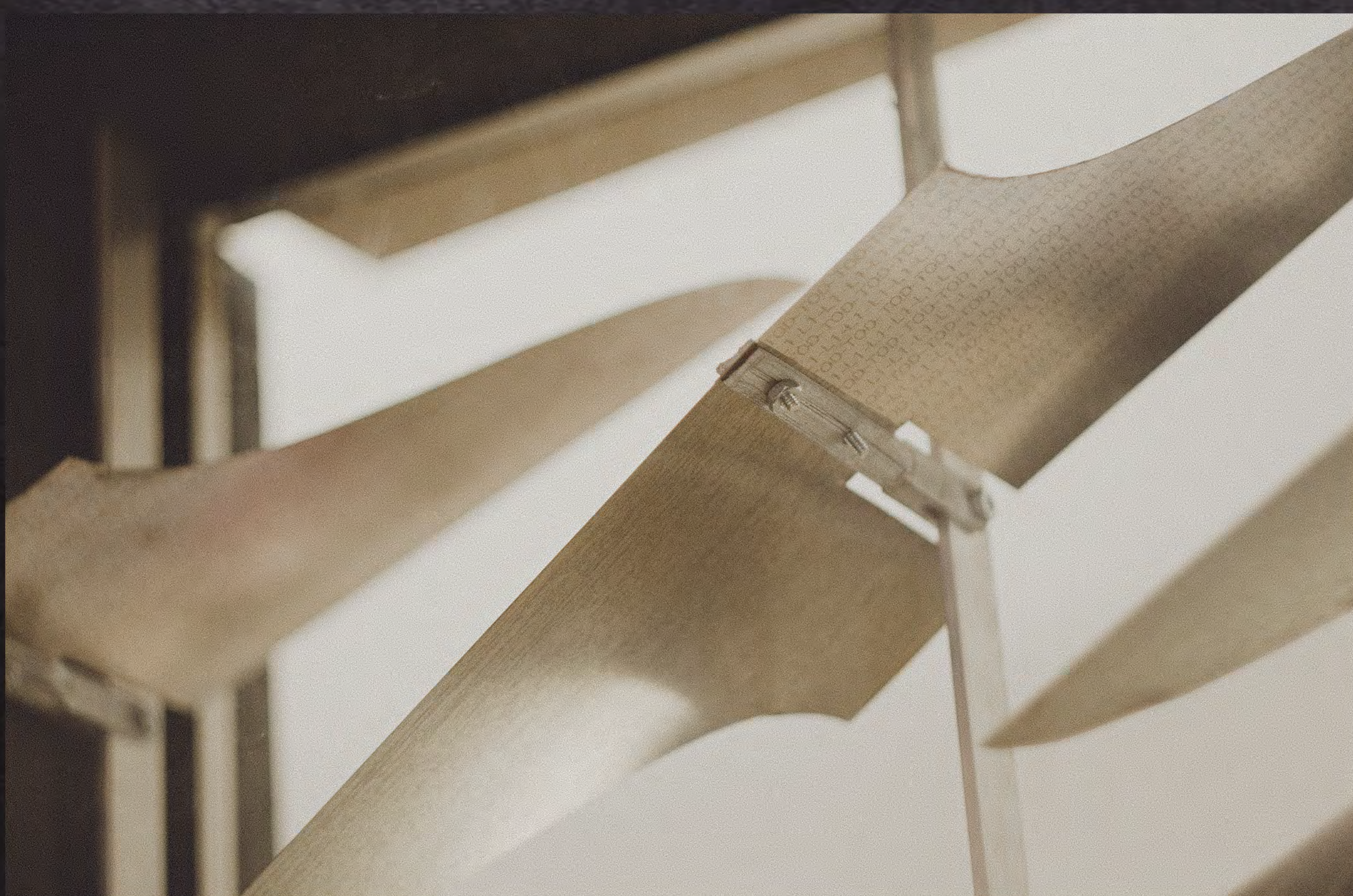
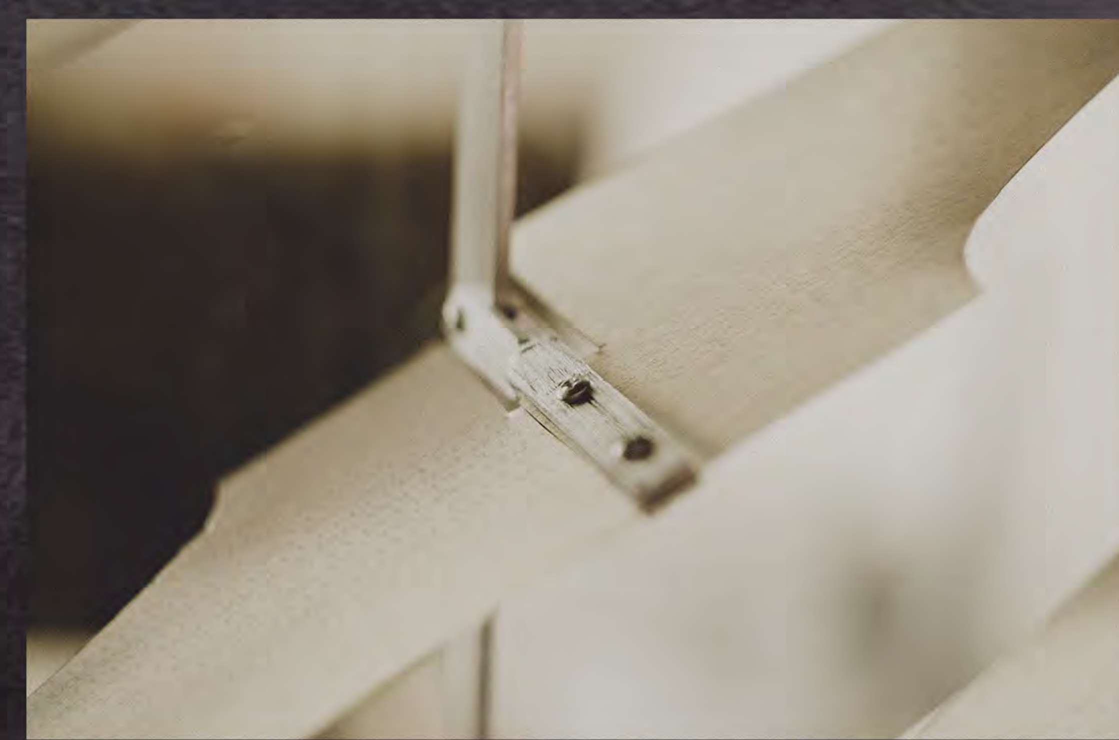
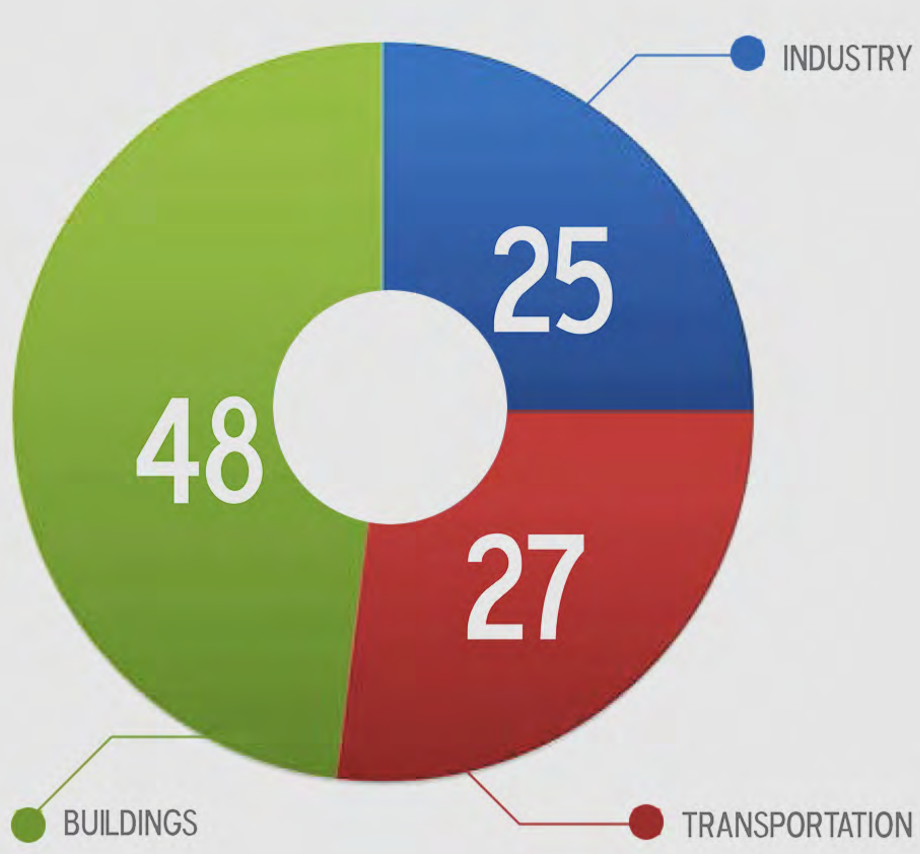
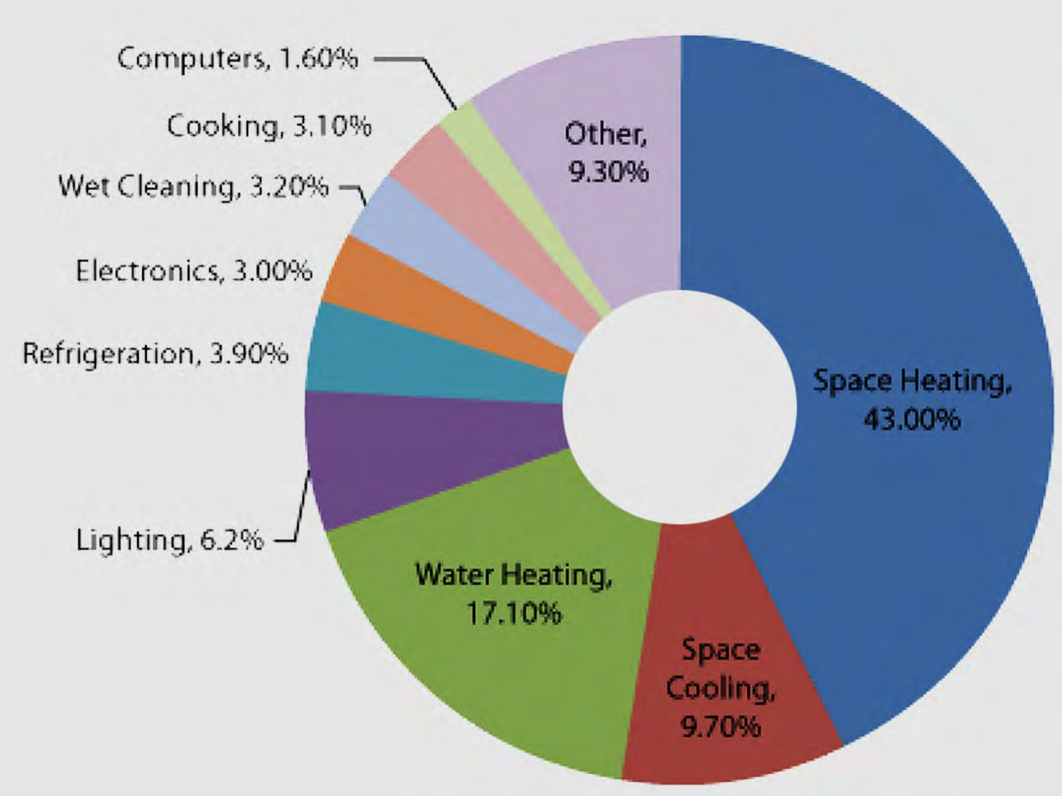
EMBEDDED RESPONSIVENESS







UNITED STATES ENERGY CONSUMPTION
SOURCE: ARCHITECTURE2030.ORG



BUILDING ENERGY CONSUMPTION
SOURCE: HTTP://WWW.EERE.ENERGY.GOV

MAXIMIZE SOLAR GAIN WHEN COLD	MINIMIZE SOLAR GAIN WHEN HOT
PROTECT FROM WEATHER	ALLOW ENVELOPE TO BREATHE
OFFER SECURITY, PRIVACY	MAINTAIN EXTERIOR, NATURAL VIEWS

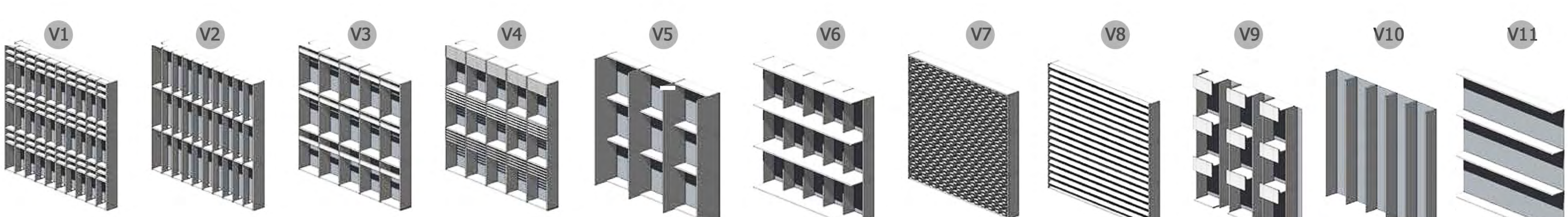
CONTRADICTORY FACADE PERFORMANCE CRITERIA

BUILDING ENERGY CONSUMPTION STATISTICS

Nearly 50% of energy consumption is used by buildings
Majority of that energy consumption is allocated to the façade
Most design solutions utilize solar shading (louver) or solar reflective glass
Problem: Solar shading must strike maximized ‘targets to block solar orientation at times of the day and year. Reflective glass prevents visual transparency of a façade
Previous solutions have been actuated facades but this increases energy consumption and also is prone to break and fail.
We are proposing to utilize thermal bi-metal as a solar mitigating façade system that can minimize heat gain while maintaining visual transparency.

ZERO ENERGY CONCEPT

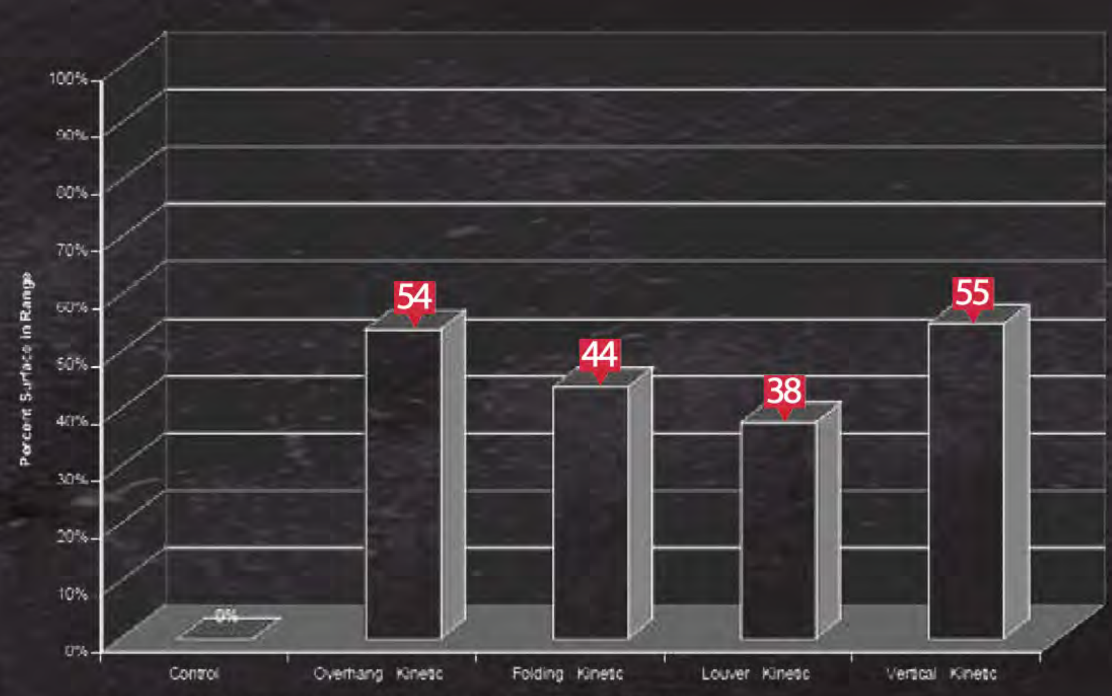
USING THE CHANGE IN ENVIRONMENT TO DICTATE THE PERFORMANCE OF THE FACADE.



GEOMETRY / BRISE SOLEIL STUDIES

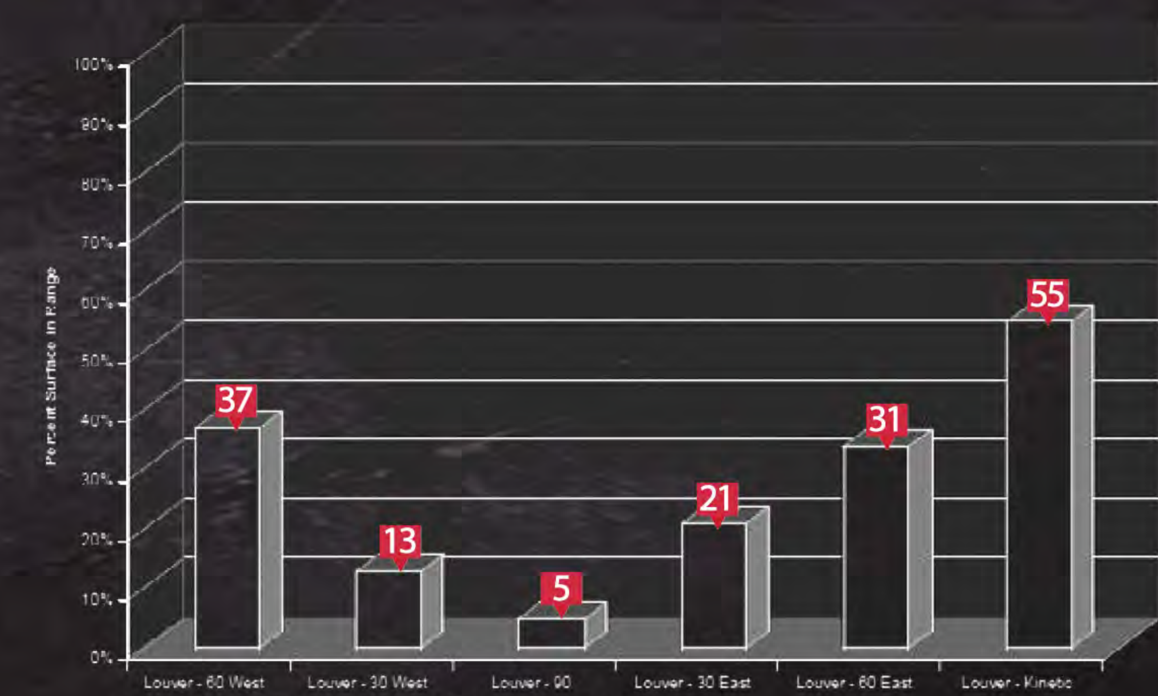
> "A building's capability for motion can be used to: enhance its aesthetic qualities; respond to environmental conditions; and perform functions that would be impossible for a static structure."

Previous studies by Ryan Hasanuwat have outlined the benefits and superior performance of kinetic facades versus static facades. Several kinetic facades are analyzed for performance and stability, and the four most common types of joints are identified. Ultimately, joints are subject to mechanical failure, so embedding the responsiveness in the material itself is ideal for maintaining a functioning façade.



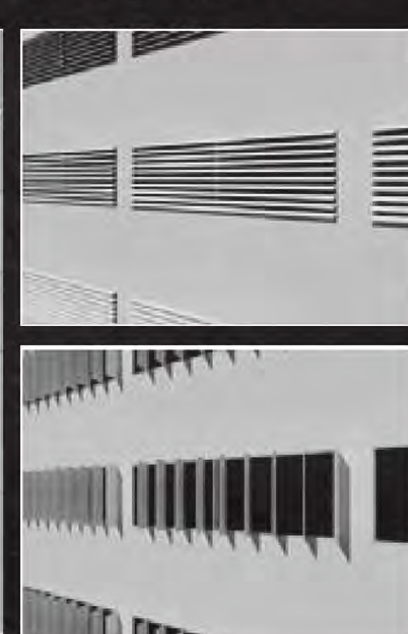
DAY LIGHTING : KINETIC VS CONTROL

Figure 55: Comparison of kinetic systems and control for daylighting control



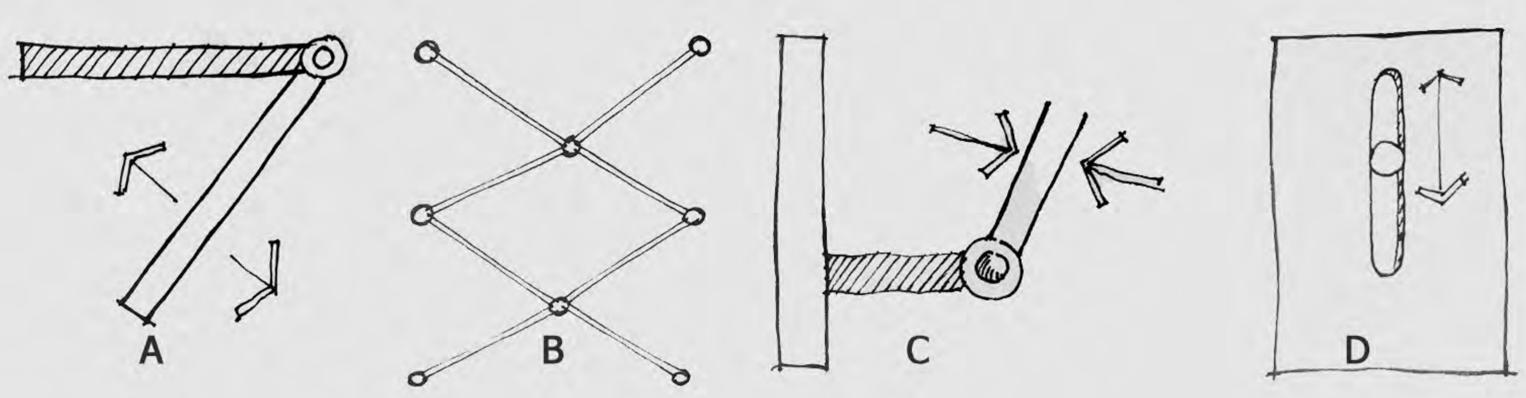
DAY LIGHTING : VERTICAL LOUVERS

HEATING	KBTU	KBTU DECREASE	% DECREASE
CONTROL	989.410	X	X
OVERHANG	689.810	299.600	30.3
FOLDING	693.420	295.990	29.9
HORIZONTAL LOUVER	687.650	301.760	30.5
VERTICAL LOUVER	709.105	280.305	28.3



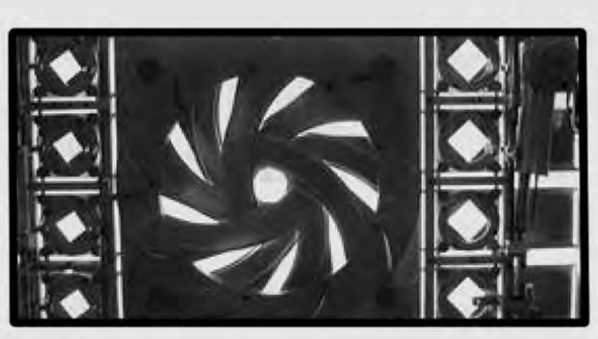
COOLING	KWH	KWH DECREASE	% DECREASE
CONTROL	128.040	X	X
OVERHANG	85.820	42.220	33.0
FOLDING	86.180	41.860	32.7
HORIZONTAL LOUVER	85.460	42.580	33.3
VERTICAL LOUVER	92.002	36.038	28.1

HOURLY ENERGY CONSUMPTION BASED ON A SIMULATION FOR AN OFFICE BUILDING DALLAS, TX SOURCE: USC KINETIC FACADE THEIS RYAN HASANUWAT MAY 2010



TYPES OF JOINTS IN KINETIC FACADES

	TYPE OF JOINT	DESCRIPTION
A	HINGED	a fixed axis rotational type of bearing that connects two solid objects together allowing limited angle of rotation between the two.
B	SCISSOR HINGED	a double-lever system with its pivot acting as a fulcrum.
C	BALL AND SOCKET	a joint in which a ball shaped surface of a component fits into a cup like depression of another.
D	LINEAR ACTUATED	the movement of the individual pieces past each other in a linear fashion characterizes sliding systems.



LINEAR ACTUATED
ARAB INSTITUTE : JEAN NOUVEL

SCISSOR HINGE CONNECTION
IRIS DOME : CHUCK HOBERMAN

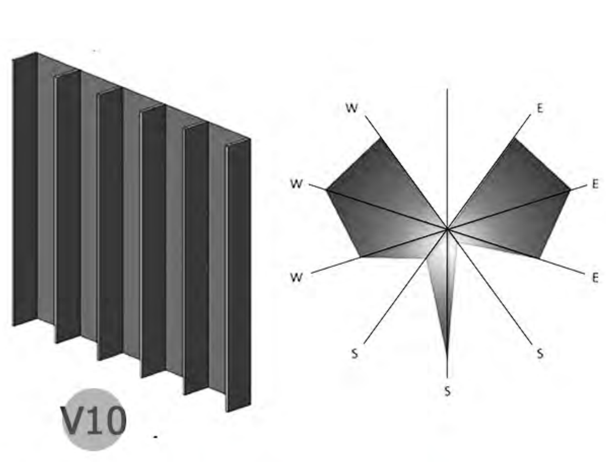
HINGE CONNECTION
ERNSTING WAREHOUSE : SANTIAGO CALATRAVA

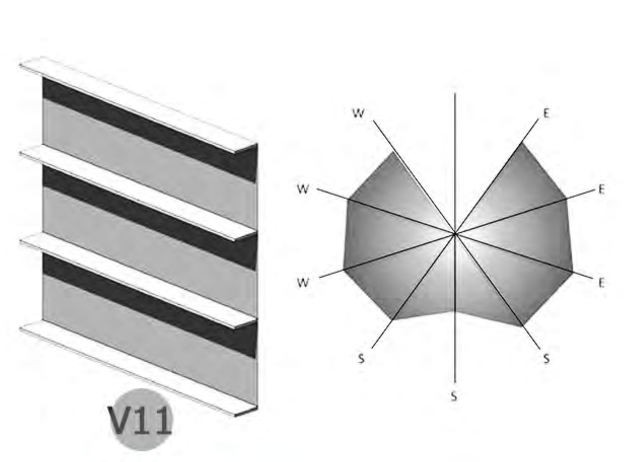
KINETIC FACADE PRECEDENT / NEW DIRECTION

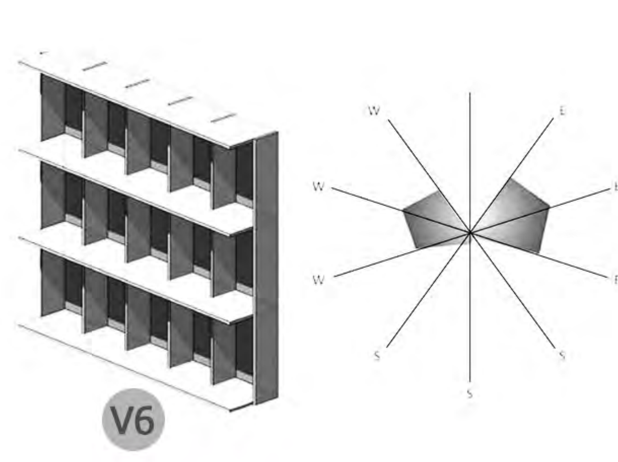
The following issues will allow the bi-metal façade to provide maximized solar protection while maintaining visual transpar :ncy:

1- Calibration of the bi metal panel geometry through computational software
2- The configuration of panels to work in unison
3- The analytical feedback data provided by diva, and the thermal testing box
4- Triple glazed system providing a stable environment for activation

Eleven different brise soleil geometries were tested for their effectiveness in blocking direct light from the east, south and west. The most effective geometries are those that offer a combination of vertical and horizontal elements to mitigate sunlight throughout the course of a day, and those that maintain exterior views.







	West			South			East		
	Dez 8am	Sept 8am	Jun 8am	Dez 4pm	Dez 12am	Dez 8am	Jun 4pm	Sept 4pm	Dez 4pm
V 1	33 %	42 %	34 %	2 %	27 %	7 %	41 %	49 %	42 %
V 2	42 %	57 %	52 %	2 %	43 %	10 %	56 %	63 %	50 %
V 3	40 %	54 %	45 %	5 %	35 %	12 %	50 %	61 %	48 %
V 4	36 %	51 %	40 %	5 %	28 %	11 %	46 %	56 %	47 %
V 5	47 %	68 %	56 %	1 %	50 %	8 %	61 %	75 %	55 %
V 6	39 %	49 %	36 %	5 %	9 %	11 %	47 %	58 %	50 %
V 7	7 %	17 %	8 %	1 %	7 %	2 %	17 %	21 %	10 %
V 8	23 %	29 %	13 %	22 %	0 %	20 %	22 %	28 %	31 %
V 9	46 %	56 %	38 %	45 %	56 %	37 %	50 %	63 %	47 %
V 10	63 %	88 %	78 %	11 %	90 %	25 %	78 %	89 %	66 %
V 11	80 %	77 %	71 %	79 %	53 %	73 %	79 %	81 %	86 %

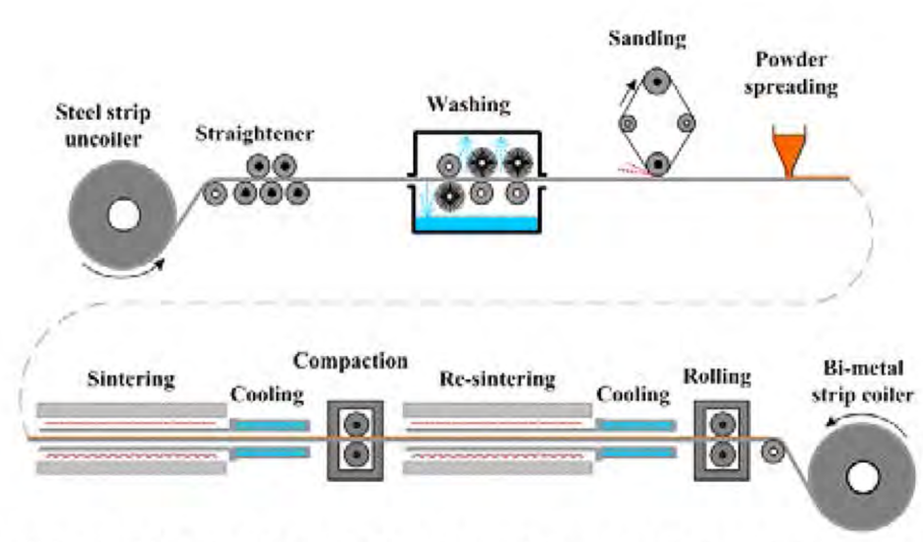
2 ALLOYS WITH GREATLY DIFFERENT COEFFICIENTS ARE CHOSEN.
THE LARGER EXPANSION IS CALLED THE ACTIVE COMPONENT,
THE LOWER IS CALLED THE PASSIVE COMPONENT.

ACTIVE TYPICALLY NICKEL, IRON, MANGANESE, OR CHROME
PASSIVE TYPICALLY INVAR, AN IRON-NICKEL ALLOY

ACCORDING TO THEIR THERMAL EXPANSION COEFFICIENT

WHEN DIFFERENT MATERIALS ARE HEATED,
THEY EXPAND AT DIFFERENT RATES,
& WHEN TEMPERATURE IS REDUCED, THIS PROCESS IS REVERSED.

- COMPONENTS ARE MELTED IN HIGH-FREQUENCY FURNACES.
- SAMPLES ARE TAKEN TO ANALYZE EXPANSIVE PROPERTIES.
- TWO COMPONENTS ARE JOINED BY COLD BONDING.
- STRIPS ARE THEN HEAT-TREATED IN ANNEALING FURNACES.



SINTERING PROCESS FOR COPPER BASED BI-METAL STRIPS
SOURCE : HTTP://WWW.SUBSTECH.COM

ADVANTAGES

-high accuracy and reliable operation over an extremely wide range of temperatures.
-well-suited for making automated measurements

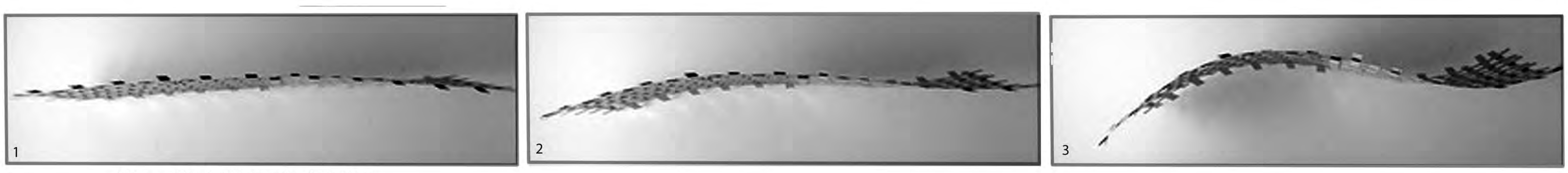
DISADVANTAGES

-errors caused by their use over an extended period of time.
-also subject to corrosion.

ADVANTAGES & DISADVANTAGES OF BI-METAL

Cost & Typical Dimension
Bi-Metallic Coil / Price: £1.75 / Length 17 mm. dia. 5 mm
Strip size 0.25 x 2.0 mm - 6 Turns
Bi-Metallic Strip / Price: £1.25 / Supplied in strips of 20 cm long

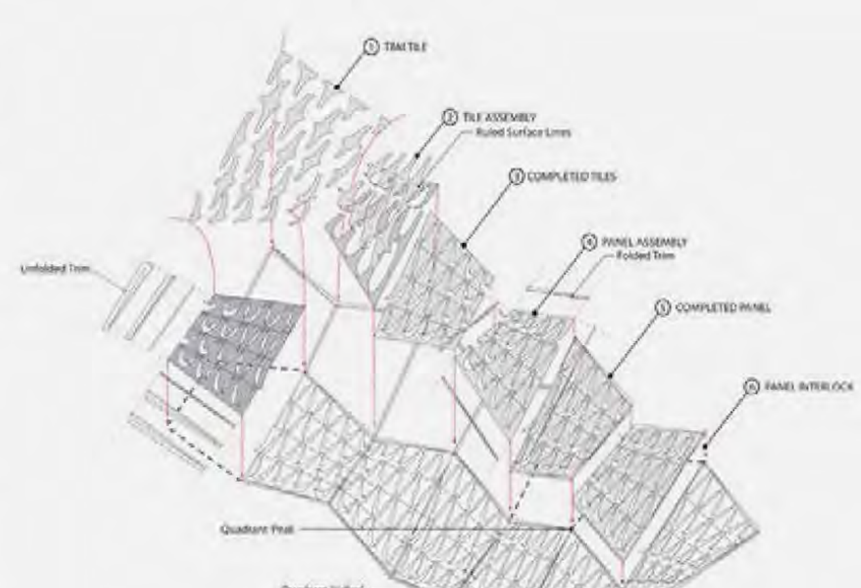
MANUFACTURING



Weave Effect // University At Buffalo

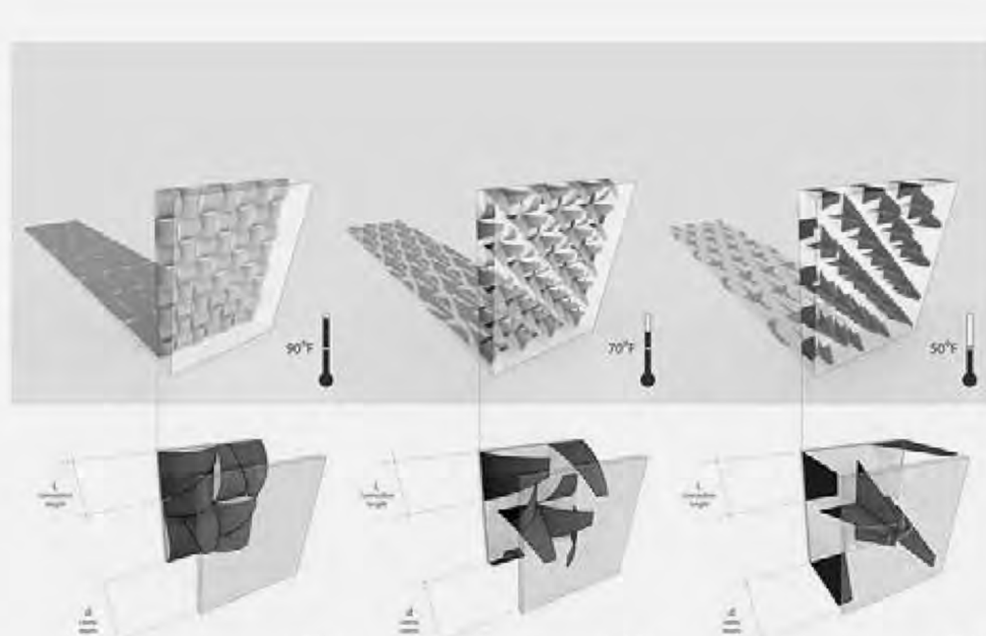
BLOOM
DO-SU STUDIO

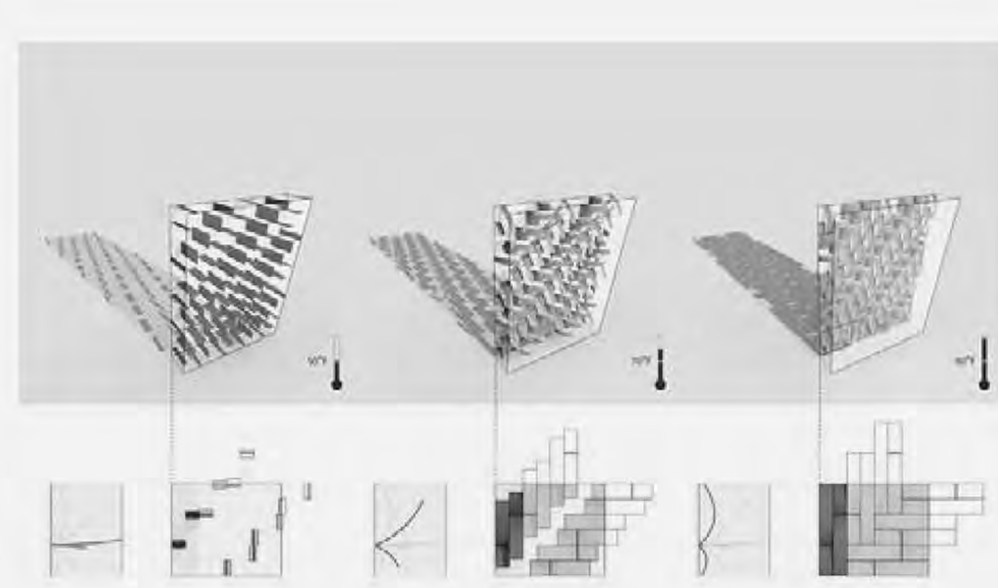
A sun-tracking instrument indexing time and temperature. "Bloom" stitches together material experimentation, structural innovation, and computational form/patternmaking into an environmentally responsive installation. The form's responsive surface is made primarily out of 14,000 smart thermobimetal tiles, where no two pieces are alike. Each individual piece automatically curls a specified amount when the outdoor ambient temperature rises above 70F or when the sun penetrates the surface.

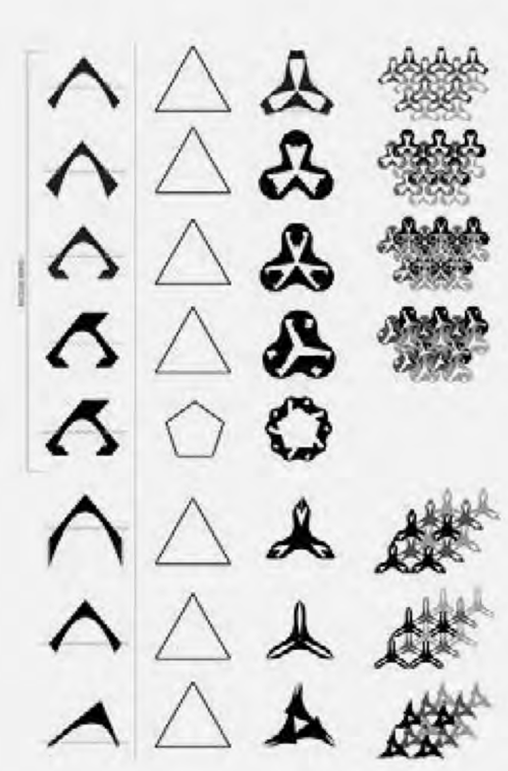


GLASS PANEL SHUTTER SYSTEM
DO-SU STUDIO

Various other building components for the market can also incorporate the material of thermobimetal. The metal can be cut into small pieces and assembled in a matrix of individual pieces that can operate like an organic shutter system and sandwiched between two panes of glass as part of a double-glazed window panel system. When the sun penetrates the exterior surface of glass and heats the interior cavity, the bimetal will curl and constrict light from passing. Depending on the brightness of the day, the bimetal shutter system can be calibrated to completely black-out the interior space, if necessary. Applied to a large sun-facing surface, this panel system can help reduce heatgain, reduce the need for artificial air-conditioning, and conserve energy. Without the need for manual controls or power, this product can operate tirelessly, effortlessly and endlessly.





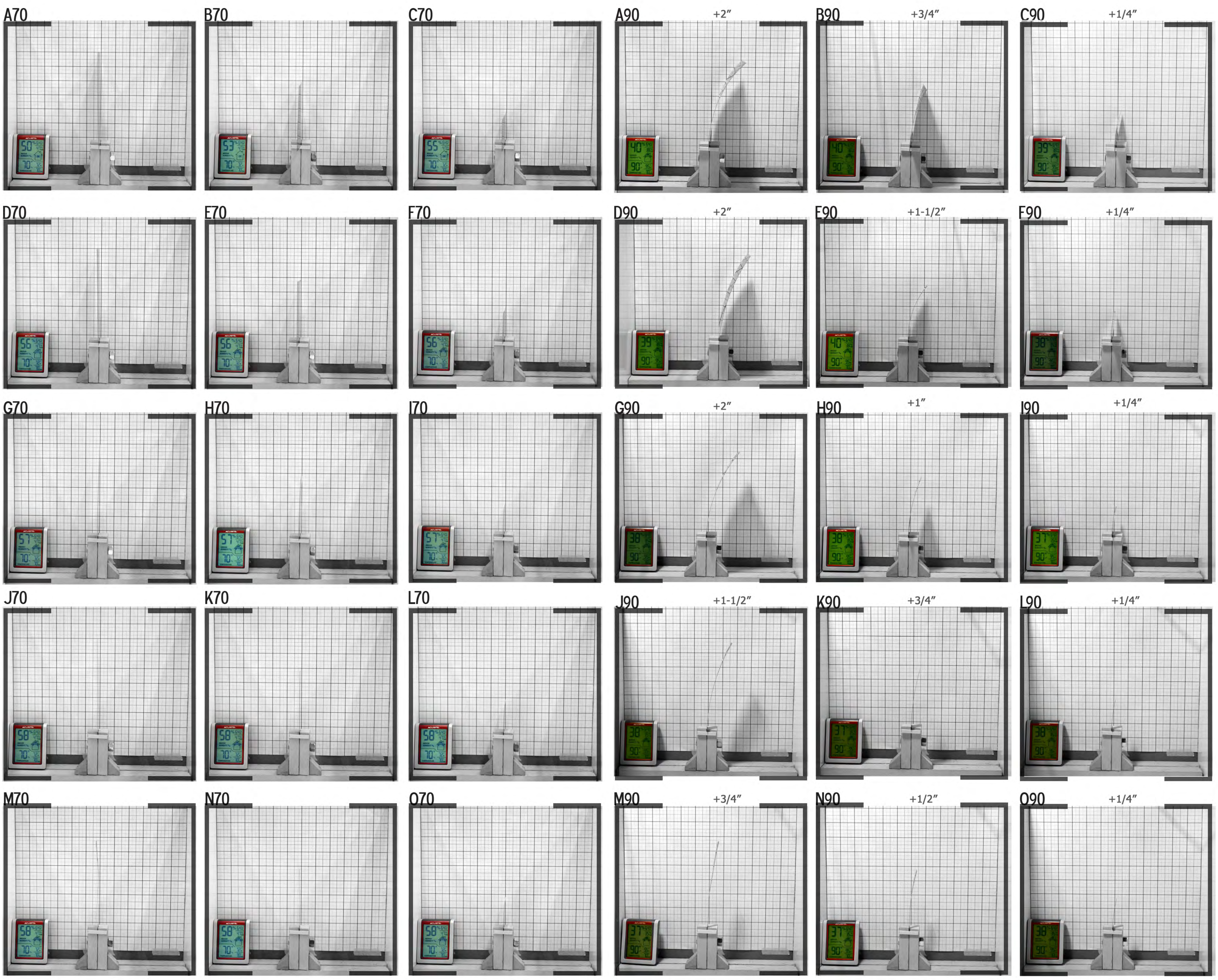


THERMAL BIMETAL PRECEDENT : DORIS KIM SUNG

MATERIAL SCIENCE : THERMAL BIMETAL

By cuting bi-metal strip into pieces with different length / width and testing in diferent temperature, we can see and compare how they react.

TESTING DESCRIPTION

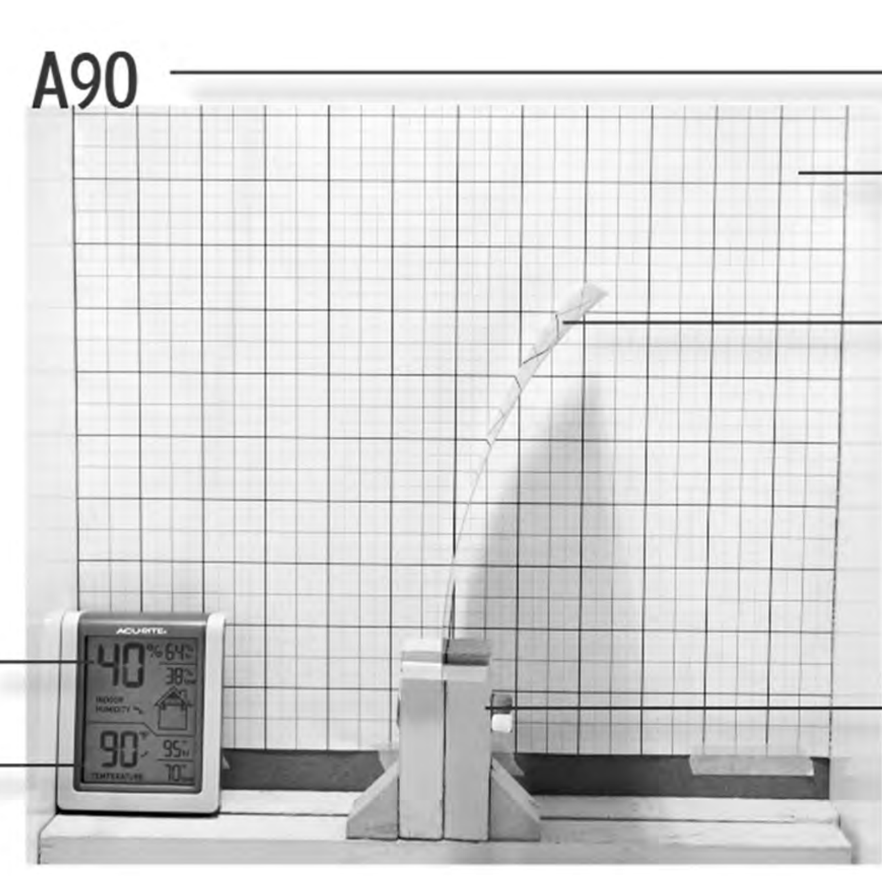


Conclusion: Material’s width affects its deflection more than its length

	4"	3"	2"	1"	0.5"
6"	A	D	G	J	M
4"	B	E	H	K	N
2"	C	F	I	L	O

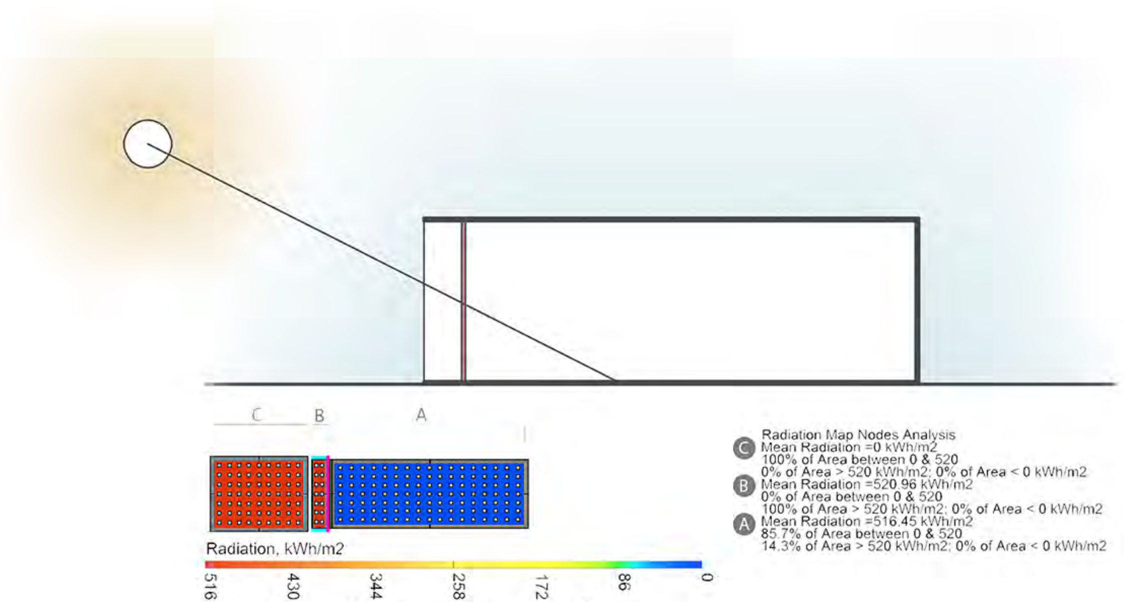
MATERIAL THICKNESS: 0.009″

CUT SHEET

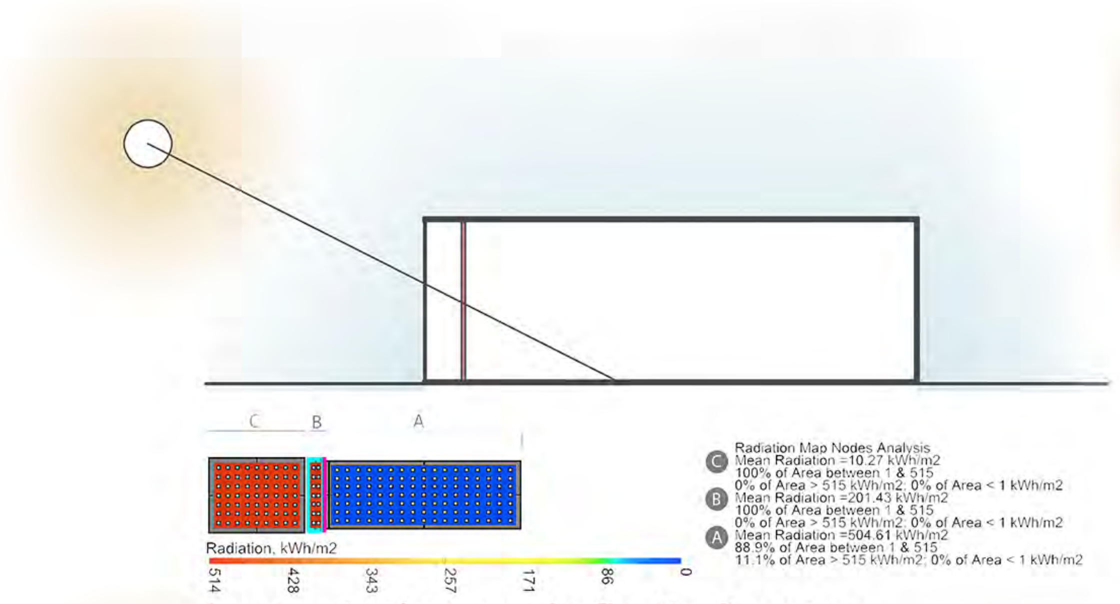


LEGEND

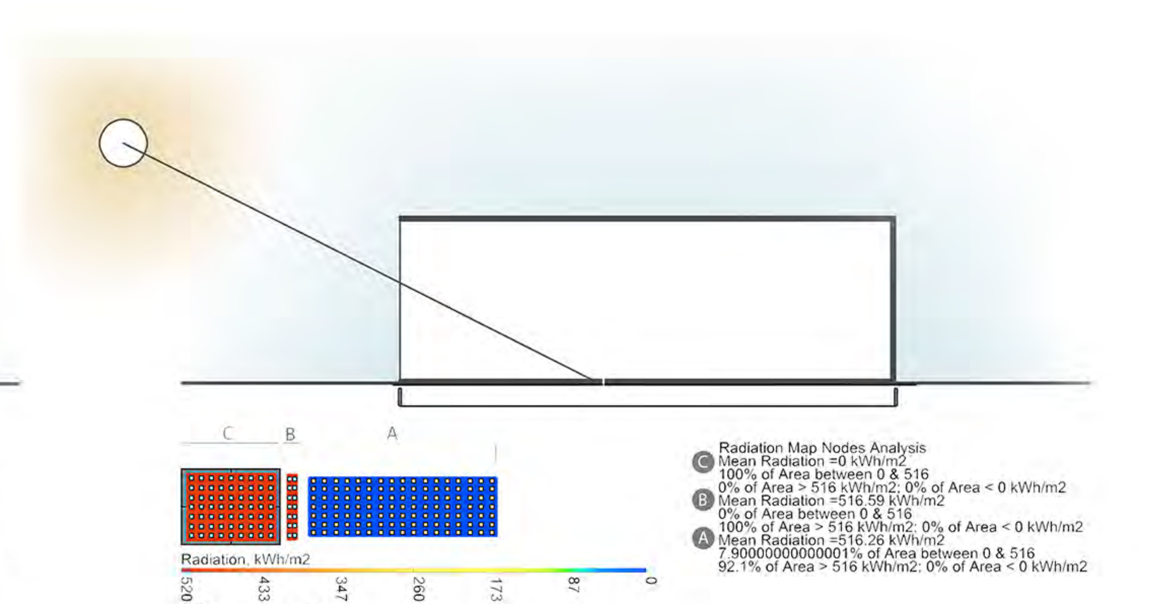
TESTING PROCEDURE



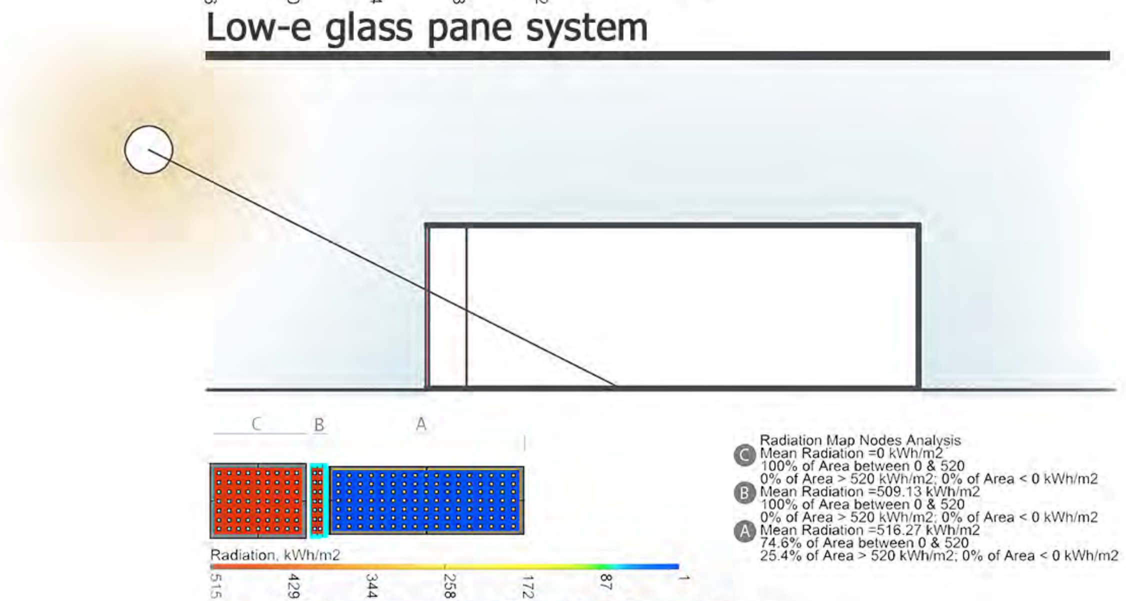
Low-e glass pane system



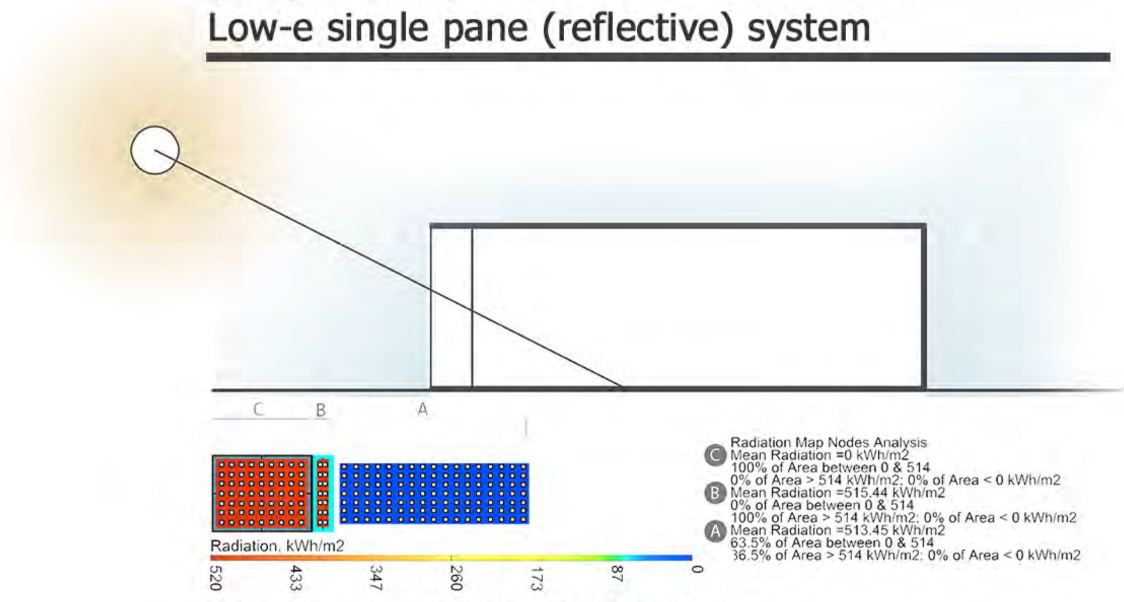
Low-e single pane (reflective) system



No pane



Double pane (reflective) system

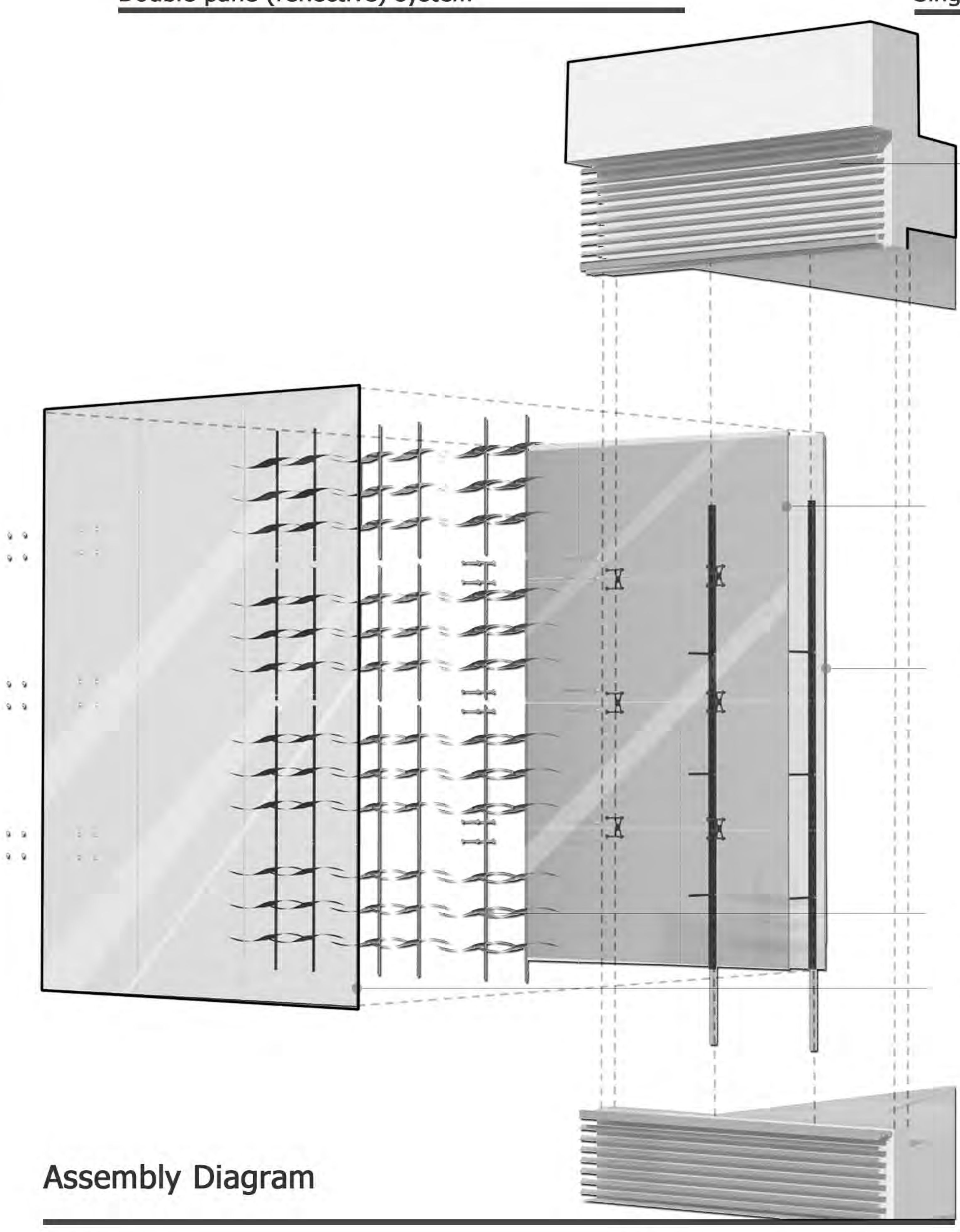


Single pane (reflective) system

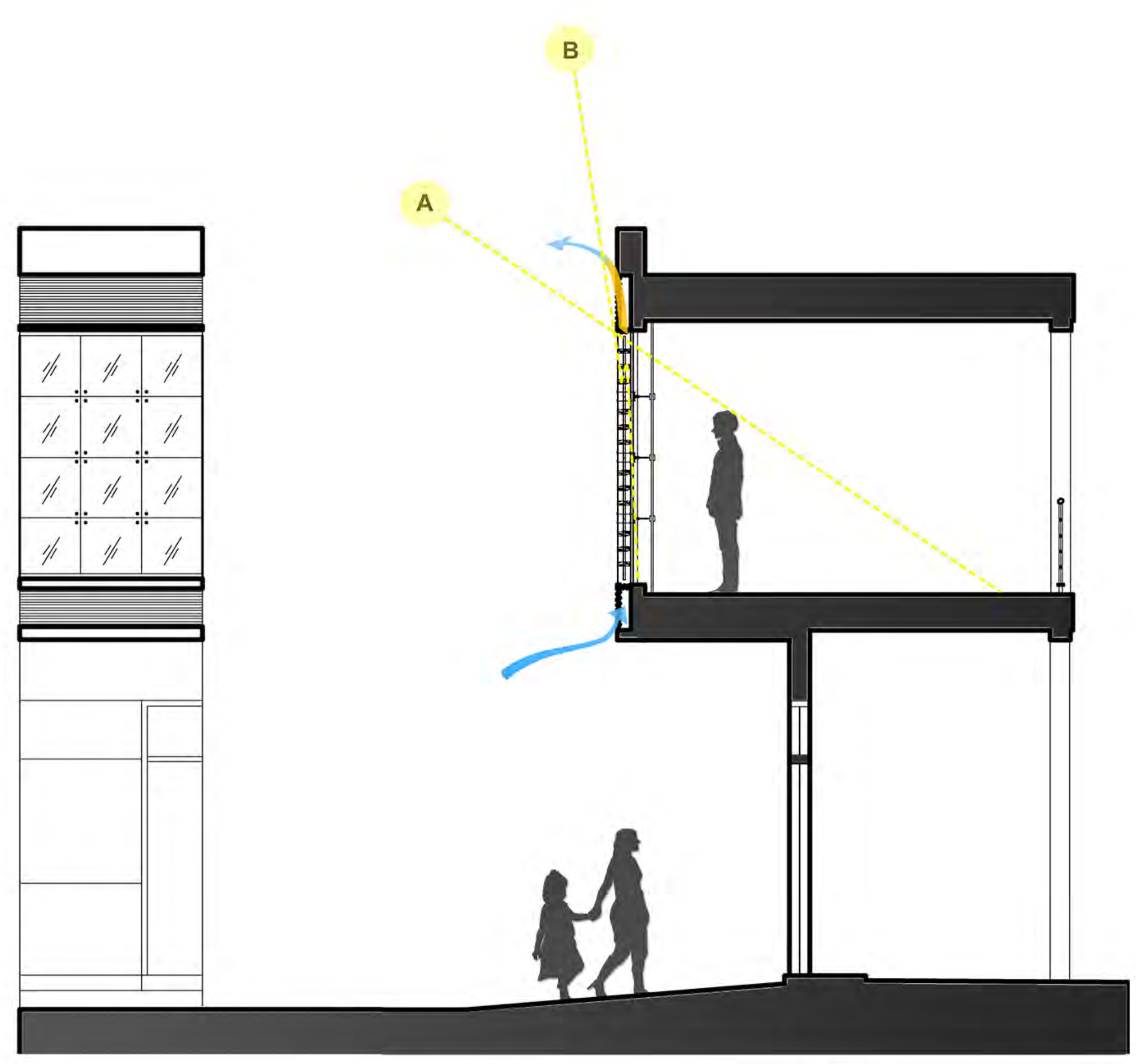
Material	R-Values
Air Gap	R-0.68
Single Pane	R-0.76
Reflective Pane	R-0.9
Low E Glass	R-1.2

Unit	Surface A	Surface B	Surface C
No Pane	92.1% surface > 516 KWH/m2	100% surface > 516 KWH/m2	100% surface > 516 KWH/m2
Singe Pane	36.5% surface > 516 KWH/m2	100% surface > 516 KWH/m2	100% surface > 516 KWH/m2
Double Single Pane reflective	25.4% surface > 520 KWH/m2	100% surface > 516 KWH/m2	100% surface > 516 KWH/m2
Low E Pane	14.3% surface >514 KWH/m2	100% surface > 516 KWH/m2	100% surface > 516 KWH/m2
Low E and SinglePane (reflective)	**11.1% surface > 515 KWH/m2**	100% surface > 516 KWH/m2	100% surface > 516 KWH/m2

Radiation Gain



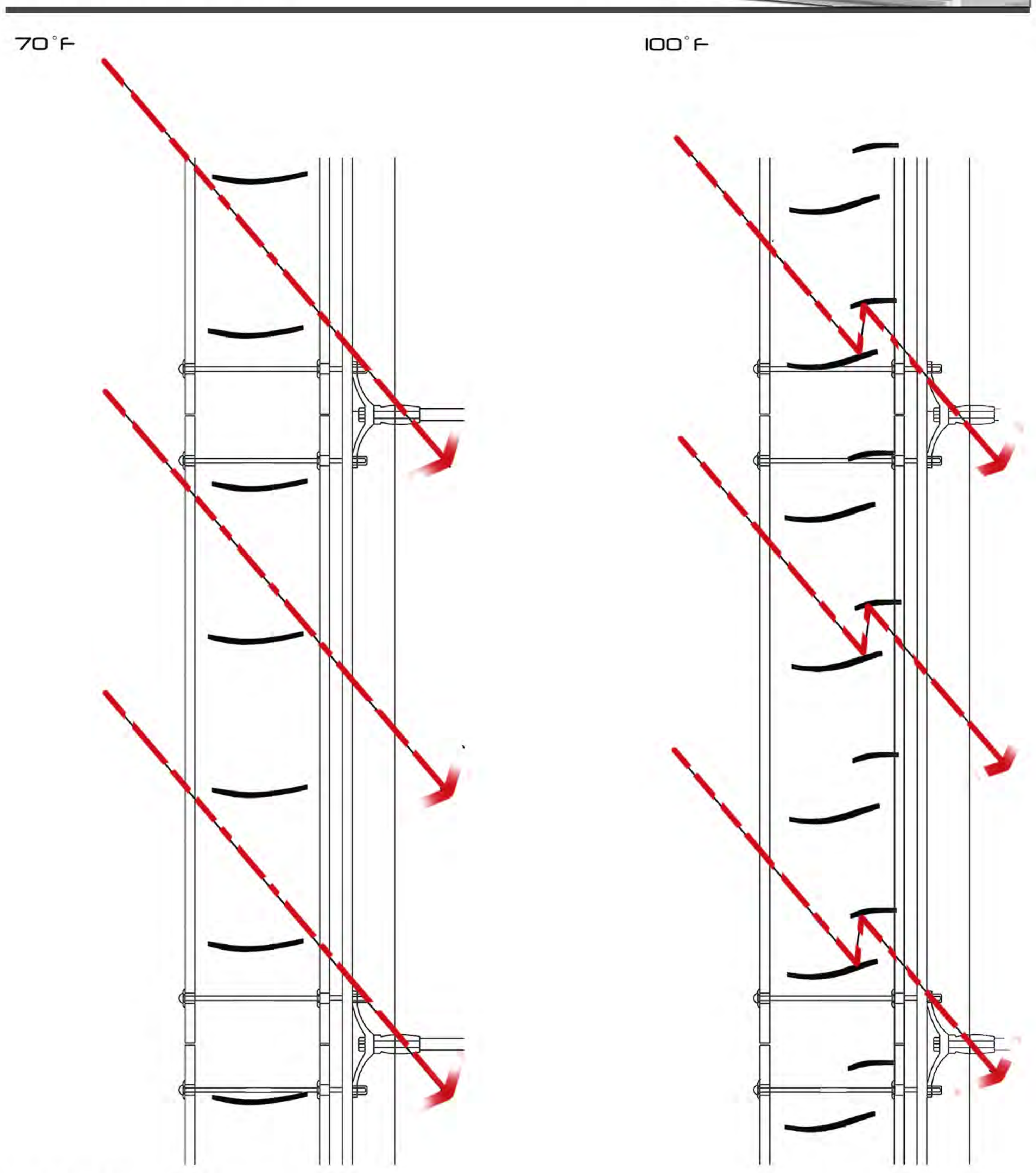
Assembly Diagram



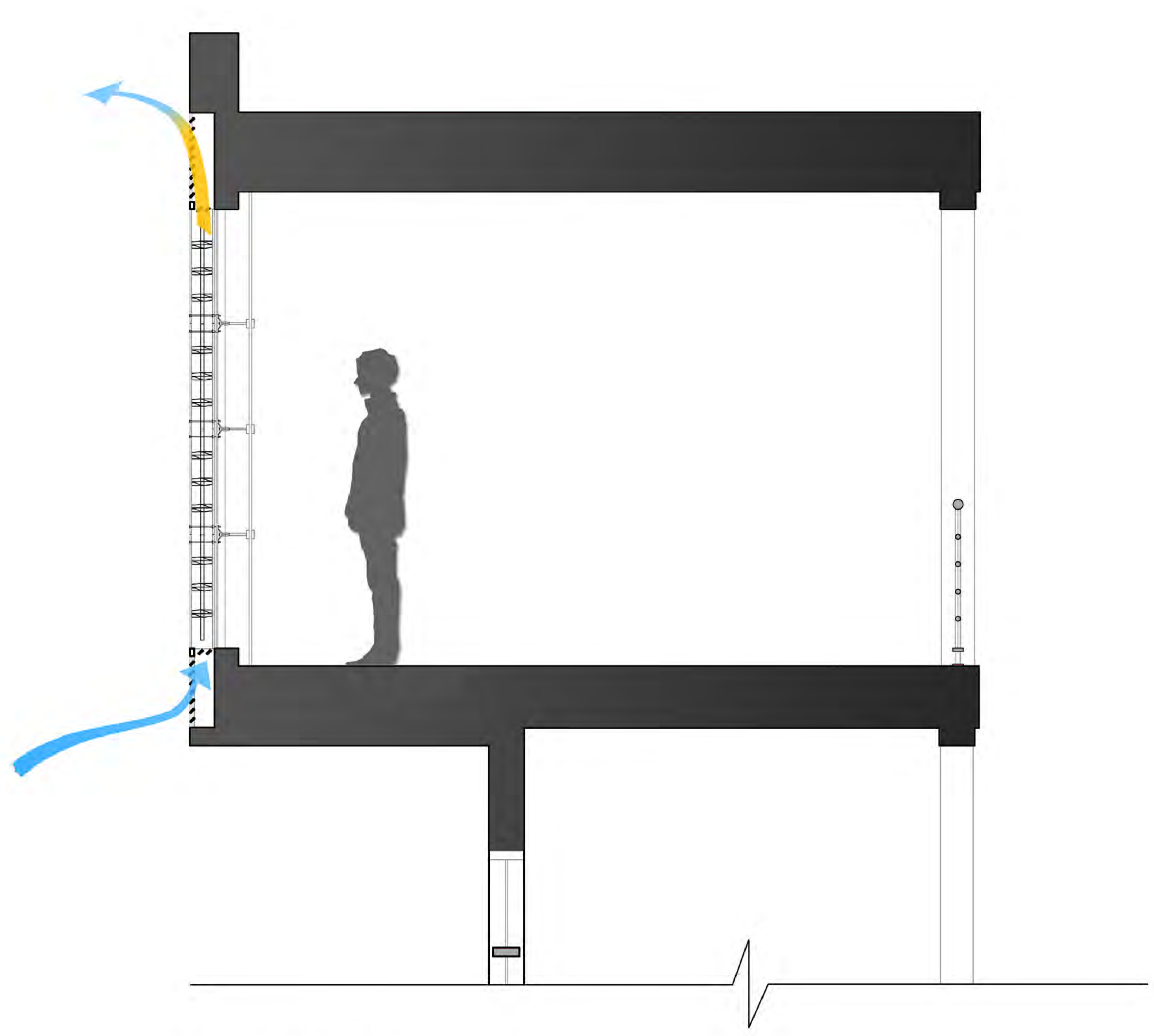
Sun Angle A
Solar Time : 12 noon
Altitude : 34°
Bearing : 50°
South Profile : 34°
West Profile : N/A

Sun Angle B
Solar Time : 12 noon
Altitude : 82°
Bearing : 50°
South Profile : 82°
West Profile : N/A

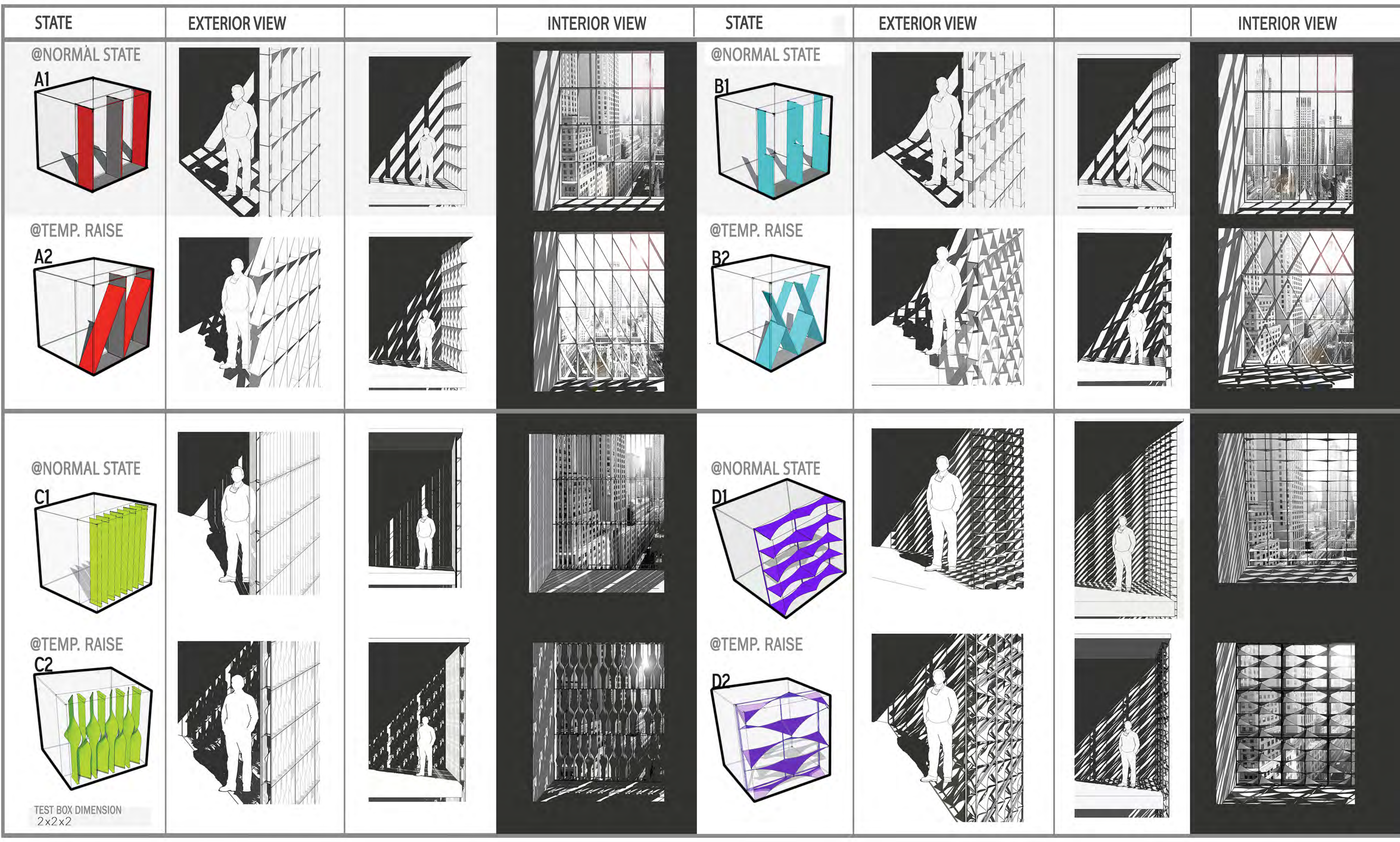
Sun Patterns
scale 1/4"=1'-0"



Deflection Diagram
scale 3"=1'-0"



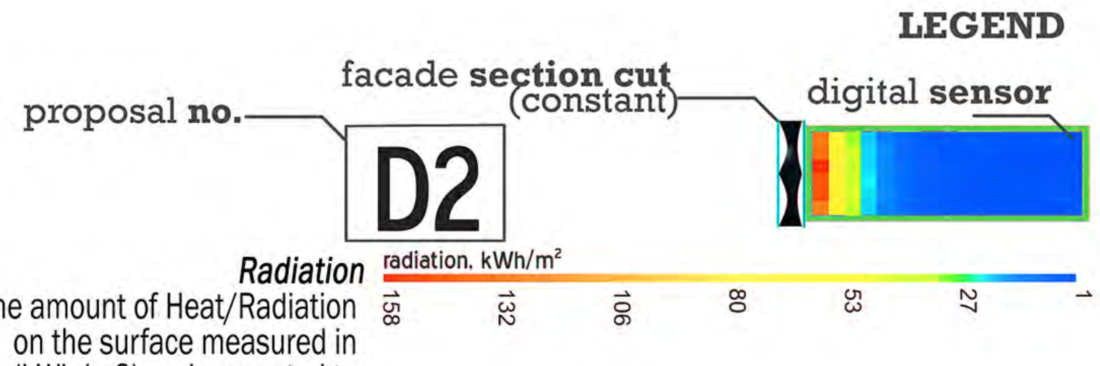
Ventilation Diagram
scale 1/2"=1'-0"



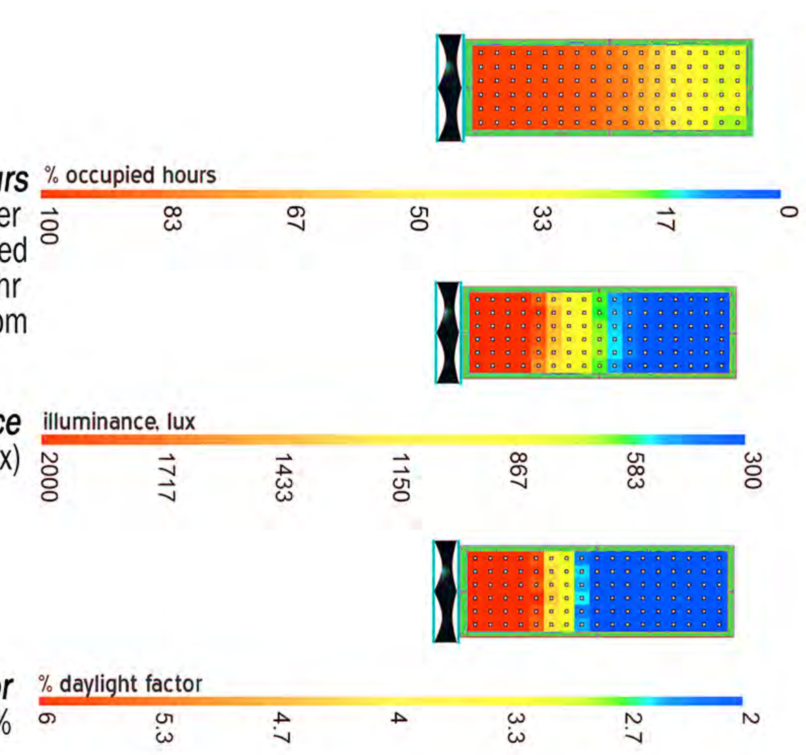
PARAMETERS Materials Used Matt Silver: To Mimic surface behavior of thermal Bi-meral Testing Location: Houston Texas

DIVA, a thermal analysis plug-in for Rhino, is used to analyze the four basic geometries. The four geometries were governed by a primarily vertical geometry, a primarily horizontal geometry, a primarily diagonal geometry, and a lateral twisting geometry. DIVA produces data based on radiation, occupied hours, illuminance, and daylighting, as illustrated in the data interpretation legend.

LEGEND



Radiation
The amount of Heat/Radiation on the surface measured in (kWh/m2) and converted to BTU/hr/ft^2

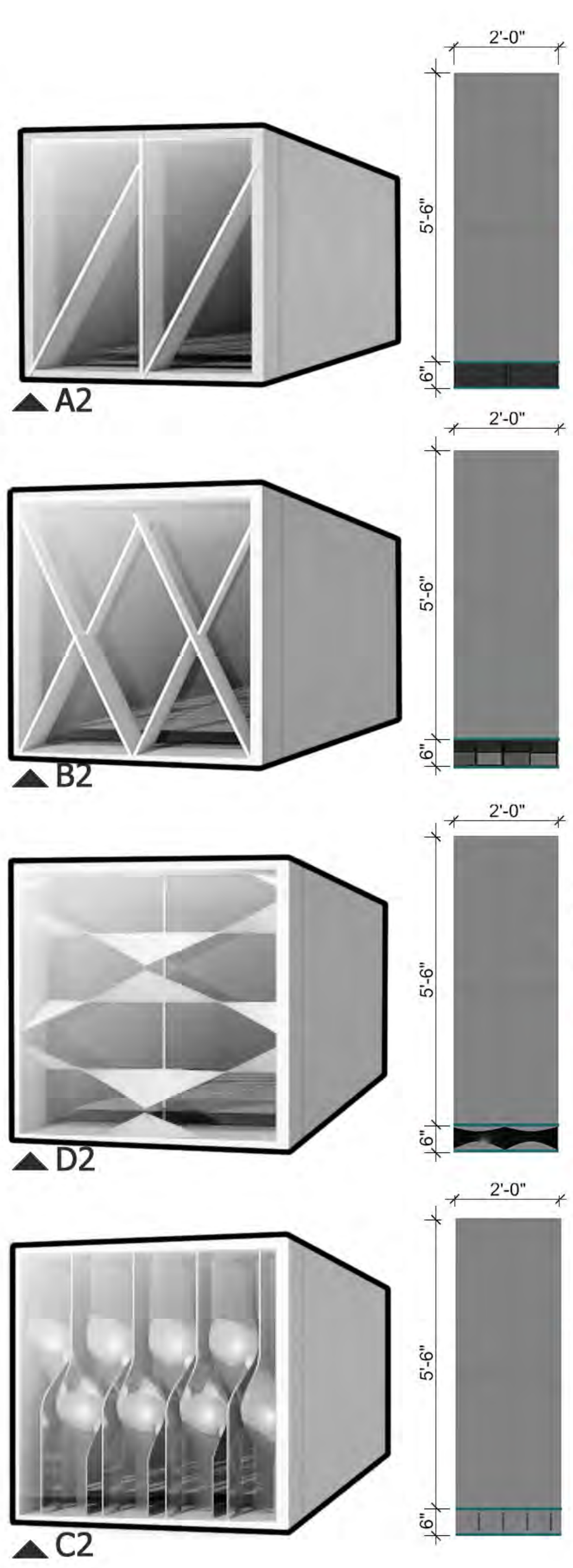


Occupied Hours
% of Daylight Autonomy over period of time occupied
Occupied over a 10 hr period 8am-6pm

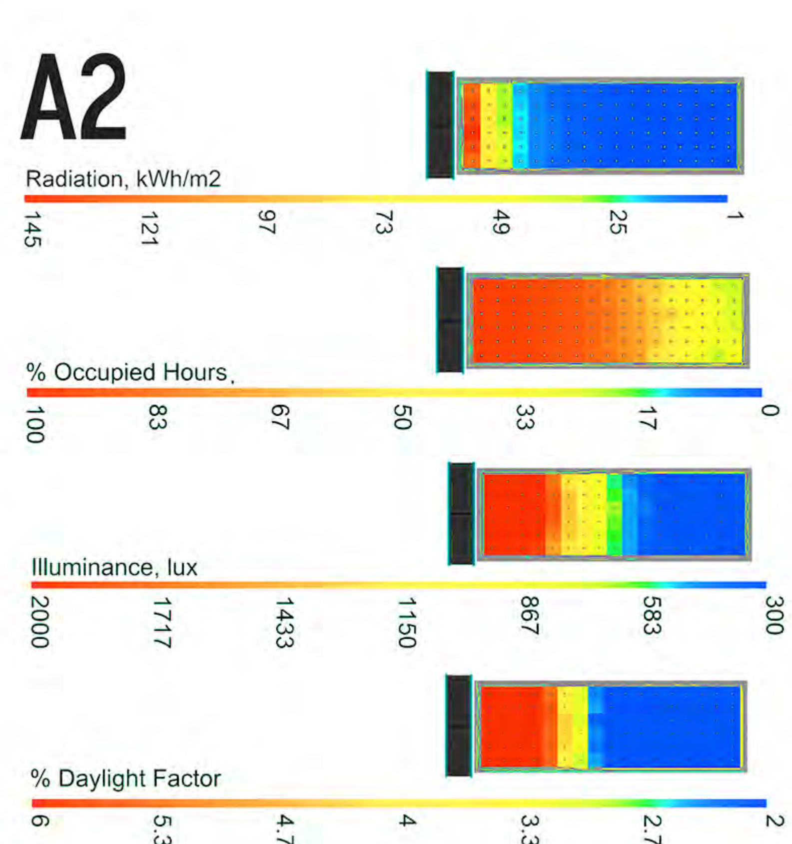
Illuminance
Portion of the surface that's illuminated (lux)

Daylight Factor
Portion of the surface that has direct daylight in %

Illuminance	Surfaces illuminated by
0.0001 lux	Moonless, overcast night sky
0.002 lux	Moonless clear night sky with airglow
0.27–1.0 lux	Full moon on a clear night
3.4 lux	Dark limit of civil twilight under a clear sky
50 lux	Family living room lights
80 lux	Office building hallway/toilet lighting
100 lux	Very dark overcast day
320–500 lux	Office lighting
400 lux	Sunrise or sunset on a clear day.
1000 lux	Overcast day; typical TV studio lighting
10000–25000 lux	Full daylight (not direct sun)
32000–130000 lux	Direct sunlight



A2



Radiation Map Nodes Analysis
Mean Radiation =18.37 kWh/m2 = 5827 BTU/HOUR/SQ. FT
99% of Area between 1 & 145
1% of Area > 145 kWh/m2; 0% of Area < 1 kWh/m2

Simulation
Daylight Autonomy (300 lux)
Mean Daylight Autonomy =70.05 % of time occupied

Illuminance Nodes Analysis
Sky Condition, Month, Date and Time: +s 09 21 09
Mean Illuminance =2080.05 lux
48.1% of Area between 300 & 2000 lux
22.5% of Area > 2000 lux; 29.4% of Area < 300 lux

Daylight Factor Nodes Analysis
Mean Daylight Factor =4.51 %
23.6% of Area between 2 & 6
23.5% of Area > 6 %; 52.9% of Area < 2 %

B2

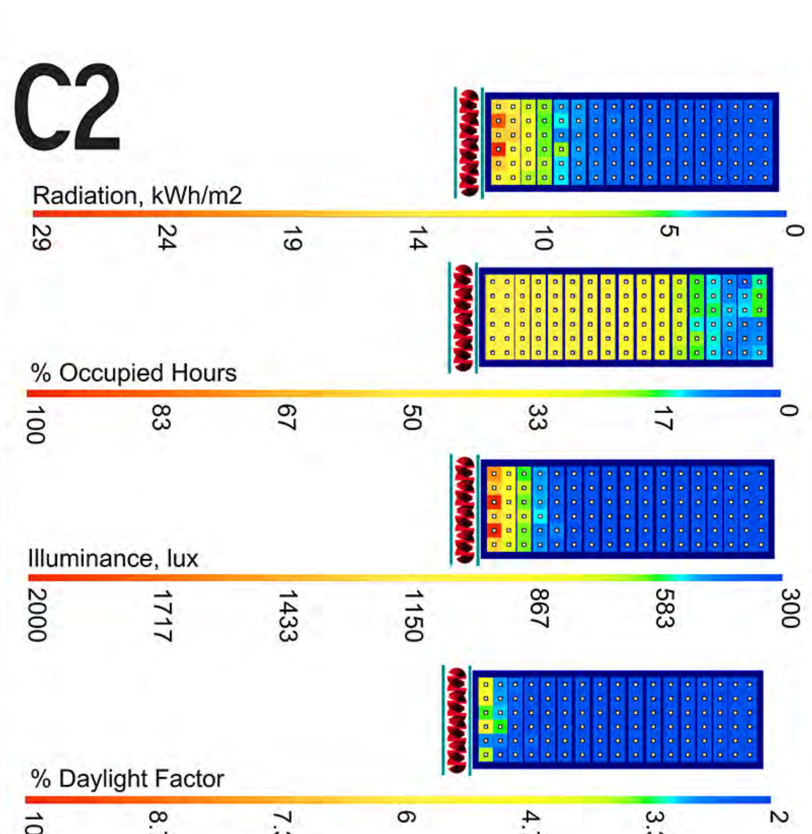
Radiation Map Nodes Analysis
Mean Radiation =21.49 kWh/m2 = 6816 BTU/HOUR/SQ. FT
95.1% of Area between 2 & 161
1% of Area > 161 kWh/m2; 3.9% of Area < 2 kWh/m2

Simulation
Daylight Autonomy (300 lux)
Mean Daylight Autonomy =73.04 % of time occupied

Illuminance Nodes Analysis
Sky Condition, Month, Date and Time: +s 09 21 09
Mean Illuminance =2543.68 lux
43.1% of Area between 300 & 2000 lux
26.5% of Area > 2000 lux; 30.4% of Area < 300 lux

Daylight Factor Nodes Analysis
Mean Daylight Factor =4.96 %
18.6% of Area between 2 & 6
29.4% of Area > 6 %; 52% of Area < 2 %

C2



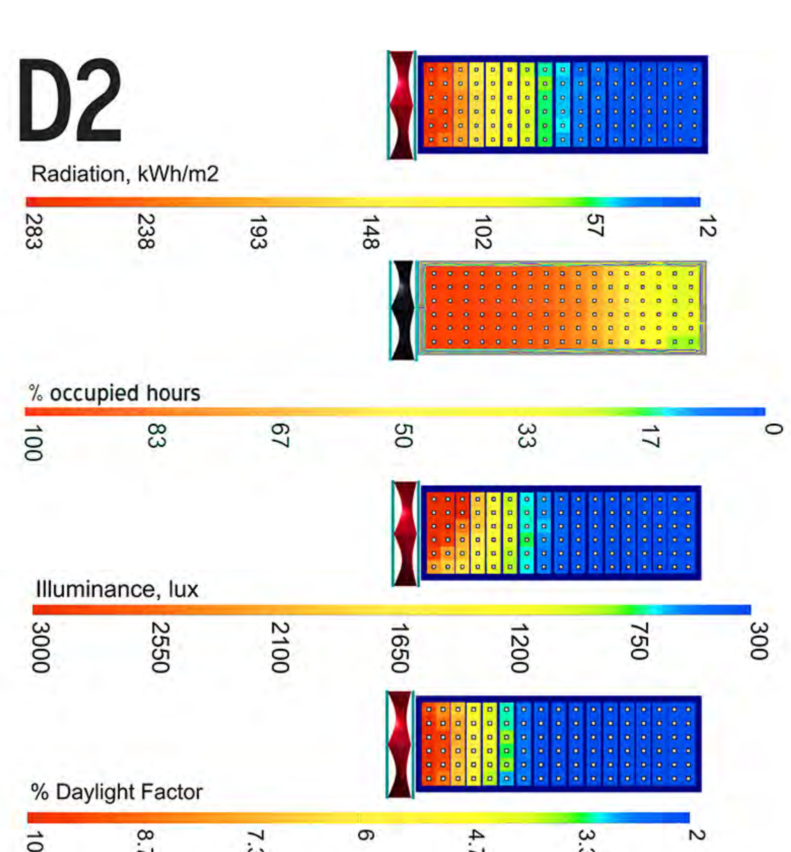
Radiation Map Nodes Analysis
Mean Radiation =3.73 kWh/m2 = 1183 BTU/HOUR/SQ. FT
99% of Area between 0 & 29
1% of Area > 29 kWh/m2; 0% of Area < 0 kWh/m2

DIVA-for-Rhino Simulation
Daylight Autonomy (300 lux)
Mean Daylight Autonomy =32.78 % of time occupied

Illuminance Nodes Analysis
Month, Date and Time: +s 09 21 09
Mean Illuminance =317.36 lux
29.4% of Area between 300 & 2000 lux
2% of Area > 2000 lux; 68.6% of Area < 300 lux

Daylight Factor Nodes Analysis
Mean Daylight Factor =0.99 %
18.6% of Area between 2 & 10
0% of Area > 10 %; 81.4% of Area < 2 %

D2



Radiation Map Nodes Analysis
Mean Radiation = 9.92 kWh/m2 = 3147 BTU/HOUR/SQ. FT
99% of Area between 12 & 283
1% of Area > 283 kWh/m2; 0% of Area < 12 kWh/m2

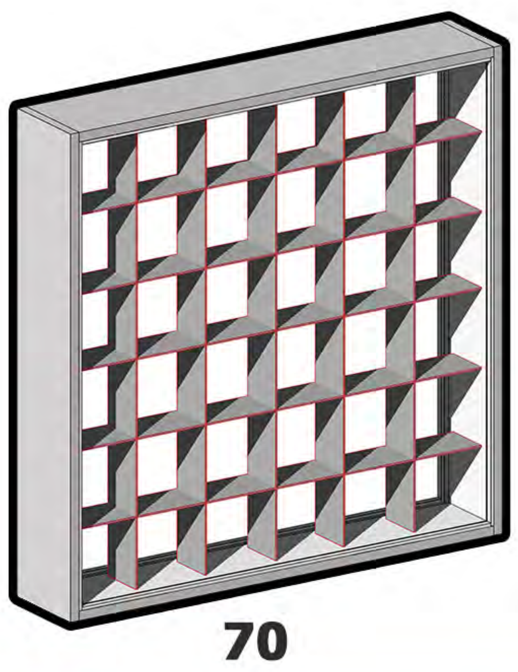
Simulation
Daylight Autonomy (300 lux)
Mean Daylight Autonomy =70.4 % of time occupied

Illuminance Nodes Analysis
Month, Date and Time: +s 09 21 09
Mean Illuminance =980.83 lux
48.1% of Area between 300 & 3000 lux
8.8% of Area > 3000 lux; 43.1% of Area < 300 lux

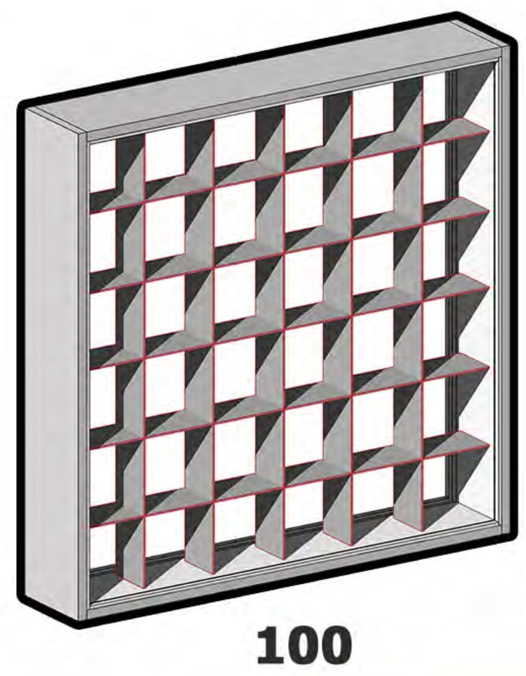
Daylight Factor Nodes Analysis
Mean Daylight Factor =2.99 %
39.2% of Area between 2 & 10
3.9% of Area > 10 %; 56.9% of Area < 2 %

DIGITAL ANALYSIS : GRASSHOPPER + DIVA

BASED ON PREVIOUS STUDIES OF BRISE SOLEIL GEOMETRIES, THERE MUST BE A COMBINATION OF VERTICAL AND HORIZONTAL ELEMENTS PLACED PERPENDICULARLY TO THE FACADE. SO VISUAL TRANSPARENCY IS ALWAYS MANTAINED.



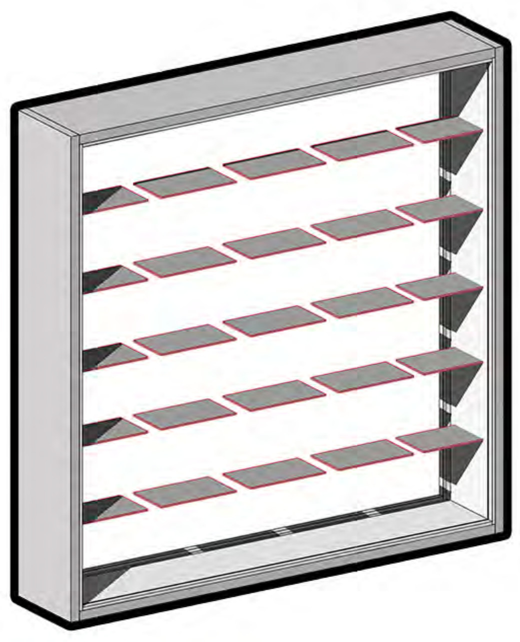
70

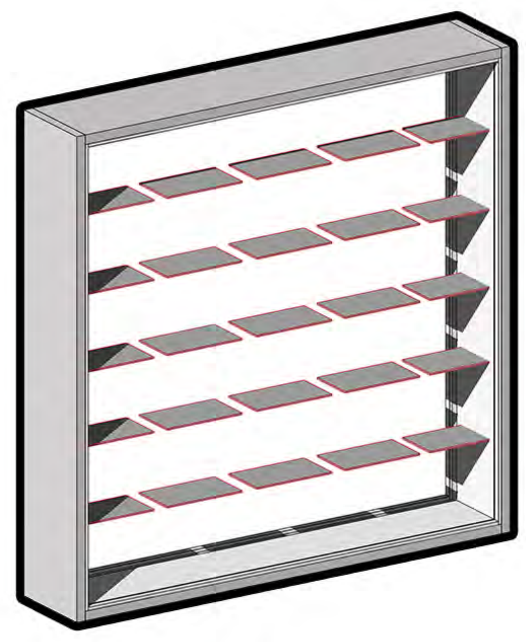


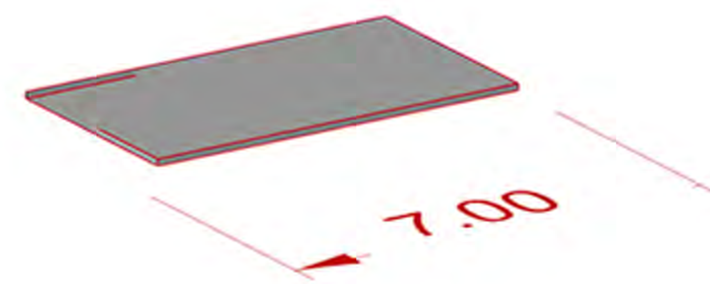
100

1. **VISUAL** TRANSPARENCY

MATERIAL TESTING PROVED THAT THE LARGER SURFACE AREAS RESULTED IN THE LARGEST DEFLECTION.
THIS DICTATED THE 4” BY 7” UNIT SIZE



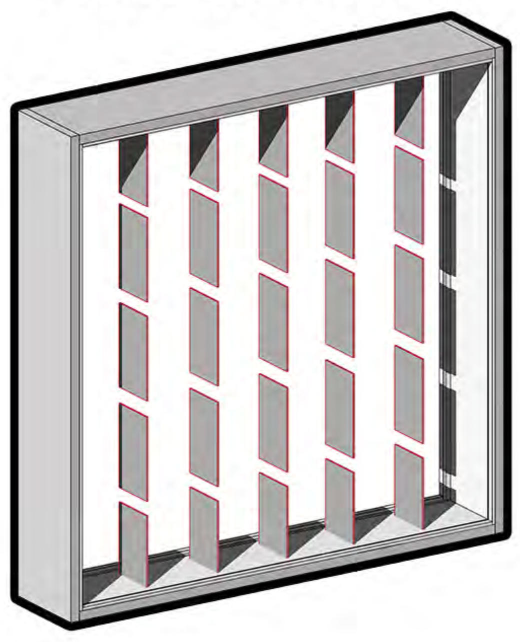


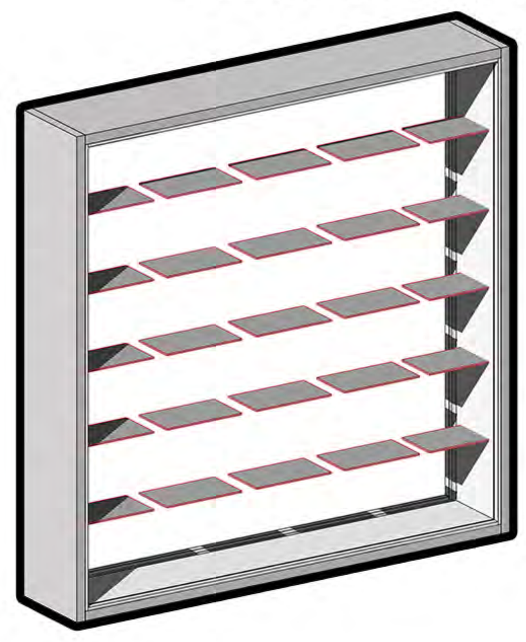


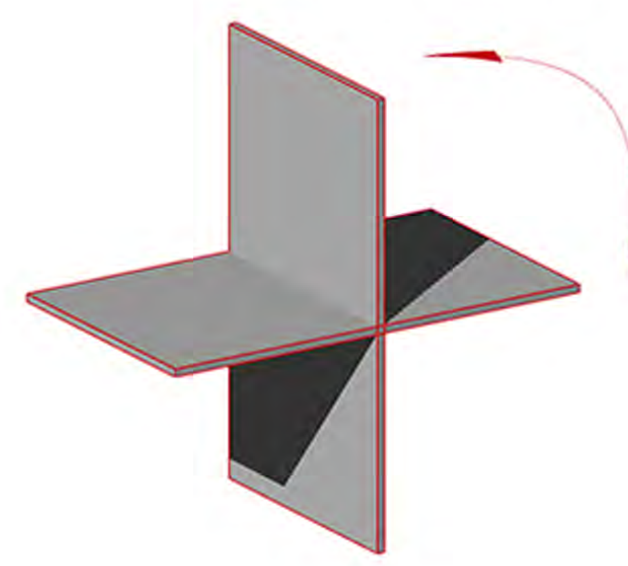
2. **SIZE** DICTATED BY TESTS

DATA ACQUISITION | DATA INTERFACE | DATA VISUALIZATION | DATA ANALYSIS

ASSUMING APPLICATION ON A SOUTH FACING FACADE, UNITS SHOULD BE ROTATED VERTICALLY TO MAXIMIZE HEAT GAIN, AND HORIZONTALLY TO MINIMIZE HEAT GAIN.

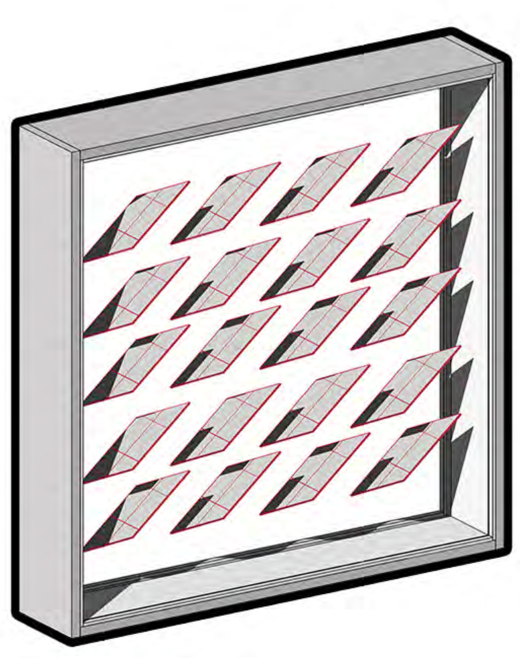


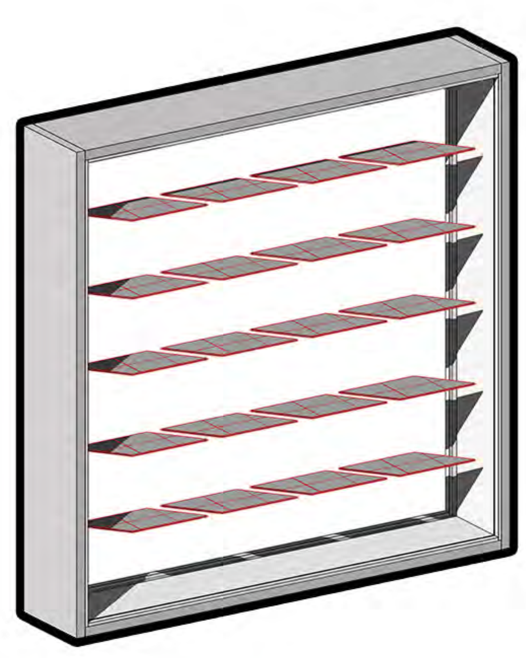


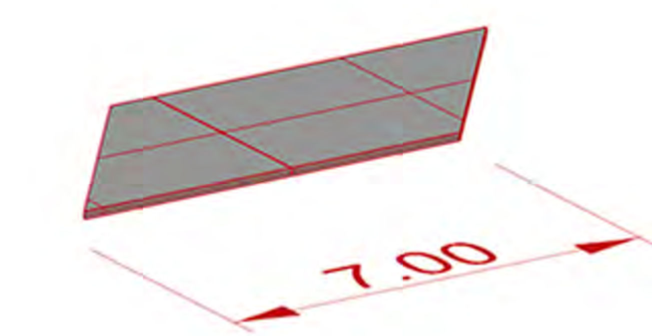


3. HOR. VS VERT. WHEN **HEATED**

BECAUSE THE UNITS CAN NOT DEFLECT TO 90 DEGREES, THE UNITS ARE ROTATED AXIMETRICALLY TO MITIGATE AFTERNOON LIGHT FROM THE WEST, AND TESELLATED TO MAXIMIZE MATERIAL EFFICIENCY AND COVERAGE.

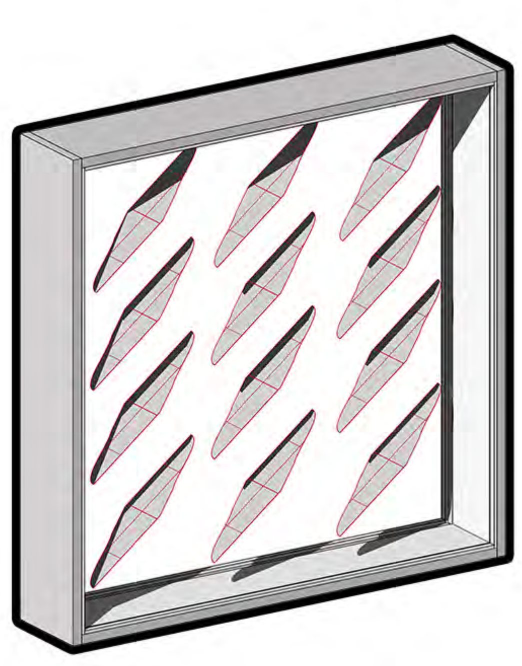


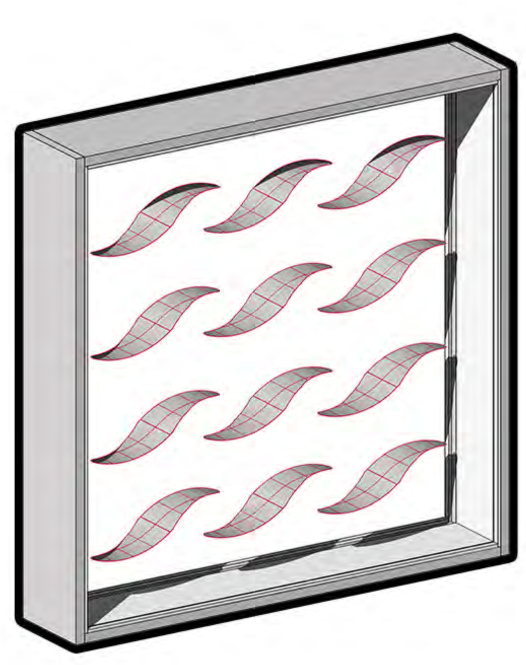


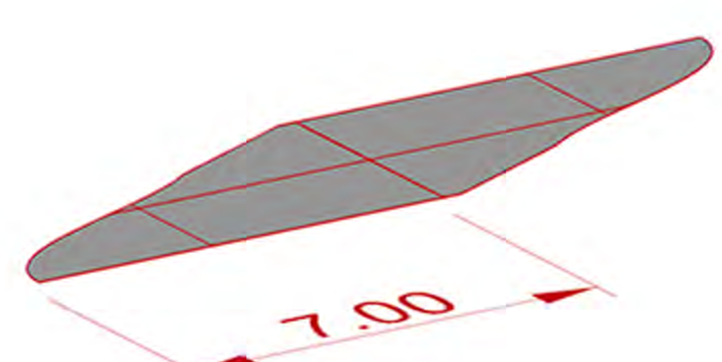


4. ASSIGN TO **WEST**, TESELLATE

THE FIRST WORKING PROTOTYPE IS SIMULATED, CONSTRUCTED, AND TESTED. EACH ITERATION IS TESTED IN DIVA AND PARAMETRICALLY REFINED.

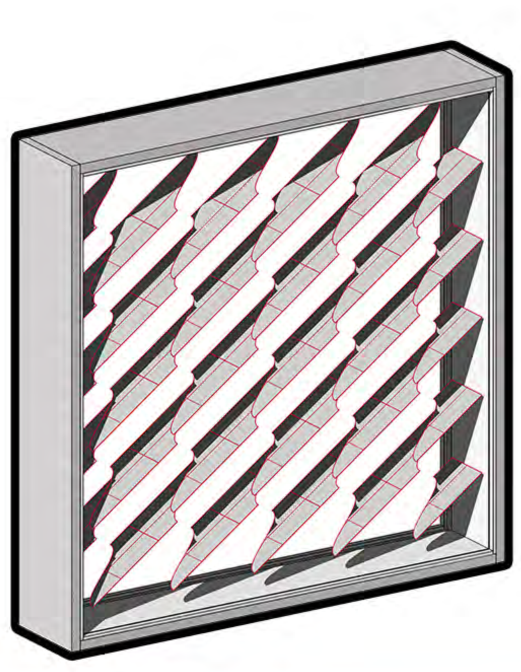


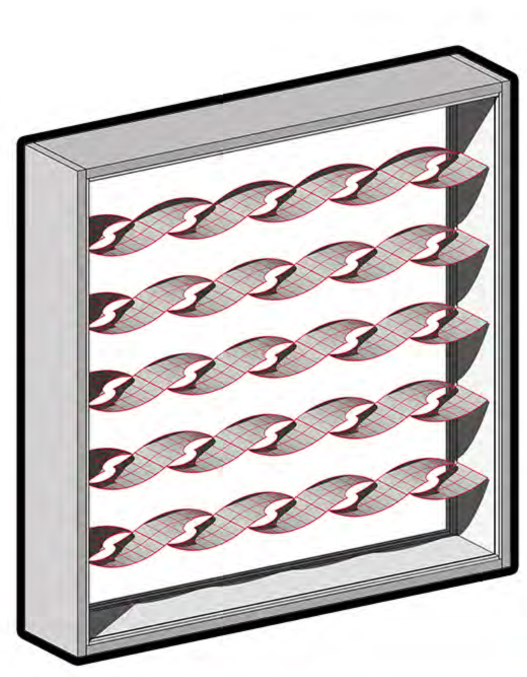


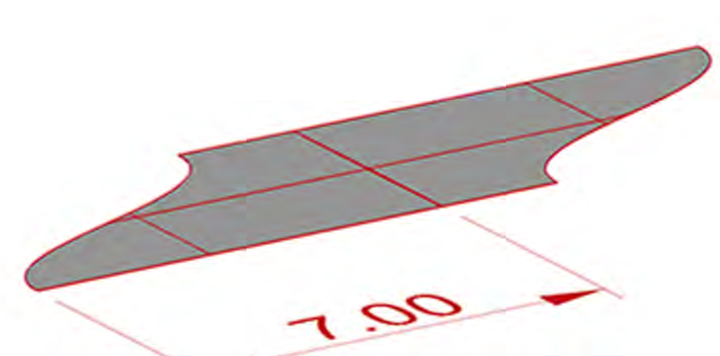


5. PROTO. **I**

AFTER SEVERAL ITERATIONS, WE ARRIVE AT THE FINAL PROTOTYPE. THE DENSITY IS ADJUSTED FOR MAXIMUM COVERAGE, AND SO THE HORIZONTAL CONFIGURATION PERFORMS AS A LIGHT SHELF.





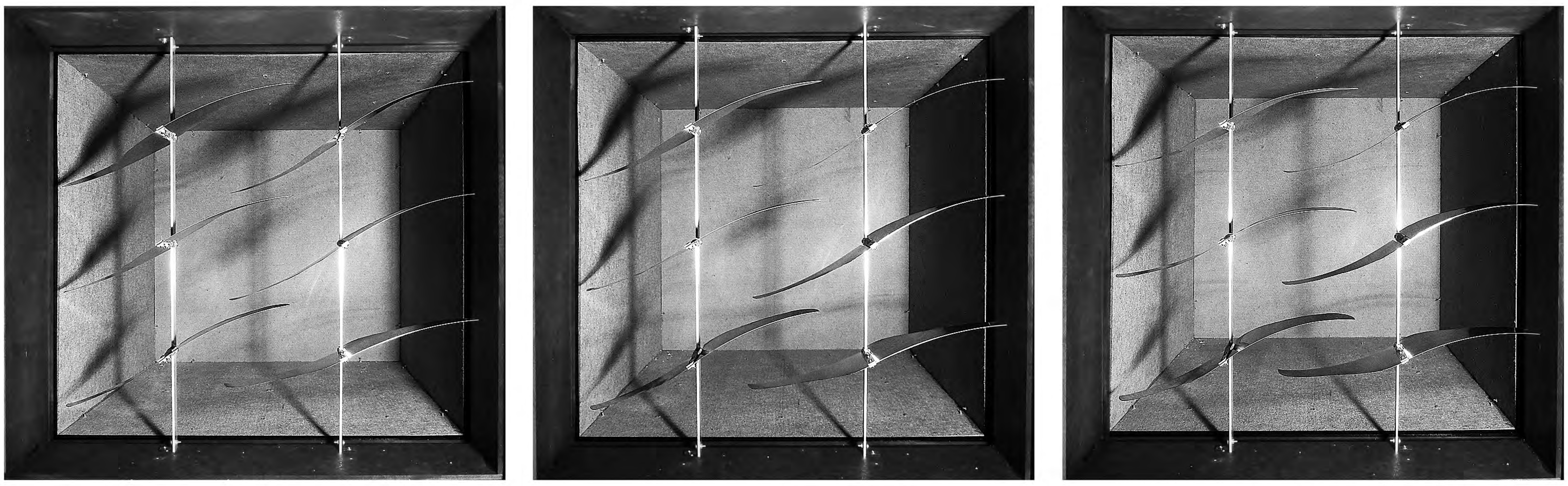


6. PROTO. **II**

GEOMETRY DEVELOPMENT

2'x2'x6" wood frame
2 vertical aluminium
6 connection pieces
12 bimetal lourvers

glass type
front // single pane
back // low e pane



PROTOTYPE I

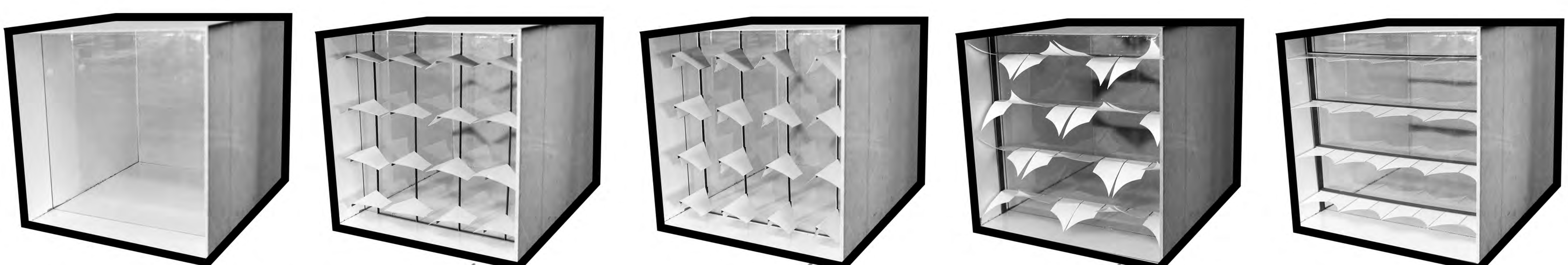
@ 75 DEGREES | @ 85 DEGREES | @ 95 DEGREES

2'x2'x6" wood frame
4 vertical aluminium
12 connection pieces
18 bimetal lourvers
air ventilation on top

glass type
front // single pane
back // **reflected low-e pane**

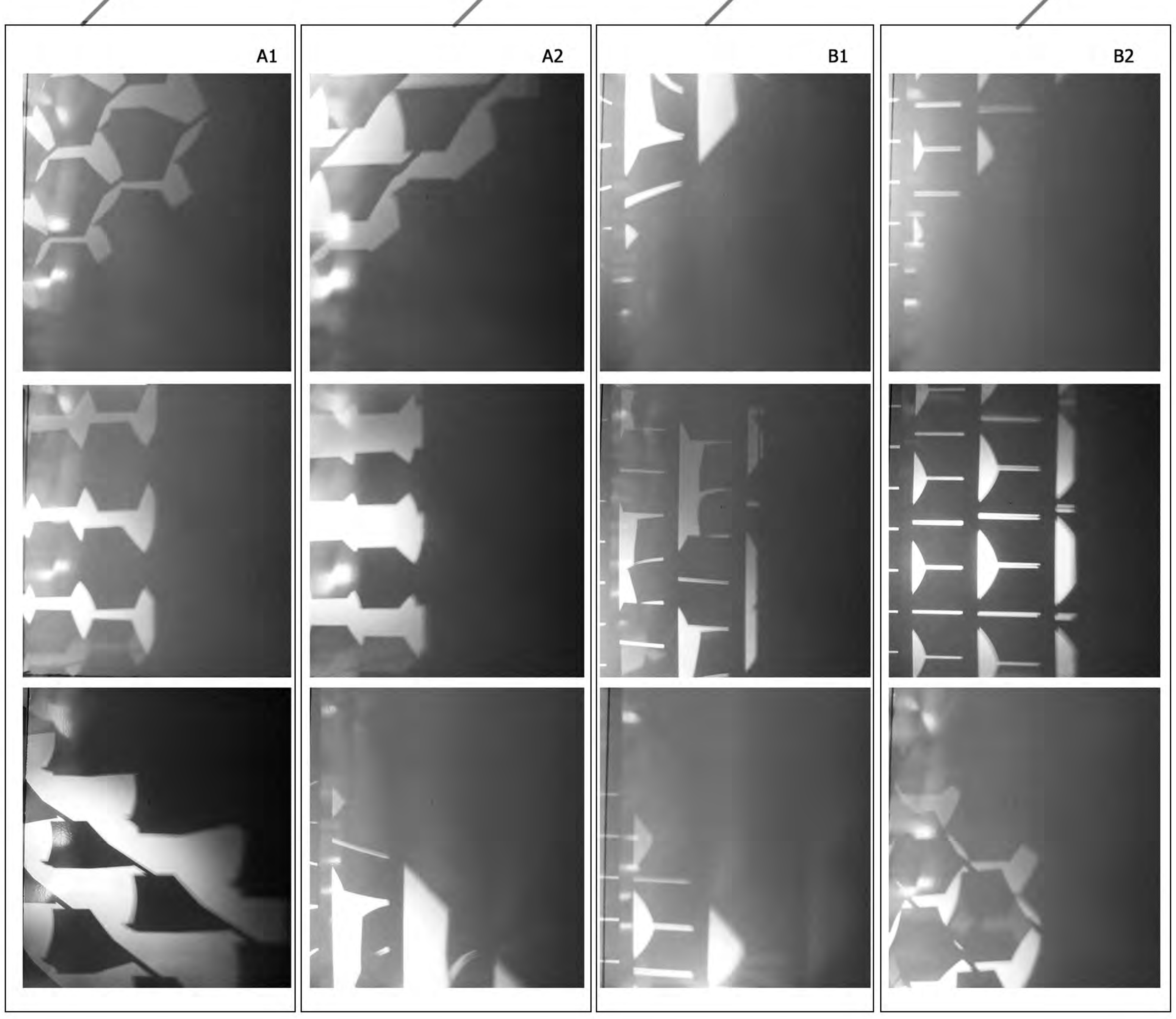
PROTOTYPE II

@ 75 DEGREES | @ 85 DEGREES | @ 95 DEGREES



▲ BASE GEOMETRIES : DESIGN

A1 A2 B1 B2



TIME OF THE DAY
MORNING

NOON

AFTERNOON

DAYLIGHT TESTING : PHYSICAL MODEL

PROGRESS

3'x3'x6" wood frame

6 vertical aluminium

30 connection pieces (3D printed and silver spray painted)

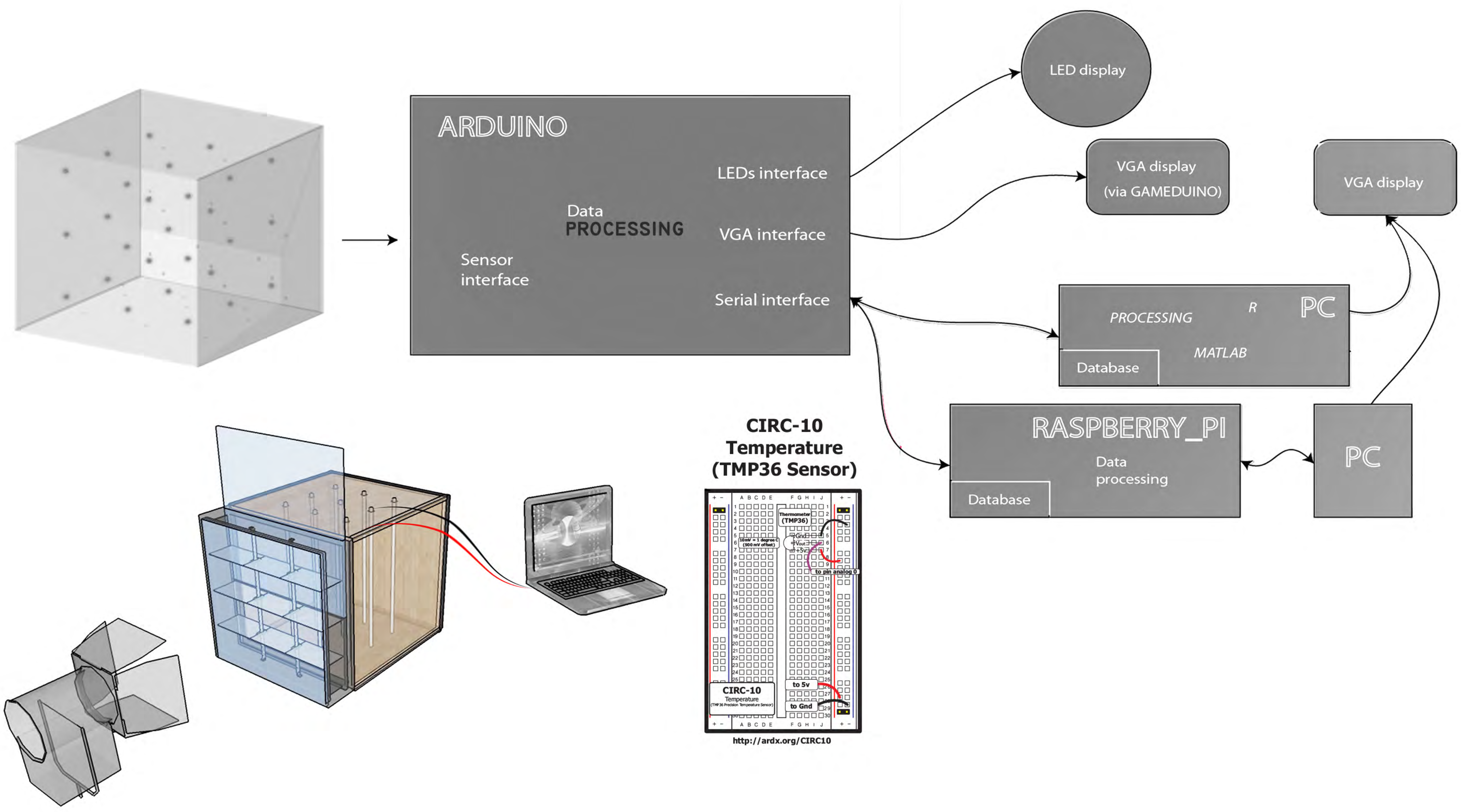
50 bimetal lourvers

glass type

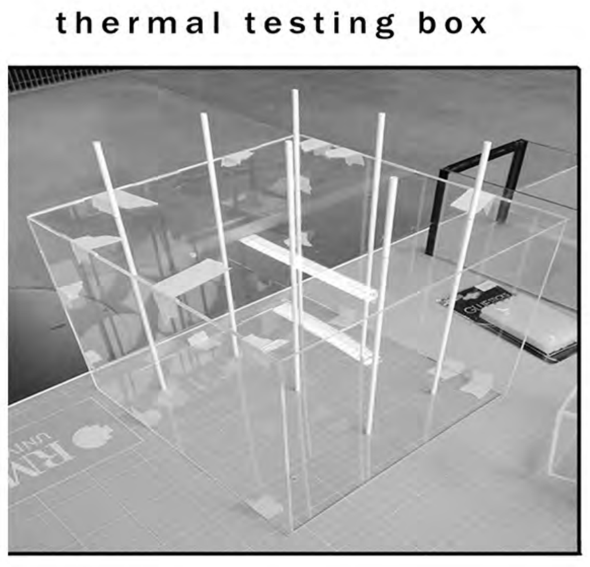
front // single pane

back // low e pane

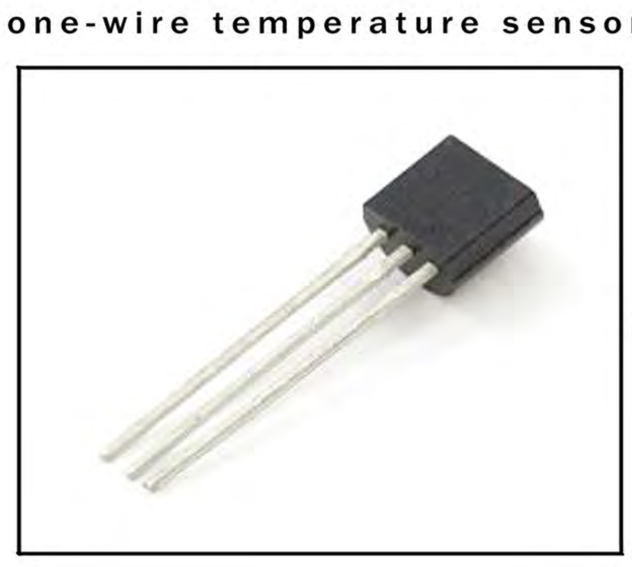
PROTOTYPE III



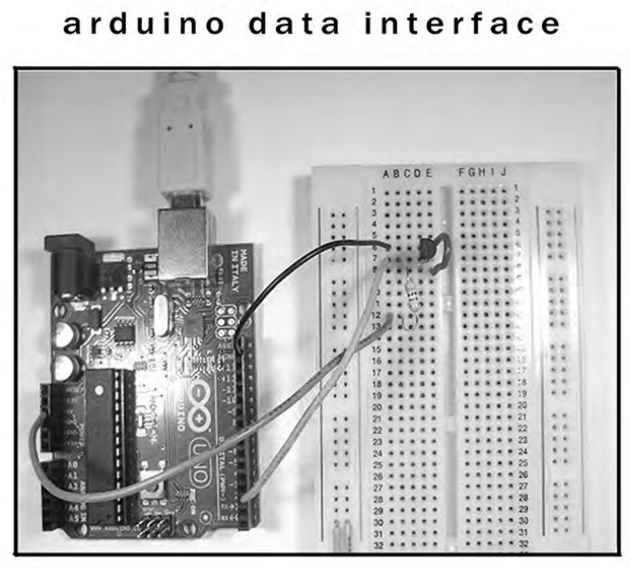
thermal testing box



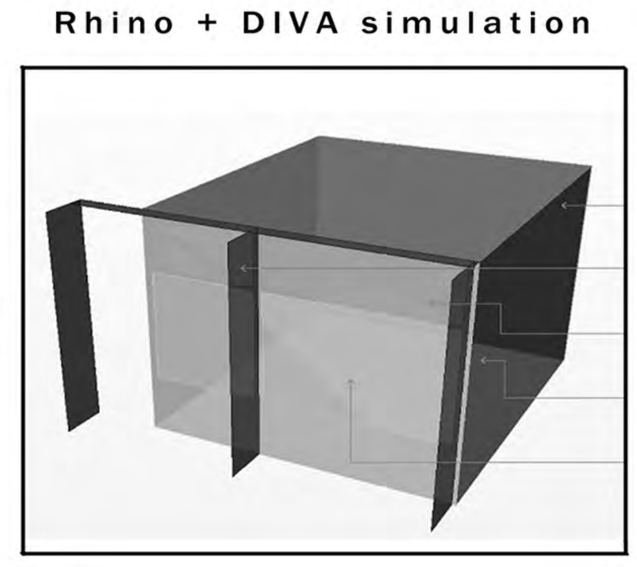
one-wire temperature sensor



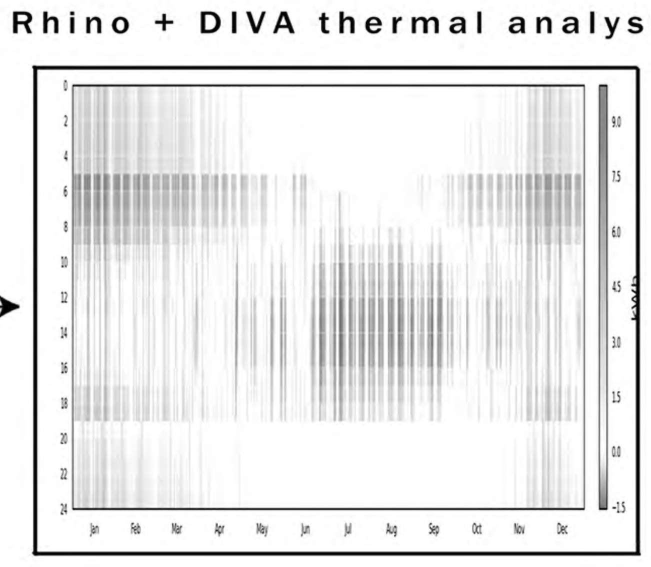
arduino data interface



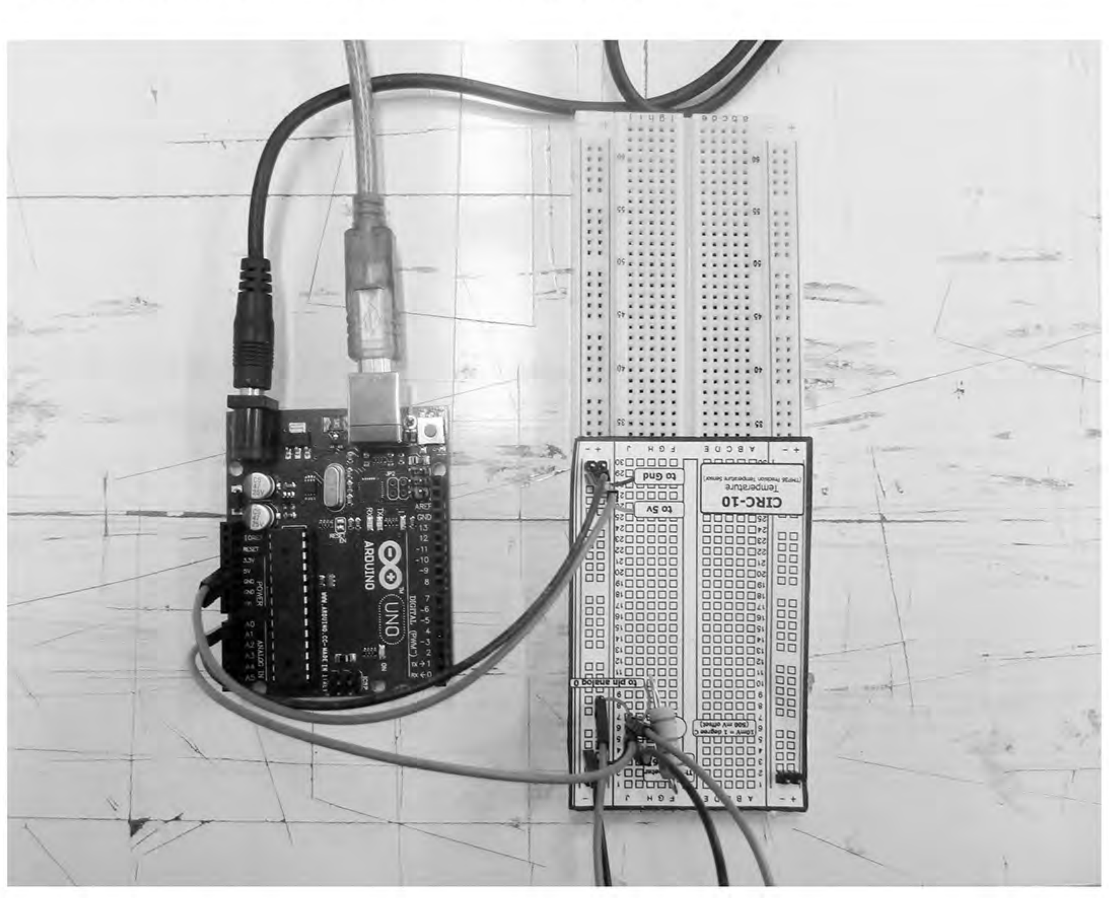
Rhino + DIVA simulation



Rhino + DIVA thermal analysis



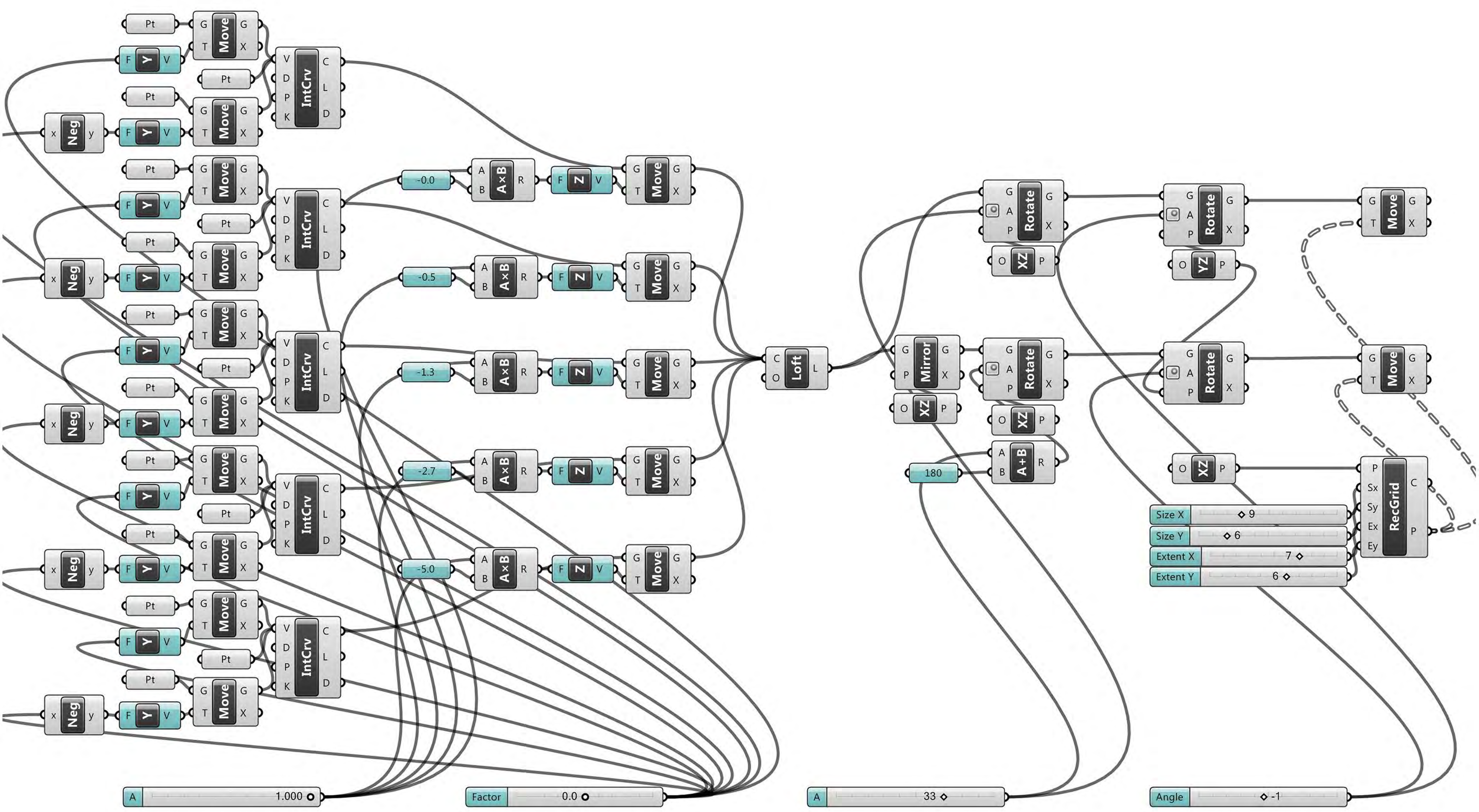
PHYSICAL TESTING DIAGRAM



ARDUINO BOARD SETUP

TEMPERATURE SENSOR GRID

PROTOTYPE THERMAL ANALYSIS

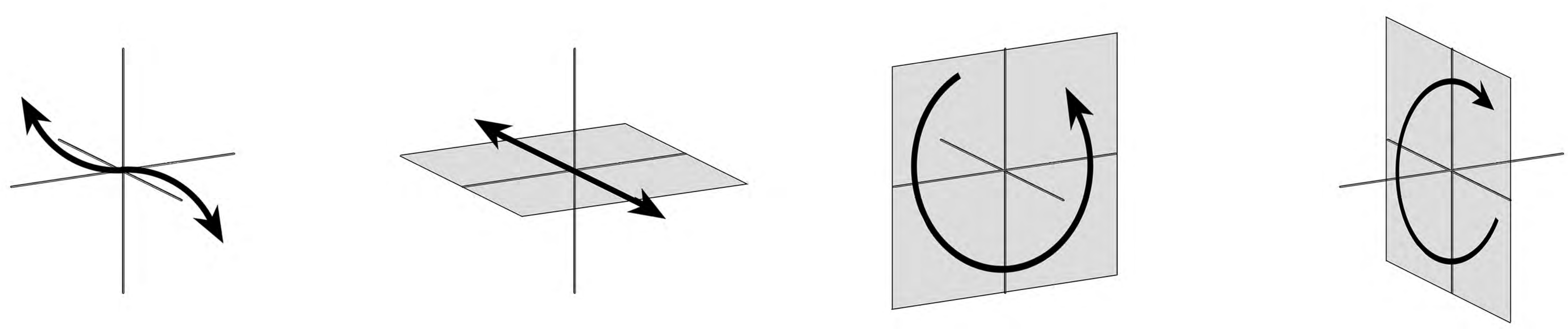


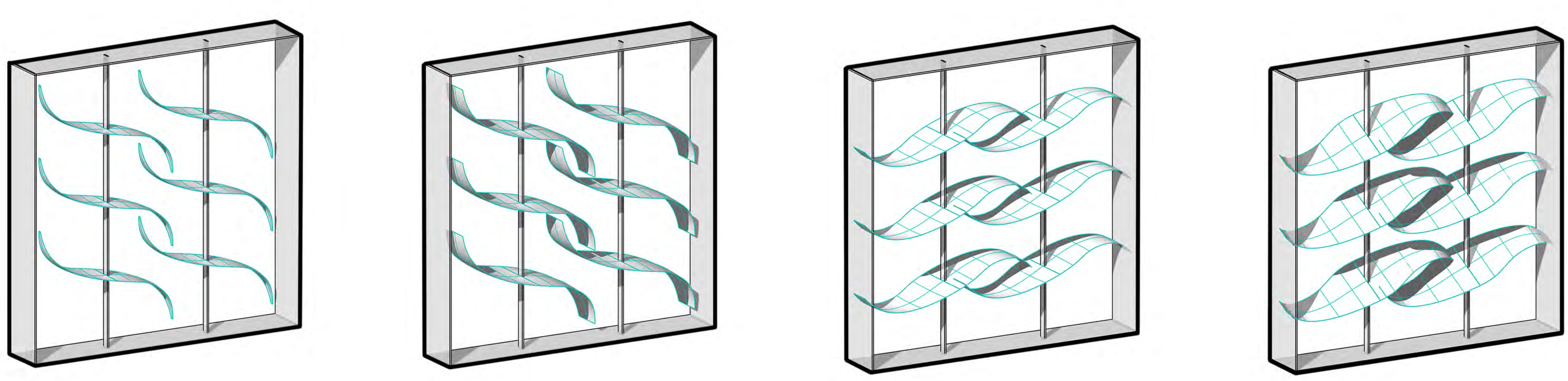
BENDING SIMULATION

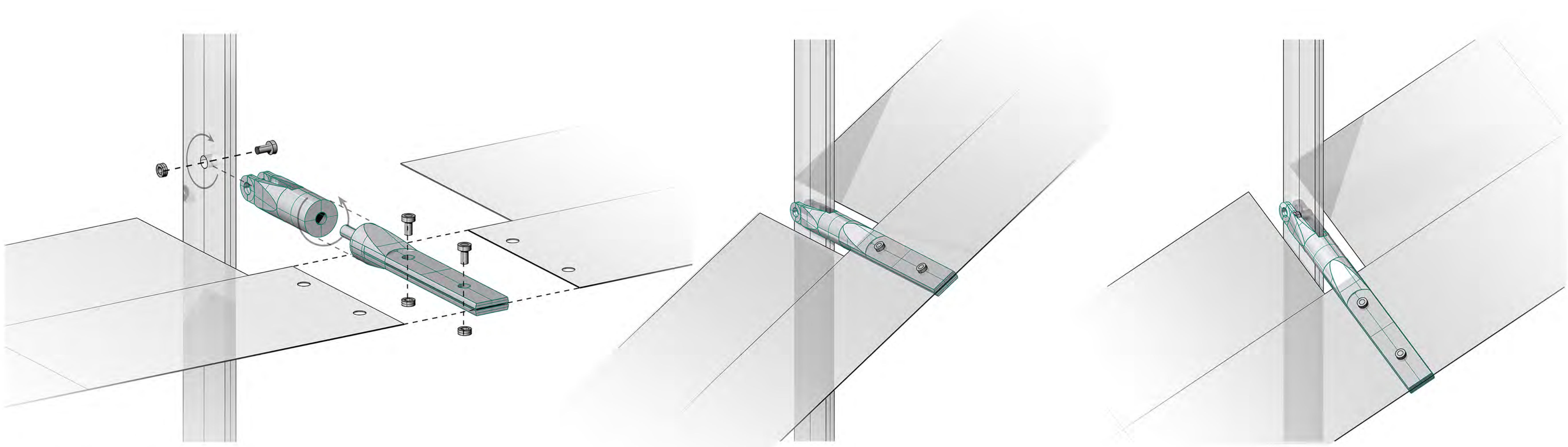
DEPTH (Y DIRECTION)

ROTATION (XZ PLANE)

ROTATION (YZ PLANE)

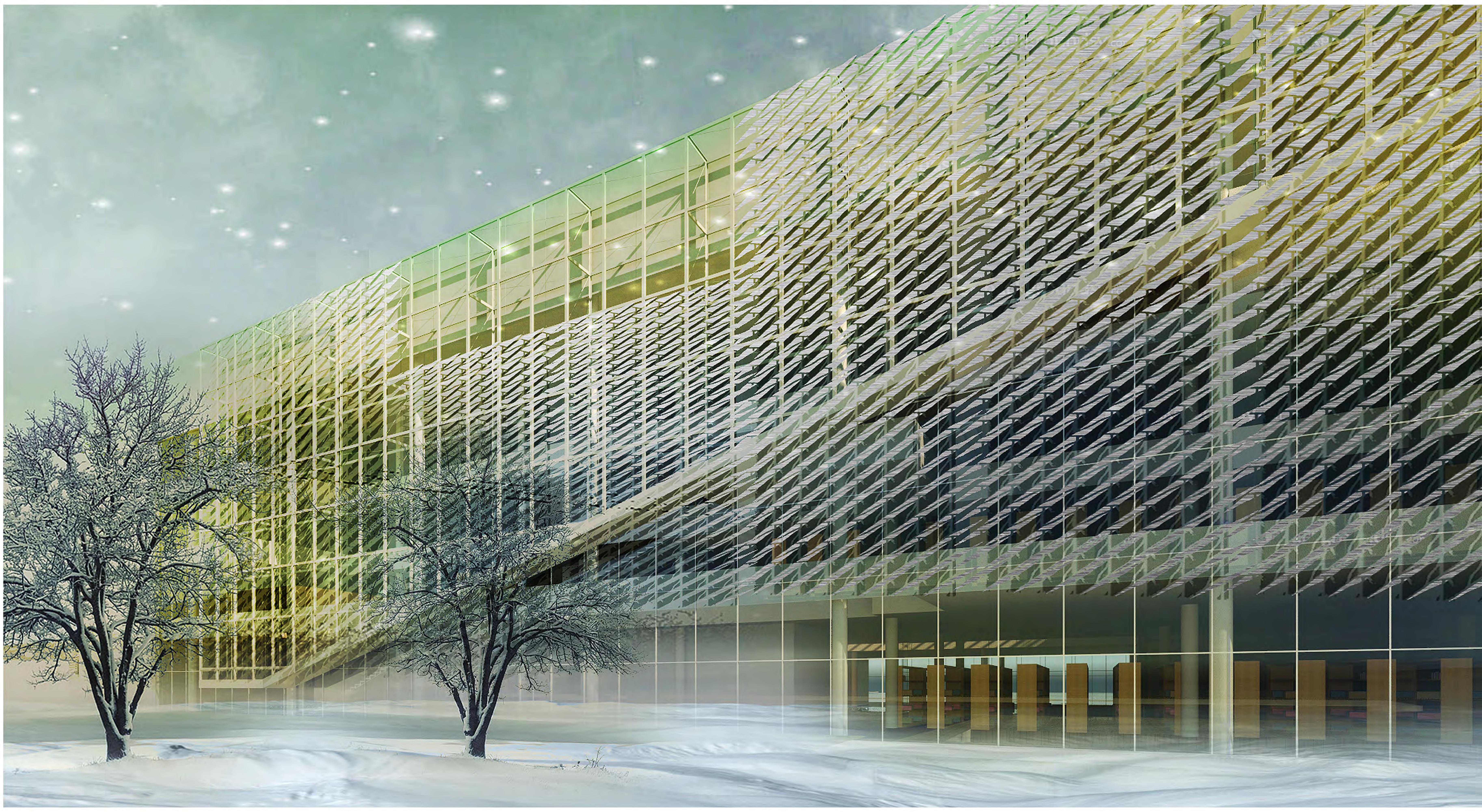




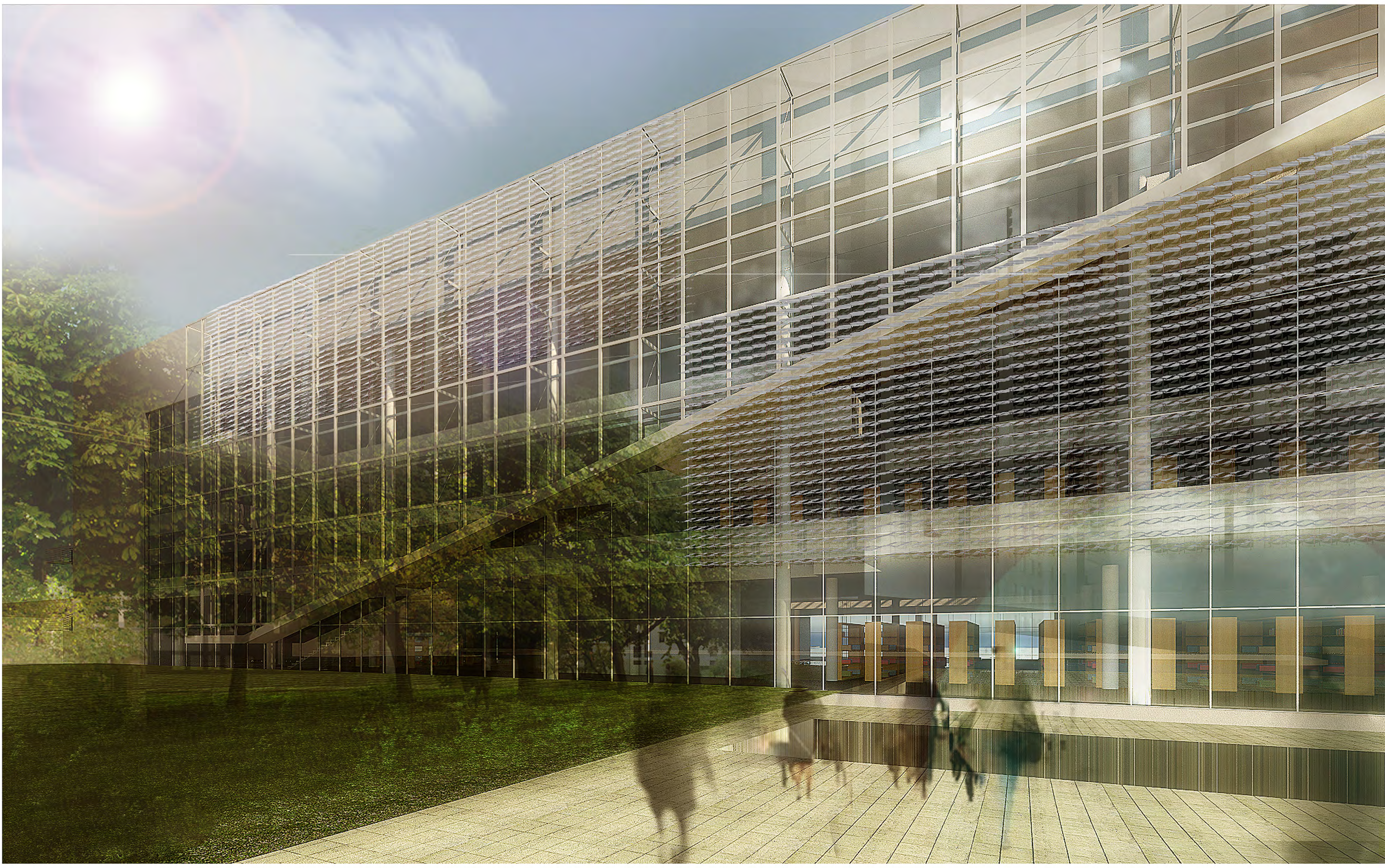


ROTATING JOINT

GEOMETRY REFINEMENT : RHINO + GRASSHOPPER



SATURDAY, DECEMBER 21 WINTER SOLSTICE @40ºF



SATURDAY, JUNE 21 SUMMER SOLSTICE @100ºF

APPLICATION FACADES @DIFFERENT TIME OF YEAR