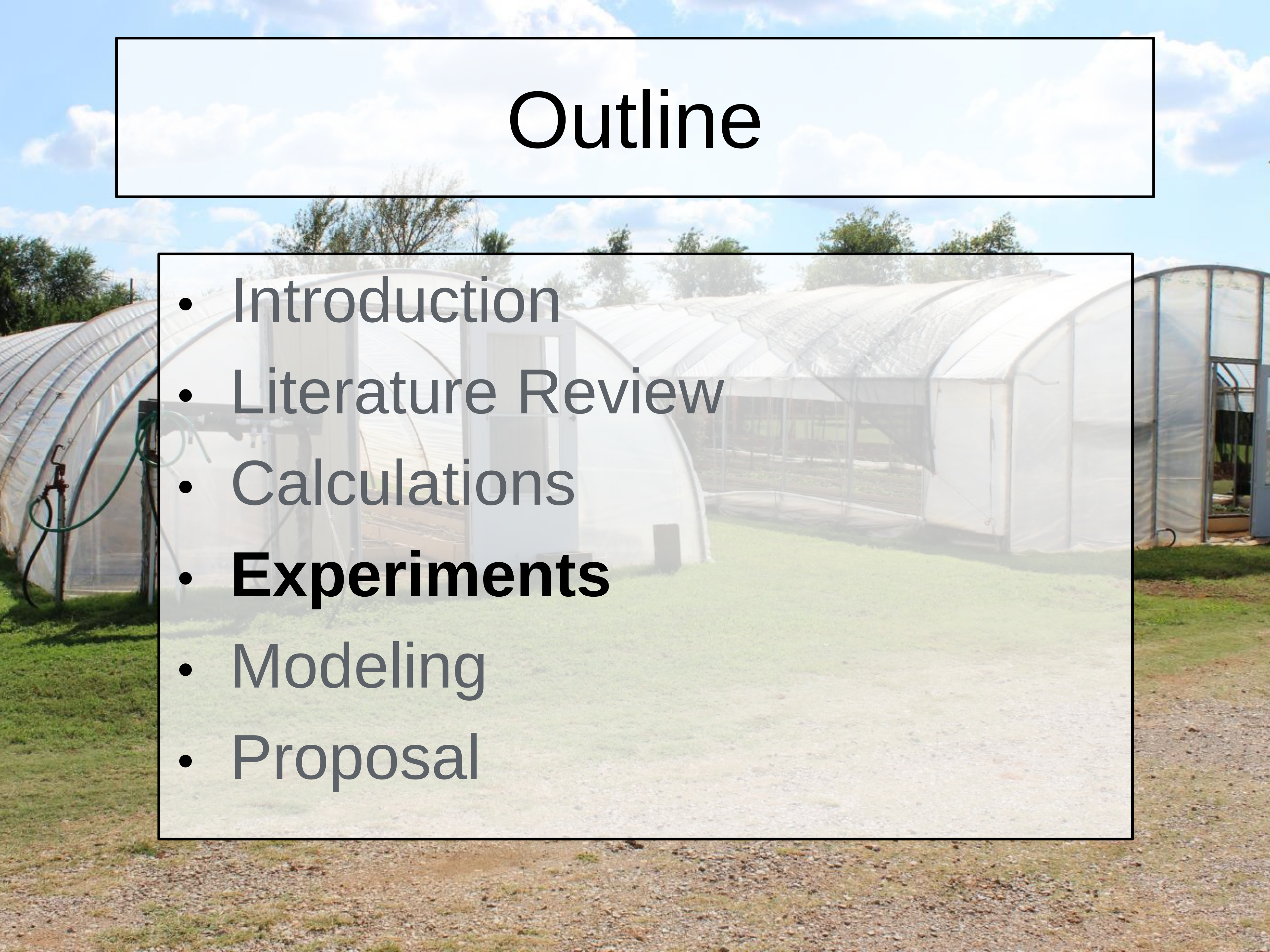
Effect of Climate on Energy Transfer

- When the ambient temperature is much higher or lower than the goal temperature, more energy is required.
- Evaporative cooling is not effective below the dew point.
- Irrigation water is supplied at a temperature near the average yearly temperature.
- System should be designed to function in the most demanding conditions.

Conditions at Mesonet Station near Phocas Farms



Outline



- Introduction
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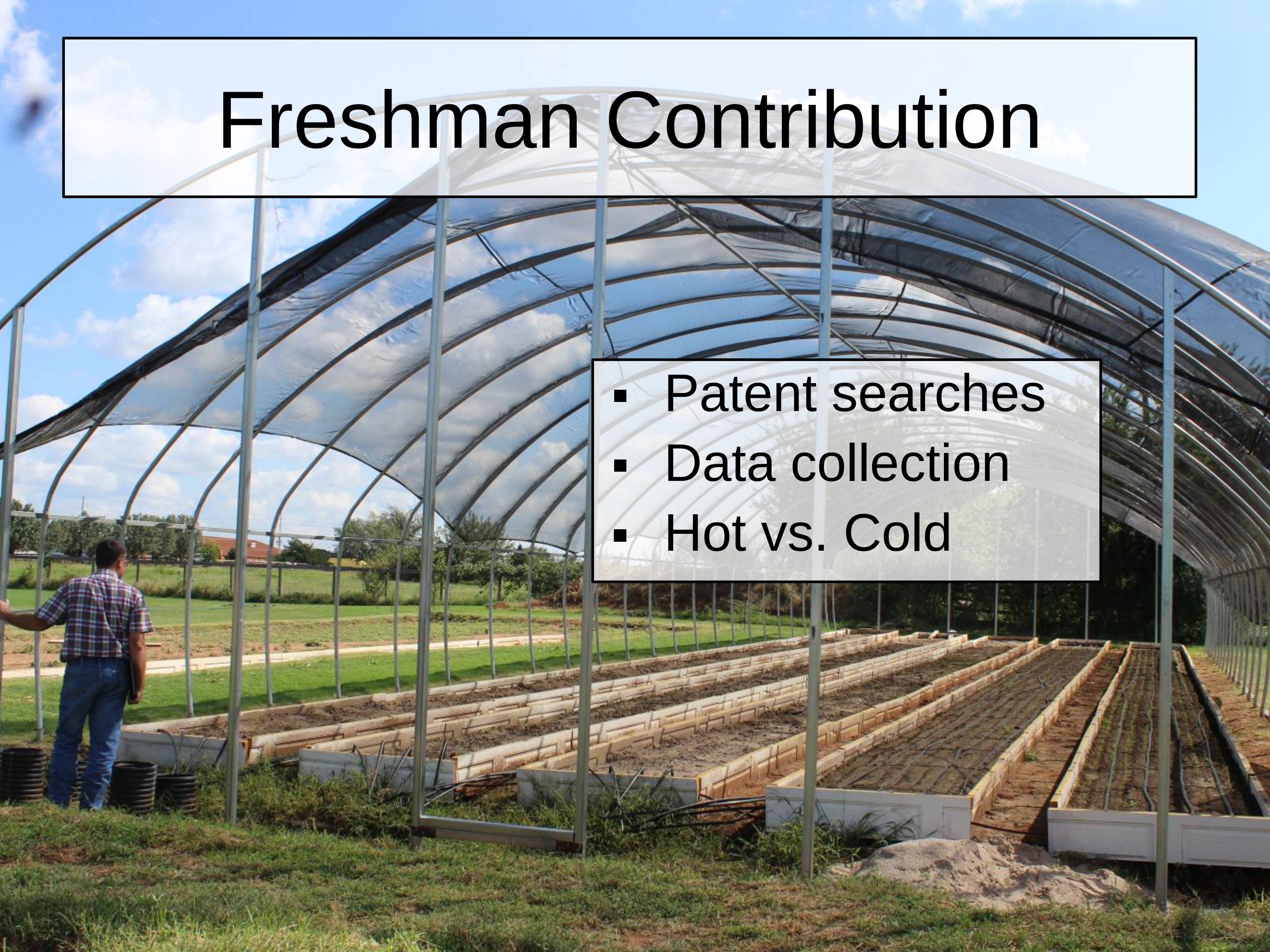
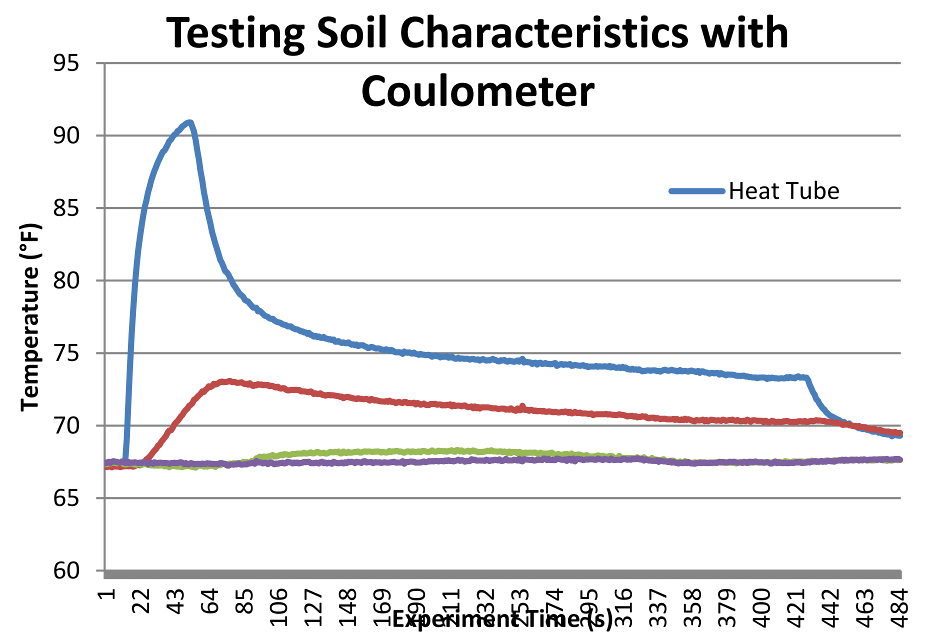
Freshman Contribution



- Patent searches
- Data collection
- Hot vs. Cold

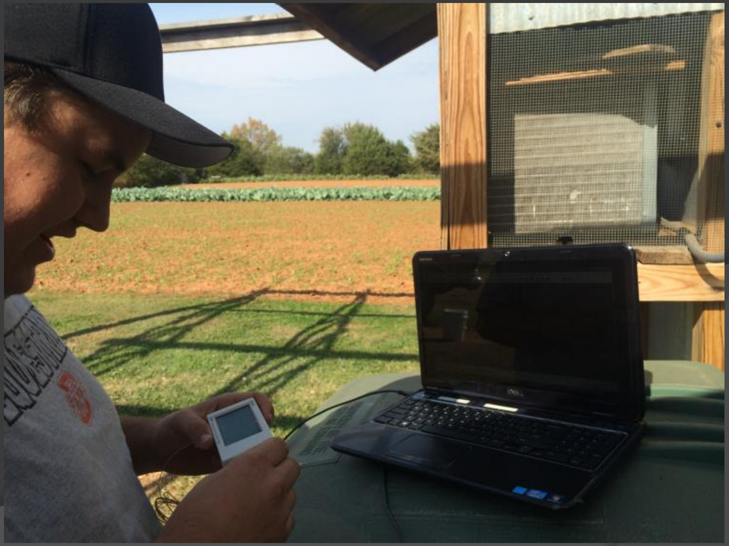
Soil Testing

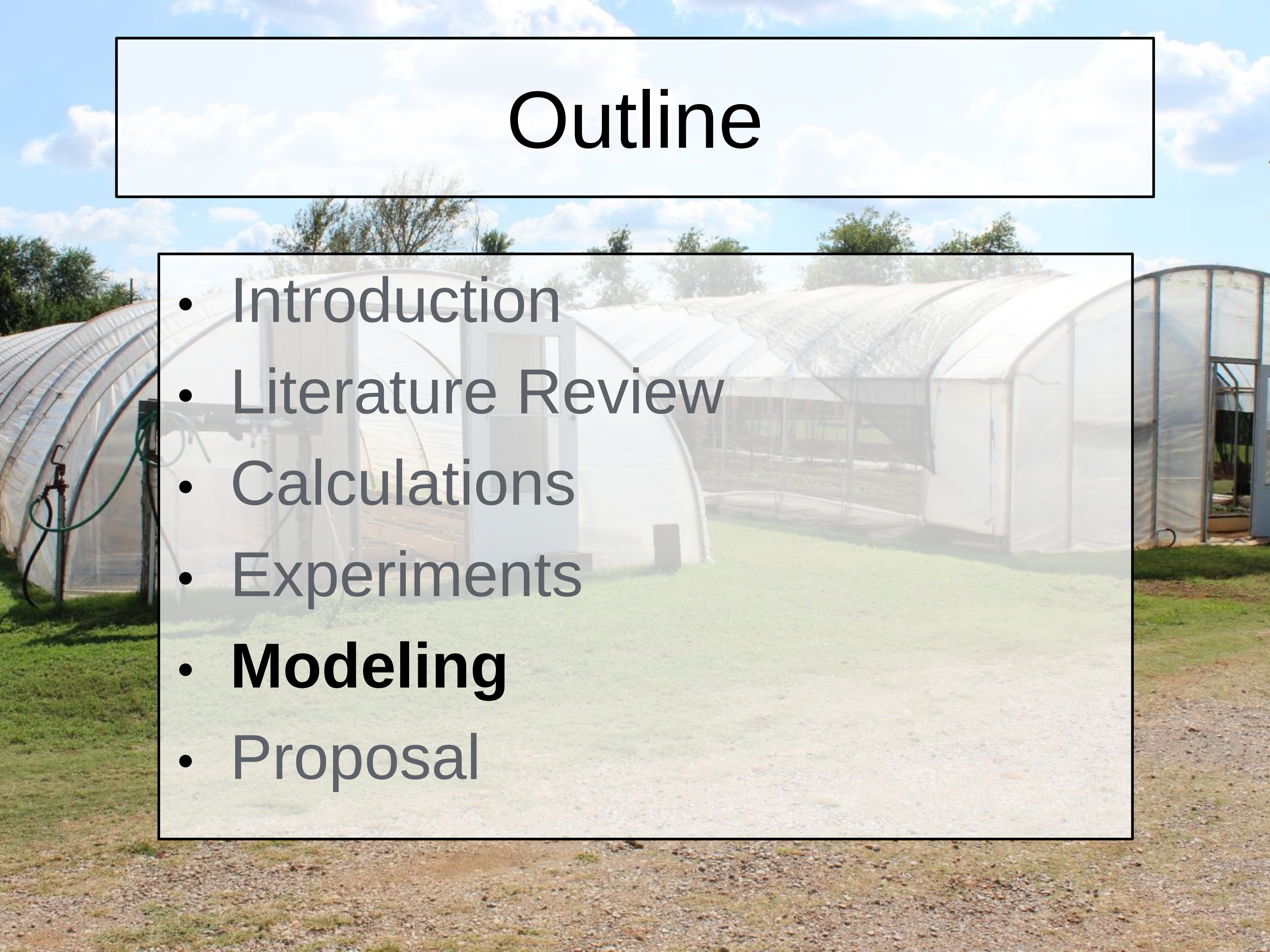
Freshman team built a coulometer and used it to test the thermal conductivity and specific heat capacity of a soil sample.


Testing Soil Characteristics with Coulometer

Isothermal Probe Experiment

- HOBO temperature application software
- Thermal probes
- 1.1 kW heating element
- 4 thermal couples positioned 1 ft. away from heat source





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Modeling Isothermal Probe Experiment

Assumptions:

- Disturbed clay near the source less compact, thermal conductivity about half normal published value
- Heater maintained constant surface temperature
- Constant temperature at soil depth of 4 ft.
- Air modeled as forced convection

Comparing Model to Experiment

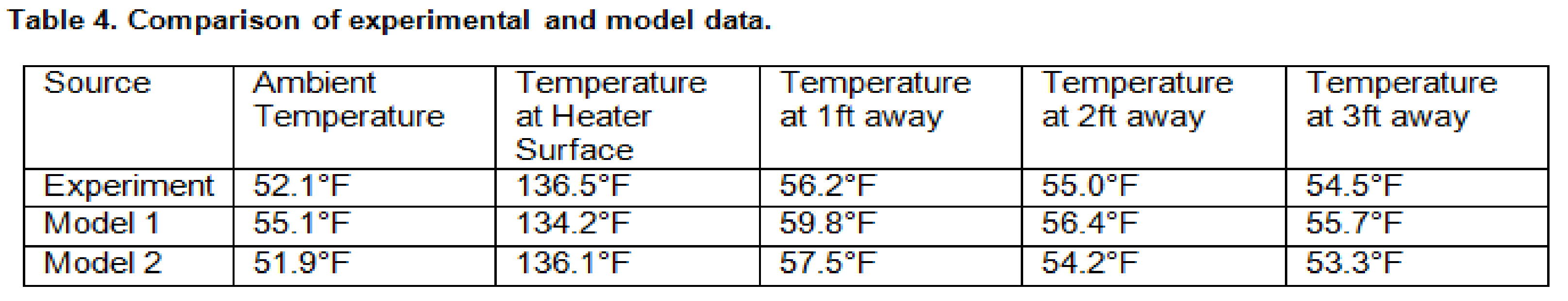


Table 4. Comparison of experimental and model data.

Source	Ambient Temperature	Temperature at Heater Surface	Temperature at 1ft away	Temperature at 2ft away	Temperature at 3ft away
Experiment	52.1°F	136.5°F	56.2°F	55.0°F	54.5°F
Model 1	55.1°F	134.2°F	59.8°F	56.4°F	55.7°F
Model 2	51.9°F	136.1°F	57.5°F	54.2°F	53.3°F

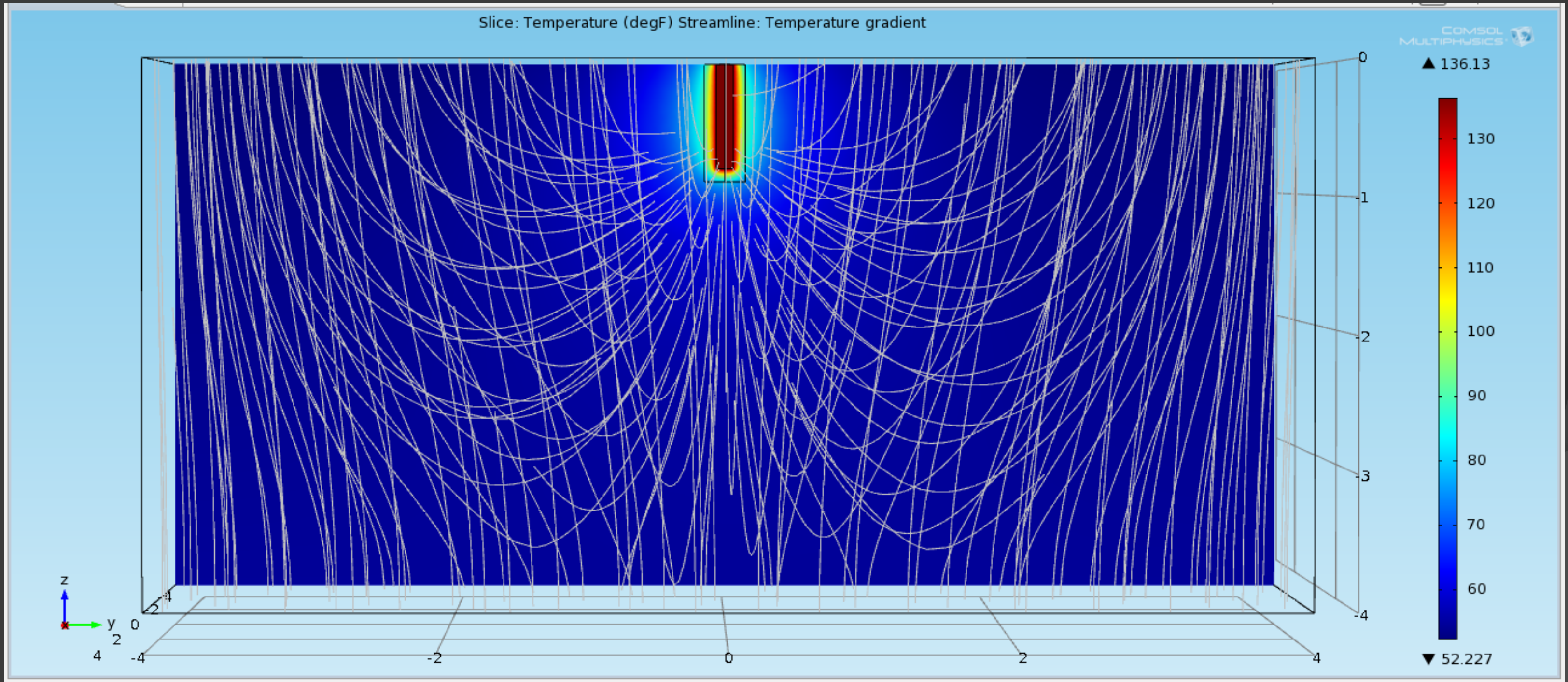
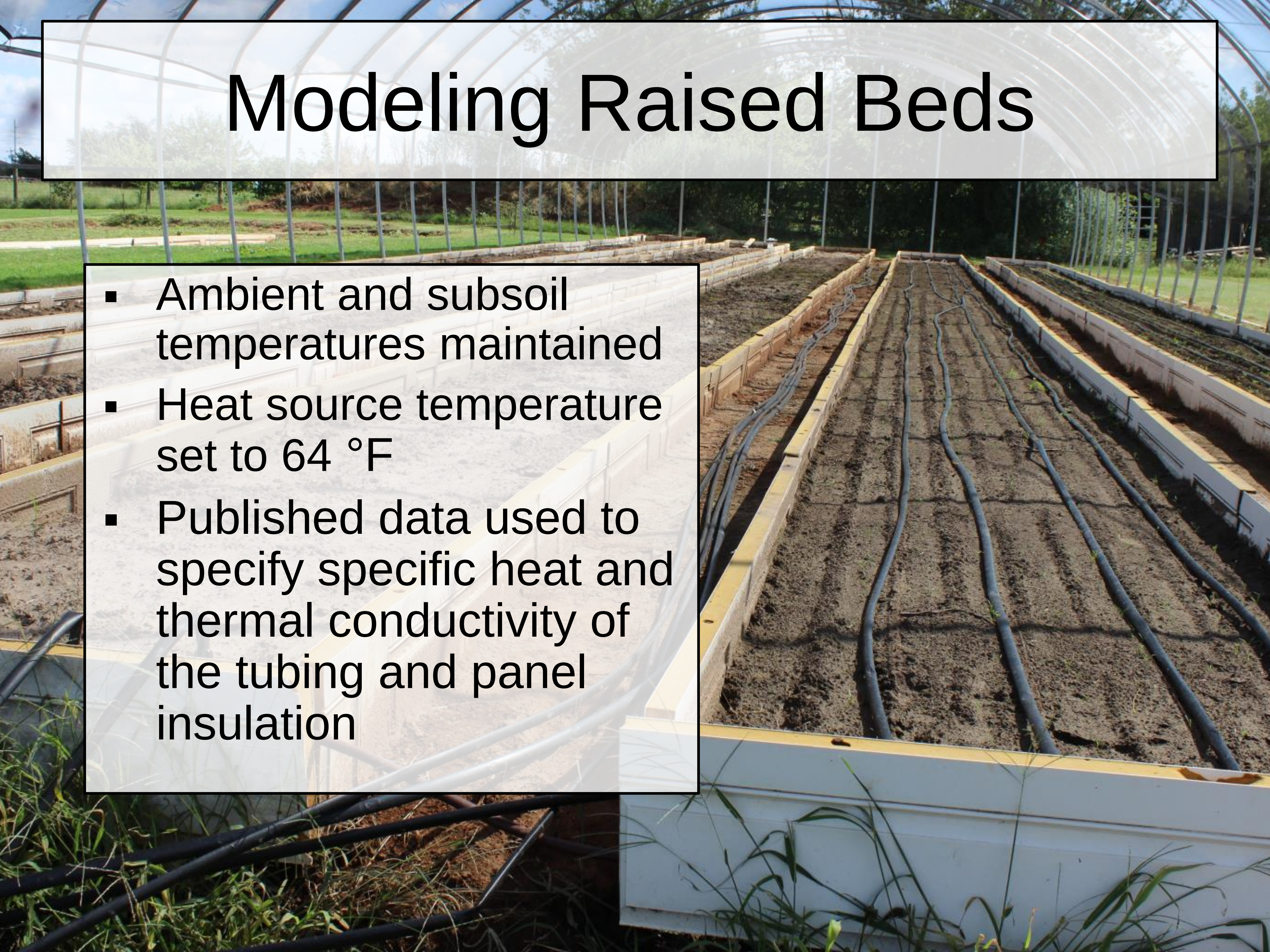


Figure 5. Model of isothermal probe experiment

Modeling Raised Beds



- Ambient and subsoil temperatures maintained
- Heat source temperature set to 64 °F
- Published data used to specify specific heat and thermal conductivity of the tubing and panel insulation

Modeling Temperature Distribution

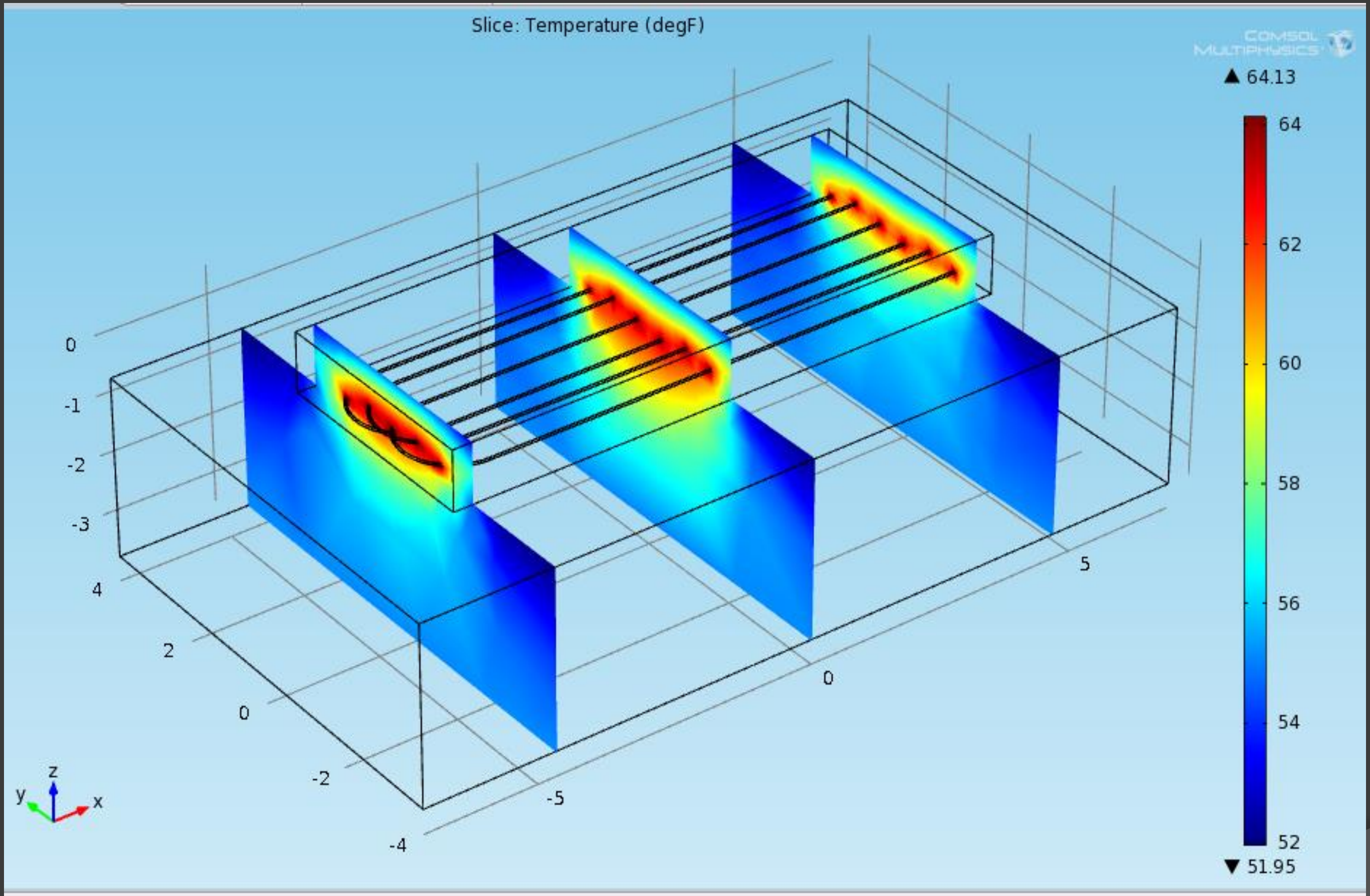


Figure 6. Vertical temperature distribution of existing raised beds.

Modeling Temperature Distribution

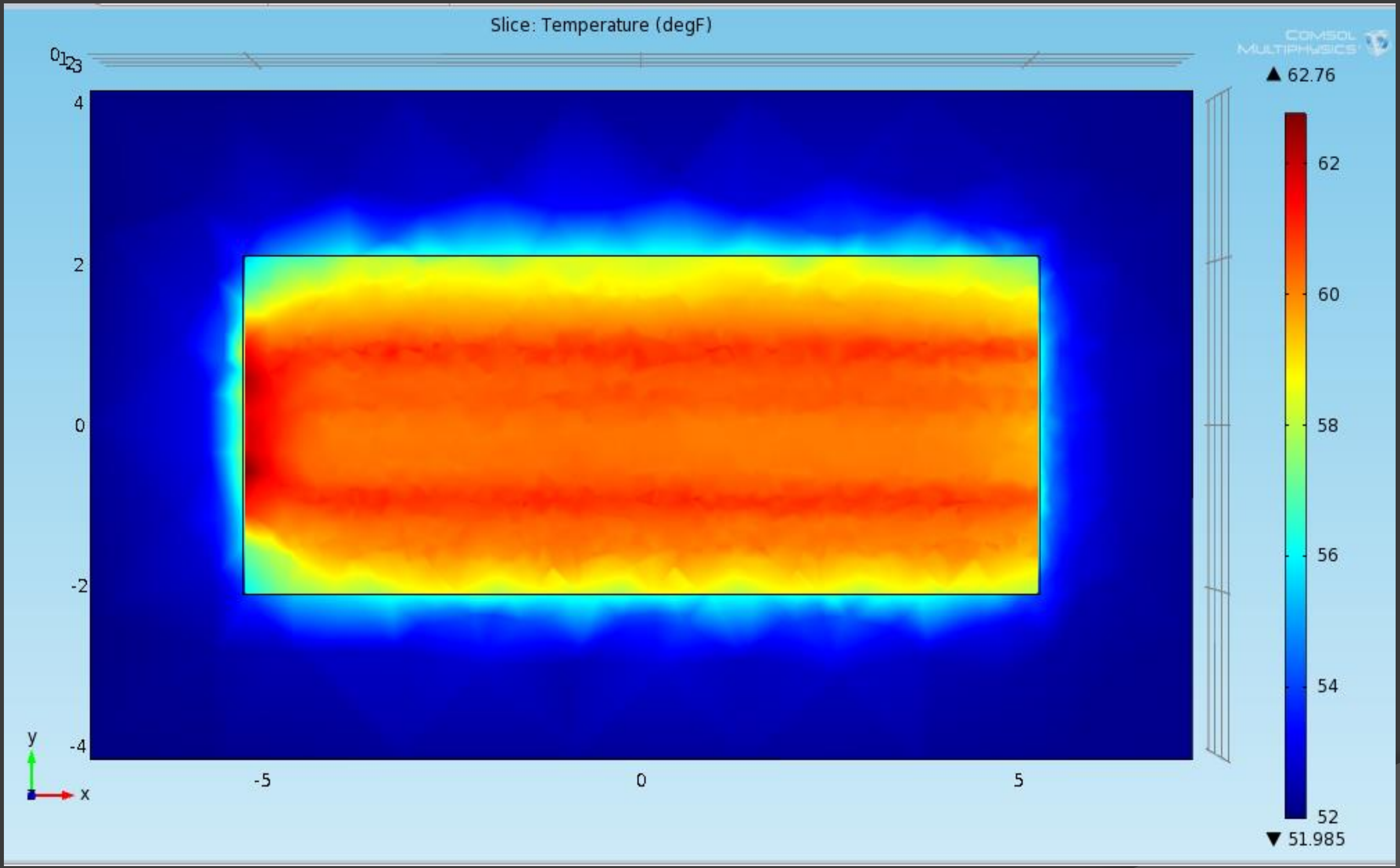


Figure 7. Horizontal temperature distribution of existing raised beds.

Modeling Temperature Distribution

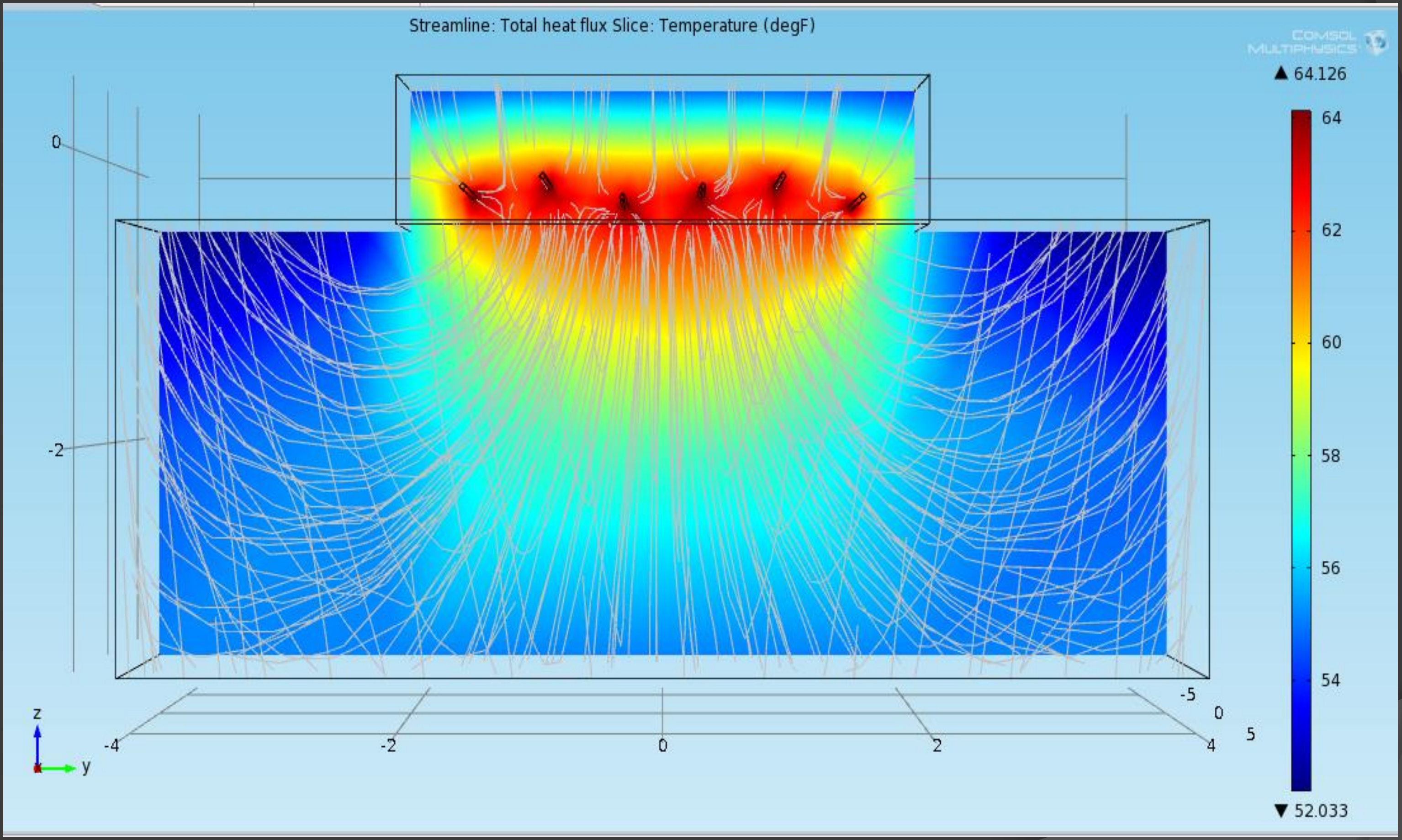
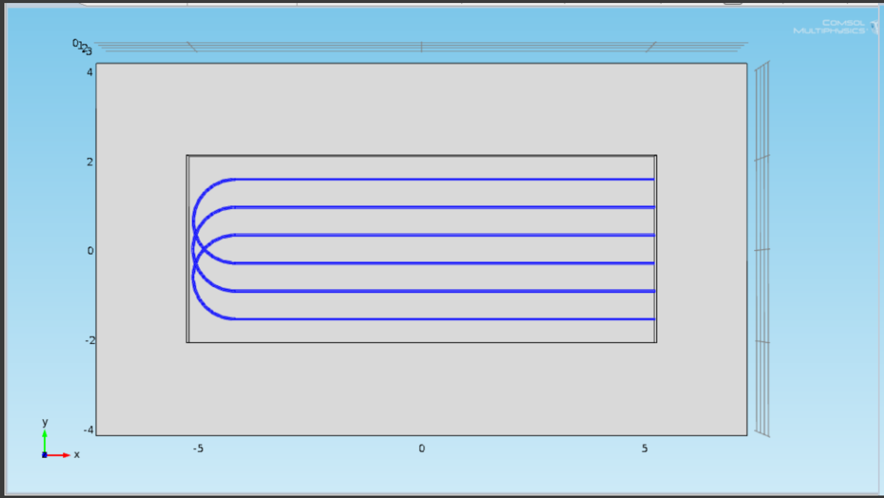
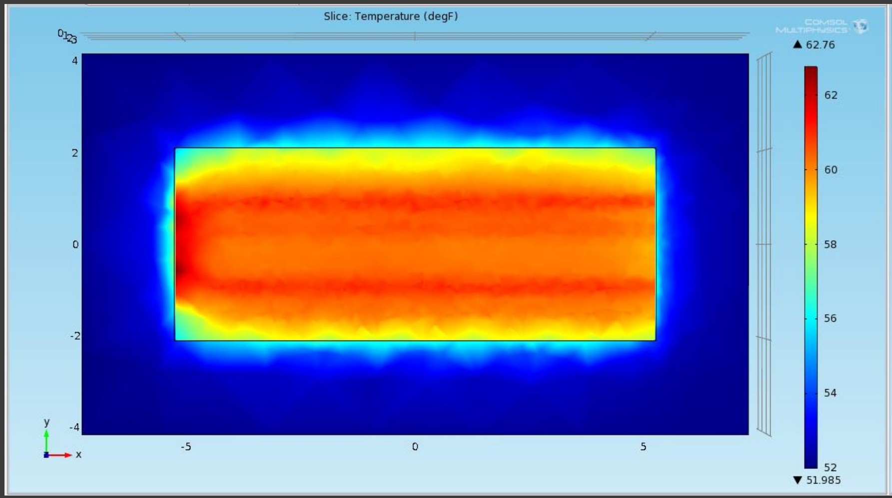


Figure 8. Heat flow in existing raised beds.

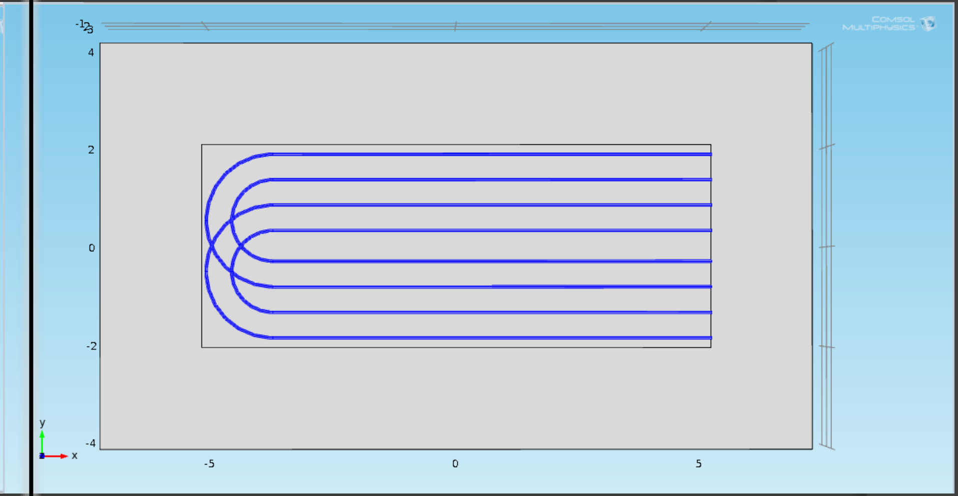
Heating Design Considerations

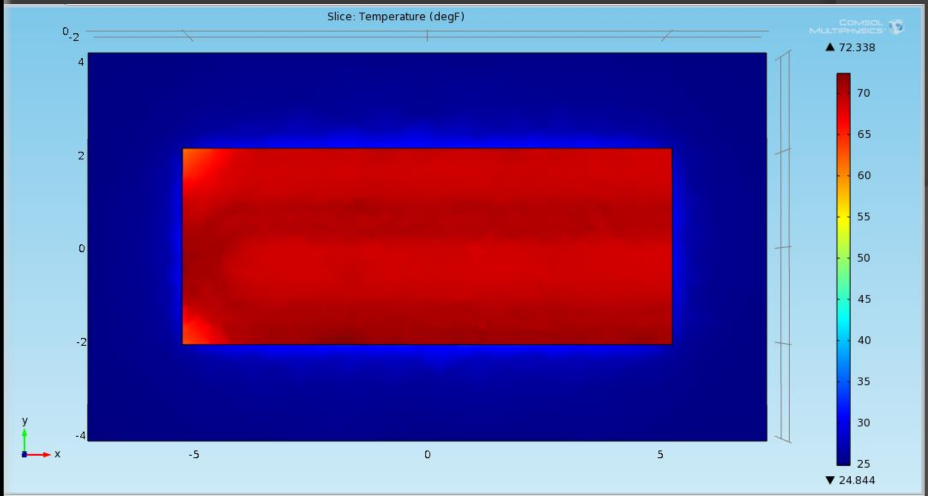
Current Recirculation Pattern





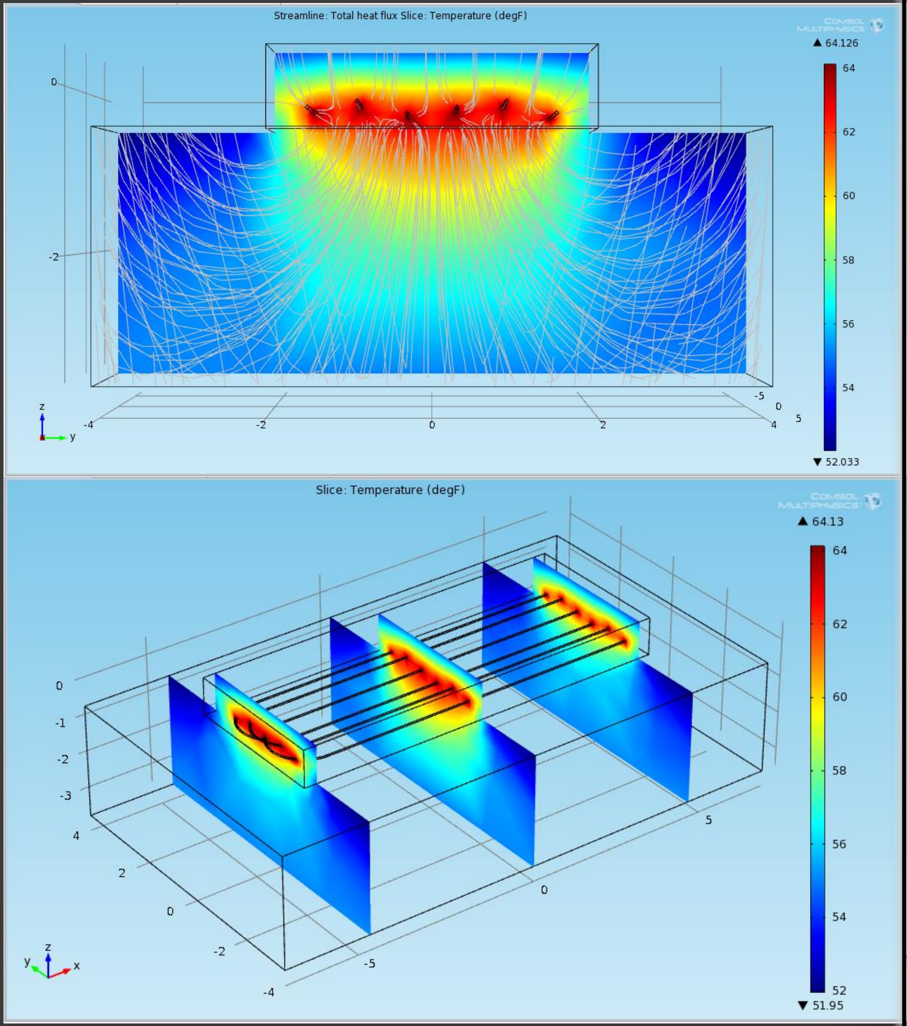
Improved Recirculation Pattern



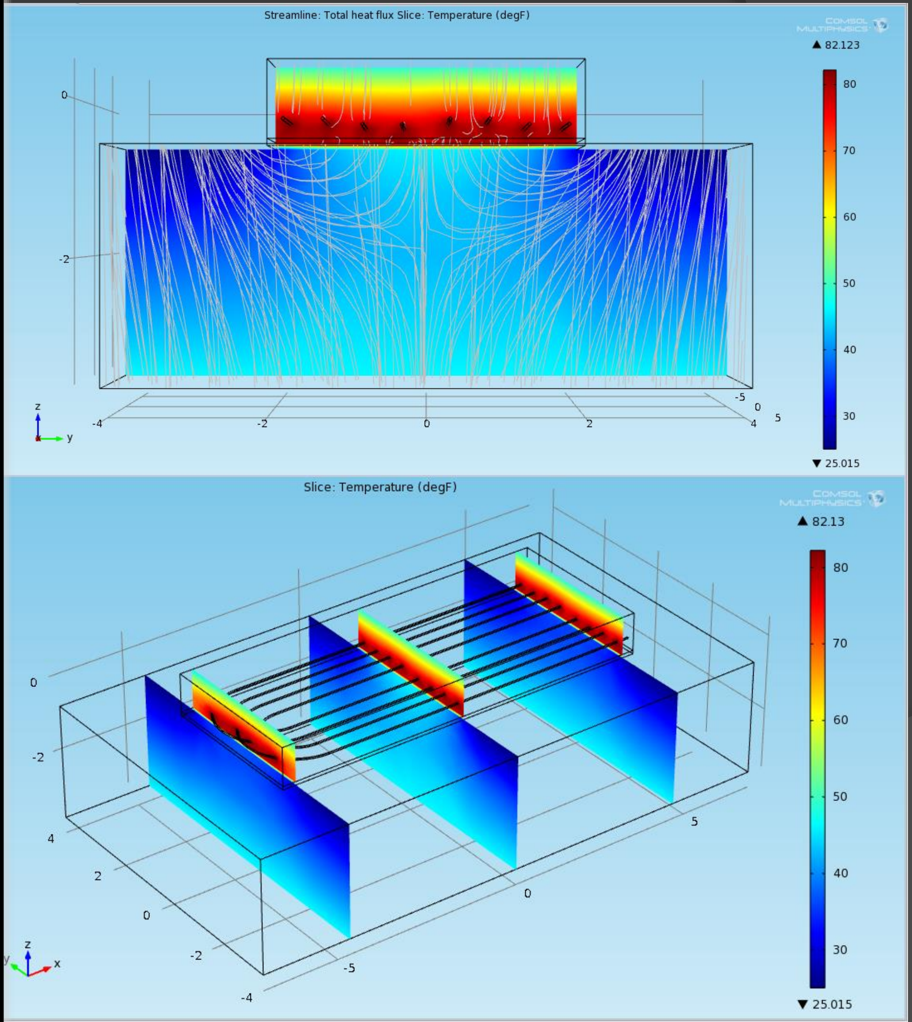


Heating Design Considerations

Current Heat Flow

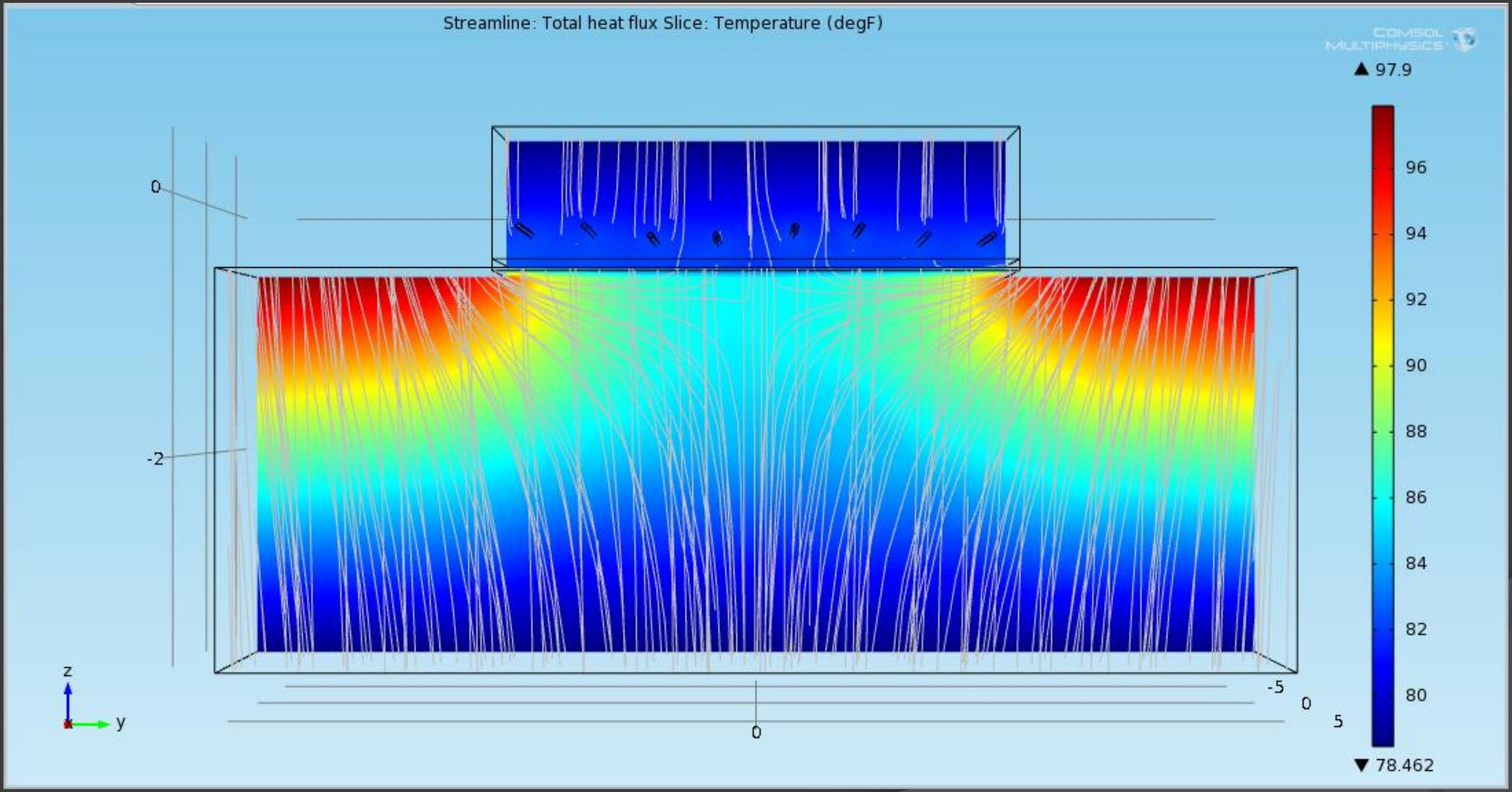


Heat Flow with Insulation



Cooling Design Considerations

- Cooled pipes and evaporative cooling



Outline

- Introduction
- Literature Review
- Calculations
- Experiments
- Modeling
- **Proposal**

Heating Design Proposal

- Add layer of 1 in Cellofoam Polyshield polystyrene insulation beneath the raised beds
- Add layer of bubble wrap above raised bed in the winter to help keep heat near the carrots as they germinate

Cooling Design Proposal

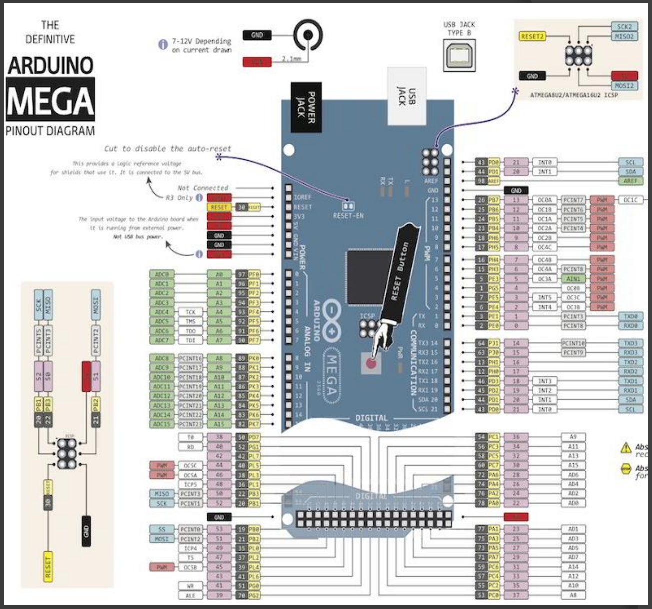
- Install a single misting tube above each raised bed to spray downward
- Tie all misting supply lines together to a single solenoid valve
- Supply misting water from the pressure side of the recirculation pump

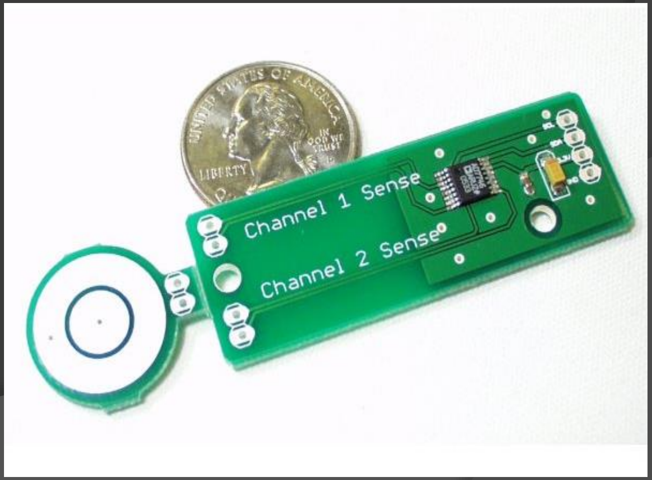
Control System Proposal A

- Use a Pentair EasyTouch programmable logic system and manufactured probes to control heating and cooling
- May not be flexible enough to adequately control all functions
- May be impractical because entry price is $1000 total

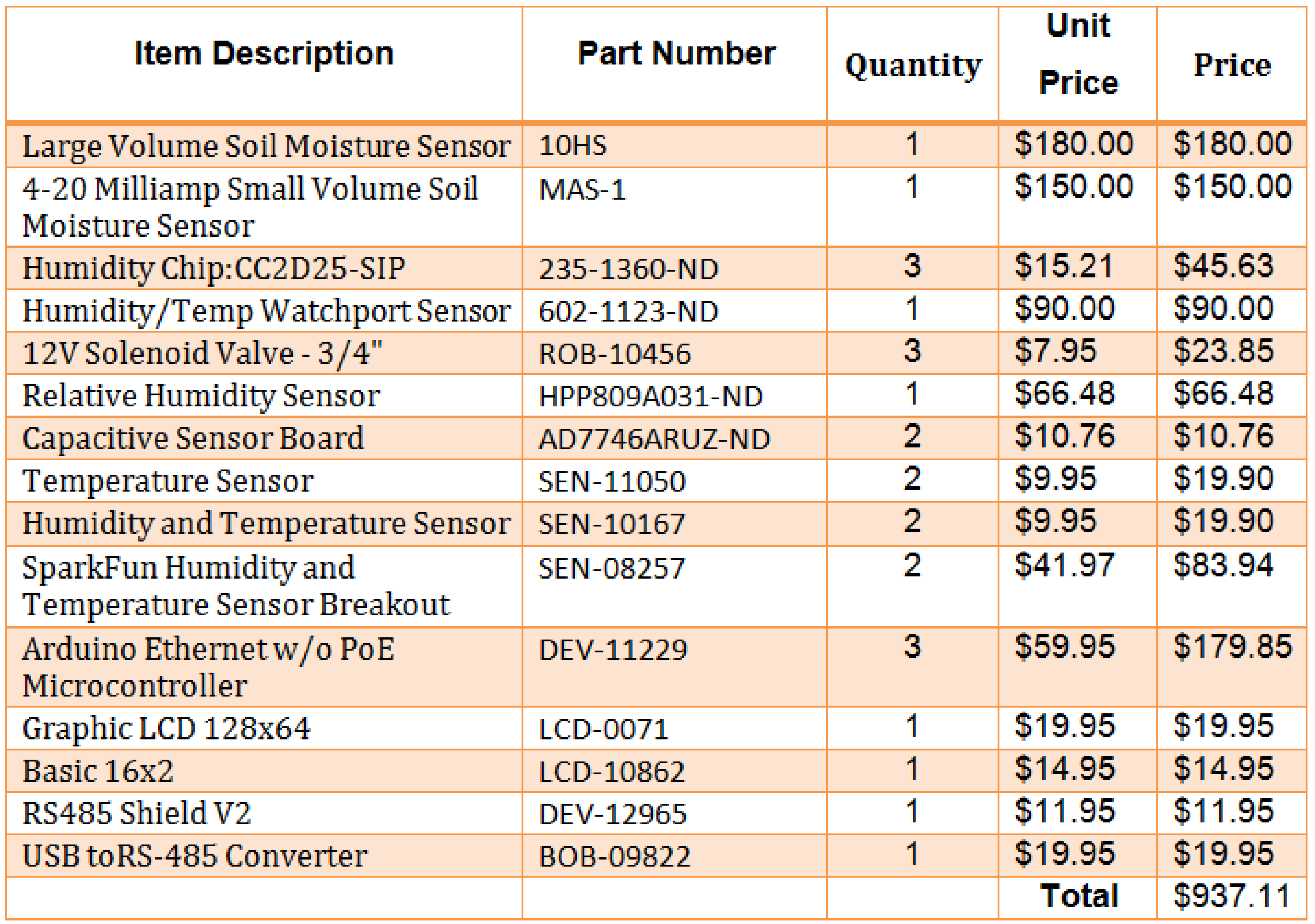
Control System Proposal B

- Design a control system using custom made sensors and microcontroller circuit.
- Complete programming and data logging flexibility
- Cuts cost to $300 for base system, making a product that is profitable for sale
- Greatest savings come in price of sensors, allowing more data points and better control for the same price



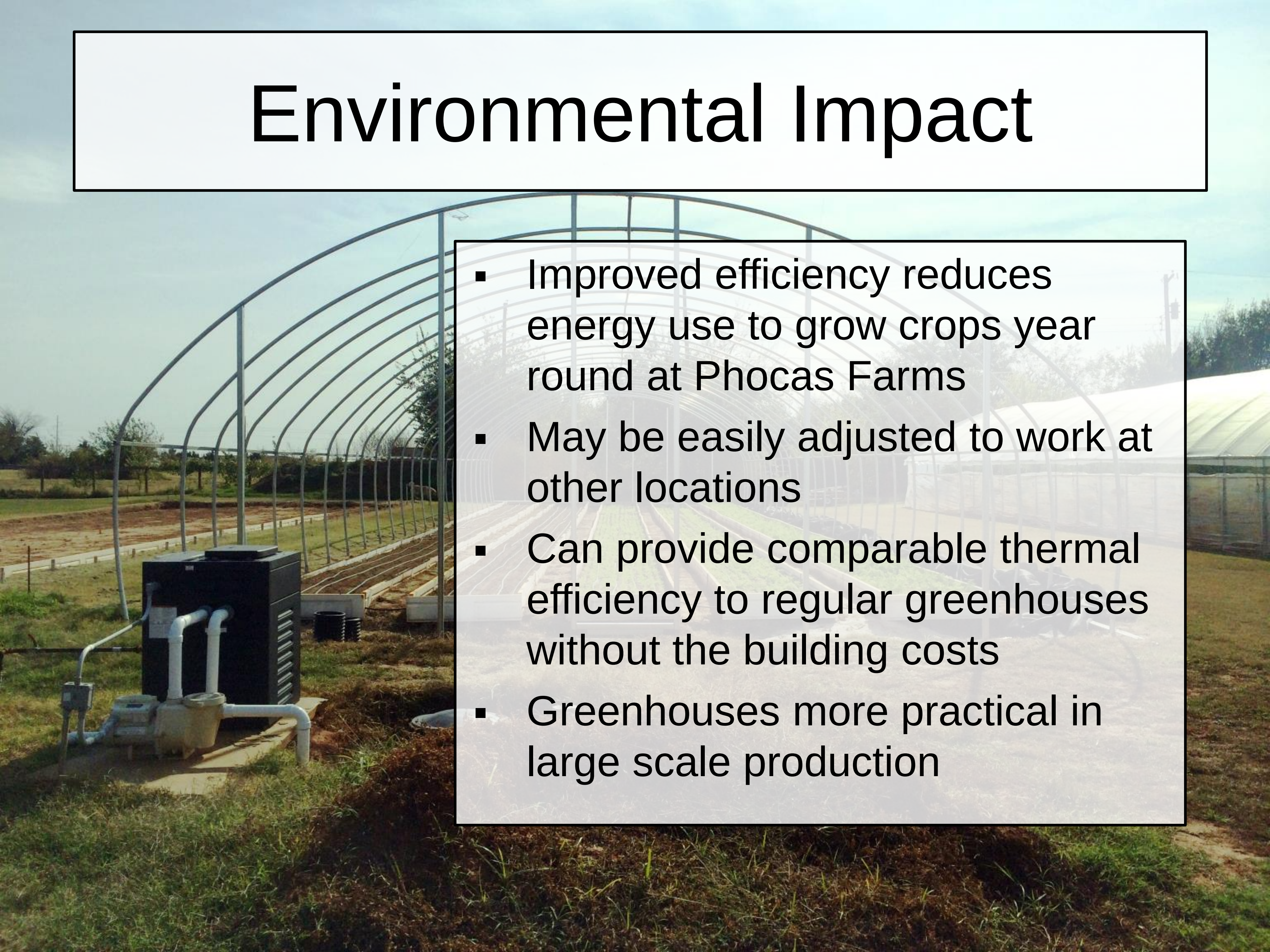


Proposed Design Budget



Item Description	Part Number	Quantity	Unit Price	Price
Large Volume Soil Moisture Sensor	10HS	1	$180.00	$180.00
4-20 Milliamp Small Volume Soil Moisture Sensor	MAS-1	1	$150.00	$150.00
Humidity Chip:CC2D25-SIP	235-1360-ND	3	$15.21	$45.63
Humidity/Temp Watchport Sensor	602-1123-ND	1	$90.00	$90.00
12V Solenoid Valve - 3/4"	ROB-10456	3	$7.95	$23.85
Relative Humidity Sensor	HPP809A031-ND	1	$66.48	$66.48
Capacitive Sensor Board	AD7746ARUZ-ND	2	$10.76	$10.76
Temperature Sensor	SEN-11050	2	$9.95	$19.90
Humidity and Temperature Sensor	SEN-10167	2	$9.95	$19.90
SparkFun Humidity and Temperature Sensor Breakout	SEN-08257	2	$41.97	$83.94
Arduino Ethernet w/o PoE Microcontroller	DEV-11229	3	$59.95	$179.85
Graphic LCD 128x64	LCD-0071	1	$19.95	$19.95
Basic 16x2	LCD-10862	1	$14.95	$14.95
RS485 Shield V2	DEV-12965	1	$11.95	$11.95
USB toRS-485 Converter	BOB-09822	1	$19.95	$19.95
			Total	$937.11

Environmental Impact

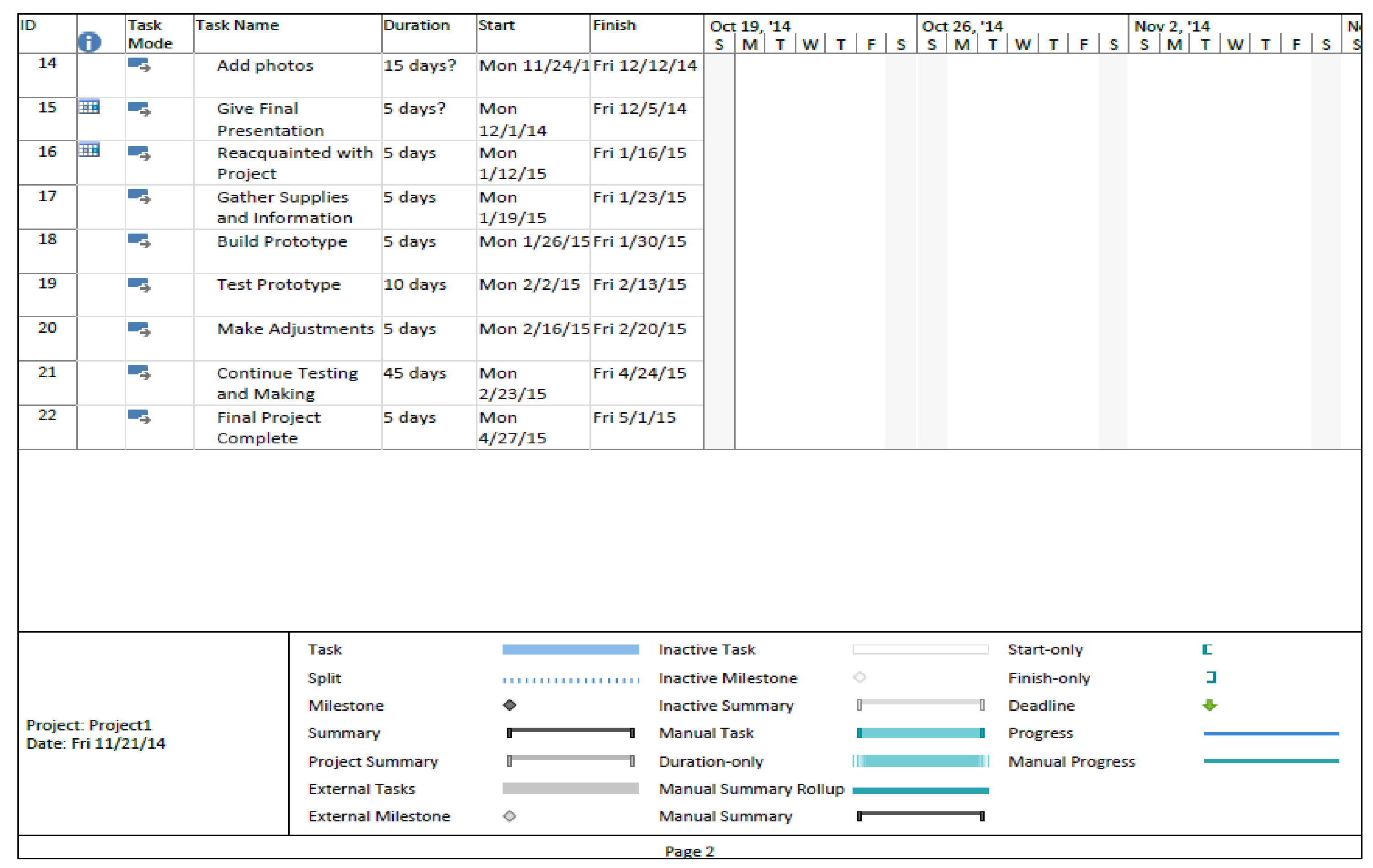


- Improved efficiency reduces energy use to grow crops year round at Phocas Farms
- May be easily adjusted to work at other locations
- Can provide comparable thermal efficiency to regular greenhouses without the building costs
- Greenhouses more practical in large scale production

Future Testing

- Build proposed model
- Test model
- Collect our own data by manipulating the environment of the raised bed
- Temperature probes, moisture sensors, thermal profile imaging

Next Semester Plans



ID		Task Mode	Task Name	Duration	Start	Finish
14			Add photos	15 days?	Mon 11/24/1	Fri 12/12/14
15			Give Final Presentation	5 days?	Mon 12/1/14	Fri 12/5/14
16			Reacquainted with Project	5 days	Mon 1/12/15	Fri 1/16/15
17			Gather Supplies and Information	5 days	Mon 1/19/15	Fri 1/23/15
18			Build Prototype	5 days	Mon 1/26/15	Fri 1/30/15
19			Test Prototype	10 days	Mon 2/2/15	Fri 2/13/15
20			Make Adjustments	5 days	Mon 2/16/15	Fri 2/20/15
21			Continue Testing and Making	45 days	Mon 2/23/15	Fri 4/24/15
22			Final Project Complete	5 days	Mon 4/27/15	Fri 5/1/15

Project: Project1
Date: Fri 11/21/14

Task	Inactive Task	Start-only
Split	Inactive Milestone	Finish-only
Milestone	Inactive Summary	Deadline
Summary	Manual Task	Progress
Project Summary	Duration-only	Manual Progress
External Tasks	Manual Summary Rollup	
External Milestone	Manual Summary	

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