

# Cool Charge

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1

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# Background

- Developing an all electric fork truck
- Replacing an internal combustion engine
- Battery pack made from 7 battery modules

2



# The Problem

Battery pack will be generating heat when charged and discharged

The battery current flow will be limited if temperatures exceed the threshold

3



iPhone overheat warning



# The Project

Design a heavy-duty cooling system for the battery pack

## Needs

Maintain internal battery  
temperatures below  
55 degrees Celsius

## Constraints

Perform this task in ambient  
temperature of  
40 degrees Celsius

Fit in the space  
behind the battery pack

**PROPRIETARY  
INFORMATION  
AND IMAGES  
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# Heat Generation

Battery voltage is 51 Volts

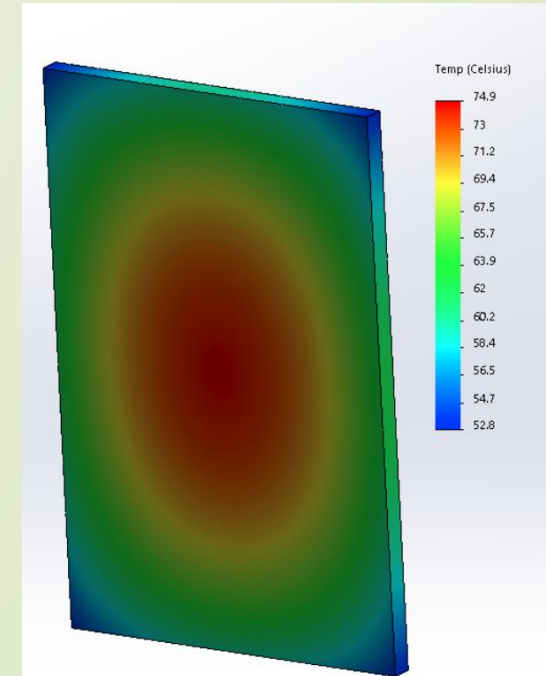
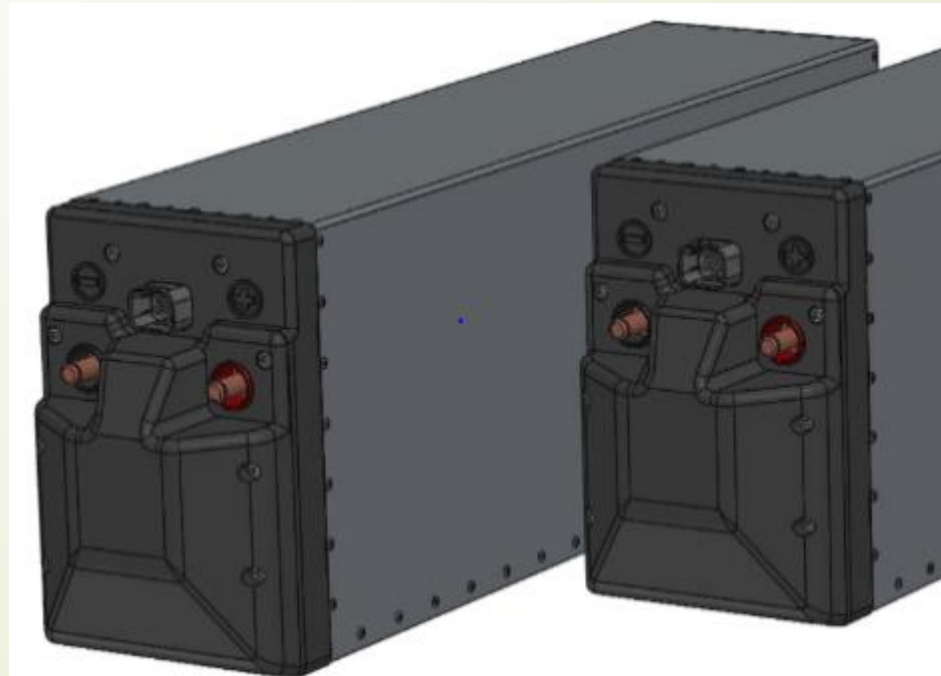
To find power:  $V \cdot A = W$

Maximum discharge current is  
(usually not constant) 350 amps

17.8 kW

Max fast charge is 1C or  
(constant) 174 amps

8.87 kW

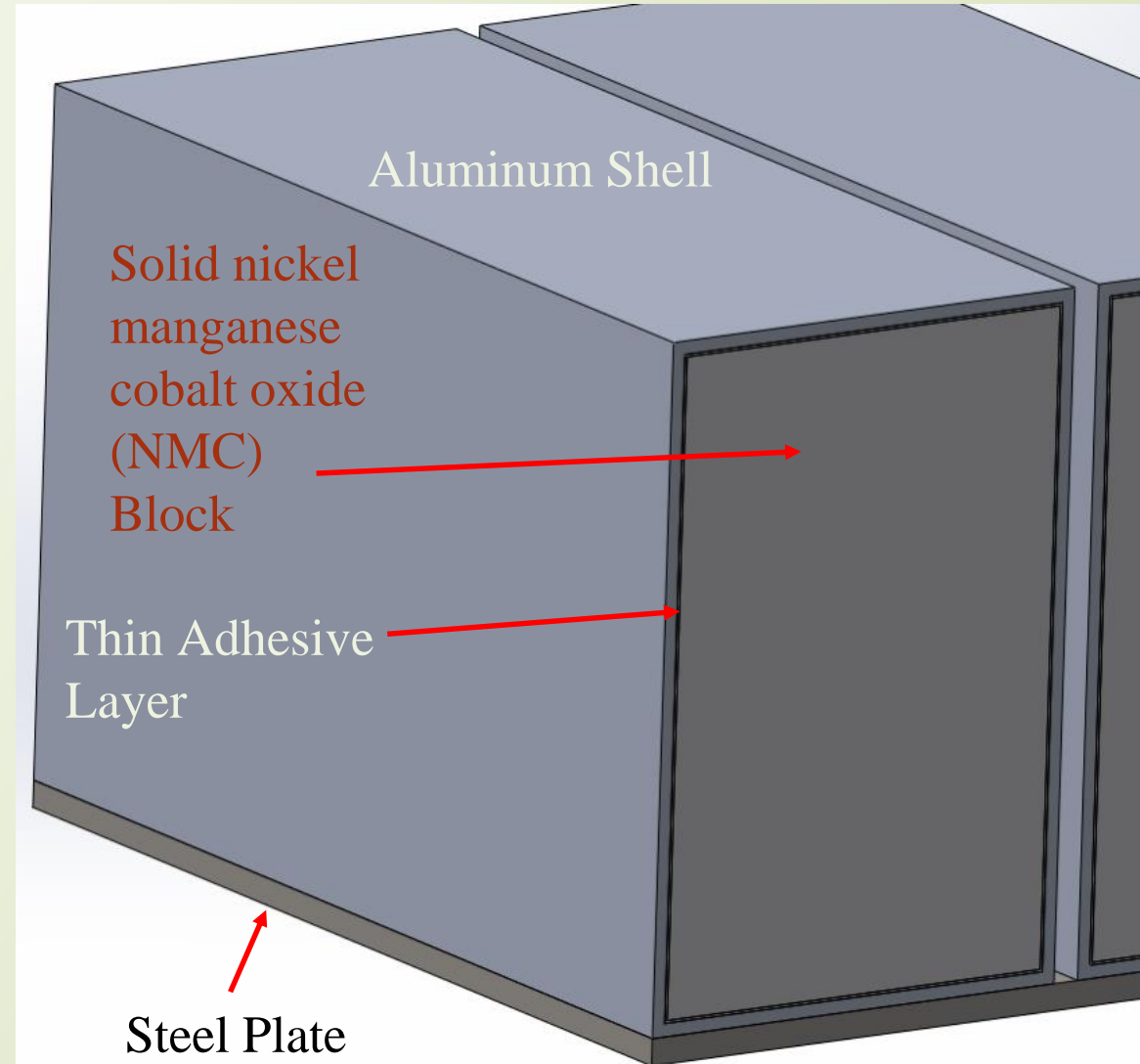


# Modeling

- Section view shows the layers of the battery in our SolidWorks model
- This model is then used to visualize temperature distribution

6

Note: NMC is chosen for most electric vehicles



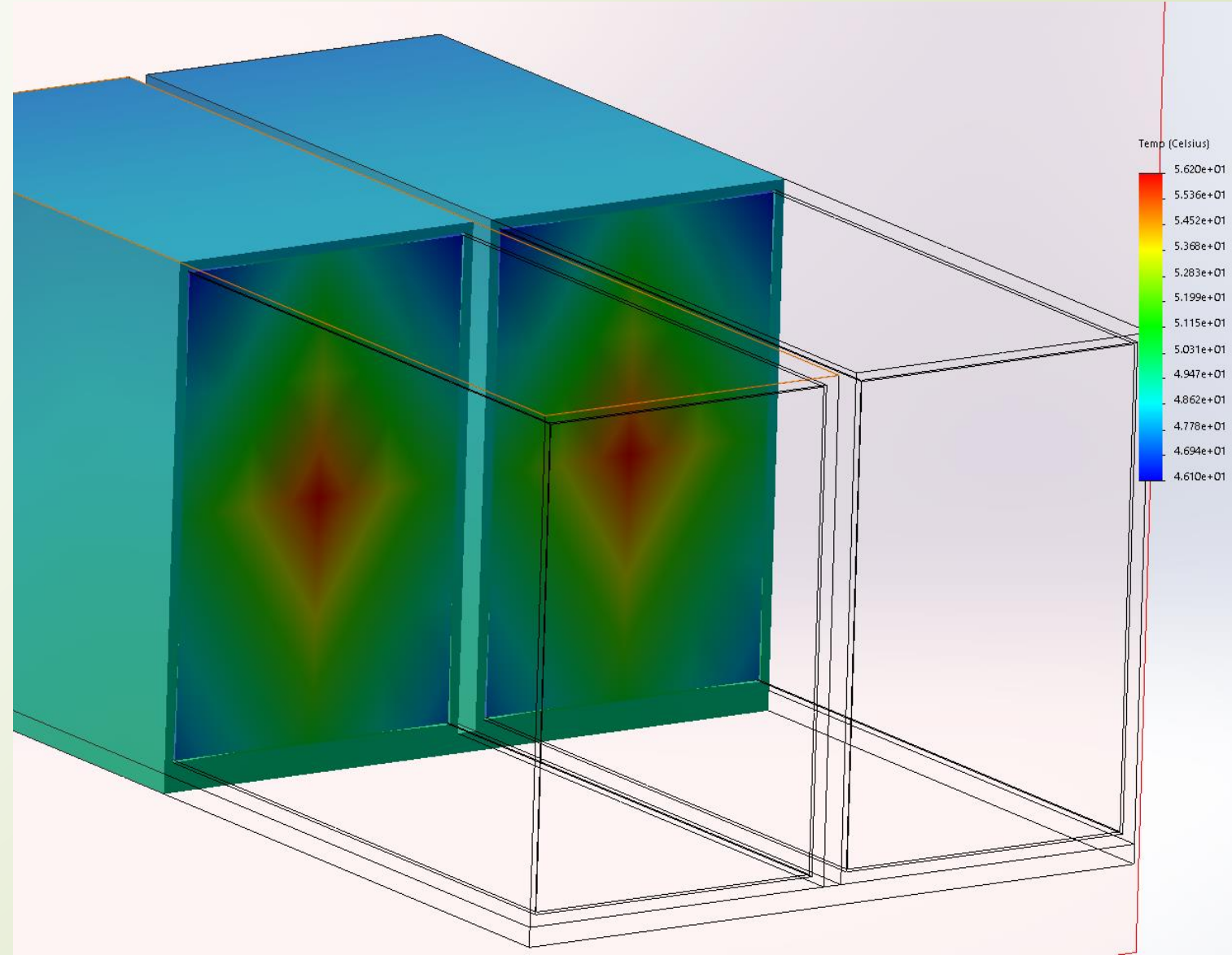


# Thermal Study

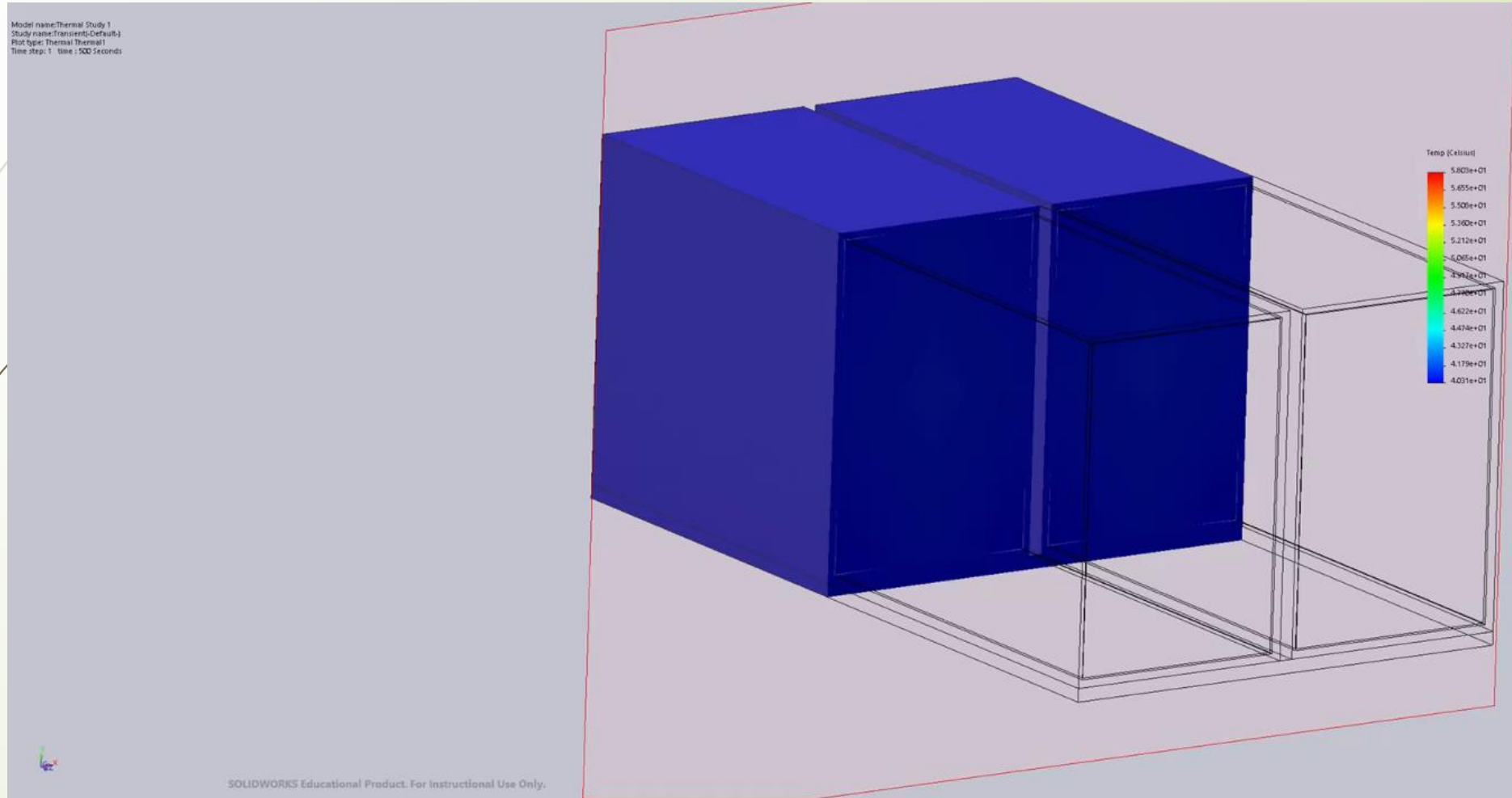
Full size module  
thermal study  
proves hand  
calculations

7

Wall temperature of  
50.7 degrees Celsius



# Temperature Rise



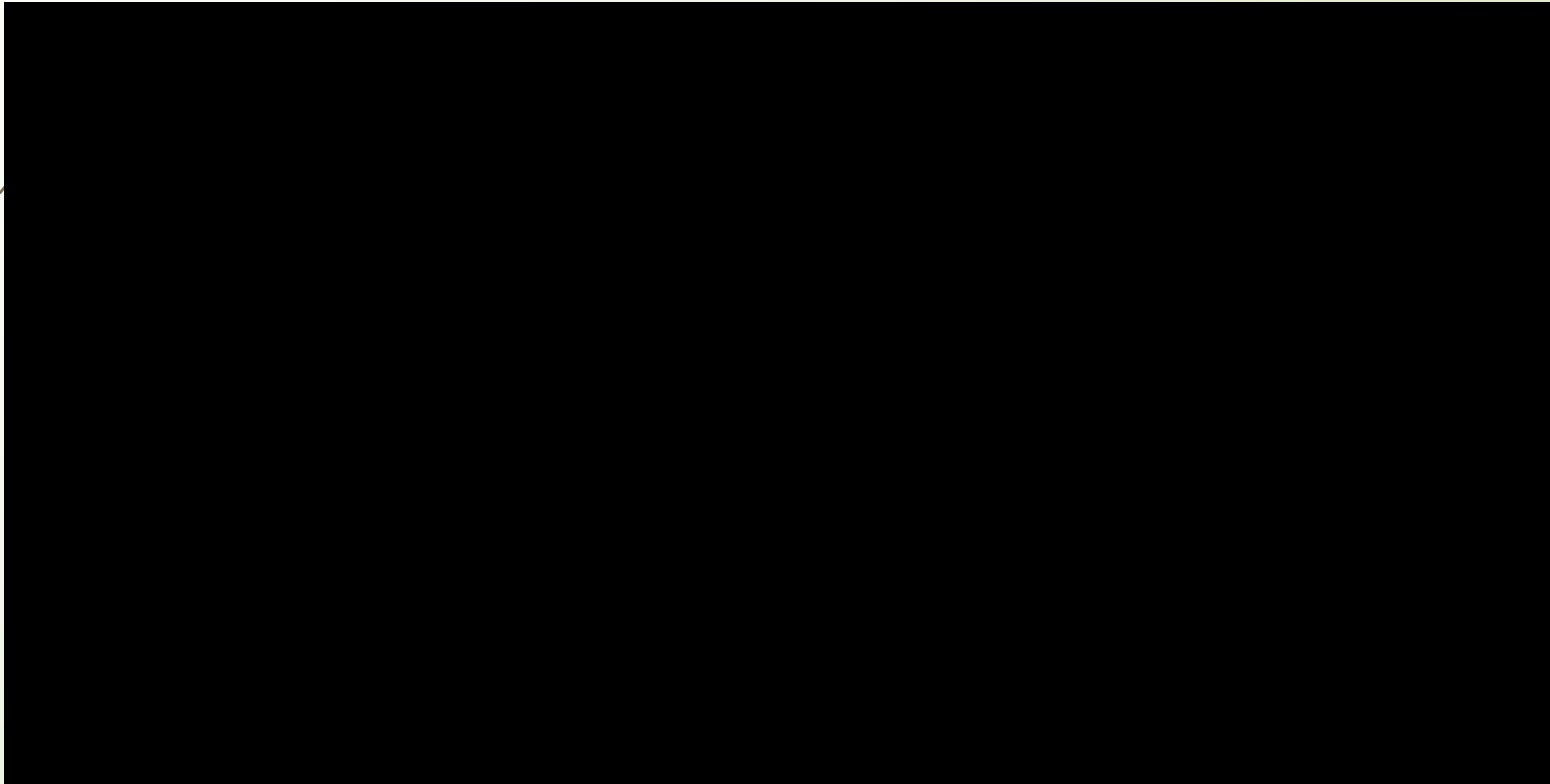


# Air Flow

This CFD model shows how much the air slows down from the beginning of the slot to the end

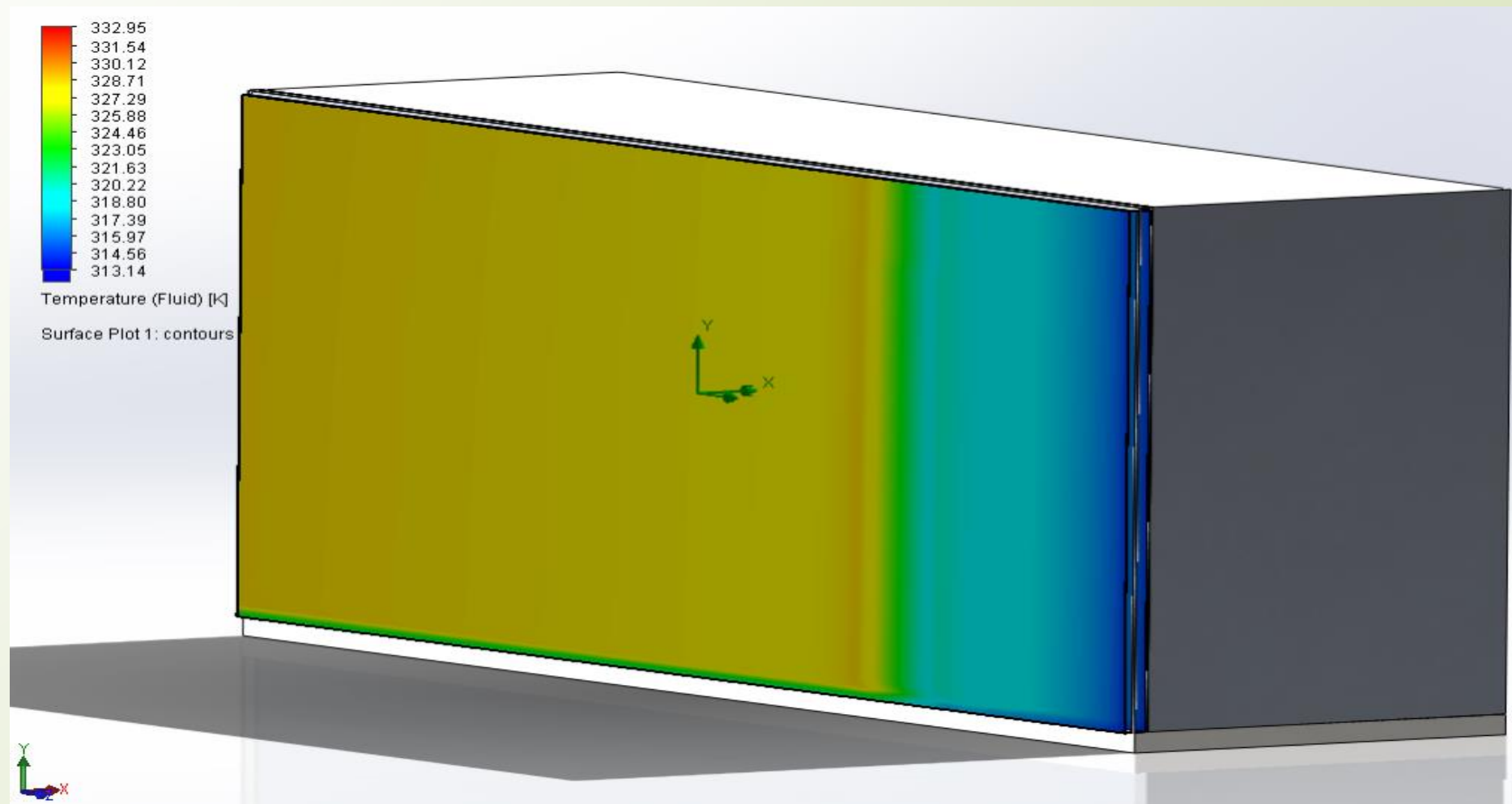
Air enters at 50 m/s

(calculated from volumetric flow and cross sectional area of entrance)



# CFD with Thermal Study

- Air enters the slot @ 225 CFM. Ambient Temp. is 40 C
- Wall temperature is 50 C
- Air is cold for only 1/3 the distance needed



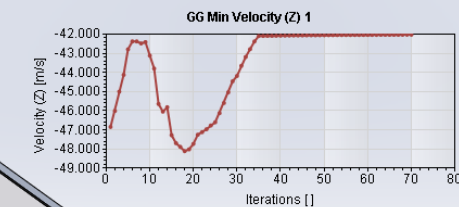
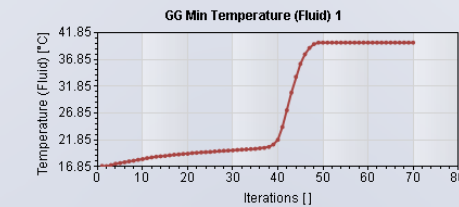
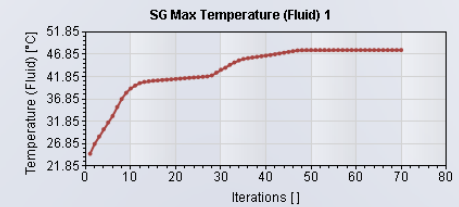
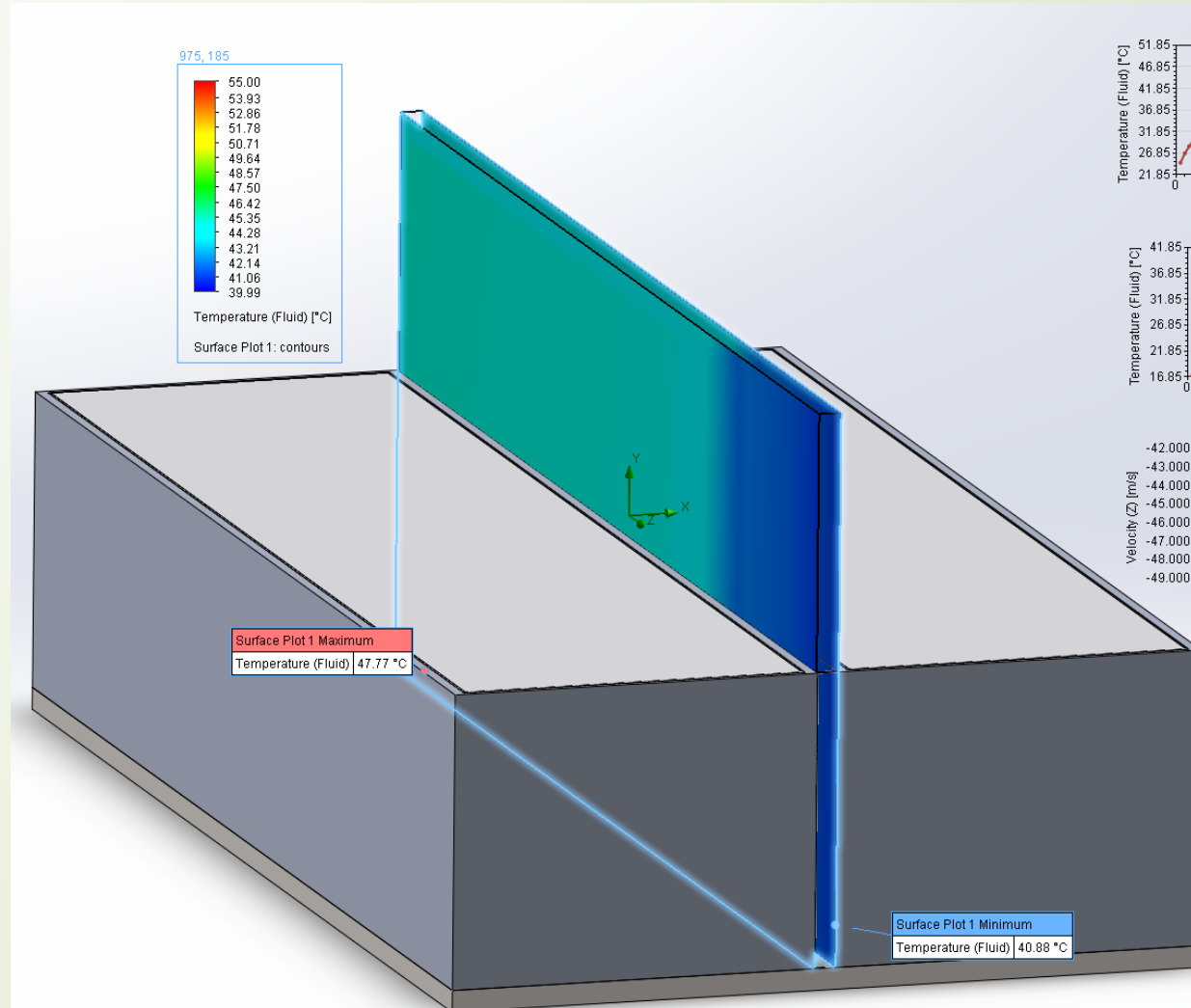
# Project Learning

Wall temp is 50 C

Air enters @ 40 C

Air exits @ 48 C

11



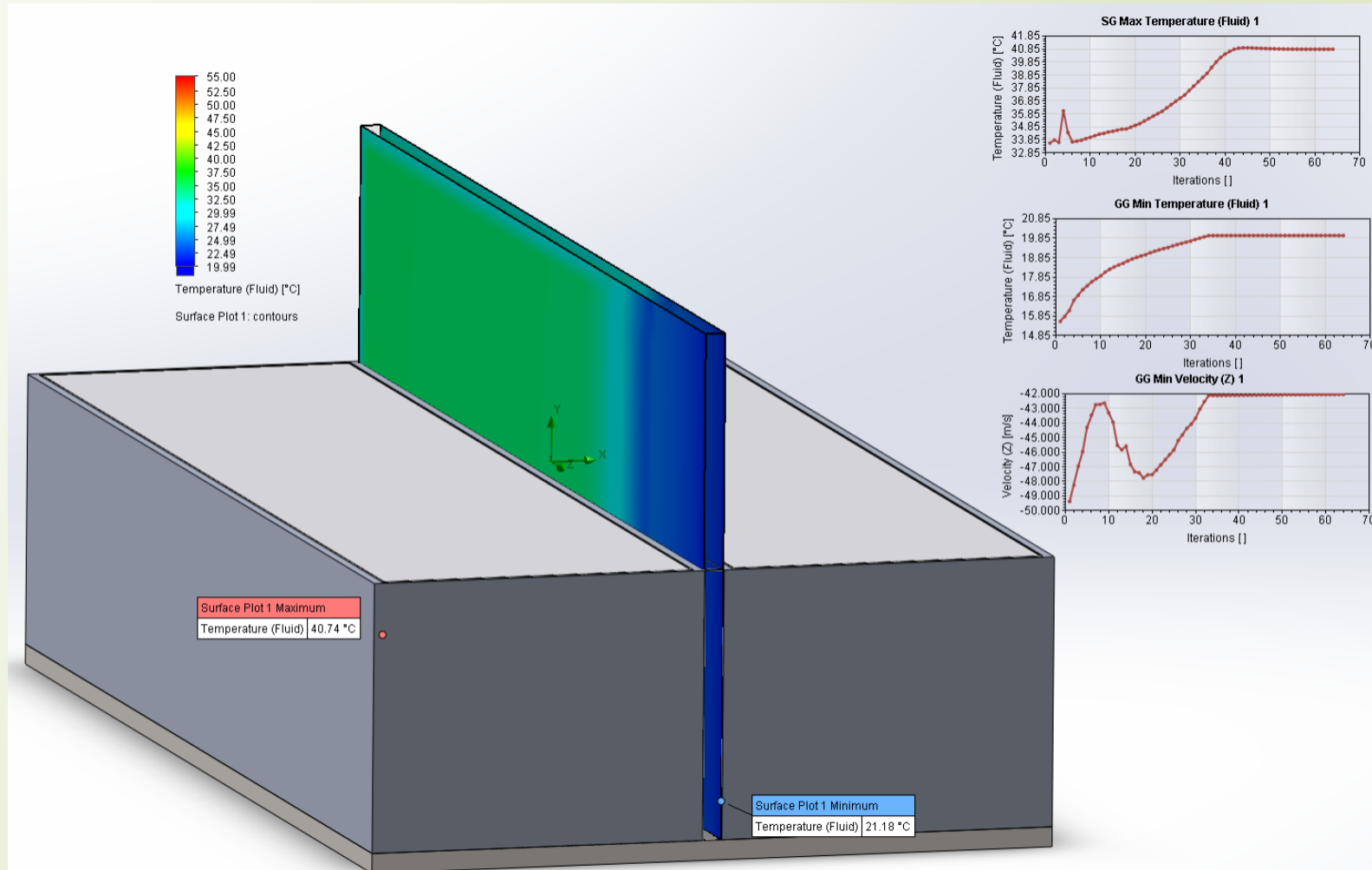
# Project Learning

Wall temp is 50 C

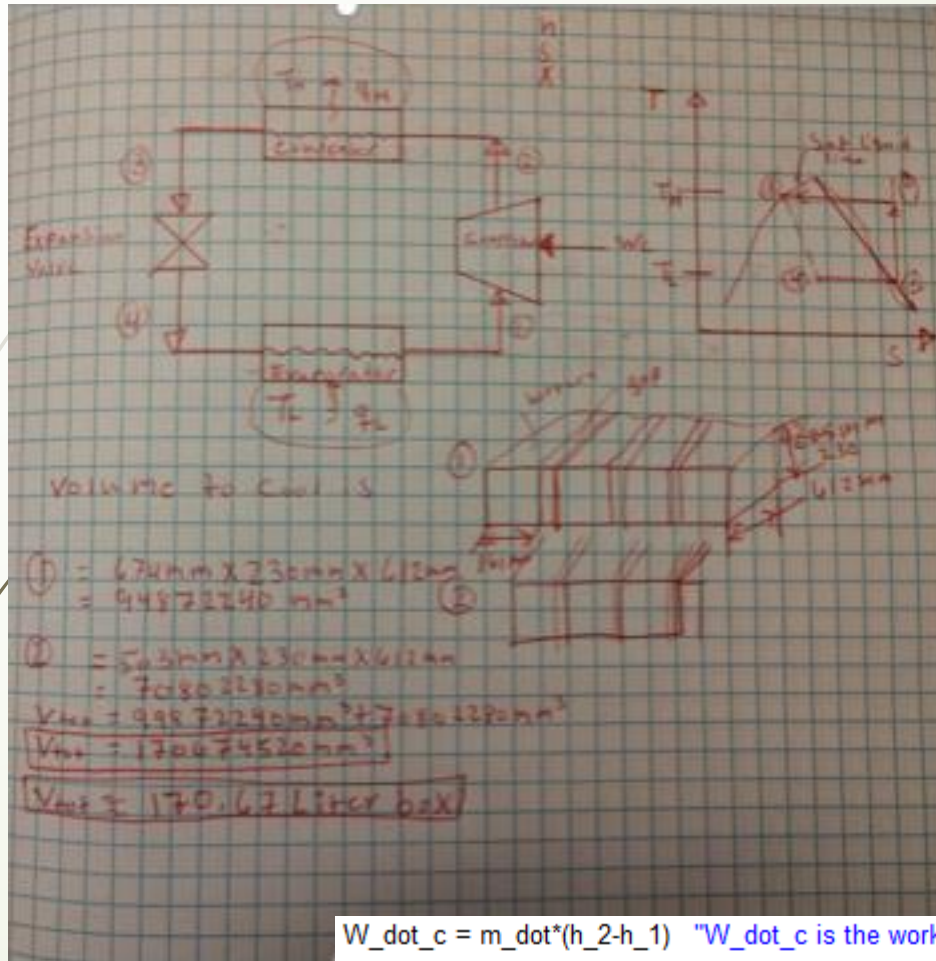
Air enters @ 20 C

Air exits @ 40 C

12



# Ideal Vaper Compression



f\$ = 'R134a'

"State #1"

$T_1 = \text{temperature}(f$,  $P=P_1, x=x_1$ )$

$P_1 = 320[\text{kpa}]$

$h_1 = \text{enthalpy}(f$,  $P=P_1, x=x_1$ )$

$s_1 = \text{entropy}(f$,  $P=P_1, x=x_1$ )$

$x_1 = 1$

"State #2"

$T_2 = \text{temperature}(f$,  $P=P_2, s=s_1$ )$

$P_2 = 1200[\text{kpa}]$

$h_2 = \text{enthalpy}(f$,  $P=P_2, s=s_1$ )$

$s_2 = s_1$

$x_2 = \text{quality}(f$,  $P=P_2, s=s_1$ )$

"(Ideal System)"

"State #3"

$T_3 = 46.29 \{t_{\text{sat}}(f$,  $P=P_3)\}$$

$P_3 = P_2$

$h_3 = \text{enthalpy}(f$,  $T=T_3, P=P_3$ )$

$s_3 = \text{entropy}(f$,  $T=T_3, P=P_3$ )$

$x_3 = \text{quality}(f$,  $T=T_3, P=P_3$ )$

"State #4"

$T_4 = \text{temperature}(f$,  $P=P_4, h=h_4$ )$

$P_4 = P_1$

$h_4 = h_3$

$s_4 = \text{entropy}(f$,  $P=P_4, h=h_4$ )$

$x_4 = \text{quality}(f$,  $P=P_4, h=h_4$ )$

$m_{\text{dot}} = 3 [\text{kg/s}]$

"mass flow rate"

$W_{\text{dot}_c} = m_{\text{dot}}(h_2 - h_1)$  "W\_dot\_c is the work of the compressor"

$Q_{\text{dot}_E} = m_{\text{dot}}(h_1 - h_4)$  "Cooling load of the evaporator"

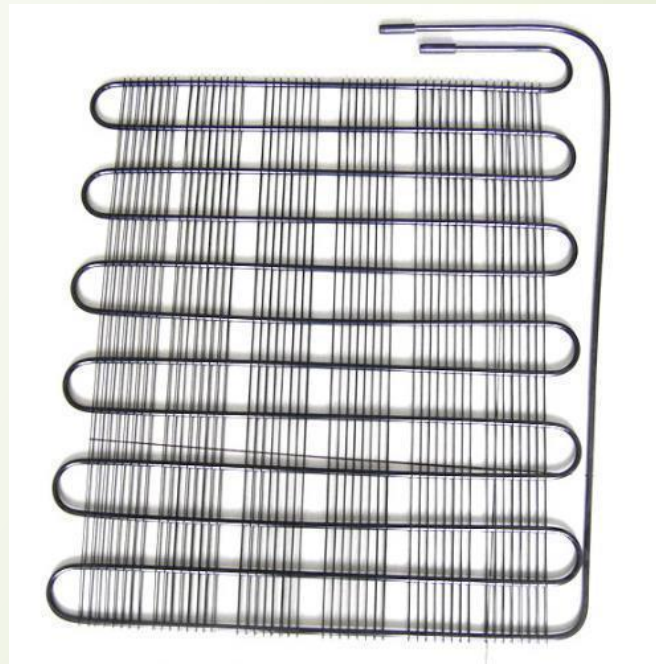
$Q_{\text{dot}_C} = m_{\text{dot}}(h_2 - h_3)$  "Heat rejected by condenser"

$\text{COP} = Q_{\text{dot}_E} / W_{\text{dot}_c}$  "Coefficient Of Performance"

$Q_{\text{dot}_E} = U \cdot A \cdot (T_4 - T_1)$



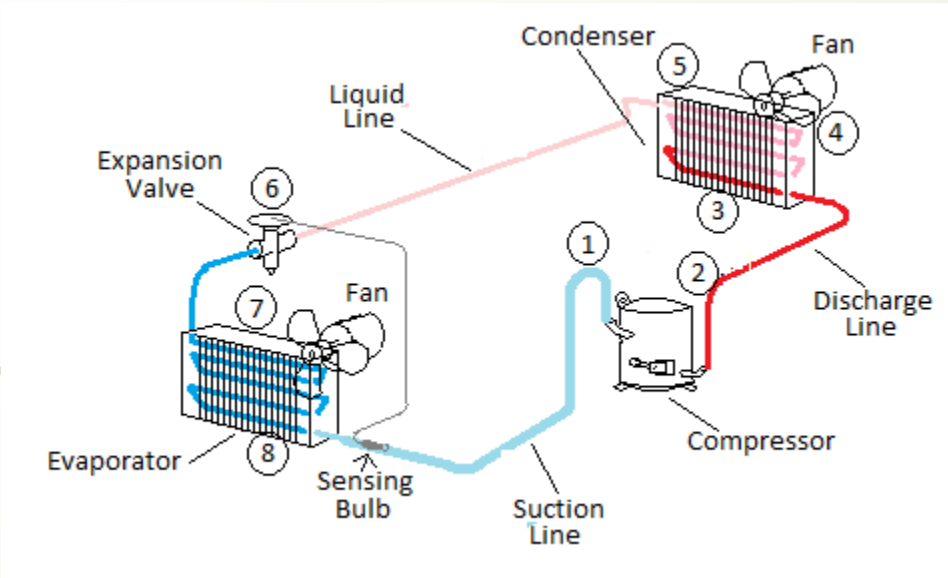
# Refrigeration Components







# Pros and Cons



16

## Refrigeration Pros

- Heavy duty cooling
- 12v system

## Refrigeration Cons

- Size
- Cost

## Thermoelectric Pros

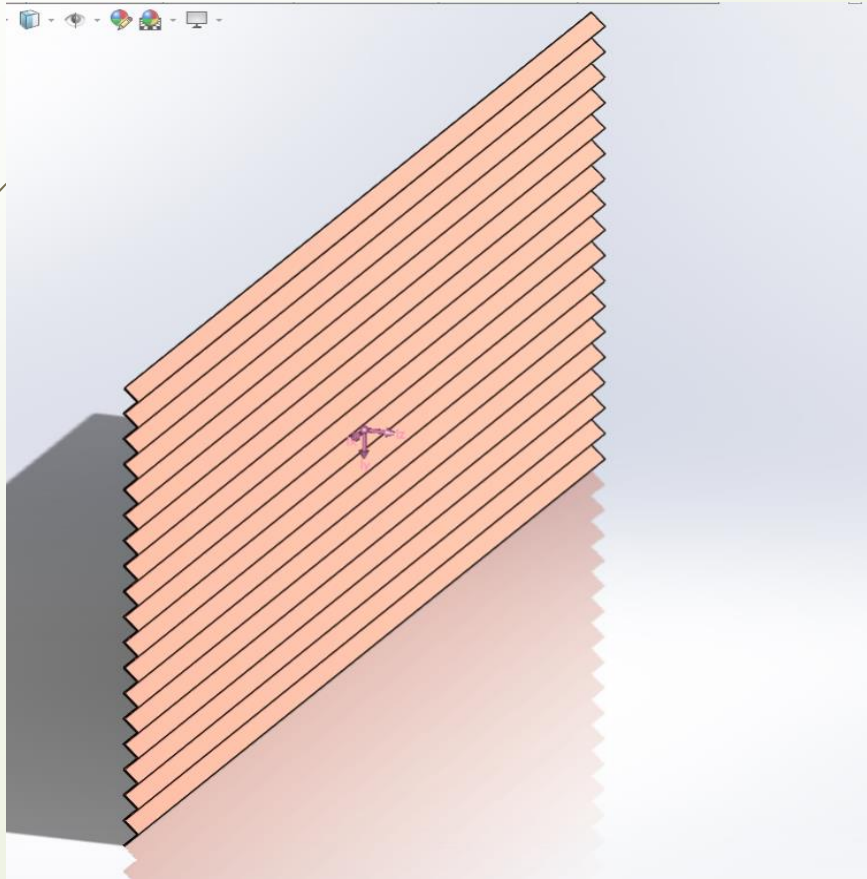
- Size
- Cost
- 12v system

## Thermoelectric Cons

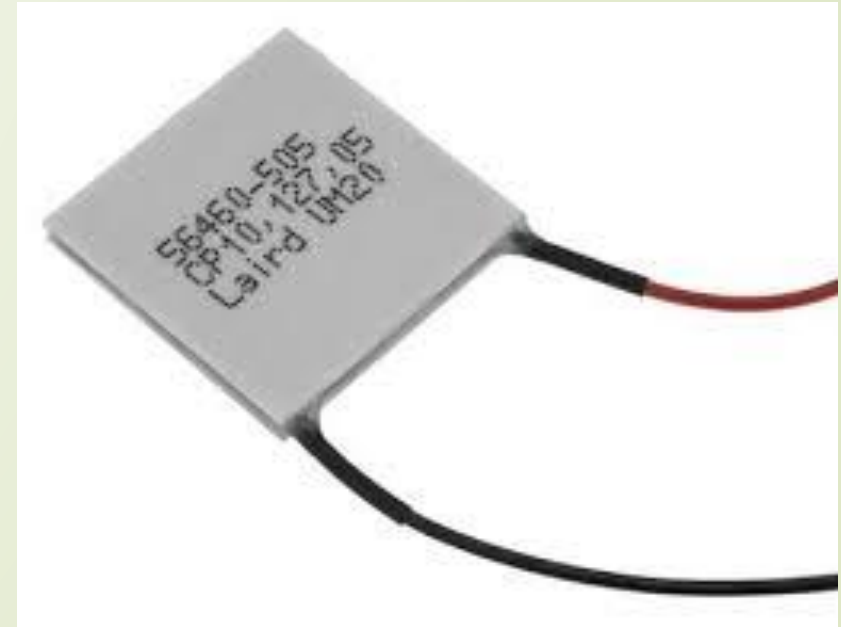
Less Cooling

# Concepts and Ideas

- Increasing surface area between battery modules using fins or pipes

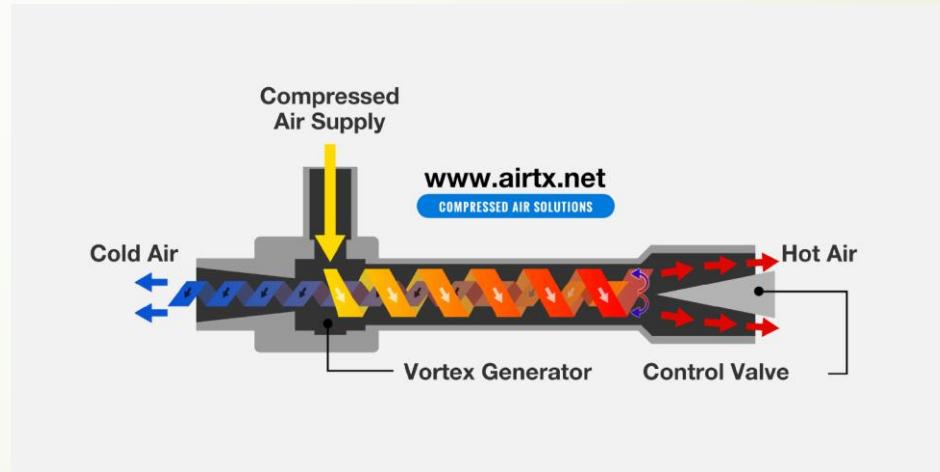


- Peltier Modules to remove heat from battery walls



# Concepts and Ideas

- Pre Cooling Air with Vortex tubes



- Heat Pipes





# Recommendations

During normal forklift operation:  
Ducting to direct airflow efficiently

During Charging:  
Precooling at Charging Station

**PROPRIETARY  
INFORMATION  
AND IMAGES  
REMOVED**



# Budget

Total Refrigeration fan and ducting component costs  
\$3978

20

Capstone Project Budget Template - Summer/Fall												
Project:		HYG										
Last Updated		11/2/18										
Expense Items	Year								Item Total			
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr				
<b>Equipment/Tools:</b>									\$ -			
									\$ -			
<b>Travel:</b>												
Trip To HYG							\$ 750		\$ 750			
									\$ -			
									\$ -			
<b>Supplies / Parts / Services:</b>												
Fans					\$ 250				\$ 250			
Wood				\$ 50					\$ 50			
Hardware				\$ 150					\$ 150			
Refrigeraton Componets					\$ 200	\$ 400			\$ 600			
3D Printer Filiment					\$ 80				\$ 80			
Power supply					\$ 100				\$ 100			
Sensors					\$ 250				\$ 250			
Display/Presentation							\$ 45		\$ 45			
Final Prototype Expences							\$ 200		\$ 200			
<b>Shop Usage (est. Hrs):</b>									Hours			
Shop Time				10	10	10	10	10	50			
									Graduate Student Support	\$ 779	including fringe	
									Shop Overhead	\$ 600		
									University Overhead	\$ 124	5% of all expenses	
									<b>Totals</b>	<b>\$ 3,978</b>	\$ 4,000	\$ 22
											Budget	Excess



# Schedule

## Key dates:

- Build mock battery over winter break
- Order, mount and test fans in January – February
- Order and test precooling components early April

	November	December	January	February	March	April	May
Concept Design Review	27th						
Capstone Snapshot	30th						
Mock Battery Build		10th - 14th					
Order test fans			21st				
3D print most efficient nozzles			28th - 31st				
Mount Fans with nozzles				4th - 8th			
Test fans with proposed ducting				11th - 15th			
Visit Client					11th		
Order refrigeration components if necessary					18th - 22nd		
Test precooling components (onboard or offboard)						1st - 5th	
Prepare for Design Expo						15th - 25th	
Present at Design Expo						26th	
Deliver prototype / computer models to Client							6th - 10th

Questions ?

Thank You !