



Beverage machine Cooling Analysis

Content

- ∞ Design requirement
 - 5L water be cooled from 25°C to 4°C
 - Must cool down less than 30min
- ∞ Software benchmark
 - Cylinder geometry
 - Fluid behavior
- ∞ Boundary conditions
 - Transient analysis
 - TEC
 - Air/ Liquid cooling



Design Requirement



∞ 5L water, $T_0 = T_a = 25^\circ\text{C}$, $T_{1800s} = 4^\circ\text{C}$

∞ Properties of Water

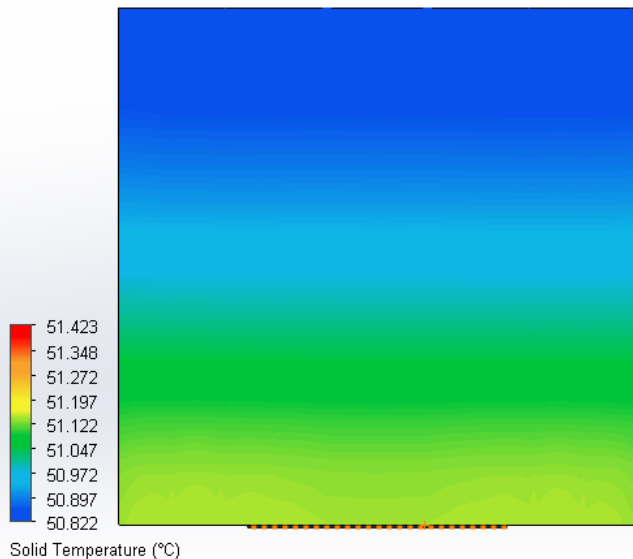
- Density: 997kg/m^3
- Specific heat: 4181.6J/kg K
- Thermal Conductivity: 0.607W/mK

∞ Internal energy change

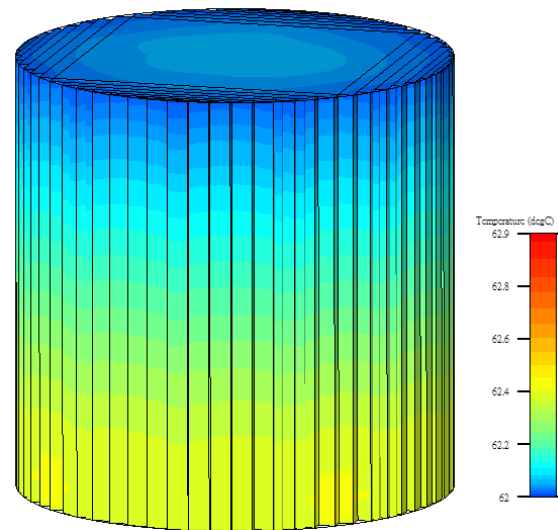
- $\Delta U = mC_p\Delta T = 0.005 \times 997 \times 4181.6 \times (25 - 4) = 437,750 \text{ J}$
- 30min to reach the target temperature
 - Average power is $437750/1800 = 243.2\text{W}$
 - If the TEC cooling capability is 50W , we need at least 5

Geometry Impact

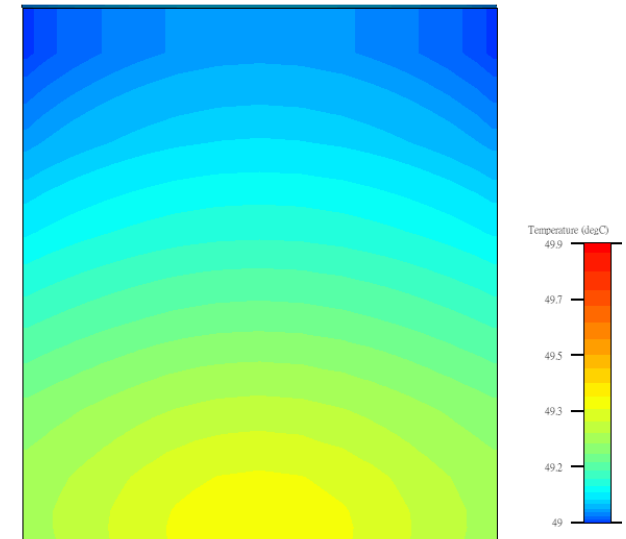
- ∞ Consider the natural convection and radiation effects
- Simple cylinder model to check the convection
 - 60W loading, check surface temperature by solid conduction
 - $\varepsilon=1$, $D=200\text{mm}$, $H=200\text{mm}$, $T_a=20^\circ\text{C}$, $T_{\text{surface}}=53^\circ\text{C}$ by theoretical solution



FloTHERM XT Cylinder
 $T_{\text{surface}}=51^\circ\text{C}$



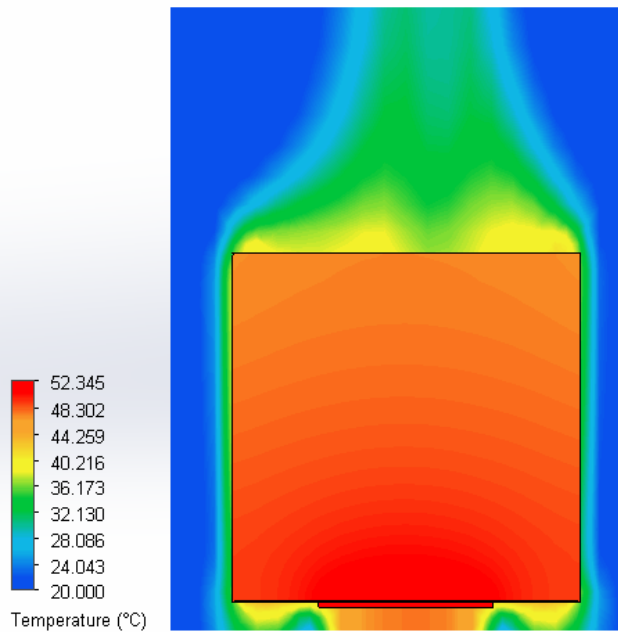
FloTHERM Cylinder
 $T_{\text{surface}}=62.5^\circ\text{C}$



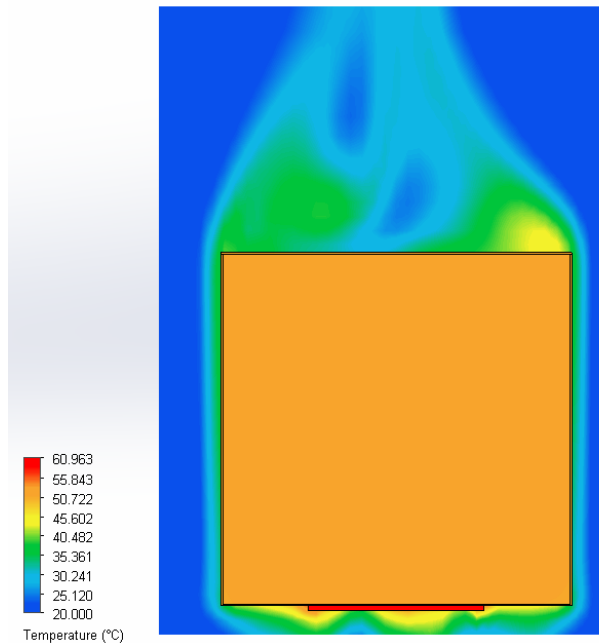
FloTHERM Cuboid
 $T_{\text{surface}}=50^\circ\text{C}$

Modeling Issue

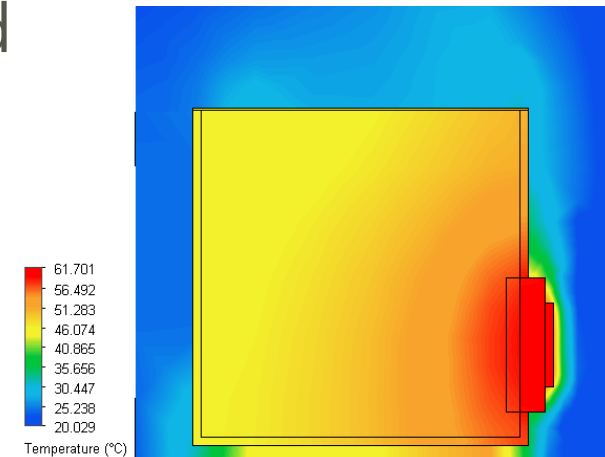
- Usually we use solid component instead of fluid to simulate the conduction
- If the fluid stirred?
 - How to set K value for interface?



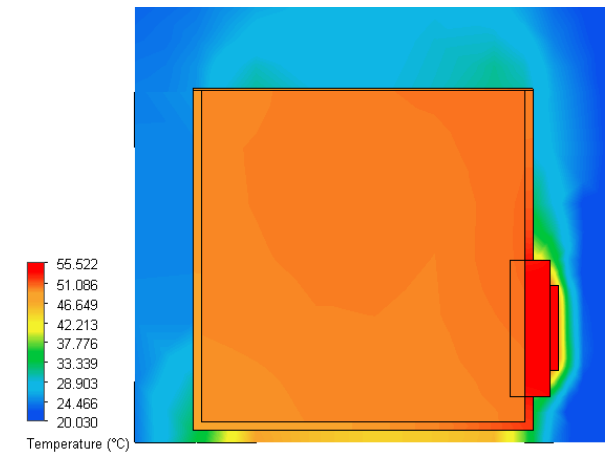
Solid Component
 $K=0.607\text{W/mK}$



Fluid Subdomain
Water

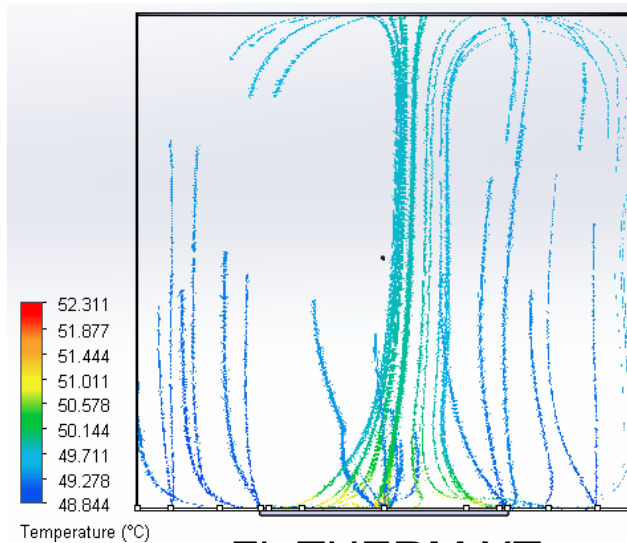


Solid Component
 $K=0.607\text{W/mK}$



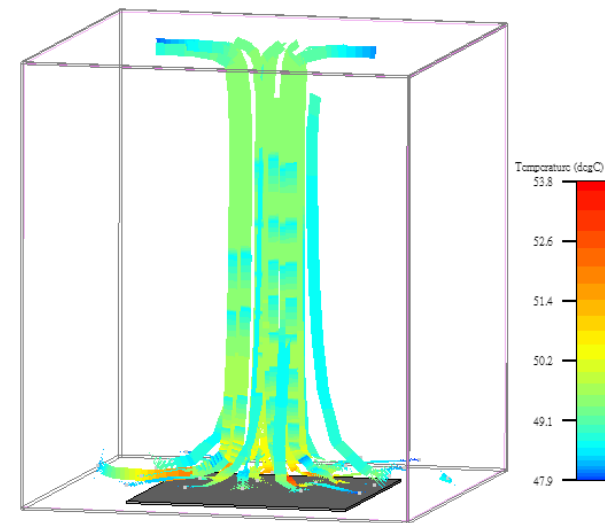
Fluid Subdomain
Water

Fluid Behavior- Convection



FloTHERM XT

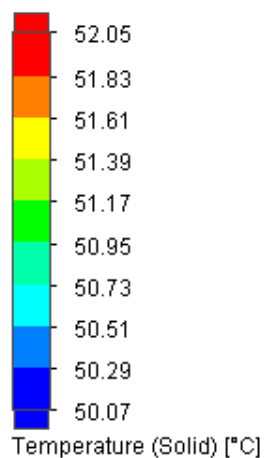
- Flotherm XT (Fluid Subdomain)
- Fluid density defined by table
 - Density= $f(\text{temp})$



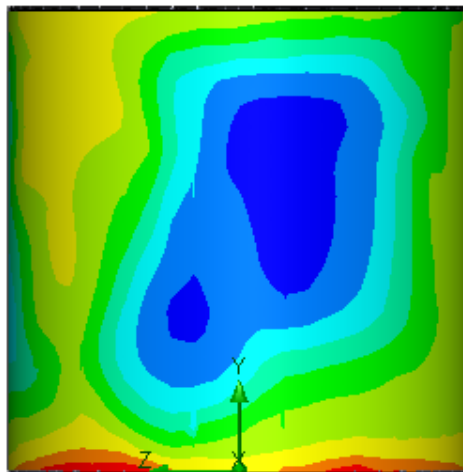
FloTHERM

Flotherm (Region)

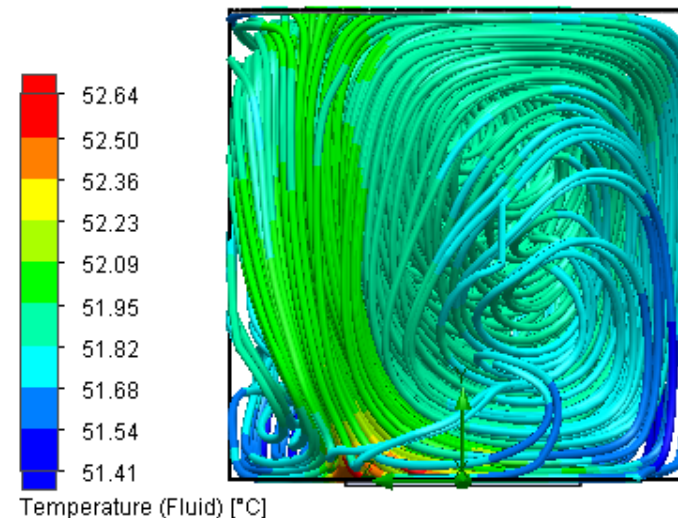
- Fluid density is constant
- Defined expansivity= $f(\text{temp})$



Surface Plot 1: contours



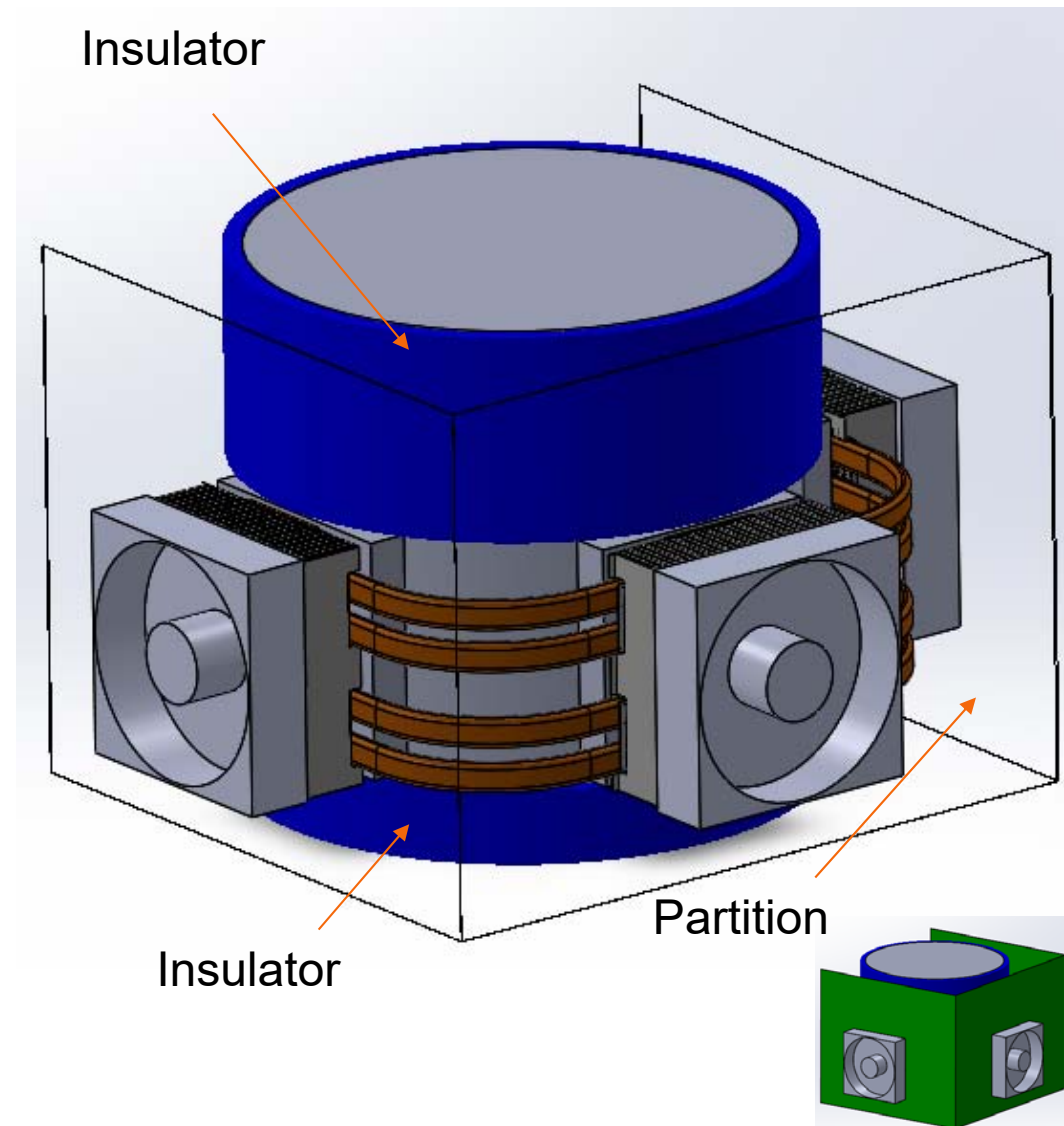
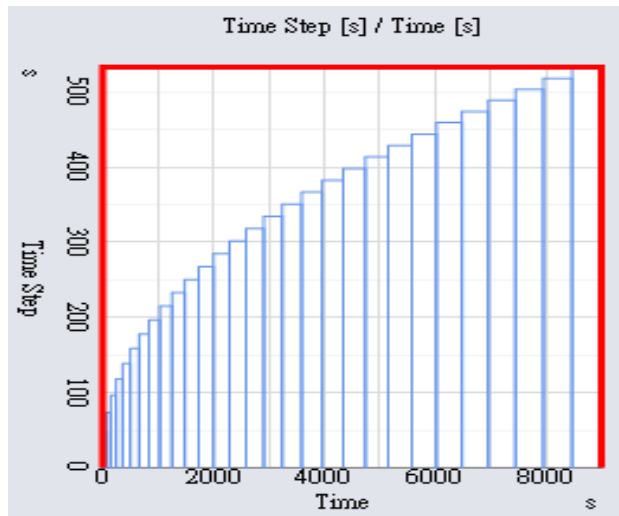
FloEFD



System Model Setup

- Operating temperature 25°C
- 2L water, $T_0=25^\circ\text{C}$
- 6 TECs, 3 fans, 4 heat pipes
- Neglect radiation due to the tank surface emissivity is low
- Transient simulation
 - From 0s to 9000s

0



TEC Setting by XT

TEC1-12706 Datasheet

Hot Side Temperature (° C)	25° C	50° C
Qmax (Watts)	50	57
Delta Tmax (° C)	66	75
I _{max} (Amps)	6.4	6.4
V _{max} (Volts)	14.4	16.4
Module Resistance (Ohms)	1.98	2.30

Thermo Electric Cooler

X: 40.000 mm

Y: 40.000 mm

Z: 3.8000 mm

☐ Show Component Orientation

Parameters

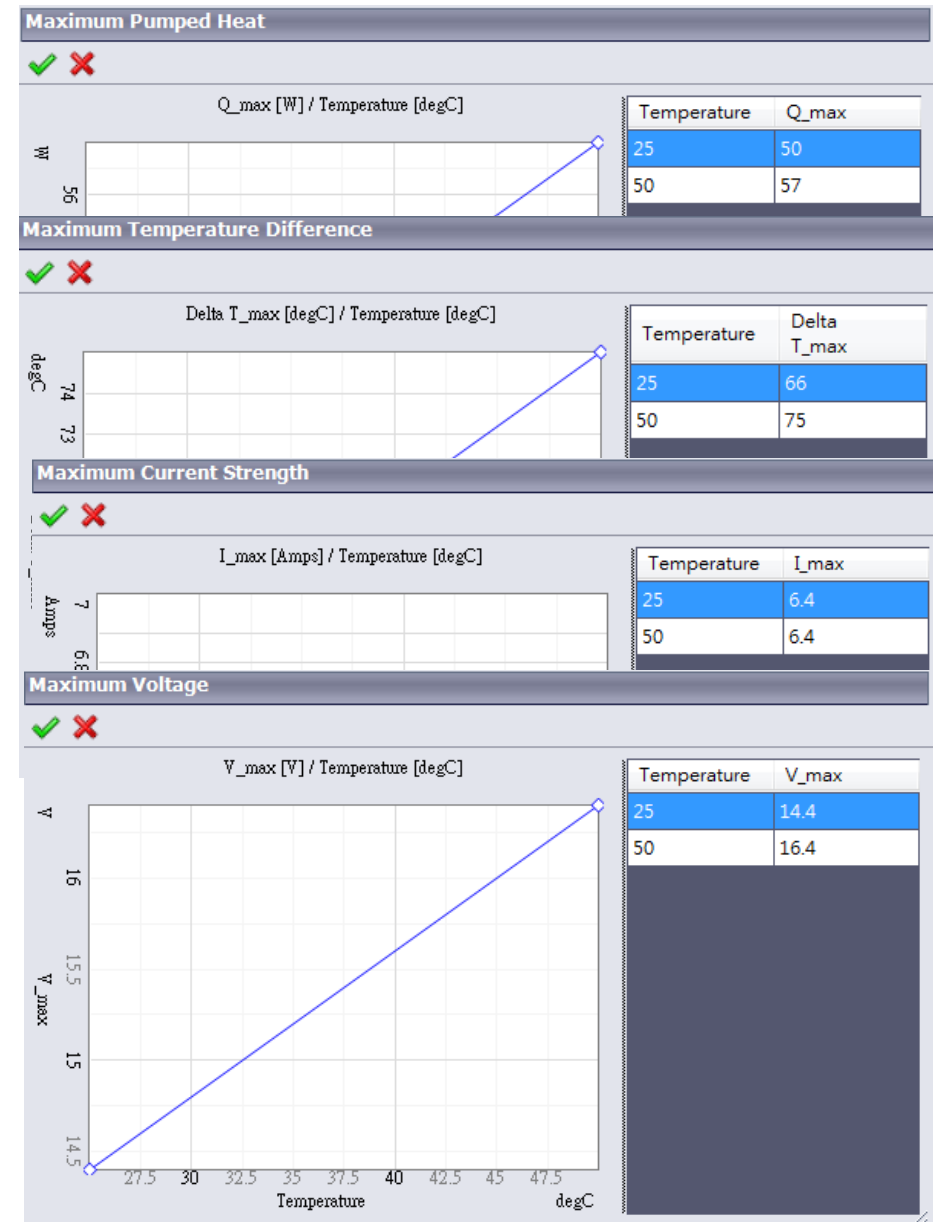
TEC Operational Current: 6.4000 Amps

Maximum Pumped Heat >>

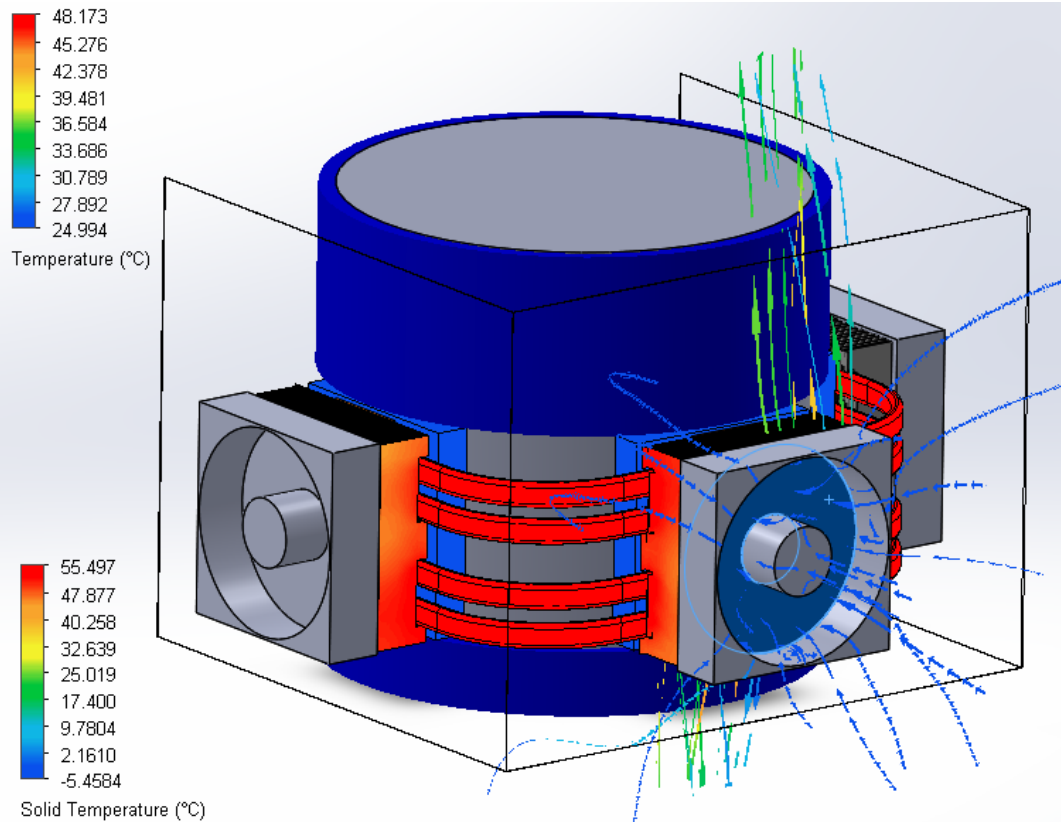
Maximum Temperature Difference >>

Maximum Current Strength >>

Maximum Voltage >>

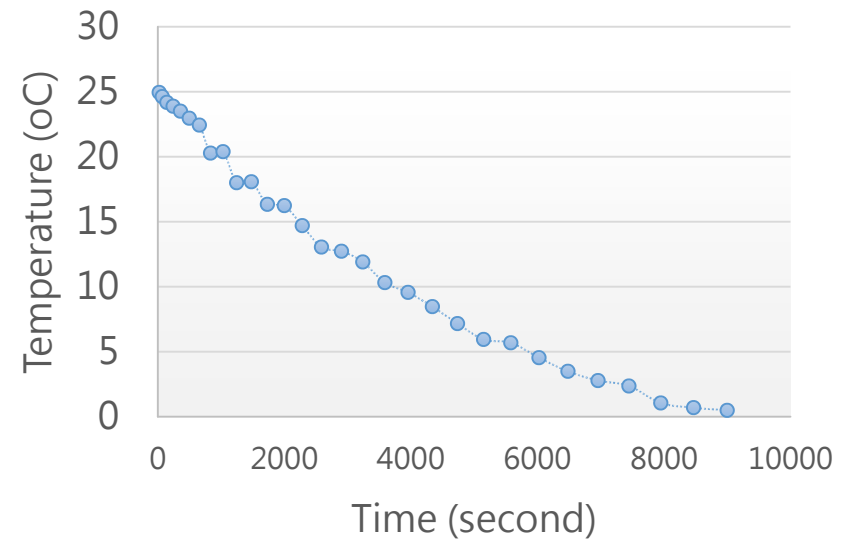


Temperature Profile



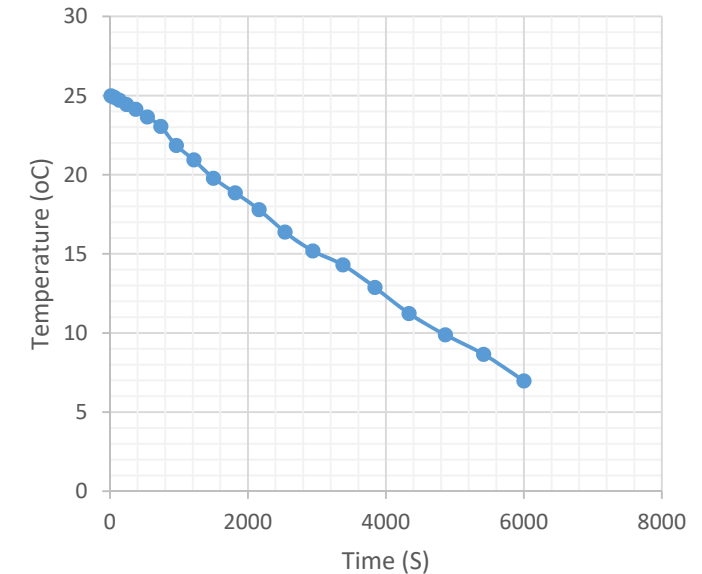
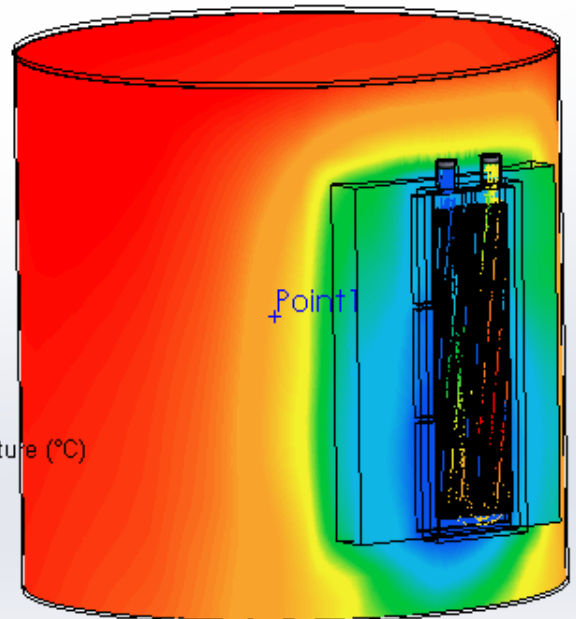
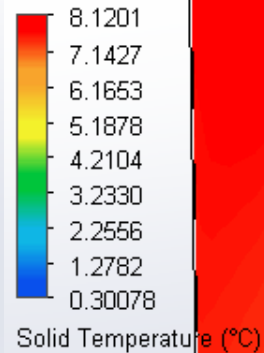
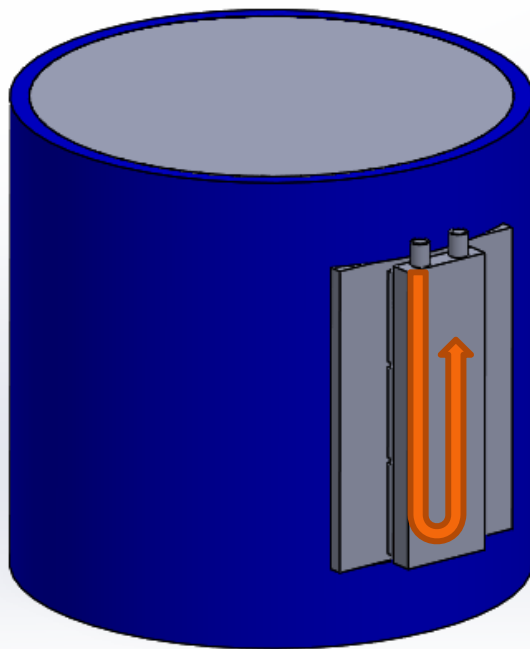
- Time=9000s

Water Center Temperature



- Still need 6000s to cool down to 4°C
- Preheated air impact the performance

Water Cooling Solution

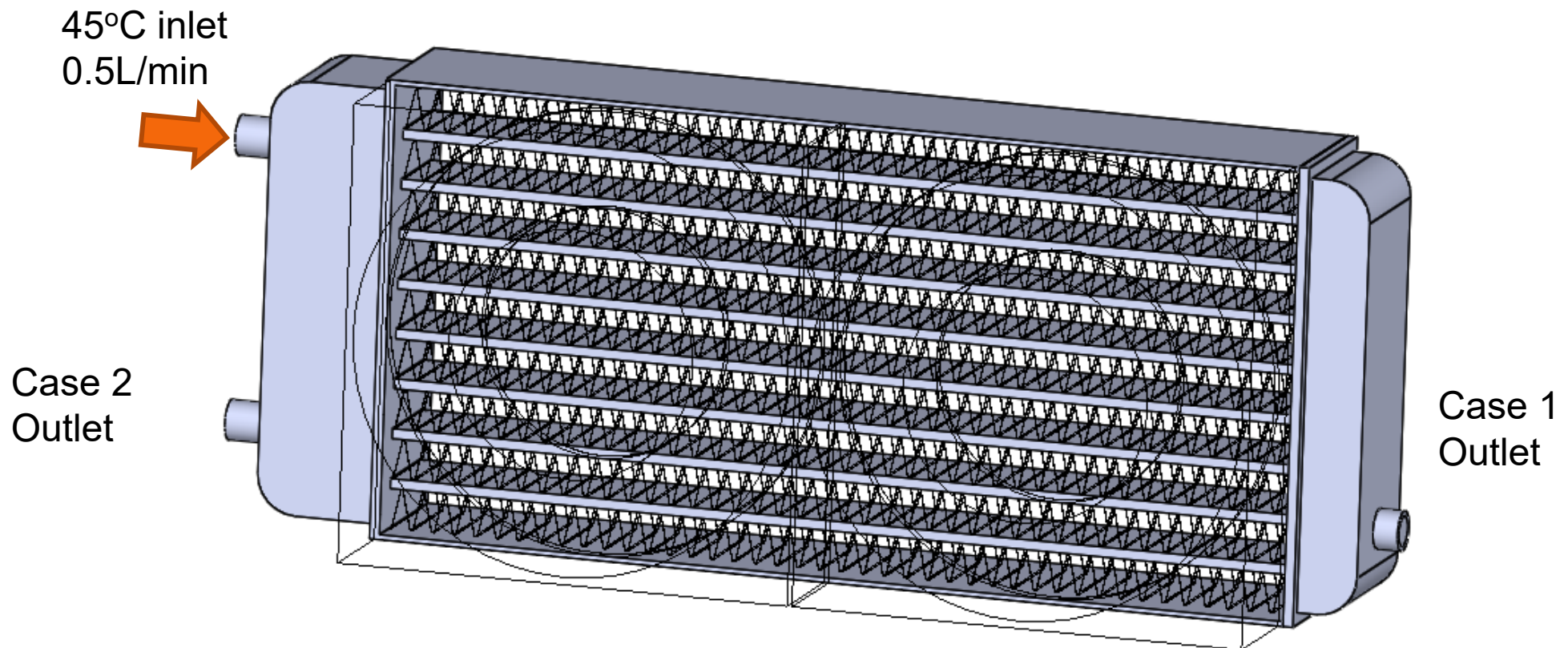


- Inlet Condition:
Fixed flow: 1L/min, $T=30^{\circ}\text{C}$
- Outlet Condition:
Pressure: default ambient
Calculate temperature 35.2°C

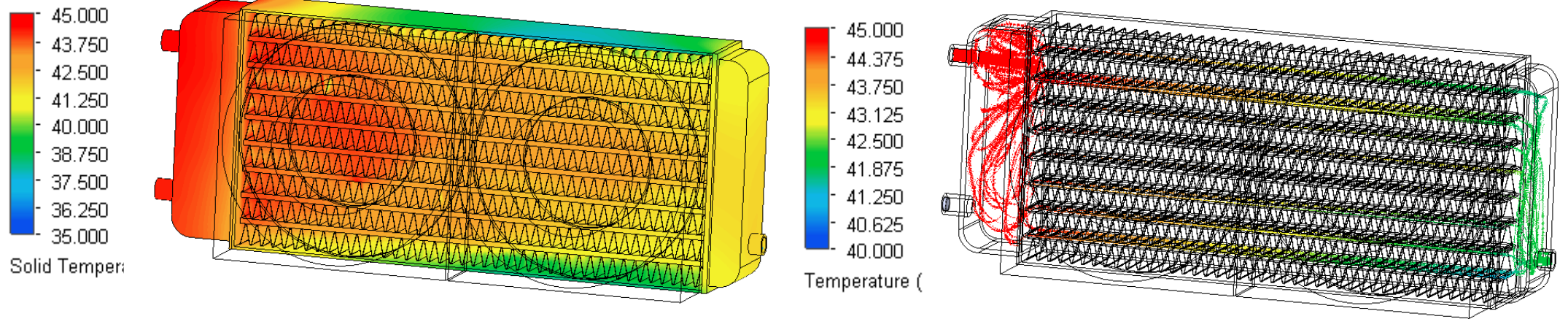
TEC Hot side: 39.5°C , Cold side 1.33°C
Overall heat transfer 118W/pc

Radiator Model

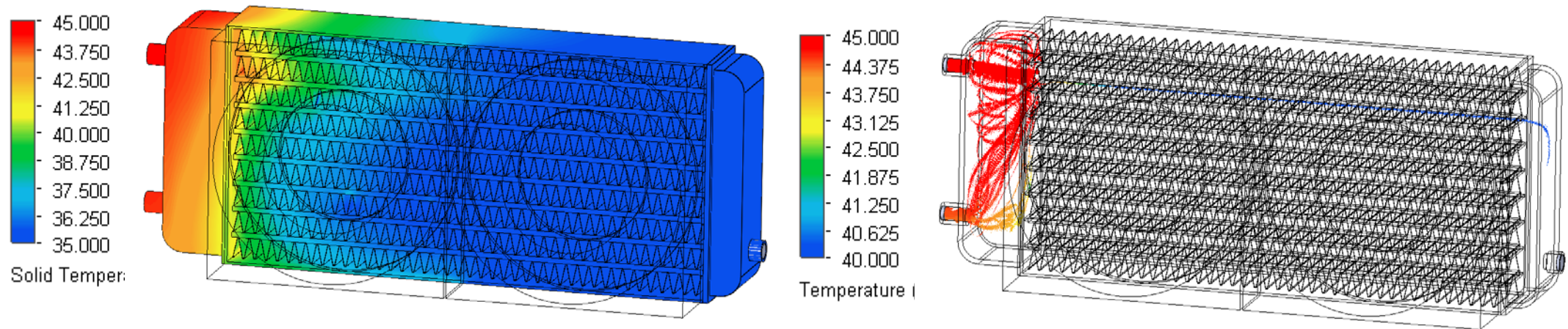
- ∞ Compare flow channel design
- ∞ 9225 fan * 2, 35°C Ta



Radiator Design

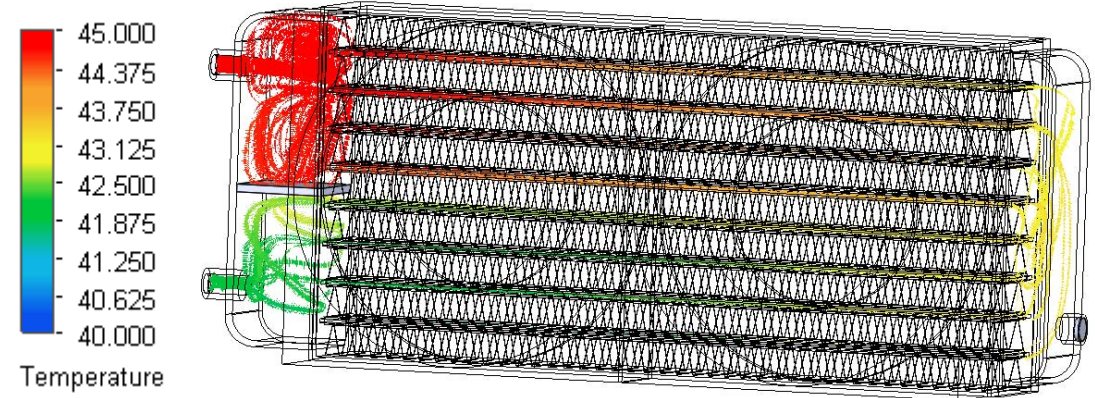
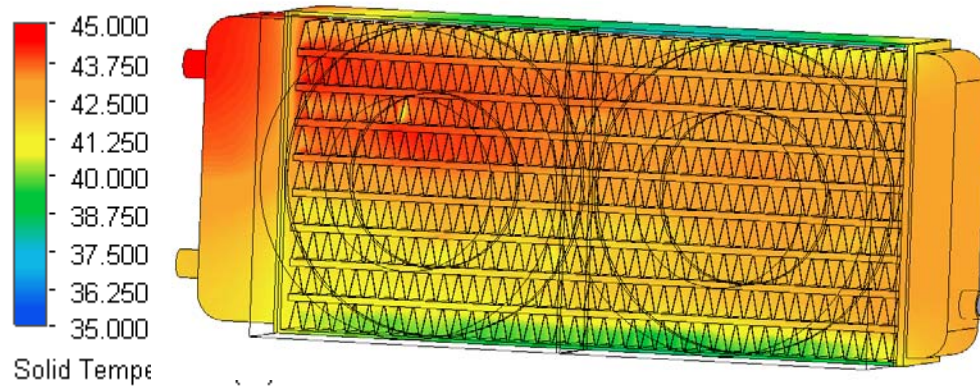


- Case 1



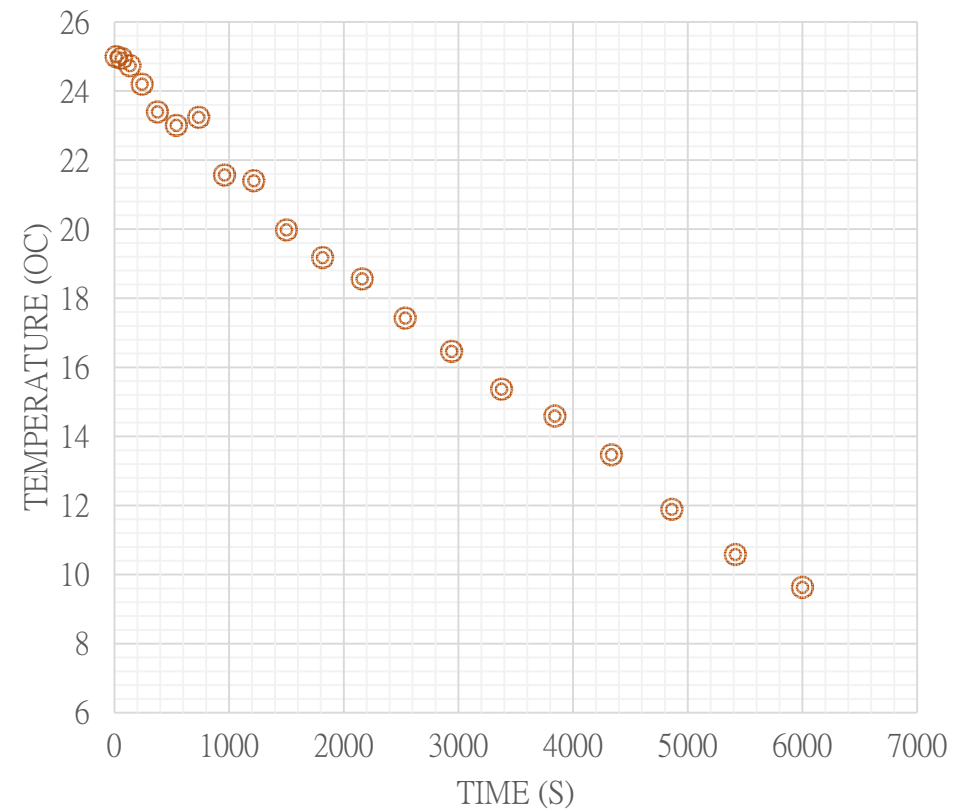
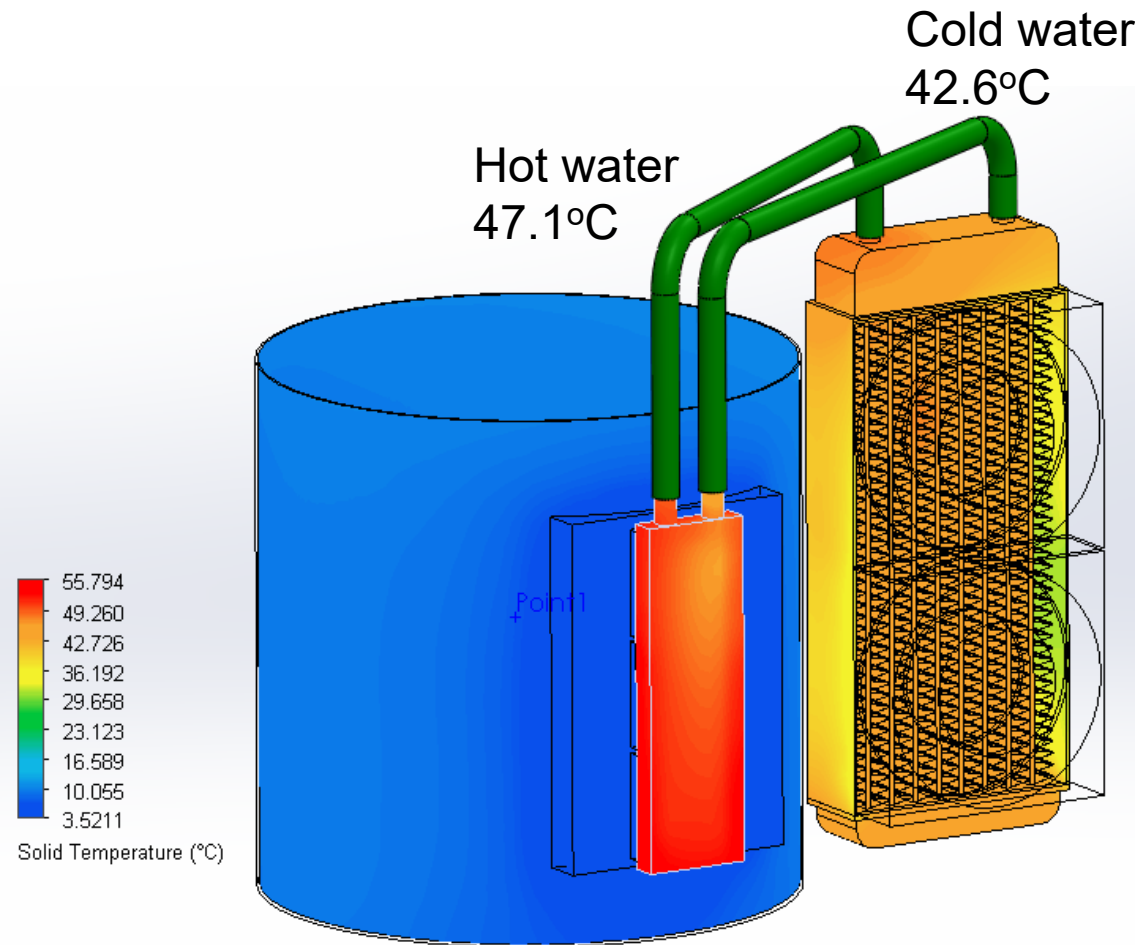
- Case 2

Case 2 Modified



	Case 1	Case 2	Case 2
Inlet Temperature	45	45	45
Outlet	41.943	44.41	41.968
Pressure Drop (Pa)	752	761	1025

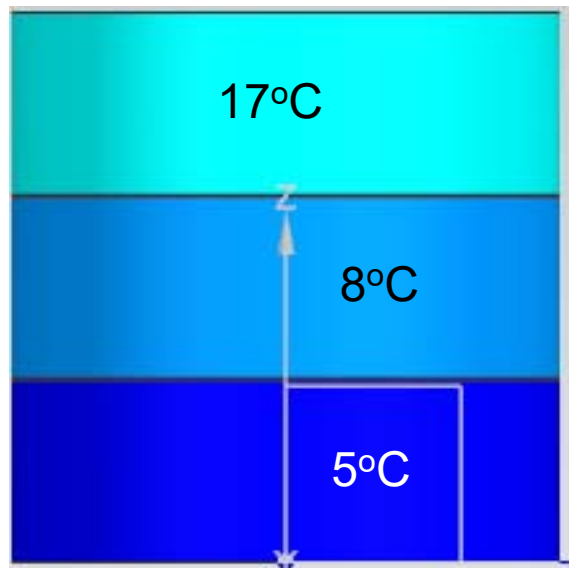
Whole Liquid Cooling System



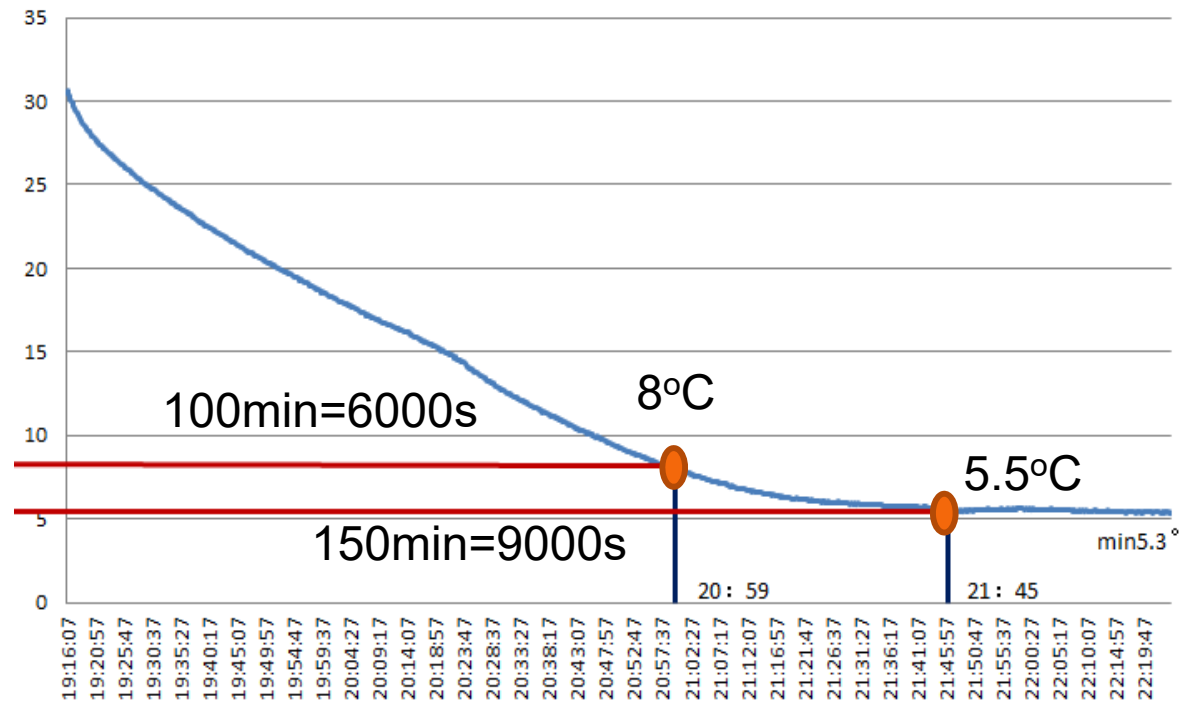
Actual Test Result



6 TECs

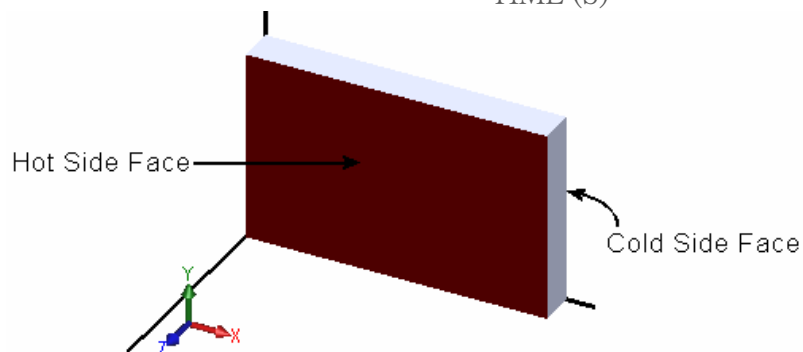
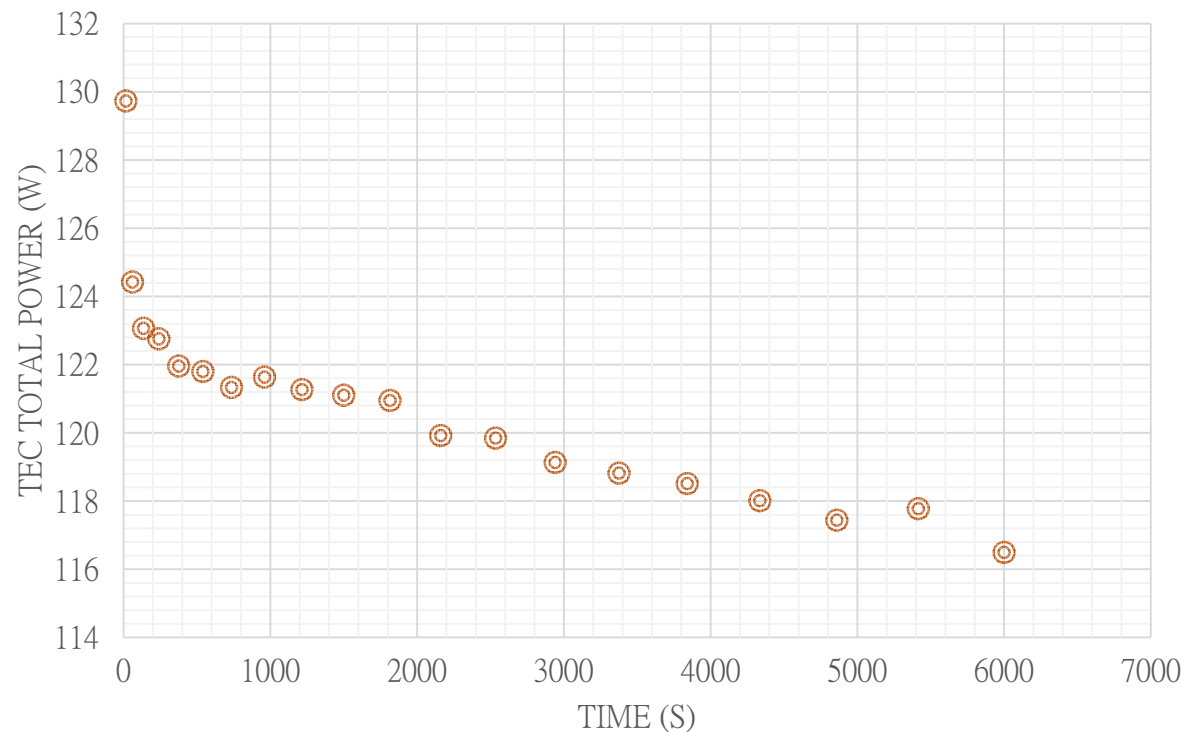


Water Temperature

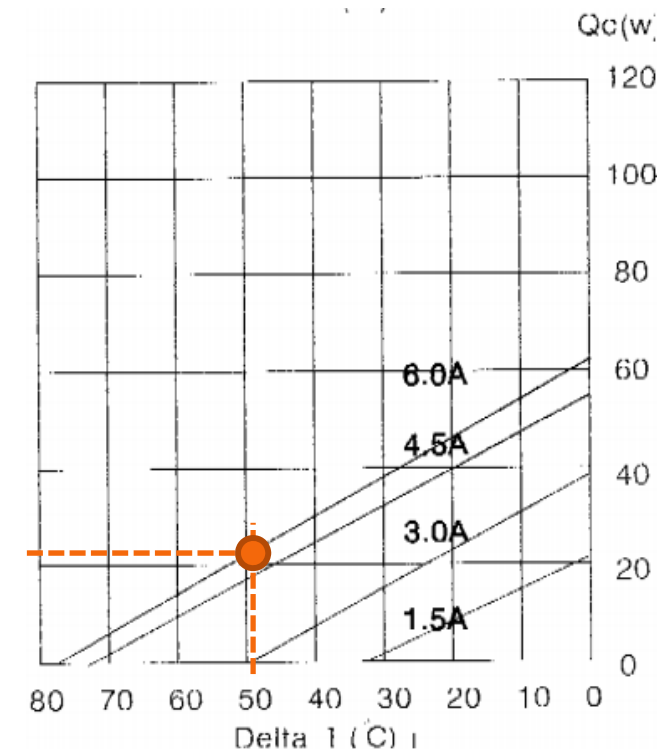


- Error analysis
 1. Without effective insulator
 2. TEC placement, constrained by system mechanical design

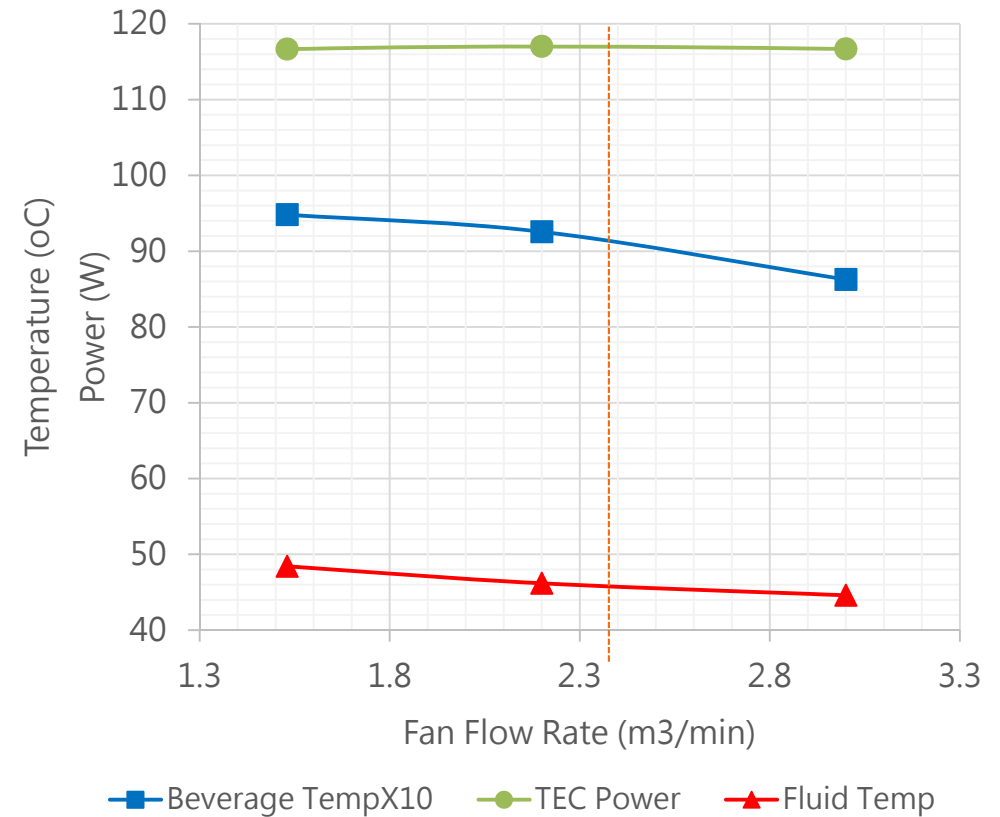
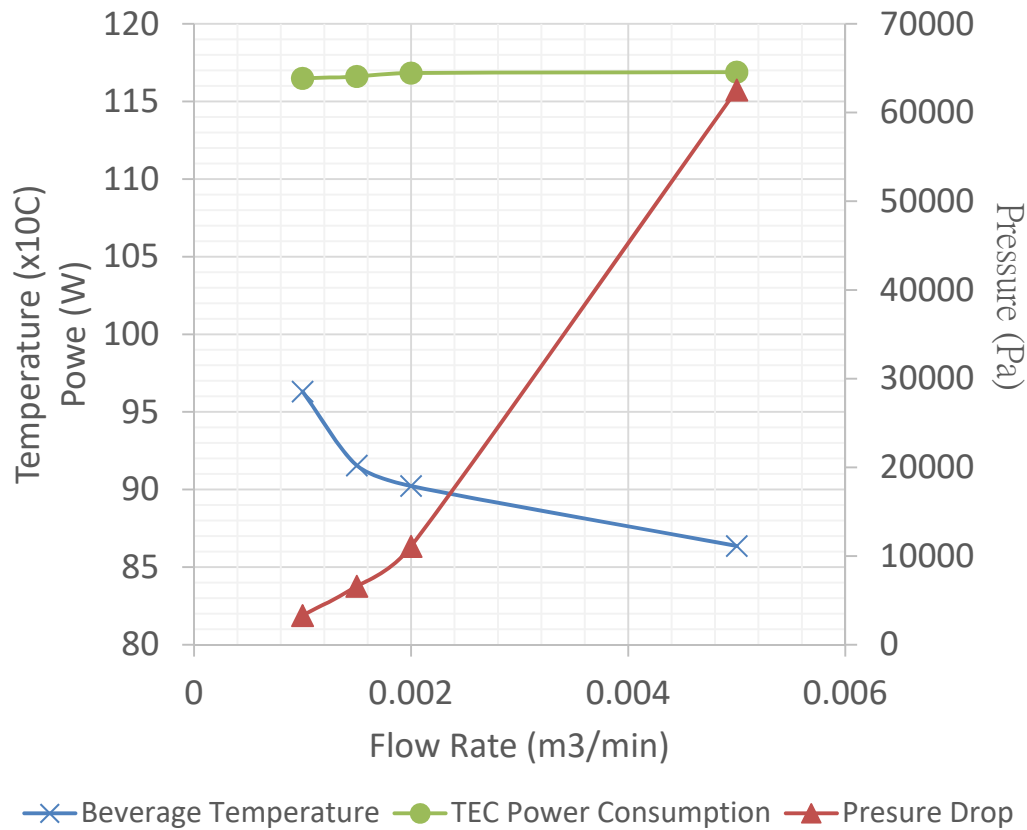
TEC Power vs Time



- Hot side $T=52.85^{\circ}\text{C}$
- Cold side $T=4.014^{\circ}\text{C}$
- Heat Pumped= 20.7W
- Total heat transfer rate is 117.3W



Parametric Study

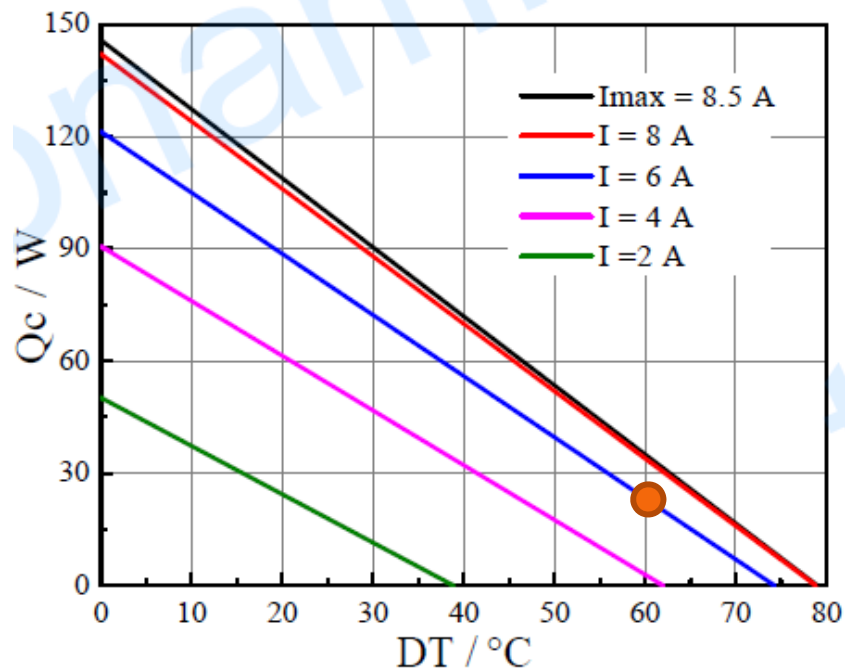


TEC1-19908



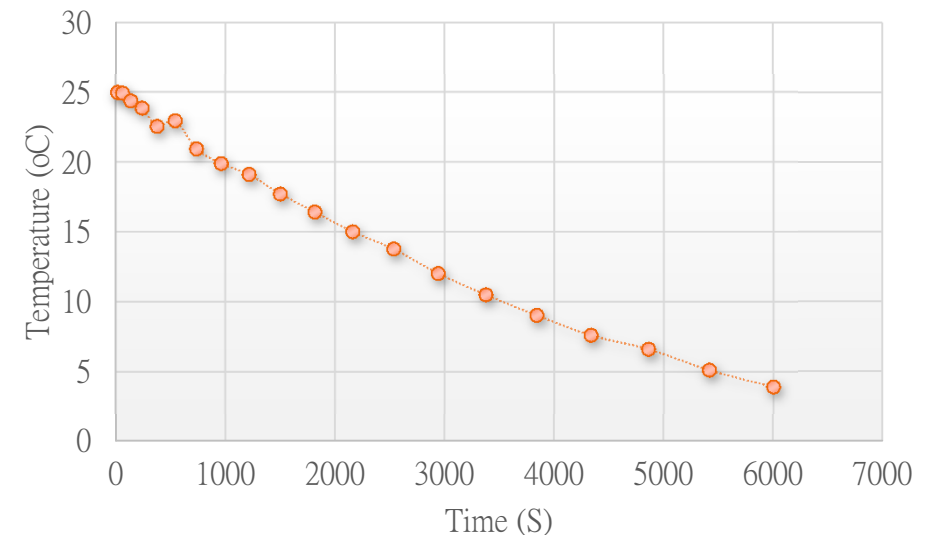
Hot side temperature (°C)	27	50
$Q_{\max}$ (Watts)	133.4	145.8
Delta $T_{\max}$ (°C)	70	79
$I_{\max}$ (Amps)	8.5	8.5
$V_{\max}$ (Volts)	25	26.9
Module Resistance (Ohms)	2.25	2.49

Performance Curves at $T_h=50\text{ }^{\circ}\text{C}$



Goals	Data Inspector	Messages	Parametric Study			
Face	Component	Parameter	Min	Max	Average	
HotFace	Thermo Electric Cooler-1	Temperature (Solid) [°C]	90.118	90.118	90.118	
HotFace	Thermo Electric Cooler-1	Convective/Conductive Heat Transfer Rate [W]			248.98	
HotFace	Thermo Electric Cooler-1	Total Heat Transfer Rate [W]			248.98	
Face < 1 >	Thermo Electric Cooler-1	Temperature (Solid) [°C]	3.4058	3.4058	3.4058	
Face < 1 >	Thermo Electric Cooler-1	Convective/Conductive Heat Transfer Rate [W]			-14.841	
Face < 1 >	Thermo Electric Cooler-1	Total Heat Transfer Rate [W]			-14.841	

Face	Component	Parameter	Min	Max	Average	
Face < 1 >	Thermo Electric Cooler-1	Temperature (Solid) [°C]	-4.8216	-4.8216	-4.8216	
Face < 1 >	Thermo Electric Cooler-1	Convective/Conductive Heat Transfer Rate [W]			-22.974	
Face < 1 >	Thermo Electric Cooler-1	Total Heat Transfer Rate [W]			-22.974	
HotFace	Thermo Electric Cooler-1	Temperature (Solid) [°C]	57.809	57.809	57.809	
HotFace	Thermo Electric Cooler-1	Convective/Conductive Heat Transfer Rate [W]			139.73	
HotFace	Thermo Electric Cooler-1	Total Heat Transfer Rate [W]			139.73	



Summary



- ✎ XT can perform excellent of
 - o TEC behavior
 - o Heat pipe
 - o Fluid subdomain help to simulate the fluid convection
 - o Transient model setting is easy
 - o Parametric study
 - o Liquid cooling combine air cooling

聯絡我們



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