Active Roof System

Engineering Analysis

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Overview

- Average Solar Radiation
- Average Outside Temperature
- Average Convection Coefficients
- Transient Conduction
- Checking for Internal Circulation
- Estimating the Temperature of A/C Air
- Computer Simulated Fluid Modeling
- Conclusions

Average Solar Radiation

- For Flagstaff

Season	Average Solar Radiation per Month [W/m^2]			Average per Season [W/m^2]
Fall	*Aug*	*Sep*	*Oct*	**804.17**
	881.25	831.25	700	
Winter	*Nov*	*Dec*	*Jan*	**491.67**
	531.25	450	493.75	
Spring	*Feb*	*Mar*	*Apr*	**789.58**
	625	781.25	962.5	
Summer	*May*	*Jun*	*Jul*	**1058.33**
	1081.25	1156.25	937.5	

Average Fall & Winter = 647.92 [W/m^2]

Average Spring & Summer = 923.96 [W/m^2]

Average Outside Temperature

- For Flagstaff

Season	Average High Temperature per Month [^oF]			Average per Season [^oF]
Fall	*Sep*	*Oct*	*Nov*	**49.67**
	37	62	50	
Winter	*Dec*	*Jan*	*Feb*	**43.67**
	43	43	45	
Spring	*Mar*	*Apr*	*May*	**58.67**
	50	58	68	
Summer	*Jun*	*Jul*	*Aug*	**79.00**
	78	81	78	

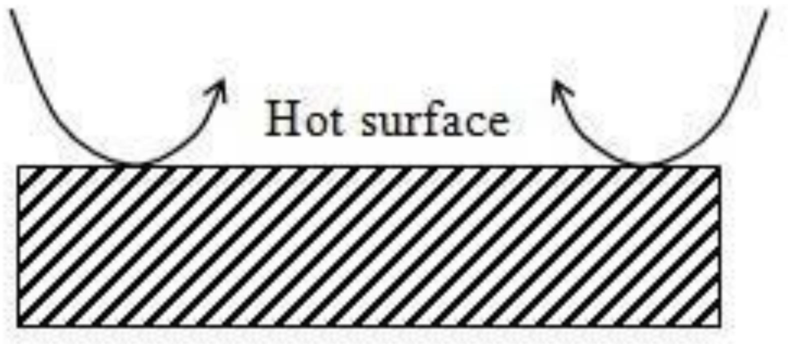
Average Fall & Winter = 46.67^{o}F

Average Spring & Summer = 68.83^{o}F

Average Convection Coefficients

- Average convection coefficent: h_{avg}

- Finding h_{avg} for Natural Convection of air above roof
    - Horizontal Plate with Hot Upper Surface



Average Convection Coefficients Cont.

- Calculating h_{avg} is an Iterative process (Matlab code)
  - 1st: Guess a roof surface temperature (T_s)
  - 2nd: Calculate h_{avg} using guessed T_s
  - 3rd: Calculate the T_s using h_{avg}
  - 4th: If needed run the program again with a new guessed T_s value
    - Based on how close the guessed and calculated Ts values are

Average Convection Coefficients Cont.

- Important Values used to Calculate T_s
  - Emissivity
    - Black Paint: 0.92
    - White Paint: 0.99
    - Reflective Panels (Polished Aluminum): 0.05
  - Estimated % of Solar Radiation Reflection

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.

- Average property values

Property	Symbol	Average	Units
Density	ρ	37.05	kg/m^3
Thermal Conductivity	k	0.03	W/m·K
Specific Heat	Cp	1246.5	J/kg·K

Transient Conduction Cont.

- Finding time it would take for internal air of prototypes to reach $T_{umcomfortable}$
  - $T_{umcomfortable} = 75^{o}F$

	Time to Reach 75ºF from 70ºF (min)	
Prototype	**Winter/Fall**	**Spring/Summer**
Control	2.657	80.392
Passive	2.660	80.672
Active	2.656	105.747

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

    - Since all Ra_L >1708 there will be natural air circulation within the prototypes 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
    - so $m_{1hot}=m_{1cold}=0.5m_2$
  - $T_{1hot}=75\,^{o}F$ & $T_2=70^{o}F$

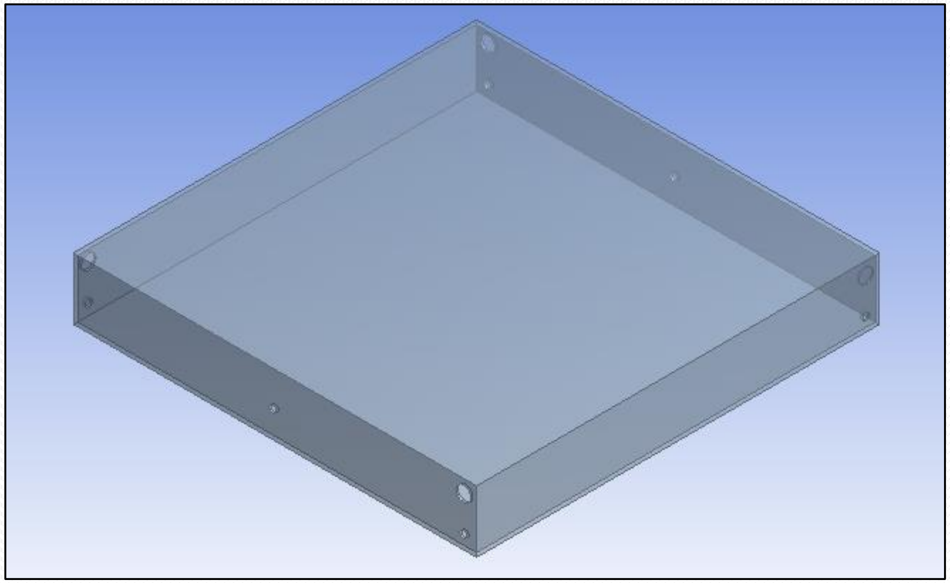
Estimating the Temperature of A/C Air

- Energy Balance leads to
  - $$u_{1Cold} = \frac{m_2 u_2 - m_1 u_{1Hot}}{m_1}$$
    - u_{1cold}=207.97 kJ/kg

So T_{1cold}=65.0ºF

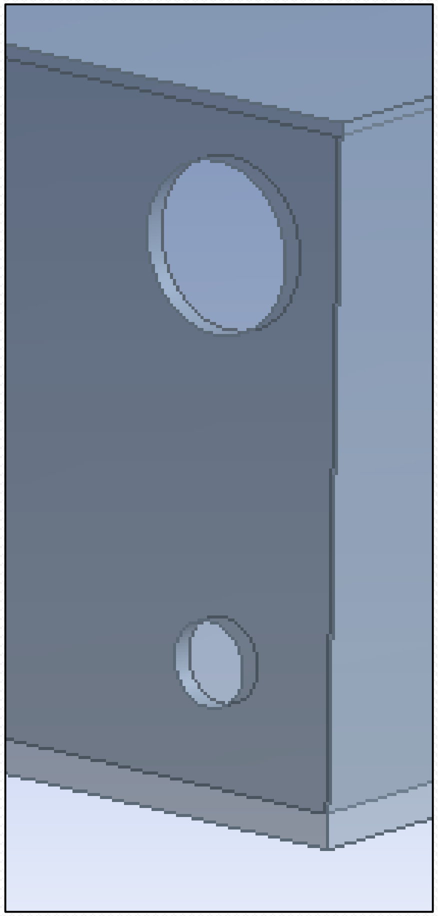
Computer Simulated Fluid Modeling

- Prototype Dimensions
  - Width 4.5 ft
  - Length 4.5 ft
  - Height 0.65 ft



Computer Simulated Fluid Modeling Cont.

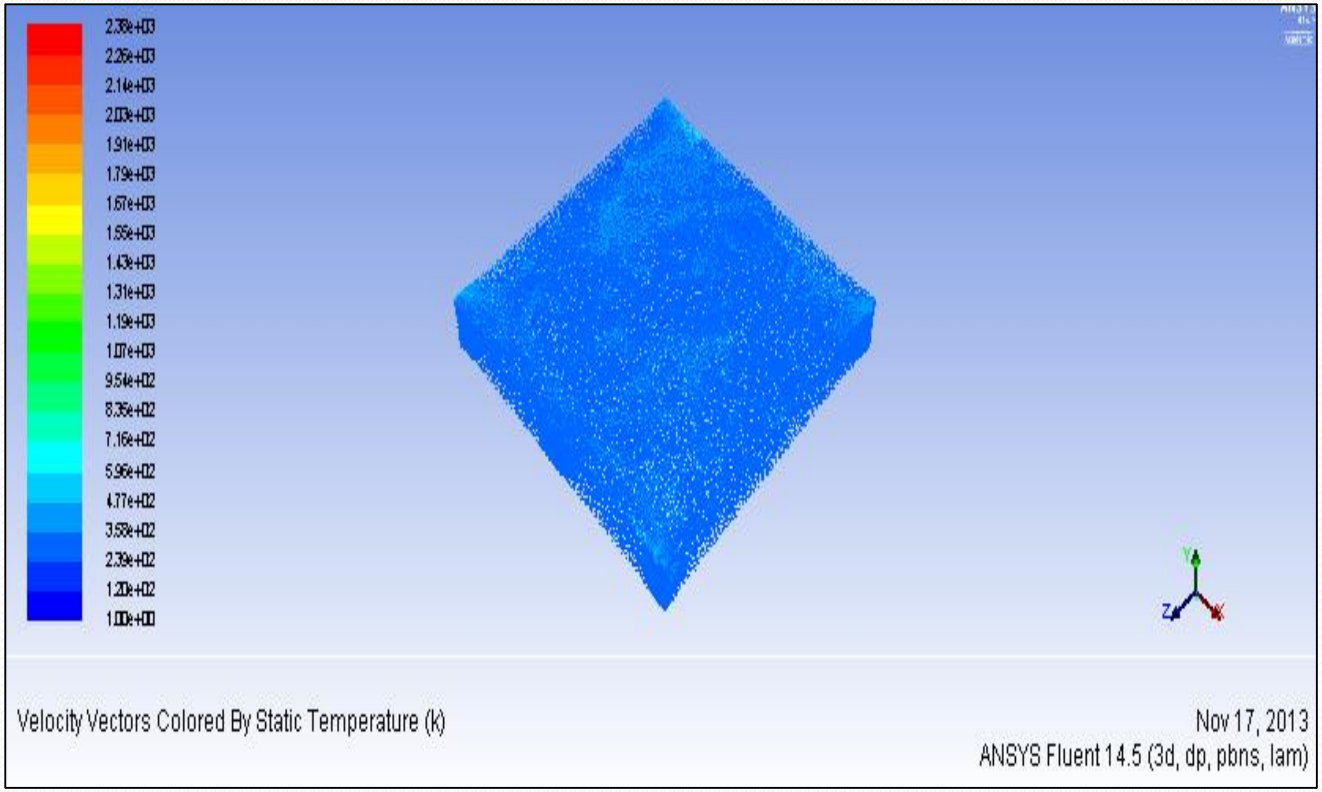
- Inlet
  - 6 inlets
  - 1 inch diameter
  - Fan velocity of 10m/s
  - Temperature of 290K, roughly 62ºF
- Outlet
  - 4 outlets
  - 2 inch diameter
  - Natural outflow



Computer Simulated Fluid Modeling Cont.

For a worst case in the summer

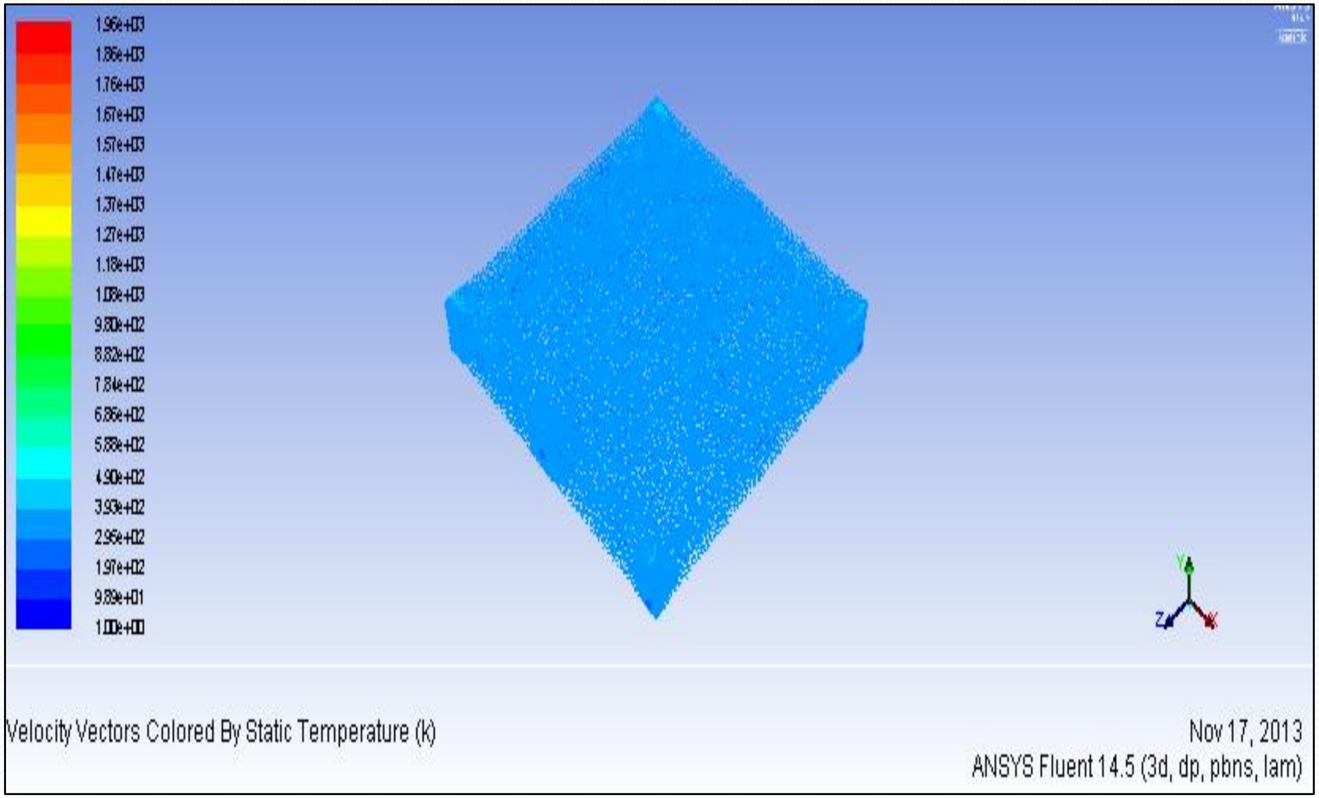
- Q = 924 W/m^2
- T = 77ºF



Computer Simulated Fluid Modeling Cont.

For winter

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



Conclusions

- Building geometry
  - 6 inlets with 1 in diameter
  - 4 outlets with 2 in diameter

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

Conclusions Cont.

- Prototype Simulation
  - Based on calculations the A/C temperature was 62ºF
  - Summer temperature average inside will be 77ºF
  - Winter temperature average inside will be 71ºF

References

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