Thermal Fluids Analysis Workshop
August 22, 2008

HIGH-HEAT SHIELD DESIGN CONCEPTUAL STUDY USING PHASE CHANGE MATERIALS

by

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PRESENTATION OUTLINE

- Introduction
- Objective
- Methodology
- Benchmark Cases
- Model Setup
- Results
- Optimization
- Conclusion
- Questions

OBJECTIVE

- Design a phase change material based shield which can sustain high-heat loads for aerospace applications

  - Absorbing the thermal energy coming from external stream friction
  - Re-usable system
  - Using the absorbed energy for internal spacecraft usage

INTRODUCTION

- Phase Change Materials (PCMs)
  - Having high heats of fusion
    - Absorbing energy during melting while temperature remains constant
  - Remain the temperature constant during phase change
    - Making it is useful for keeping the subject at a steady temperature for a long time

- Importance of absorbing Thermal Energy
  - Thermally shield vehicle’s Outer Mold Line (OML)
  - Converting the energy to electrical propulsion
  - Using the converted energy for internal Spacecraft usage

METHODOLOGY

- SINDA/ FLUINT for simulating the internal heat transfer

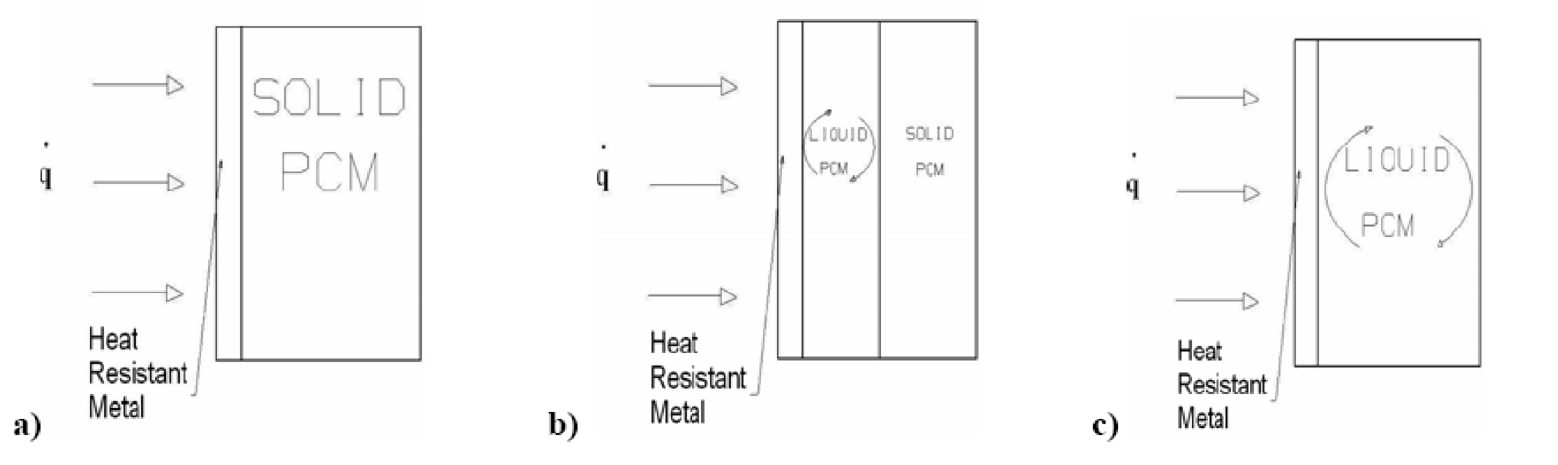


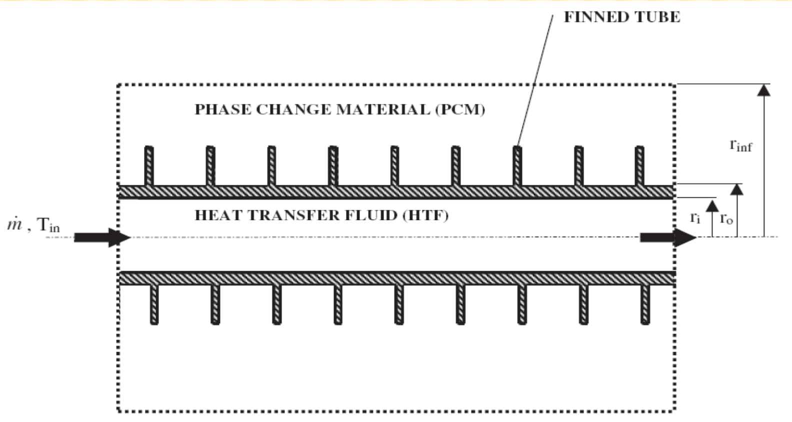
Figure 1 a, b, c. "Buoyancy Effect" of Natural Convection and Melting propagation through the PCM

- CFD codes for the externals heat flux
  - Used exciting data
- Ideal simulation include combination of both methods

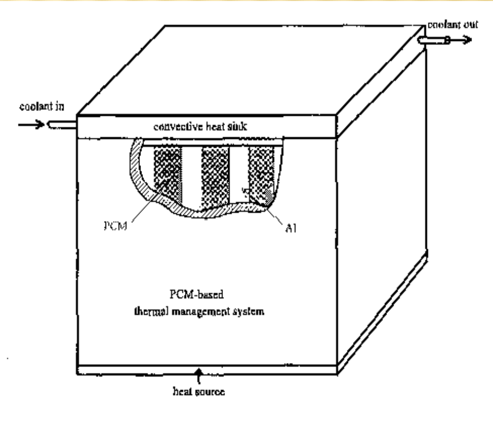
MODEL SETUP / BENCHMARK CASES

- Goals
  - Model validation against experimental data

- Benchmark Cases
  - Thermal Energy Storage System (TES)
  - Thermal Management System (TMS)



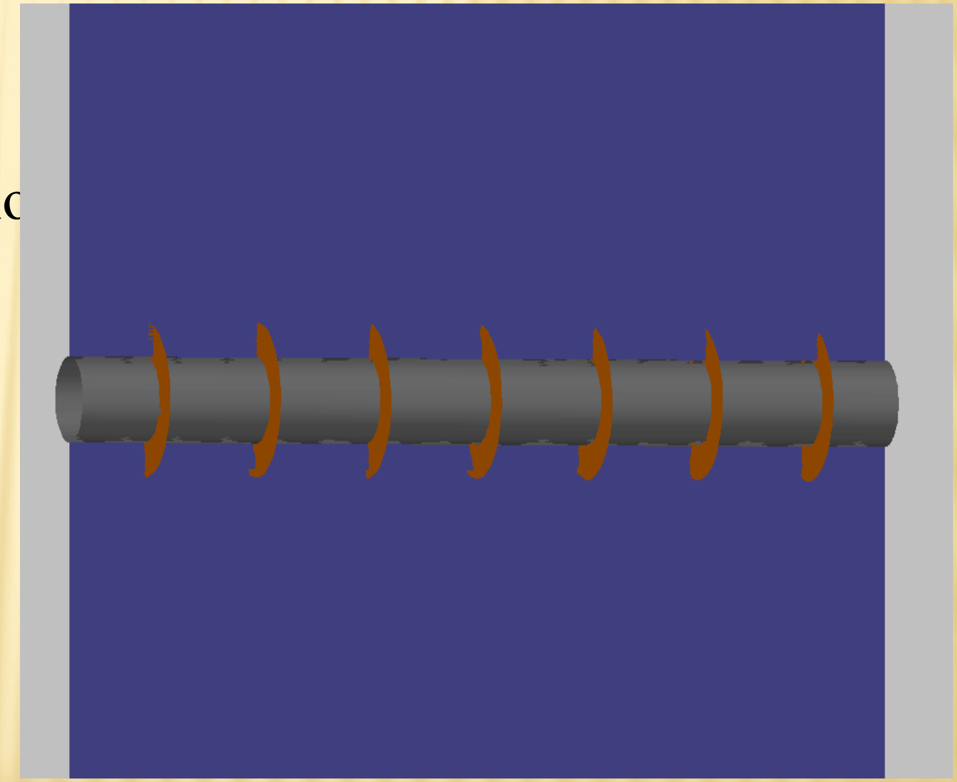
TES Case



TMS Case

TES CASE

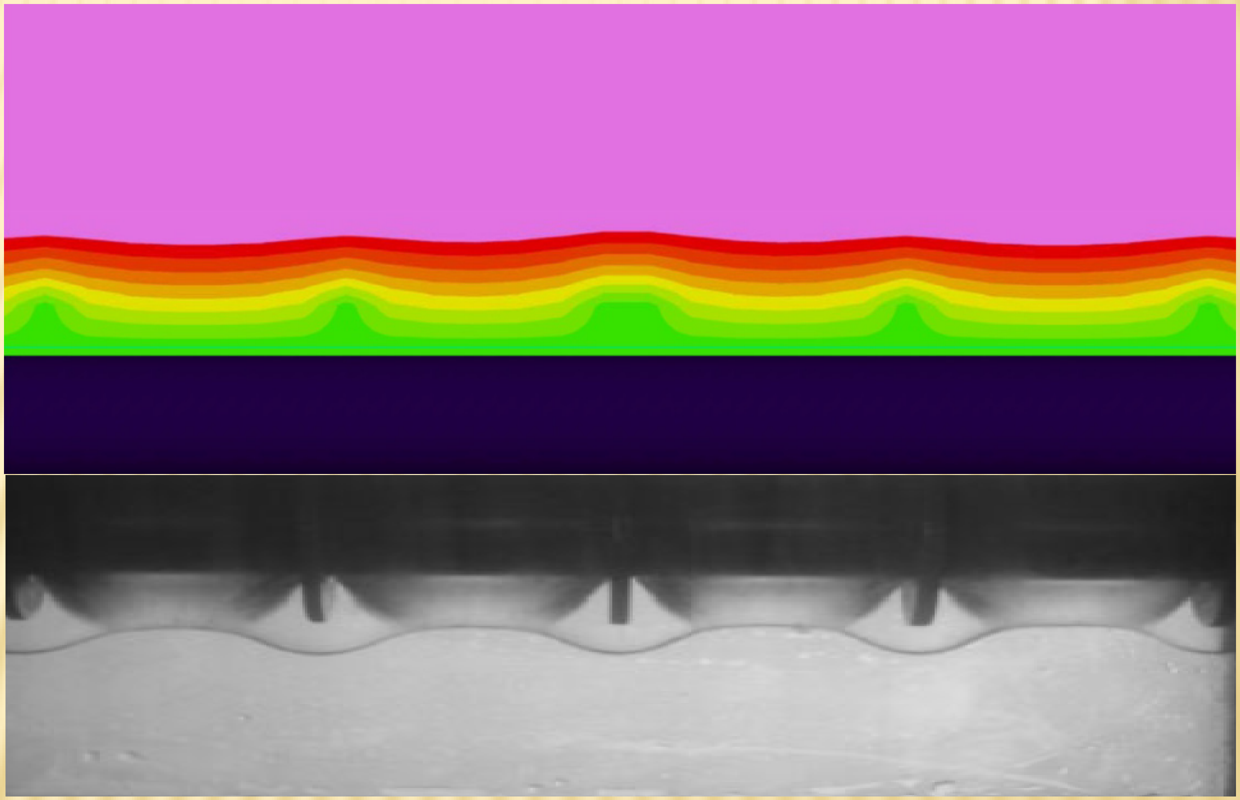
- PCM-based thermal energy storage system
  - Water freezing was studied
  - Initial Temperature of 0.3 °C
  - Bronze finned tube – cold source
  - Ethyl Alcohol as a coolant is flo
    - At a temperature range of



Model of thermal energy storage system

TES CASE – RESULTS – 1

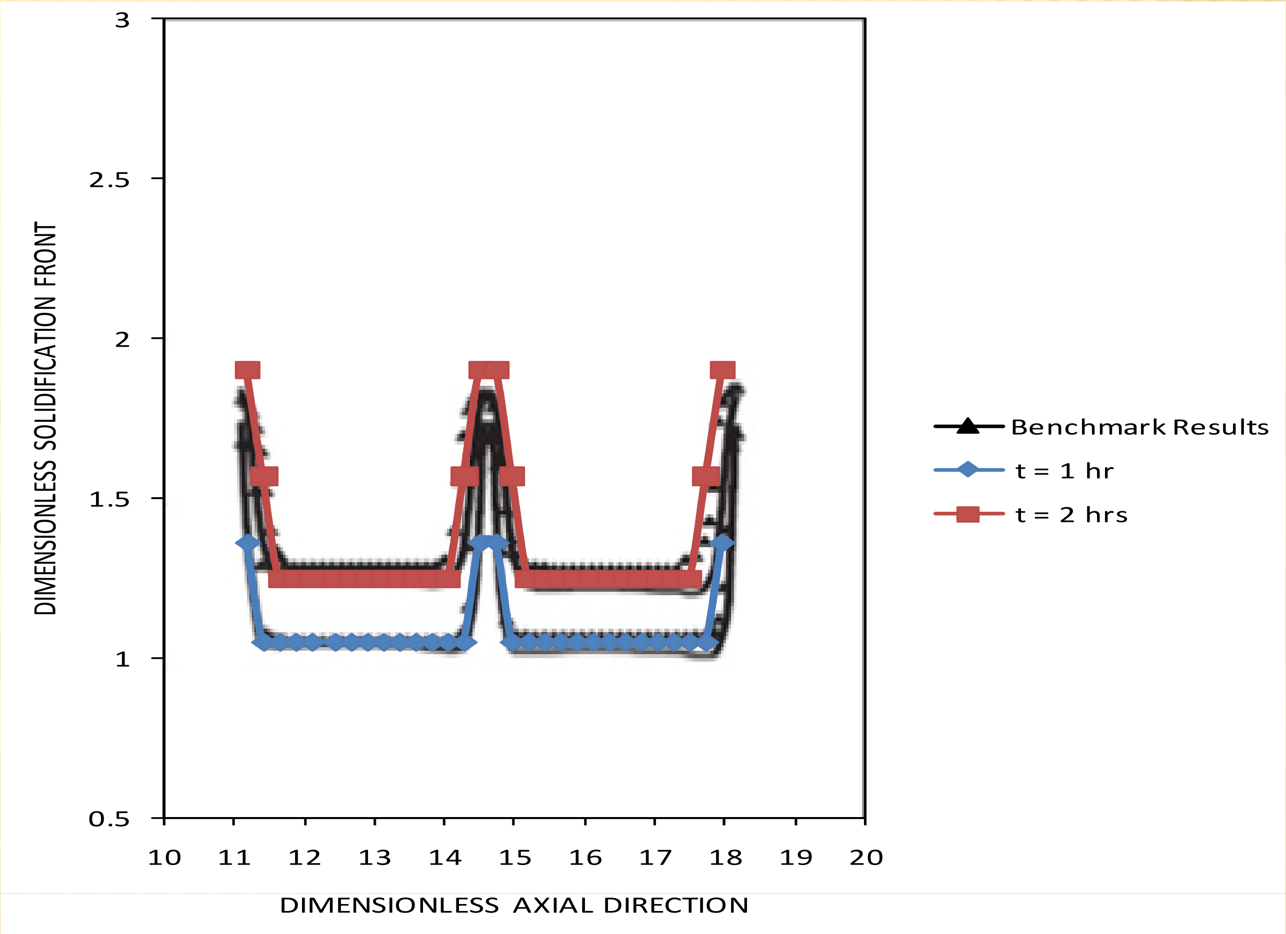
- Comparison and Analysis



Water solidification next to finned tube after 2 hour

TES CASE – RESULTS – 2

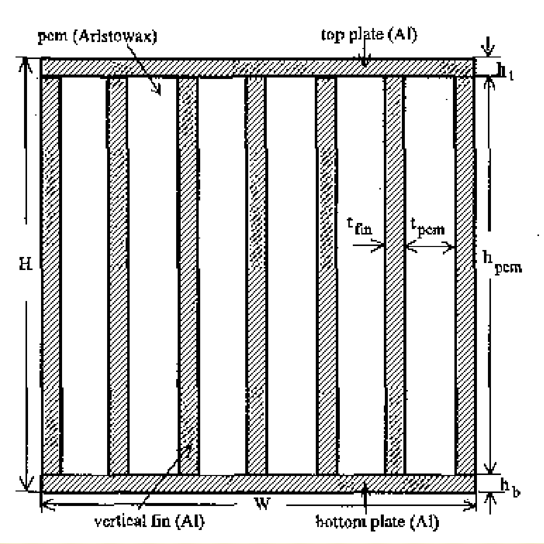
- Comparison and Analysis

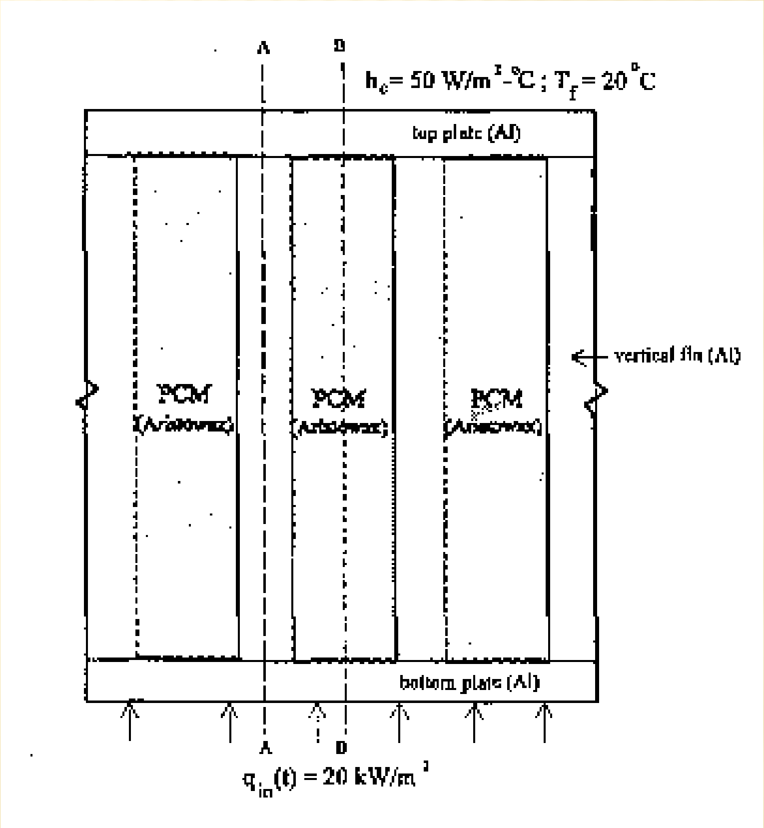


solidification front propagation

TMS CASE

- PCM-based cooling arrangement
  - built of aluminum fins
  - PCM - Aristowax
  - Considered convective cooling of
    - $h_c = 50\ W/m^2\text{-}^oC$ on the top
  - Applied study heat load of
    - q in = 20 kW/m2 to the bottom

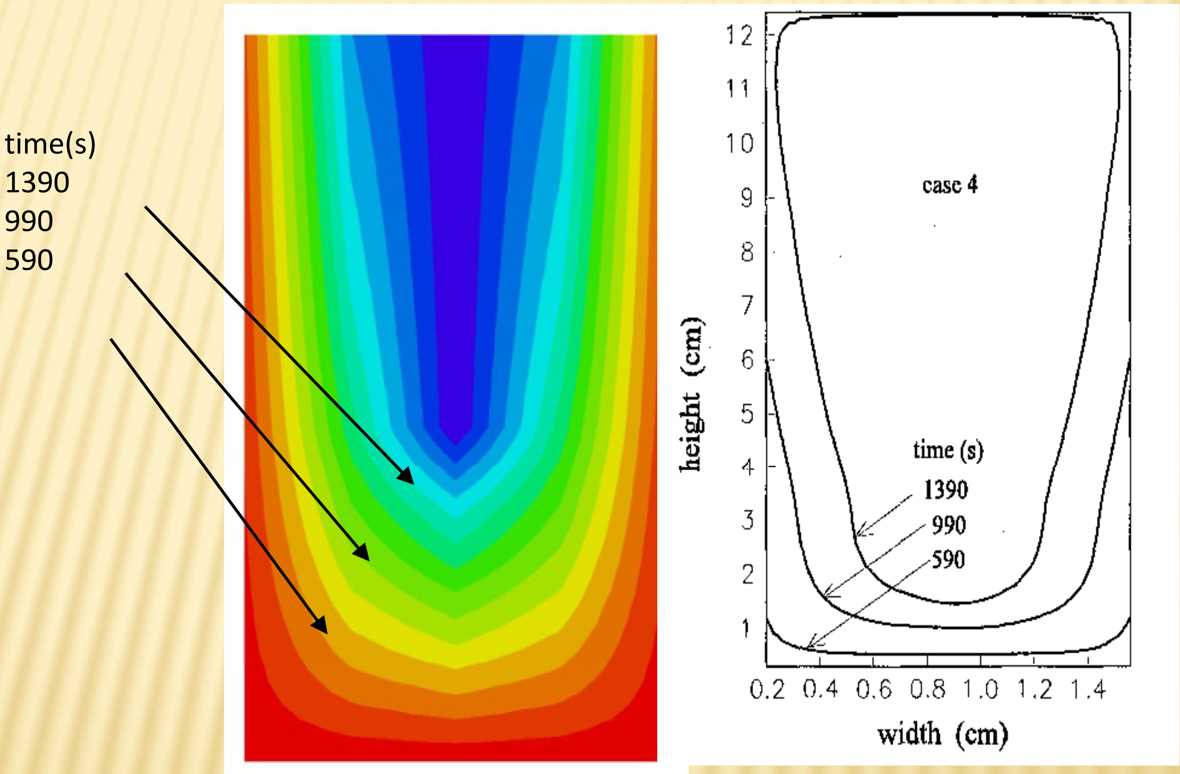




A simple schematic of the device

TMS CASE – RESULTS – 1

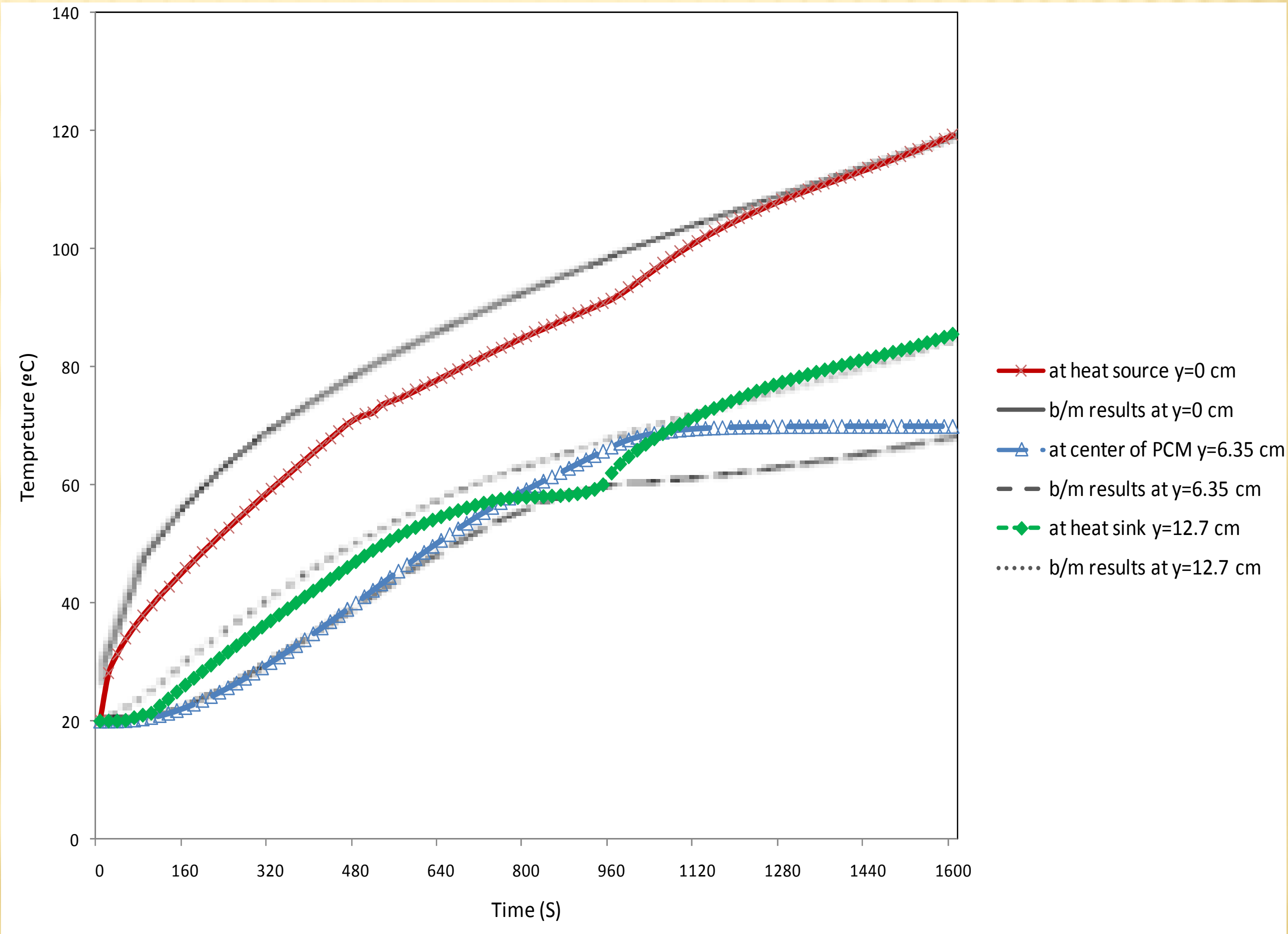
- Comparison and Analysis



Propagation of the melt-front into the PCM with time

TMS CASE – RESULTS – 2

- Comparison and Analysis



Compared results between benchmark and new simulation

CASE STUDY CONCLUSION

- In TES Case
  - PCM solidified around the finned tube
  - Model verified
- In TMS Case
  - Simulation results match benchmark results
  - Slightly different in the beginning but converged to the end
  - Acceptable error, about 5-10 %

APPLICATION – BACKGROUND

- Importance of designing thermal shield
  - Used to absorb and to store thermal energy
  - Convert the thermal energy into electrical power
  - Maintain the temperature of the heat shield below melting point
  - Used as a main component for controlling vehicle temperature

MATERIAL SELECTION

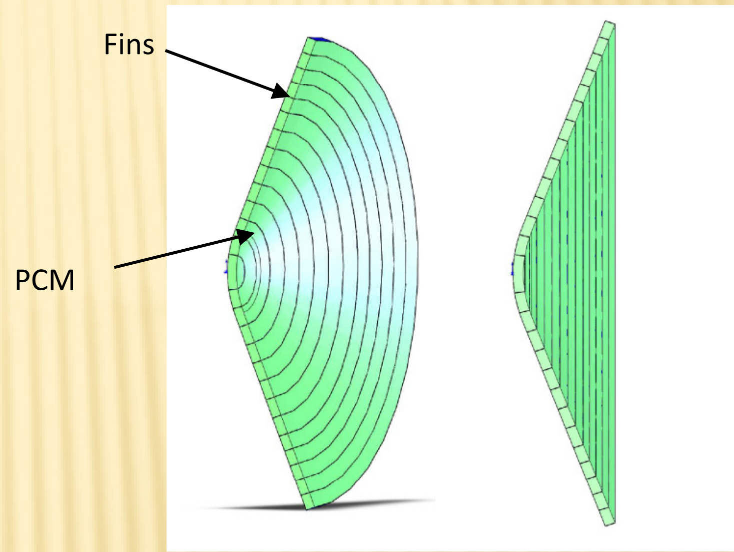
- Important Parameters for PCM selection:
  - Density, Heat of fusion, Heat Capacity, Melting Pt., Boiling Pt.
- Potential materials:
  - High and Low Temperature PCM candidates:

High Temperature PCMs		Low Temperature PCMs	
Material	*Melting point ℃*	*Material*	*Melting point ℃*
LiF	848.2	AlBr3	97.5
LiBr3	552	GaI3	212
CuCl	430	TaCl5	216
CsNO3	414	BiBr3	218

PARAMETERS OF THE MODEL

Details of the initial designed model

$t_{fin(cm)}$	$t_{heat\ shield(cm)}$	$t_{PCM(cm)}$	$d\_1_{fin(cm)}$
0.2	0.3	4.7	10
$T_{outside(ºC)}$	$T_{initial(ºC)}$	$q_{in-peak(W/cm^2)}$	$d\_2_{fin(cm)}$
-150	0	119	5

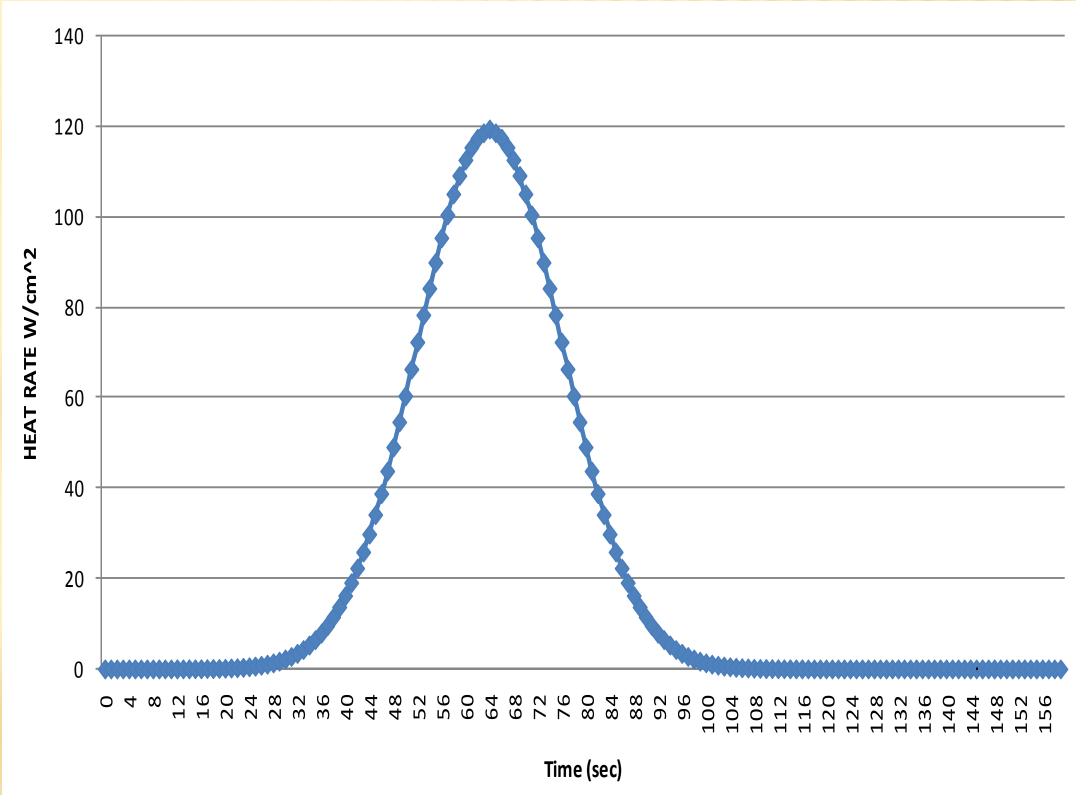


Properties of materials used in the design

Property	*Carbon-Carbon*	*LiF*
Density-solid, kg/m^3	1800	2640
Density-liquid, kg/m^3	---	2640
Specific heat-solid, J/kg-K	2102.96	1548.08
Heat of fusion, kJ/kg	---	1044.4
Melt-temperature, ºC	3500	848.4
Conductivity-solid, W/m-K	250	11.3

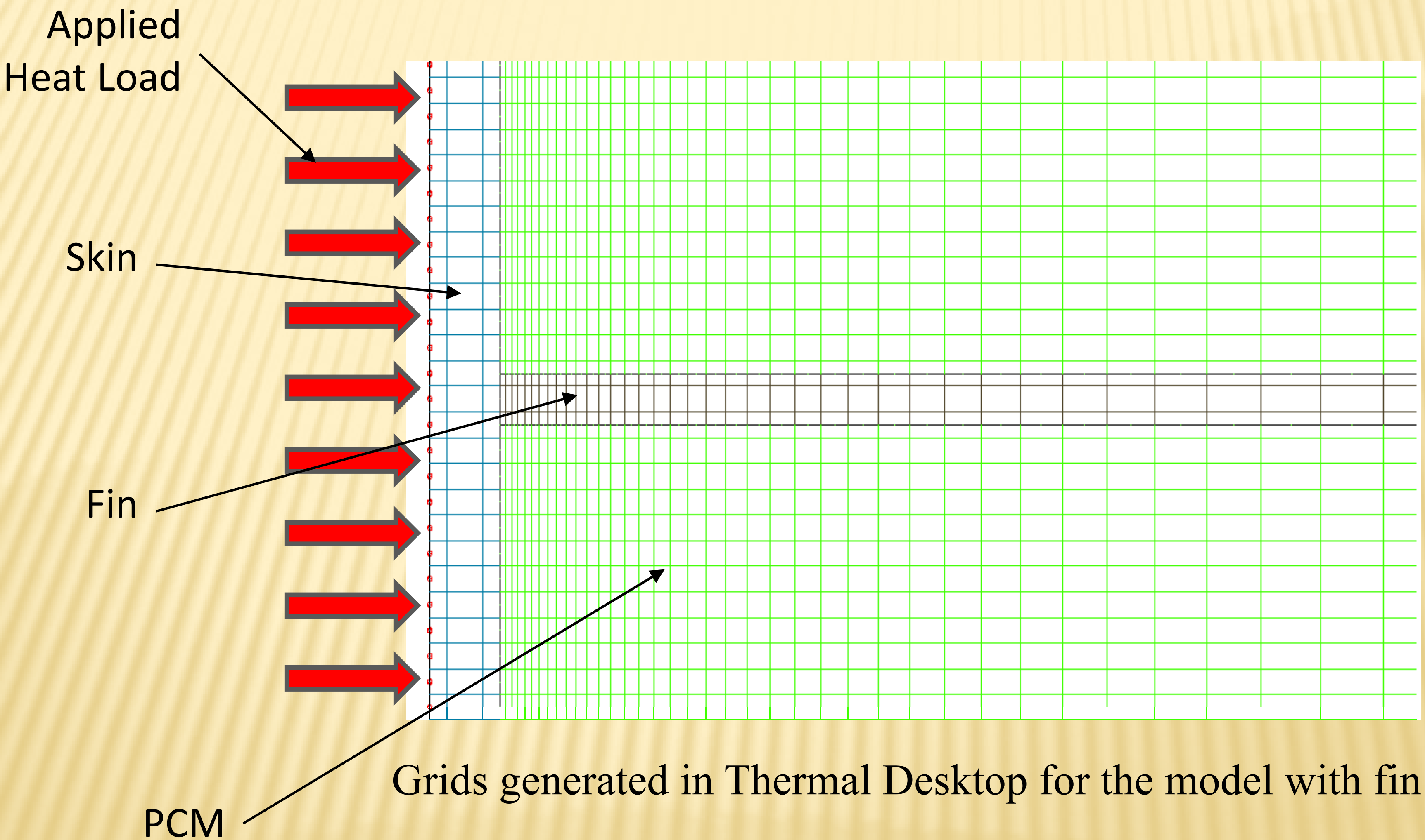
HEAT LOAD

- Considered only the maximum heat load
- Applied to stagnation point only
- Gaussian distribution of the heat load vs. time



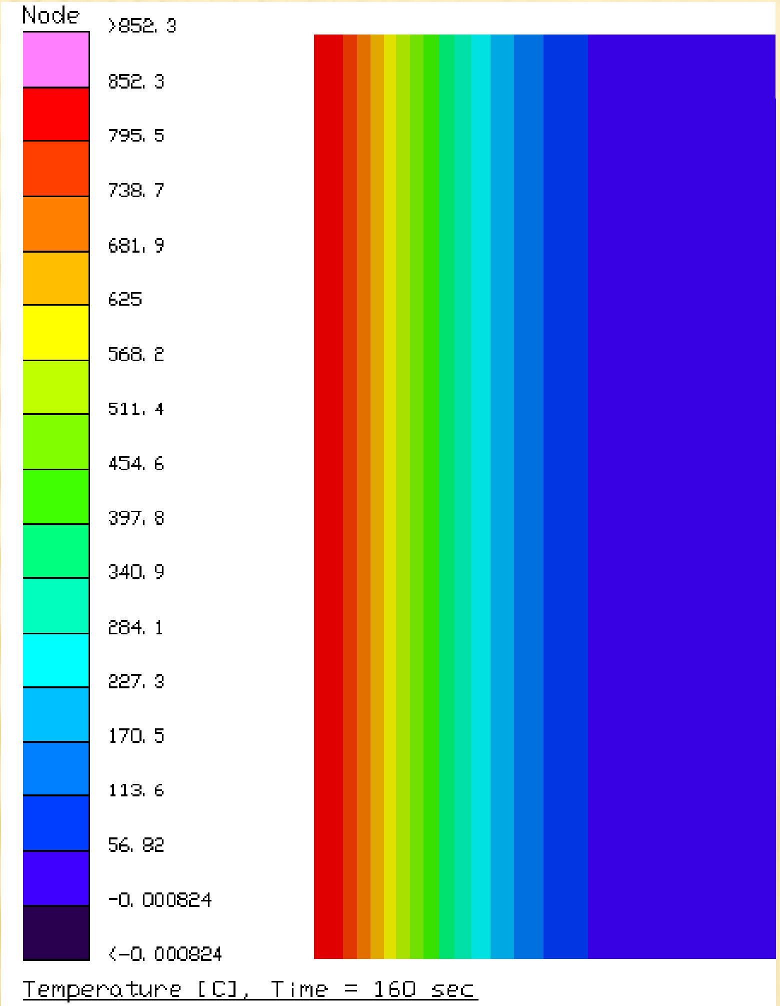
test case heating pulse

MESH

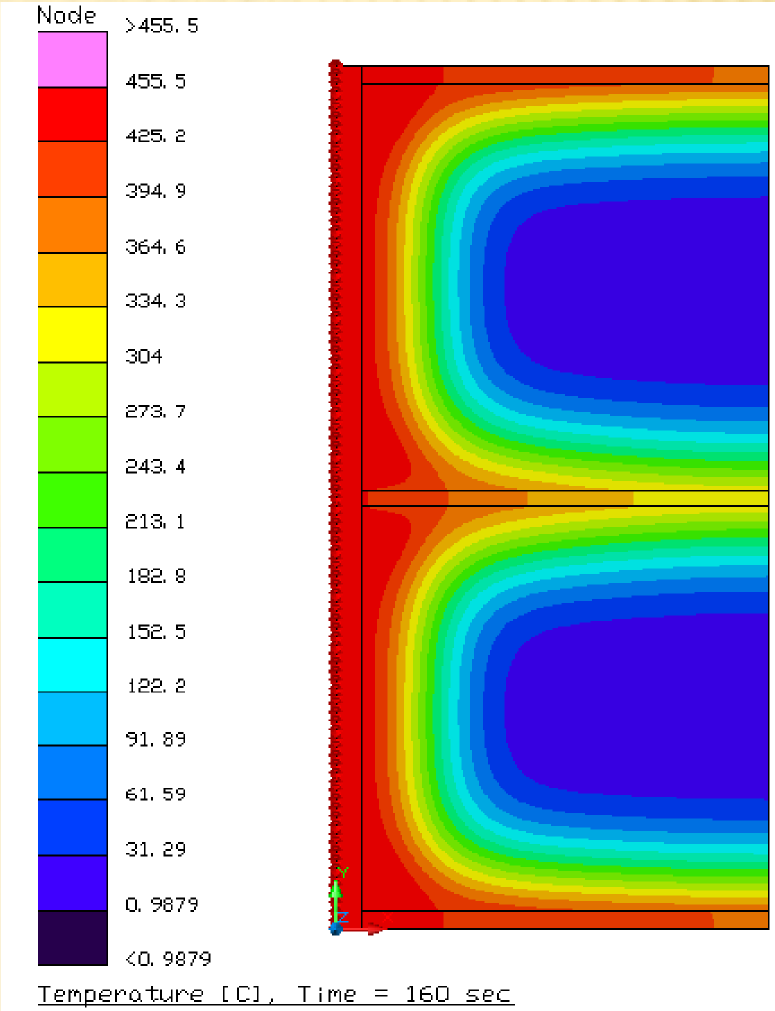


Grids generated in Thermal Desktop for the model with fin

TEMPERATURE DISTRIBUTION

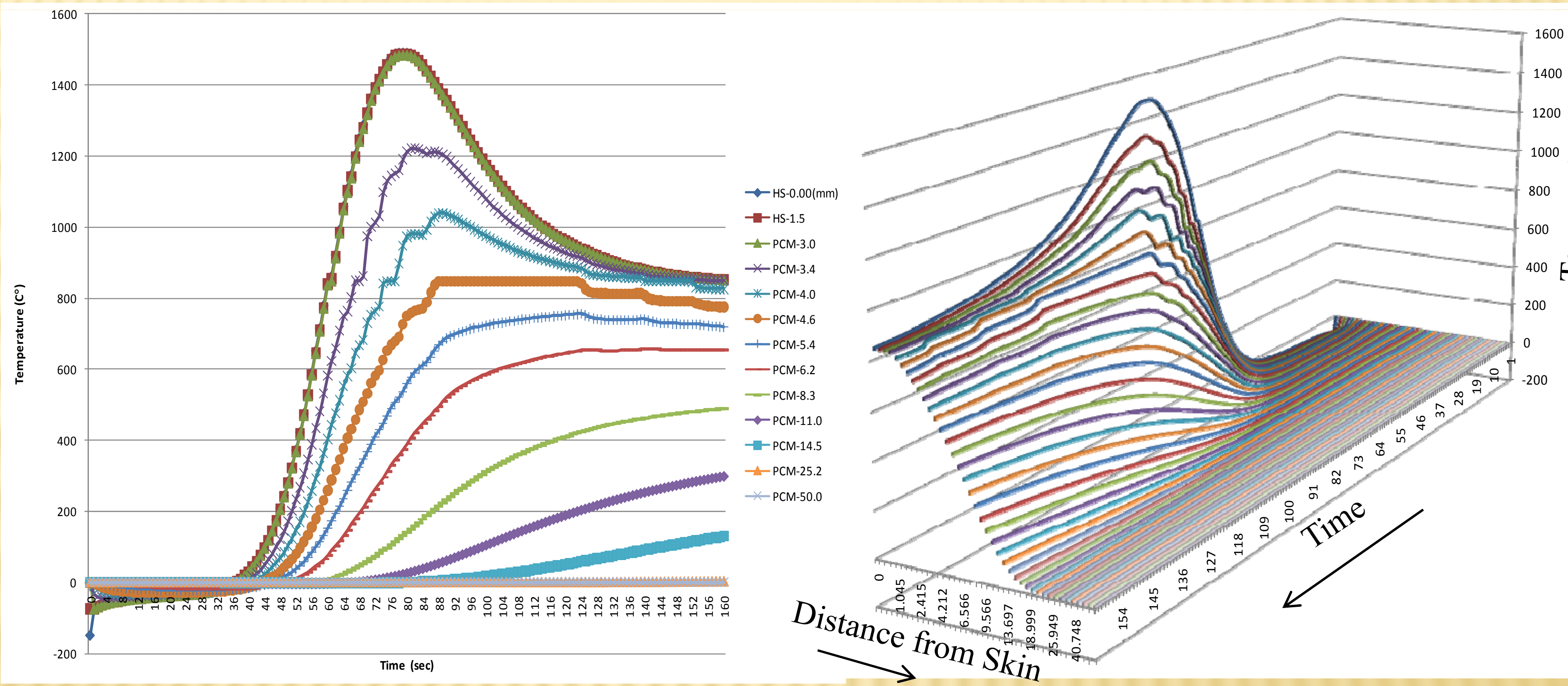


No Fin



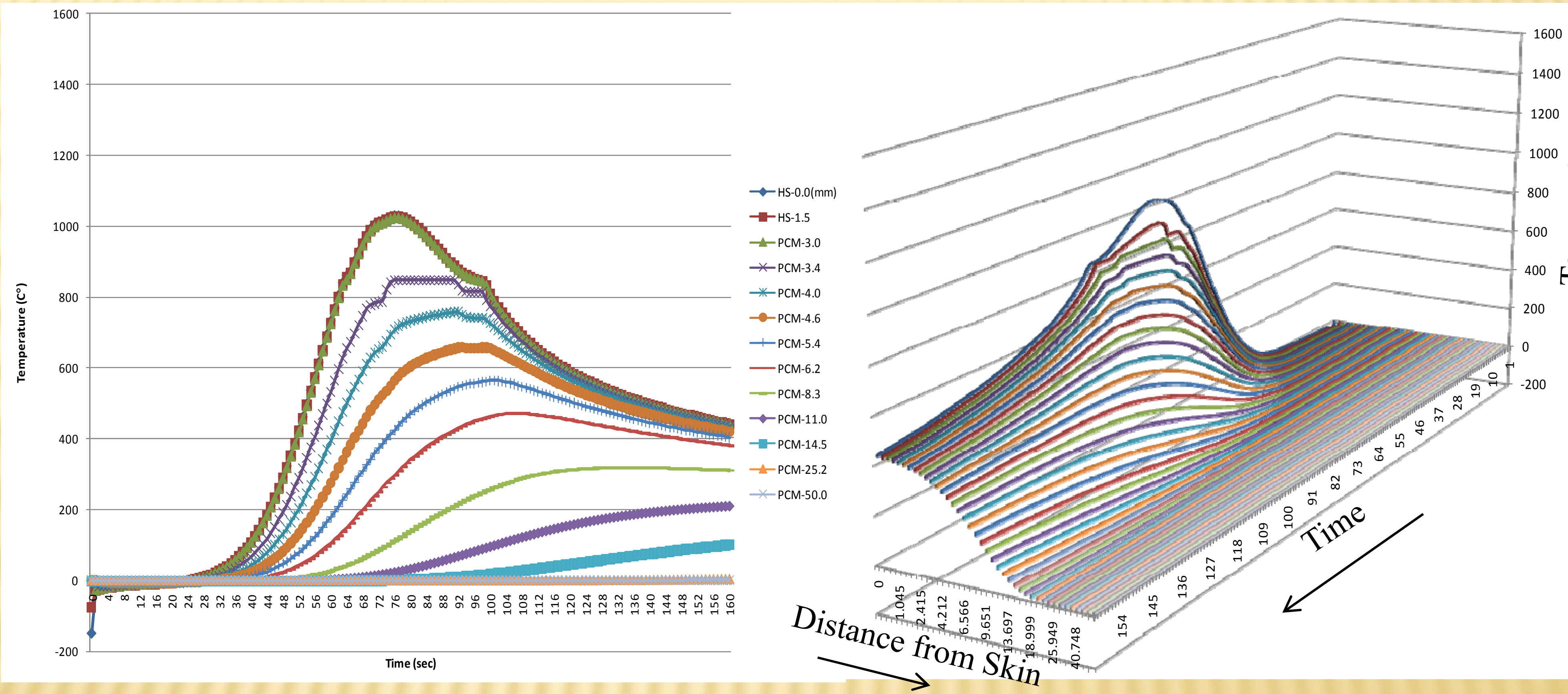
With Fins

RESULTS – 1



Temperature distribution at different depth into PCM
for model with no fin

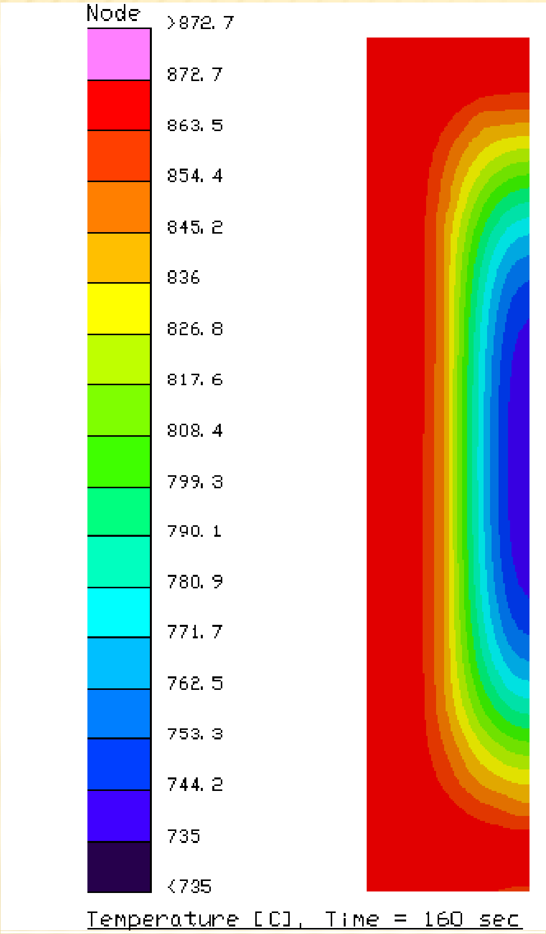
RESULTS – 2

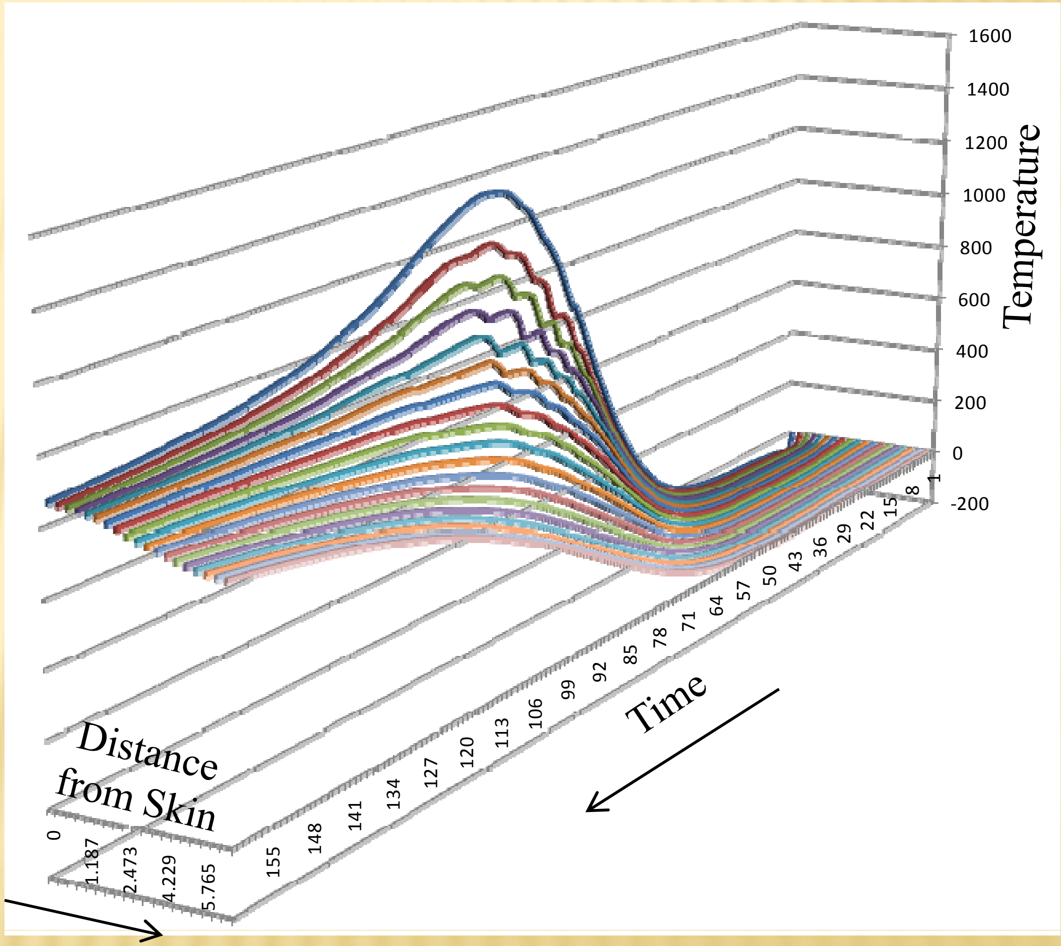


Temperature distribution at different depth into PCM
distance between fins 5 cm

OPTIMIZATION

- 80% reduction of PCM thickness





Demonstration of propagation of the temperature into PCM distance between fins 5 cm for optimized design

CONCLUSION

- The incident energy can be stored
- Lithium Fluoride (LiF) was selected as PCM
  - High latent heat of fusion
  - Enables it to absorb a significant amount of thermal energy
  - The total energy absorbed by the model: 33.593 kJ
- Total amount of energy absorbed by the PCM shielding: 91.3 MJ
  - Equivalent to 25.36 kWh.
  - Specific energy density of the typical Lithium-ion battery is about 150-200 Wh/kg

QUESTIONS