Radiant Heating Panel
Thermal Analysis

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Analysis Objective

- Perform a thermal test on a small sample of the concrete to determine the Thermal Conductivity and Specific Heat of the concrete
- The thermal conductivity and specific heat of the concrete is unknown. The results of the conductivity test will be used in the thermal model with the known conductivities of the other materials
- Generate a thermal model of the panel and heating fluid to determine the heat added to the room per panel for various inlet water flow rates and temperatures
- Document the thermal analysis results

Major Assumptions

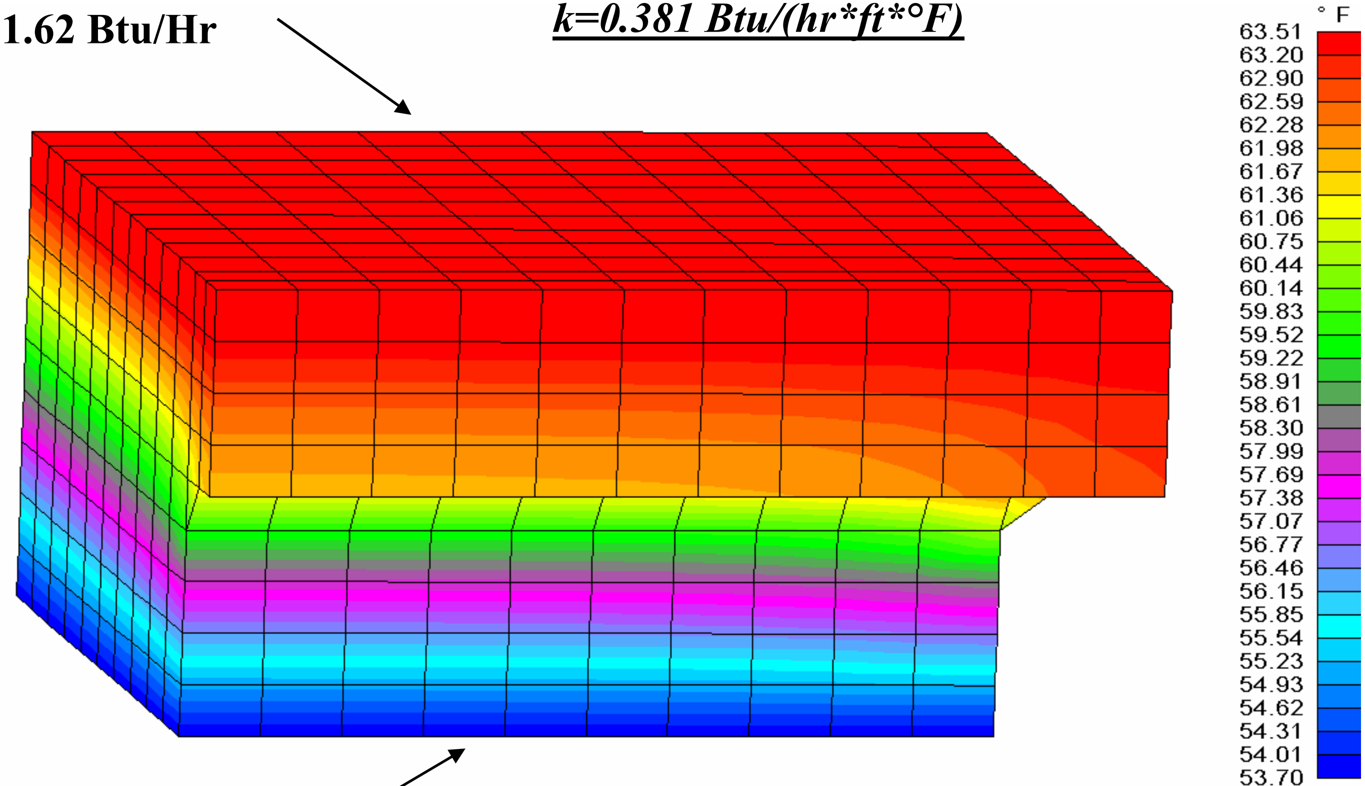
- Plastic housing on concrete constructed of Polystyrene or equivalent material with thickness of 0.093 inches
- PEX tubing wall thickness = 0.062 inches
- PEX tubing deforms to fill the groove in the concrete
- Sub flooring consists of ½-inch thick plywood with no insulation
- Room temperature remains constant at 68 °F
- No material on top of concrete
- Radiation emissivity is 0.8 for sub floor and 0.95 for concrete

Thermal Conductivity Test - Procedure

- The purpose of the test was to determine the thermal conductivity of the concrete for use in the thermal model. The concrete thermal conductivity is the only unknown information required for the thermal model
- A constant heat load (1.62 Btu/Hr) was applied to one surface of the concrete while the opposite surface was clamped to a coldplate
- Heat load consisted of a resistor attached to a ¼ inch thick aluminum plate
- Thermal grease was used at all interfaces
- The sample was heated to a stabilized temperature of 63.5 °F
- Coldplate was maintained at a constant temperature of 53.7 °F
- A thermal model was generated to verify the test results
- Based on the results, the thermal conductivity of the concrete was calculated to be 0.381 Btu/(hr*ft*°F)

Thermal Conductivity Model

Constant heat source at 1.62 Btu/Hr



Constant coldplate temperature at 53.7 °F

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Specific Heat Test - Procedure

- The purpose of the test was to determine the Specific Heat of the concrete which is the unknown property
- Panel sample was heated to a stabilized temperature (63.4 °F) then allowed to cool down with no heat applied
- Coldplate was held to a constant temperature of 53.0 °F
- The heat source was then turned off
- Temperature difference between the heat source area and cold plate interface was monitored during the cool down period
- Based on the results, the Specific Heat (Cp) of the concrete was calculated to be 0.19 Btu/(lb*°F)

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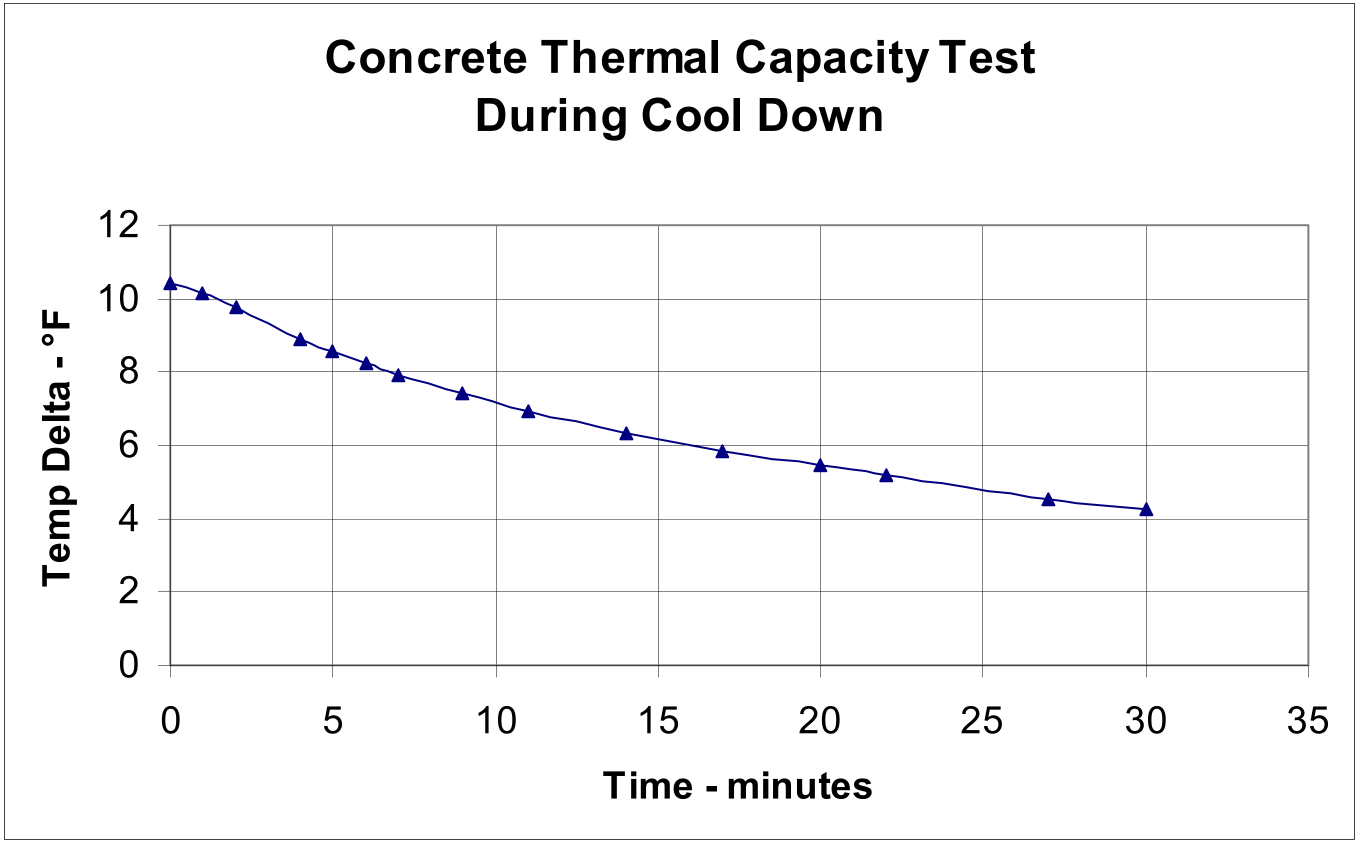
Specific Heat Test Data



Specific Heat Test - Results

- Based on heat transfer formula for the transient cooling of an object:

$$(T-T_{cp})/(T_o-T_{cp}) = e^{-(t/RC)}$$

- Tcp = coldplate temperature = 53 °F
- To = initial temperature of the sample = 63.4 °F
- t = time elapsed = 30 minutes = 0.5 Hours
- T = temperature of the sample at time elapsed = 57.2 °F
- R = Thermal resistance of the sample (extracted from thermal conductivity test) = 6.0 Hr*°F / Btu (11.4 °C/W)
- C = Capacitance of the sample = Specific Heat (Cp) x Weight

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Specific Heat Test – Results (continued)

- From the formula:

$$(57.2-53.0)/(63.4-53.0) = e^{-(0.5/(6.0*C))}$$

- C = Capacitance = 0.0929 Btu/°F
- Weight of concrete sample = 0.489 lb (222 gms)
- The Capacitance, C, = Specific Heat (Cp) x Weight
- Based on the results, the Specific Heat (Cp) of the concrete was calculated to be 0.19 Btu/(lb*°F)

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Radiant Panel Thermal Model

- A model of the radiant panel was generated using TAS (Thermal Analysis System) software
- Model included the panel, water flow, plywood subfloor, and convection and radiation
- Water inlet conditions were:
    - 0.5 gpm, 90 °F water
    - 0.5 gpm, 140 °F water
    - 2.0 gpm, 90 °F water
    - 2.0 gpm, 140 °F water:

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Material Properties
Thermal Conductivity

Number	1	2	3	4		Units
Description	PEX Tubing	Concrete	Plywood	Polystyrene		
X Conductivity	0.018300	0.031750	5.560e-003	9.180e-003		Btu/(hr-inF)
Y Conductivity	0.018300	0.031750	5.560e-003	9.180e-003		Btu/(hr-inF)
Z Conductivity	0.018300	0.031750	5.560e-003	9.180e-003		Btu/(hr-inF)

Data Source:

- **PEX Tubing** **http://www.me.umn.edu/~weiliu/research.dir/Ases99.pdf**
- **Concrete** **Thermal testing as reported**
- **Plywood** **http://www.rima.net/handbook/HandbookUpdateforConduction06021.pdf**
- **Polystyrene** **http://www.3d-cam.com/materials/polystyrene.asp**

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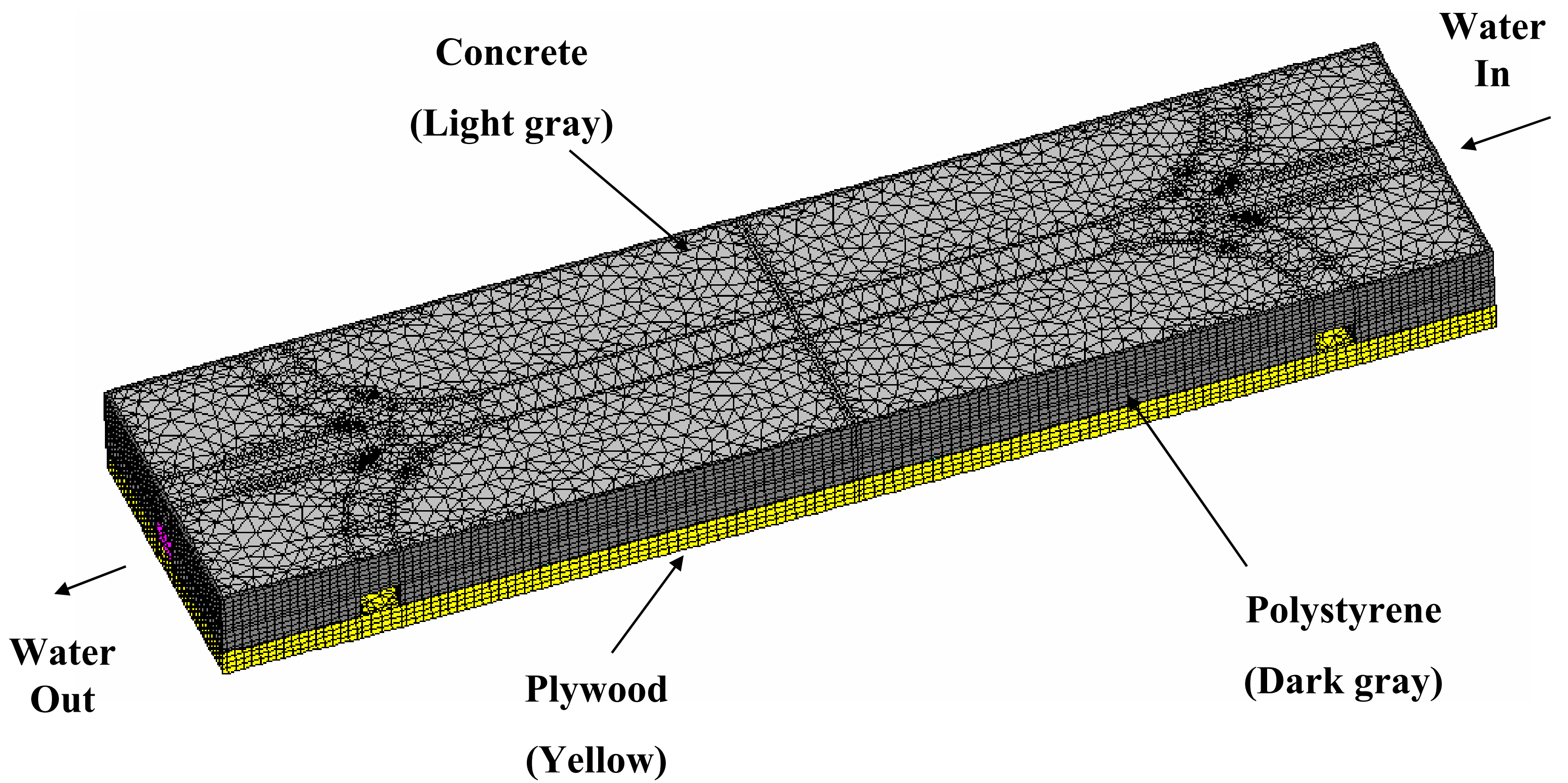
Radiant Panel Model



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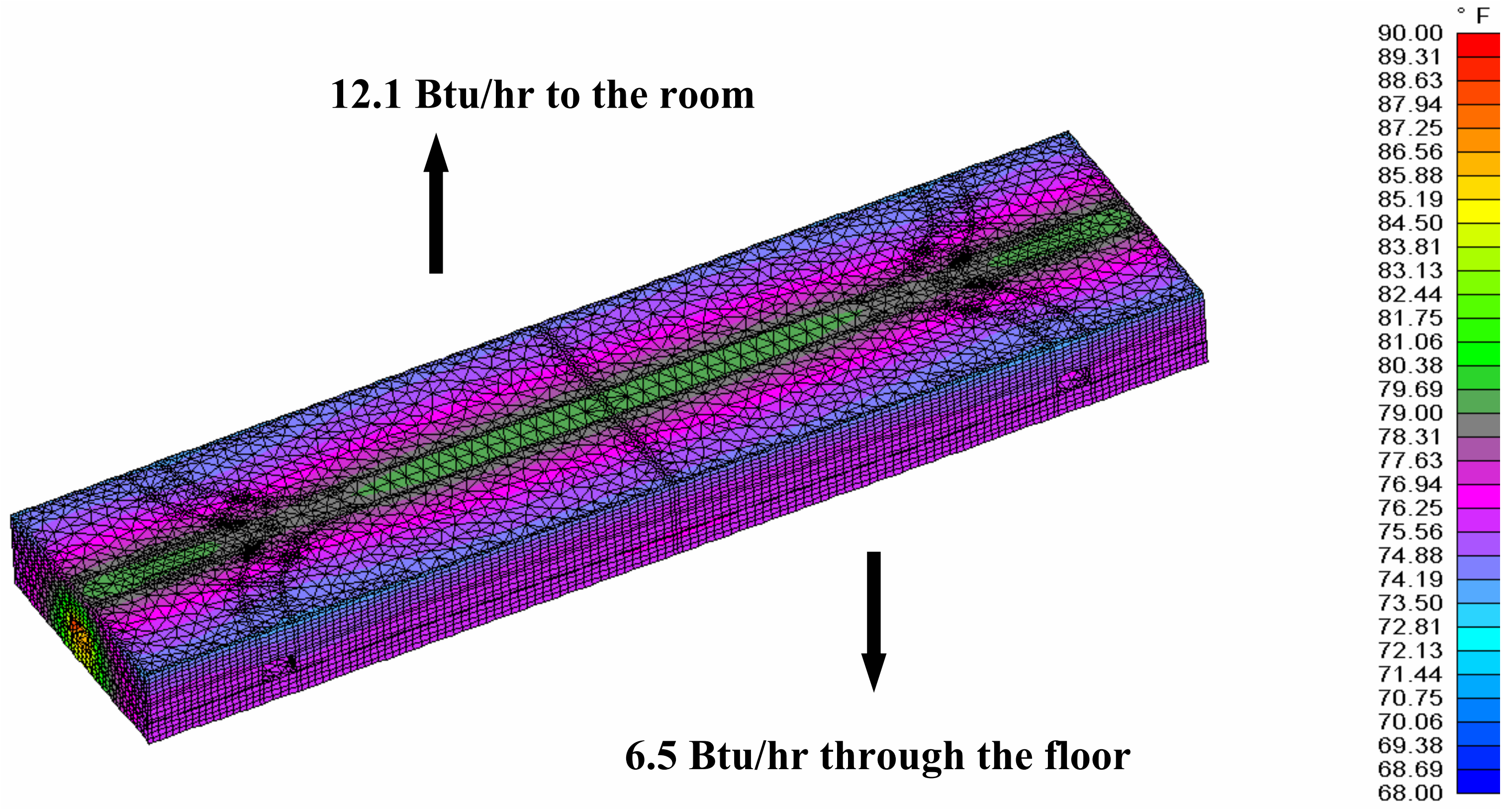
Thermal Results
0.5 GPM, 90 °F



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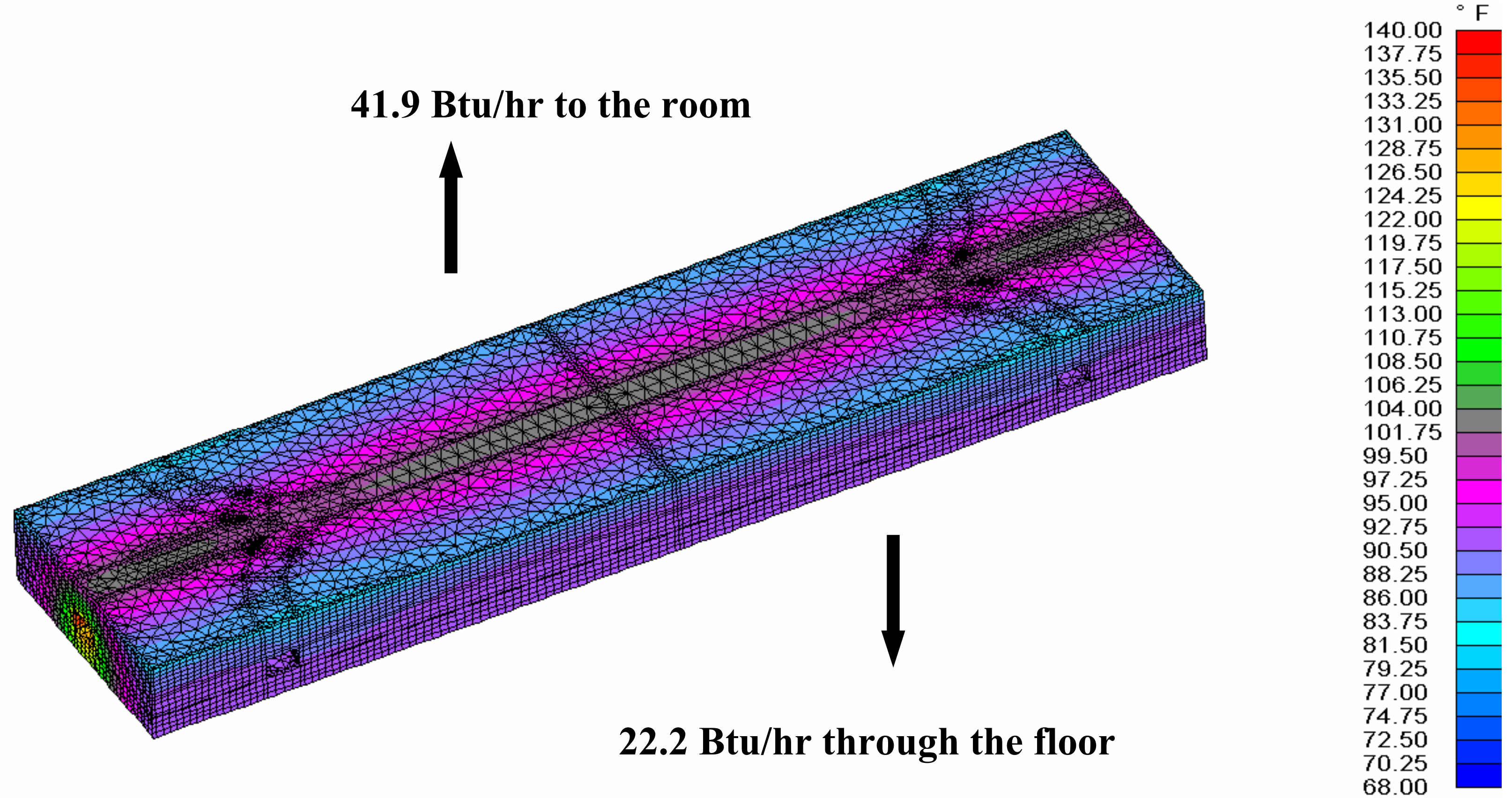
Thermal Results
0.5 GPM, 140 °F



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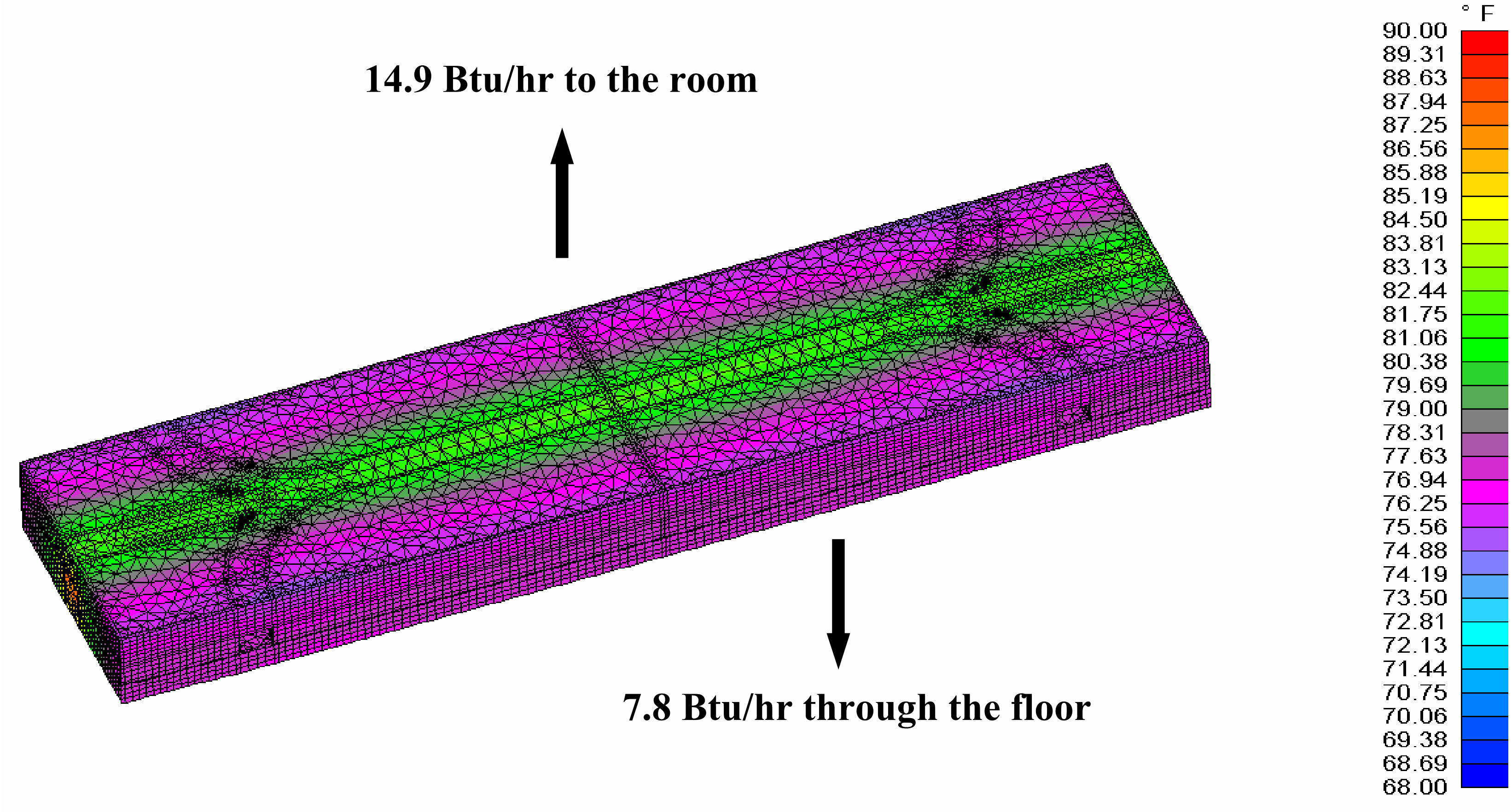
Thermal Results
2.0 GPM, 90 °F



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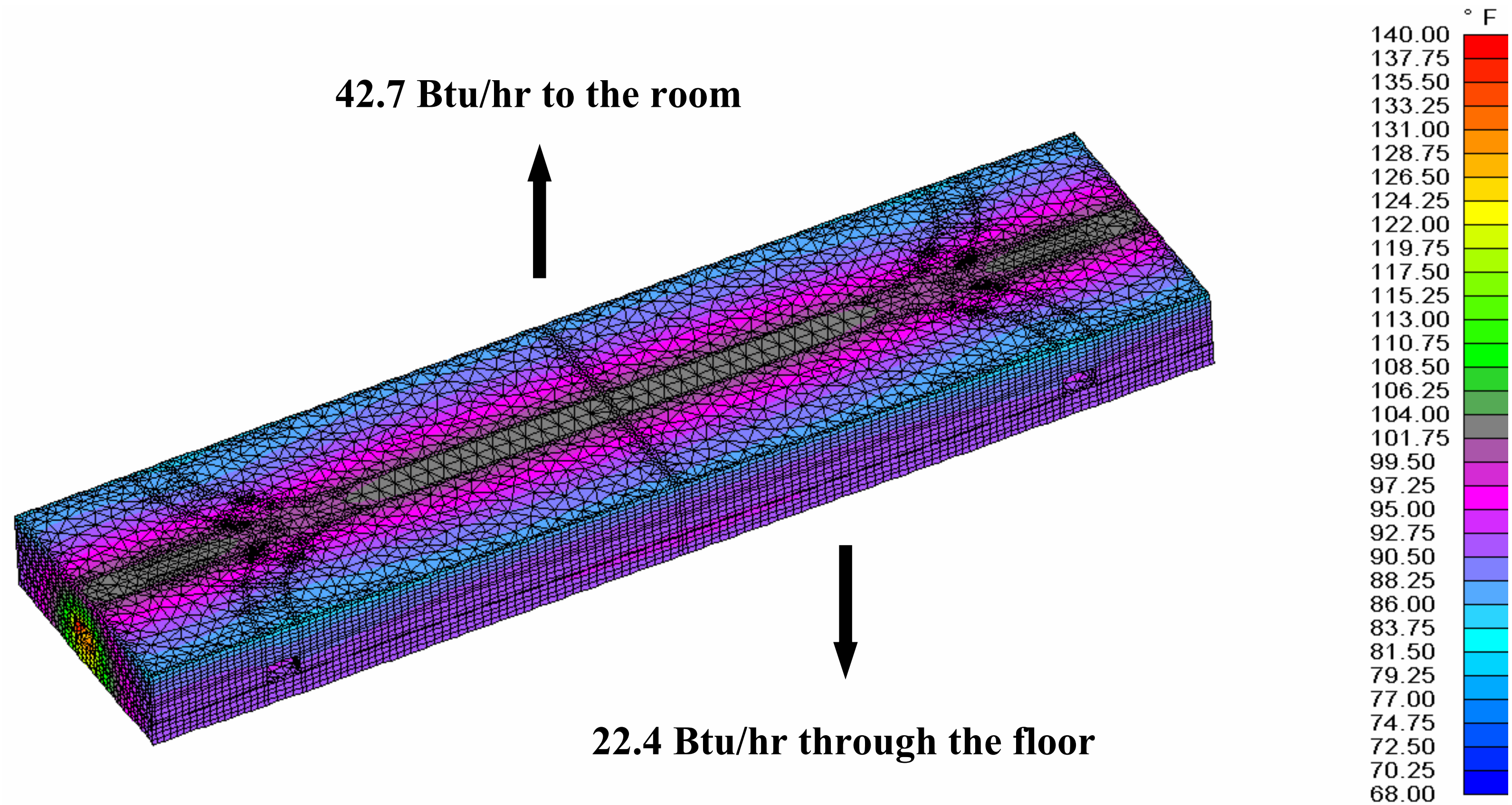
Thermal Results
2.0 GPM, 140 °F



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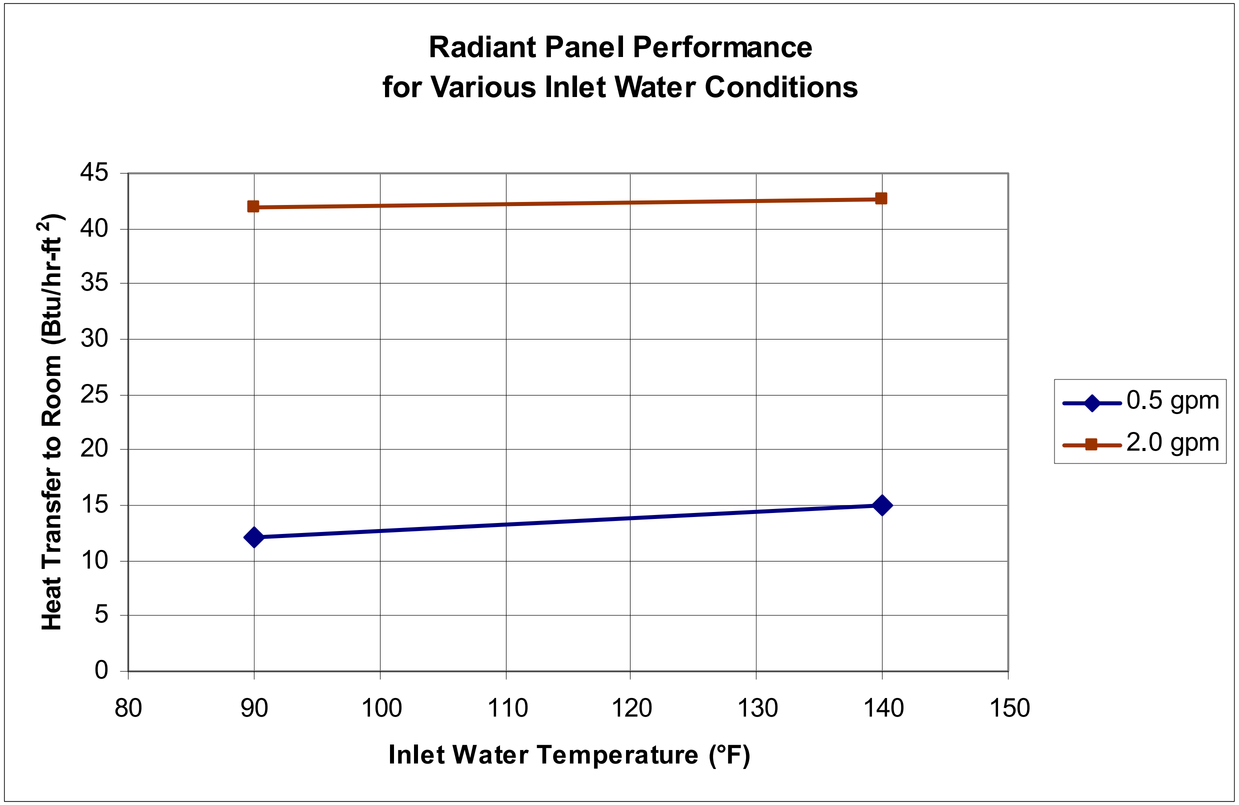
Radiant Panel Performance Summary



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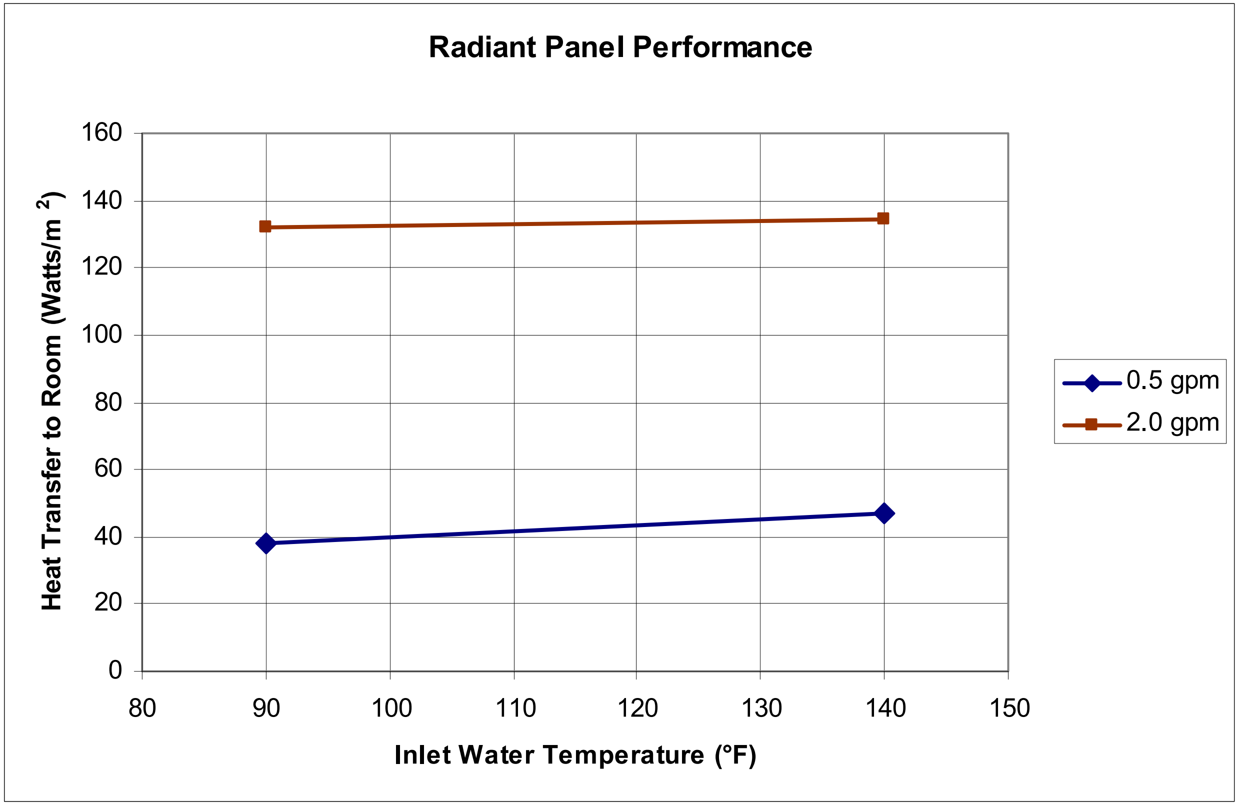
Radiant Panel Performance Summary
SI Units



Summary

- The Thermal Conductivity (k) of the concrete was tested to be:

  $k = 0.381$ Btu/hr-ft-°F

- The Specific Heat (Cp) of the concrete was tested to be:

  $Cp = 0.19$ Btu/lbm-°F

- The heat transfer rate to the room, per panel, was analyzed to be:

0.5 gpm, 90 °F water:	12.1 Btu/hr-ft^2	(38 W/m^2)
0.5 gpm, 140 °F water:	41.9 Btu/hr-ft^2	(132 W/m^2)
2.0 gpm, 90 °F water:	14.9 Btu/hr-ft^2	(47 W/m^2)
2.0 gpm, 140 °F water:	42.7 Btu/hr-ft^2	(135 W/m^2)

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Summary (continued)

- The equivalent heat transfer coefficient to the room, per panel, based on a temperature differential between the inlet water temperature and room temperature:

  0.5 gpm, 90 °F water: 0.551 Btu/hr-ft^2-°F (3.13 W/m^2-°C)

  0.5 gpm, 140 °F water: 1.905 Btu/hr-ft^2-°F (3.30 W/m^2-°C)

  2.0 gpm, 90 °F water: 0.679 Btu/hr-ft^2-°F (3.85 W/m^2-°C)

  2.0 gpm, 140 °F water: 1.941 Btu/hr-ft^2-°F (3.37 W/m^2-°C)

- One third of the heat is transferred through the subfloor
- Adding insulation to the subfloor will improve the heat rate to the room

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