Western Norway University of Applied Sciences

UNIVERSITY OF BERGEN

Proton Computed Tomography

WP5,Mechanical:

Detector cooling potential, Heat transfer approach

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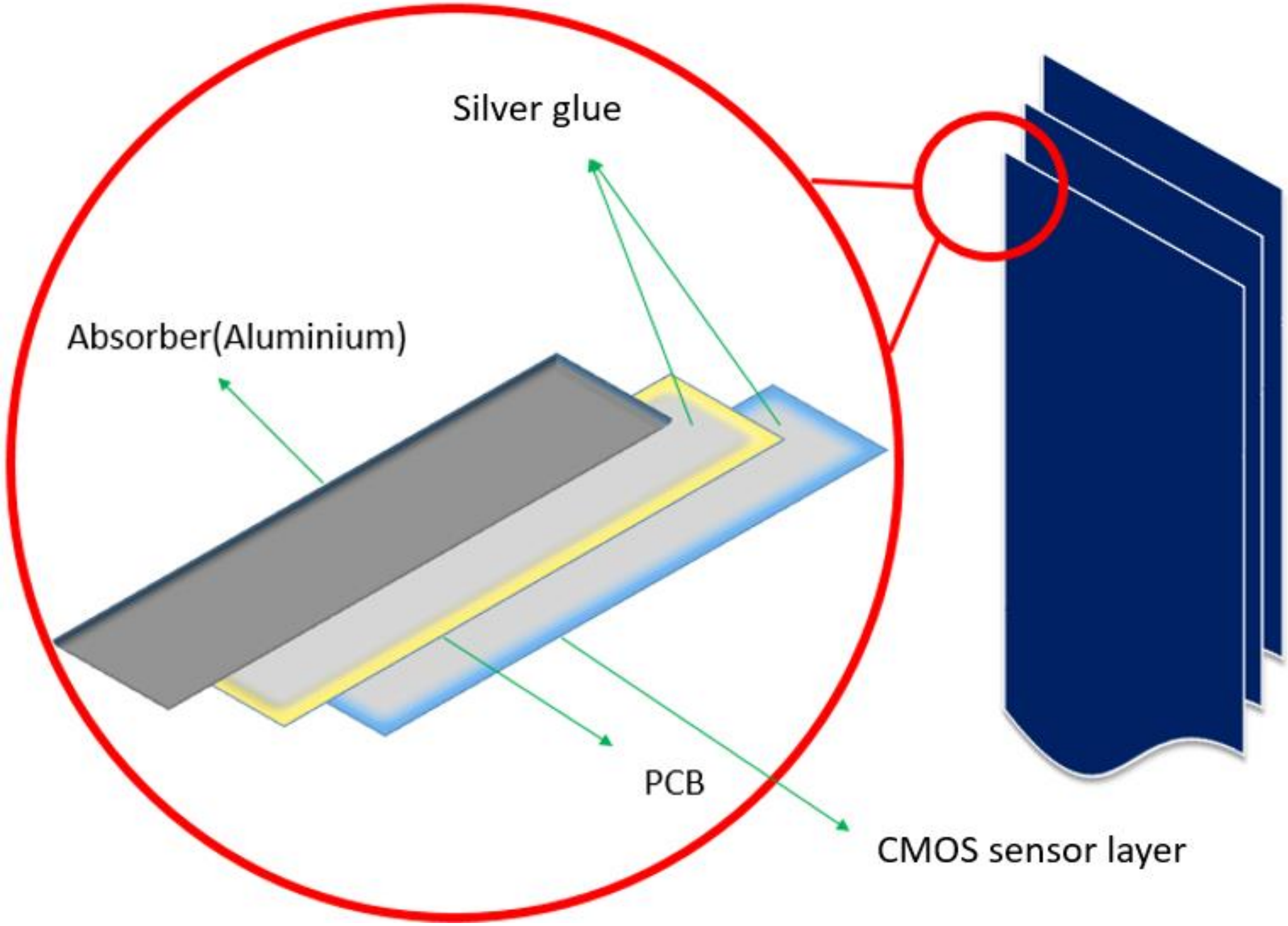
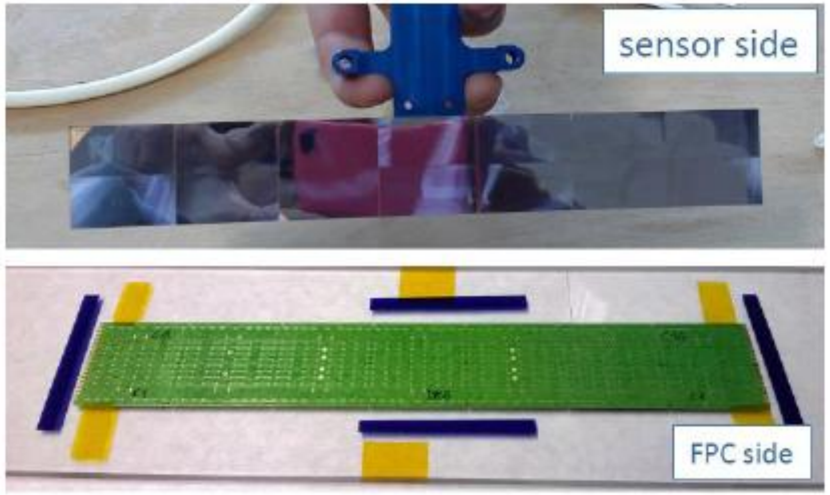
Potential cooling schemes





Study and simulation analysis of heat distribution field:

- In plate heat distribution
  - ✓ Geometry effect (length-width proportion)

$q = k\ S\ \Delta T_{overall}$

S = Shape factor

2D Geometries

Very comprehensive summary of shape factors for a large variety of geometries is given by Rohsenow and Hahne and Grigull (Heat transfer books)

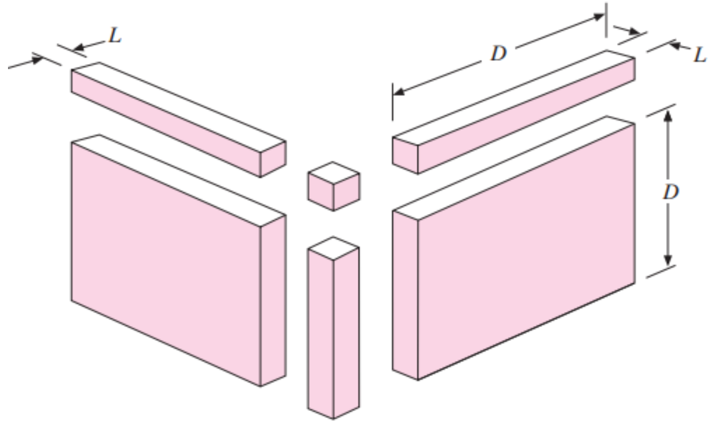
3D geometries

S_{wall} = A /L S_{edge} = 0.54D S_{corner} = 0.15L

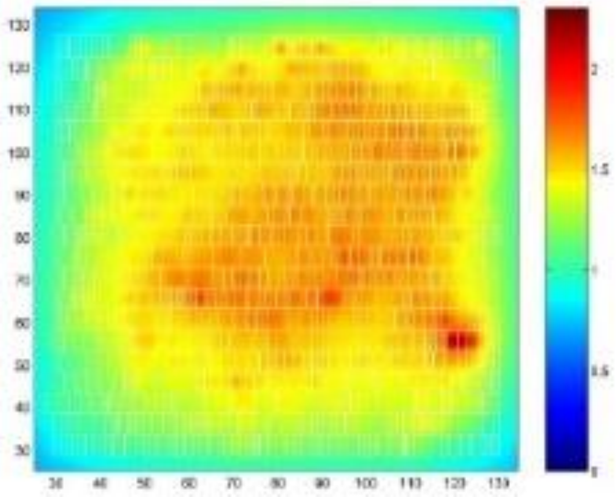
A = Area of wall

L = Wall thickness

D = Length of edge



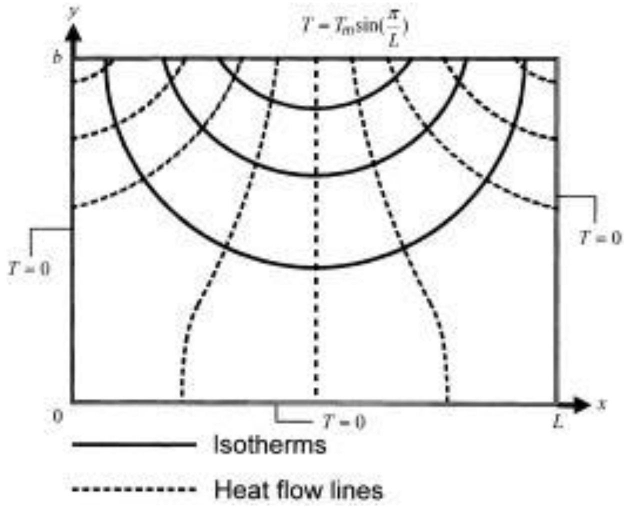
✓ Temperature gradient & heat transfer rate



a. High energy proton beams colliding location/ elec
Circuit path on PCB and heat generation spots
- energy gradient causes
- non-uniform temperature distribution

✓ Increasing conductivity of plate

a. Material/Mechanical properties of PCB, Absorber:
Higher conductivity (k) ⟺ Higher rate of heat transfer



✓ Heat spots and critical areas

✓ Effects of boundary conditions as cold sources

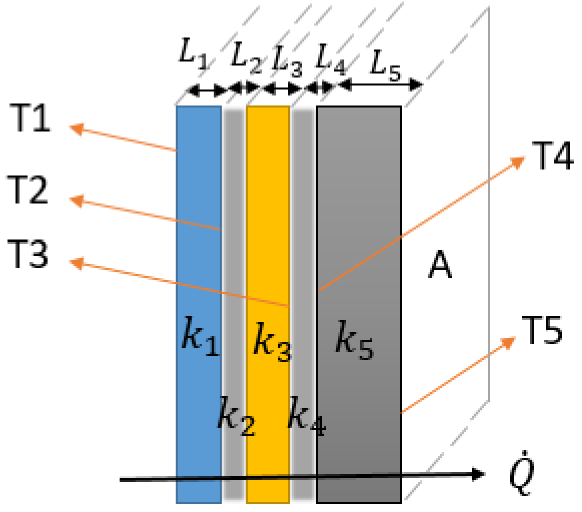
- Heat transfer through stave layers

  - ✓ Thermal conductivity of multilayer bodies(R_{Totall}):

    Sensors, PCB, Silver glue, absurber

    R=R1+R2+R3+R4+R5 = $\frac{L_1}{k_1 A_1} + \frac{L_2}{k_2 A_2} + \frac{L_3}{k_3 A_3} + \frac{L_4}{k_4 A_4} + \frac{L_5}{k_5 A_5}$

    ↑ k , A ⟷ R ↓



  - ✓ Temperature gradient & rate of heat transfer

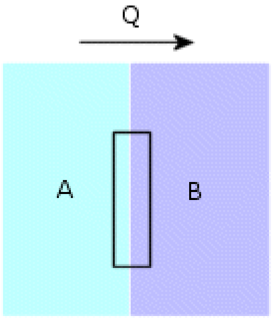
    $\dot{Q} = \frac{\Delta T}{R}$

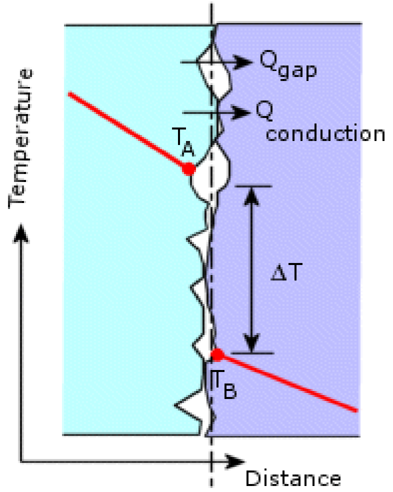
    ↑ ΔT ⟷ $\dot{Q}$ ↑

  - ✓ Thickness layers sensitivity

    ↑ L ⟷ $\dot{Q}$ ↓

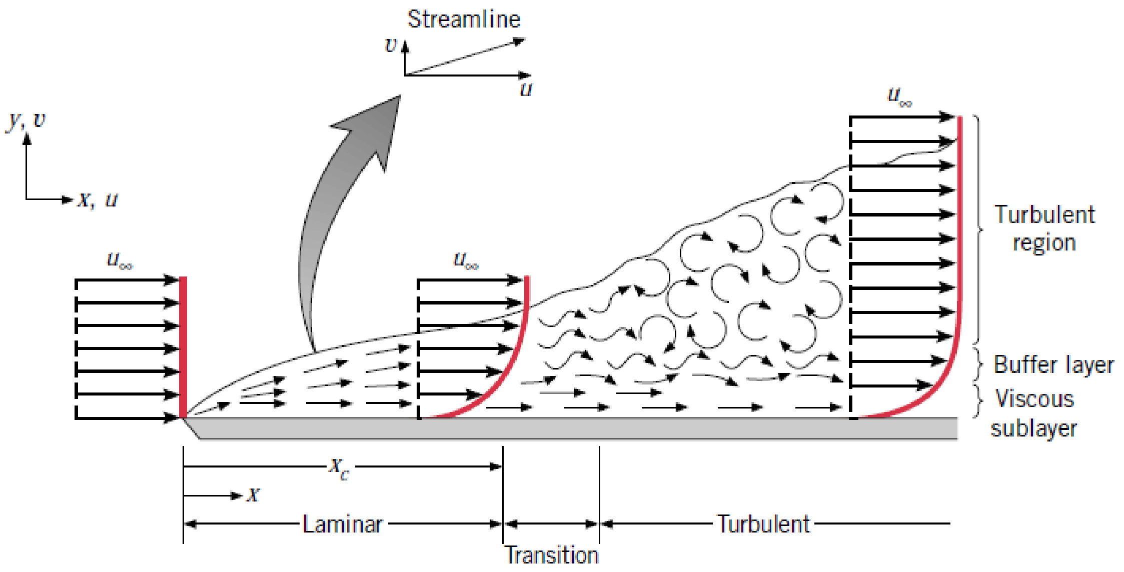
  - ✓ Critical layer in case of mechanical properties and heat capasity, deformation?!
  - ✓ Thermal contact resistance challenge

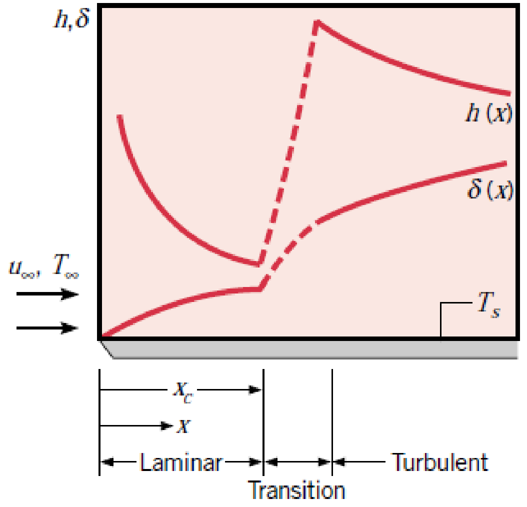




- Heat transfer between layers

  ✓ Feasibility of air cooling convection system





  ✓ Air gap sensitivity analysis → Boundary layer interaction

  ✓ Convection heat transfer rate, thermal gradient in air between layers

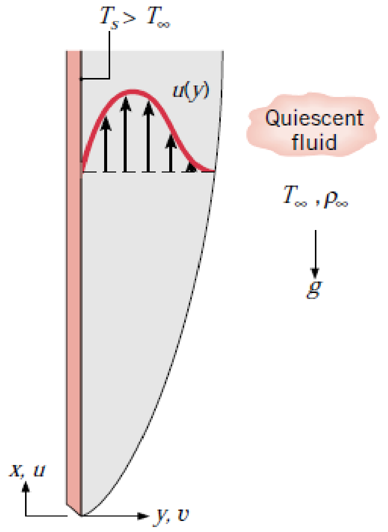
✓ Feasibility of various Convection heatr transfer:

a. Force convection   q= hA ΔT

- Reynolds Number(Re)- ratio of inertia to viscous force-
- Nusselt Number(Nu) – Thermal Boundary layer to velocity boundary layer

b. Free/Natural convection

b.1: Laminar Flow

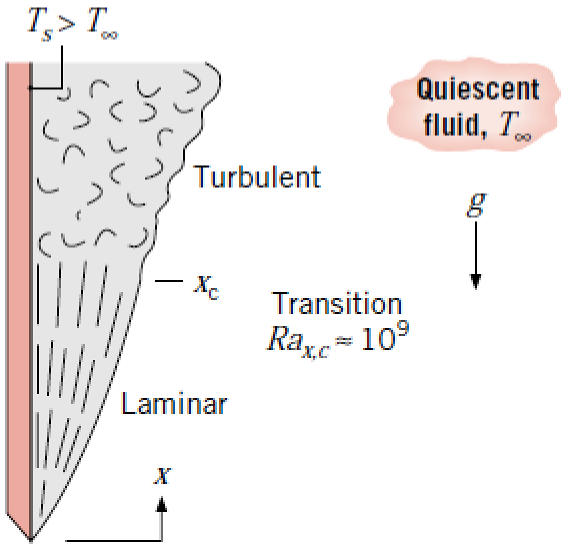


- Bouyancy Forces
- Volumetric thermal expansion coeficient (β)
- Nusselt Number(Nu)

Nu=f(Gr,Pr) = $\frac{3}{4}\left(\frac{Gr_x}{4}\right)^{\frac{1}{4}} g(Pr)$

- Grashof Number (Gr)
- Prandtle Number (Pr)

b.2: Turbulence Flow

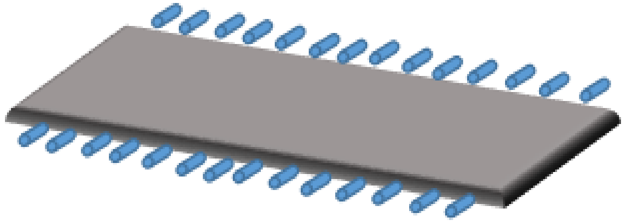


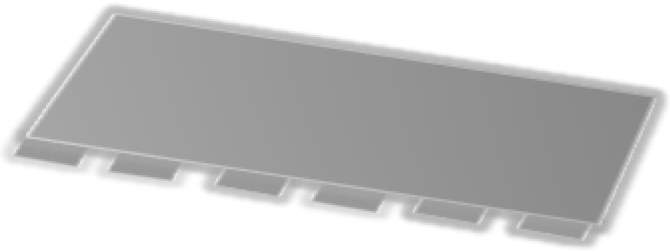
- Bouyancy Forces
- Volumetric thermal expansion coeficient (β)
- Nusselt Number(Nu)

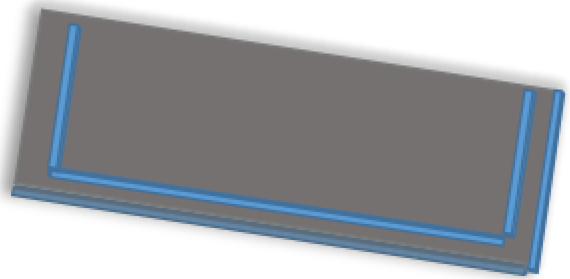
Nu=f(Ra,Pr) = $\left\{ \{0.825 + \frac{0.387 Ra^{\frac{1}{6}}}{[1+(^{0.492}/_{Pr})^{9/16}]^{8/27}} \right\}^2$

- Rayleigh Number (Ra)
- Prandtle Number (Pr)
- Thermal Diffusivity (α)

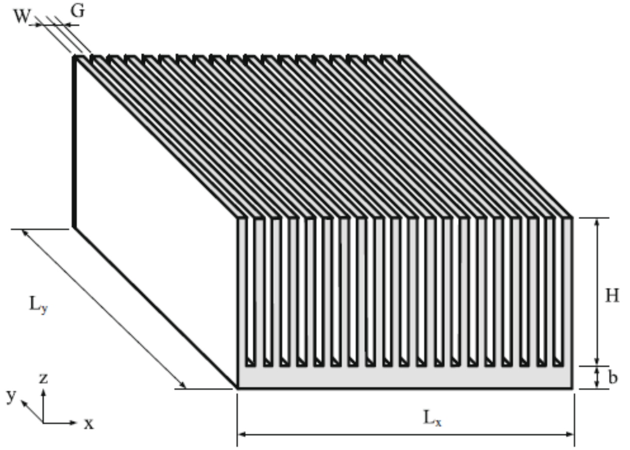
- ✓ Ventilation feasibility between air gaps and surrounding inside the calorimeter box
- ✓ Feasibility of micro bodies (e.g rectangular or cylinderical) pin on absorber free side to work as heat sink to increase convection heat transfer rate





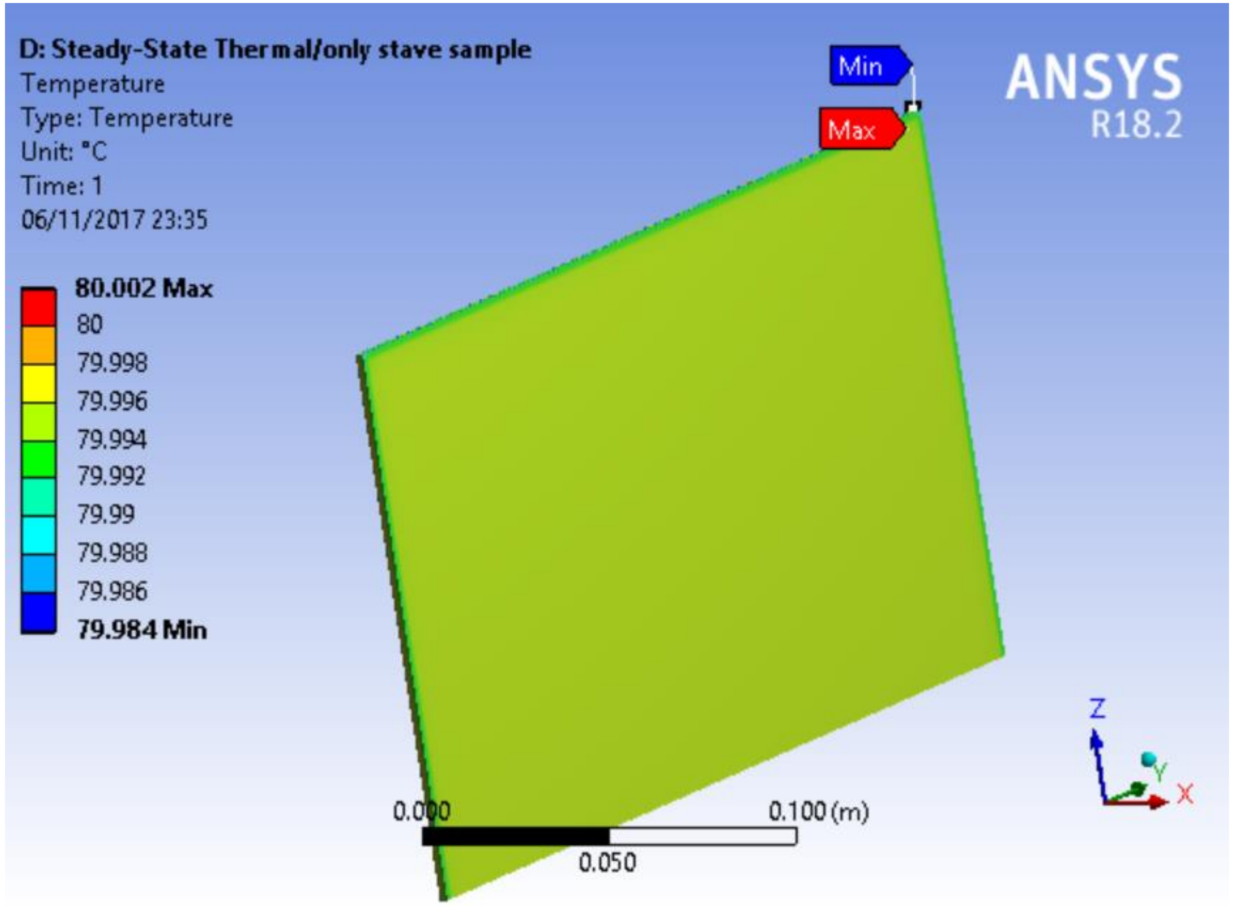


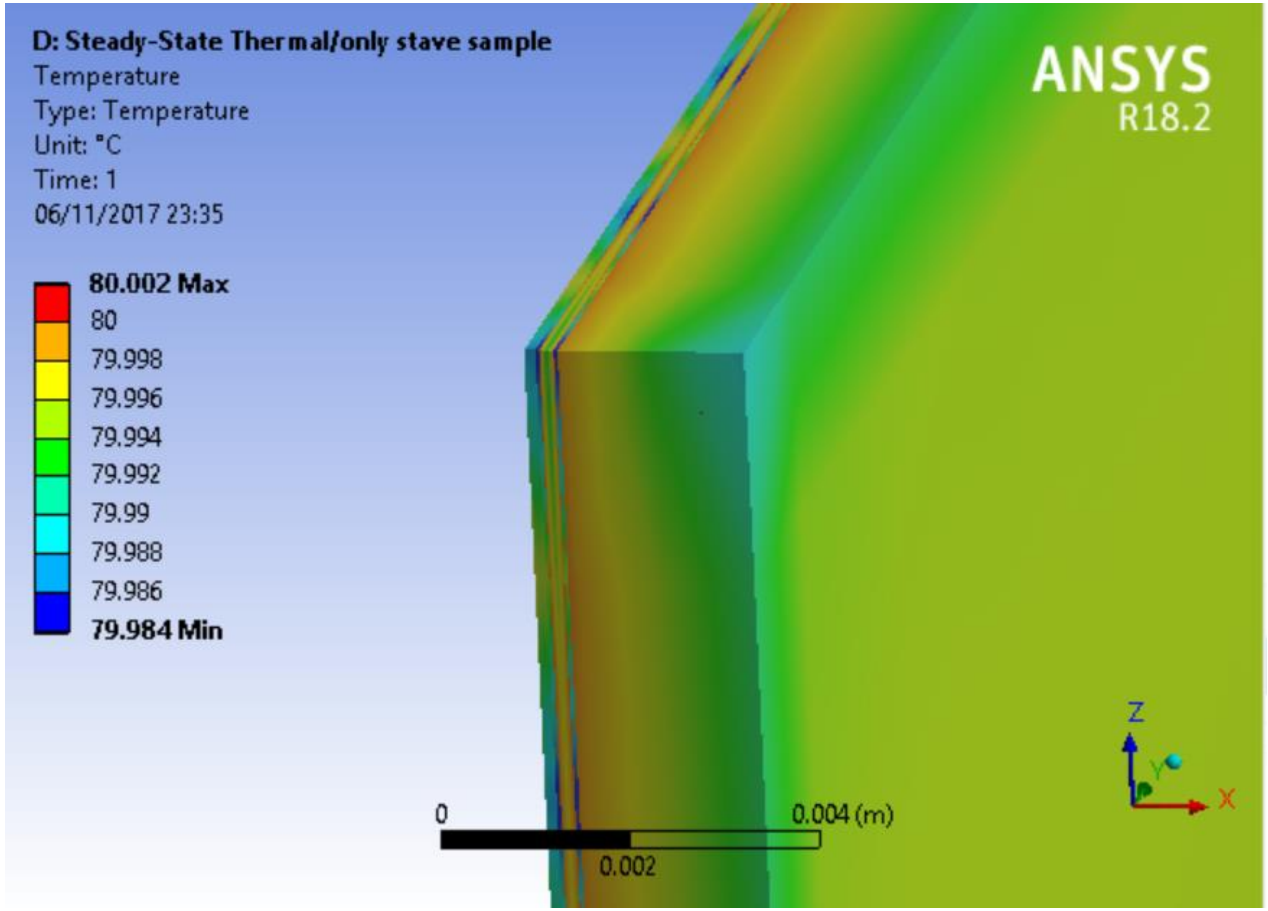
- ✓ Dual purpose design for calorimeter structure, with opportunity to work as support structure or stave rack/casing and also heat sink



In plate temperature distribution & temperature diffusion through the stave layers and:

- free convection
- 5000 W/m3 heat generation in PCB





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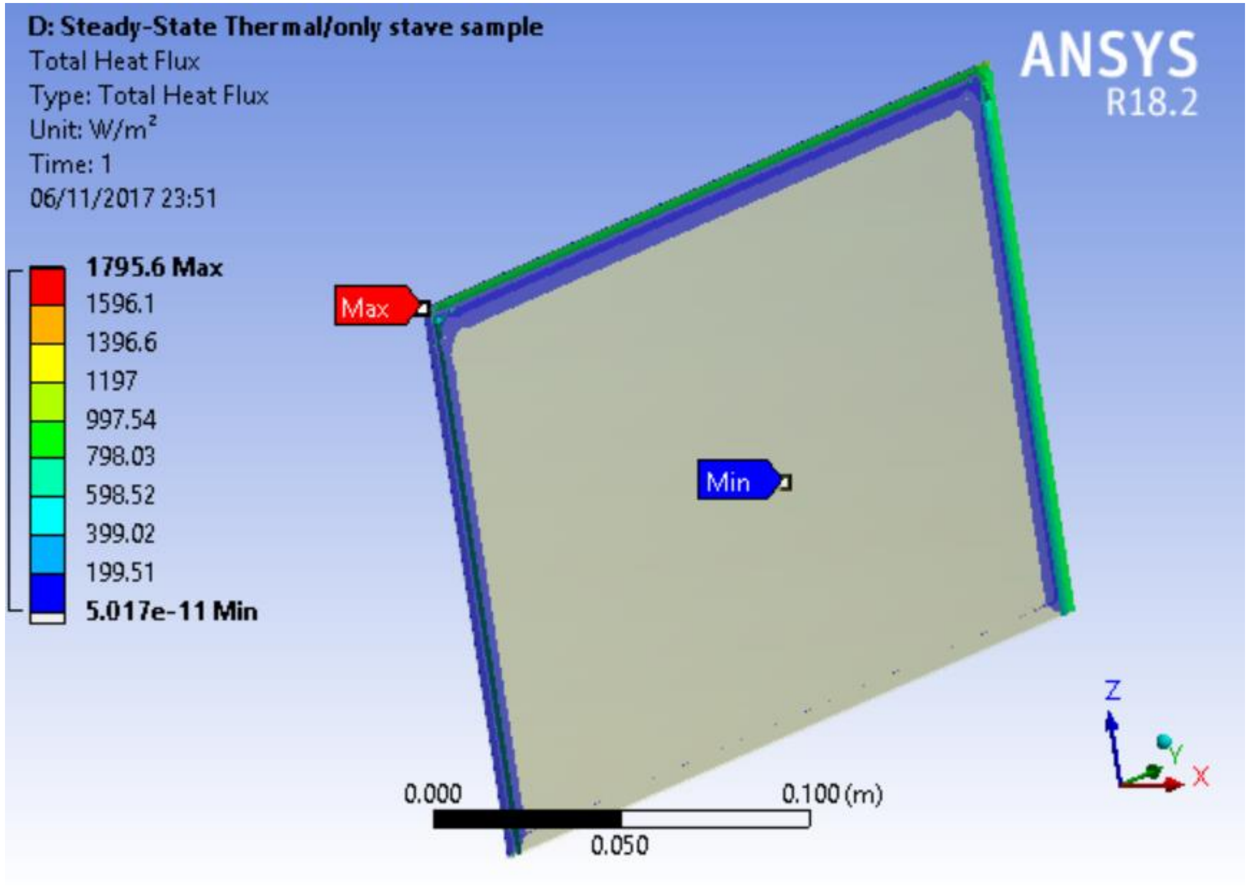
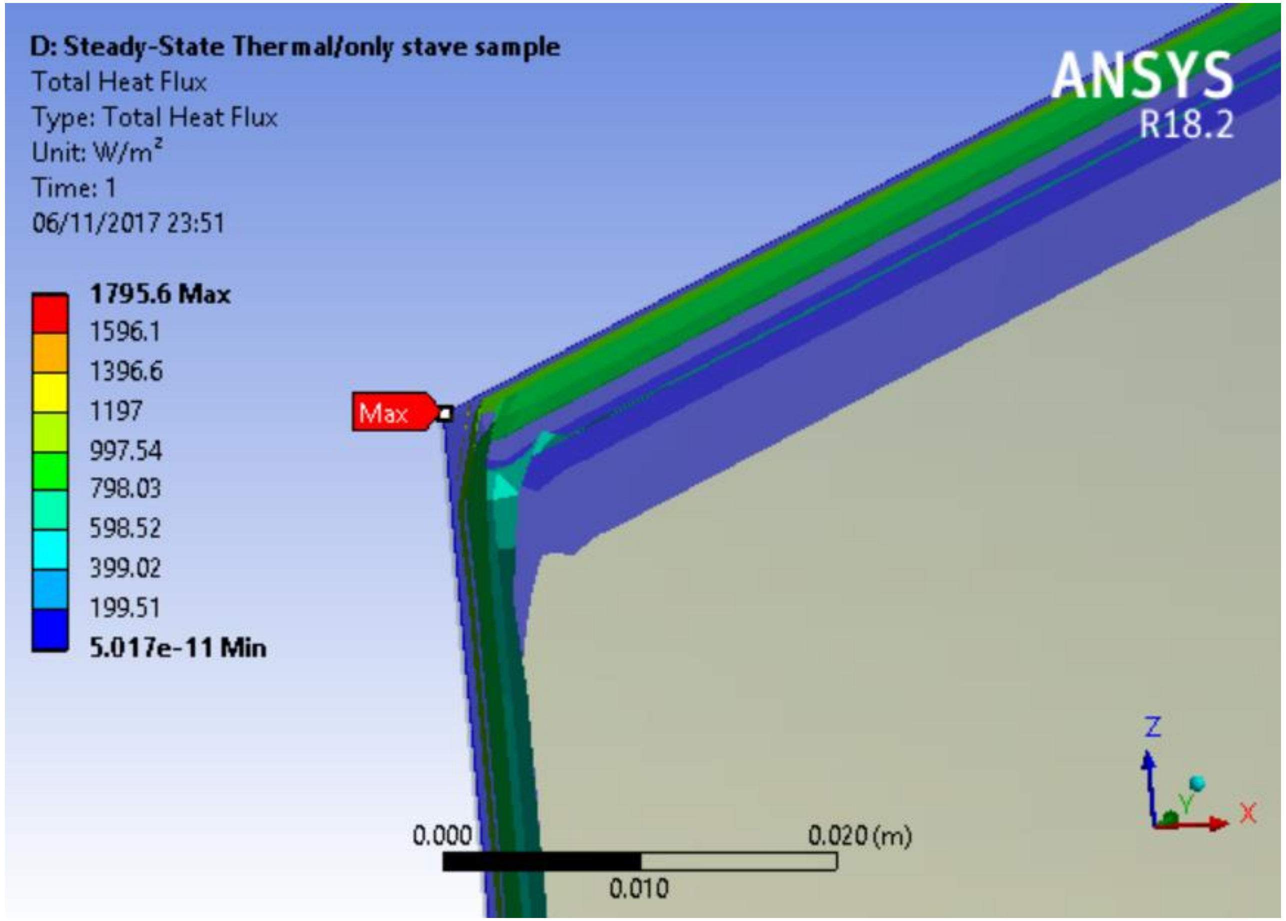
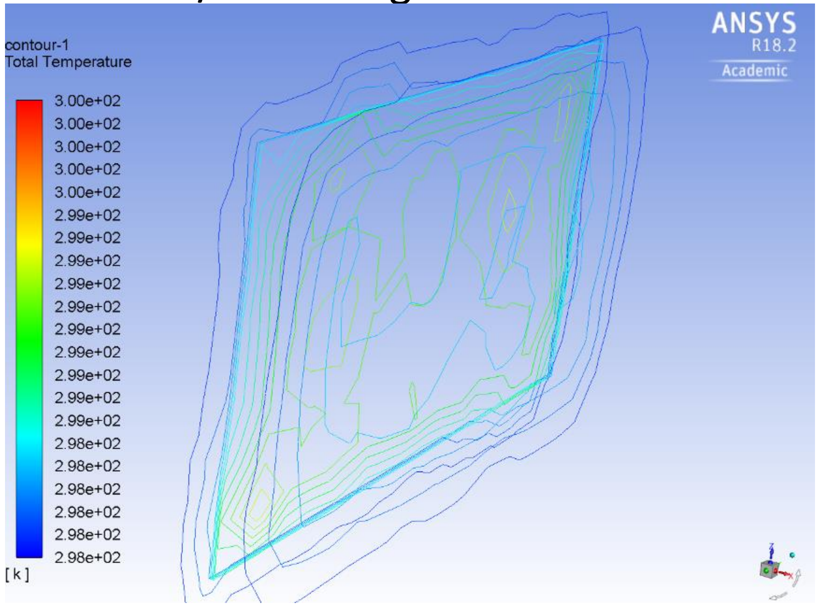
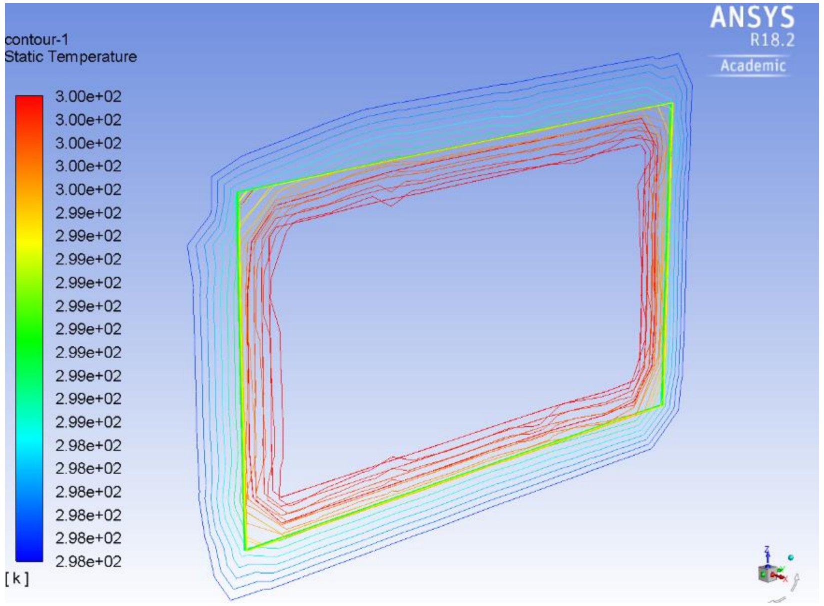


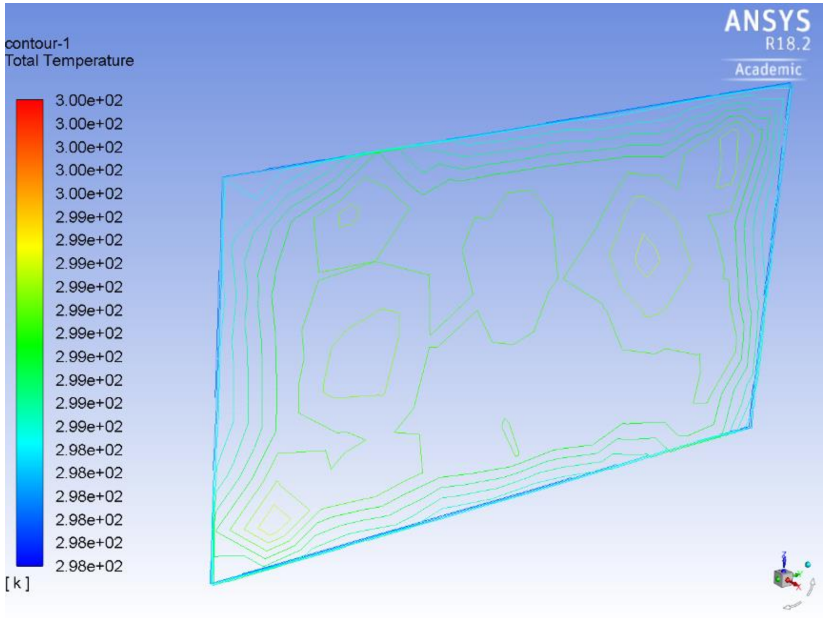


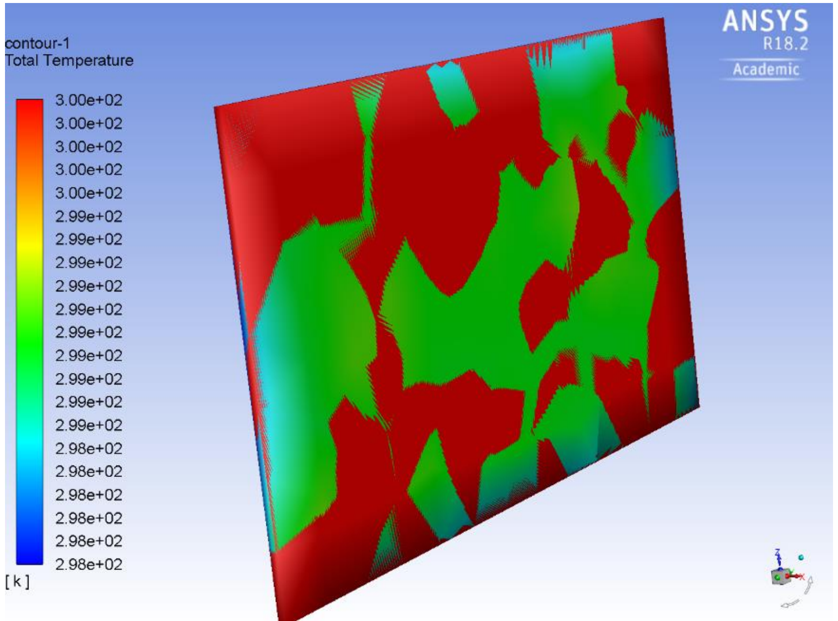
Heat transfer to surroundibg (Convection)& temperature distribution :

- free convection
- 15000 W/m3 heat generation in PCB









Heat transfer to surroundibg (Convection)& temperature distribution :

- force convection (air velocity=0.75 m/s)
- 15000 W/m3 heat generation in PCB