

EDIBLE WALLSCAPES

Green Facades for Shade and Food in the Southeastern United States



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Introduction + Hypothesis

What is the Problem?

- Increased impervious surfaces
- Rising temperatures
- Overall lack of nature within urban environments
- Rapid population growth + urbanization
- Decrease in agricultural land
- Threatened ability to meet a rising food demand

Hypothesis

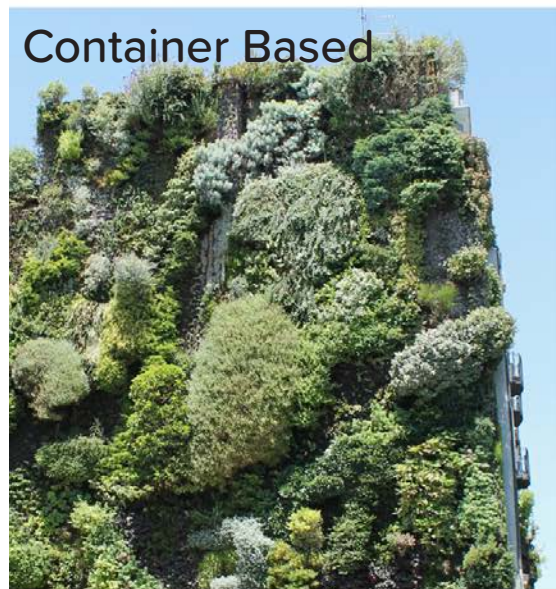
The implementation of green Facade systems in warm humid climates will reduce temperatures while serving as a food source and place-maker for the surrounding community.



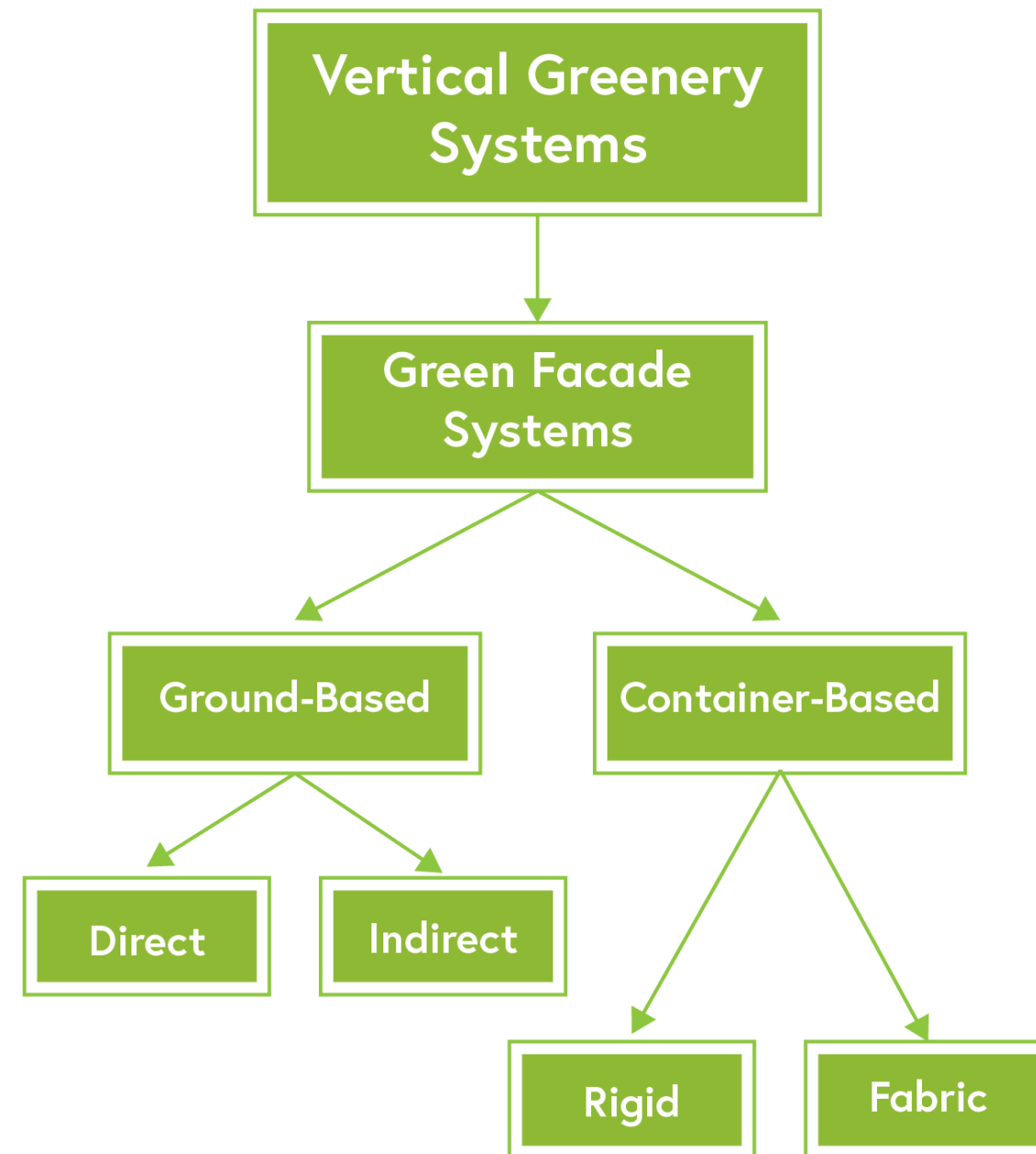


Green Facade Systems

Classification of Green Facade Systems



Examples of Green Facade Systems
(Manso, 2015)



Overview of System Types and Characteristics

System	Type		Opacity	Maintenance	Weight	Price	Additional Comments
Container Based	Potted Systems (Rigid)		Poor	Must maintain plant size	10-12 lbs/SF (LiveWall System)	\$45-65 / SF	Allows greater plant diversity
	Felt Systems (Fabric)		Poor	Must maintain plant size	1.5 lbs/SF (Dry) 5 lbs/SF (Panted + Wet)	\$30/ SF (Flora felt system)	Allows greater plant diversity, Easily moved and relocated
Ground Based	Indirect: Trellis System		Good	Easy to maintain	0.75 lb/ SF (Without Plants)	\$6/SF	Lightweight and cost effective
	Indirect: Trellis System Overhang		Great	Easy to maintain once plant growth is trained	0.6 lb/ SF (Without Plants)	\$6/SF	Does not impede view
	Indirect: Tension Wire Systems		Good	Easy to Maintain once growth is established	0.90 lbs/FT (Ottelé, 2011)	\$25/SF (Includes Installation cost)	Lightweight and aesthetically interesting
	Direct		Fair	Easy Maintenance	Plant Weight	Plant Cost	Highly dependent on facade type and structural integrity

Ground Based Green Facade Systems

Ground based systems can be categorized into two main types

- Direct
- Indirect

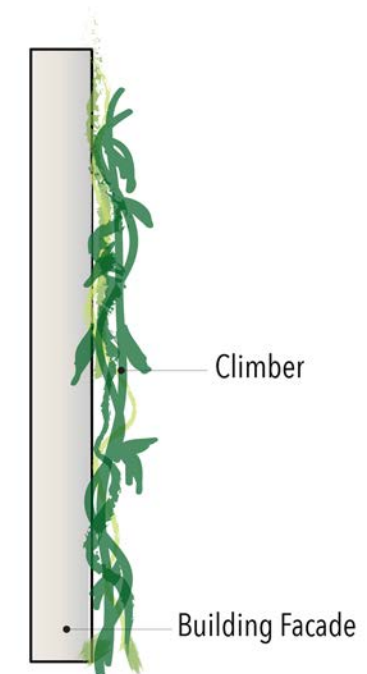
Both systems consist of climber plants that can be rooted directly into the ground or in planter beds

A direct system grows directly onto the wall

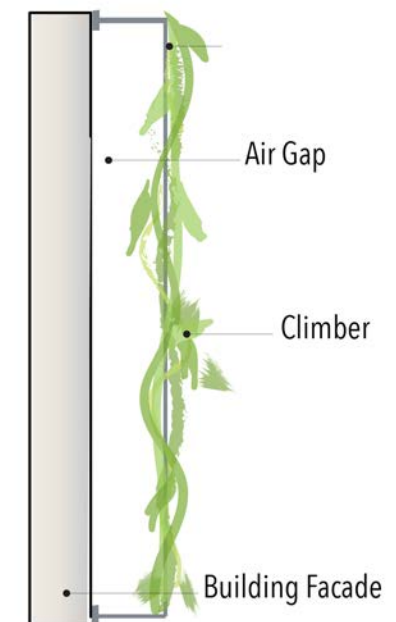
An indirect system consists of a support structure on which plant material grows



Direct system in Savannah, GA



DIRECT SYSTEM



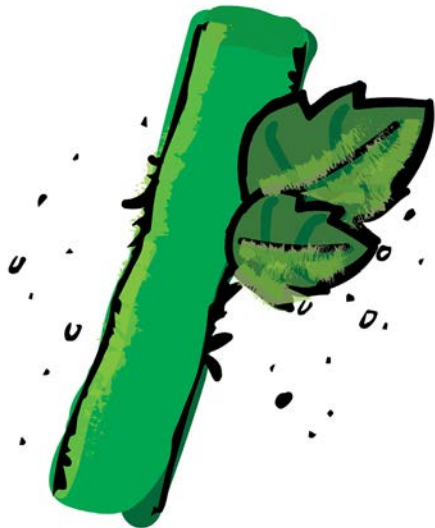
INDIRECT SYSTEM

Indirect system Configuration

Source: (<http://www.clairepotterdesign.com/>)

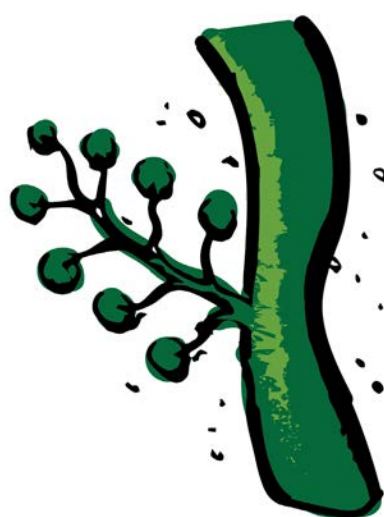
Overview of Climbing Plants

Self-Adhesive



ROOT CLIMBERS

Examples: Ivy, Trumpet Vine



ADHESIVE SUCKER

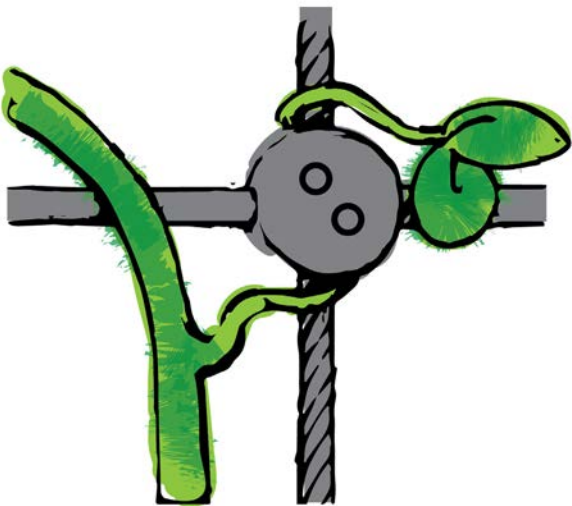
Example: Boston Ivy

Requires Support Structure



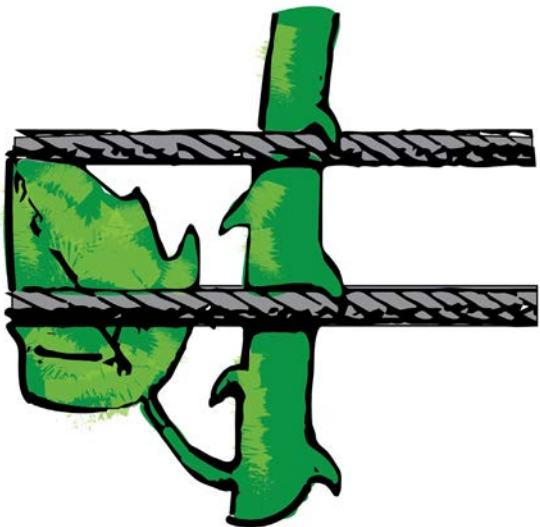
VINING CLIMBERS

Examples: Wisteria, Honeysuckle, Hops, Morning Glory



TENDRIL CLIMBERS

Examples: Clematis, Passionfruit, Grape Vines

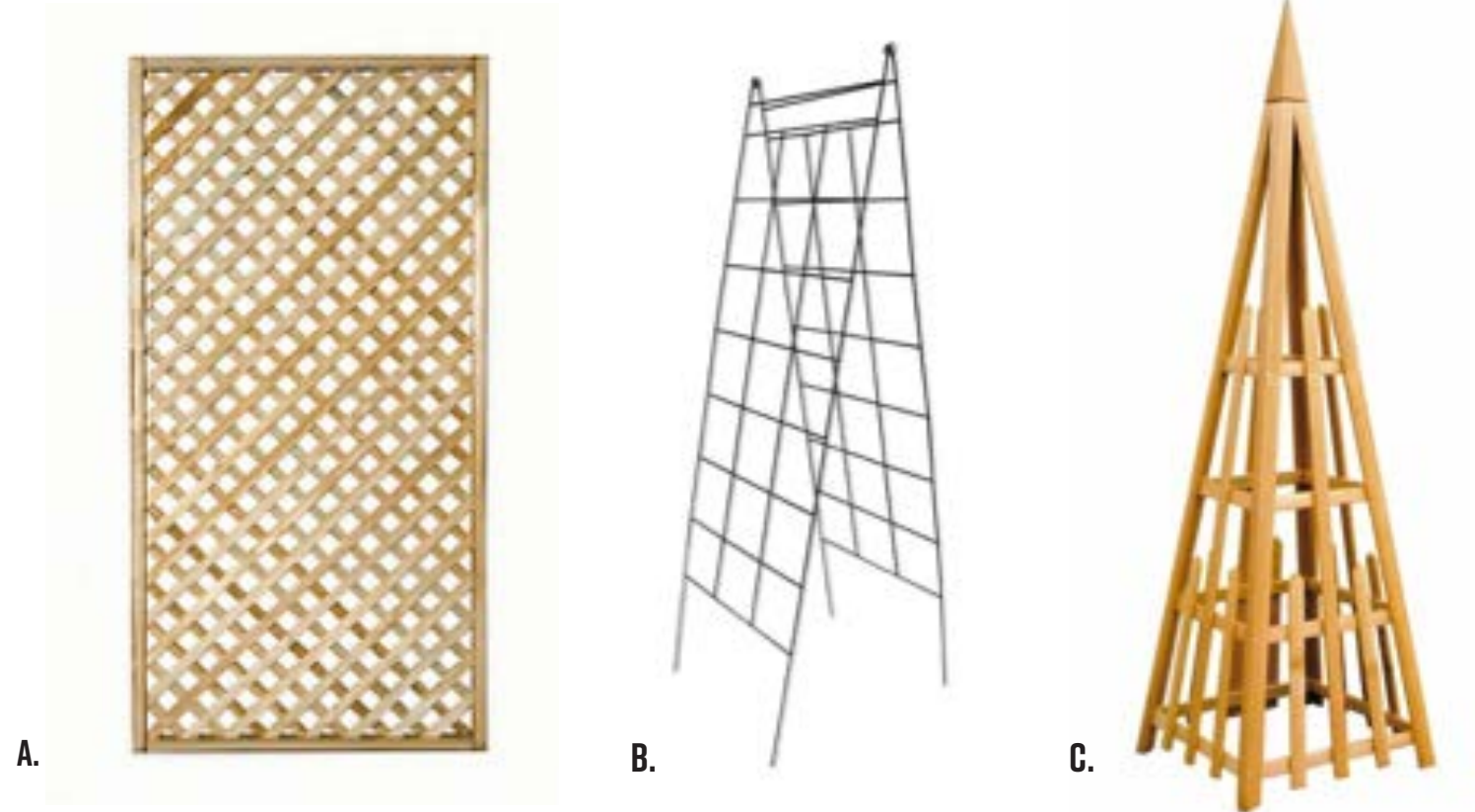


SCRAMBLING CLIMBERS

Examples: Bougainvillea, Climbing Roses, Winter Flowering Jasmine

Common Types of Ground Based Systems

Trellis and Lattice Systems



A) Wooden Flat Trellis (WICKES.CO.UK) B) Metal A-Frame Trellis (FARMANDFLEET.COM) C) Wooden Teepee Trellis (OUTDOORFURNITUREPLUS.COM)

Overhang Systems



A) Self-supporting pergola (samsclub.com) b) Wall Pergola (homeclick.com)

Tension Cable Systems

Ronstan Cable Trellis System



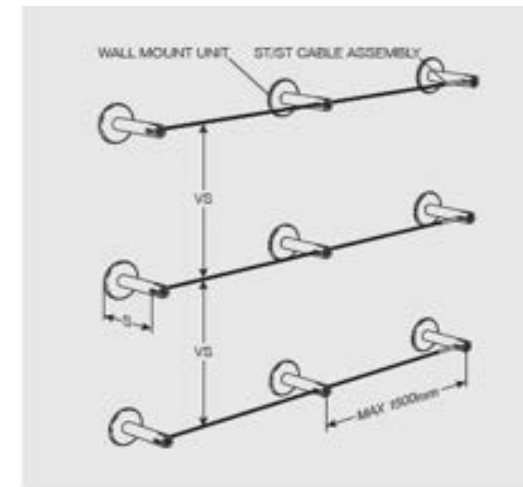
VERTICAL

Ideal for vining plants and tendril climbers. They consist of galvanized steel cables that are held off the wall using mounting brackets so that plants can easily weave around the cables.



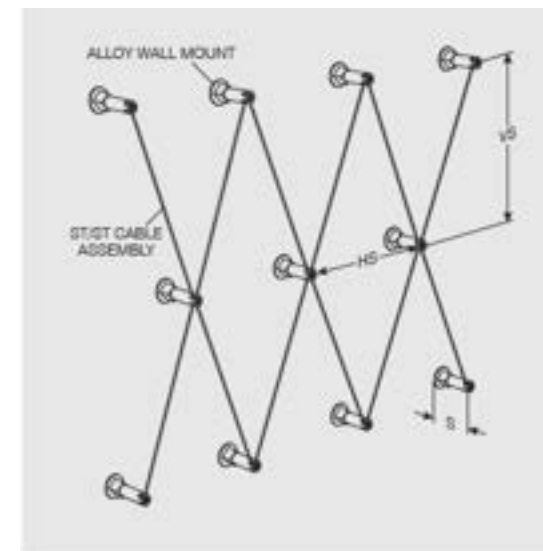
GRID

Allows plants to grow both vertically and horizontally promoting more expansive plant growth and wall covering.



HORIZONTAL

Have the ideal layout for promoting broad plant growth of scrambling plants. The system is constructed similarly to a vertical system just rotated ninety degrees to be horizontal.



DIAGONAL GRID

Provides expansive wall coverage both horizontally and vertically. Less training or pruning of the plants is needed and an interesting aesthetic effect is also achieved.

Planting Choices For Ground Based Systems

Climbing Plants Well Suited for the Southeast

Inedible



Black-eyed
Susan



Honeysuckle



Mandevilla



Morning Glory



Trumpet Vine

Edible



Runner
Beans



Pole
Beans



Muscadine
Grapes



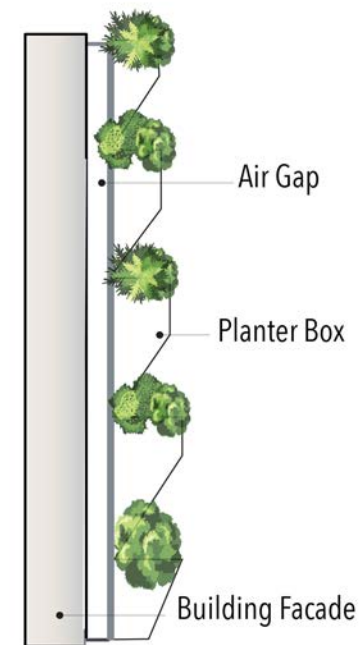
Hardy
Kiwi



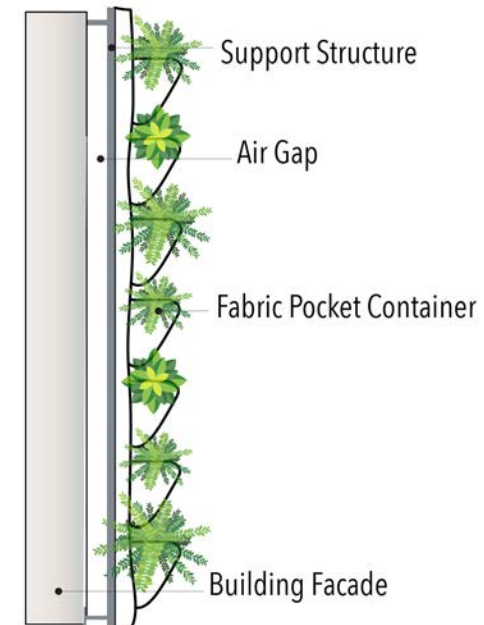
Peppers

Container Based Systems

- Allow for more uniform coverage at greater heights
- Allow for a wider variety of plant use
- Rigid and fabric based systems.



RIGID SYSTEM



FABRIC SYSTEM



Rigid Container System in Pittsburgh, PA



Florafelt Fabric System (Source: www.florafelt.com)

Planting Choices

Vegetables

Bok Choy	
Collard Greens / Chard	
Lettuce	
Radish	
Scallion	
Spinach	

Herbs

Basil	
Chives	
Mint	
Parsley	
Sage	
Thyme	

Crops by season: Southeastern U.S.

Spring Cool	Warm	Fall Cool
Asian Greens	Celery	Asian Greens
Beets	Corn	Brussel Sprouts
Onions	Cucumber	Onions
Carrots	Artichokes	Carrots
Fava Beans	Lettuce	Fava Beans
Kale, Cabbage, Broc- coli	Spinach	Kale, Cabbage, Broc- coli
Leeks	Nightshades	Leeks
Lettuce	Okra	Lettuce
Peas	Parsnips	Peas
Potatoes	Peanuts	Radishes
Radishes	Potatoes	Shallots
Southern Greens	Runner Beans	Southern Greens
Spinach	Snap Peas	Spinach
Swiss Chard	Southern Peas	Swiss Chard
	Sunflowers	
	Sweet Potatoes	

Source:
Wallace, I. (2013) Vegetable Gardening in the Southeast. Timber Press, Portland, OR

Planting + Harvesting Dates for Savannah, GA

First Frost: 11/25
Last Frost: 3/1

Plant	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
Basil												
Beans												
Carrots												
Chives												
Lettuce												
Muscadine Grapes												
Mint												
Peppers												
Radish												
Southern Greens												
Strawber-ries												
Thyme												

 Sow/Transplant Outdoors
 Harvest

Container Sizing

Plant	Soil Depth (in)	Seed Depth (in)	Seed Spacing (in)	Thinning Spacing (in)	Grow Time
Basil	6 - 8	1/2	8 - 10	As needed	40 days
Carrots	8 - 10	1/4	3 seeds/ inch	1 - 2	65-75 days
Chives	3 - 4	1/2	6 - 8	As needed	30 - 60 days
Lettuce (Looseleaf)	6-10	1/4	4 - 6	As needed	50 days
Okra	8 - 10	3/4	6 - 8	As needed	80 days
Peppers	4 - 8	1/2	6 - 8	As needed	50 days
Radishes	4 - 5	1/2	3/4 - 1	As needed	30 - 60 days
Southern Greens	10 - 12	1/4 - 1/2	2	12 - 18	60 - 75 days
Spinach	8 - 10	1/2	4 - 6	As needed	50 - 60 days
Thyme	6 - 8	1/2	6 - 8	As needed	40 - 50 days

Pocket Size	Suitable Plants
4" x 6" 	Basil, Chives and Radish
4" x 10" 	Basil, Chives, Lettuce and Radish
6" x 6" 	Basil, Chives, Lettuce, Peppers, Radish and Thyme
6" x 10" 	Basil, Carrots, Chives, Lettuce, Peppers, Radish and Thyme
8" x 10" 	Basil, Carrots, Chives, Lettuce, Peppers, Radish, Spinach and Thyme
10" x 10" 	Basil, Carrots, Chives, Lettuce, Peppers, Radish, Spinach and Thyme
12" x 10" 	Basil, Carrots, Chives, Lettuce, Peppers, Radish, Spinach, Southern Greens and Thyme



Benefits

Of Green facade systems

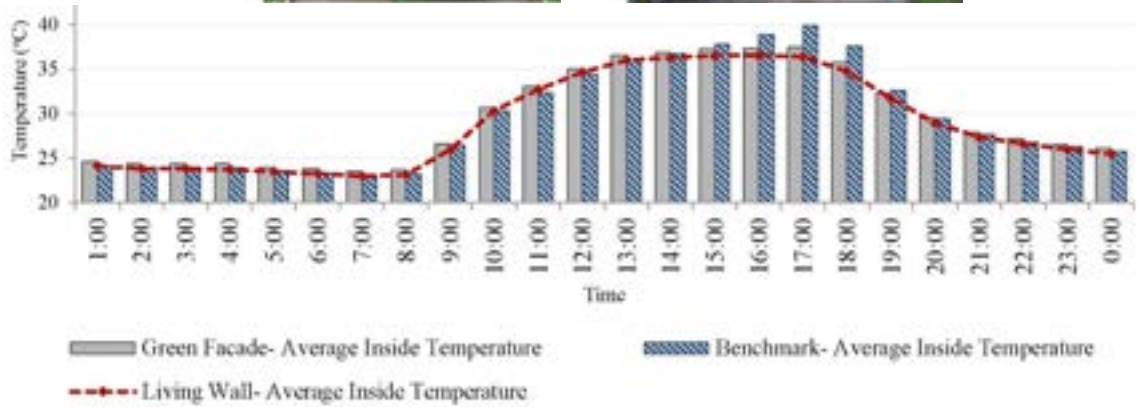
Thermal Benefits

Green facade systems use three fundamental mechanisms to act as passive conditioning systems: (Perez, 2015)

- 1. Shadow produced by the vegetation
- 2. Thermal insulation provided by the vegetation and substrate
- 3. Evaporative cooling that occurs by evapo-transpiration from the plants and the substrate

CASE STUDIES

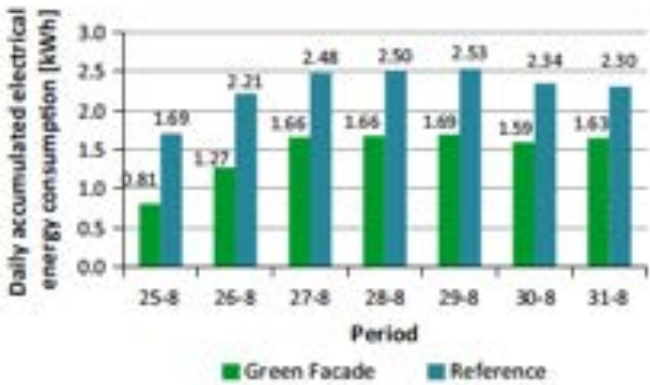
Safikhani et al (2014)



A field experiment by Safikhani et al in Malaysia found an average decrease in indoor air temperature of 3°C and 4°C of Container Based and Ground Based Indirect Facade systems respectively when compared to a bare, control wall.

Perez et al (2015)

Perez et al conducted a field experiment in Spain with measured energy use data. Perez et al found reductions in surface temperature from 15-16.4°C depending on the wall orientation and an overall reduction in energy use of 34% compared to the reference building over a week in August.



Case Study Summary

System Type	Orientation	Energy Savings (Cooling)	Temperature Decrease (Indoors)	Temperature Decrease (Outside Surface)	Location	Article
Container-Based: Rigid		43%	4.5°C		Mediterranean	Ottelé et al (2011)
Container-Based: Fabric		43%	4.5°C			
Ground-Based: Indirect		43%	4°C			
Container-Based: Fabric	West	--	3°C		Malaysia	Safikhani, T.. et al. (2014)
Ground-Based: Indirect	West	--	4°C			
Ground-Based: Direct	East + West	68%			Brazil	Alexandria, E. & Jones, P. (2008)
Ground-Based: Direct	East + West	66%			Hong Kong	
Ground-Based: Direct	East + West	52%			Montreal	
Ground-Based: Direct	East + West	43%			Athens	
Ground-Based: Direct	East + West	37%			Beijing	
Ground-Based: Direct	East + West	37%			Riyadh	
Ground-Based: Direct	East + West	35%			Mumbai	
Container-Based				10.03°C (Spring)	Singapore	Wong, N. (2010)
Ground-Based: Indirect				3.33°C (Spring)		
Container-Based: Fabric				6.58°C (Spring)		
Ground Based: Direct	North-West			1.2°C	Netherlands	Perini, K. (2011)
Ground Based: Indirect	North-East			2.7°C		
Container-Based	West			5°C		
Container-Based		7.30%			Kelowna, Canada	Feng, H. and Hewage, K. (2014)
Ground Based: Direct			11°C	13°C	Tokyo	Hoyano, A. (1988)
Ground Based: Indirect	East	34%		15°C	Puigverd de Lleida, Spain	Perez, G. et al (2017)
Ground Based: Indirect	South	34%		16°C		
Ground Based: Indirect	West	34%		16.4°C		

Social Benefits

- + Access To Nature
- + Increased Biodiversity
- + Food Production



Benefits of Biodiversity (WWF)
Source: http://www.wwf.eu/what_we_do/biodiversity/



Container System growing edible plants in Los Angeles, California
Source: <http://www.goodearthplants.com/project/pizzeria-mozza-hollywood/>

- **Green Facade Systems** provide access to fresh produce while taking up less square footage than a traditional garden
- **Environmental** benefits resulting from the saving and recycling of resources and reduced food miles.
- **Social** advantages from improving community food security, and education opportunities by linking consumers to food production.



Field Test

Savannah, GA

E. 34 Greenhouse: Savannah, GA



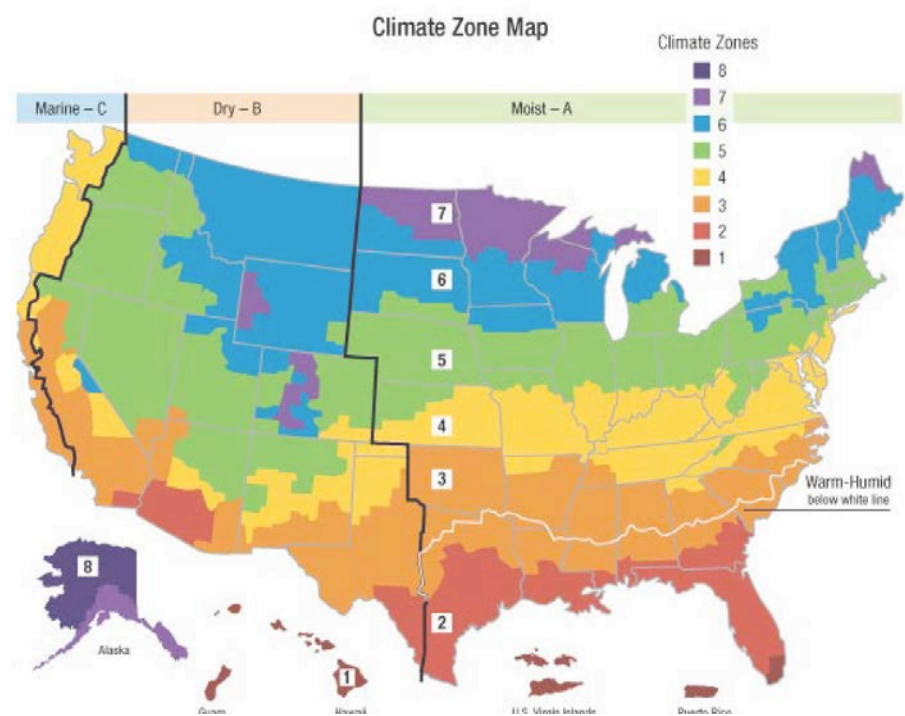
Southwest Perspective of the Field Test Building: E. 34 Green

Climate Analysis

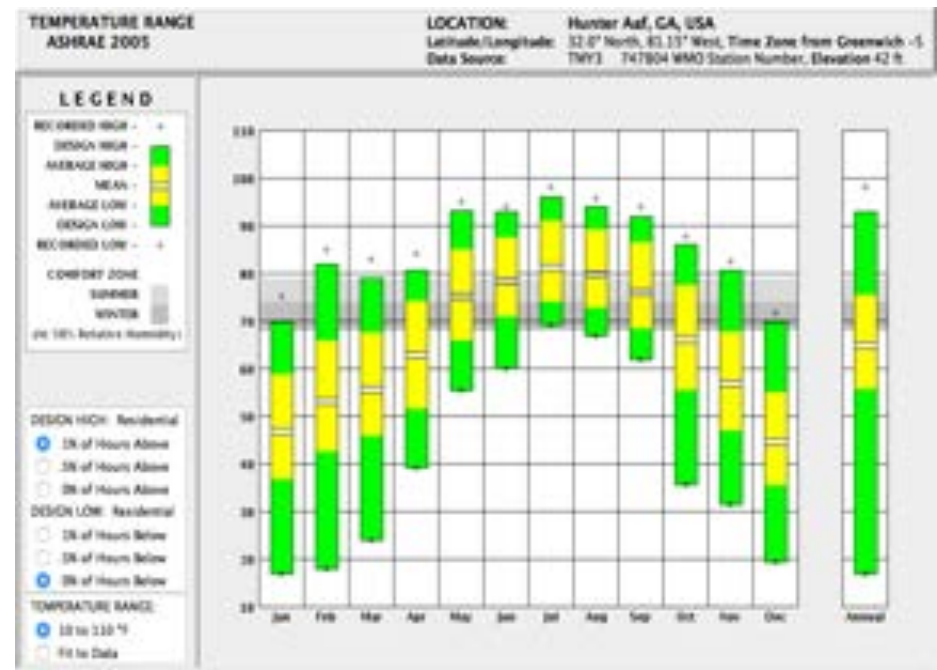
Savannah, GA is located in **Climate Zone 2A**

It is a warm and humid climate with average highs above 90 °F in the summer. In the winter temperatures rarely reach below 20 °F.

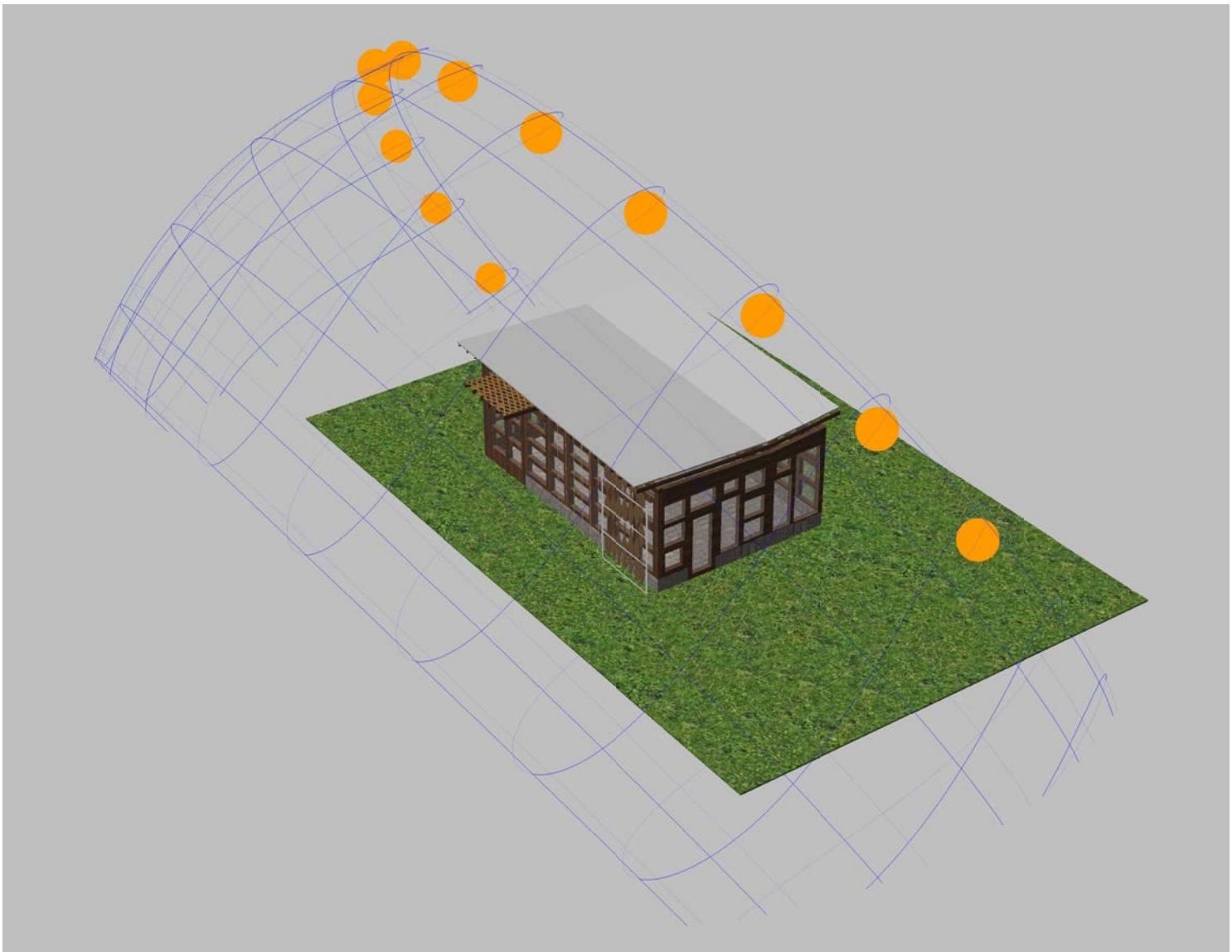
Savannah is a cooling-dominated climate with 1,840 Heating degree days (HDD) and **2,636 Cooling Degree Days** (CDD). (Bizee.com)



International Energy Conservation Code (IECC) Map.
Source: <https://energycode.pnl.gov/EnergyCodeReqs/>



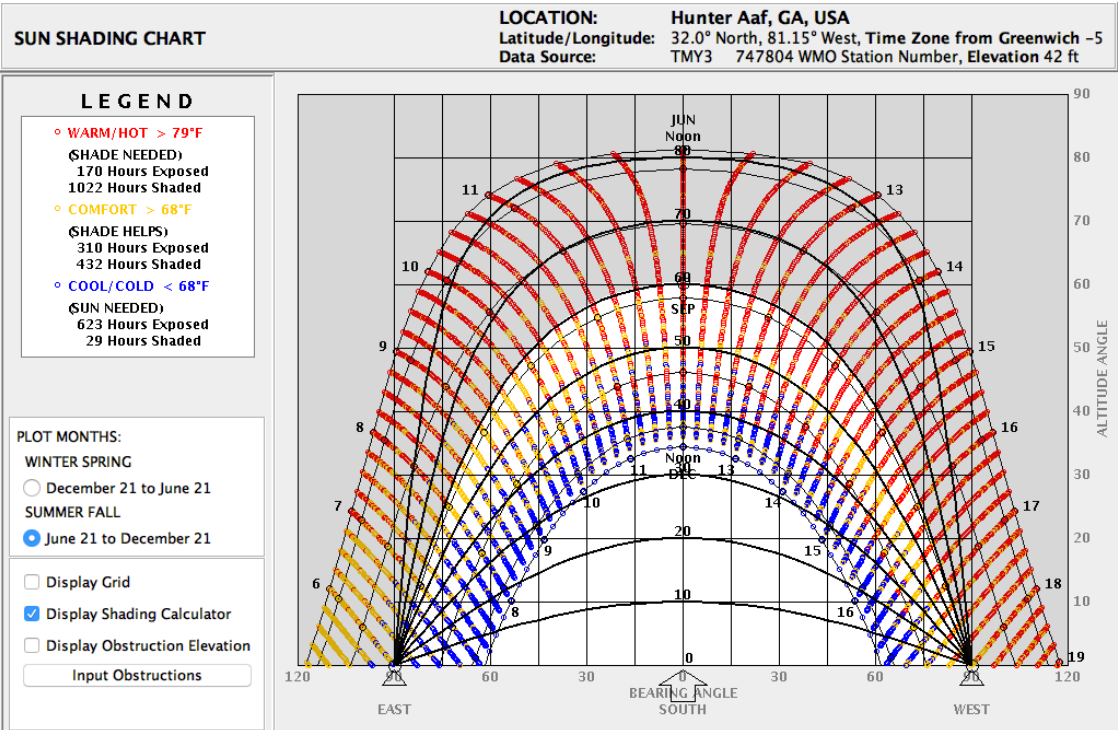
Average Temperature Range for Savannah, GA (Climate Consultant)



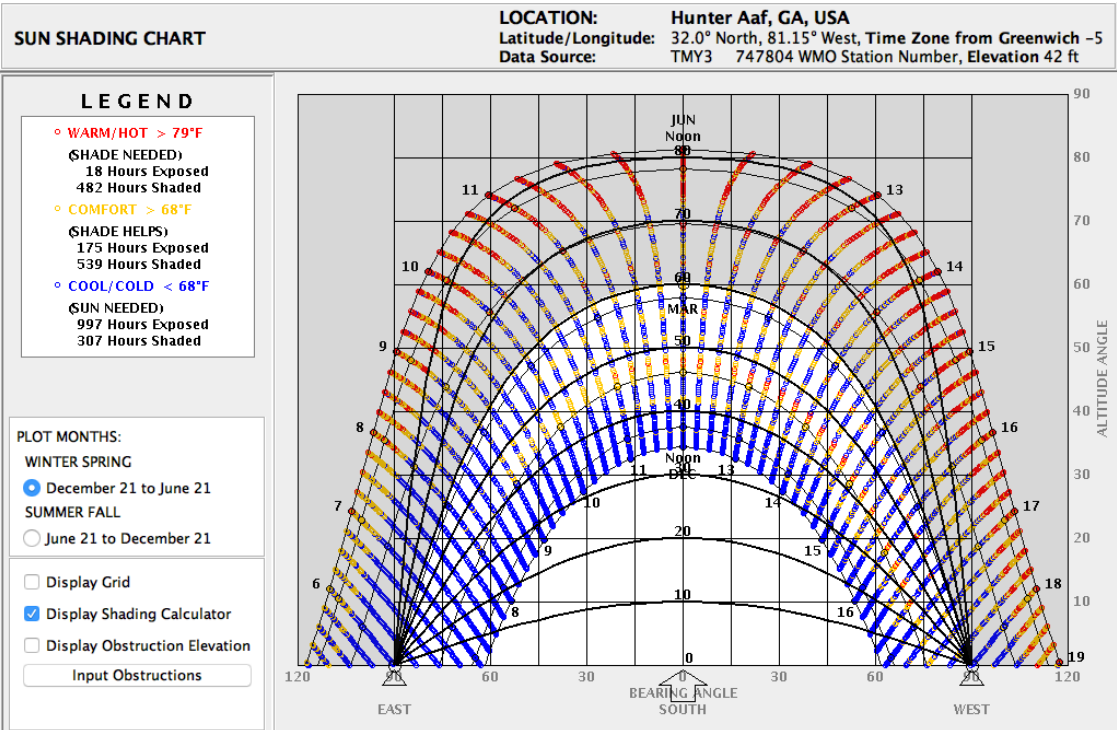
Sun Path Diagram from 8 AM to 8 PM on July 22nd

Shading Charts | Goal

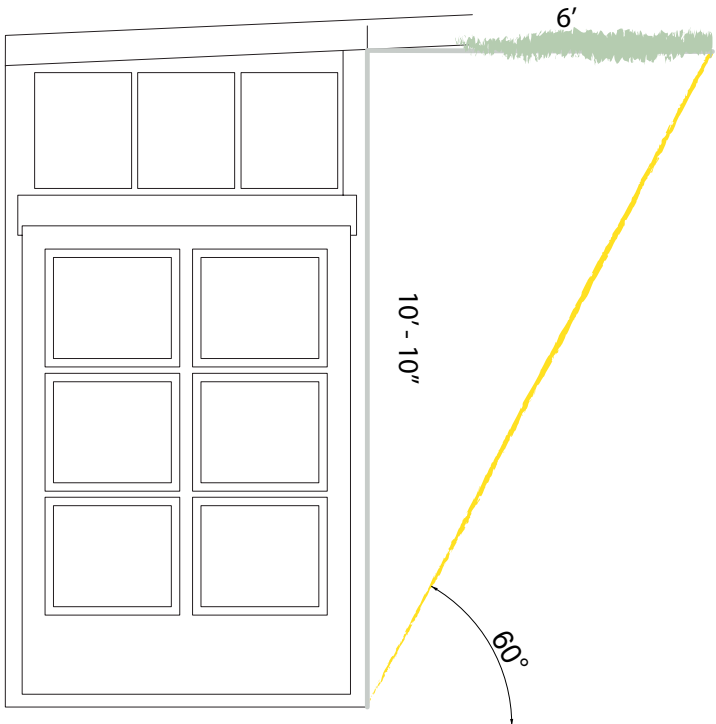
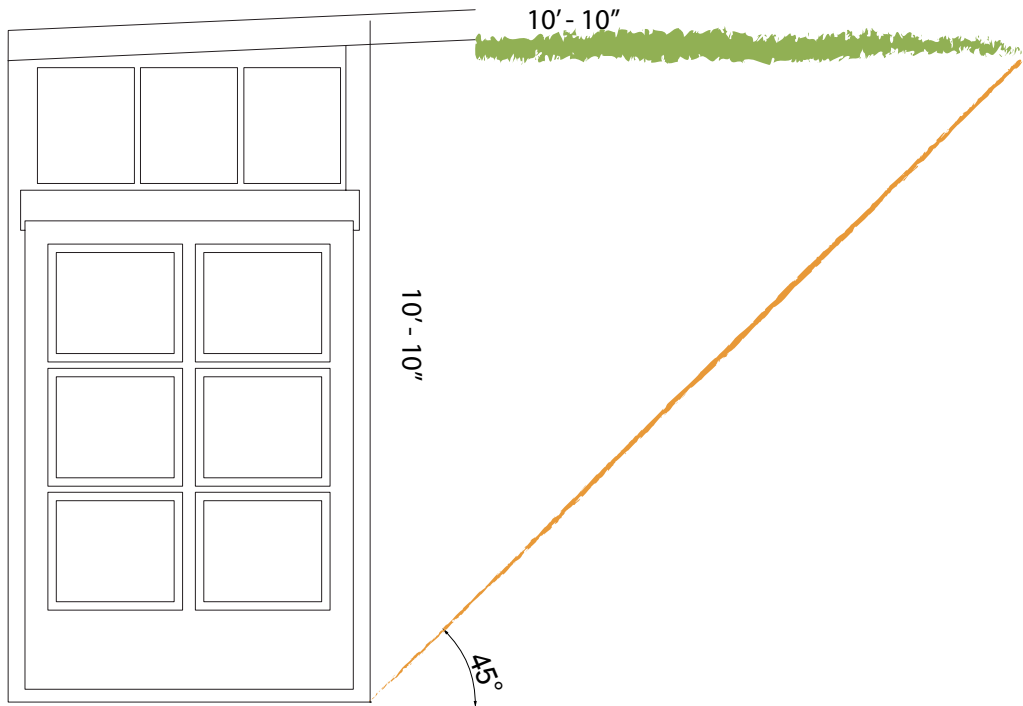
Horizontal Overhangs



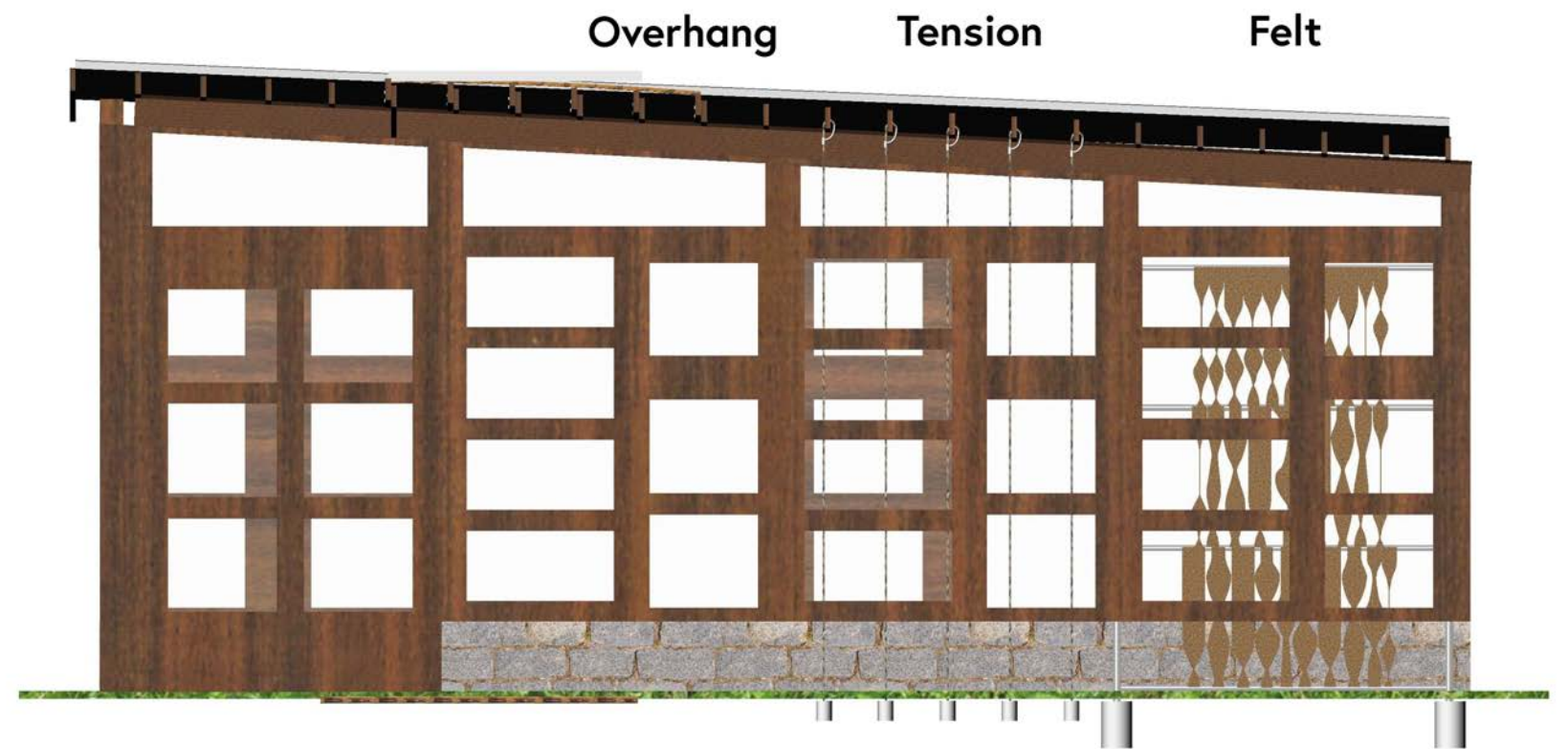
June 21 - Dec 21 Chart



Dec 21 - June 21 Chart



Chosen Facade Systems



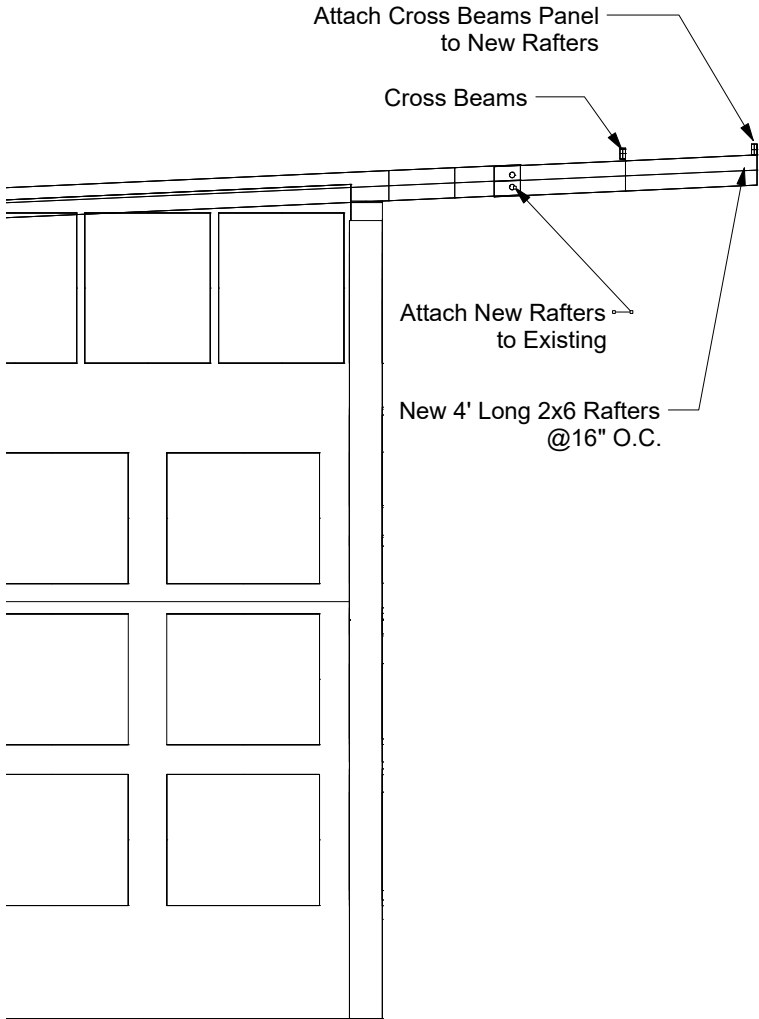
Overhang System

Testing Plant Used:

English Ivy

Edible Plant Implemented

Muscadine Grapes



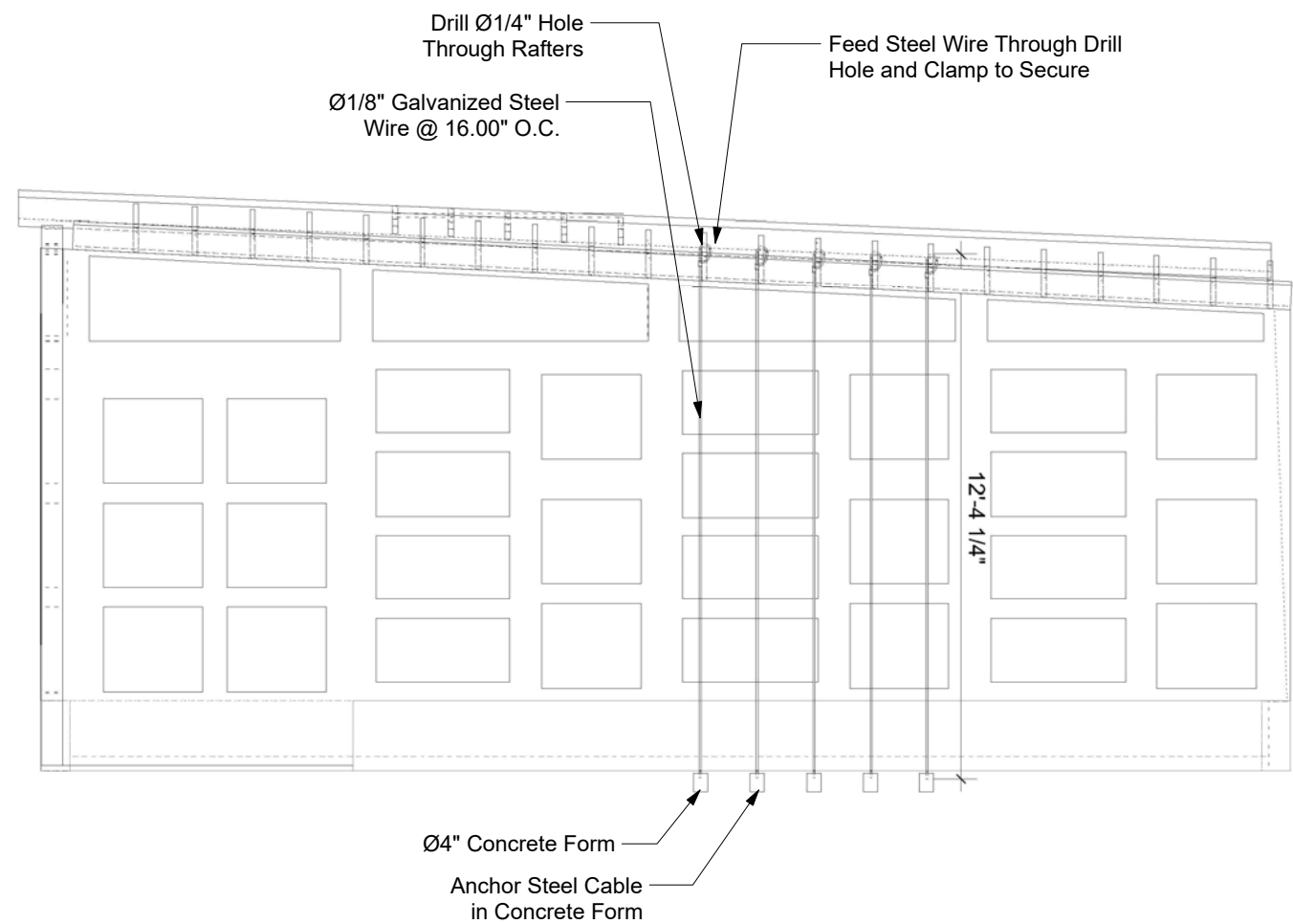
Overhang System Construction Drawings

Installation



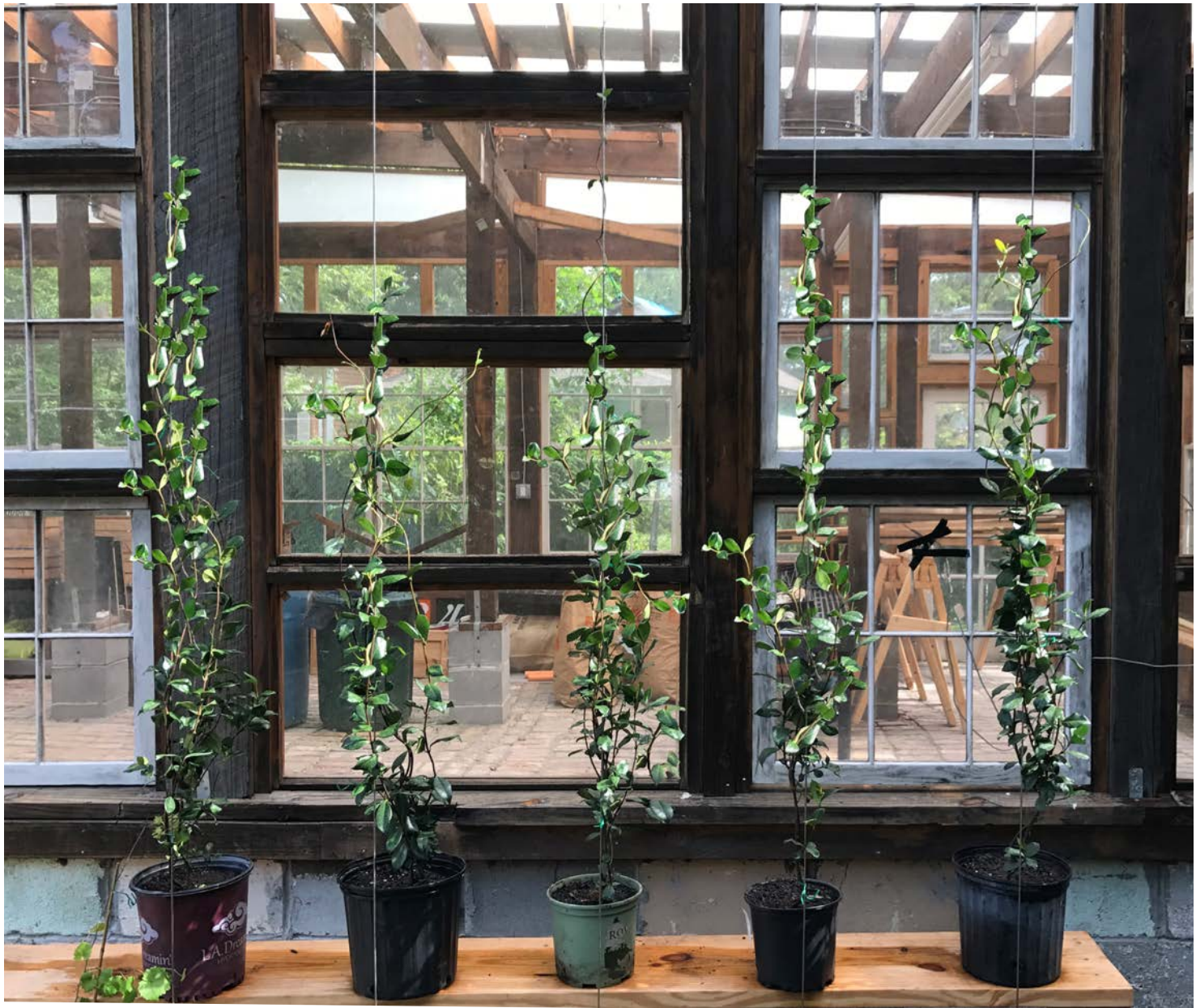
System Components	
Component	Quantity
4' Long 2x6 Rafters	5
Bolts/Screws	10
1x6 Cross Beams	2

Tension System



Tension System Construction Drawings

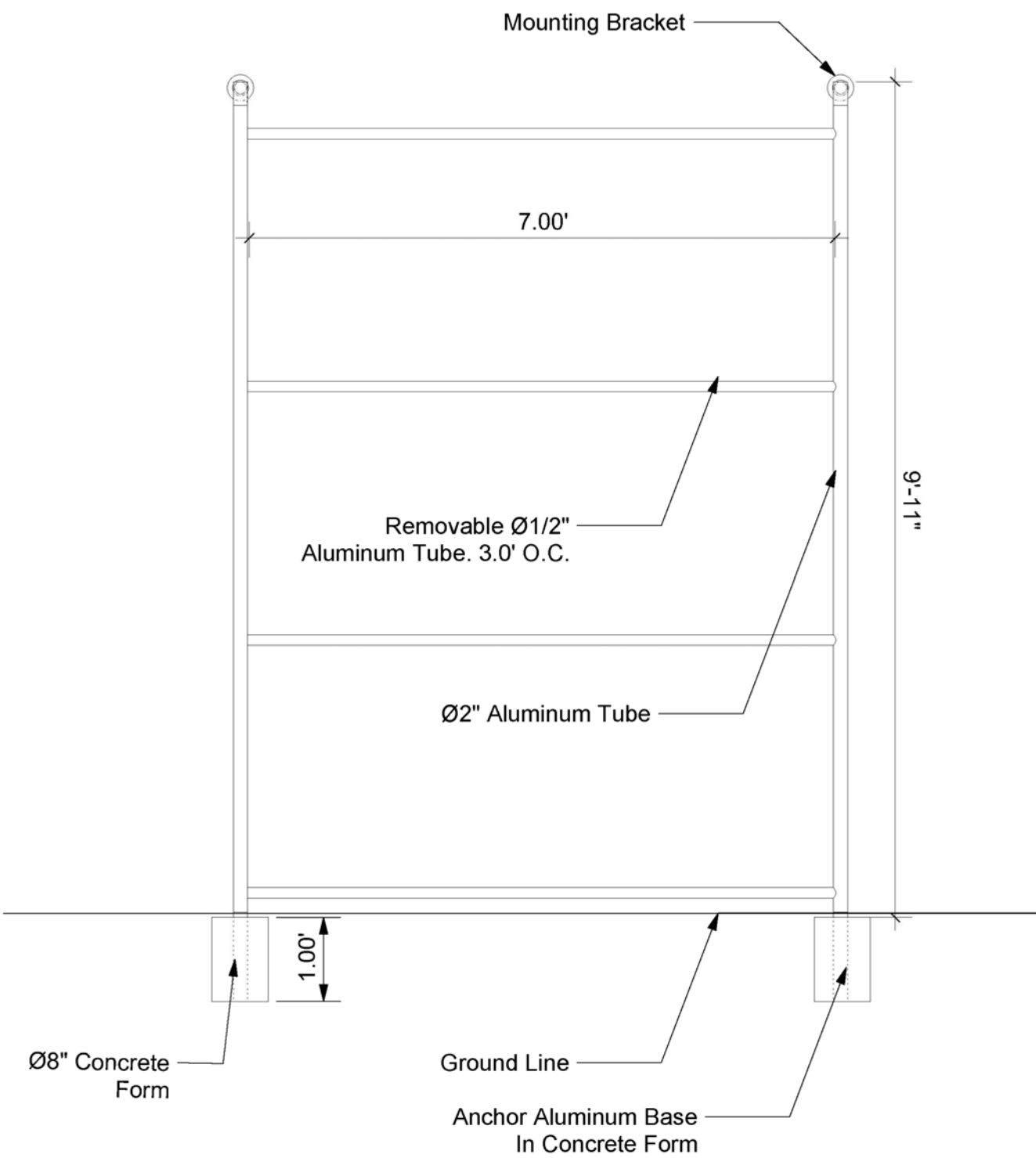
System Components	
Component	Quantity
1/8" Steel Wire (13')	5
Cable Clamp Set	5
Concrete Form	5



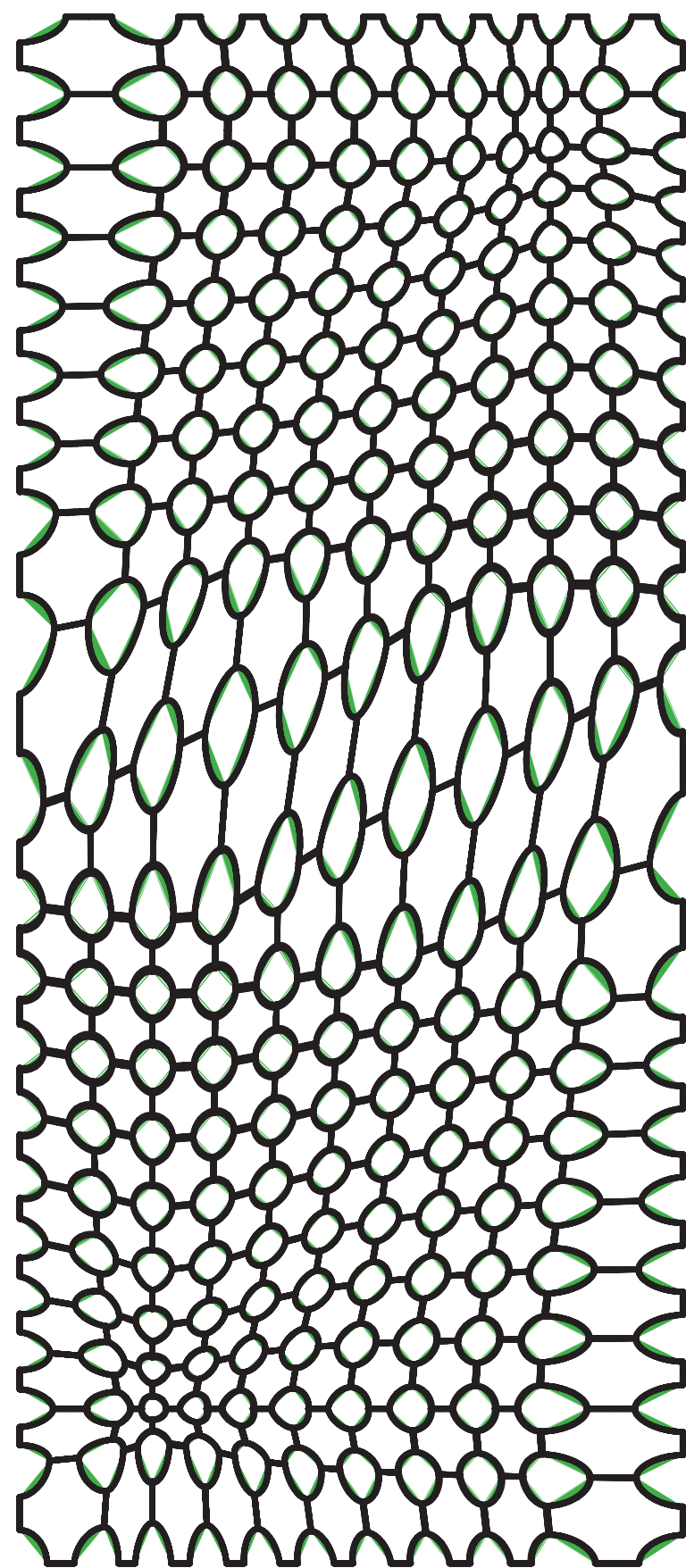
Felt System



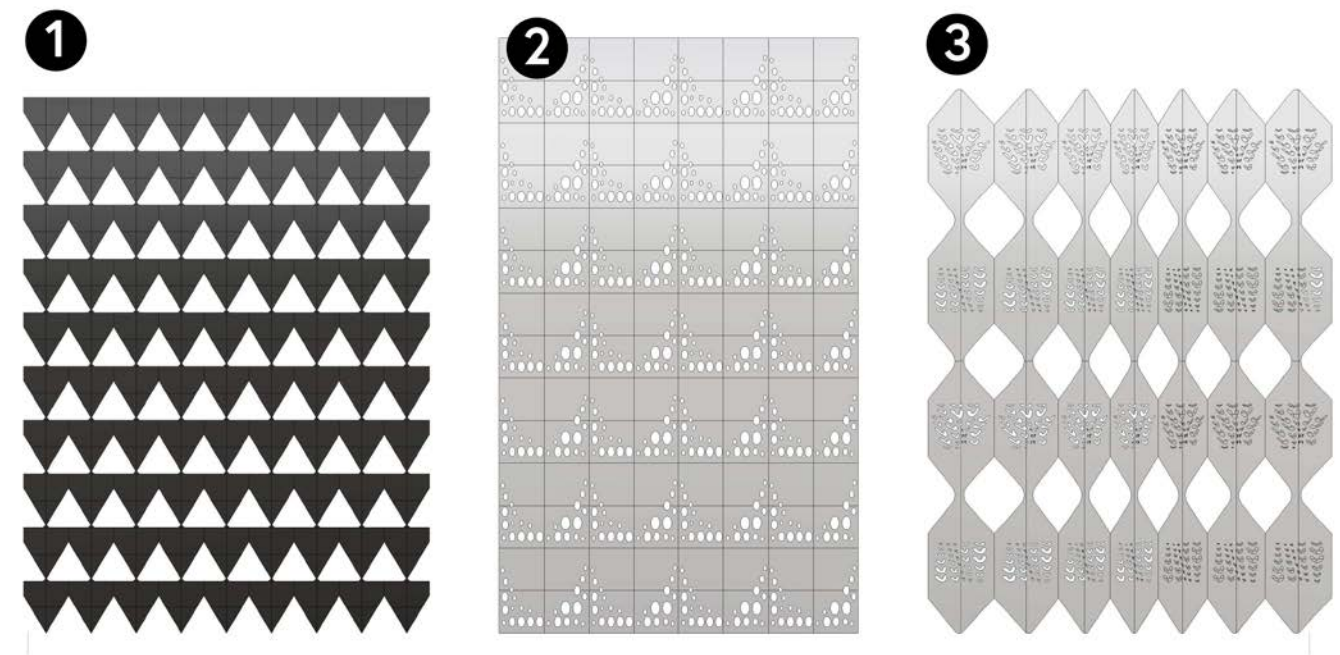
Support Structure



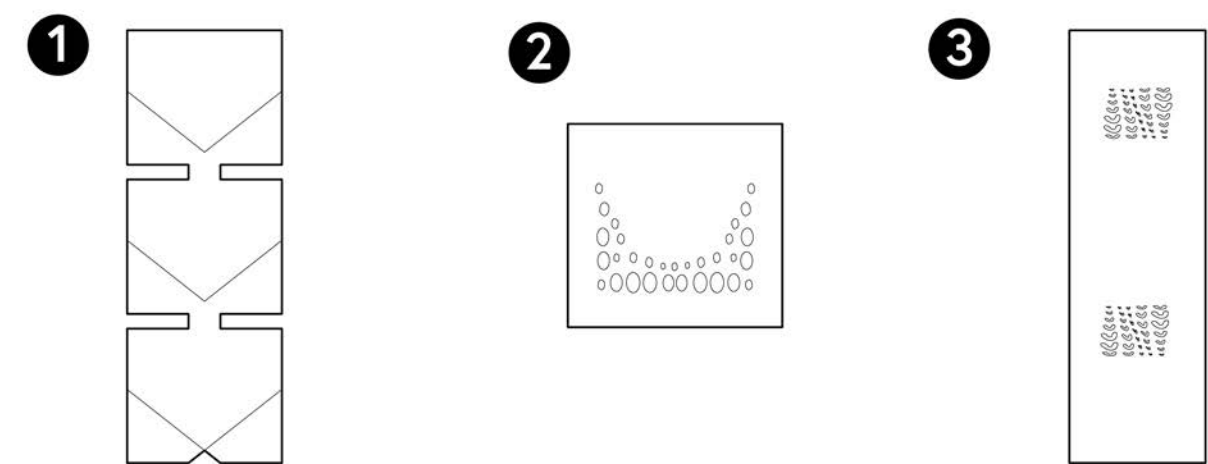
Felt System Design process



Wall Prototypes



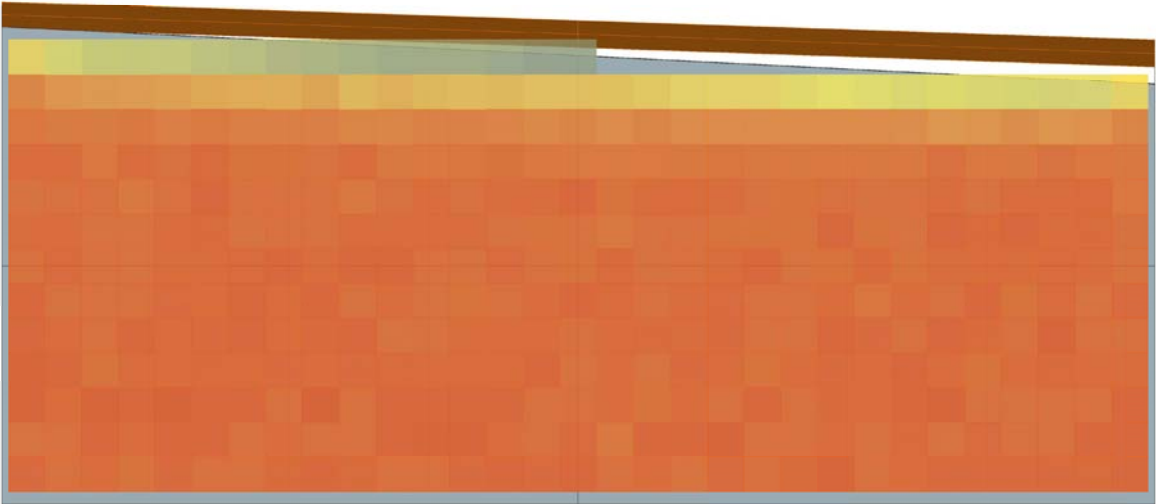
Laser Cut Pattern



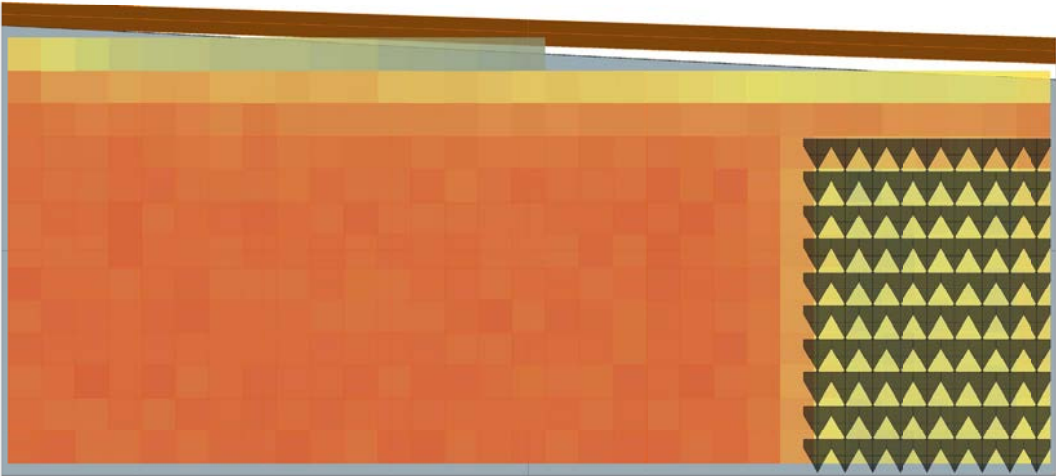
Original Prototypes: Spring 2017 | Ecologics

Seasonal Radiation Analysis

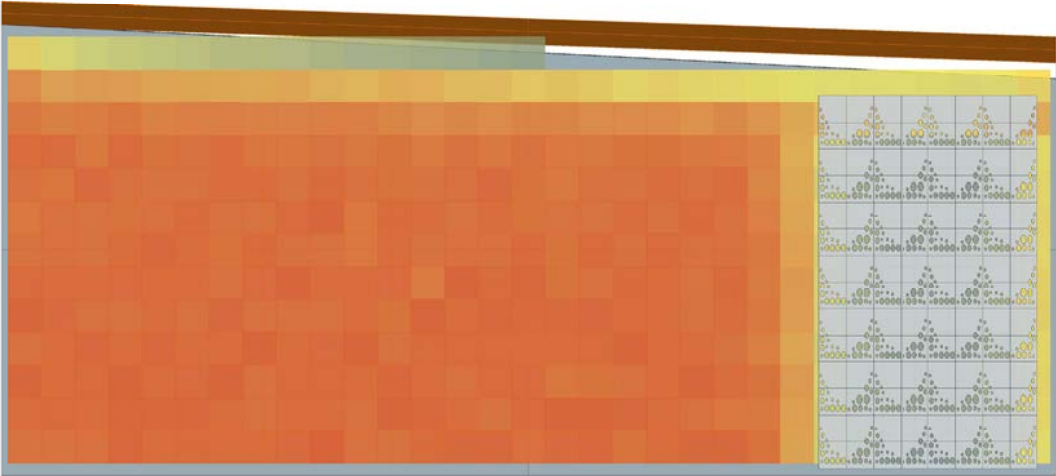
0 kWh/m²



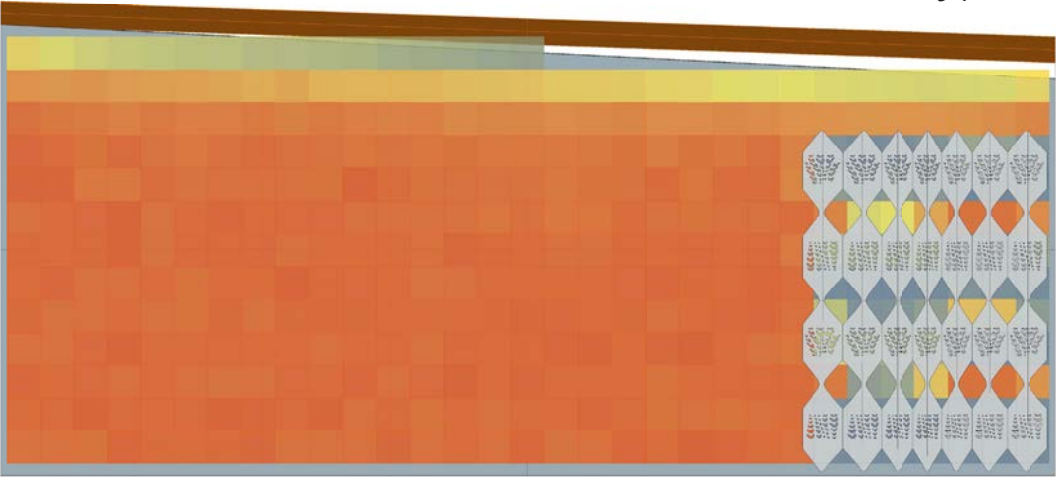
350 kWh/m²



Prototype 1

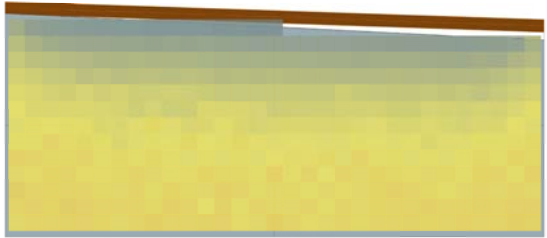
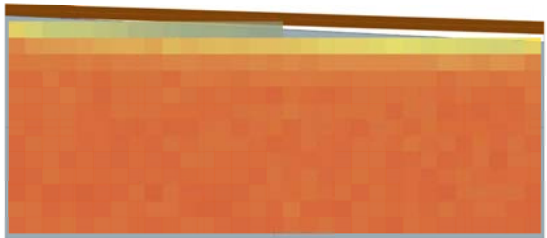
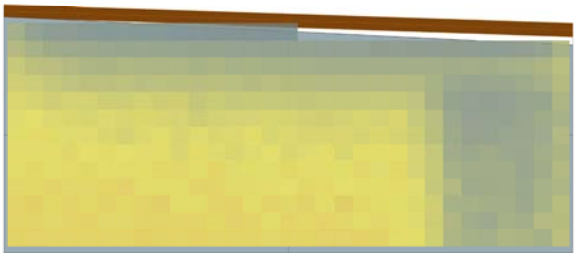
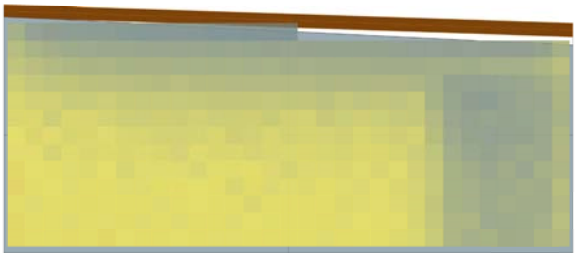
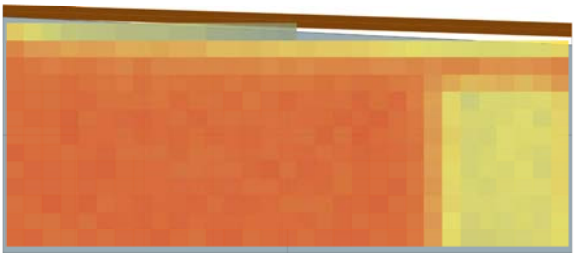
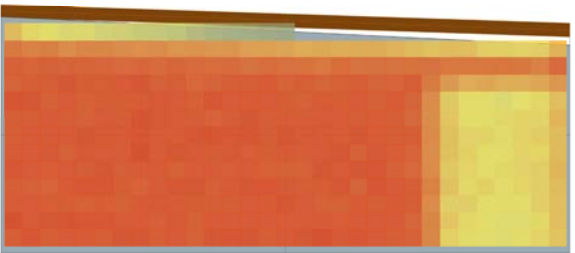
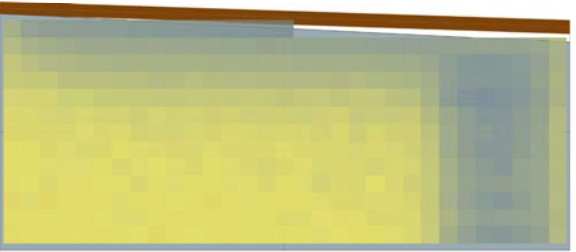
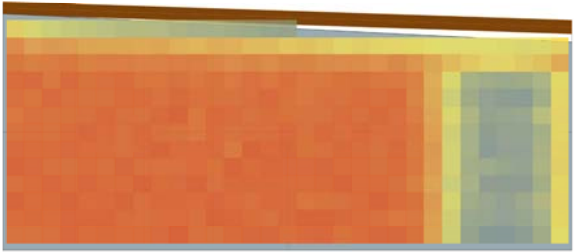
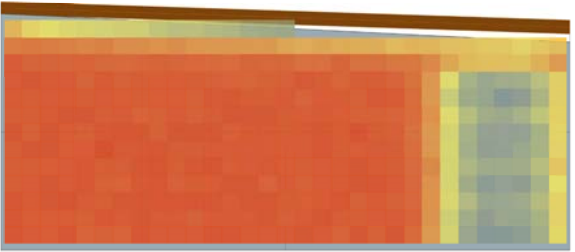
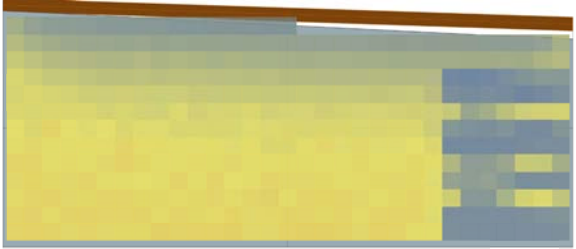
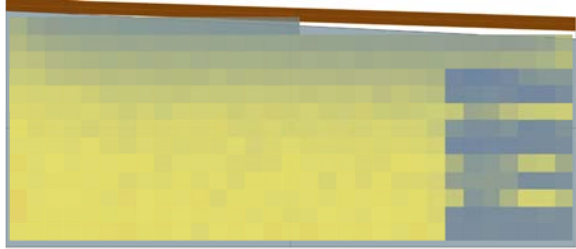
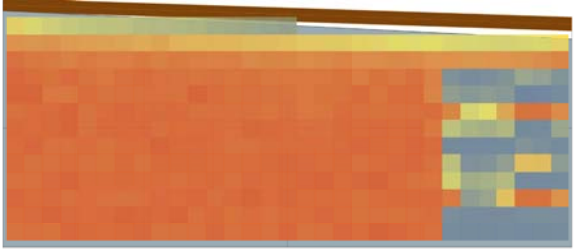
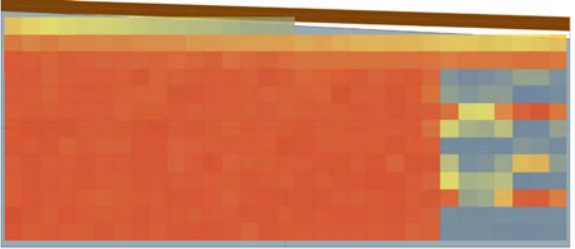


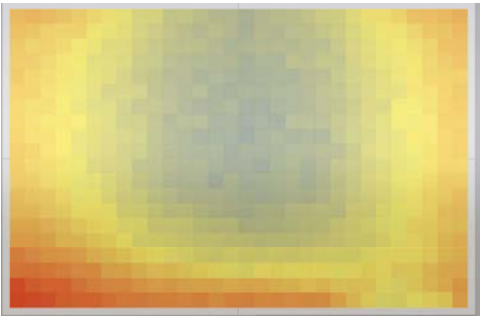
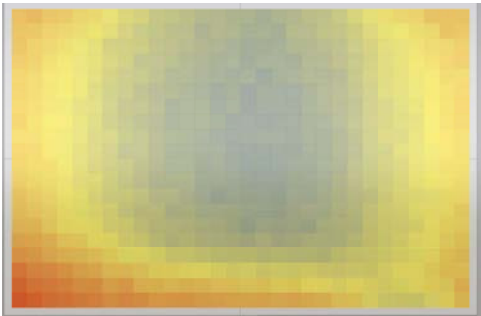
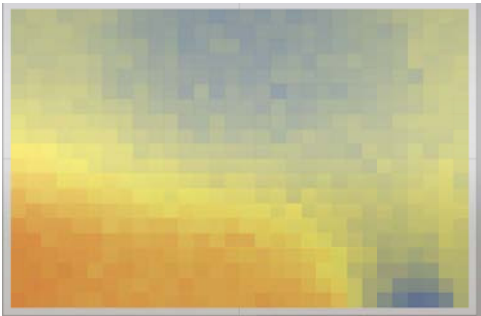
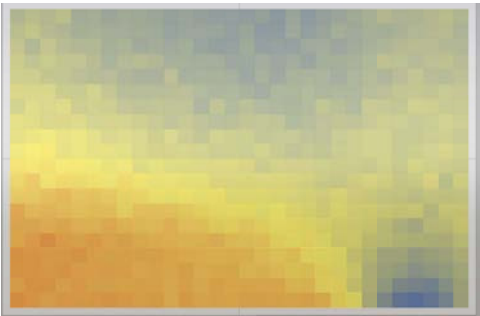
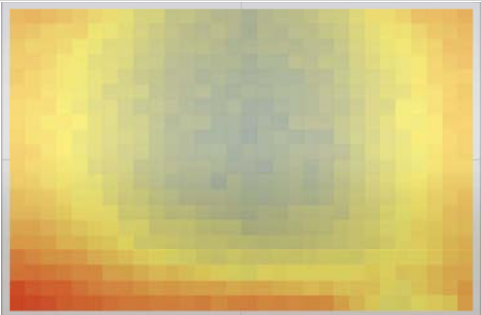
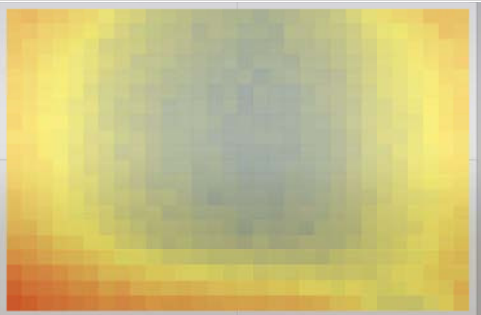
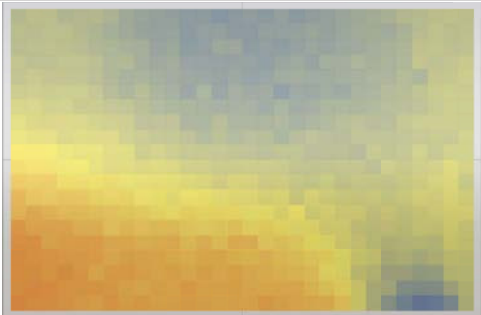
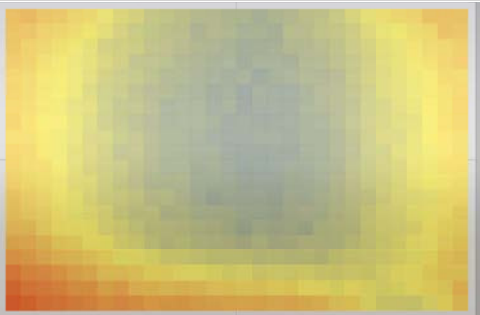
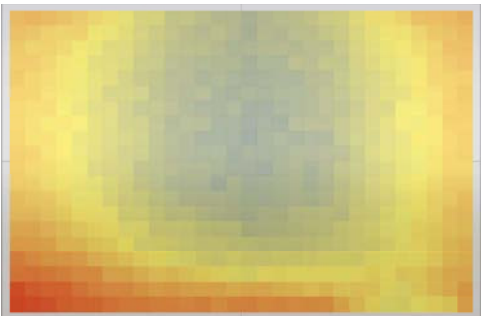
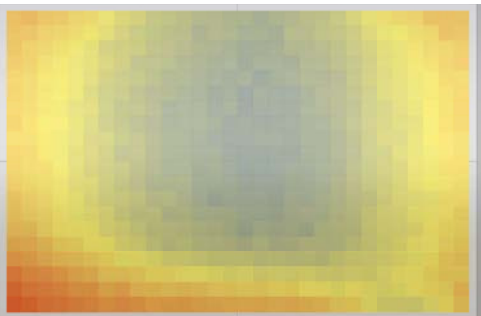
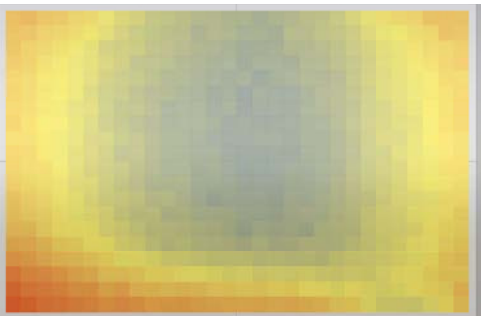
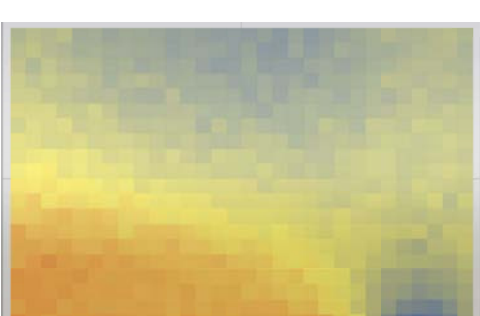
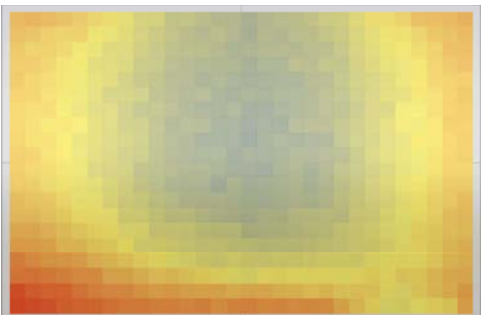
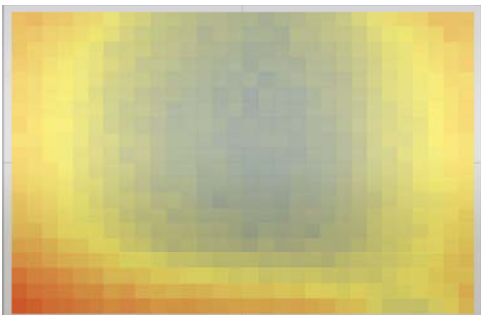
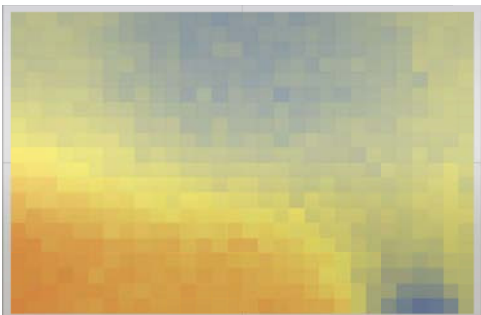
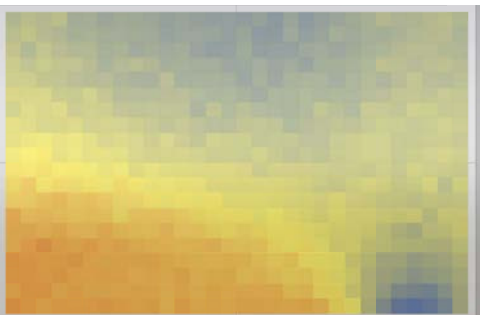
Prototype 2



Prototype 3

Seasonal Solar Analysis | South Facade

	SPRING	SUMMER	FALL	WINTER
BASE-LINE				
WALL 1				
WALL 2				
WALL 3				

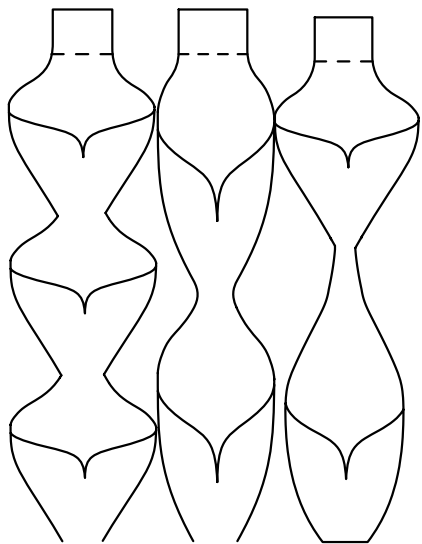
	SPRING	SUMMER	FALL	WINTER
BASE-LINE				
WALL 1				
WALL 2				
WALL 3				

SUMMARY OF RESULTS

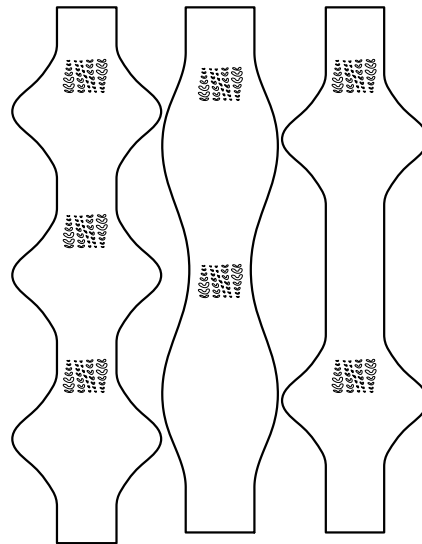
	Radiation Intensity (kWh/m²)				
Simulation	Spring	Summer	Fall	Winter	Total
South Wall (Base-line)	143.26	150.17	295.44	319.49	908.36
Interior (Baseline)	184.8	175.2	177.95	180.79	718.74
Wall 1 South Wall	134.55	128.99	268.66	292.47	824.67
(+/-) Baseline	-8.71	-21.18	-26.78	-27.02	-83.69
Wall 1 Interior	180.33	170.49	166.94	168.93	686.69
(+/-) Baseline	-4.47	-4.71	-11.01	-11.86	-32.05
Wall 2 South Wall	131.32	125.67	254.64	275.19	786.82
(+/-) Baseline	-11.94	-24.5	-40.8	-44.3	-121.54
Wall 2 Interior	179.02	169.55	163.21	164.62	676.4
(+/-) Baseline	-5.78	-5.65	-14.74	-16.17	-42.34
Wall 3 South Wall	130.55	124.85	255.5	276.42	787.32
(+/-) Baseline	-12.71	-25.32	-39.94	-43.07	-121.04
Wall 3 Interior	178.92	169.81	164.44	166.22	679.39
(+/-) Baseline	-5.88	-5.39	-13.51	-14.57	-39.35

Wall prototype 3 shows best performance for both shading in summer/spring, and allowing light into the interior space in fall/winter

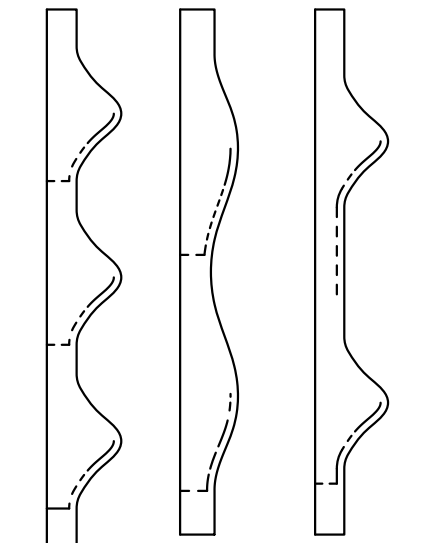
CHARACTERISTIC



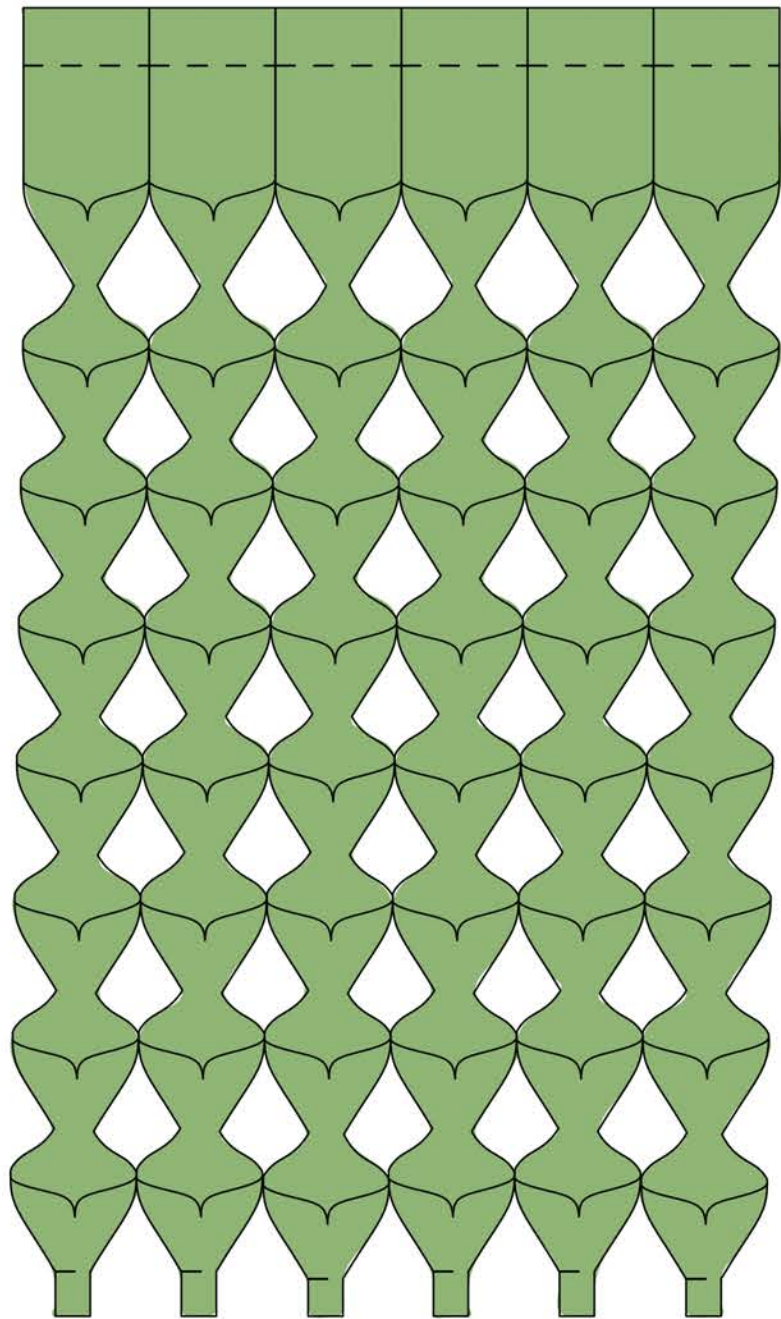
PATTERN



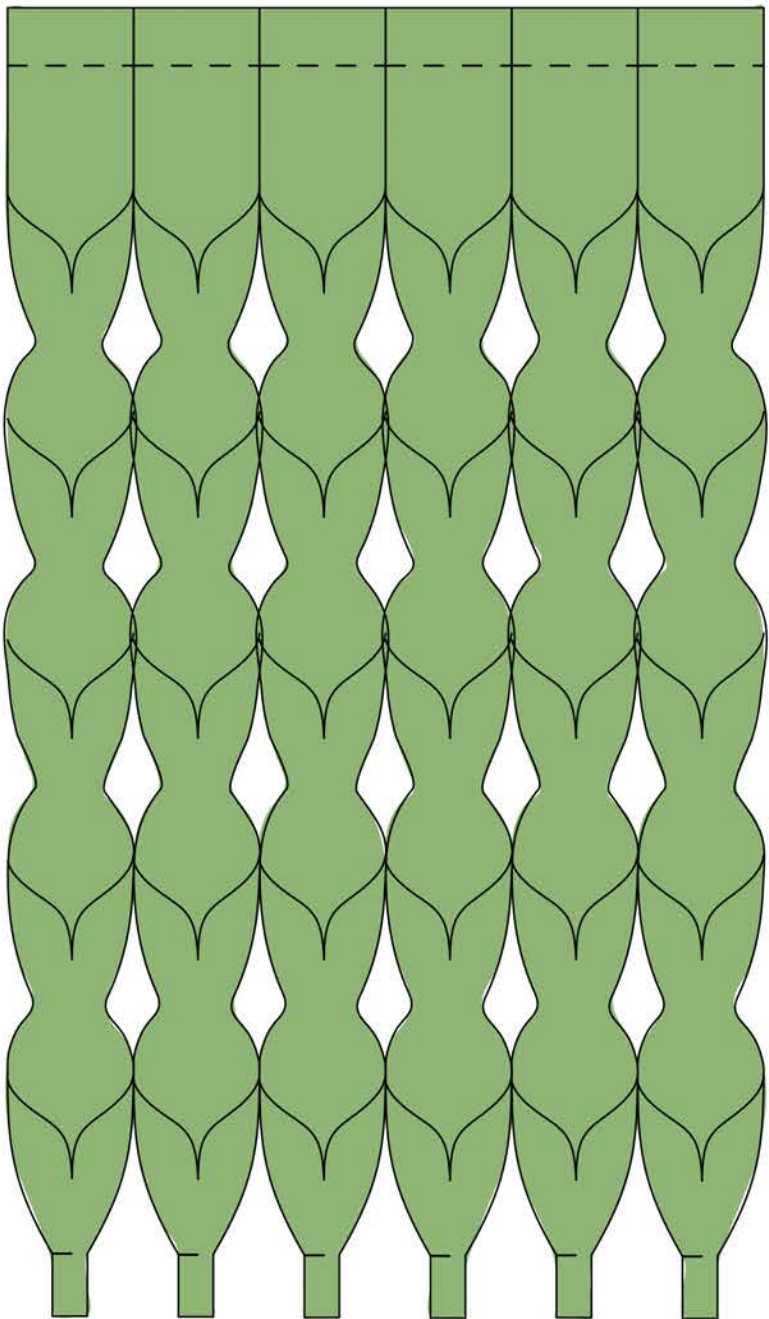
CONSTRUCTION



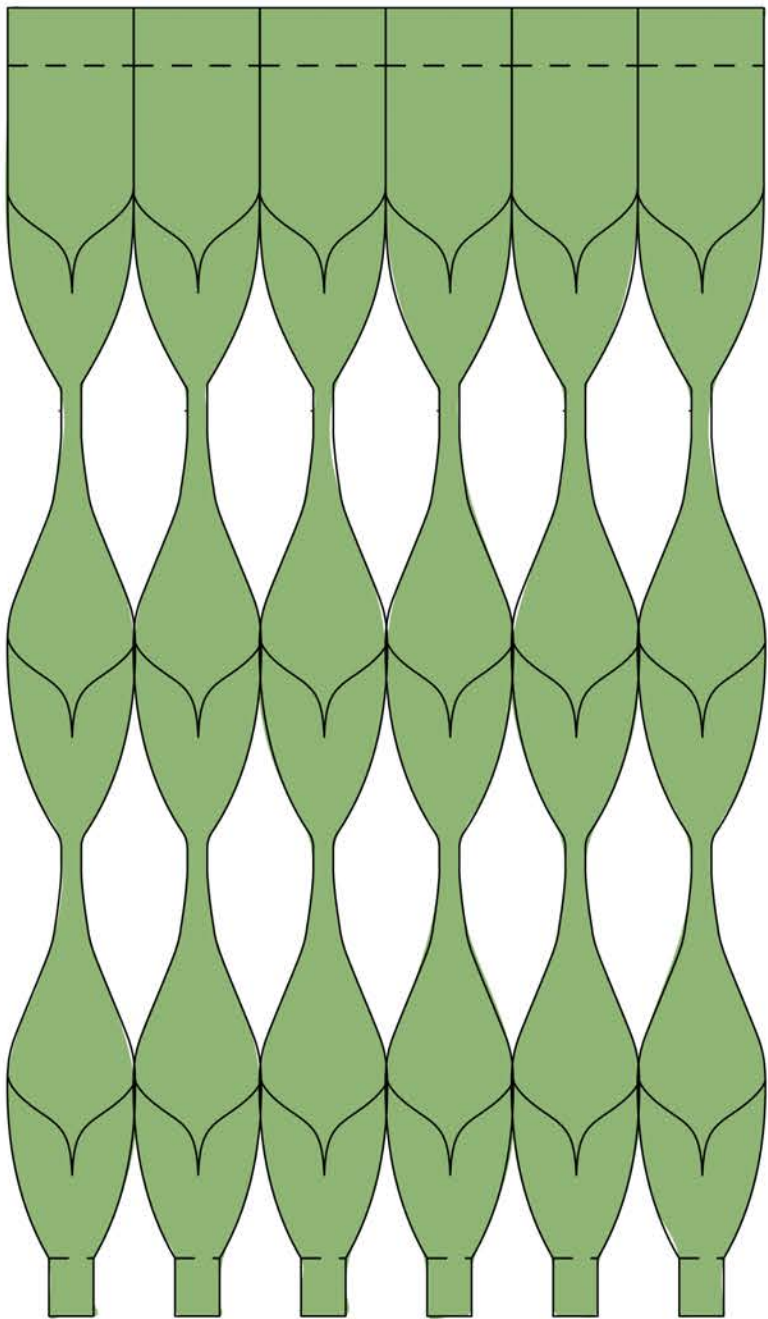
UNIFORM PATTERNS



1 % OPEN: 26
% OPAQUE: 74

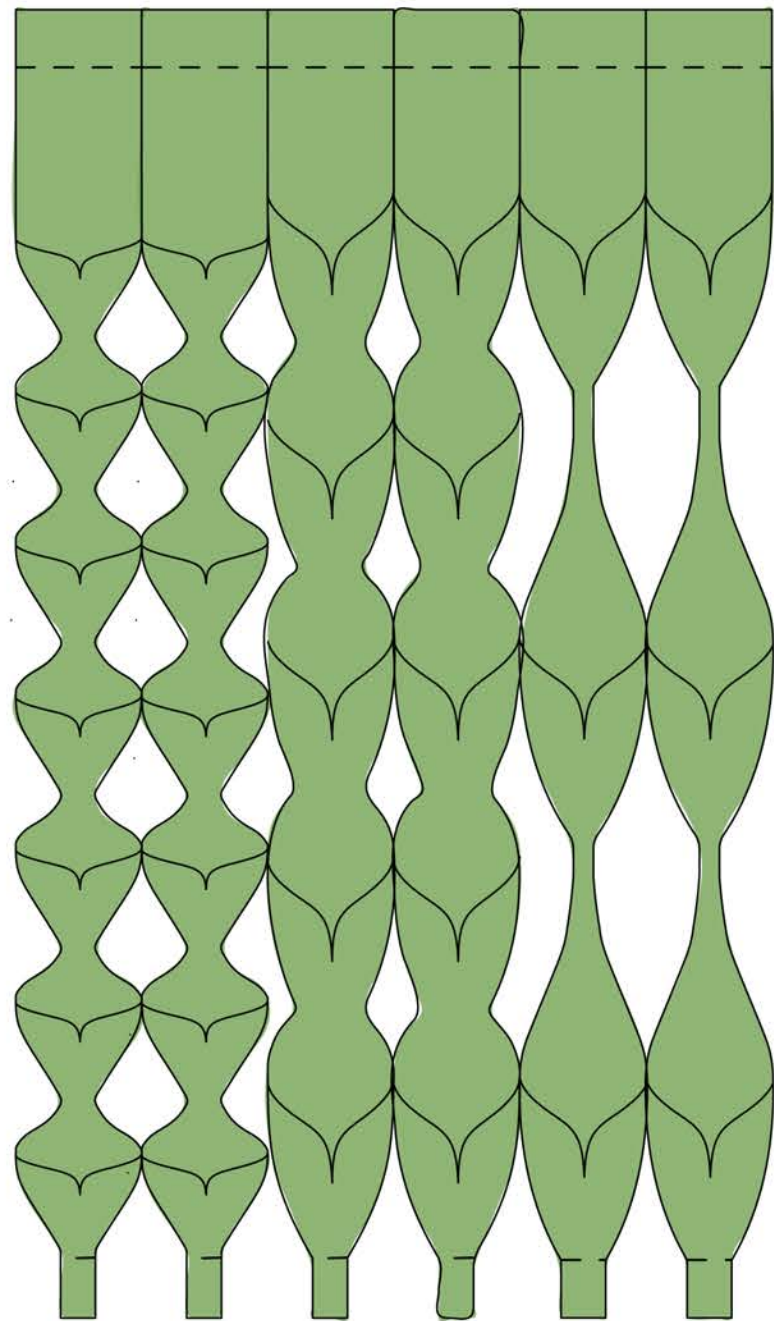


2 % OPEN: 16
% OPAQUE: 84

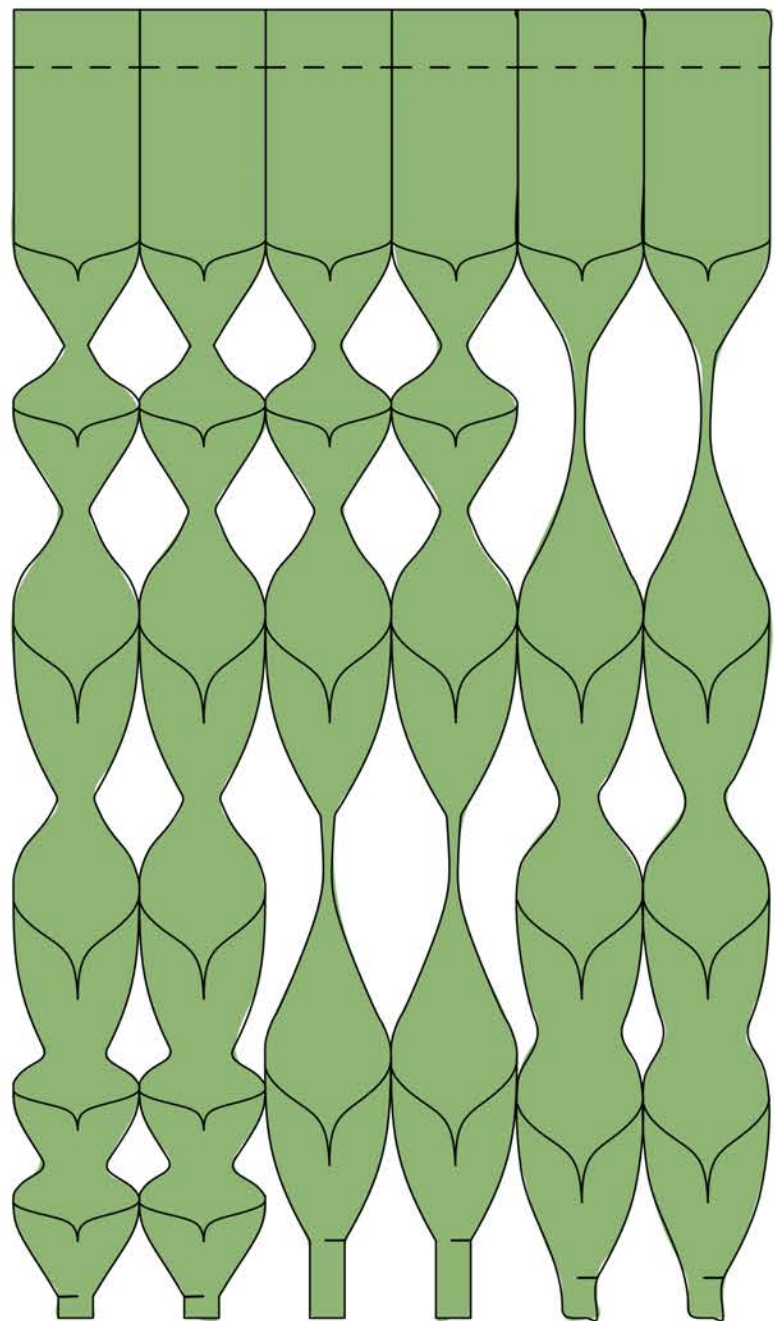


3 % OPEN: 33
% OPAQUE: 67

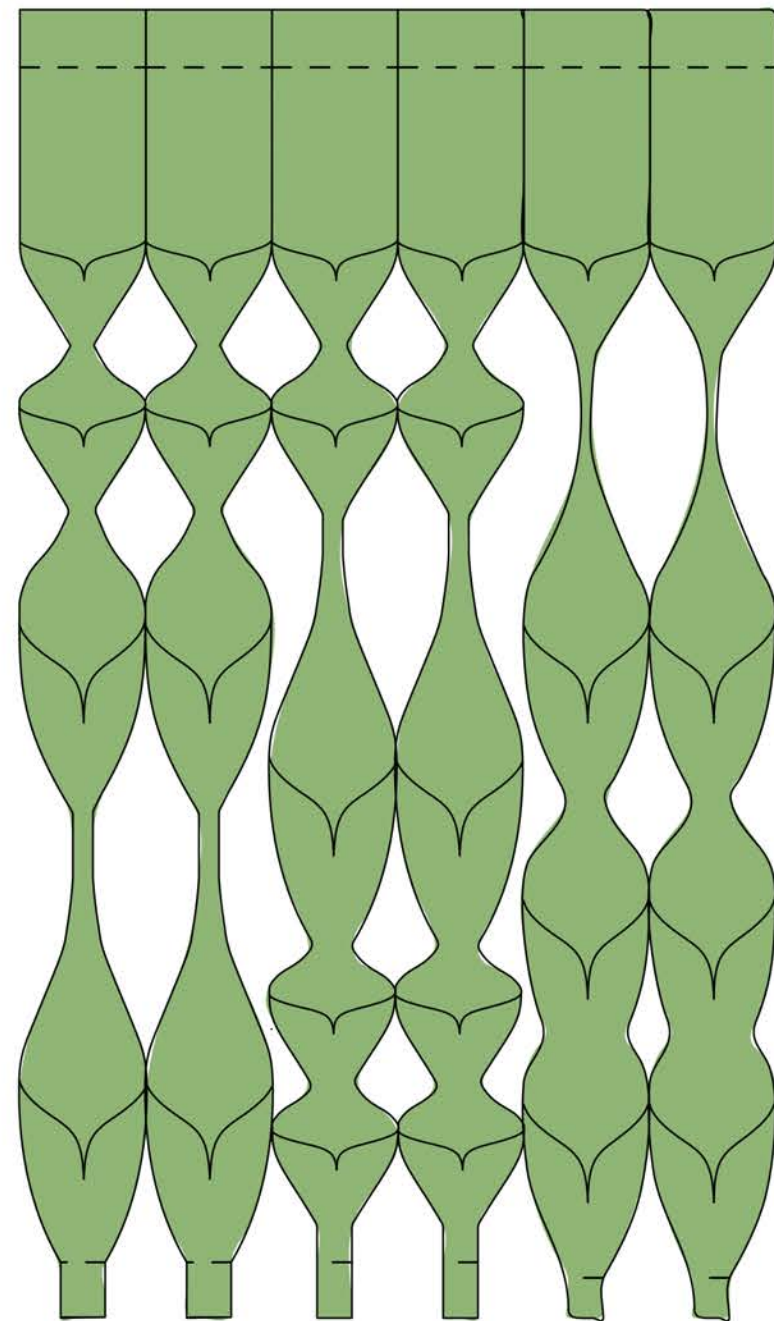
VARIATIONAL PATTERNS



4 % OPEN: 26
% OPAQUE: 74

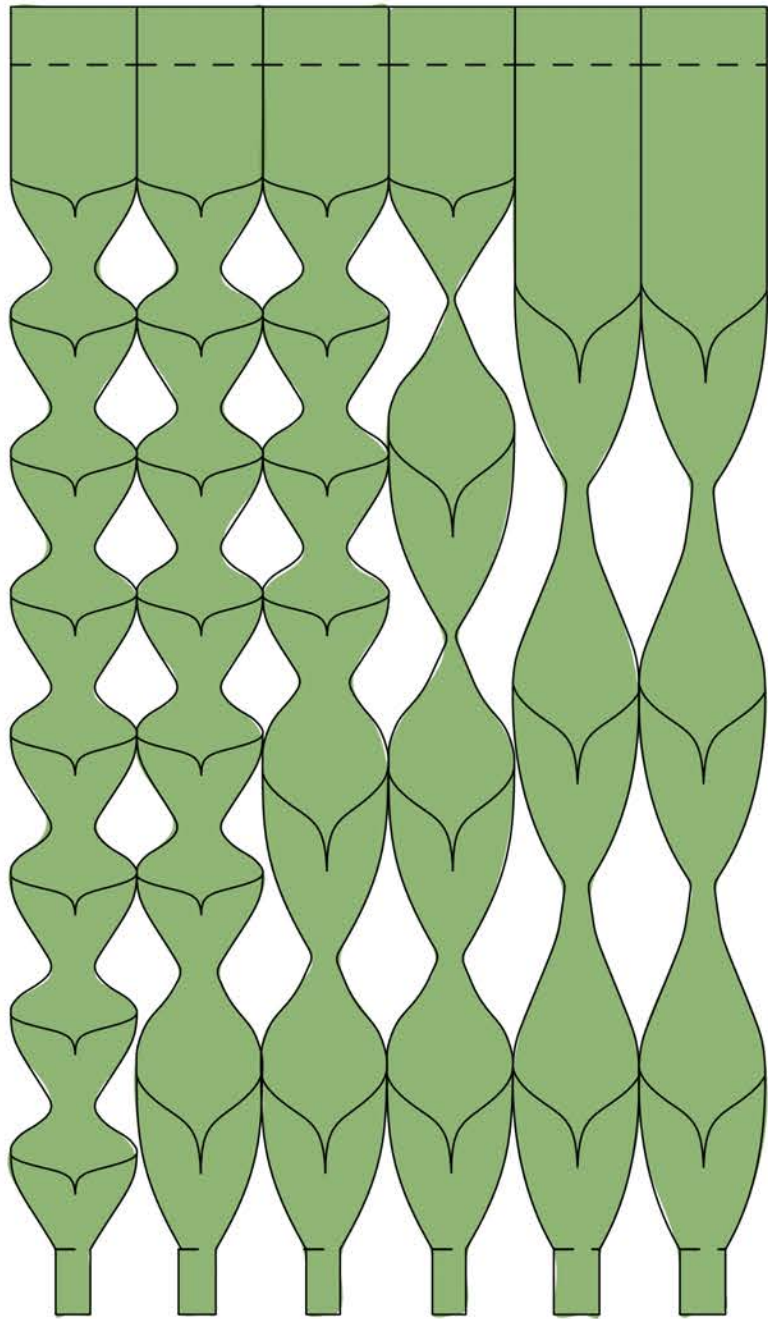


5 % OPEN: 27
% OPAQUE: 73

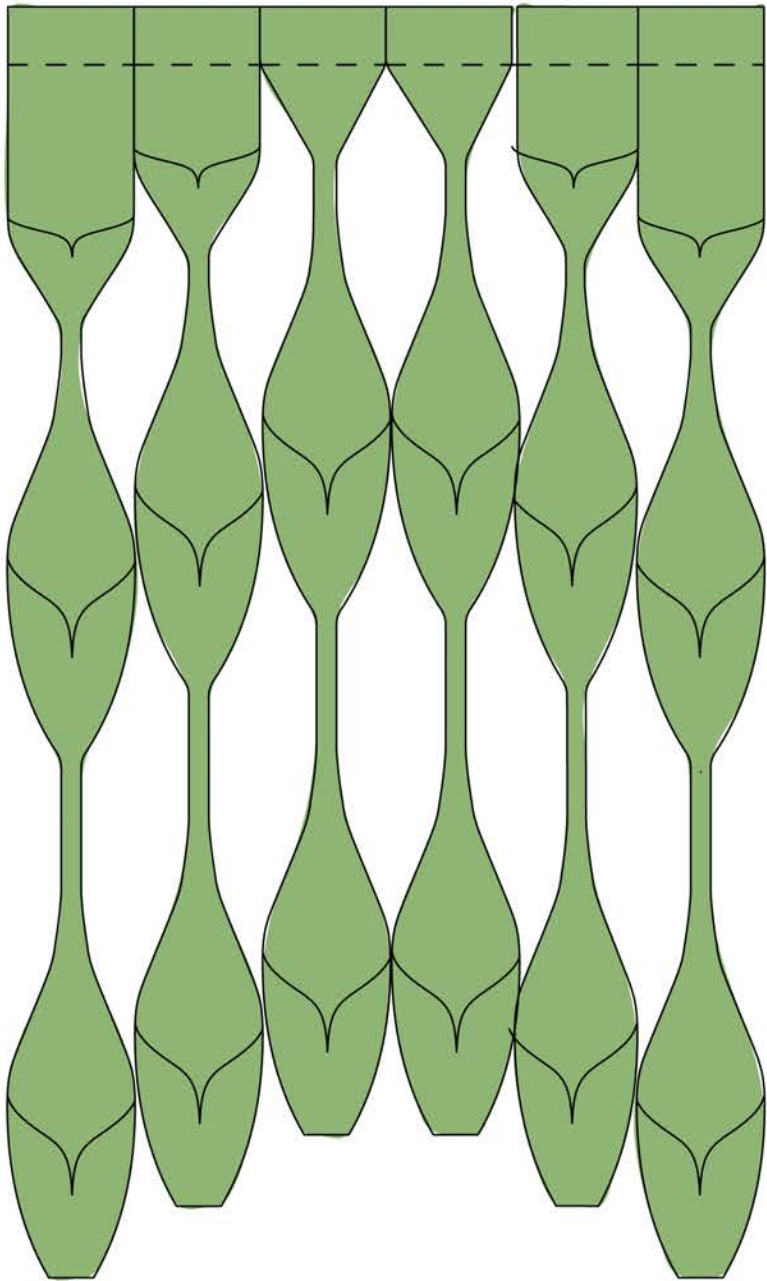


6 % OPEN: 30
% OPAQUE: 70

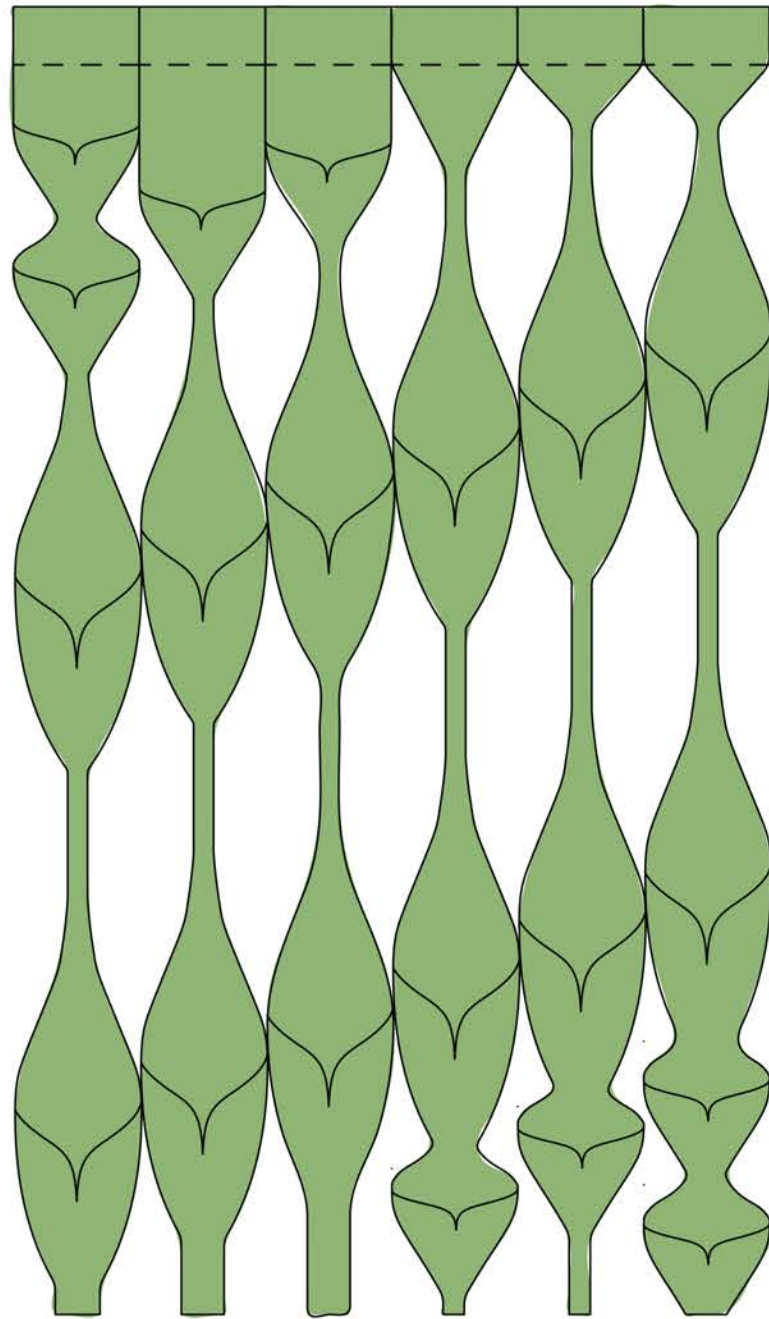
VARIATIONAL PATTERNS



7 % OPEN: 26
% OPAQUE: 74



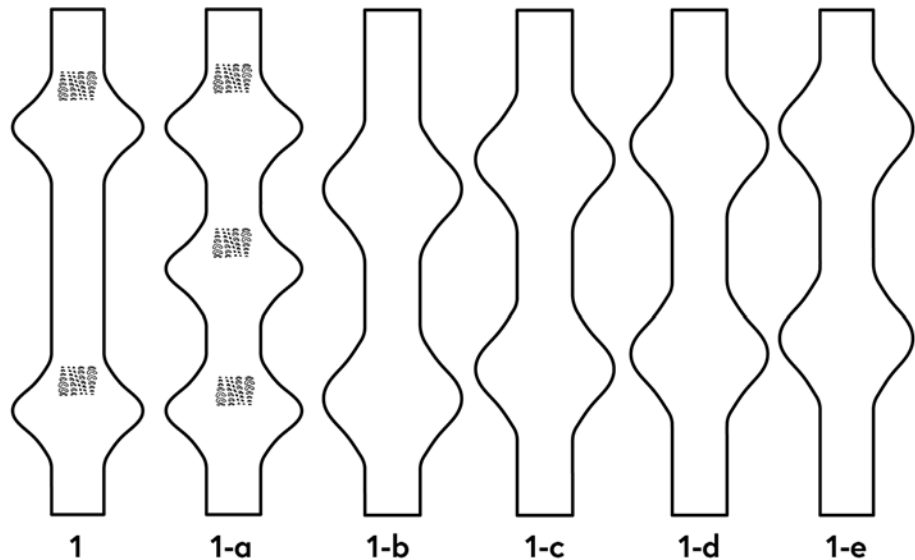
8 % OPEN: 43
% OPAQUE: 57



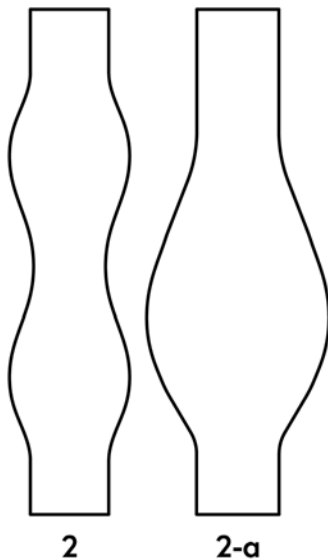
9 % OPEN: 39
% OPAQUE: 61

Full-Scale Installation Design

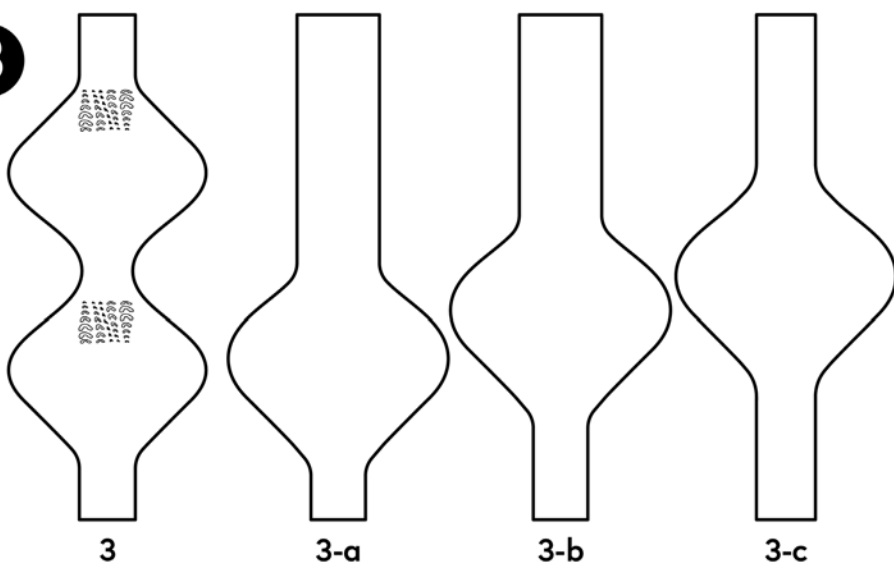
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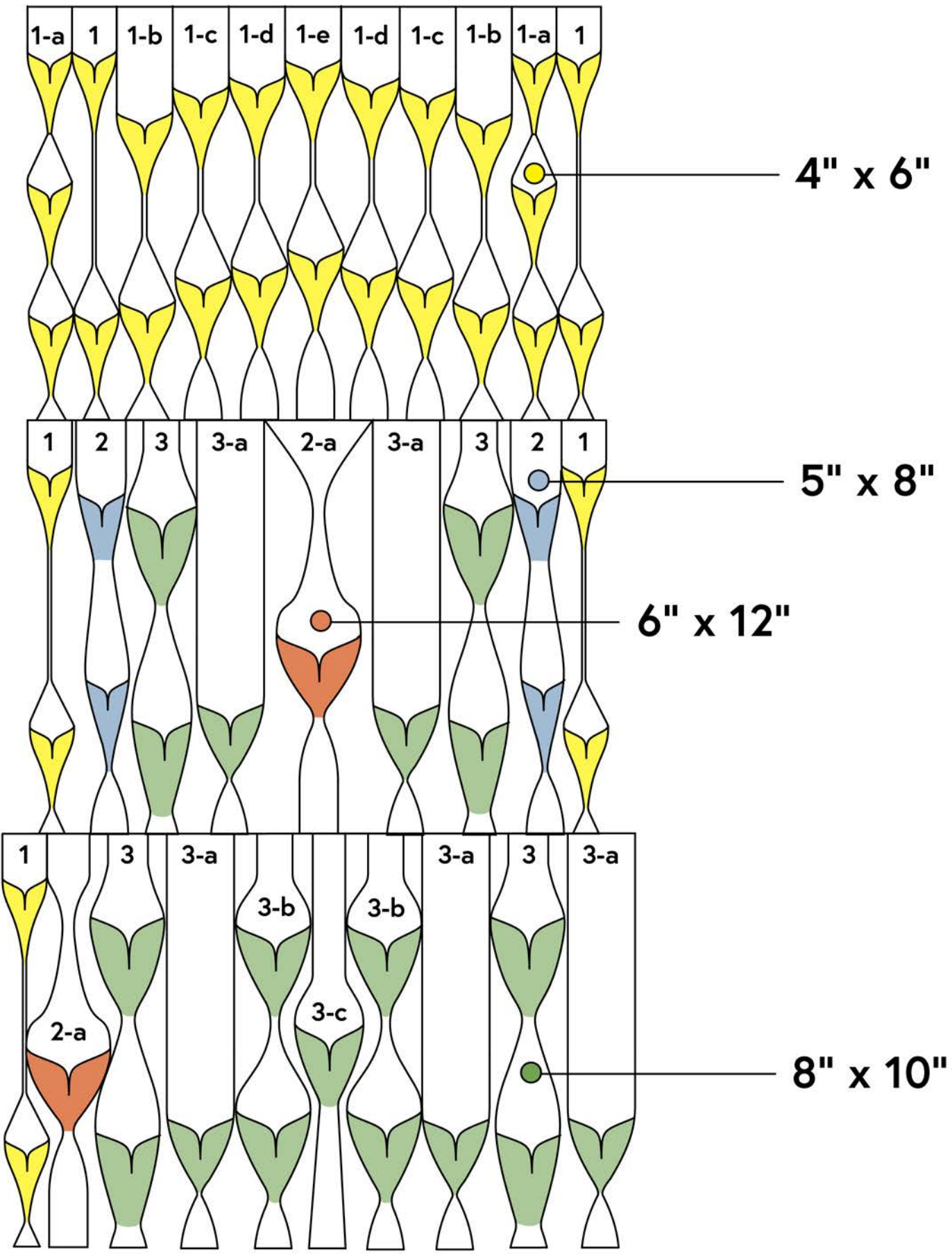
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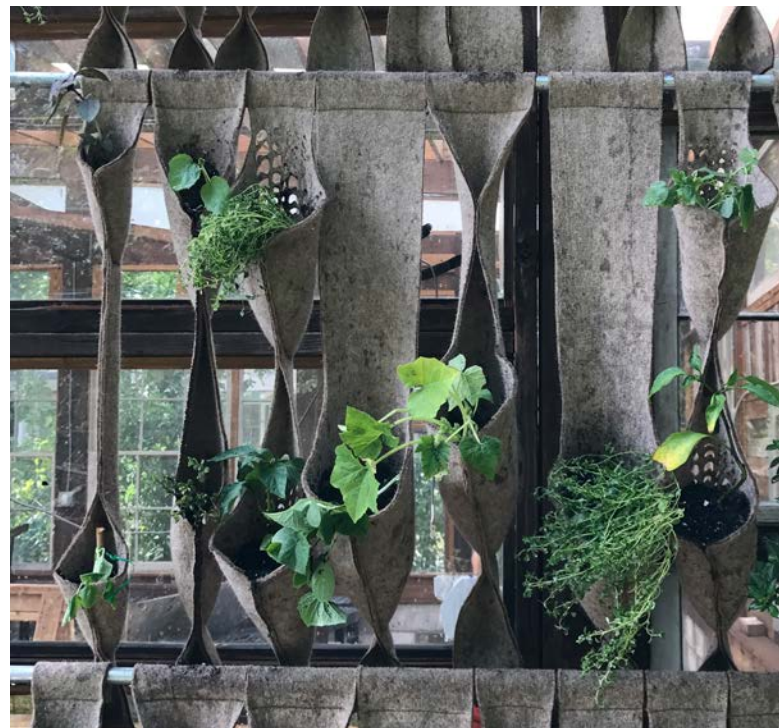
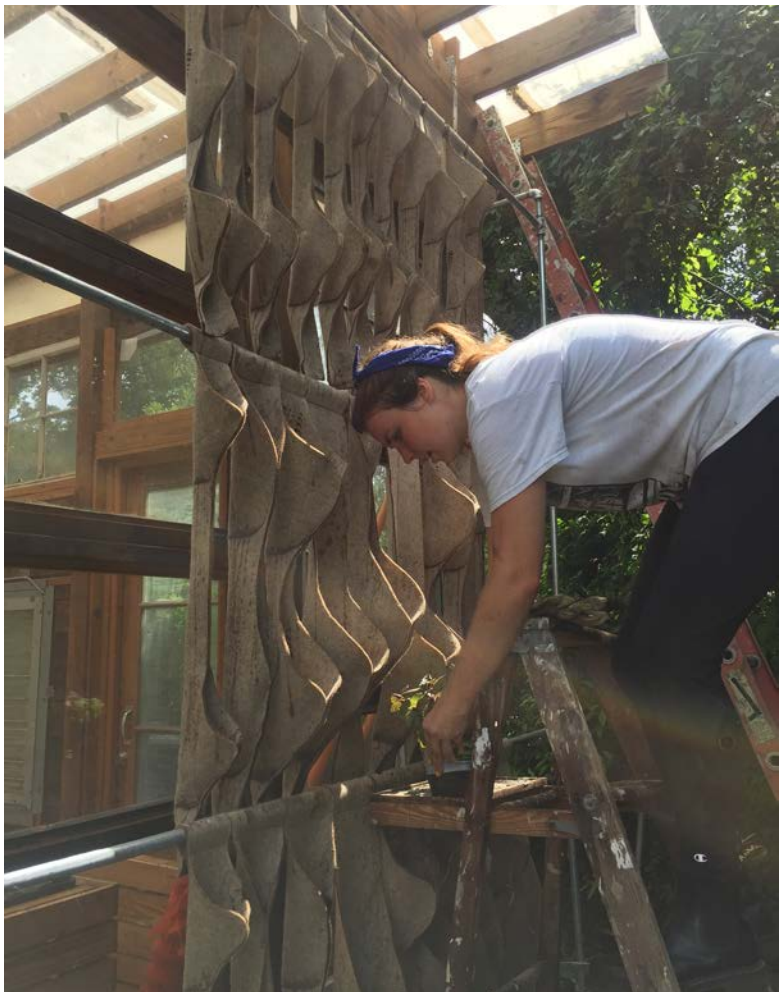
3



Pattern	Number
1	5
1-a	2
1-b	2
1-c	2
1-d	2
1-e	1
2	2
2-a	2
3	4
3-a	5
3-b	2
3-c	1
Total	30



Installation





Trellis Overhang Performance

Influence on Results



10 AM - 11:00 AM



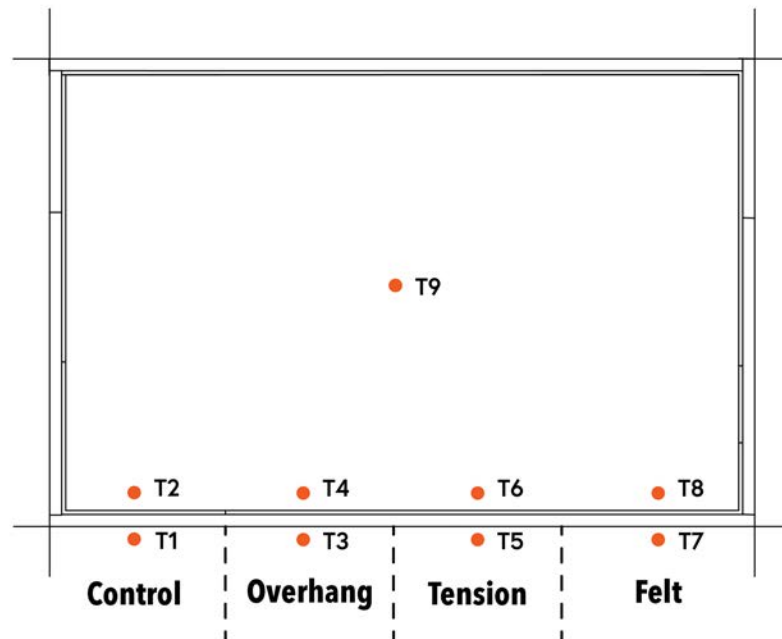
11:00 AM - 1:00 PM



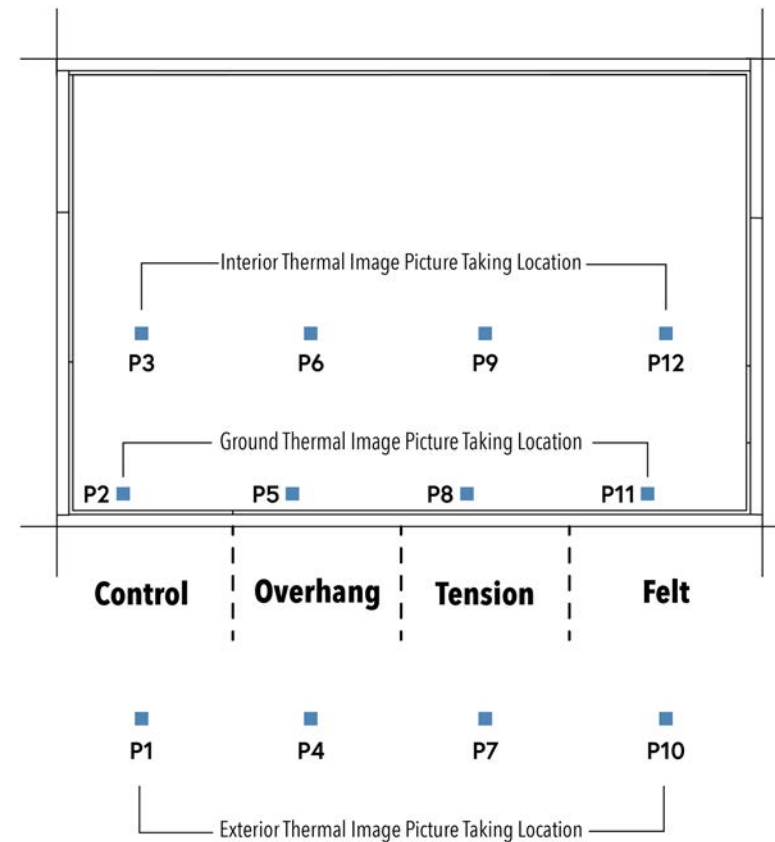
1:00 PM - 3:00 PM

Experimental Methods and Materials

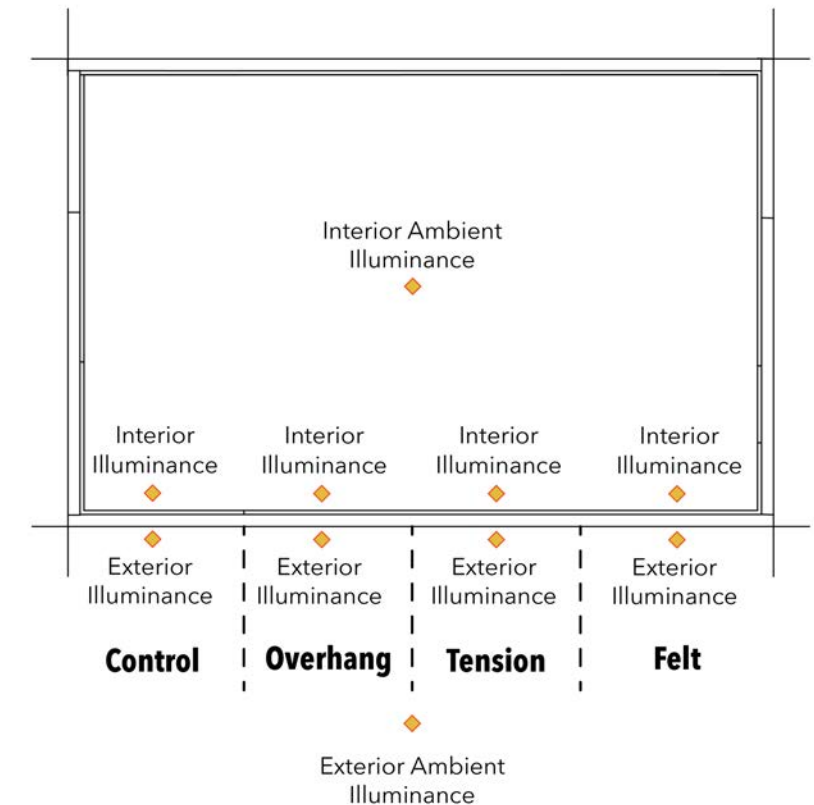
Temperature Reading Locations



Thermal Image Picture Taking Locations



Illuminance Level Reading Locations



In order to get a good picture of the performance of the facade systems three days of testing were conducted and compared to a “Control Day” of Similar Outdoor Temperature, but before the Installation was implemented.

Data Collected during the Three Testing Days

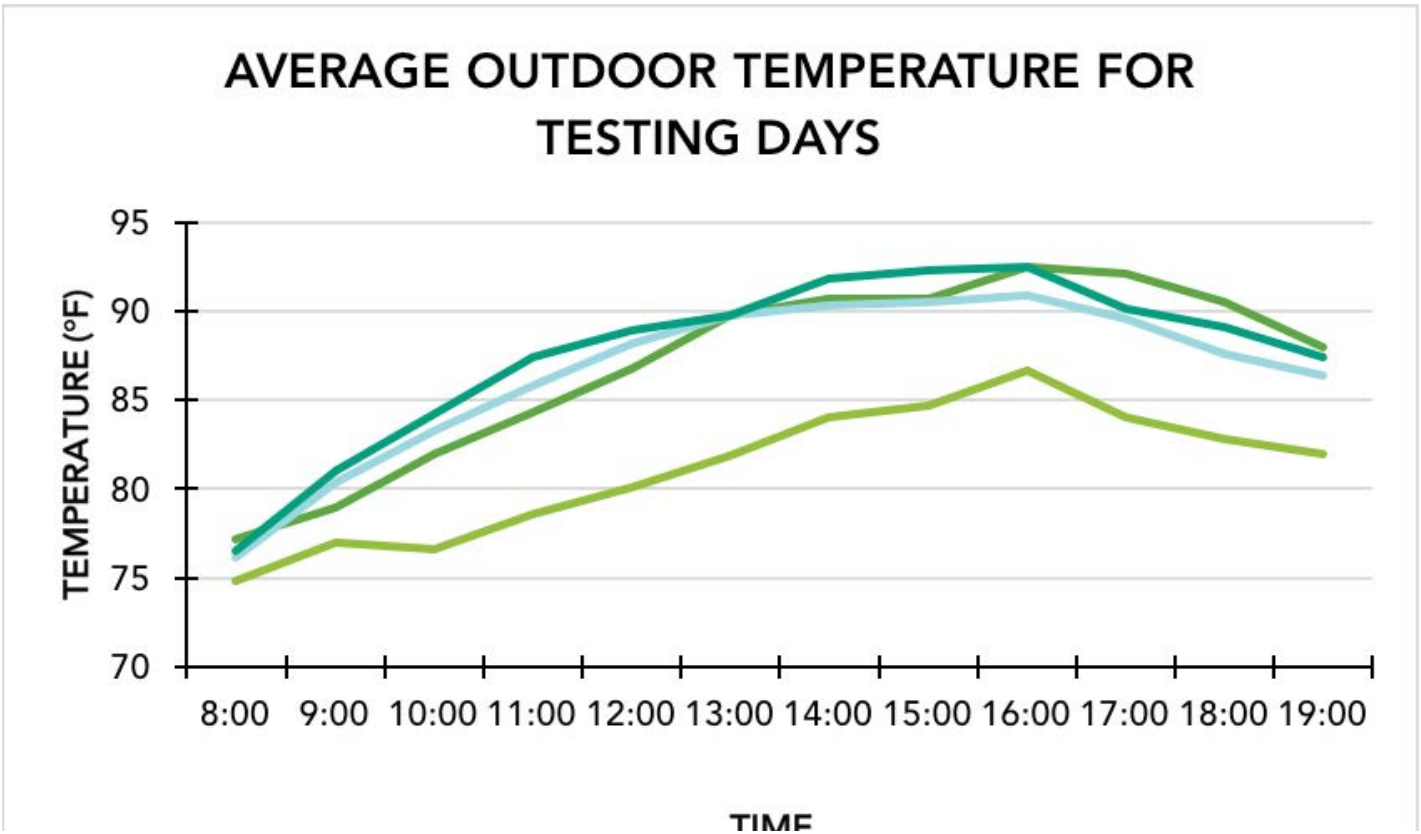
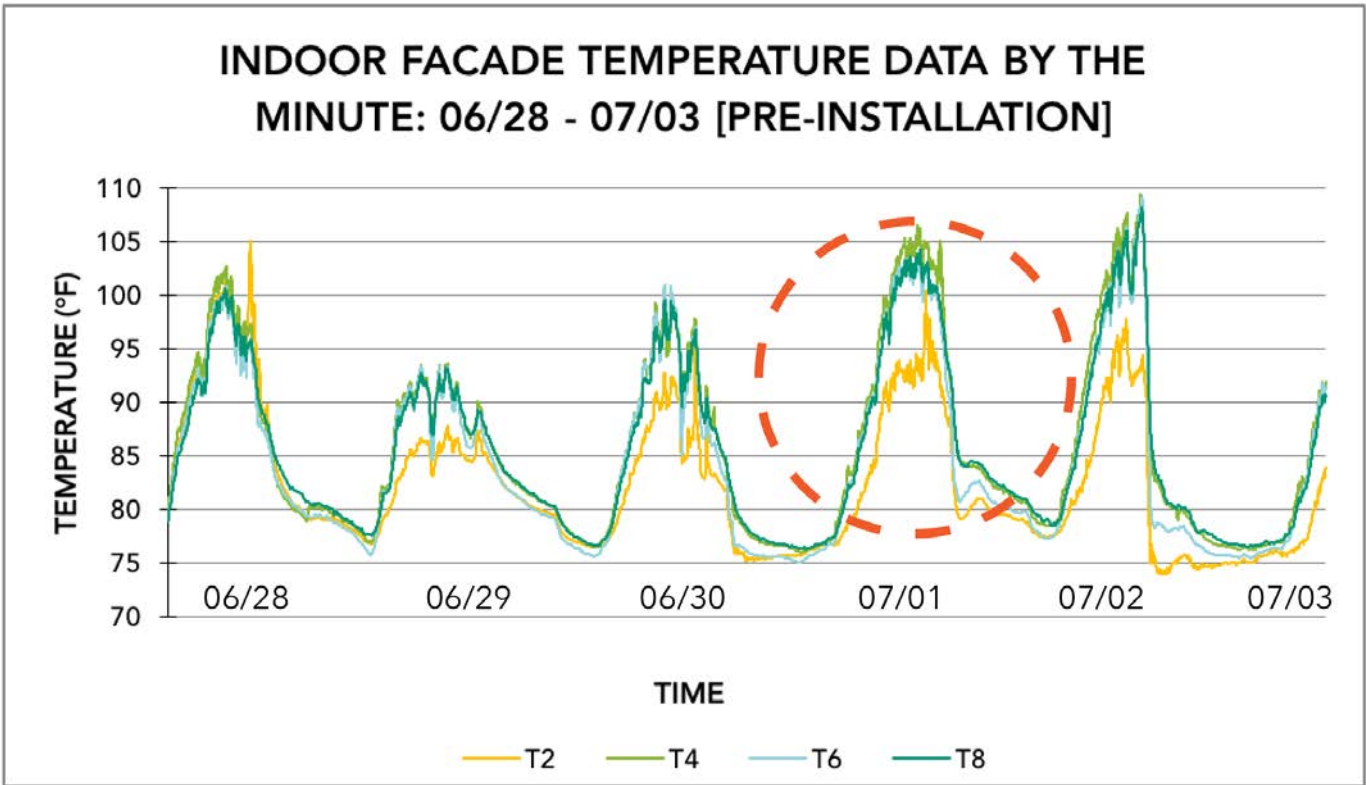
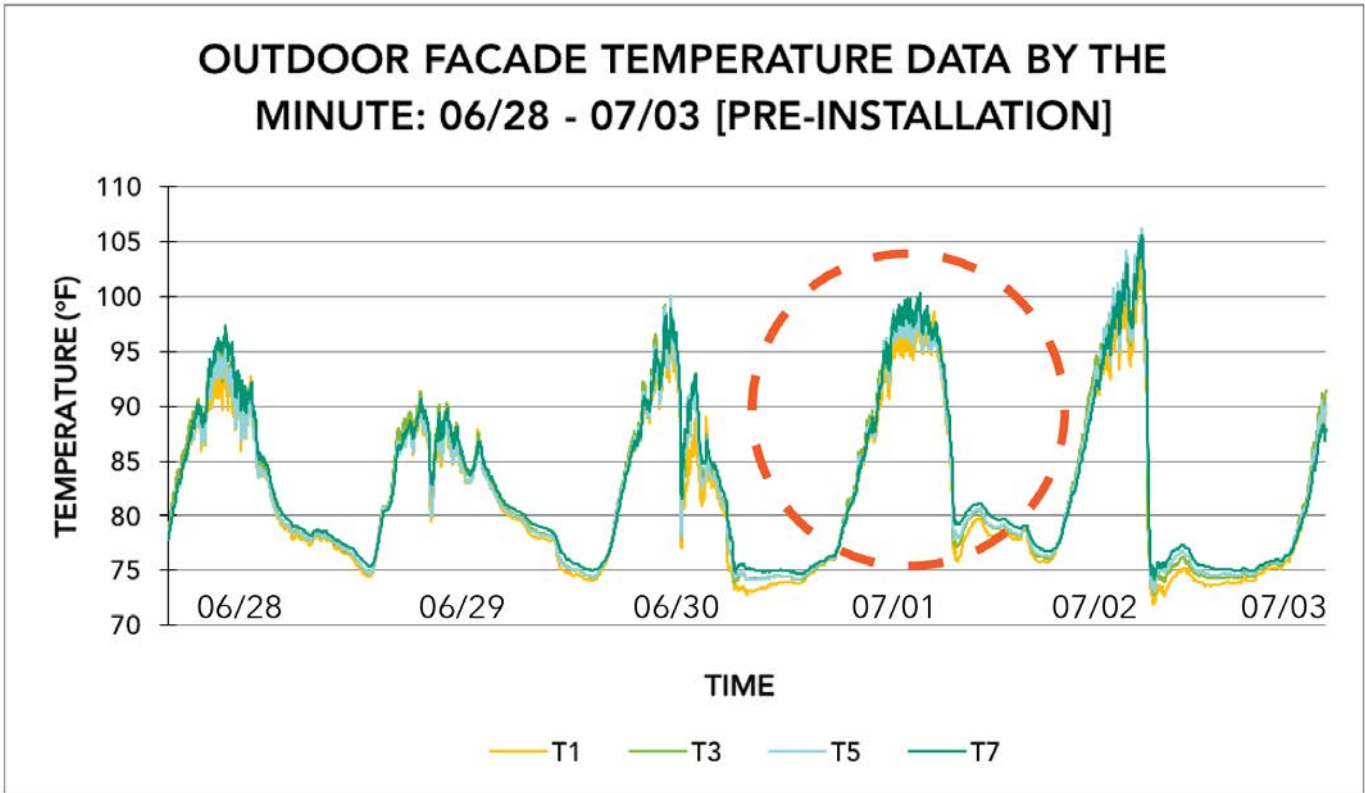
- Hourly Thermal Imaging from 8 AM - 8 PM
- Hourly Illuminance Level Readings from 8 AM - 8 PM
- Data Extracted from the Continuous HOBO Loggers from 8 AM - 8 PM on the respective Testing Days



Results

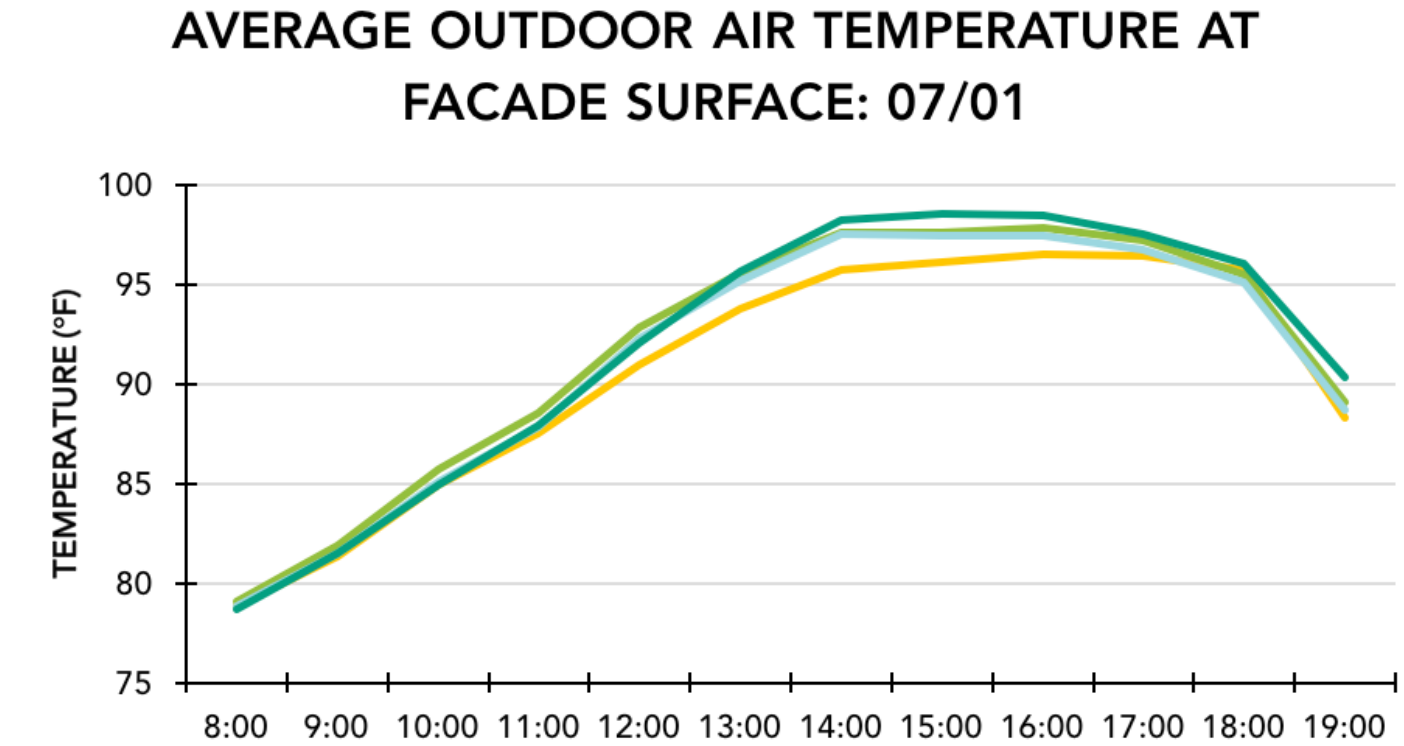
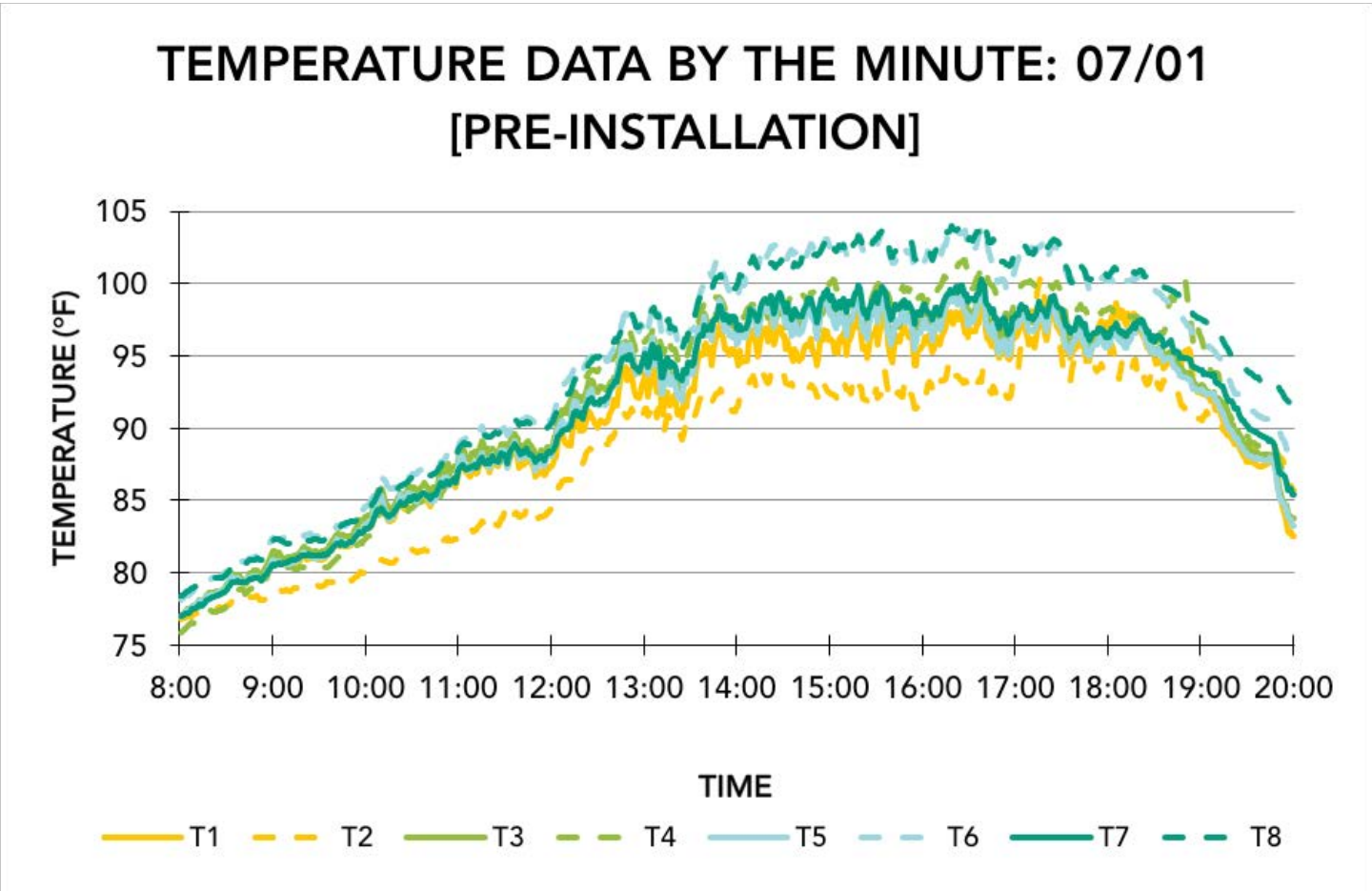


Pre-Installation

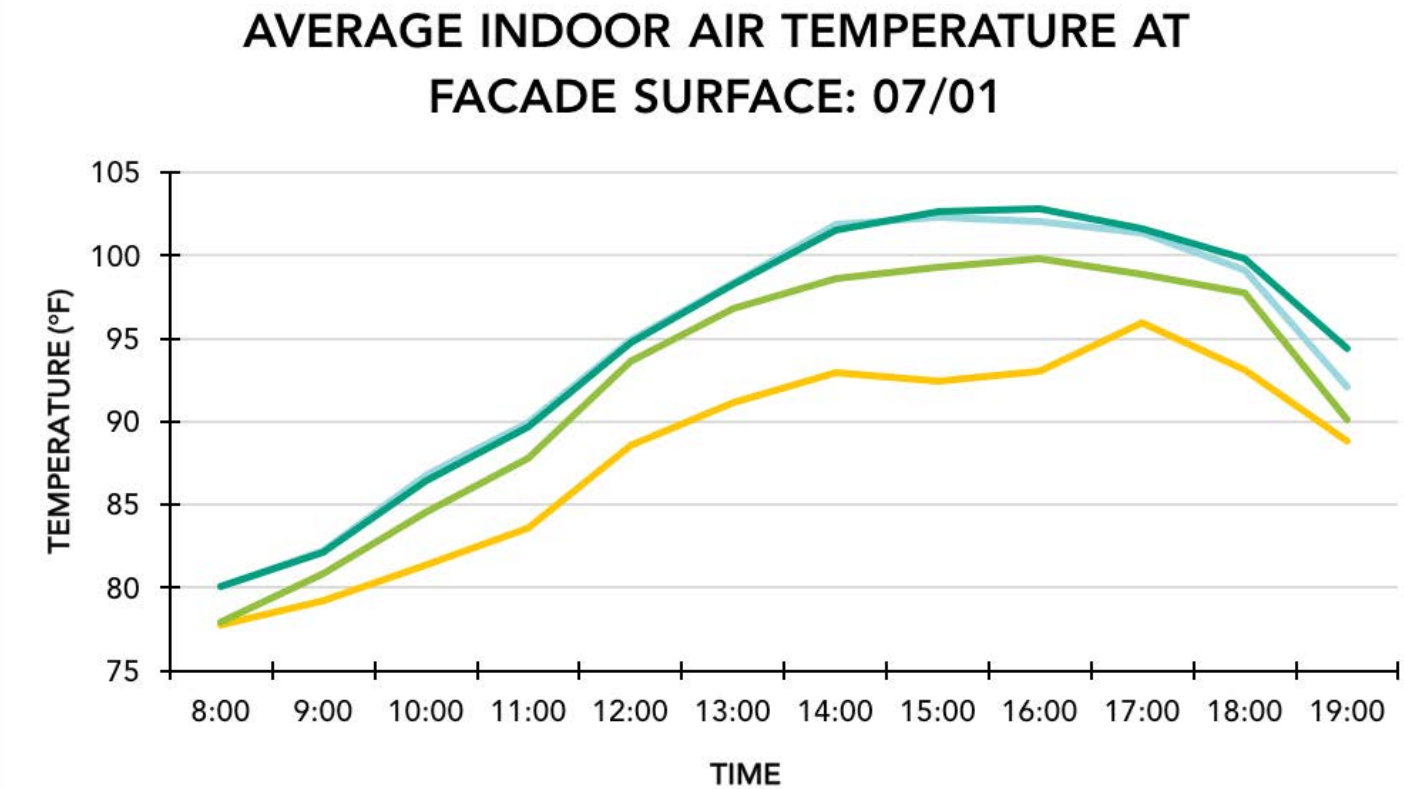


“Control Day” Chosen as July 1st:

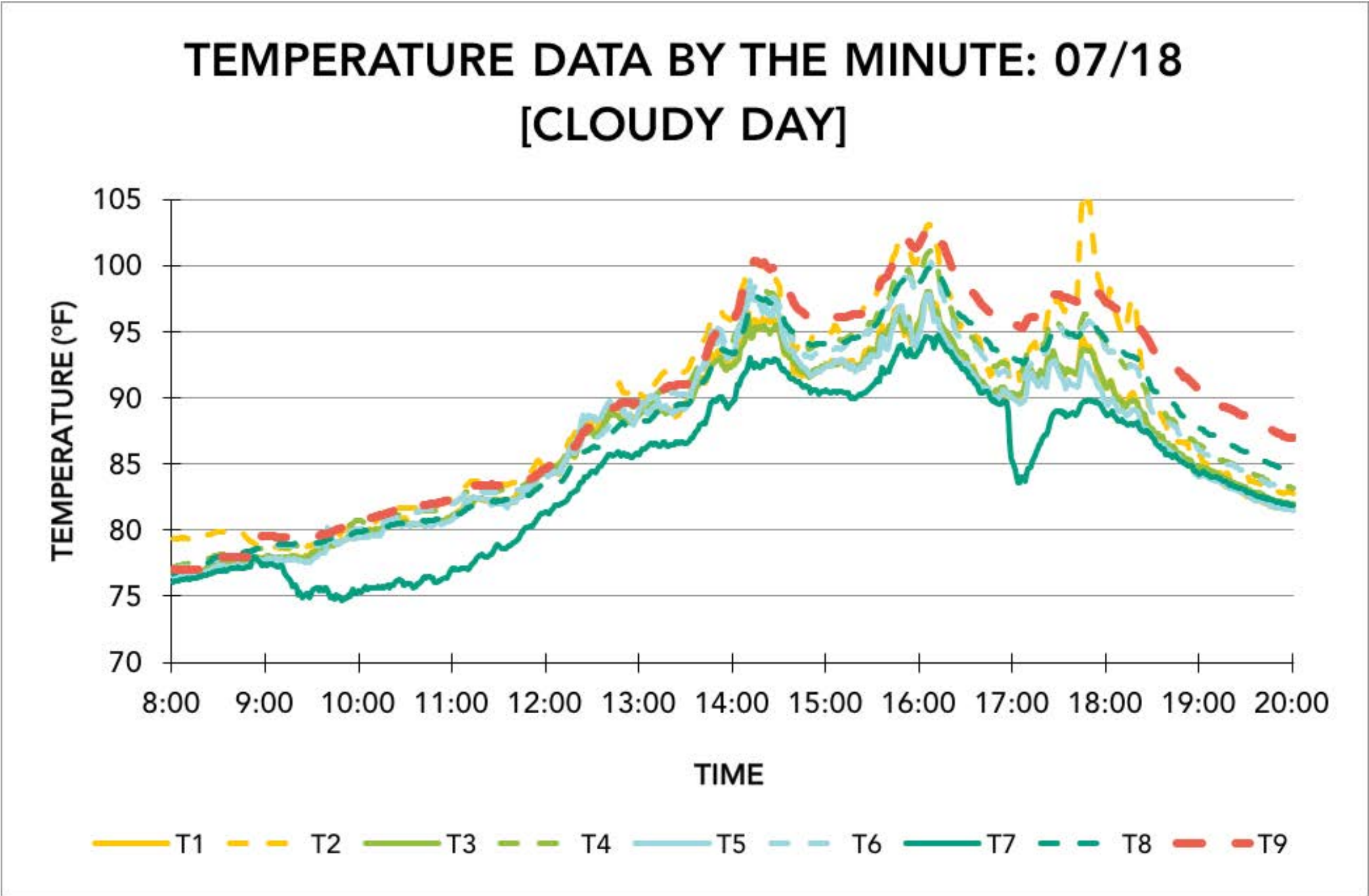
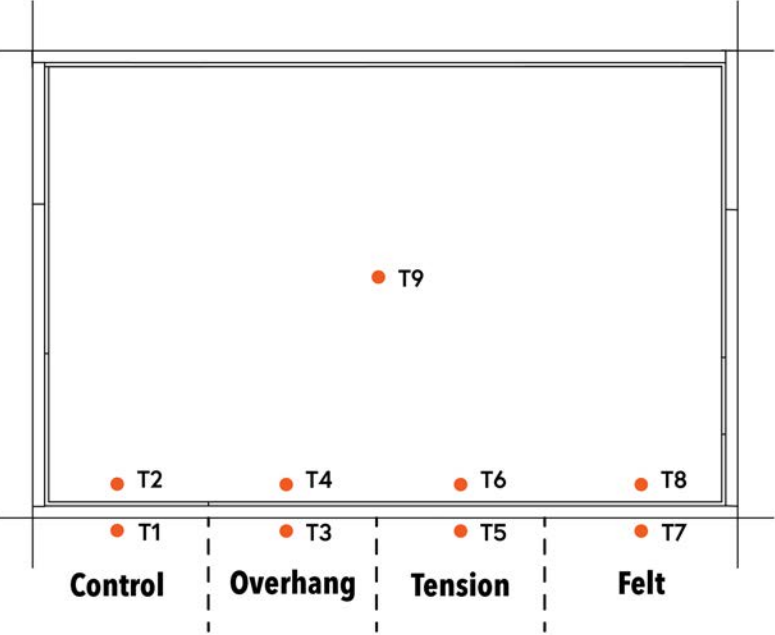
“Control” Day



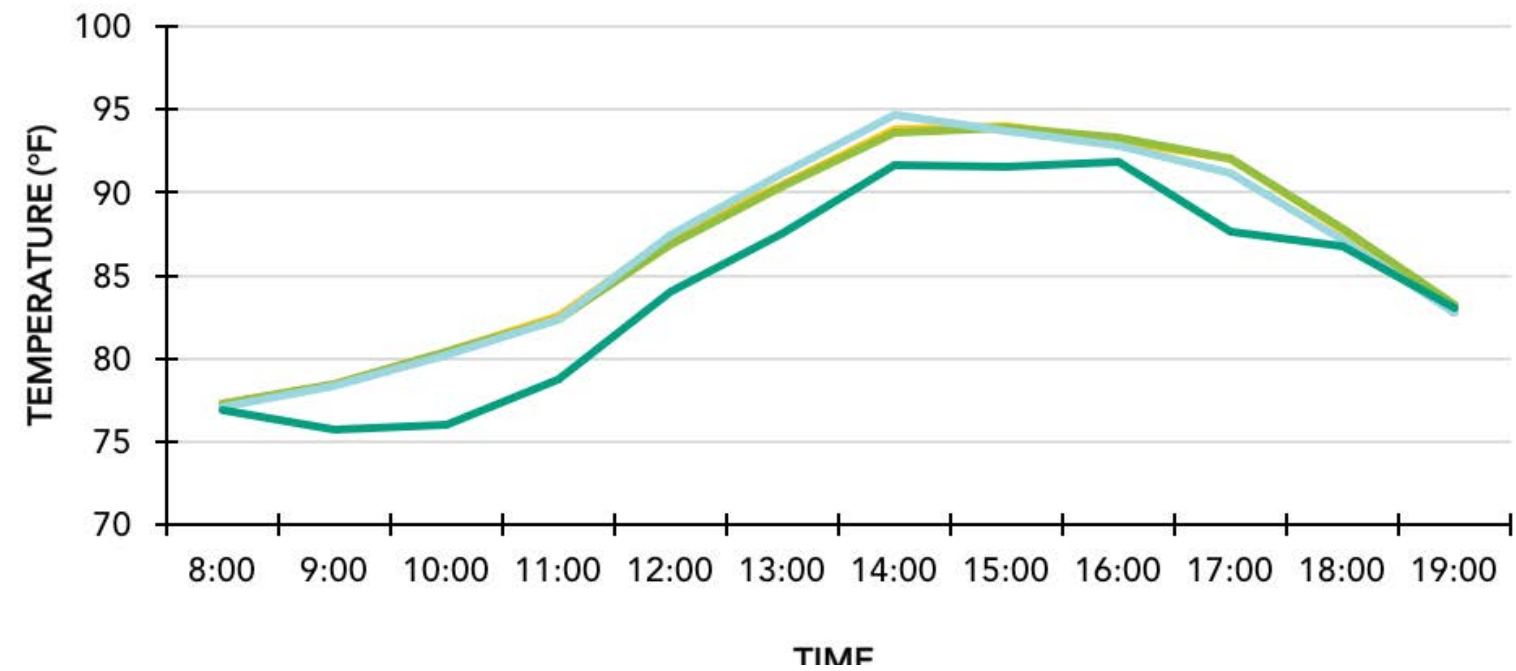
Time	Outdoor Average Temperature Difference (°F)				Time	Indoor Average Temperature Difference (°F)			
	CONTROL	OVERHANG	TENSION	FELT		CONTROL	OVERHANG	TENSION	FELT
8:00 AM	---	+0.24	+0.05	-0.10	8:00 AM	---	+0.20	+2.39	+2.34
9:00 AM	---	+0.56	+0.11	+0.10	9:00 AM	---	+1.63	+2.96	+2.87
10:00 AM	---	+0.77	+0.19	+0.04	10:00 AM	---	+3.23	+5.41	+5.07
11:00 AM	---	+1.02	+0.35	+0.42	11:00 AM	---	+4.23	+6.33	+6.11
12:00 PM	---	+1.92	+1.38	+1.13	12:00 PM	---	+5.14	+6.39	+6.22
1:00 PM	---	+1.80	+1.47	+1.92	1:00 PM	---	+5.66	+7.20	+7.10
2:00 PM	---	+1.89	+1.78	+2.45	2:00 PM	---	+5.61	+8.91	+8.57
3:00 PM	---	+1.51	+1.30	+2.43	3:00 PM	---	+6.87	+9.93	+10.24
4:00 PM	---	+1.36	+0.91	+1.97	4:00 PM	---	+6.78	+9.06	+9.82
5:00 PM	---	+0.80	+0.29	+1.11	5:00 PM	---	+2.86	+5.35	+5.63
6:00 PM	---	-0.21	-0.58	+0.32	6:00 PM	---	+4.61	+6.00	+6.70
7:00 PM	---	+0.76	+0.37	+2.08	7:00 PM	---	+1.32	+3.24	+5.55
AVG.	---	+1.03	+0.63	+1.16	AVG.	---	+4.01	+6.10	+6.35



Temperature Reading Locations

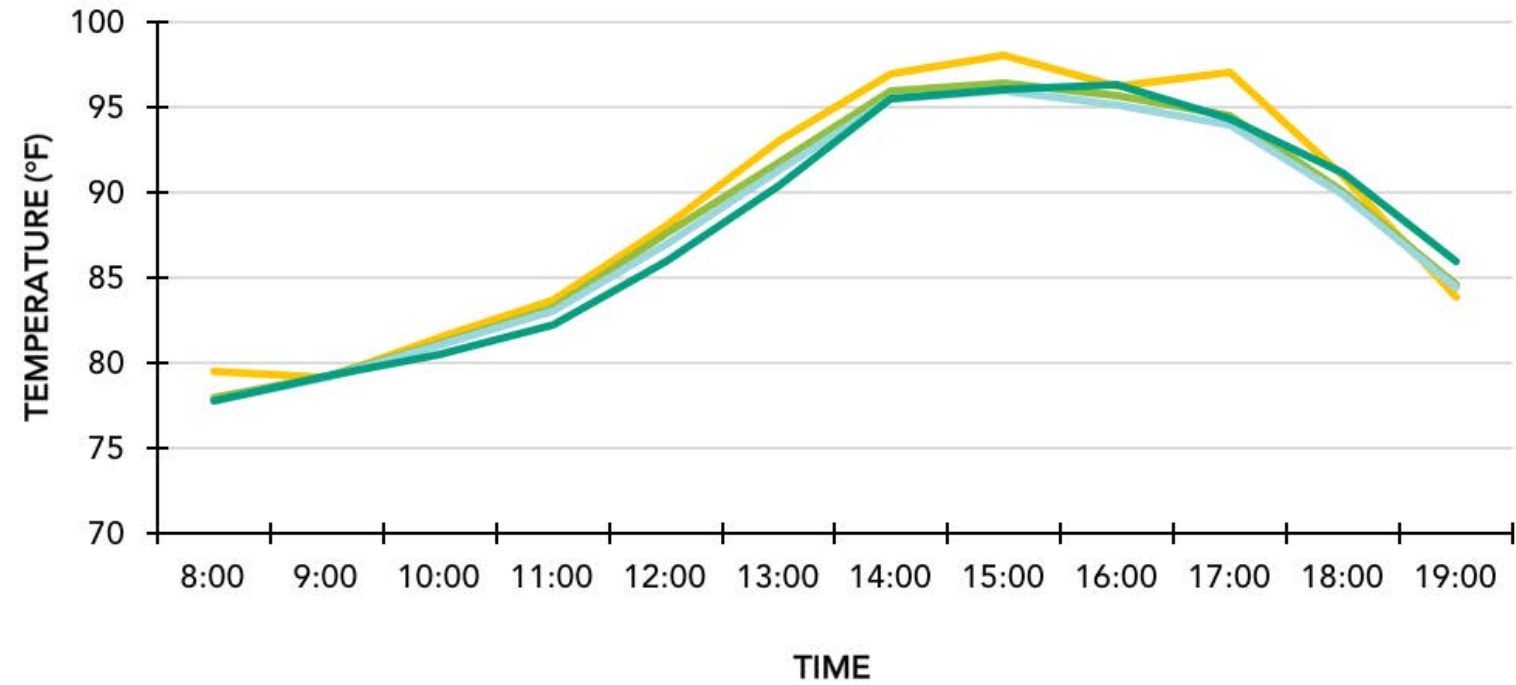


AVERAGE OUTDOOR AIR TEMPERATURE AT
FACADE SURFACE: 07/18



Time	Outdoor Average Temperature Difference (°F)			
	CONTROL	OVERHANG	TENSION	FELT
8:00 AM	---	+0.05	-0.18	-0.40
9:00 AM	---	+0.01	-0.15	-2.72
10:00 AM	---	0.00	-0.19	-4.44
11:00 AM	---	-0.13	-0.13	-3.79
12:00 PM	---	-0.40	+0.20	-3.27
1:00 PM	---	-0.18	+0.60	-3.00
2:00 PM	---	-0.15	+0.93	-2.14
3:00 PM	---	-0.12	-0.27	-2.43
4:00 PM	---	+0.21	-0.24	-1.22
5:00 PM	---	+0.03	-0.85	-4.44
6:00 PM	---	+0.13	-0.50	-0.92
7:00 PM	---	+0.47	-0.05	+0.25
AVG.	---	-0.01	-0.07	-2.38
PRE-INSTALL		+1.03	+0.63	+1.16
OVERALL		-1.04	-0.70	-3.54

AVERAGE INDOOR AIR TEMPERATURE AT
FACADE SURFACE: 07/18

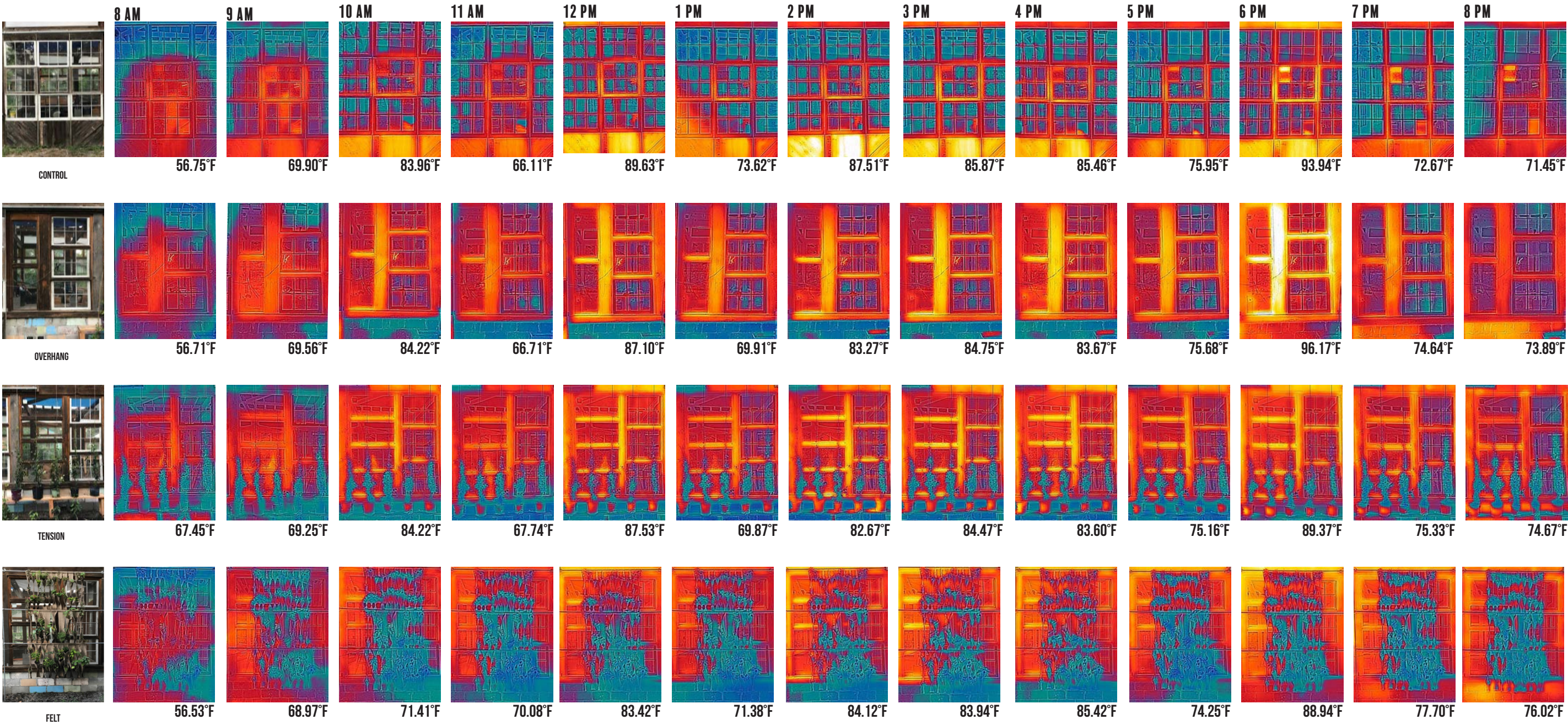


Time	Indoor Average Temperature Difference (°F)			
	CONTROL	OVERHANG	TENSION	FELT
8:00 AM	---	-1.50	-1.74	-1.68
9:00 AM	---	+0.09	-0.03	+0.02
10:00 AM	---	-0.35	-0.50	-1.03
11:00 AM	---	-0.47	-0.62	-1.48
12:00 PM	---	-0.47	-1.14	-2.05
1:00 PM	---	-1.26	-1.73	-2.61
2:00 PM	---	-0.98	-1.43	-1.45
3:00 PM	---	-1.59	-2.11	-2.01
4:00 PM	---	-0.48	-1.05	+0.14
5:00 PM	---	-2.52	-3.07	-2.68
6:00 PM	---	-0.92	-1.14	+0.15
7:00 PM	---	+0.73	+0.56	+2.08
AVG.	---	-0.81	-1.17	-1.05
PRE-INSTALL	---	+4.01	+6.10	+6.35
AVG.	---	-4.82	-7.27	-7.40

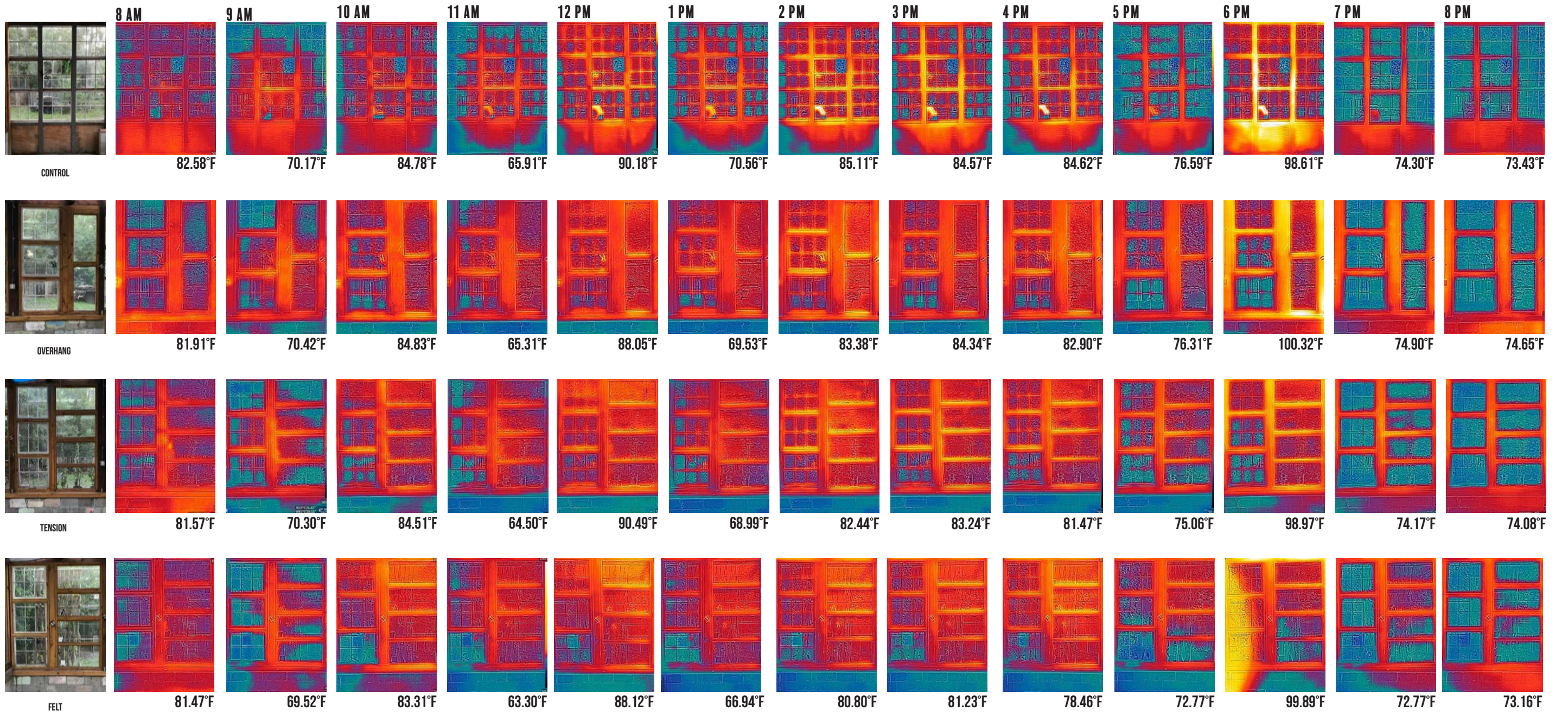
Hourly Thermal Images

JULY 18, 2017
CLOUDY

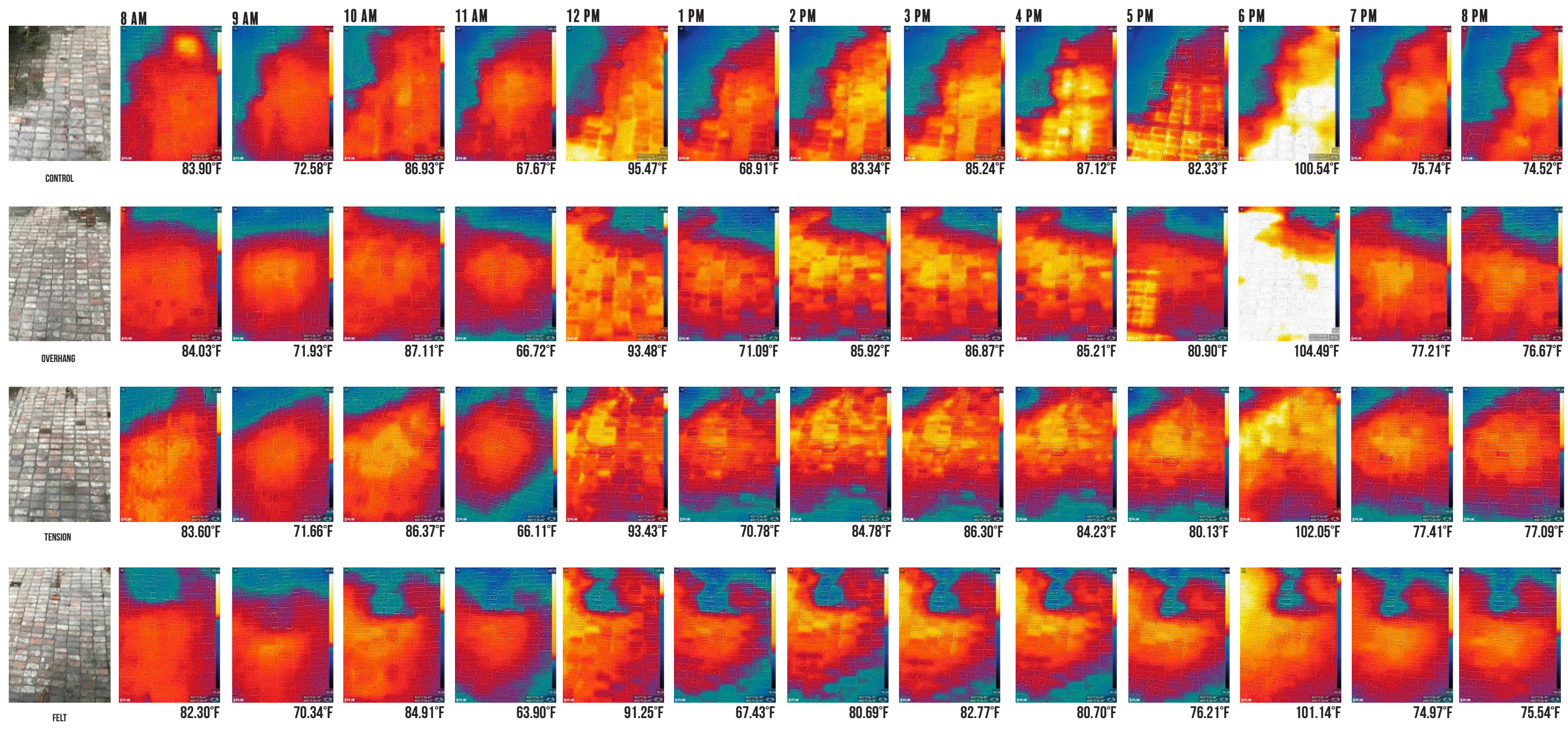
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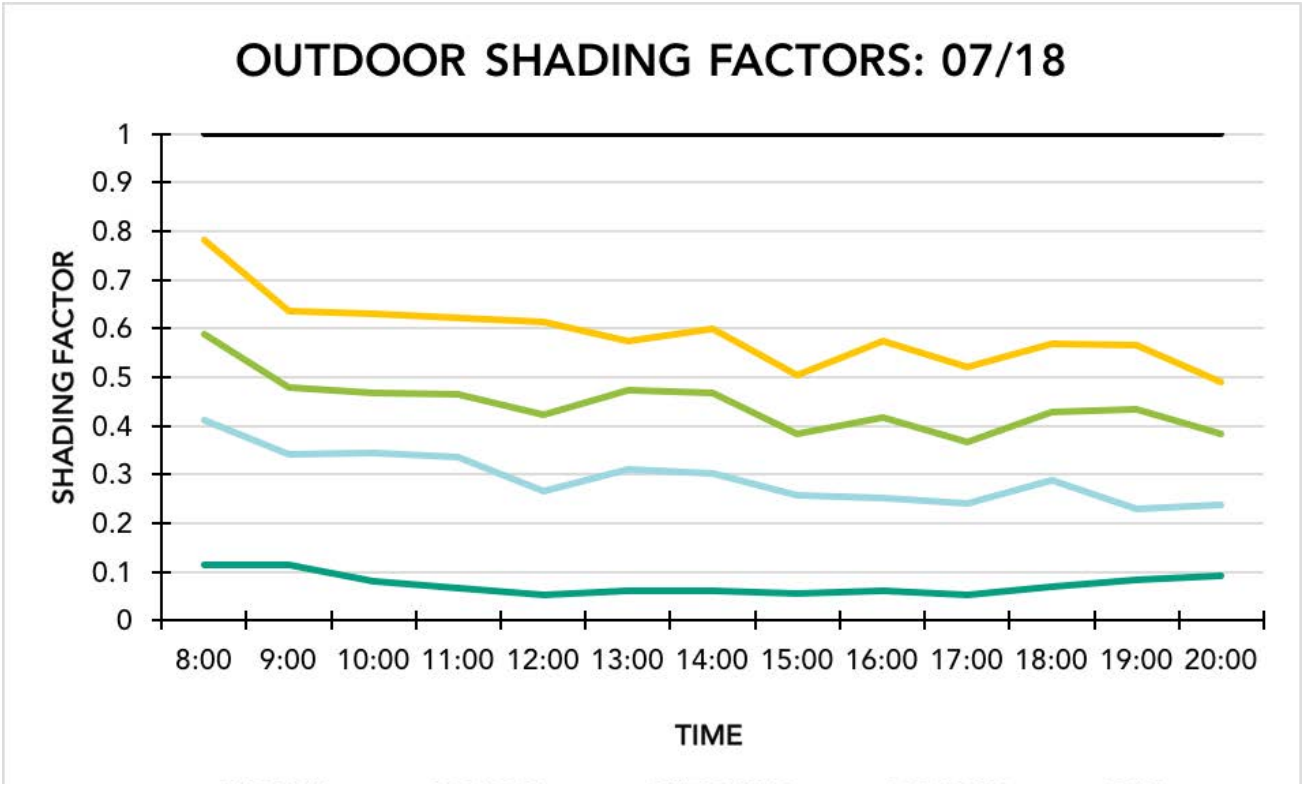


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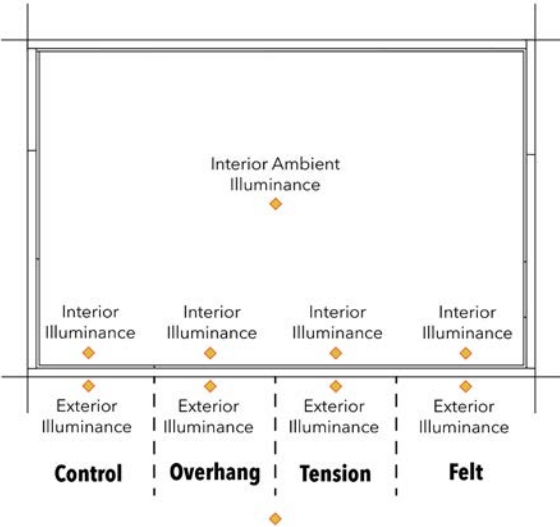
Illuminance Levels

Time	OUTDOOR ILLUMINANCE (LX)				
	AMBIENT	CONTROL	OVERHANG	TENSION	FELT
8:00 AM	5330	4160	3140	2190	613
9:00 AM	6760	4300	3240	2300	774
10:00 AM	9875	6214	4622	3400	798
11:00 AM	13410	8350	6230	4500	894
12:00 PM	42500	26100	18000	11340	2190
1:00 PM	33900	19500	16000	10500	2020
2:00 PM	31500	18900	14700	9490	1890
3:00 PM	39000	19600	15000	9990	2170
4:00 PM	32100	18400	13340	8070	1940
5:00 PM	28055	14615	10243	6760	1502
6:00 PM	12010	6830	5130	3450	845
7:00 PM	3460	1960	1500	791	286
8:00 PM	311	152	119.5	73.8	28.2

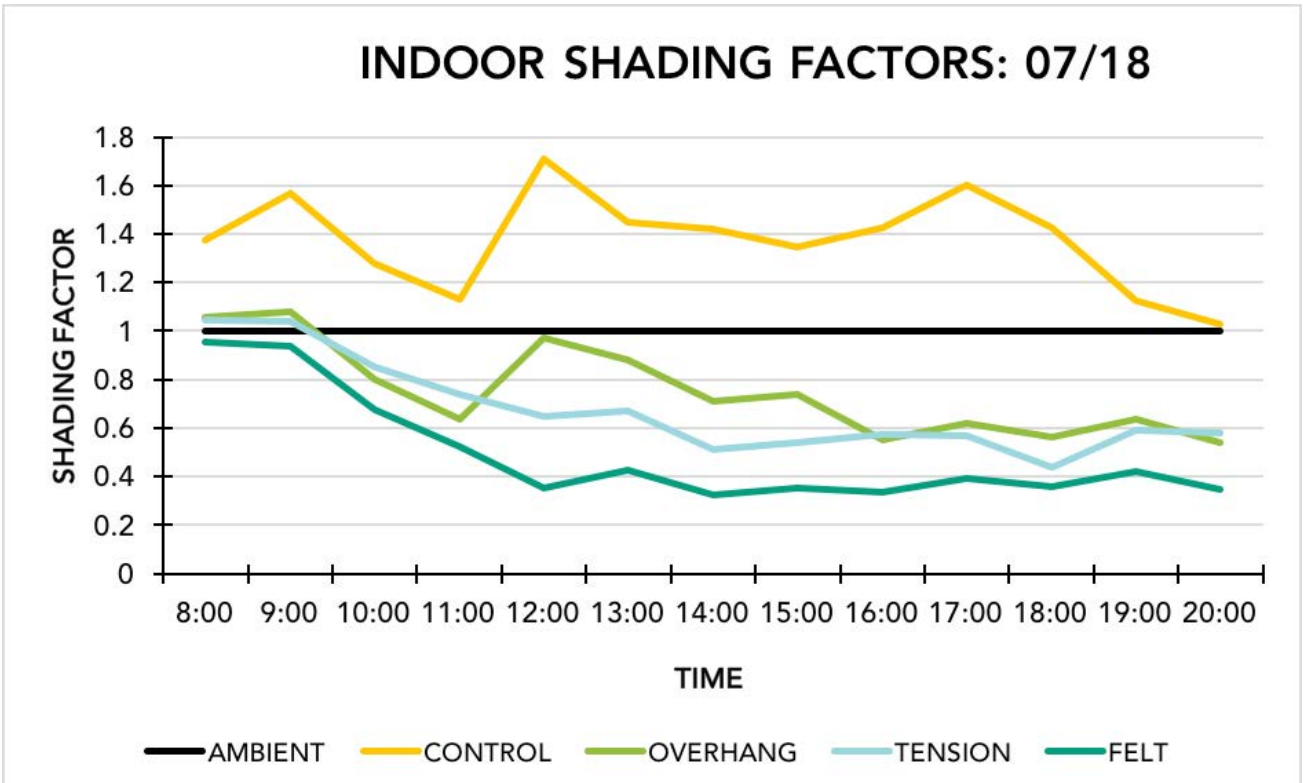


AVERAGE OUTDOOR SHADING FACTOR				
AMBI-ENT	CON-TROL	OVER-HANG	TEN-SION	FELT
1.00	0.60	0.45	0.30	0.07

Illuminance Level Reading Locations

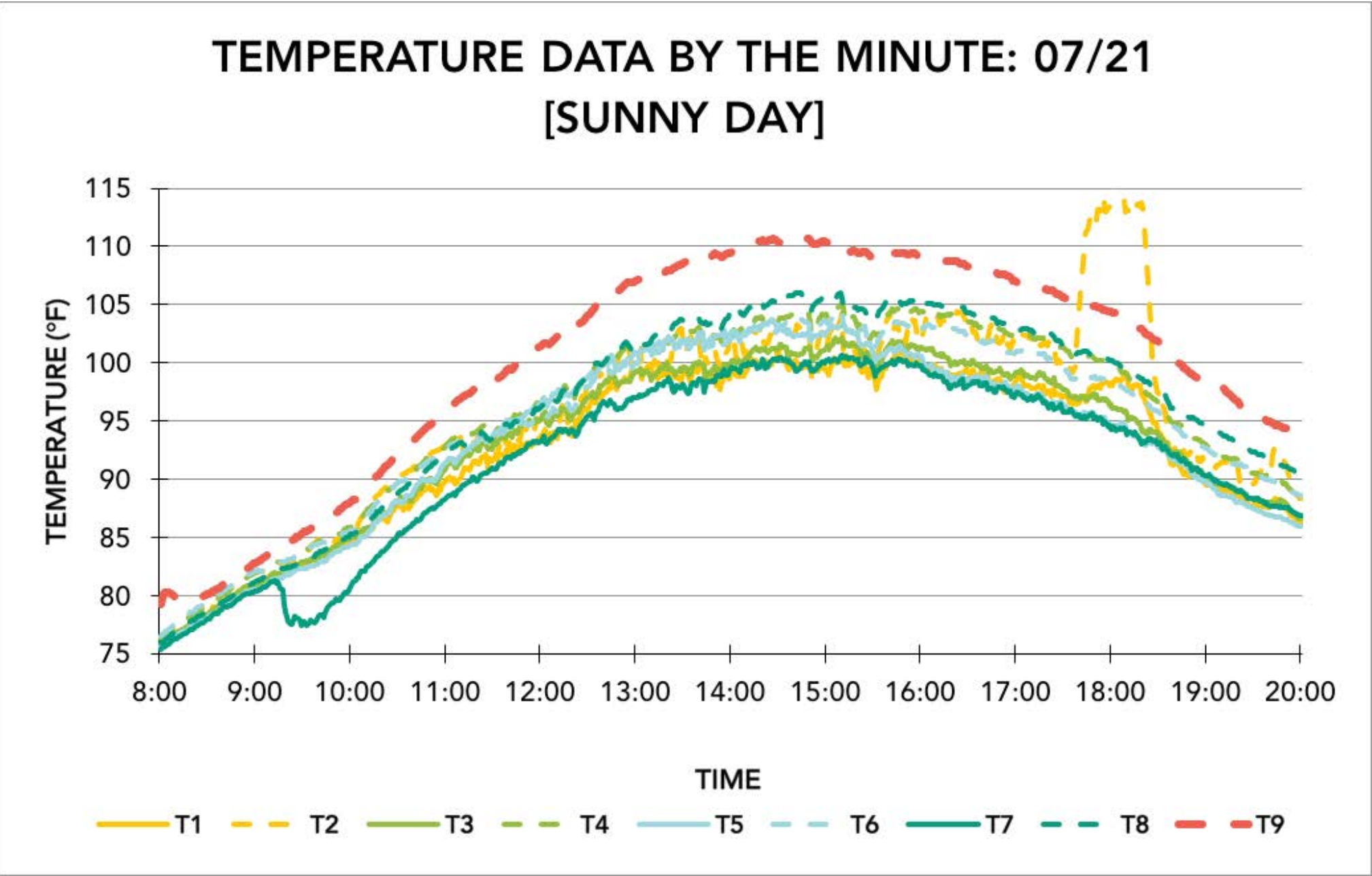
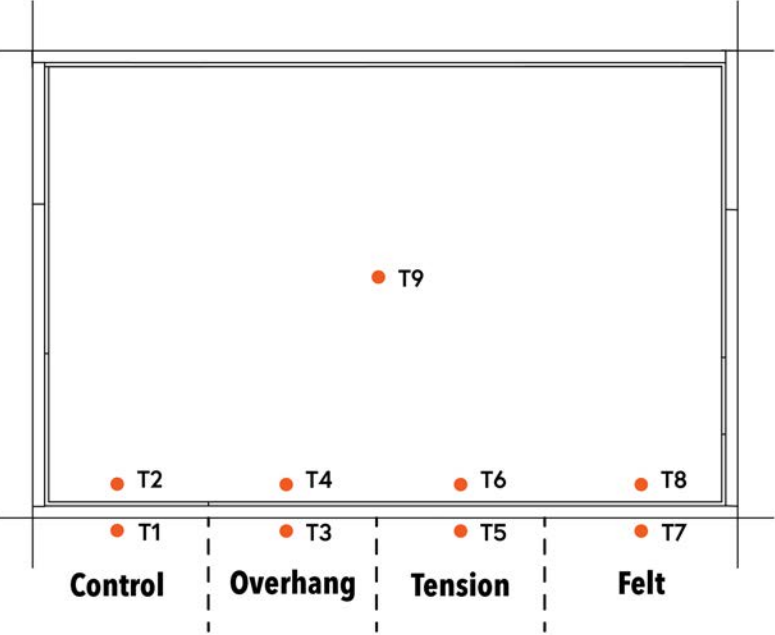


Time	INDOOR ILLUMINANCE (LX)				
	AMBIENT	CONTROL	OVERHANG	TENSION	FELT
8:00 AM	1540	2120	1630	1610	1470
9:00 AM	1500	2350	1620	1560	1410
10:00 AM	2110	2700	1695	1798	1421
11:00 AM	2780	3150	1770	2060	1450
12:00 PM	6290	10750	6100	4090	2220
1:00 PM	7800	11290	6860	5230	3320
2:00 PM	7450	10580	5290	3810	2430
3:00 PM	7920	10650	5860	4270	2790
4:00 PM	7130	10160	3950	4100	2380
5:00 PM	5320	8513	3301	3015	2083
6:00 PM	2610	3720	1469	1138	933
7:00 PM	791	888	504	467	333
8:00 PM	70.3	72.1	38.1	40.9	24.5

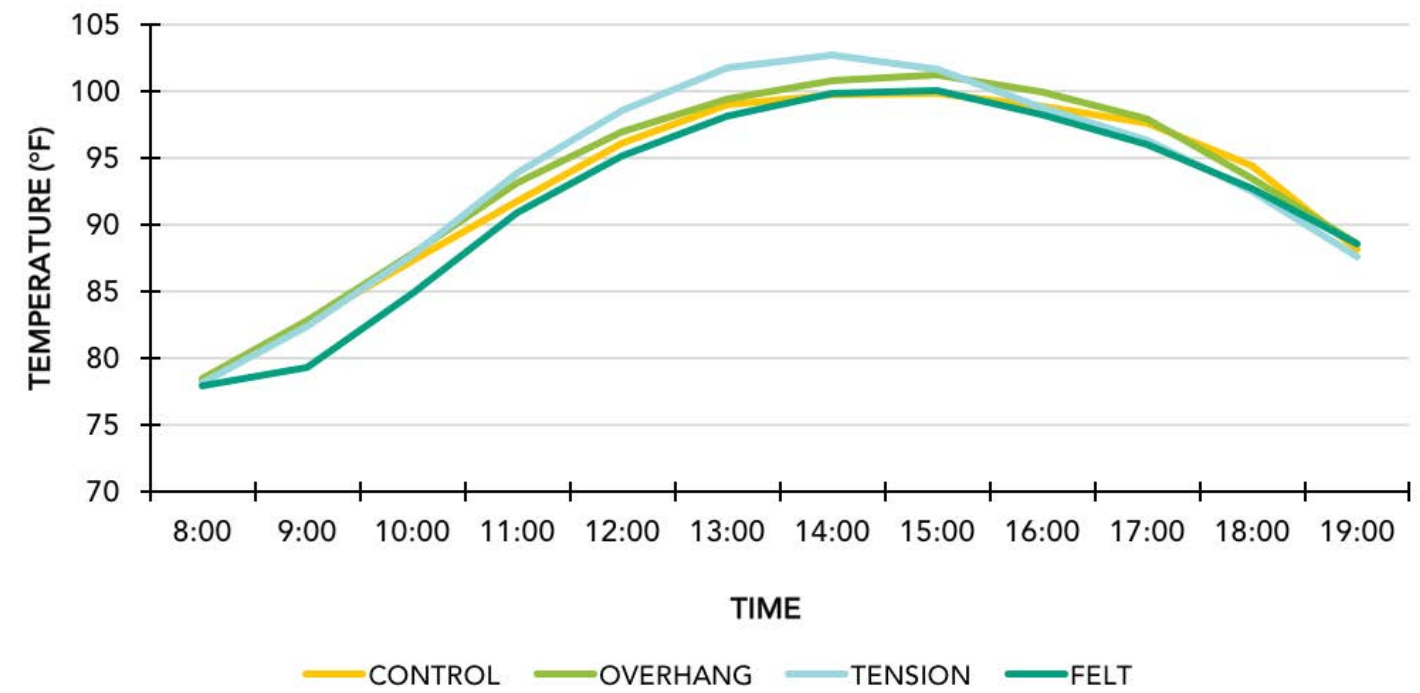


AVERAGE INDOOR SHADING FACTOR				
AMBI-ENT	CON-TROL	OVER-HANG	TEN-SION	FELT
1.00	1.40	0.77	0.68	0.50

Temperature Reading Locations

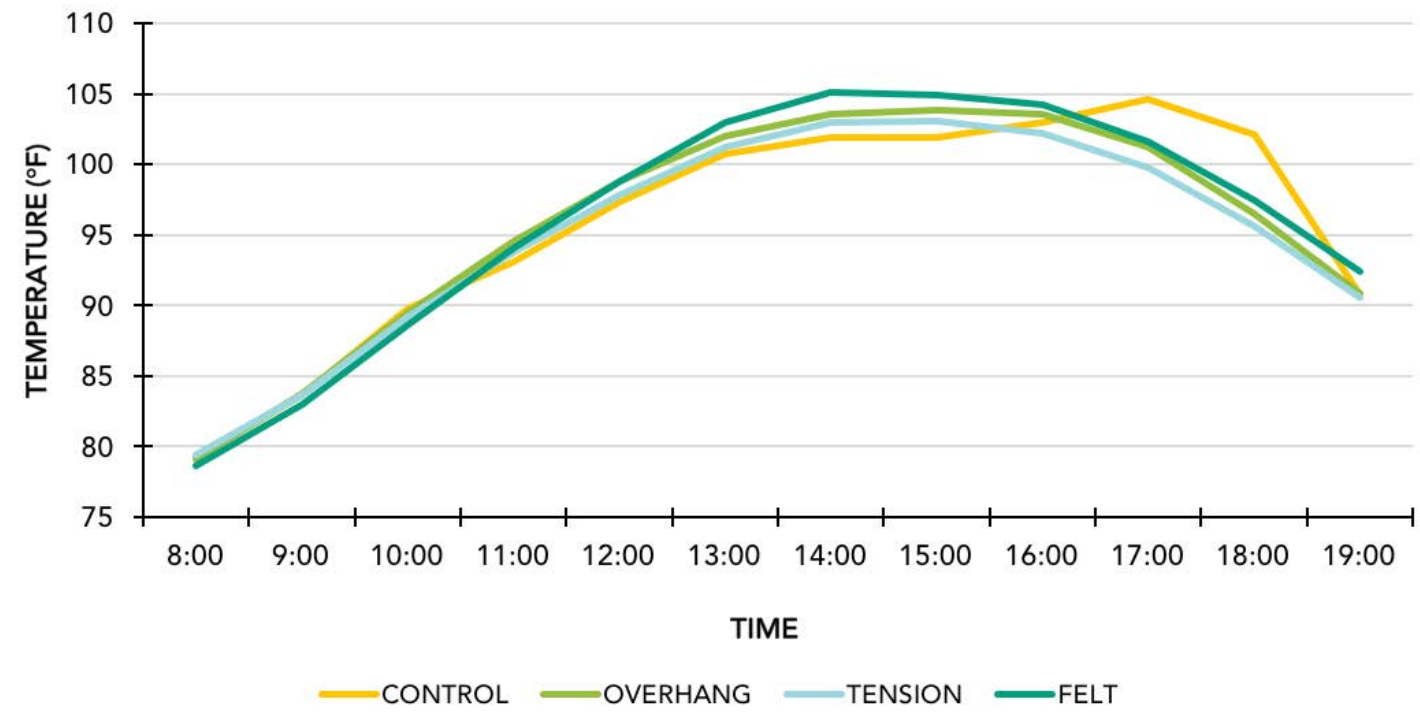


AVERAGE OUTDOOR AIR TEMPERATURE AT
FACADE SURFACE: 07/21



Time	Outdoor Average Temperature Difference (°F)			
	CONTROL	OVERHANG	TENSION	FELT
8:00 AM	---	0.00	-0.34	-0.52
9:00 AM	---	+0.12	-0.36	-3.45
10:00 AM	---	+0.50	+0.46	-2.45
11:00 AM	---	+1.41	+2.15	-0.80
12:00 PM	---	+0.80	+2.49	-0.98
1:00 PM	---	+0.40	+2.75	-0.90
2:00 PM	---	+1.08	+2.96	+0.10
3:00 PM	---	+1.37	+1.80	+0.18
4:00 PM	---	+1.04	-0.20	-0.71
5:00 PM	---	+0.27	-1.33	-1.56
6:00 PM	---	-0.89	-1.83	-1.64
7:00 PM	---	+0.39	-0.55	+0.34
AVG.	---	0.54	0.67	-1.03
PRE-INSTALL		+1.03	+0.63	+1.16
OVERALL		-0.49	0.04	-2.19

AVERAGE INDOOR AIR TEMPERATURE AT FACADE
SURFACE: 07/21



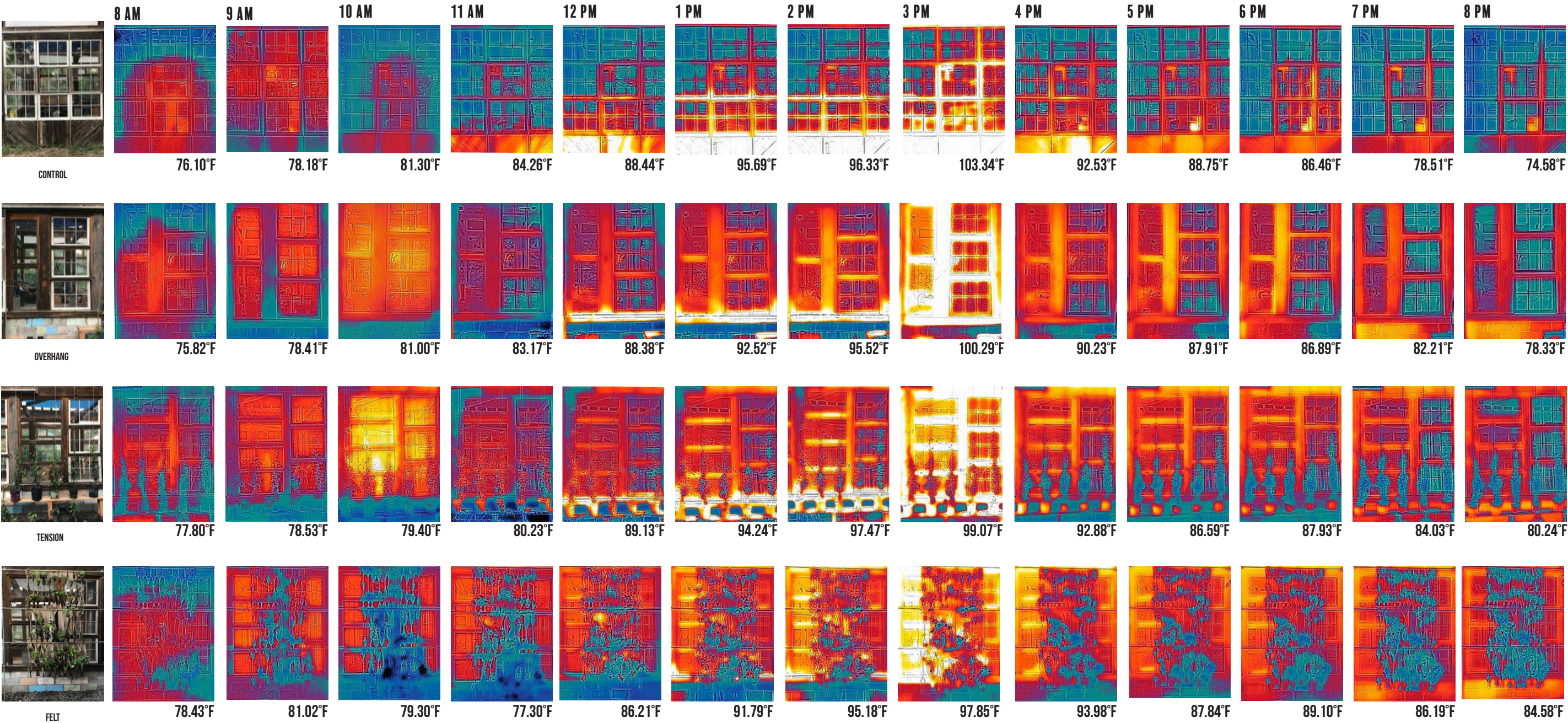
Time	Indoor Average Temperature Difference (°F)			
	CONTROL	OVERHANG	TENSION	FELT
8:00 AM	---	-0.08	0.20	-0.61
9:00 AM	---	+0.07	0.00	-0.67
10:00 AM	---	-0.27	-0.51	-1.14
11:00 AM	---	+1.44	+0.64	+0.95
12:00 PM	---	+1.41	+0.40	+1.44
1:00 PM	---	+1.31	+0.56	+2.28
2:00 PM	---	+1.69	+1.06	+3.21
3:00 PM	---	+1.96	+1.15	+3.01
4:00 PM	---	+0.54	-0.78	+1.21
5:00 PM	---	-3.34	-4.87	-2.96
6:00 PM	---	-5.65	-6.48	-4.63
7:00 PM	---	+0.03	-0.18	+1.67
AVG.	---	-0.07	-0.73	0.31
PRE-INSTALL	---	+4.01	+6.10	+6.35
AVG.	---	-4.08	-6.83	-6.04

Hourly Thermal Images

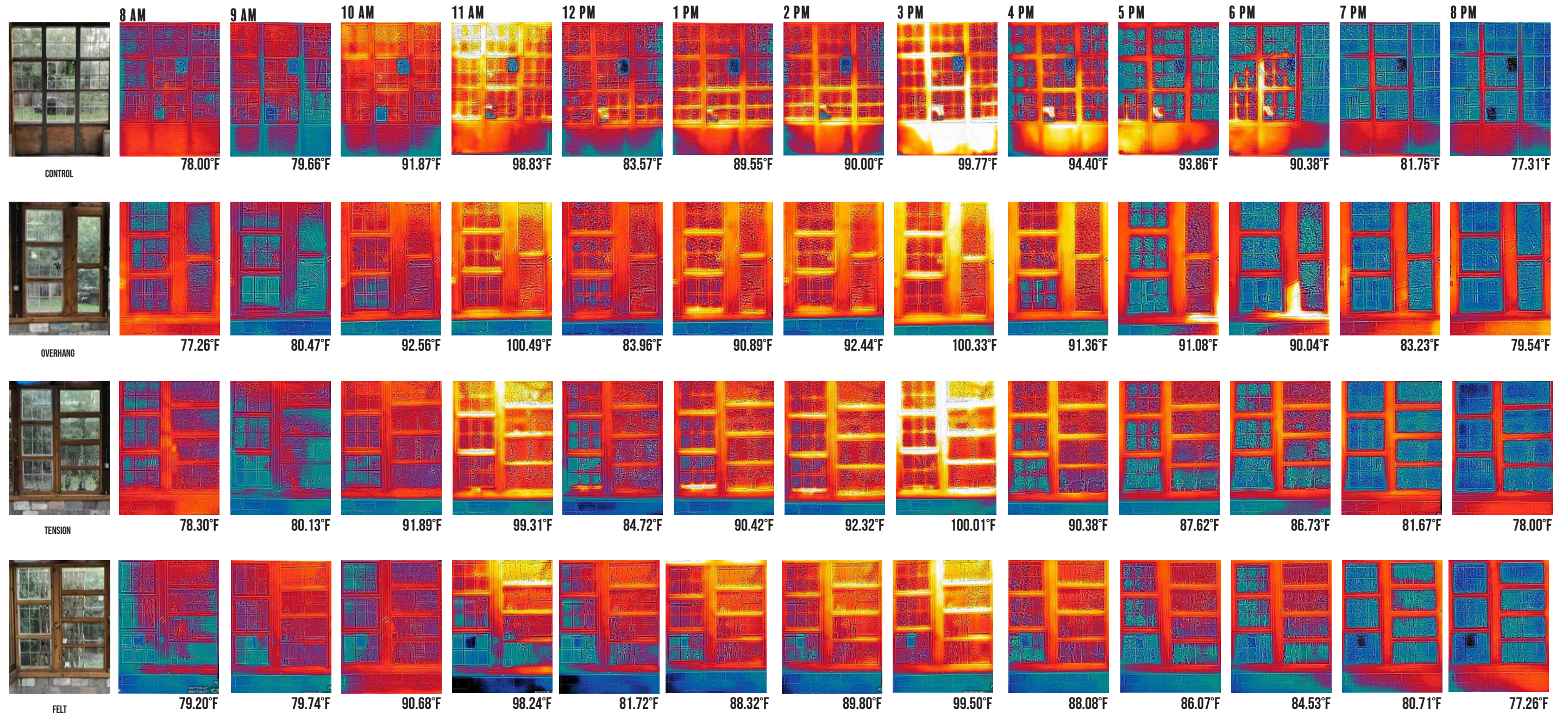
JULY 21, 2017

SUNNY

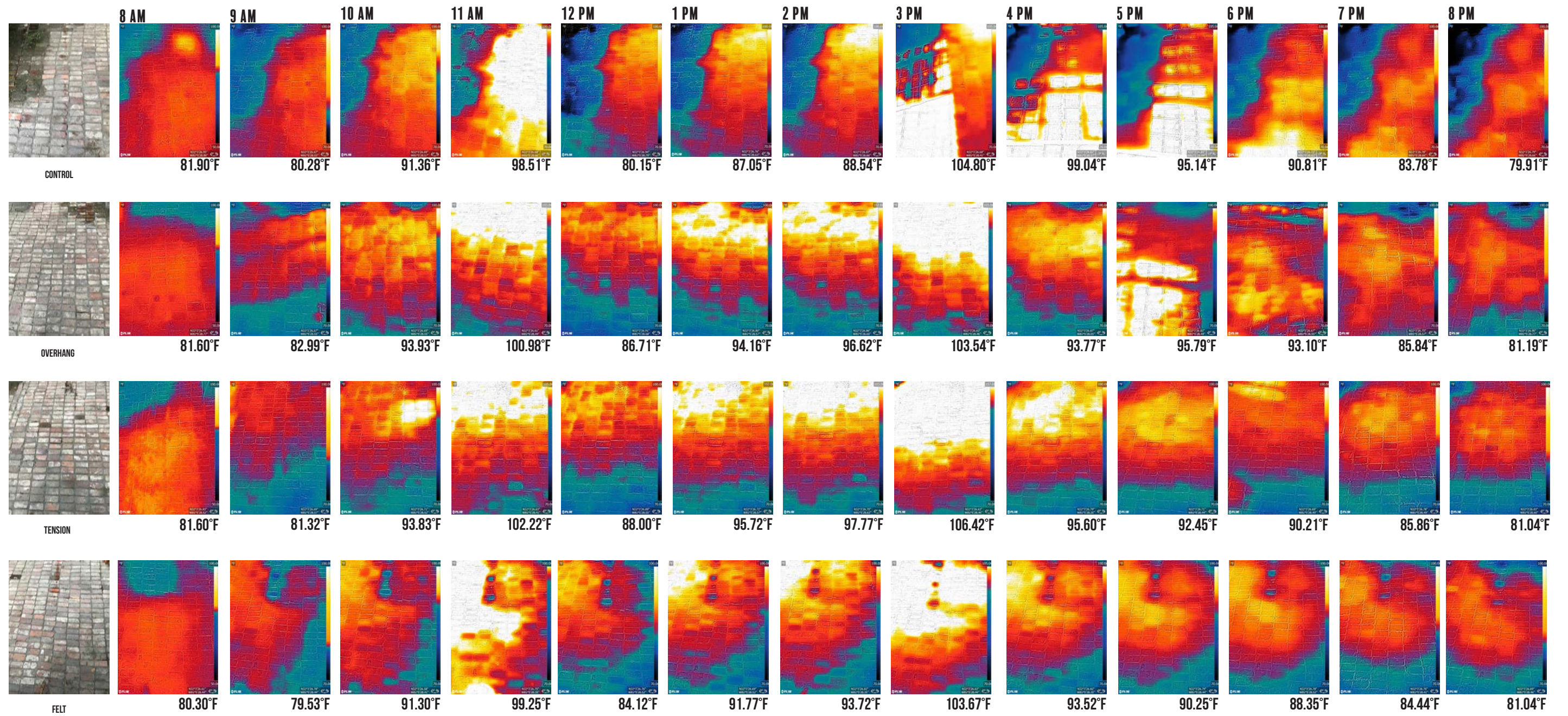
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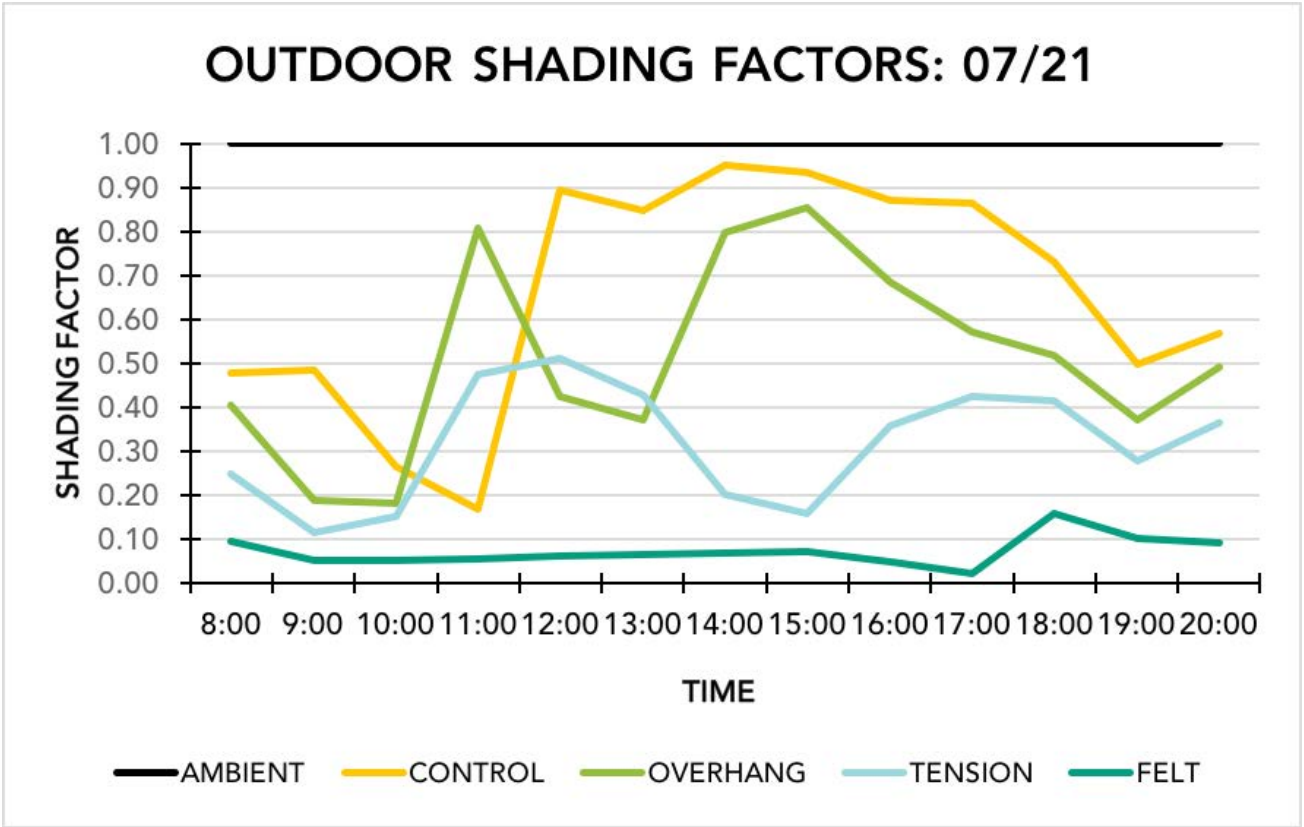


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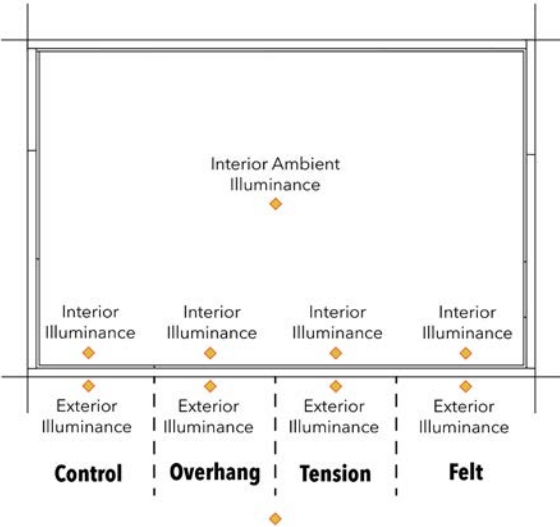
Illuminance Levels

Time	OUTDOOR ILLUMINANCE (LX)				
	AMBIENT	CONTROL	OVERHANG	TENSION	FELT
8:00 AM	6215	2970	2510	1530	583
9:00 AM	15800	7673	2980	1830	785
10:00 AM	20600	5440	3710	3100	1027
11:00 AM	78100	13200	62900	37100	4200
12:00 PM	78800	70400	33490	40200	4860
1:00 PM	81600	69200	30300	35000	5360
2:00 PM	82050	78050	65400	16495	5575
3:00 PM	82500	76900	70500	12990	5790
4:00 PM	72000	62700	49210	25830	3370
5:00 PM	56900	49100	32480	24180	1241
6:00 PM	6350	4630	3280	2640	1010
7:00 PM	3710	1850	1377	1036	372
8:00 PM	1363	774	668	495	123



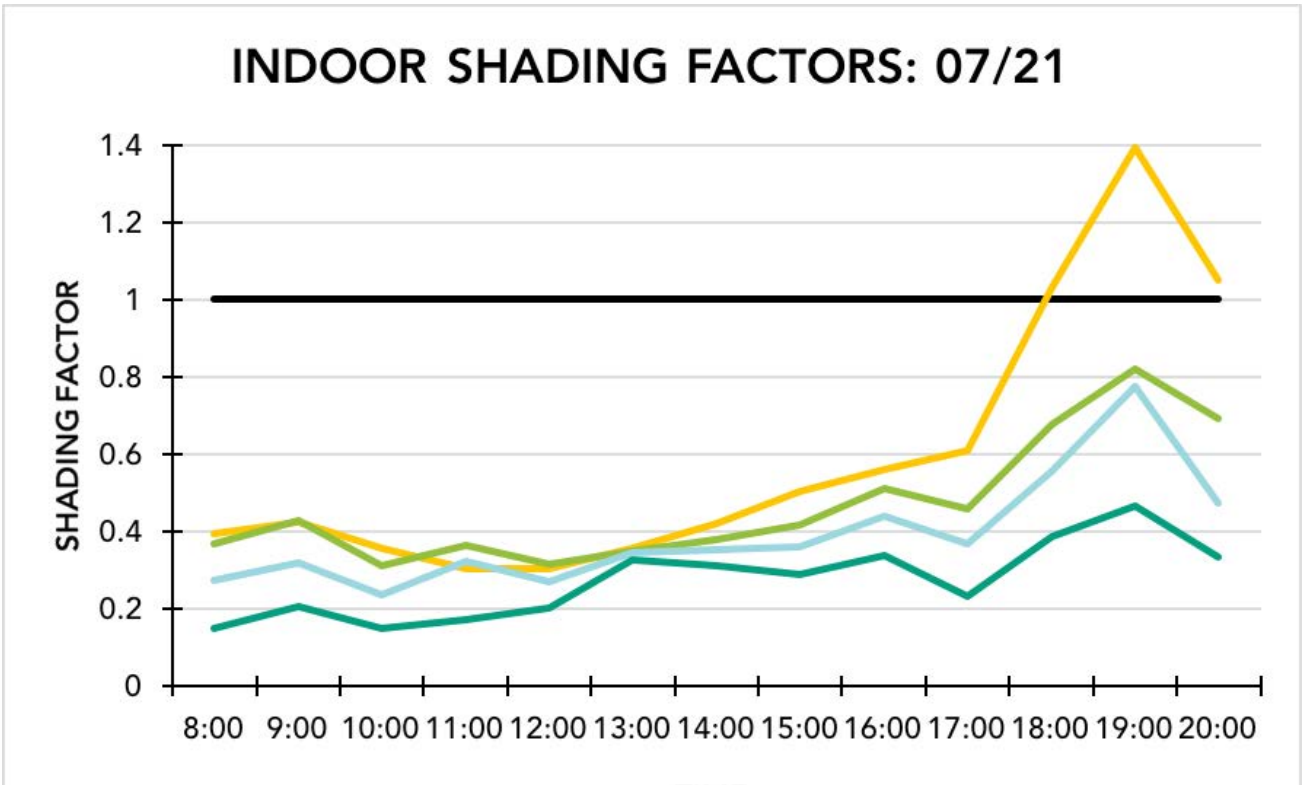
AVERAGE OUTDOOR SHADING FACTOR				
AMBI-ENT	CON-TROL	OVER-HANG	TEN-SION	FELT
1.00	0.67	0.52	0.31	0.07

Illuminance Level Reading Locations

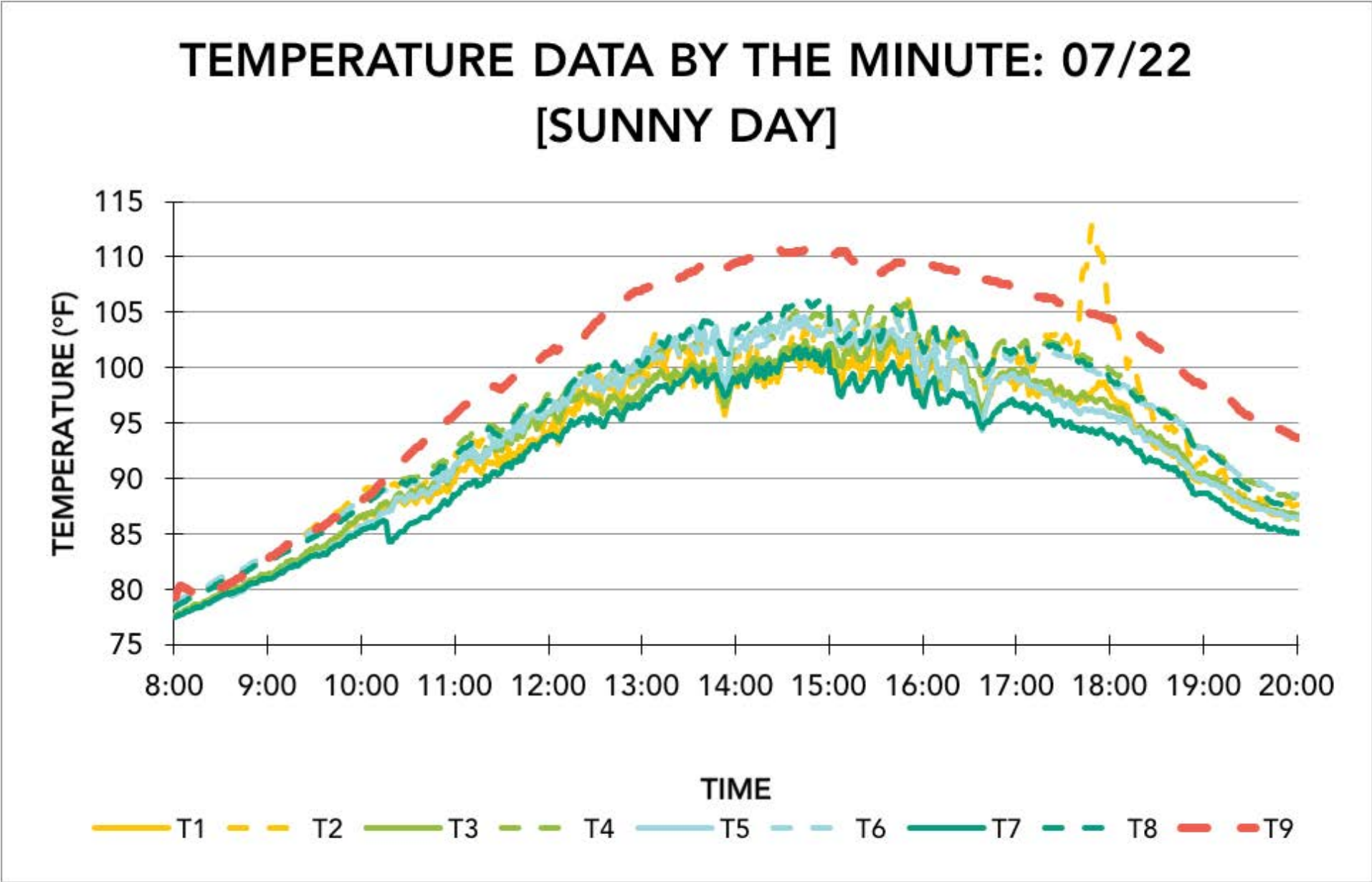
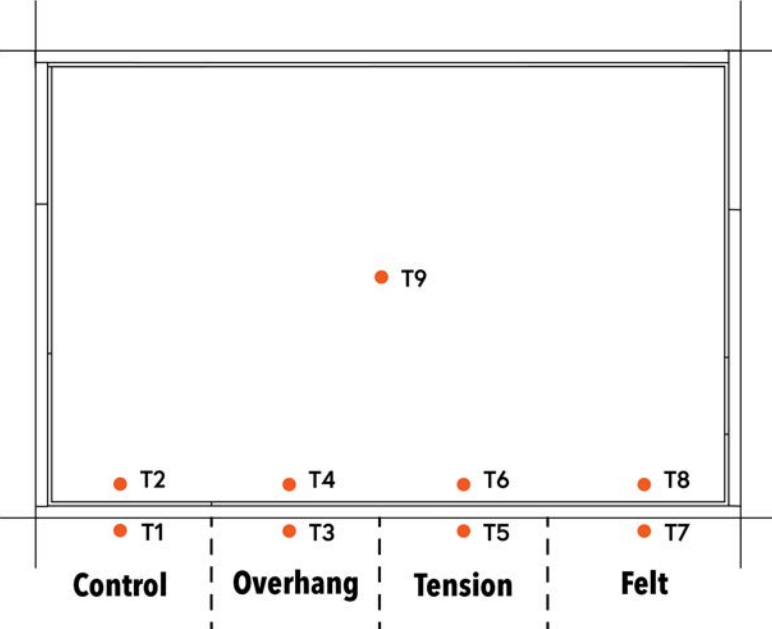


AVERAGE INDOOR SHADING FACTOR				
AMBI-ENT	CON-TROL	OVER-HANG	TEN-SION	FELT
1.00	0.59	0.47	0.39	0.27

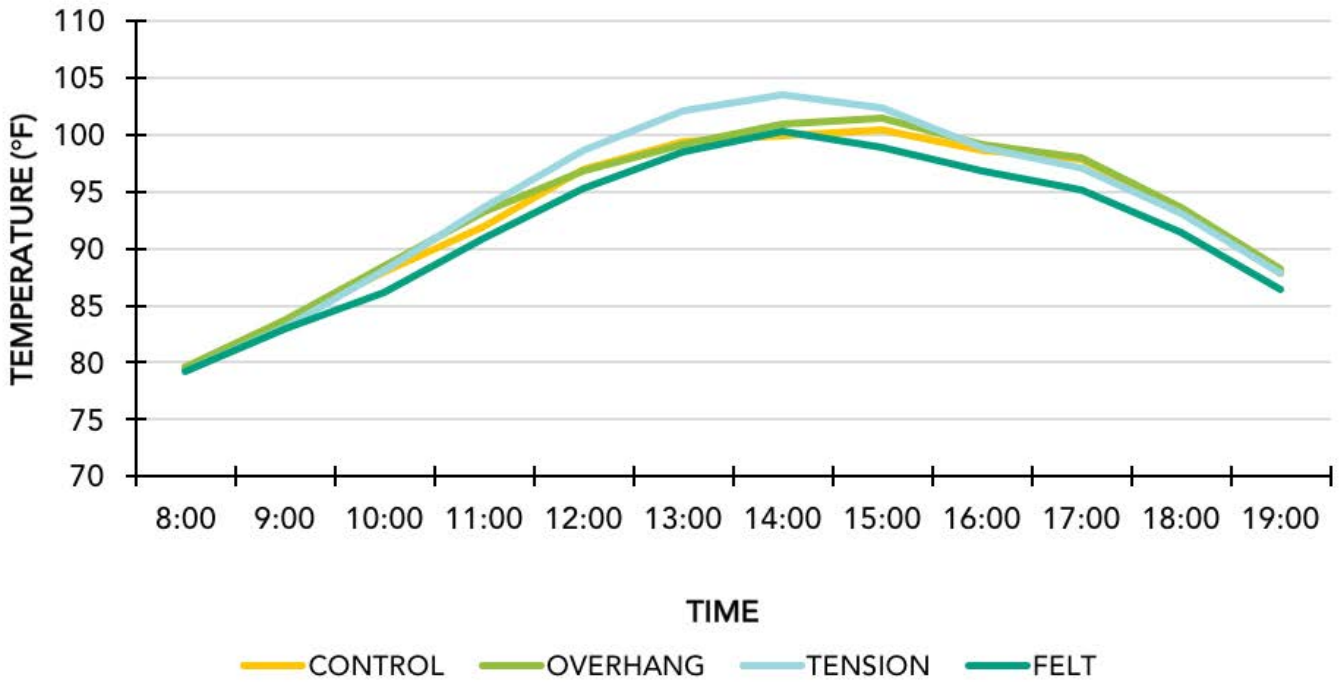
Time	INDOOR ILLUMINANCE (LX)				
	AMBIENT	CONTROL	OVERHANG	TENSION	FELT
8:00 AM	4100	1622	1501	1125	614
9:00 AM	4300	1822	1840	1366	891
10:00 AM	6960	2490	2170	1649	1050
11:00 AM	10900	3330	3980	3510	1870
12:00 PM	14800	4480	4680	4020	3010
1:00 PM	14900	5340	5210	5170	4880
2:00 PM	13095	5510	4955	4620	4080
3:00 PM	11290	5680	4700	4070	3280
4:00 PM	7640	4270	3900	3360	2580
5:00 PM	5270	3210	2420	1931	1231
6:00 PM	3050	3150	2060	1700	1180
7:00 PM	991	1381	812	767	463
8:00 PM	412	433	285	195	138



Temperature Reading Locations

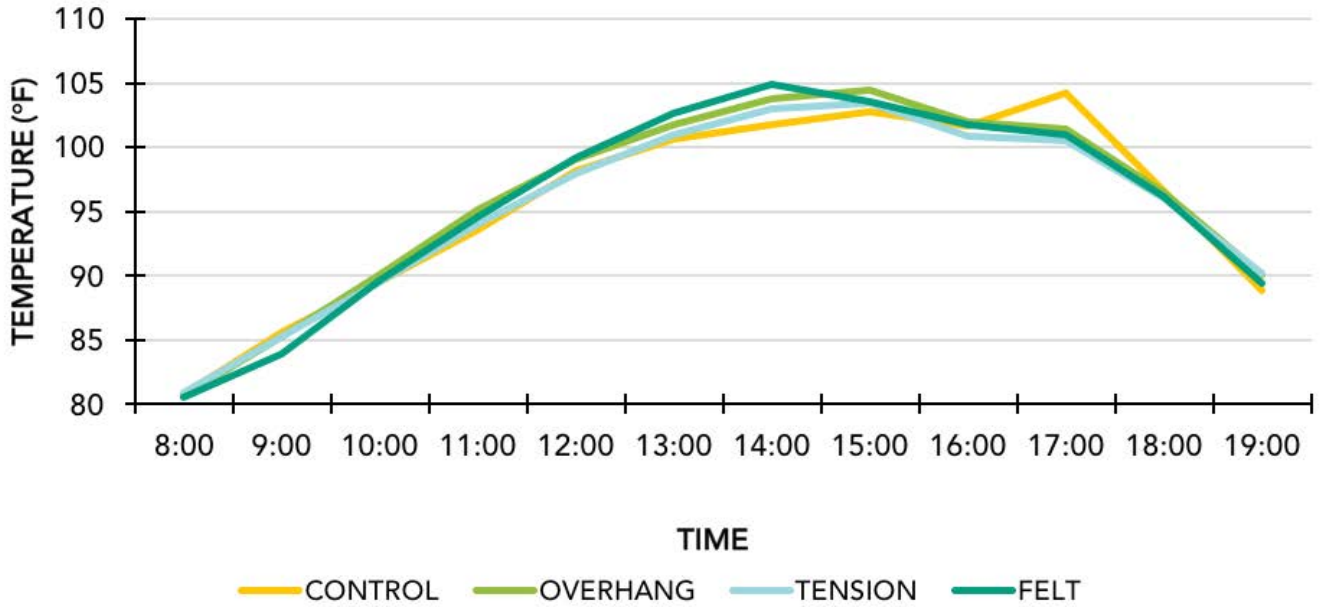


AVERAGE OUTDOOR AIR TEMPERATURE AT
FACADE SURFACE: 07/22



Time	Outdoor Average Temperature Difference (°F)			
	CONTROL	OVERHANG	TENSION	FELT
8:00 AM	---	+0.14	-0.23	-0.15
9:00 AM	---	+0.18	-0.44	-0.56
10:00 AM	---	+0.57	+0.19	-1.76
11:00 AM	---	+1.30	+1.69	-0.98
12:00 PM	---	-0.07	+1.67	-1.66
1:00 PM	---	-0.25	+2.67	-0.90
2:00 PM	---	+0.99	+3.53	+0.40
3:00 PM	---	+1.12	+1.95	-1.52
4:00 PM	---	+0.56	+0.19	-1.84
5:00 PM	---	+0.12	-0.74	-2.66
6:00 PM	---	+0.23	-0.26	-1.89
7:00 PM	---	+0.39	+0.12	-1.30
AVG.	---	+0.44	+0.86	-1.24
PRE-INSTALL		+1.03	+0.63	+1.16
OVERALL		-0.59	+0.23	-2.40

AVERAGE INDOOR AIR TEMPERATURE AT
FACADE SURFACE: 07/22

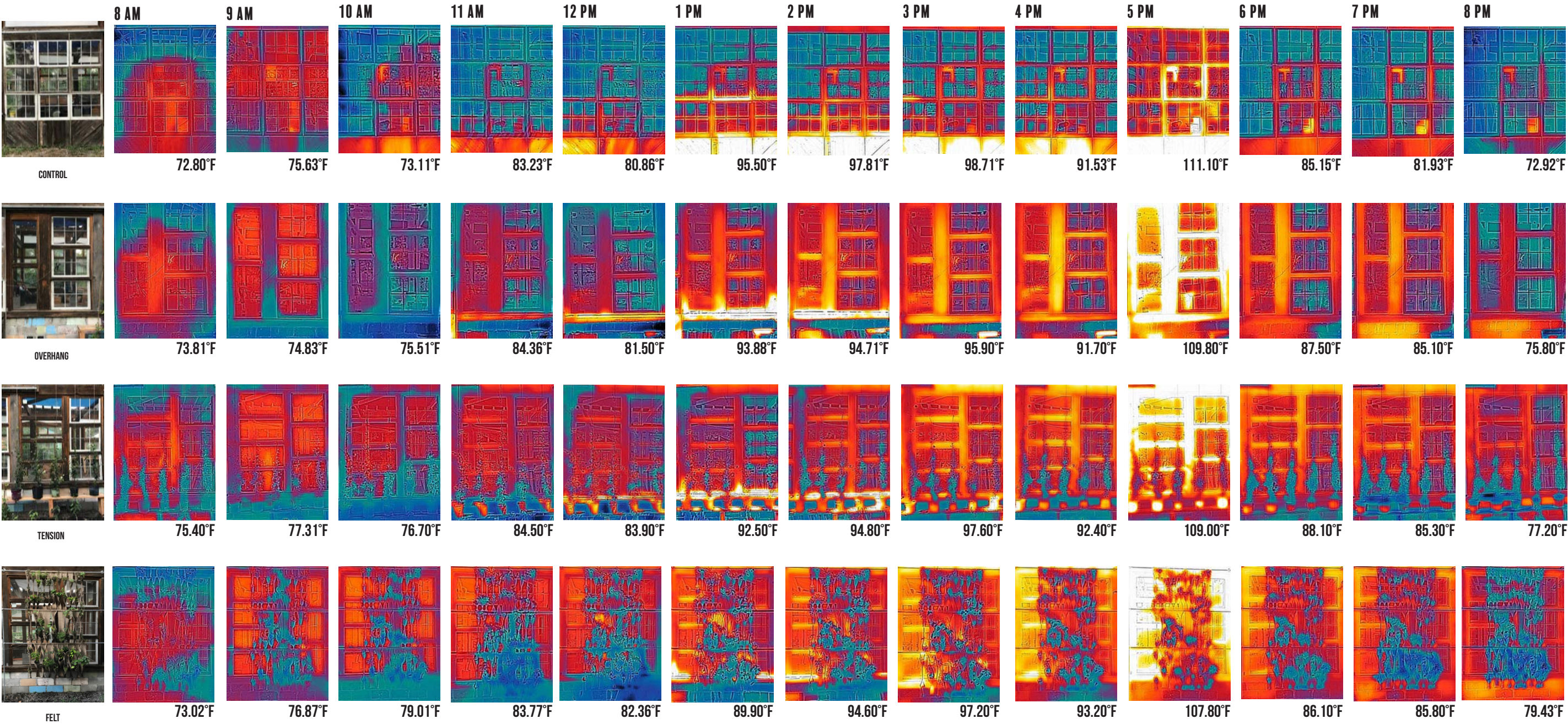


Time	Indoor Average Temperature Difference (°F)			
	CONTROL	OVERHANG	TENSION	FELT
8:00 AM	---	-0.12	+0.18	-0.23
9:00 AM	---	-0.29	-0.26	-1.68
10:00 AM	---	+0.58	+0.00	+0.15
11:00 AM	---	+1.57	+0.43	+1.05
12:00 PM	---	+0.96	-0.23	+1.08
1:00 PM	---	+1.13	+0.39	+1.98
2:00 PM	---	+1.98	+1.18	+3.17
3:00 PM	---	+1.70	+0.70	+0.81
4:00 PM	---	+0.29	-0.79	+0.11
5:00 PM	---	-2.75	-3.66	-3.25
6:00 PM	---	-0.08	-0.47	-0.42
7:00 PM	---	+1.19	+1.34	+0.56
AVG.	---	+0.51	-0.10	+0.28
PRE-INSTALL	---	+4.01	+6.10	+6.35
AVG.	---	-3.50	-6.20	-6.07

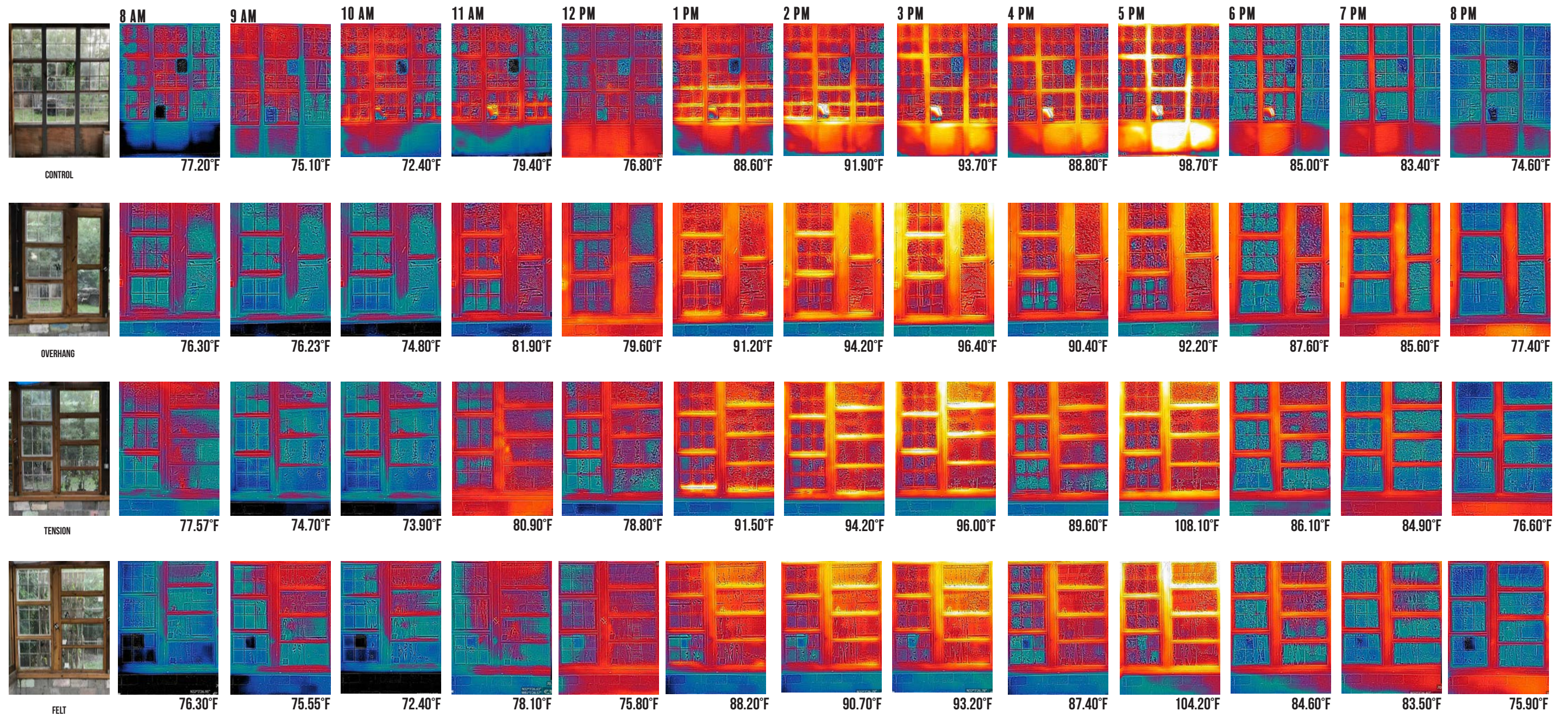
Hourly Thermal Images

JULY 22, 2017
SUNNY

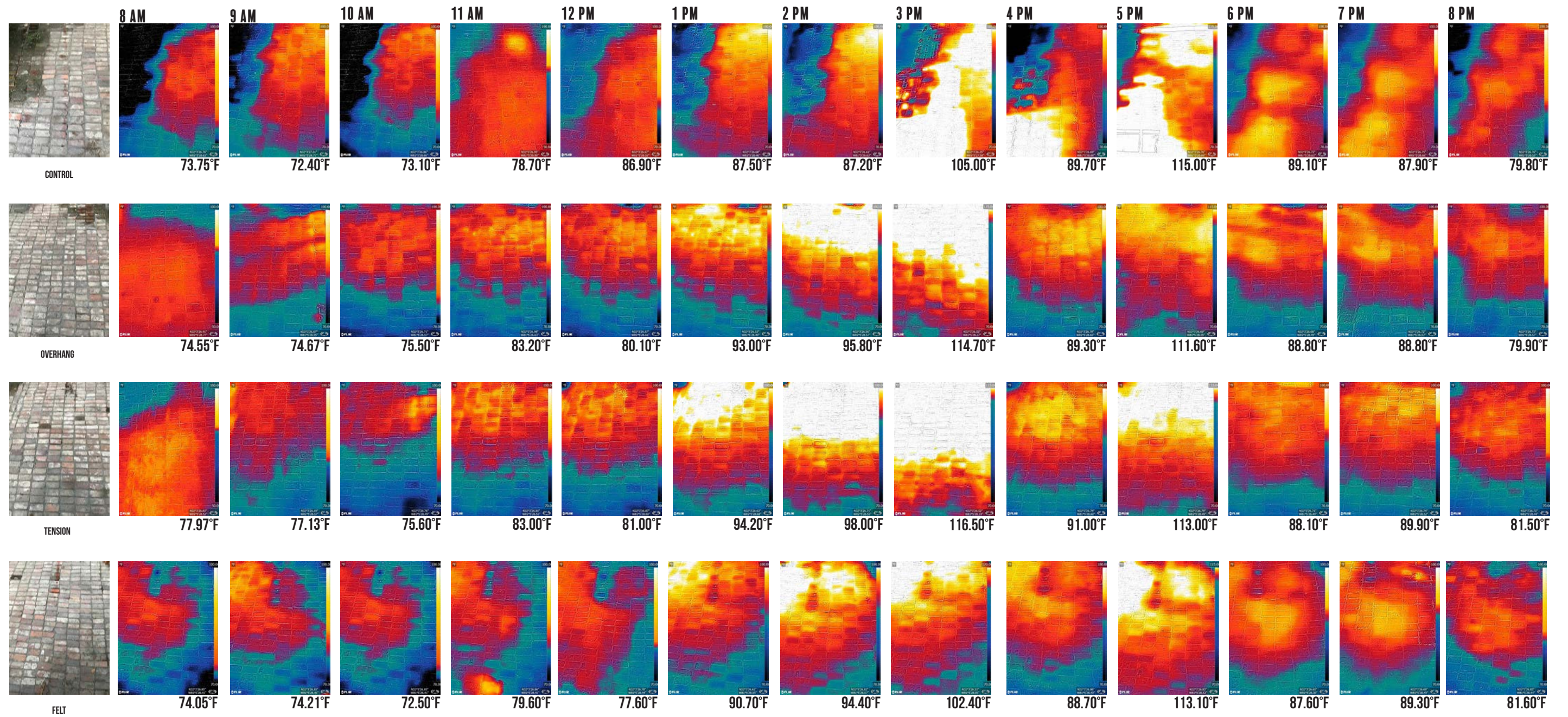
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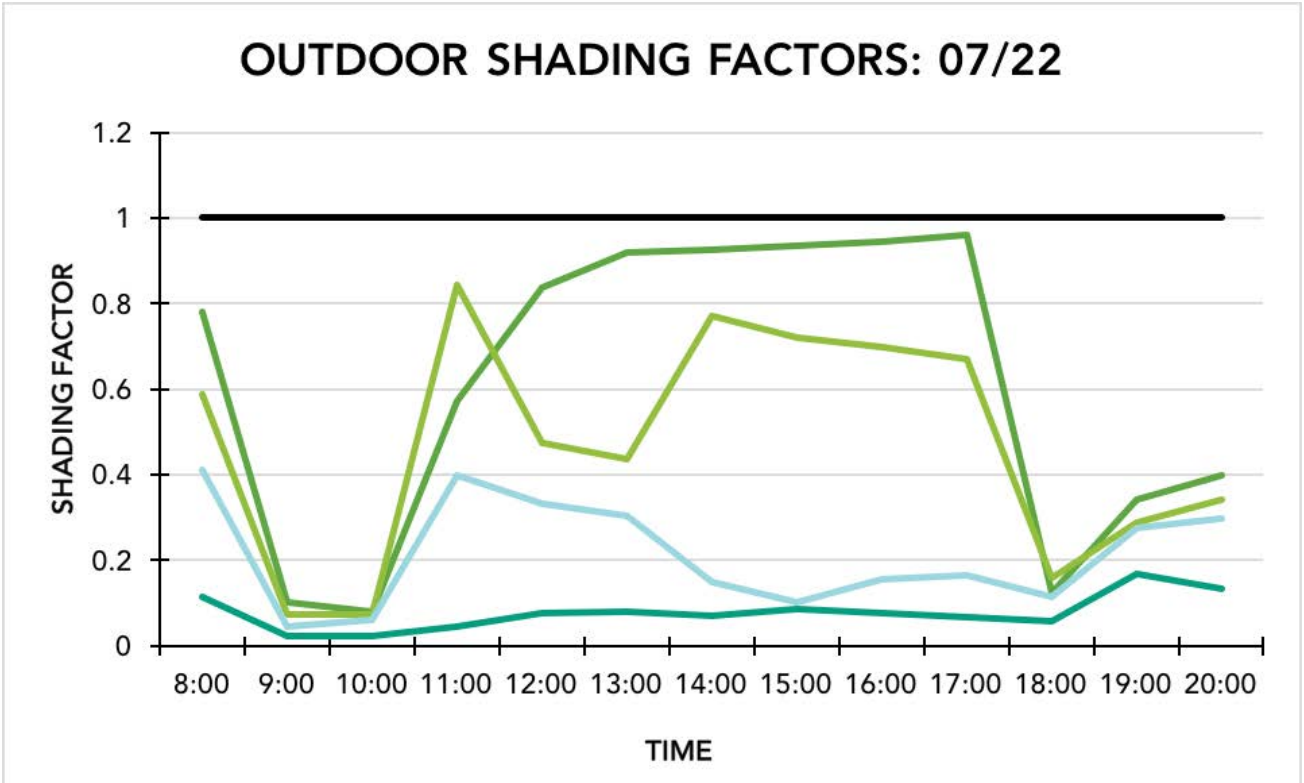


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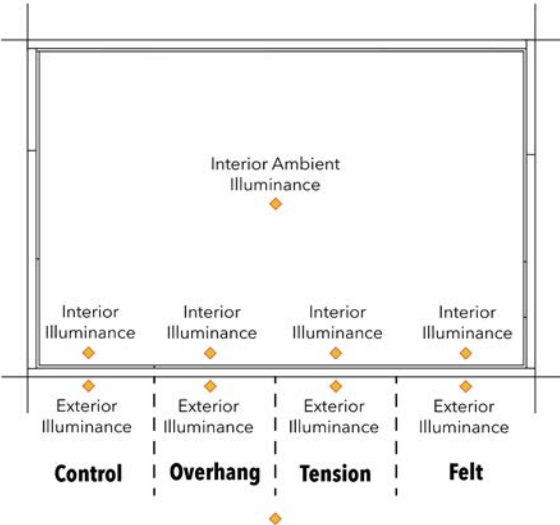
Illuminance Levels

Time	OUTDOOR ILLUMINANCE (LX)				
	AMBIENT	CONTROL	OVERHANG	TENSION	FELT
8:00 AM	5330	4160	3140	2190	613
9:00 AM	45300	4600	3350	2055	1030
10:00 AM	71900	5760	5290	4420	1670
11:00 AM	80600	46000	68000	32080	3550
12:00 PM	81300	68000	38500	27000	6190
1:00 PM	84300	77400	36800	25700	6650
2:00 PM	80600	74600	62070	12050	5590
3:00 PM	82000	76700	59020	8380	6950
4:00 PM	66950	63250	46860	10470	5205
5:00 PM	51900	49800	34700	8560	3460
6:00 PM	22700	2810	3590	2630	1320
7:00 PM	4660	1590	1350	1281	786
8:00 PM	1180	470	402	352	159

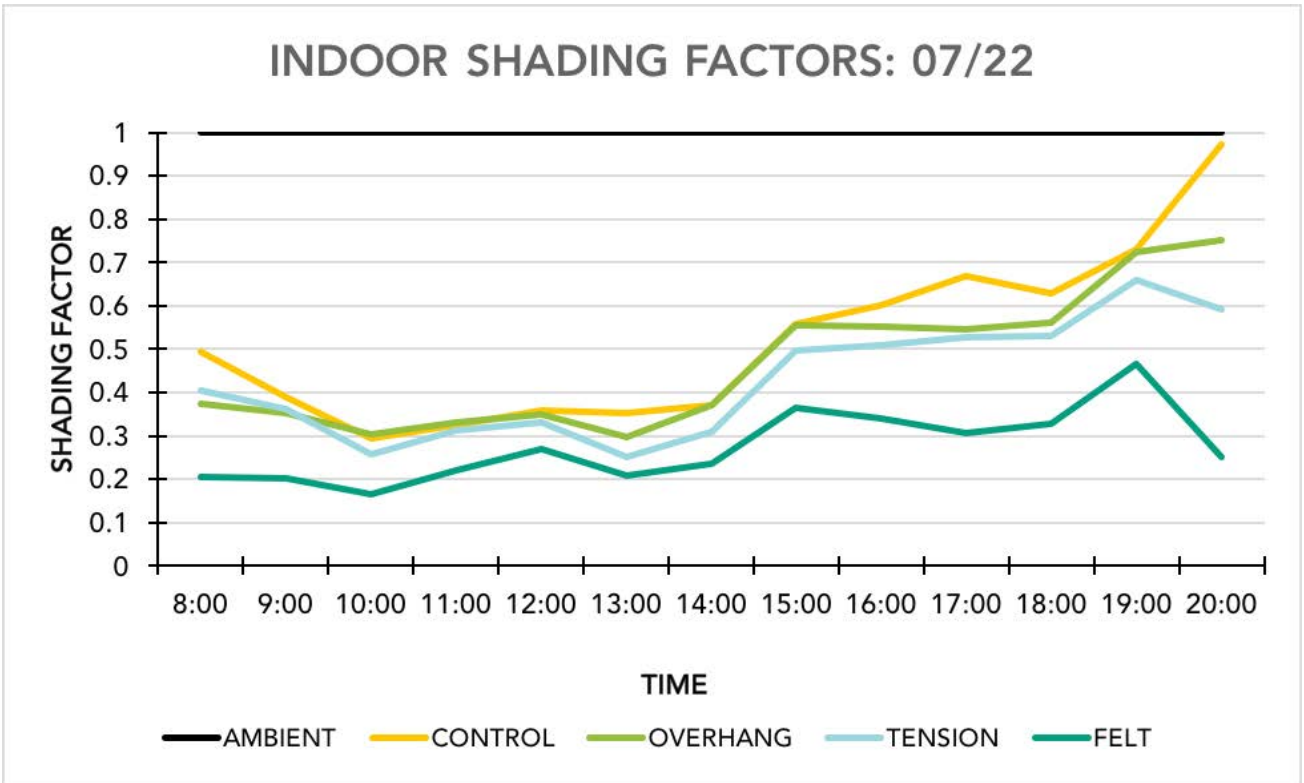


AVERAGE OUTDOOR SHADING FACTOR				
AMBIENT	CONTROL	OVERHANG	TENSION	FELT
1.00	0.63	0.48	0.21	0.07

Illuminance Level Reading Locations



Time	INDOOR ILLUMINANCE (LX)				
	AMBIENT	CONTROL	OVERHANG	TENSION	FELT
8:00 AM	3500	1730	1304	1413	716
9:00 AM	5100	1985	1798	1836	1024
10:00 AM	7950	2330	2420	2050	1320
11:00 AM	11470	3730	3780	3600	2530
12:00 PM	11470	4120	4000	3780	3080
1:00 PM	17400	6110	5170	4380	3630
2:00 PM	14390	5350	5320	4440	3400
3:00 PM	8750	4890	4860	4350	3180
4:00 PM	7205	4335	3970	3670	2455
5:00 PM	5660	3780	3080	2990	1730
6:00 PM	2590	1631	1453	1372	846
7:00 PM	1233	899	891	813	573
8:00 PM	290	282	218	172	73



AVERAGE INDOOR SHADING FACTOR				
AMBIENT	CONTROL	OVERHANG	TENSION	FELT
1.00	0.52	0.47	0.43	0.27

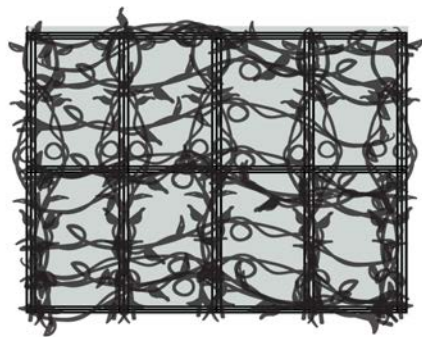
AVERAGE DECREASE IN OUTDOOR TEMPERATURE (°F)				
	CONTROL	OVERHANG	TENSION	FELT
JULY18	---	-1.04	-0.7	-3.54
JULY 21	---	-0.49	0.04	-2.19
JULY 22	---	-0.59	0.23	-2.4
AVERAGE	---	-0.71	-0.14	-2.71

AVERAGE DECREASE IN INDOOR TEMPERATURE (°F)				
	CONTROL	OVERHANG	TENSION	FELT
JULY18	---	-4.82	-7.27	-7.4
JULY 21	---	-4.08	-6.83	-6.04
JULY 22	---	-3.5	-6.2	-6.07
AVERAGE	---	-4.13	-6.77	-6.50

AVERAGE OUTDOOR SHADOW FACTOR				
	CONTROL	OVERHANG	TENSION	FELT
JULY18	0.60	0.45	0.30	0.07
JULY 21	0.67	0.51	0.31	0.07
JULY 22	0.63	0.48	0.21	0.07
AVERAGE	0.63	0.48	0.27	0.07

AVERAGE INDOOR SHADOW FACTOR				
	CONTROL	OVERHANG	TENSION	FELT
JULY18	1.40	0.77	0.68	0.50
JULY 21	0.59	0.47	0.39	0.27
JULY 22	0.75	0.53	0.36	0.18
AVERAGE	0.92	0.59	0.48	0.32

35%
COVERAGE



Overhang System

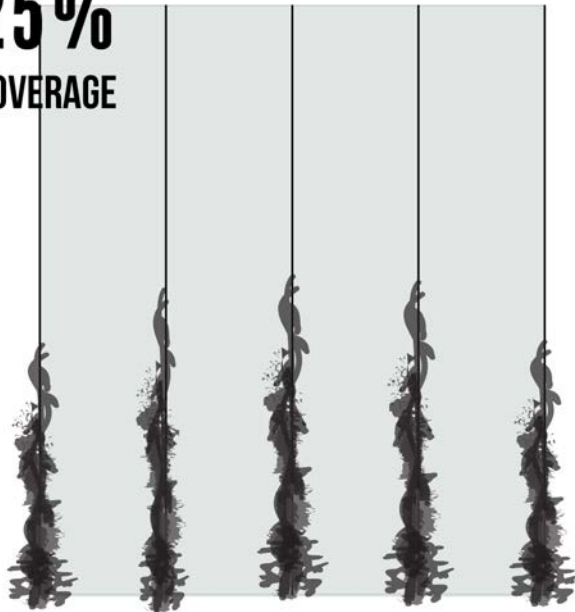
At current coverage
Decrease in Surface Temperature

Outdoor: -0.71°F
Indoor: -4.13°F

At full coverage
Decrease in Surface Temperature

Outdoor: -2.03°F
Indoor: -11.8°F

25%
COVERAGE



Tension System

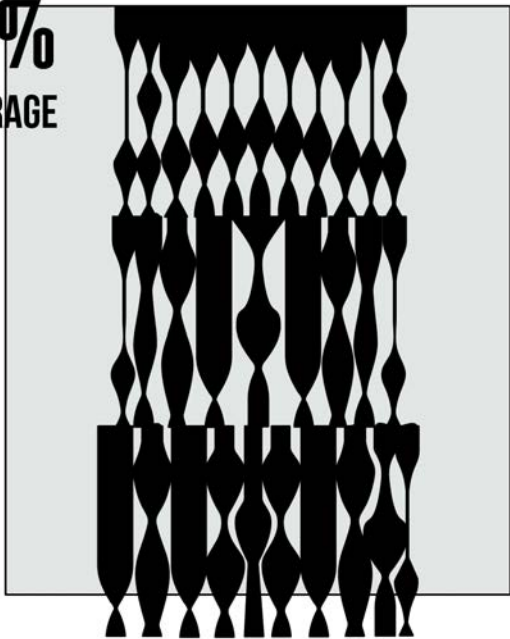
At current coverage
Decrease in Surface Temperature

Outdoor: -0.14°F
Indoor: -6.77°F

At full coverage
Decrease in Surface Temperature

Outdoor: -2.71°F
Indoor: -27.07°F

39%
COVERAGE



Felt System

At current coverage
Decrease in Surface Temperature

Outdoor: -2.71°F
Indoor: -6.50°F

At full coverage
Decrease in Surface Temperature

Outdoor: -6.95°F
Indoor: -16.17°F



Agricultural Potential

Of Green facade systems

Tension and Overhang Systems

Overhang System



MUSCADINE GRAPES

Common Yield:
2 Tons/ Acre *

30 SF Growing Area Available =

2.75lbs
Predicted yield

*Source: NC State University (2003)

Tension System

BEANS

5 Rows @ 16" O.C

Expected Yield:

3.50lbs
*per Growing Season

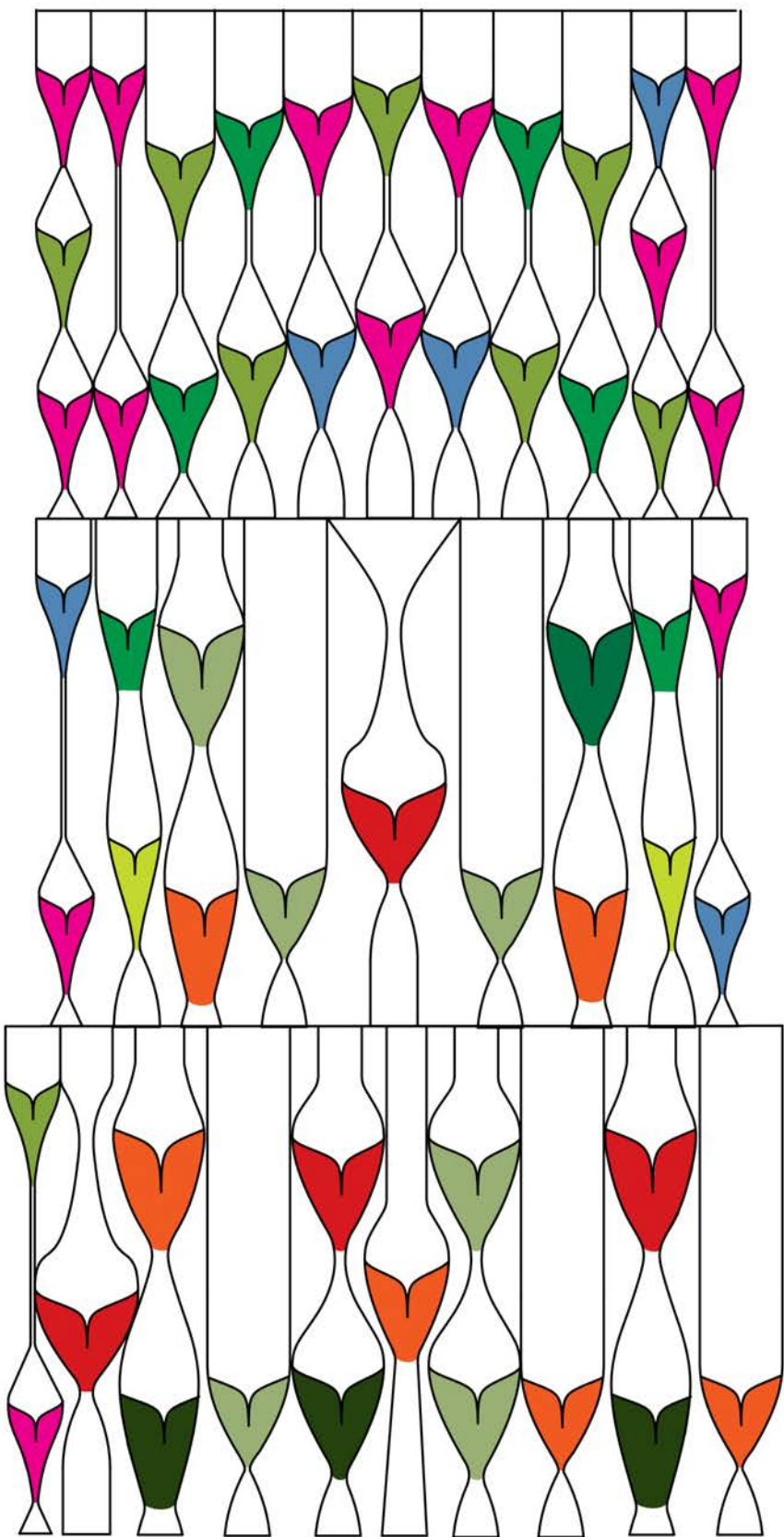
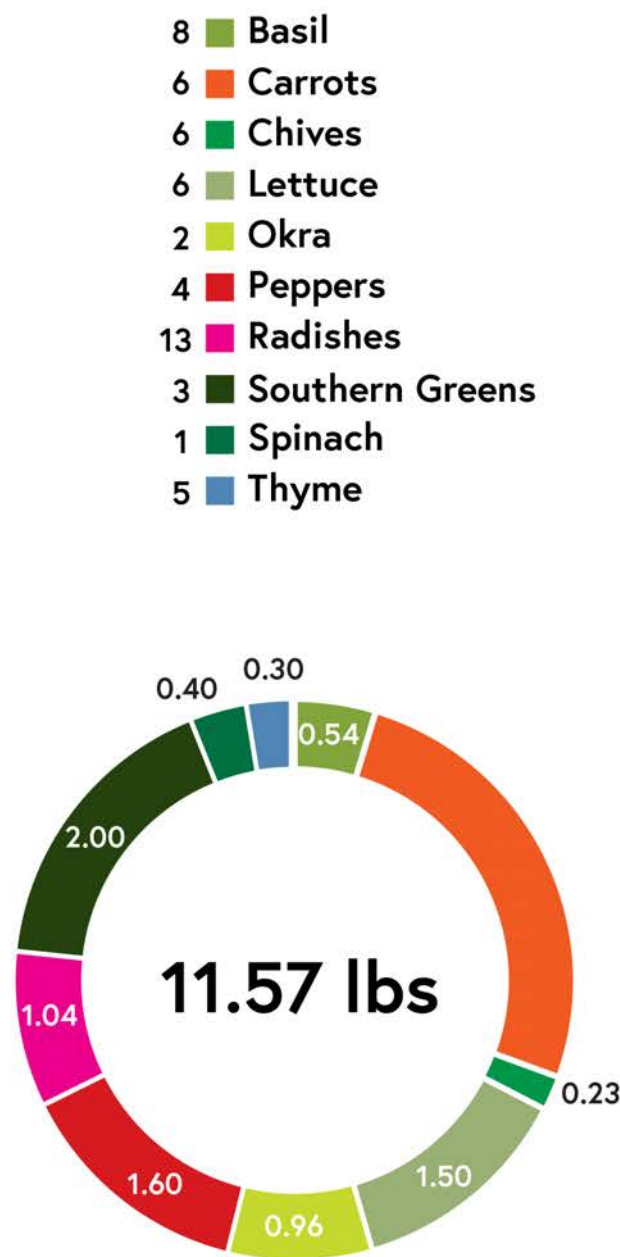


*Source: <http://www.ufseeds.com/Crop-Calculators.html>

Agricultural Possibilities: Felt System

54 Pockets
7 Ft³ of growing medium

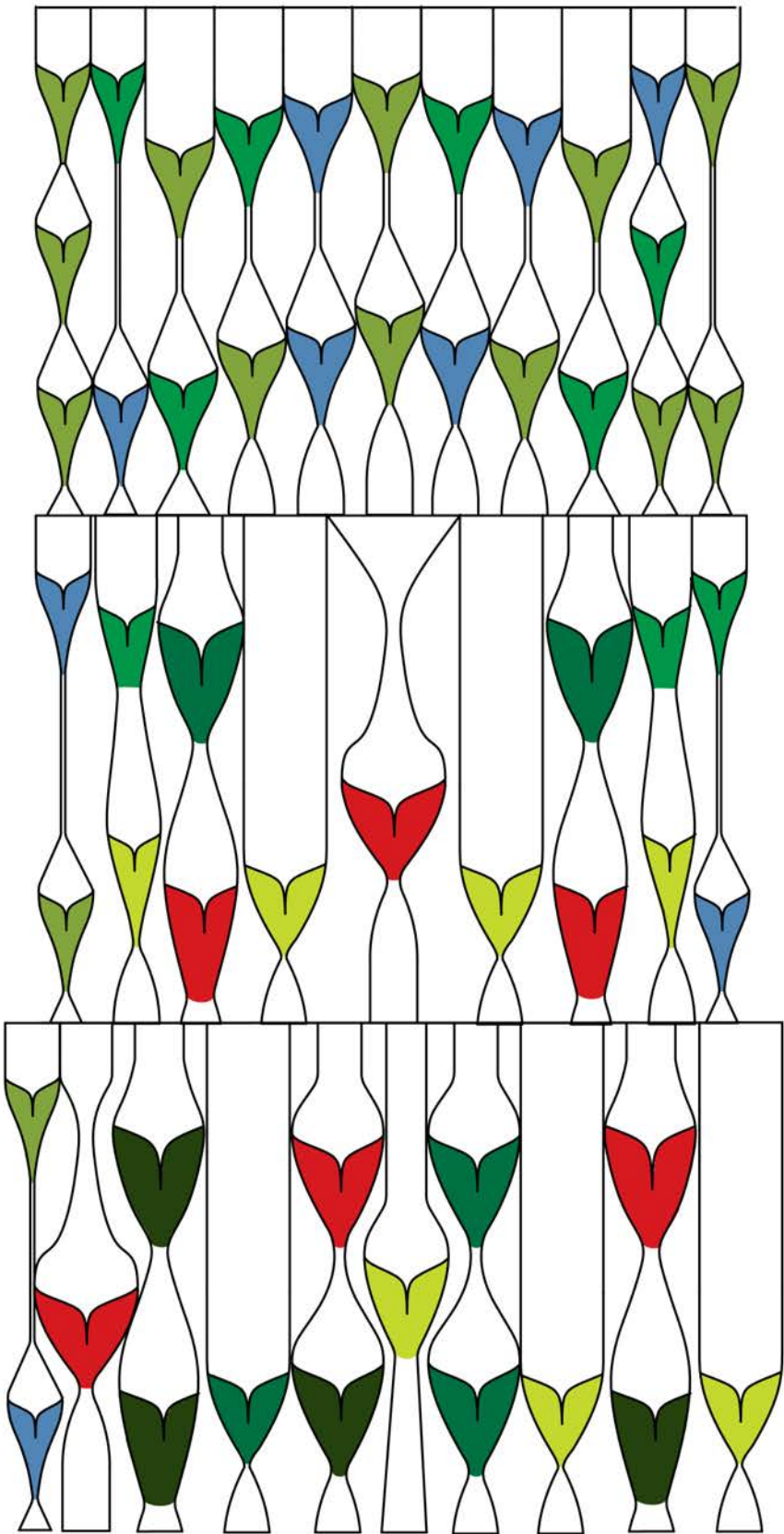
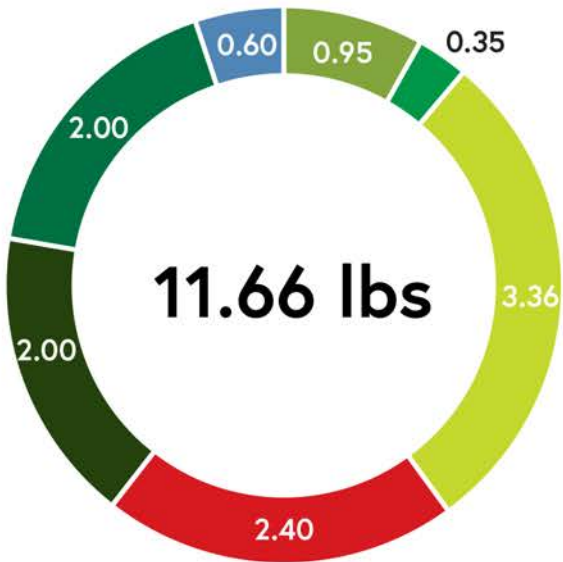
Late Spring / Early Summer



Agricultural Possibilities: Felt System

Full Summer

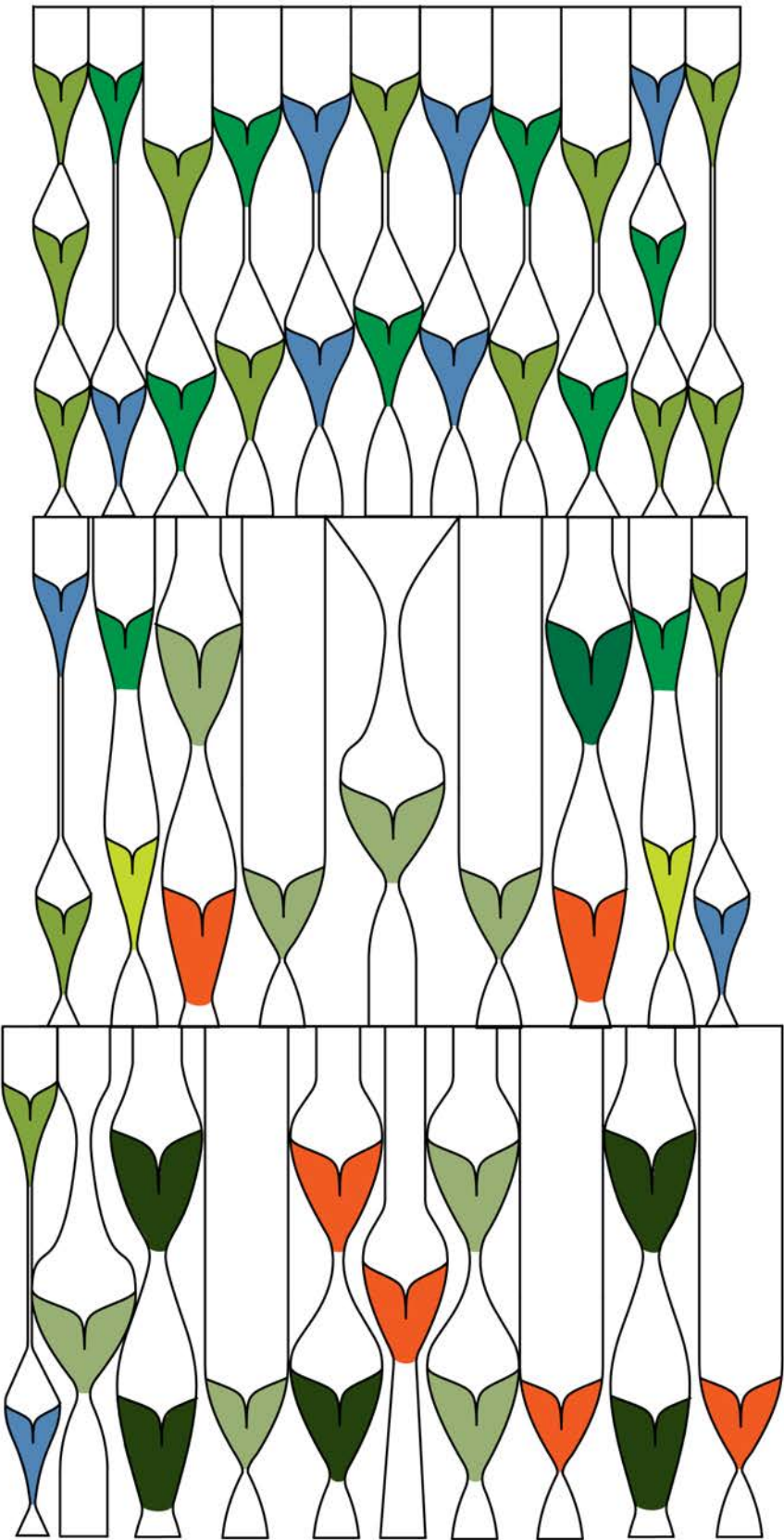
- 14 Basil
- Carrots
- 9 Chives
- Lettuce
- 7 Okra
- 6 Peppers
- Radishes
- 4 Southern Greens
- 5 Spinach
- 9 Thyme



Agricultural Possibilities: Felt System

Late Summer / Early Fall

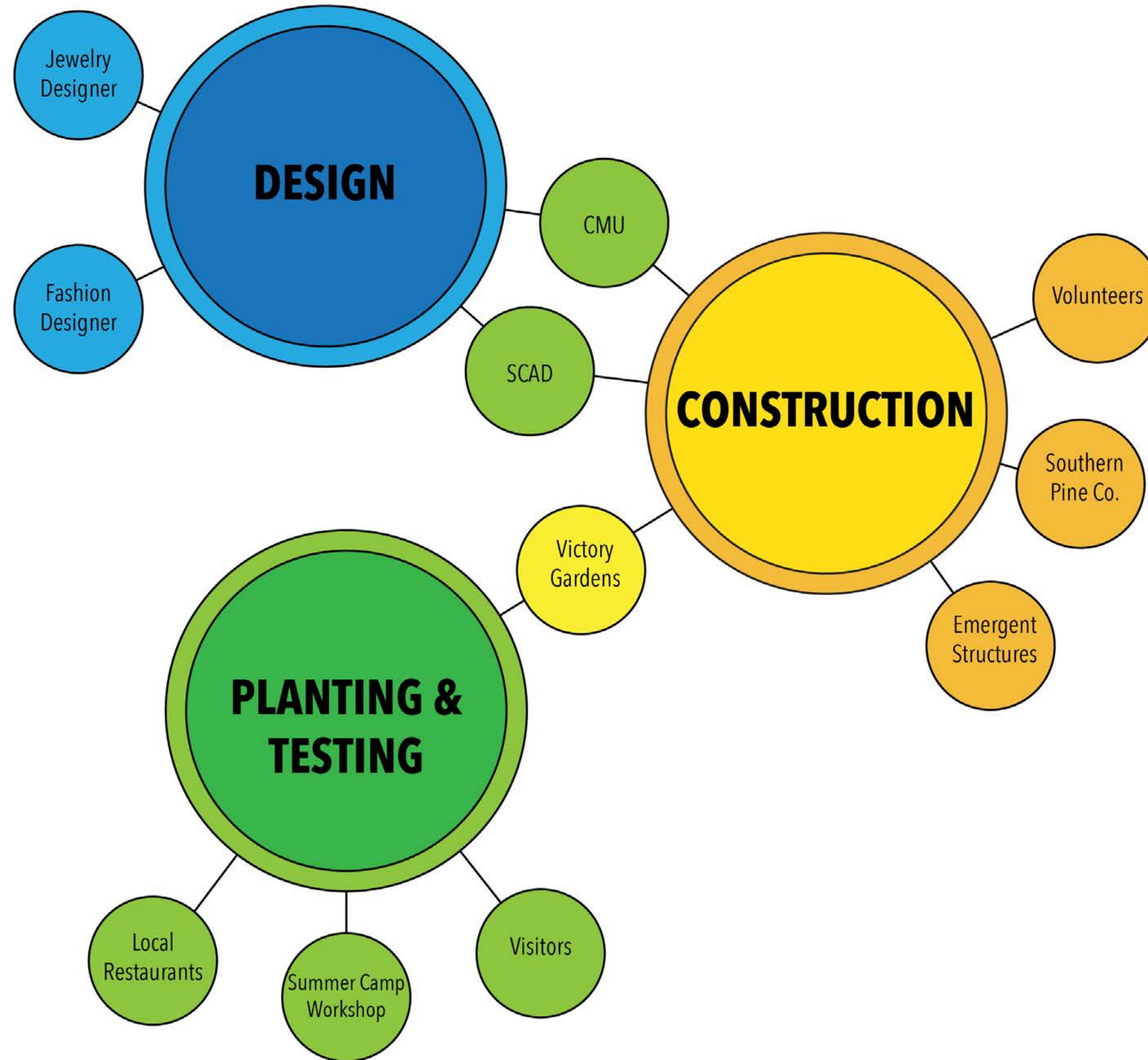
- 14 Basil
- 6 Carrots
- 9 Chives
- 8 Lettuce
- 2 Okra
- Peppers
- Radishes
- 5 Southern Greens
- 1 Spinach
- 9 Thyme

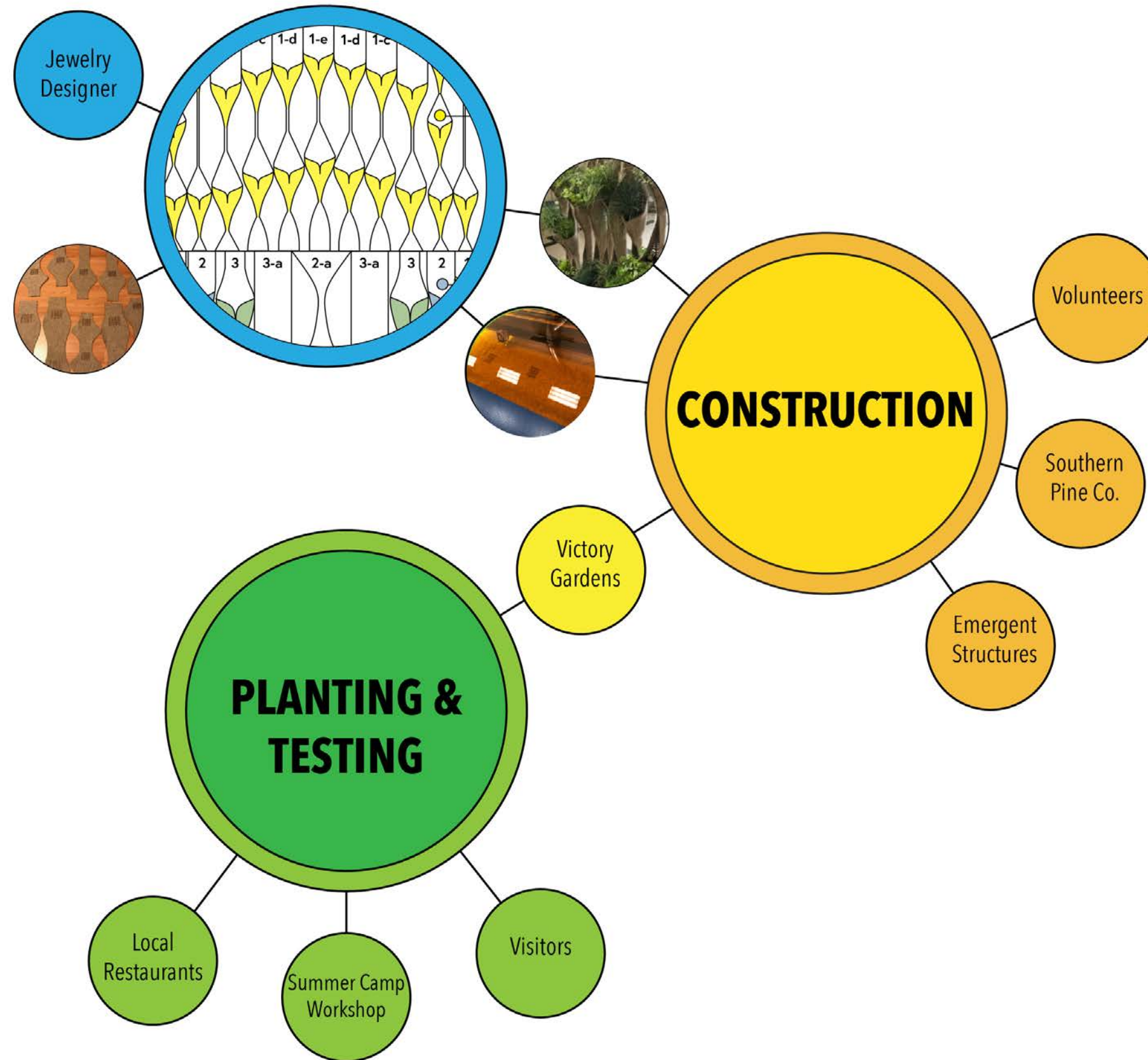


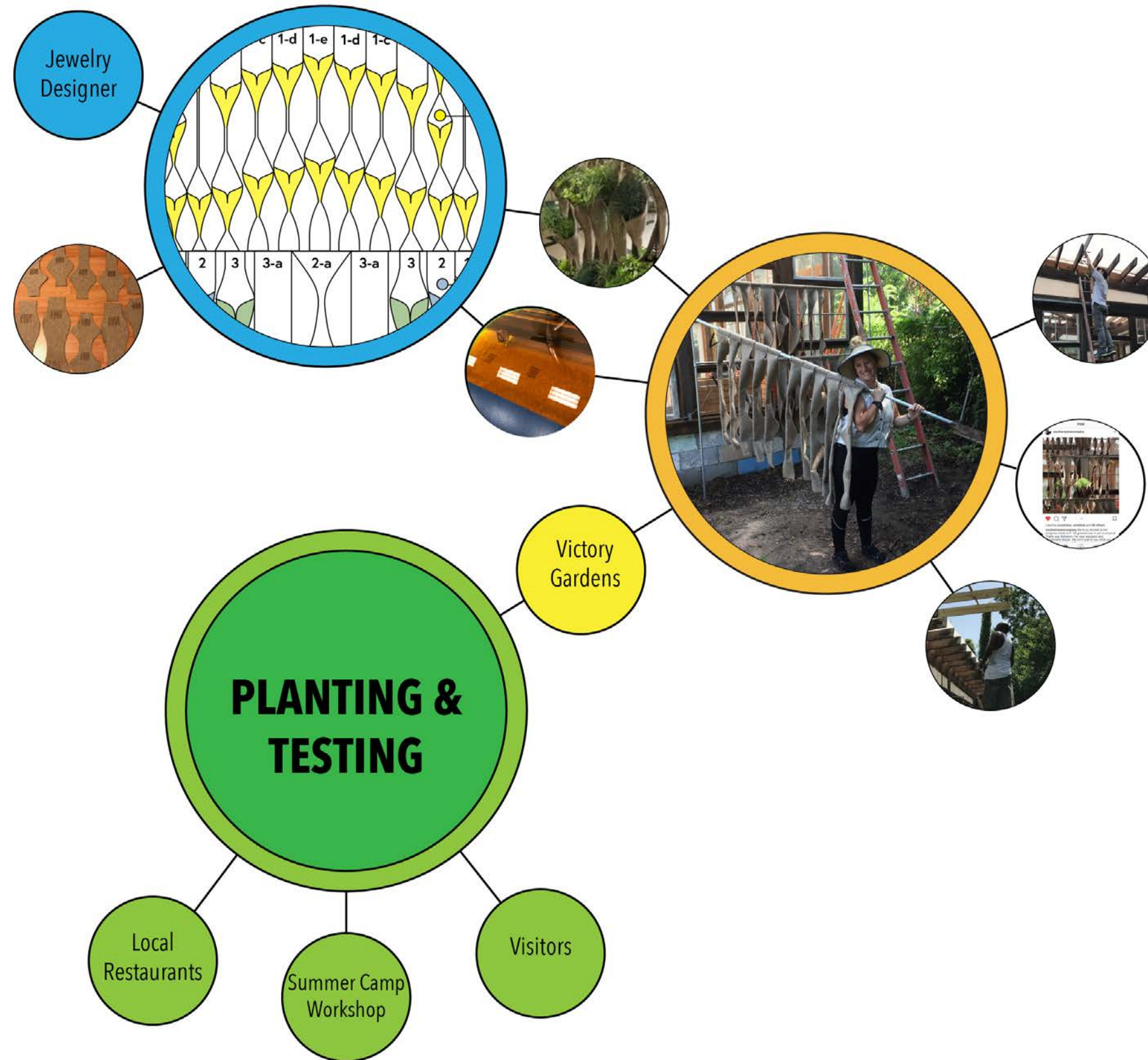


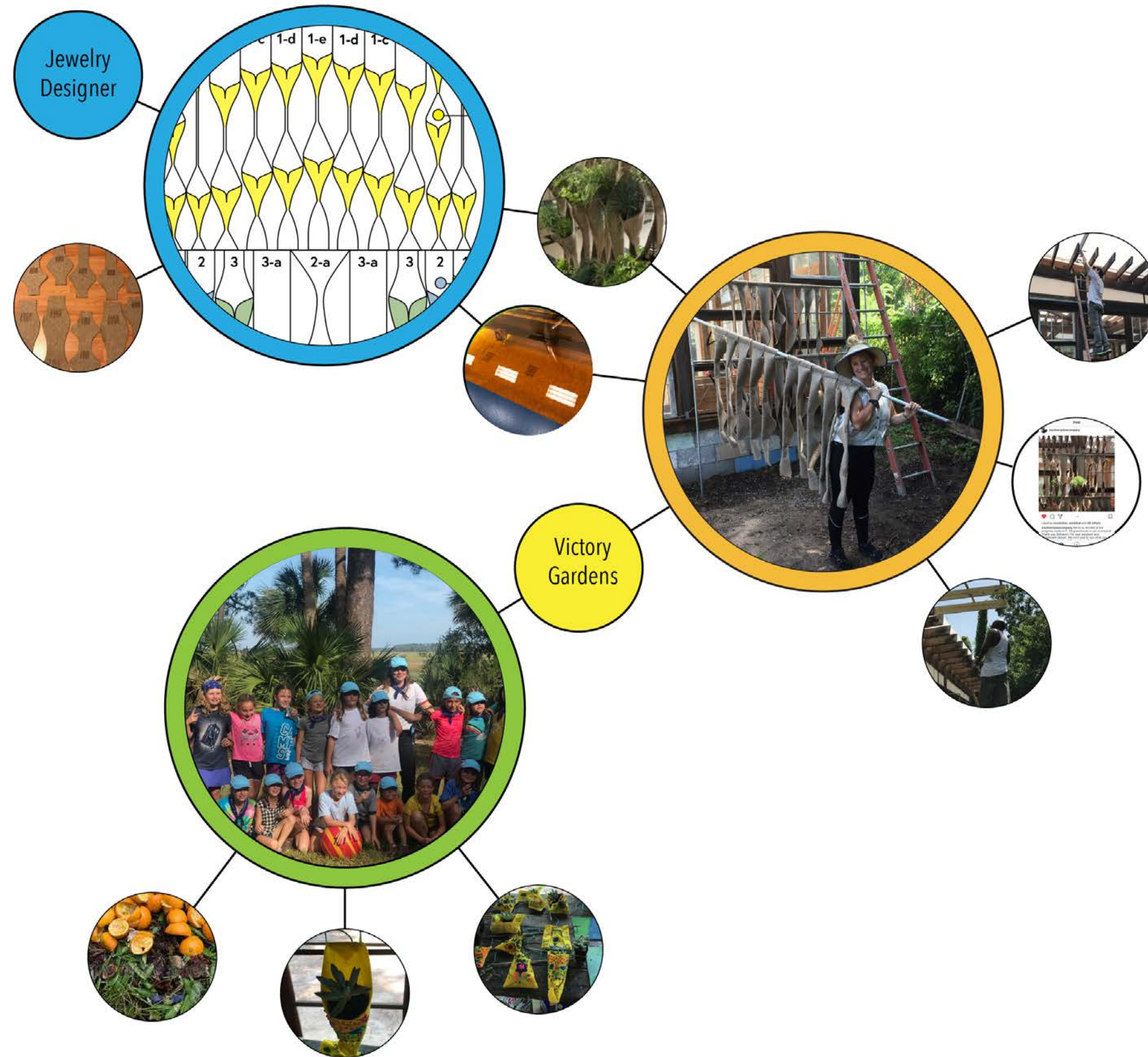
Social Impacts

Of the E. 34 Greenhouse field Test









Conclusion



Green Facade Systems:

- Act as a Shading Device
- Decrease Temperature Indoors
- Decrease Temperature between the Facade and the Building
- Have Great Potential for Urban Agriculture
- Add Beauty to a Space and Get People's Attention!



Thank You!

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