Active Roof System

Final Presentation

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Project Introduction

- Amount of power consumption due to cooling and heating of large warehouse buildings it too high
  - Project will investigate roof designs that will lower this power consumption

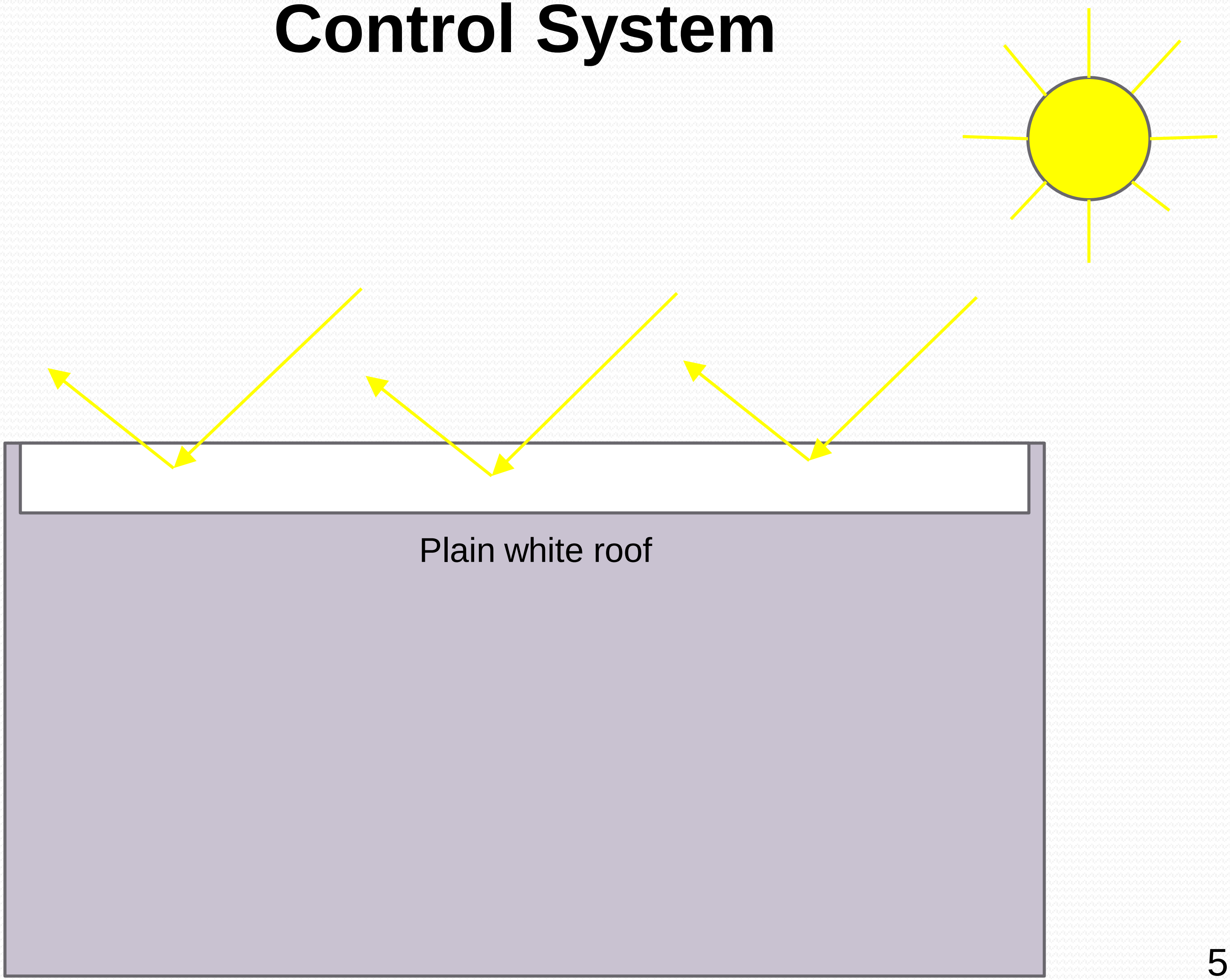
- Project Clients
  - Dr. Michael Shafer (NAU Professor)

Need Statement & Project Goal

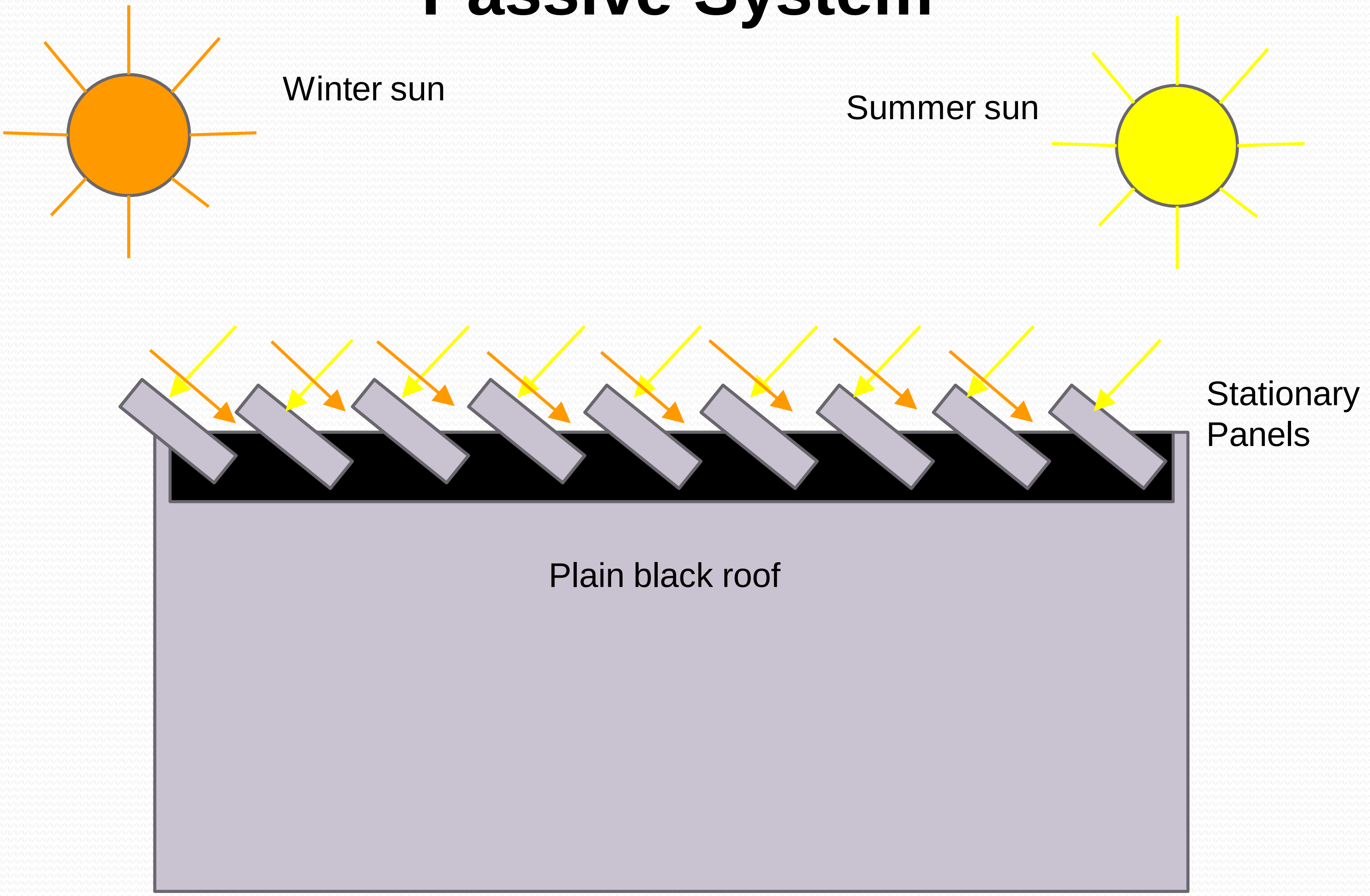
- Need Statement
  - The amount of power usage to keep the interior of large buildings at a comfortable, cool temperature is too high.

- Project Goal
  - To design and build roof system prototypes that can maintain the interior at constant temperature of a building model while using minimal power.

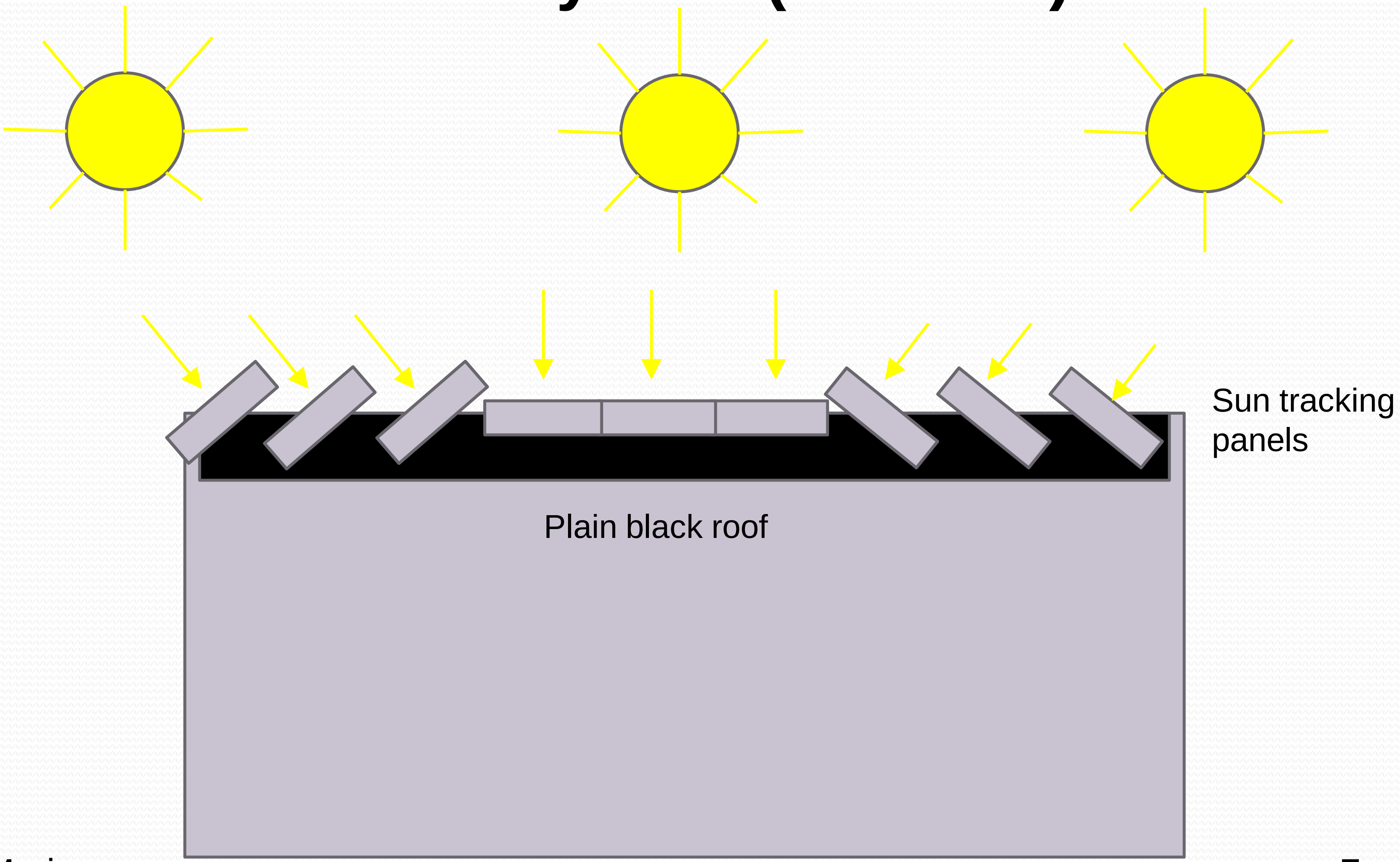
Control System



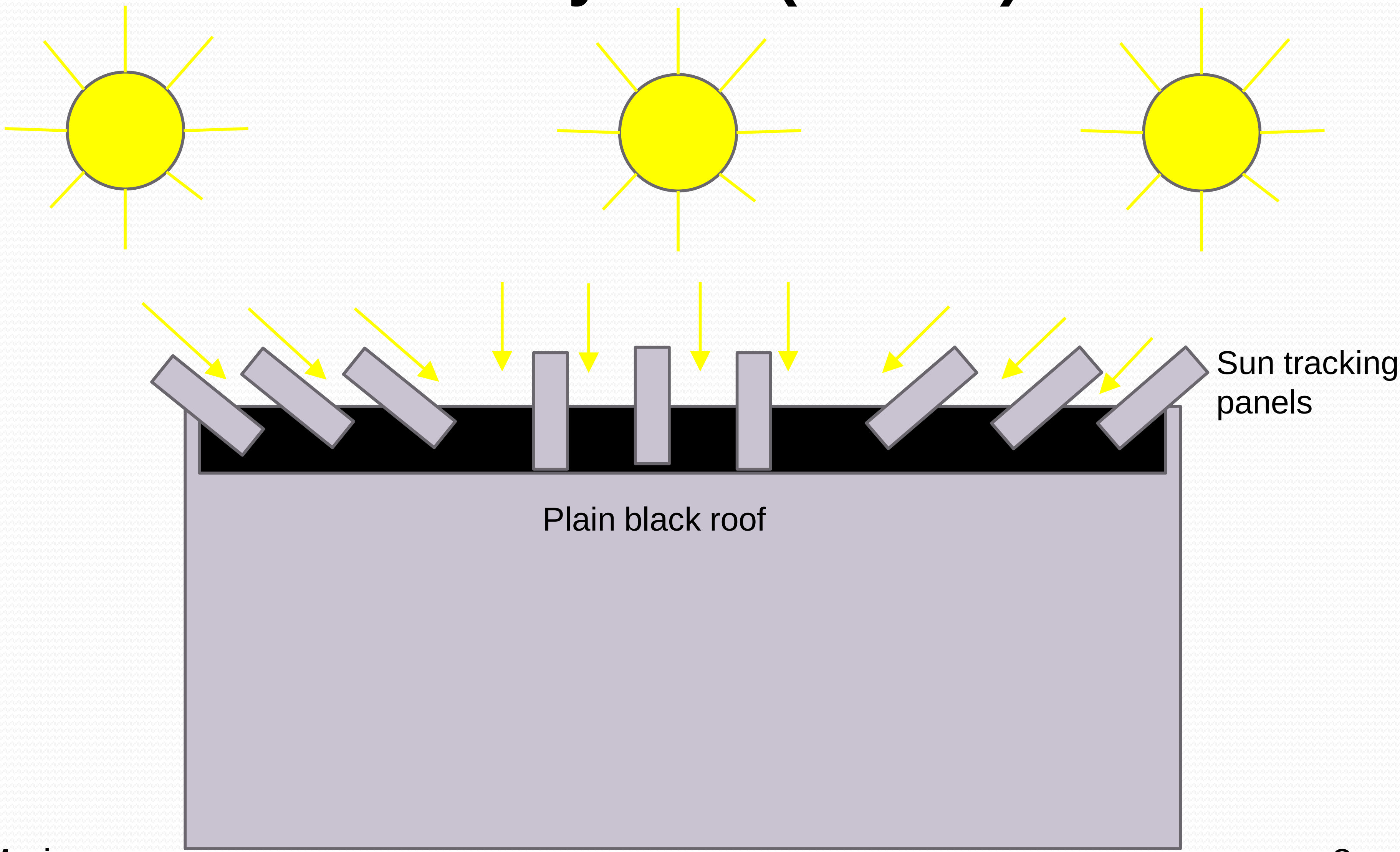
Passive System



Active System (Summer)

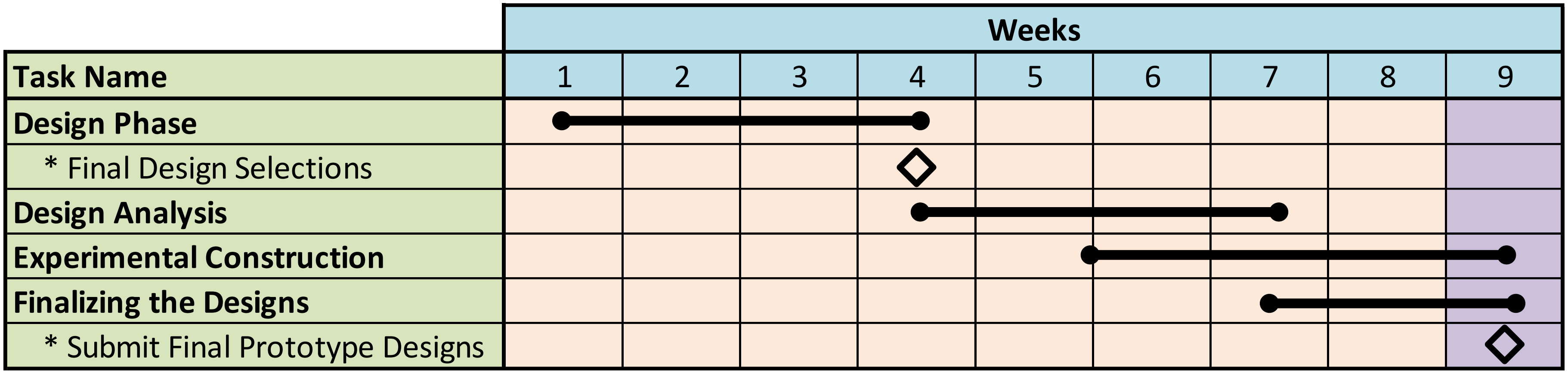


Active System (Winter)



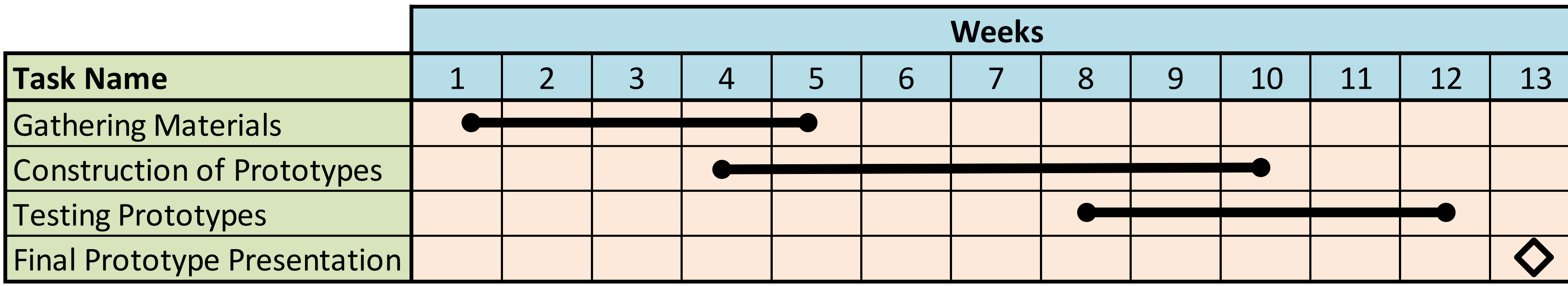
Project Timeline

- For Fall 2013



Project Timeline Cont.

- For Spring 2014



Project Objectives

Objective	Measurement Basis	Units
Maintain Constant Internal Temperature of 70^{o}F	Interior Temperature of Structure Throughout a Day	^{o}F
Reflect/Absorb the Sun's Radiation	External Roof Temperature Throughout a Day	^{o}F
Low Power Usage	Power Used by Control, Active and Passive Roof to Maintain Internal Temperature	kWh

Engineering Requirements for Analysis

- Material Strength (YS)
- Efficiency
- Weight
- Manufacturable
- Durable
- Functional
- Accuracy

Quality Function Deployment

Customer Needs	Customer Weights	Material Strength (YS)	Efficiency	Weight	Manufacturable	Durable	Functional	Accuracy	Active Design	Passive design
		Engineering Requirements							Benchmarks	
1. Seasonal	9	8	9	0	0	9	8	9	X	X
2. Light Weight	4	2	0	10	0	7	5	0		X
3. Low Cost	10	4	6	9	8	5	9	7		X
4. Minimum Power input	10	0	9	0	0	0	0	6		X
5. Stiff	6	10	0	8	0	6	6	0	X	X
6. Efficiency	8	0	10	0	0	4	9	8	X	
7. Easy to Control	7	0	0	6	0	0	6	3		X
Unit of Measure		psi	KWH	lb	Unitless	Unitless	Unitless	θ		
		Techical Target								

Prototype Design Requirements

- For all Prototypes:
  - Scaled to (smallest) Wal-mart Building
    - Chosen due to size limitations on Prototypes
    - Interior Dimensions of the smallest Wal-Mart
      - 30,000 sq ft (approx. 173.2ft x 173.2ft)
      - 25ft ceilings

Prototype Design Requirements Cont.

- Scaling Factor dependent on
  - Insulation material for model
    - Smallest thickness possible
    - Thermal resistance (R value)
      - Ability to reduce heat transfer

Prototype Design Requirements Cont.

- Estimate Walmart Insulation
  - Walls - R14 (3.5 in thick)
  - Ceiling - R34
  - Floors - R27

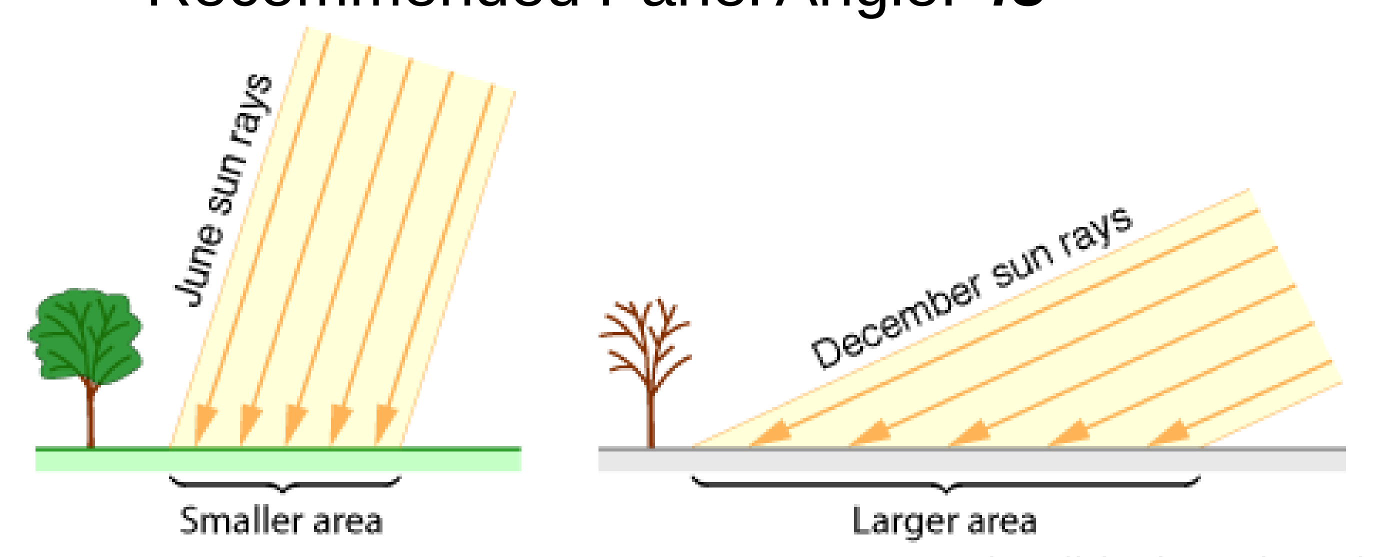
- Prototype Insulation Selected
  - Cork (Roll) (R=3.6 per inch)
    - Thickness = 3/32 inch (R= 0.3375)
    - Layers: 3 ceiling, 2 floor & 1 walls

Prototype Design Requirements Cont.

- For all Prototypes:
  - Must include heating/cooling system
    - Use to keep interior constantly at 70^{o}F
    - Be able to measure power consumption
  - Measure/Record Interior Temperature
    - Every 10 min
    - Without opening Prototype
  - Interior Dimensions of Prototypes
    - 4.5ft x 4.5ft x 0.65ft

Prototype Design Requirements Cont.

- Only for Passive Prototype:
  - Reflective Panels must be at optimum angle
    - Angled to allow reflection in summer and absorption in winter
    - Recommended Panel Angle: ***43°***



Source: http://physics.weber.edu

Prototype Design Requirements Cont.

- Only for Active Prototype:
  - Reflective Panels must rotate automatically to correct angle throughout the day
    - Angle to allow reflection in summer and absorption in winter
    - Based on Flagstaff (Testing them here)

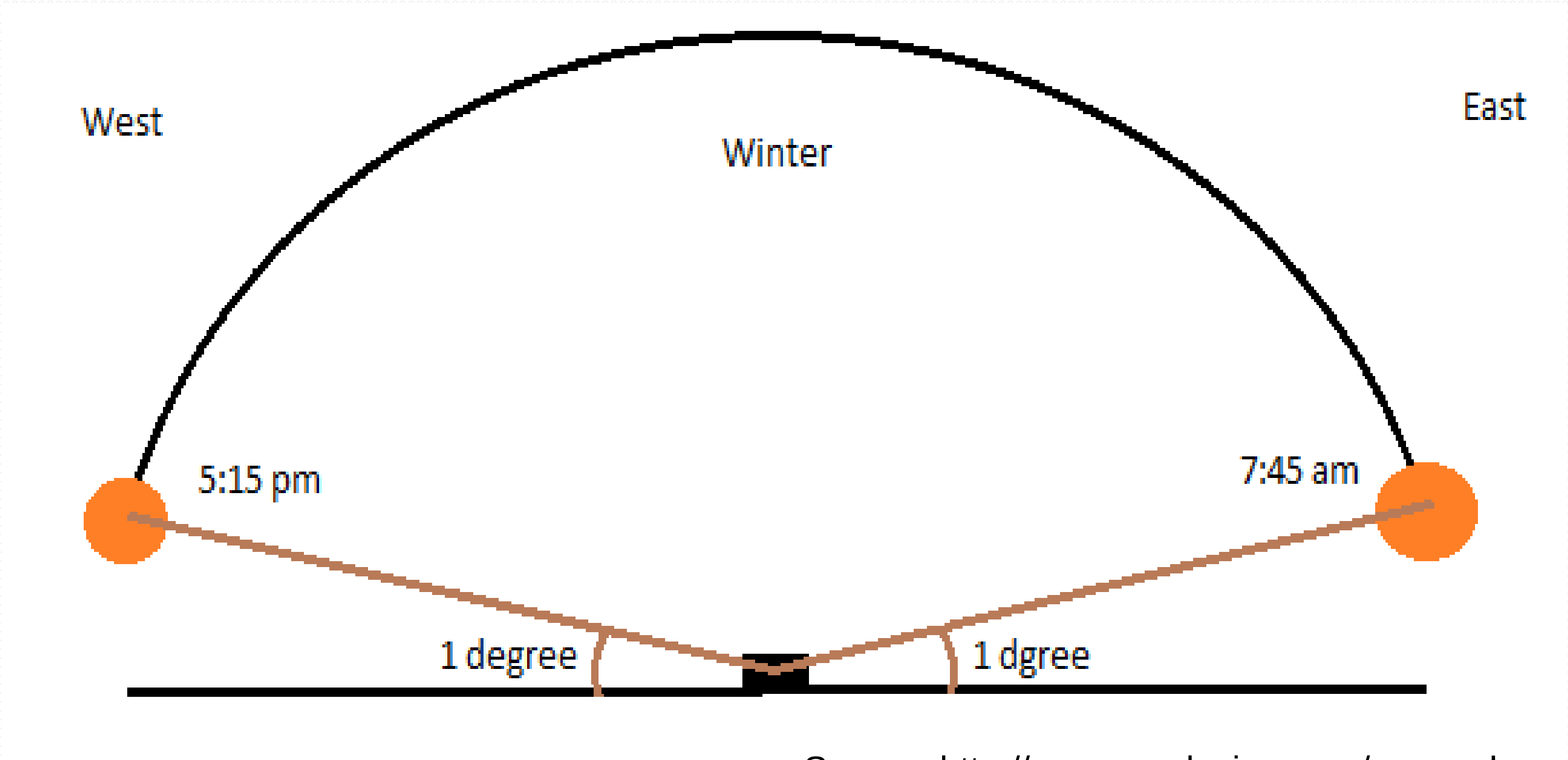
Prototype Design Requirements Cont.

- Average Sunrise and Sunset Times for each Season Based on Flagstaff

Season	Average Sunrise Time	Average Sunset Time
Winter	7:45 am	5:15 pm
Spring	6:45 am	6:30 pm
Summer	5:20 am	7:30 pm
Fall	6:20 am	6:20 pm

Prototype Design Requirements Cont.

Ex. Sunrise and Sunset Angle Based on Flagstaff

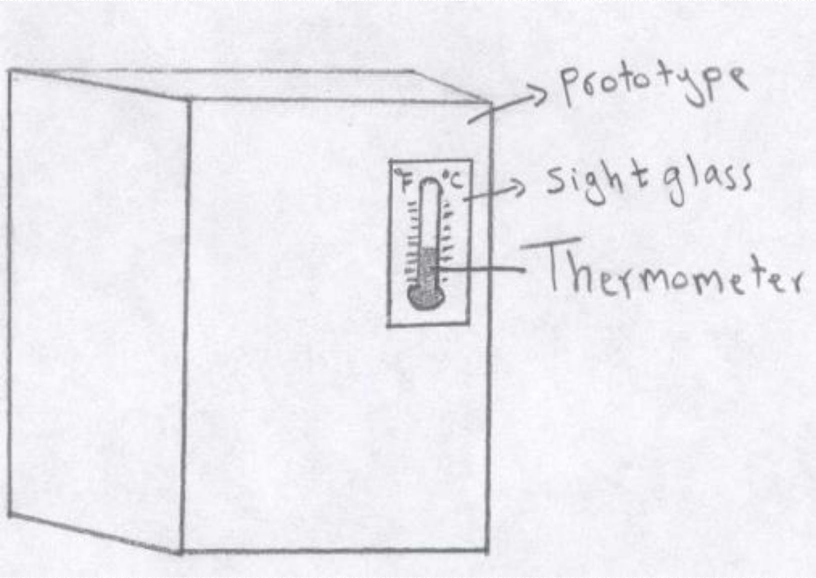


Source: http://www.susdesign.com/sunangle

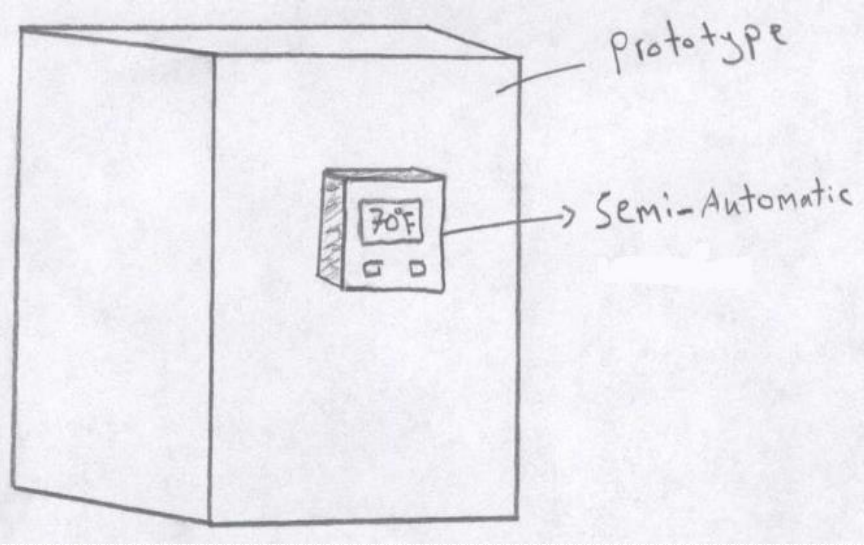
Internal Temperature Measurements

- **Considered 3 Designs**

Manual Data



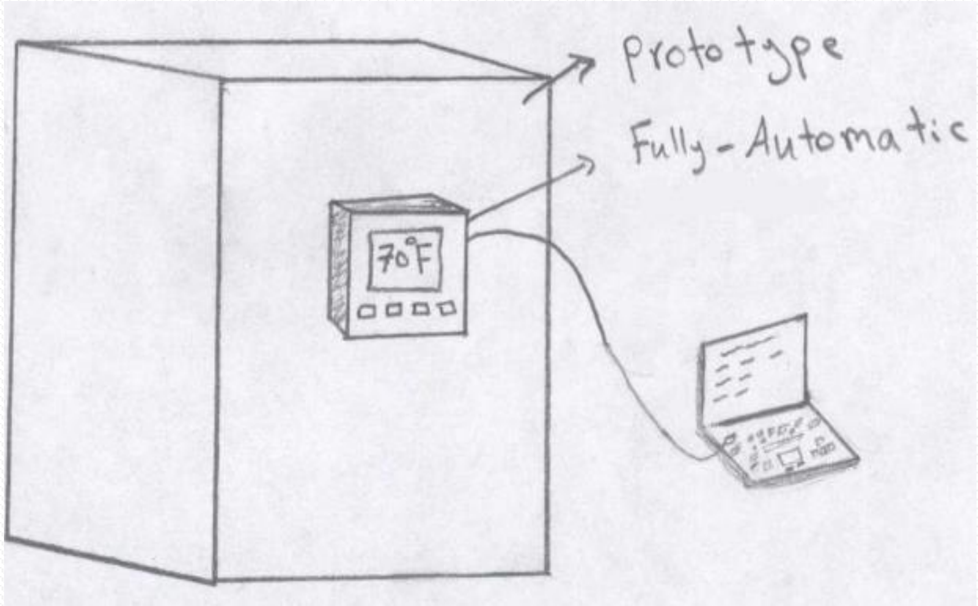
Semi-Automatic



Internal Temperature Measurements Cont.

Fully Automatic (Chosen Design)

- Advantages
  - Accurate
- Disadvantage
  - Expensive

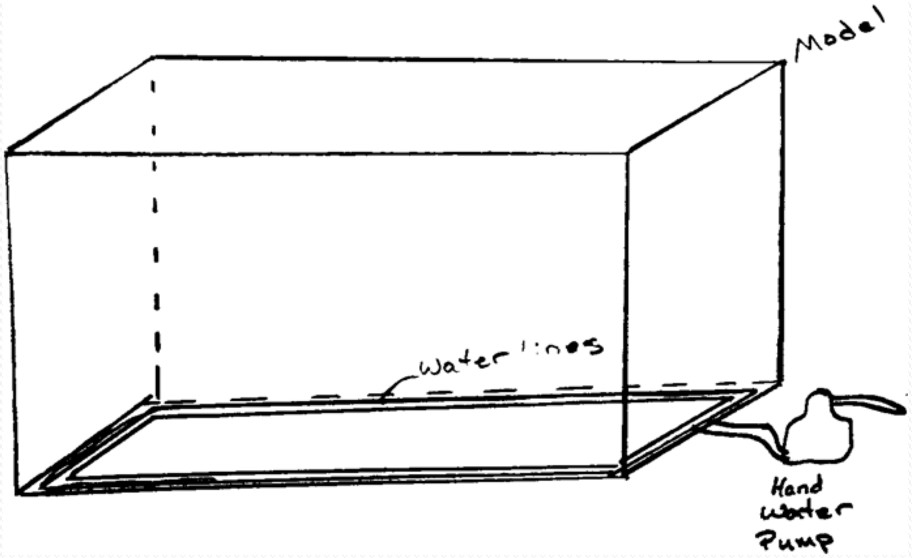


- Use device that can be programmed to read and record the temperature

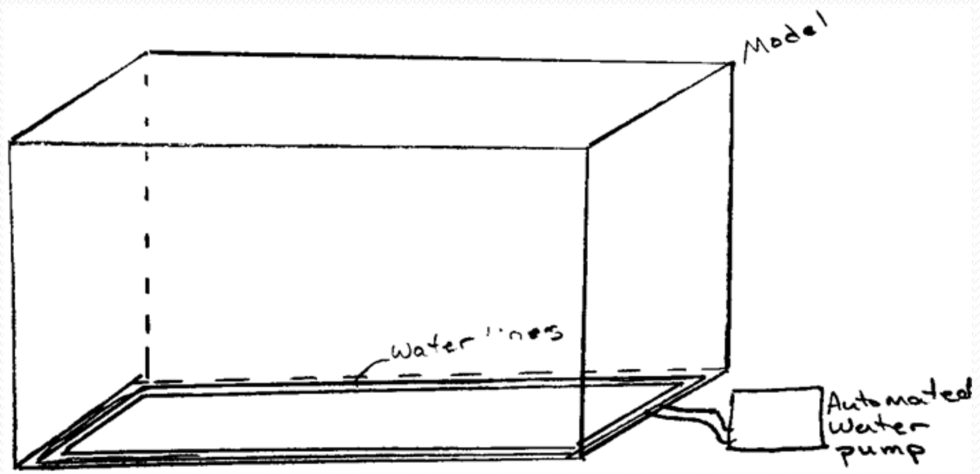
Internal Heating/Cooling System

- **Considered 3 Designs**

Manual Control

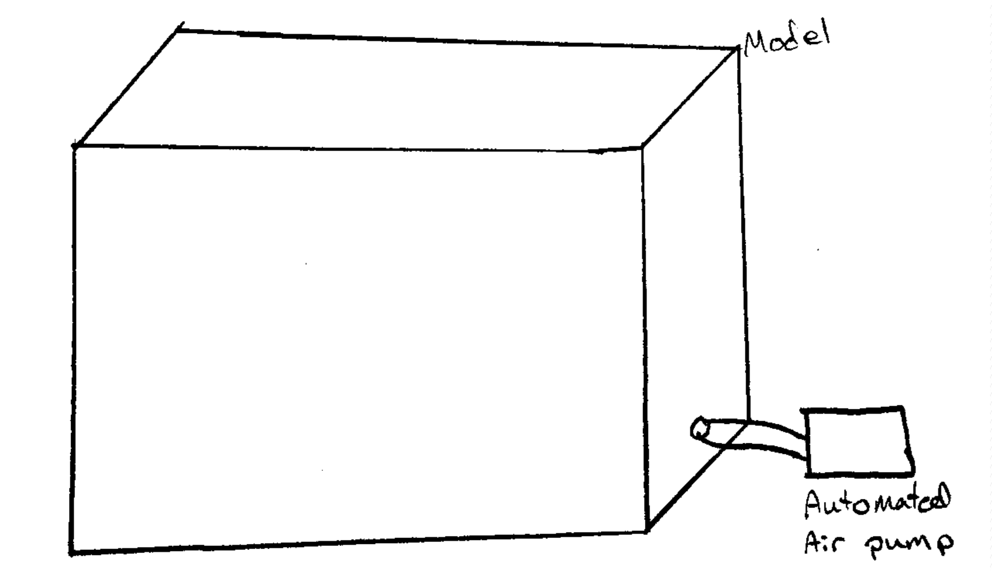


Automated Water



Internal Heating/Cooling System Cont.

Automated Air (Chosen Design)



- Automated heating/cooling system using air
- Program device to pump hot/cold air
- Similar to A/C

Control Systems

- Two arduino board control systems
  - 1 ~ Programmed to control the motor rotating the refective panels on active roof design
    - Panels attached on one shaft mechanism and rotated simultanteous with motor
  - 2 ~ Uses internal temperature measurements to control the heating/cooling system

Average Envirnomental Conditions

- Average Values for Flagstaff, AZ
  - Solar Radiation
    - Fall & Winter: 647.92 W/m^2
    - Spring & Summer: 923.96 W/m^2
  - Outside Temperature
    - Fall & Winter: 46.67^oF
    - Spring & Summer : 68.83^oF

Calculating Surface Temperature of Roof

- Important Values used to Calculate T_s
  - Average convection coefficent: h_{avg}
    - Horizontal Plate with Hot Upper Surface
  - Emissivity
    - Black Paint: 0.92
    - White Paint: 0.99
    - Reflective Panels (Polished Aluminum): 0.05
  - Estimated % of Solar Radiation Reflected

Prototype	Fall/Winter	Spring/Summer	
Active	0	100	←*Ideal*
Passive	35	65	←*Estimated*

Transient Conduction

- Assuming
  - No internal circulation due to buoyancy forces
    - Due to small ceiling height (h=0.65ft)
    - Therefore, heat is transferred through air by conduction
  - Combine ceiling insulation and internal air into one "solid" object
    - Using weighted average based on thickness
      - t_{air} = 0.65ft & t_{ins} = 0.0234ft

Transient Conduction Cont.

- Finding time it would take for internal air of prototypes to reach $T_{uncomfortable}$ by conduction heat transfer
  - $T_{uncomfortable} = 75^{o}F$

	Time to Reach 75^{o}F from 70^{o}F (min)	
Prototype	Winter/Fall	Spring/Summer
Control	2.657	80.392
Passive	2.660	80.672
Active	2.656	105.747

  - Based on our calculations a heating system is not required for the winter months.

Checking for Internal Circulation

- For the Natural Convection of Enclosures
  - If calculated Ra_L Number <1708
    - No circulation within the enclosure

	Ra_L Number ($*10^9$)for Different $T_{ceiling}$ (^oF)				
T_{floor} (^oF)	70	75	80	85	90
70	0	0.7	1.38	2.02	2.64
75	-	0	0.67	1.32	1.94

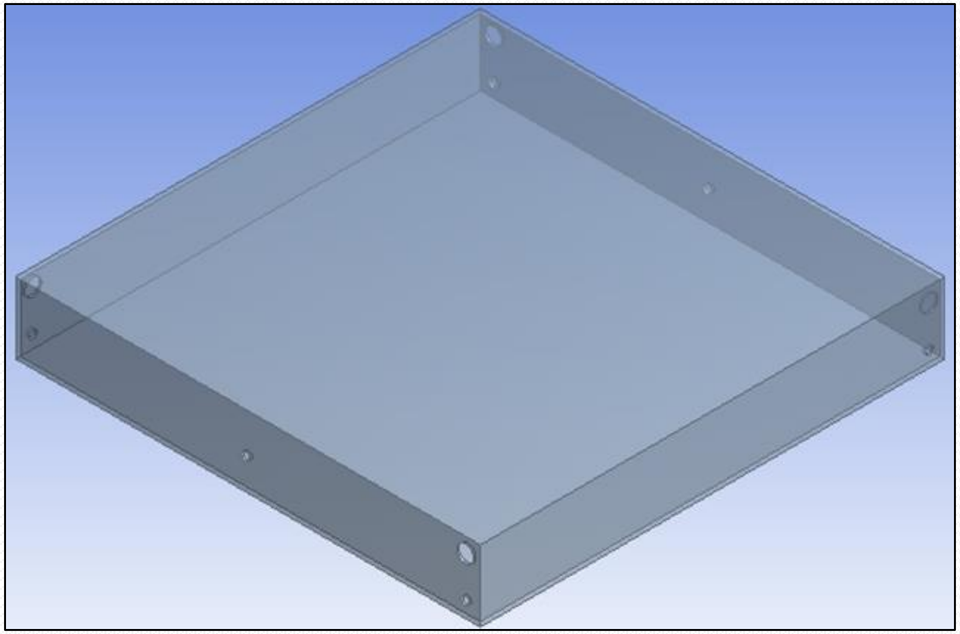
    - There will be natural air circulation for all expected $T_{ceiling}$

Estimating the Temperature of A/C Air

- Basic Model of Ideal Gas Mixture of Air
  - Assuming half the hot air goes out vents
  - T_{1hot}=75 º F & T_2=70ºF
  - Thermodynamic Energy Balance leads to $T_{A/C}$≈65.0ºF

Computer Simulated Fluid Modeling

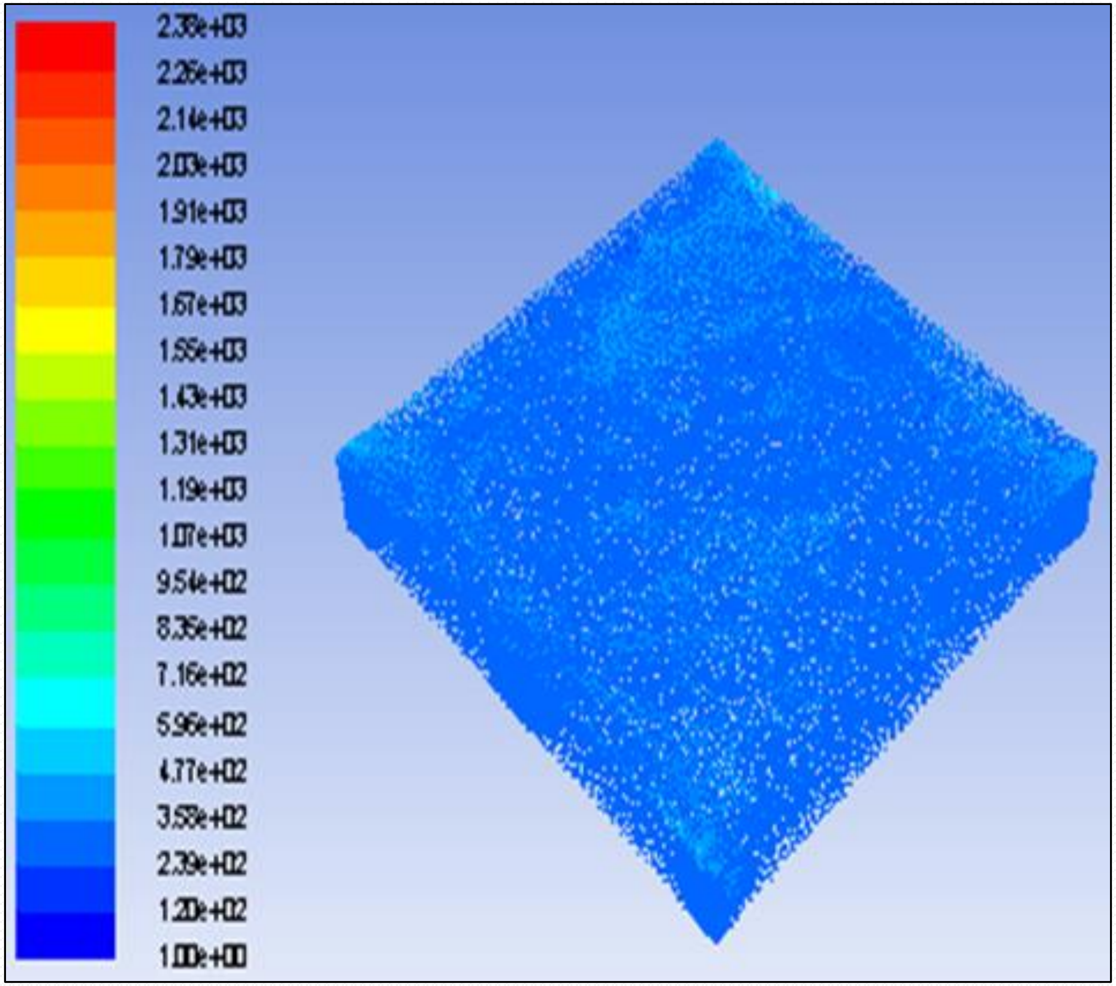
- 6 Inlets
  - 1 inch diameter
  - Fan flow rate of 2 ft^2/min
  - Blowing T_{air}=290K≈62ºF
- 4 Outlets
  - 2 inch diameter
  - Natural outflow



Computer Simulated Fluid Modeling Cont.

Worst Case Scenerio: Summer

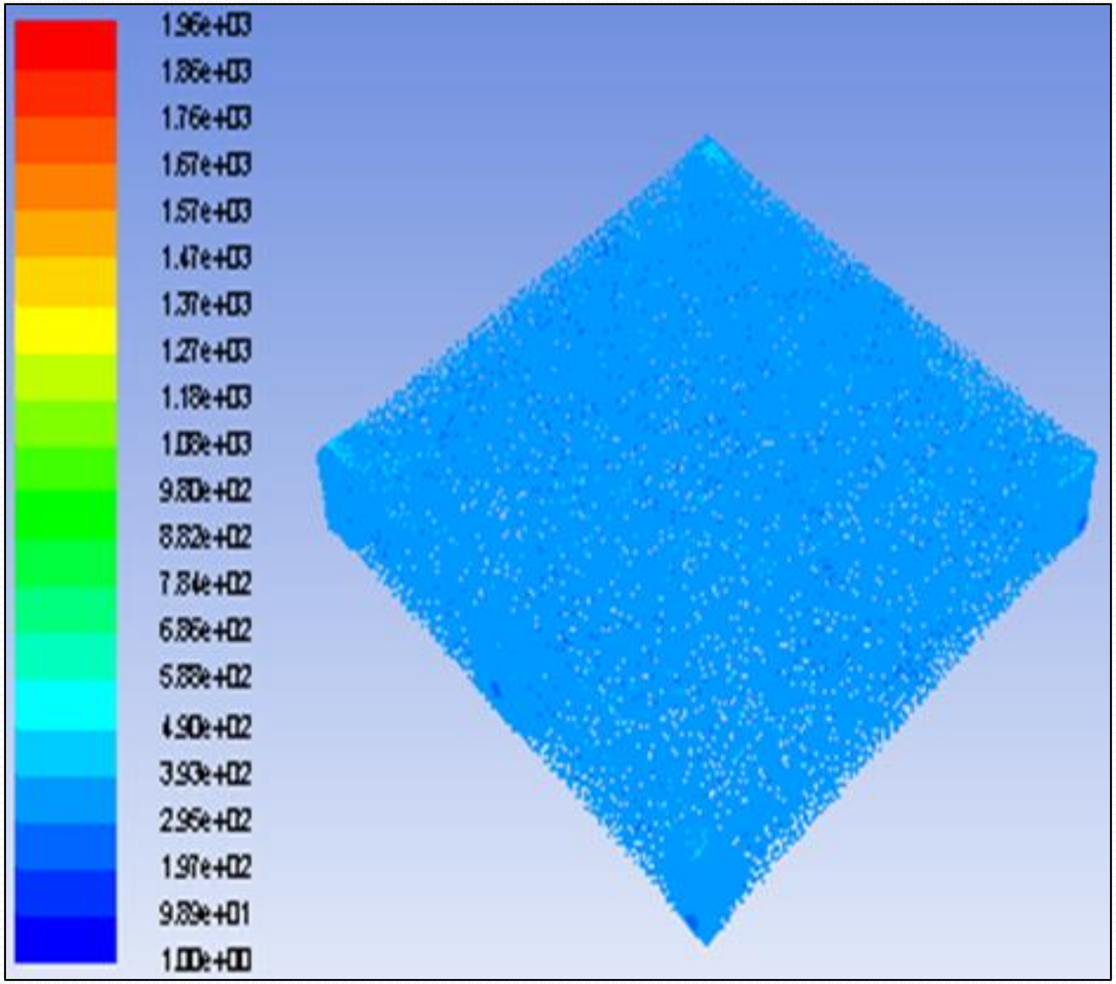
- Q = 924 W/m^2
- T = 77ºF



Computer Simulated Fluid Modeling Cont.

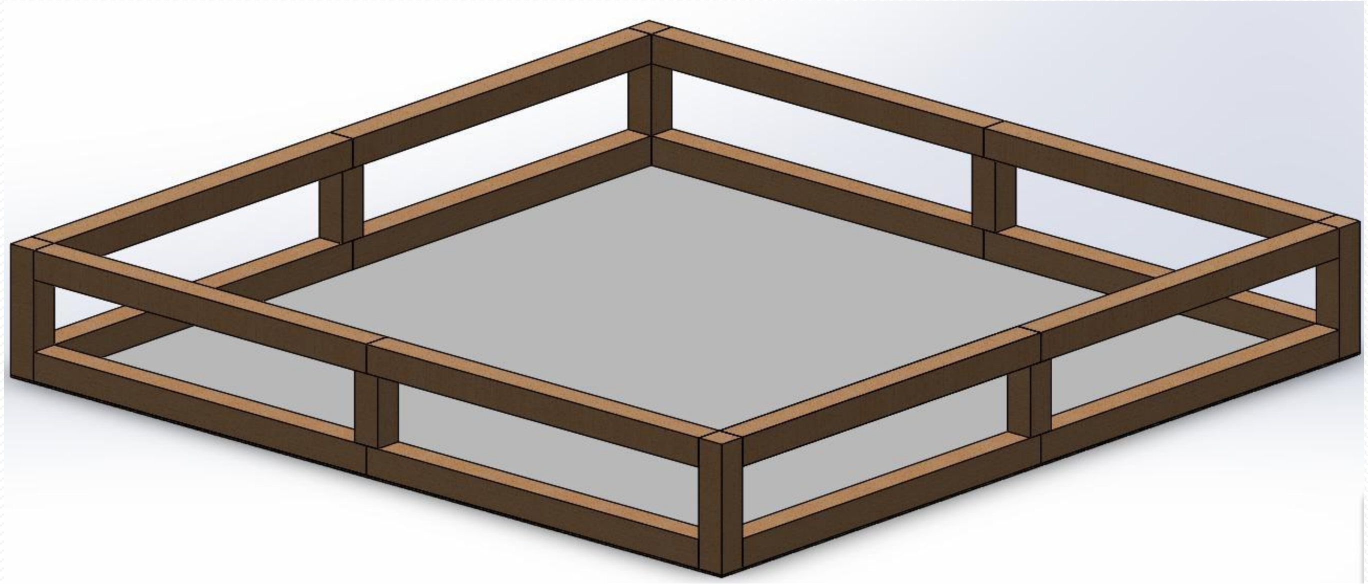
Worst Case Scenerio: Winter

- Q = 648 W/m^2
- T = 71^{o}F



Final Prototype Designs

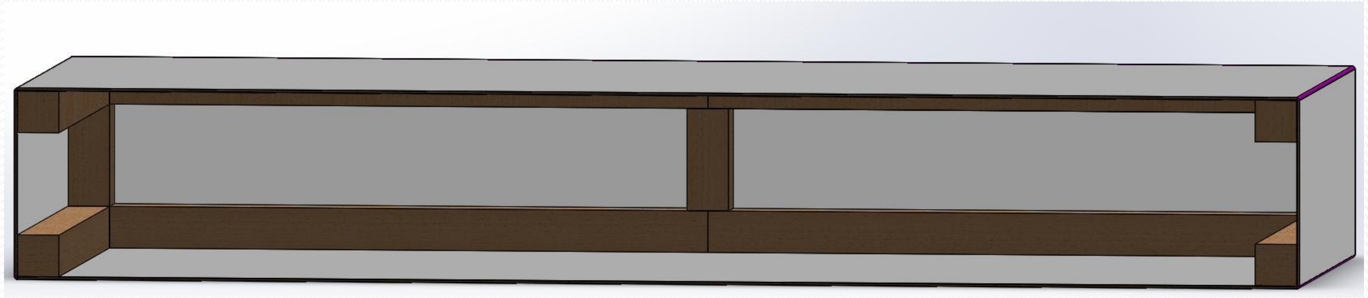
- Internal Frame of Prototype



    - 36 in. x 1 in. Wood Square Dowels

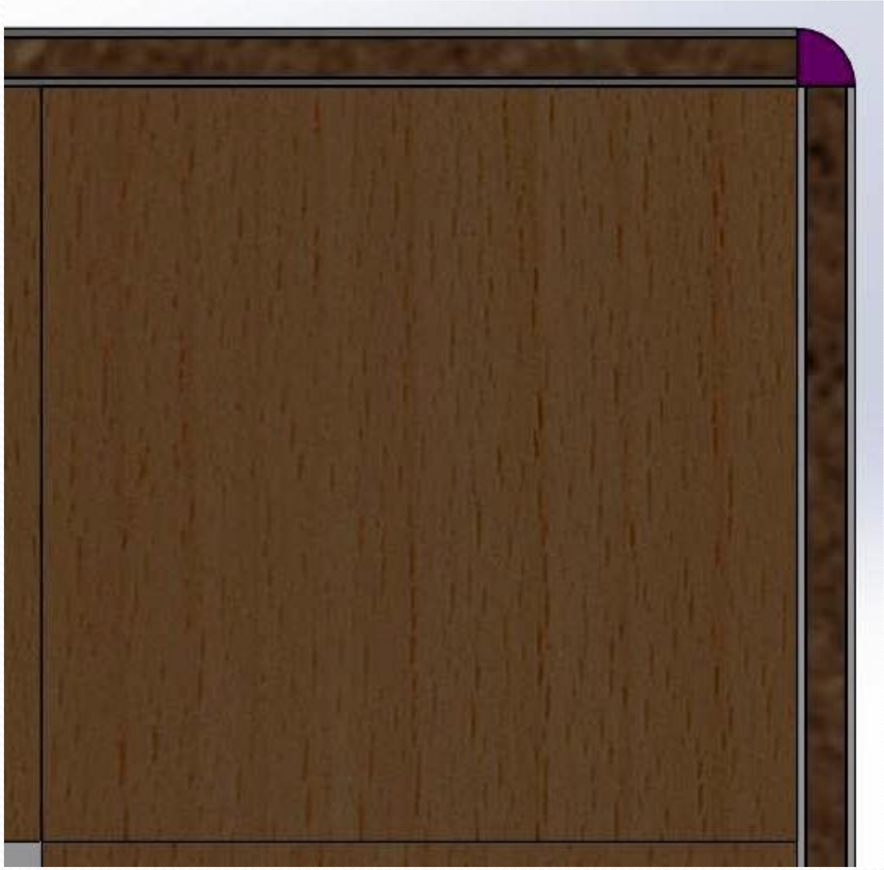
Final Prototype Designs Cont.

- Inside of all three prototypes



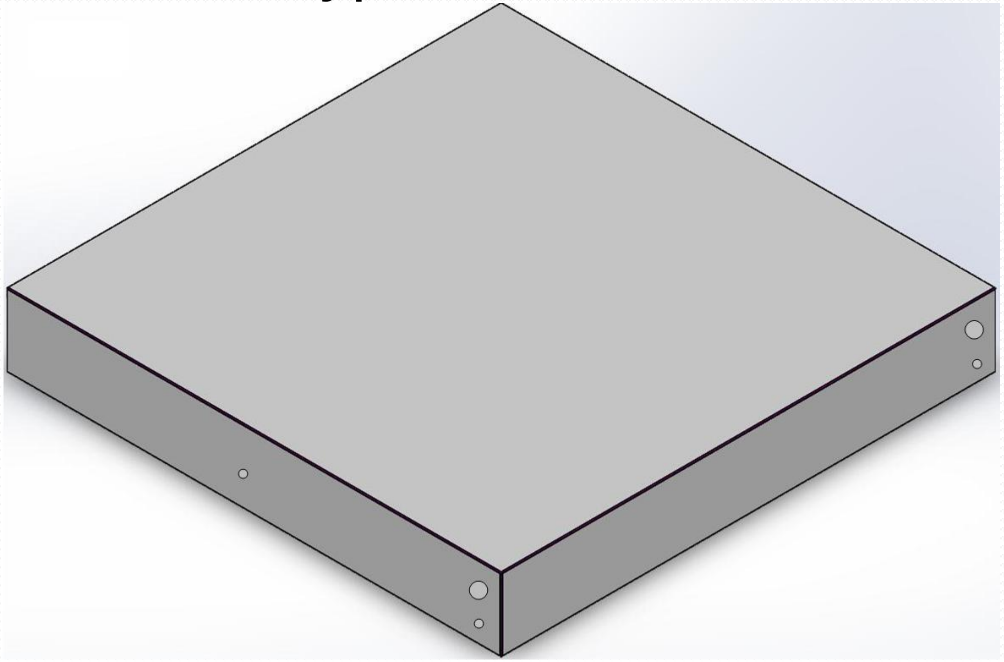
Final Prototype Designs Cont.

- Zoomed in on a Wall-Wall corner of the prototypes



Final Prototype Designs Cont.

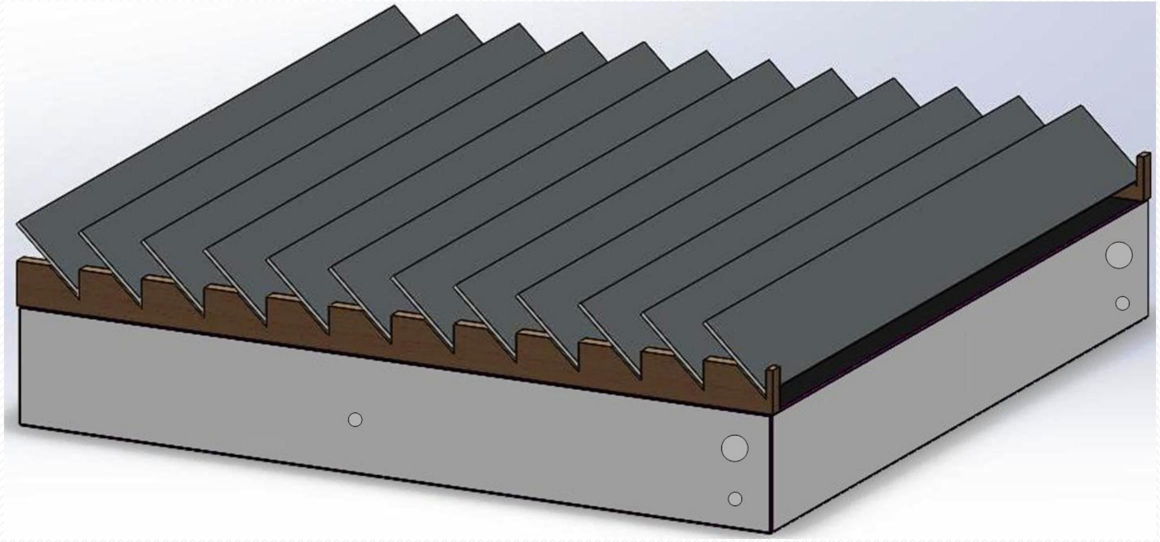
- Control Roof Prototype



  - Plain white roof

Final Prototype Designs Cont.

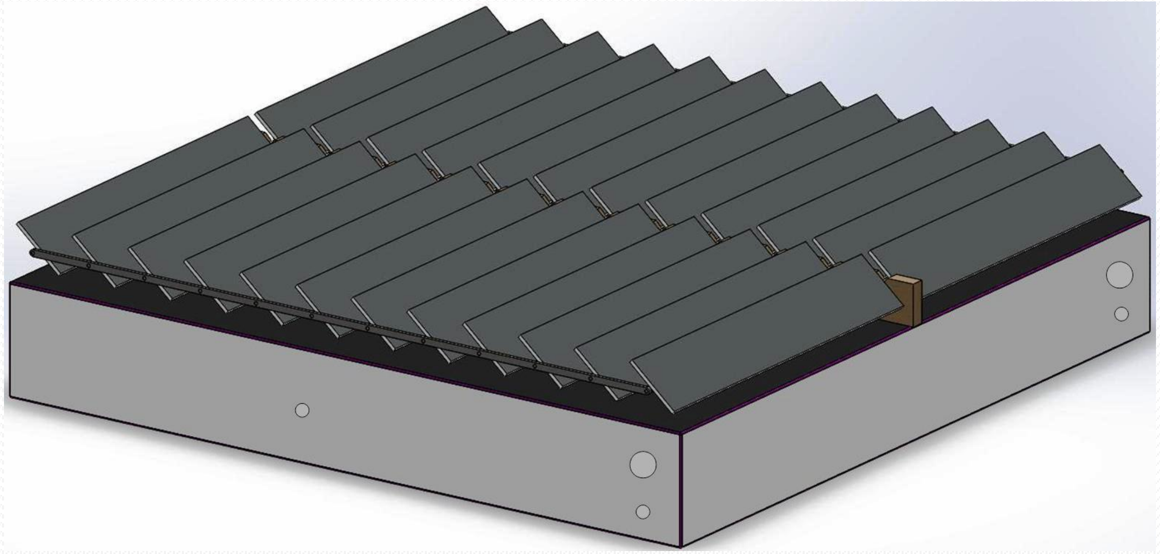
- Passive Roof Prototype



  - Stationary Reflective Panels with Black Roof

Final Prototype Designs Cont.

- Active Roof Prototype



  - Auto-Rotating Reflective Panels with Black Roof

Material List & Estimated Cost

For	Material	Price per Unit	Quantity Needed	Cost
Frame/ Panel Cradles	Square Wooden Dowels	$3.50	72	$252.00
Walls	Poster Board	$0.99	36	$35.64
	White Duct Tape	$4.99	1	$4.99
Insulation	Light Cork Roll	$14.99	22	$329.78
Screws	Nails	$9.37	1	$9.37
Sealing	Hot Glue Gun	$6.99	1	$6.99
	Hot Glue Sticks	$6.99	2	$13.98
Panels	Mylar	$29.97	1	$29.97
	Foam Poster Board	$3.00	7	$21.00
Control Systems	Arduino Uno	$27.99	2	$55.98
Active panel motor	Arduino servo motor	$9.95	4	$39.80
Temperature Monitor	n/a	$285.00	1	$285.00
Inlet Fan	n/a	$9.99	18	$179.82
			TOTAL:	$1,264.32

**Note: Total does not include A/C units at this time*

Conclusions

- Power usage of large, warehouse like buildings is too high
  - Constructing and testing 3 different roof system prototypes
    - Control ~ Plain White Roof
    - Passive ~ Stationary Reflective Panels
    - Active ~ Rotating Reflective Panels
  - Scale Model of Small Wal-Mart
    - Interior Dimensions: 0.65 x 4.5 x4.5ft

Conclusions Cont.

- Insulation: 3/32in thick cork
  - Ceiling ~ 3 layers
  - Floor ~ 2 Layers
  - Walls ~ 1 layer
- Cost of Construction for all 3 Prototypes
  - Approximately: $1,300 (without A/C units)
- Interior of Prototypes Need to stay about 70^{o}F
  - Using fully automatic temperature measuring

Conclusions Cont.

- Only automatic A/C system is required
  - A/C air at about T=62^{o}F & flow rate=2 ft^{2}/min
  - 6 Inlets with Fans: 1in diameter
  - 4 Outlets to Naturally vent: 2 in diameter

- Control Systems for each Prototype
  - Audrino Boards
    - One connected to temperature gage and A/C unit
    - Another to connected to the motor which controls the panels on the active roof

References Cont.

- M. Shafer, Interviewee, *Project Intro and Passive/Active Roof Designs.* [Interview]. 1 October 2013
- M. Shafer, Interviewee, *Project Intro and Passive/Active Roof Designs.* [Interview]. 22 October 2013.
- "Wal-Mart Stores Inc (WMT.N)," Reuters, [Online]. Available: http://www.reuters.com/finance/stocks/companyProfile?symbol=WMT.N. [Accessed 26 10 2013].
- A. Wilson, "Expanded Cork - The Greenest Insulation Material?," BuildingGreen.com, 2013. [Online]. Available: http://www2.buildinggreen.com/blogs/expanded-cork-greenest-insulation-material. [Accessed 26 10 2013].
- C. Gronbeck, "SunAngle," Sustainable by Design, 2009. [Online]. Available: http://www.susdesign.com/sunangle/. [Accessed 27 10 2013].
- D. Shroeder, “The sun and the Seasons,” weber.edu, 2011, [Online]. Available: http://physics.weber.edu/schroeder/ua/SunAndSeasons.html [Accessed 25 10 2013]

References Cont.

- "30-49-109 Insulation Guide.pdf," 08 2009. [Online]. Available: http://www.certainteed.com/resources/30-49-109%20Insulation%20Guide.pdf. [Accessed 26 10 2013].
- J. Lochner, “Ask an Astrophysicist,” nasa.gov, 1997, [Online]. Available: http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/970210b.html [Accessed 27 10 2013]
- D. Shroeder, “The sun and the Seasons,” weber.edu, 2011, [Online]. Available: http://physics.weber.edu/schroeder/ua/SunAndSeasons.html [Accessed 25 10 2013]
- MicroDAQ, The DataLogger Store, [online] 2013, Available: http://www.microdaq.com/ [Accessed 22 October 2013]
- SunPosition, SunPosition calculator, [online] 2013, Available: http://www.sunposition.info/sunposition/spc/locations.php [Accessed 22 October 2013]

References Cont.

- "Emissivity Values for Common Materials," Infrared Services Inc., 2000. [Online]. Available: http://www.infrared-thermography.com/material-1.htm. [Accessed 13 11 2013].
- "Emissivity Table," ThermoWorks, 2013. [Online]. Available: http://www.thermoworks.com/emissivity_table.html. [Accessed 16 11 2013].
- "Monthly Averages for Flagstaff, AZ," The Weather Channel, 2012. [Online]. Available: http://www.weather.com/weather/wxclimatology/monthly/graph/USAZ0068. [Accessed 16 11 2013].
- "30-Year Average of Monthly Solar Radiation, 1961-1990," NREL (National Renewable Energy Laboratory), 1990. [Online]. Available: http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/sum2/03103.txt. [Accessed 13 11 2013].

References Cont.

- F. P. Incropera and D. P. Dewitt, Fundamentals of Heat and Mass Transfer, Jefferson City: John Wiley & Sons, Inc., 2011.
- M. J. Moran, S. N. Howard, B. D. Daisie and M. B. Bailey, Fundamentals of Engineering Thermodynamics, Wiley & Sons, Inc, 2011.
- "A/C Room Size Calculator", Engineering Toolbox [Online] Available: http://www.engineeringtoolbox.com/sizing-ducts-d_207.html [accessed 17 11 2013].