CPDLR

CFD Analysis Of Artificially Roughened Solar Air Heater

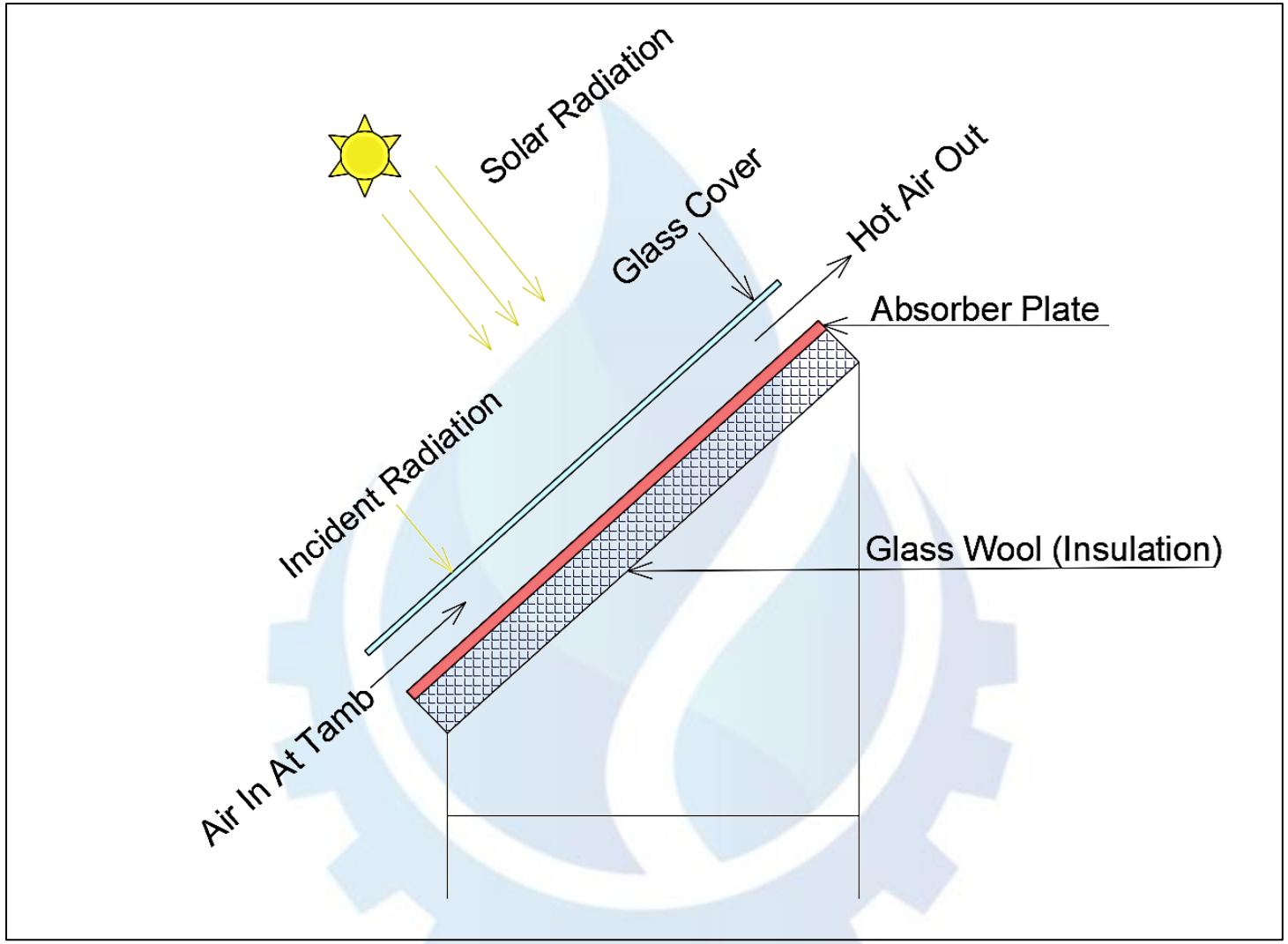
Objective Of The Case Study

- The objective of this case study is to analyze the effect of transverse continuous ribs (artificial roughness) attached to the absorber plate of solar air heater for heat transfer enhancement.

- Smooth solar air heater is first analyzed followed by solar air heater with roughness to check the heat transfer enhancement.

What is Solar Air Heater?

- It is a solar thermal technology in which the solar energy from the sun is captured by an absorbing medium and then used to heat air.

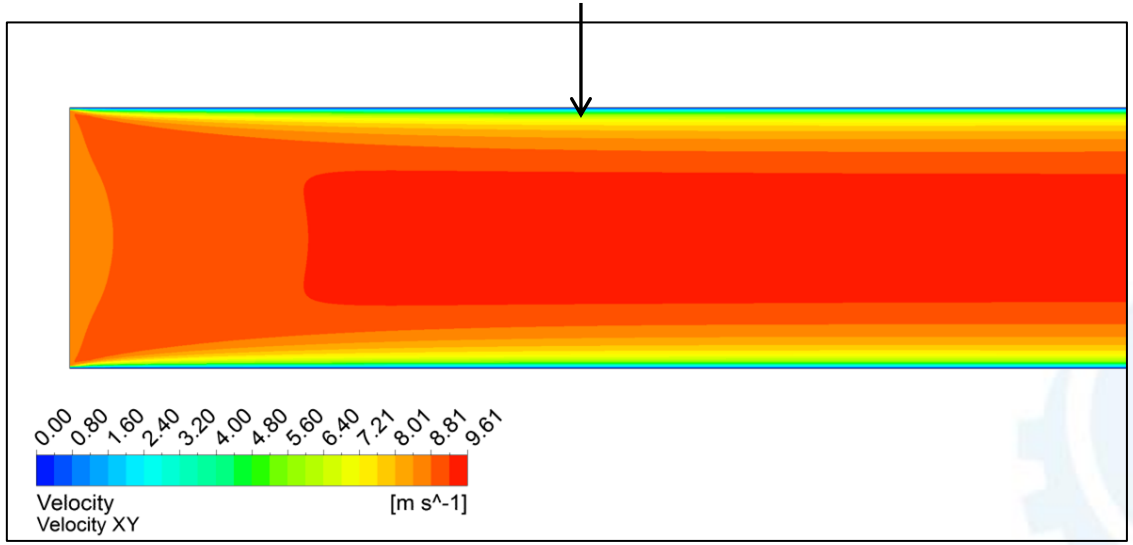


- ✓ It is a renewable energy heating technology used to heat or condition air for building or process heat applications.
- ✓ It is typically most cost effective out of all other solar technologies.

Challenges With Smooth Solar Air Heater

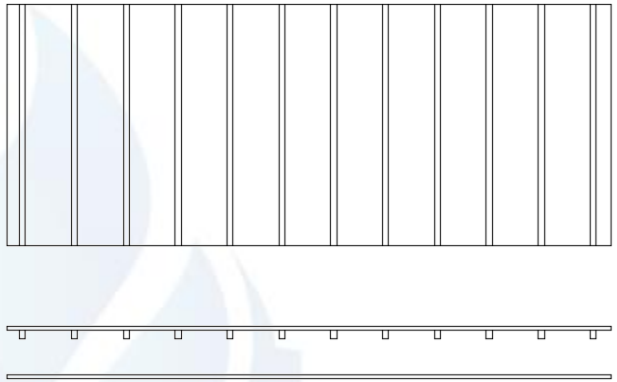
- In smooth solar air heater, the viscous laminar sub-layer formed at the surface of absorbing medium reduces the heat transfer rate as the thermal conductivity of the air is very low.
- To overcome this issue, it is important to break the viscous laminar sub-layer to increase the turbulence near the surface of absorbing medium using some artificial roughness.

Viscous Laminar Sub-Layer Near The Heating Surface Of Smooth Absorber Plate

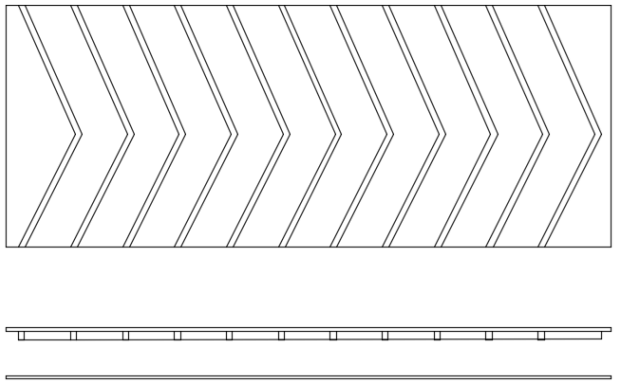


This region lowers the heat transfer rate from the heating surface to the fluid by blocking the inflow of colder fluid into this region. Therefore, it becomes necessary to break this viscous laminar sub-layer and increase turbulence in order to increase convection rate.

Transverse Continuous Roughness



V-Shaped Roughness



Different types of artificial roughness are created under the absorber plate in order to break the viscous laminar sub layer to enhance the heat transfer rate.

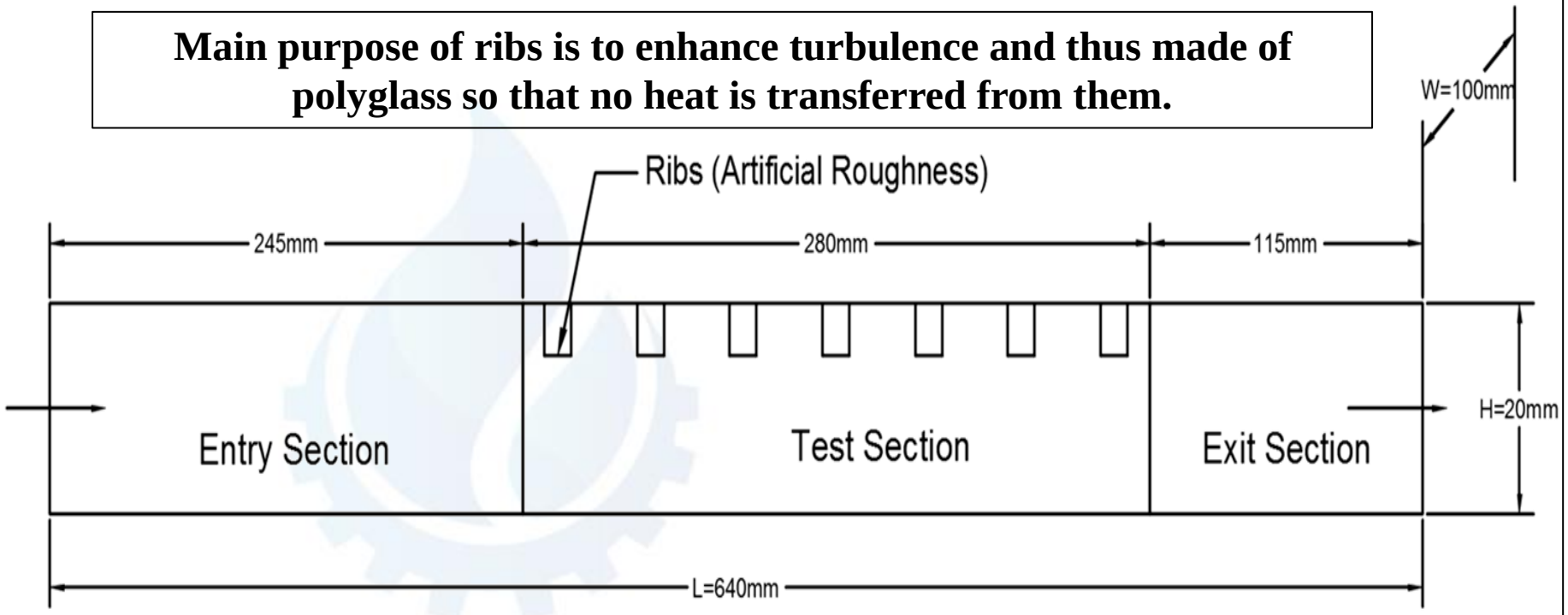
In this case study, effect of transverse continuous ribs on heat transfer rate is analyzed.

Geometry Details

- The solar air heater consists of entry section, test section and exit section of length 245mm, 280mm & 115mm respectively.
- The height and width are 20mm and 100mm. (Hydraulic Diameter of 33.33mm)
- Ribs of height 5mm and length 3mm were used with interspacing (i.e. pitch) of 40mm.
- Due to symmetry in 3rd dimension, the model was reduced to 2D planar so that the computational time can be minimized.

- The adiabatic entry section allows the flow to get fully developed before entering the test section.
- Test section is the region where the heat transfer is studied from the heat transfer surface (absorbing medium).
- The adiabatic exit section allows the flow to stabilize before exiting the domain.

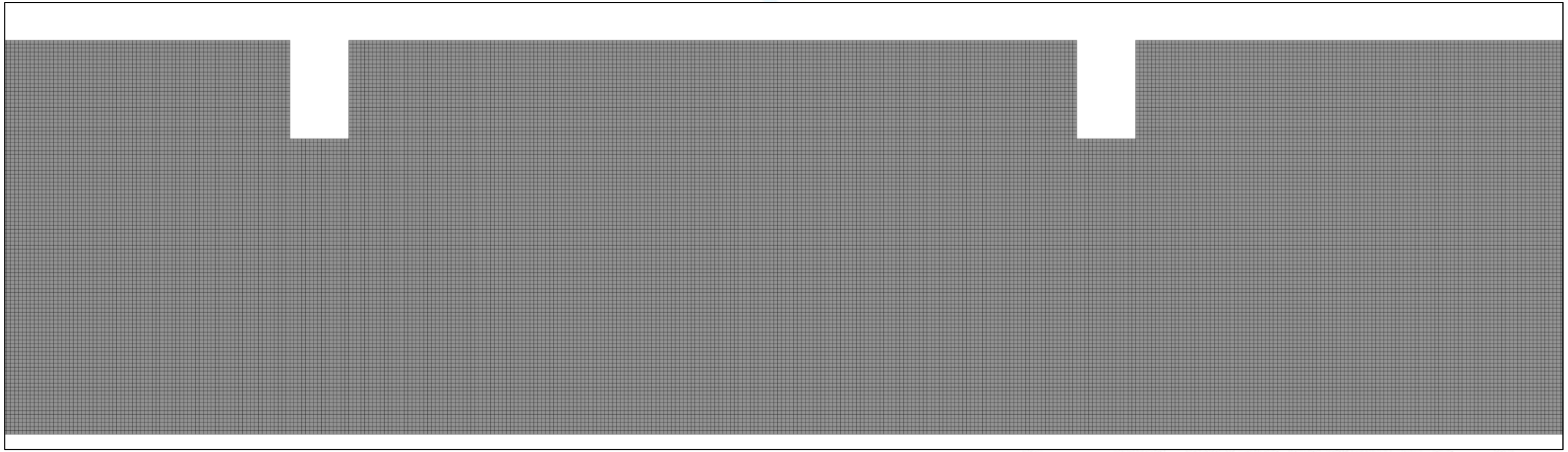
Main purpose of ribs is to enhance turbulence and thus made of polyglass so that no heat is transferred from them.



Mesh Details

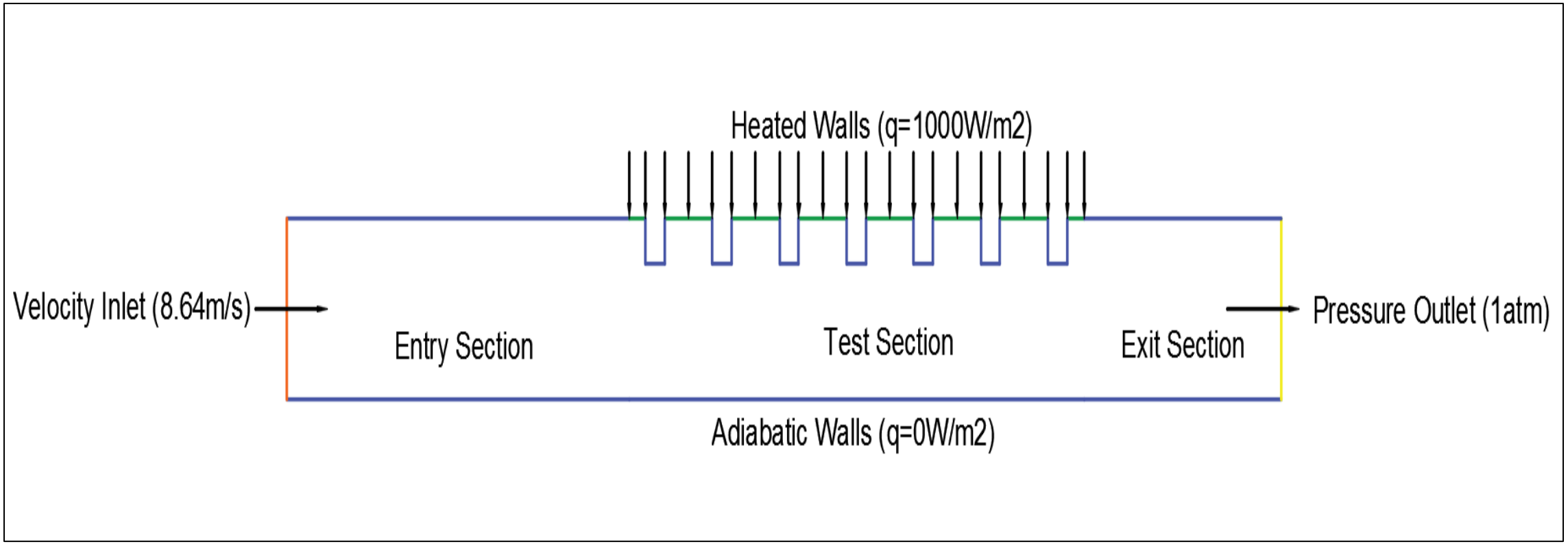
- Uniform structured mesh was generated on the flow domain by breaking it into set of mappable faces in ANSYS meshing.
- Element sizing of 0.2mm was used for the whole domain which resulted into 317375 quadrilateral elements.
- It was ensured in the simulation that the Y+ value near the walls remains less than 5 as required for enhanced wall treatment approach to properly capture the viscous laminar sub-layer.

Number Of Nodes	320851	Number Of Elements	317375	Y Plus	<5



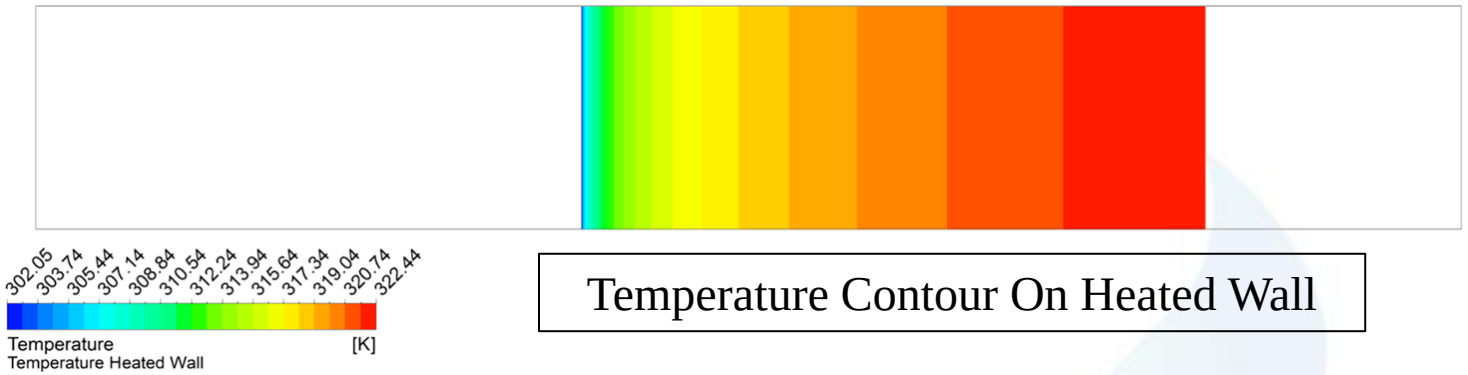
Case Setup

- Velocity inlet (Velocity For Reynolds 18000) for inlet boundary and pressure outlet (1atm) for outlet boundary.
- Heat flux of 1000W/m^2 for heating wall and all other walls were considered as adiabatic walls including ribs wall.
- Second order upwind for discretization of all the equations and SIMPLE algorithm was used for the Pressure-Velocity coupling.
- Residuals for all the equations were taken below 10e-06.

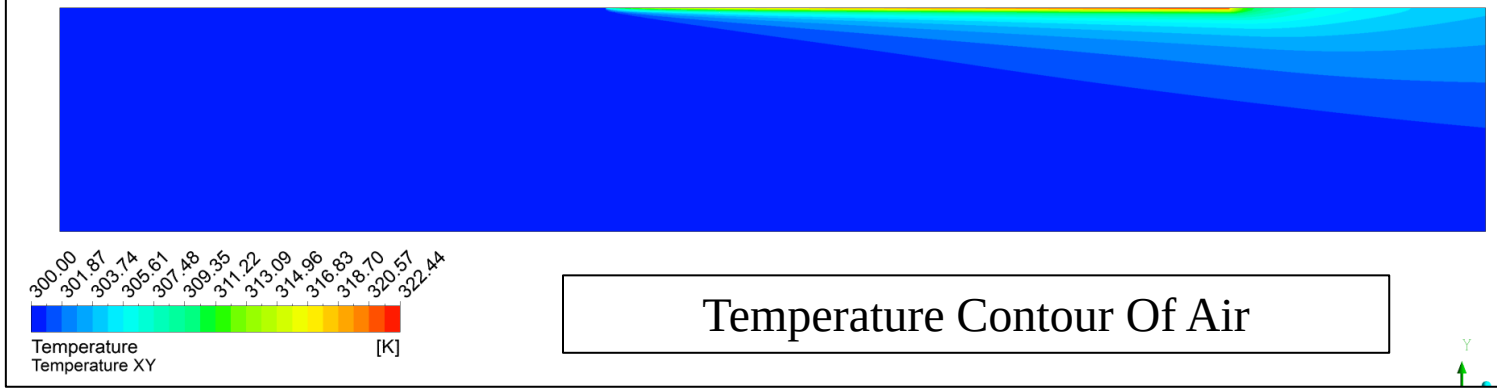


Results & Discussion (Without Ribs)

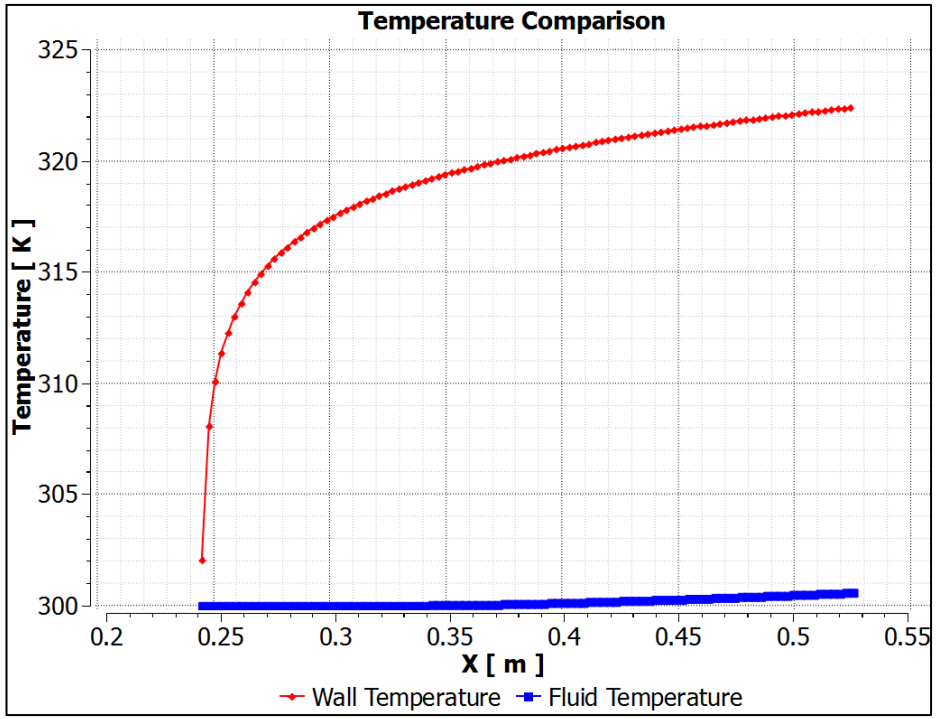
- In the absence of ribs, the average wall temperature was predicted as 319.3K and the bulk temperature was calculated as the average of inlet and outlet temperature (300.7K).
- This gives the convective heat transfer coefficient of 53.7W/m2-K and Nusselt number of 68.4 at the heated wall.
- The chart shows the temperature variation along the heated wall and the line passing through the center. (y=10mm)



Temperature Contour On Heated Wall

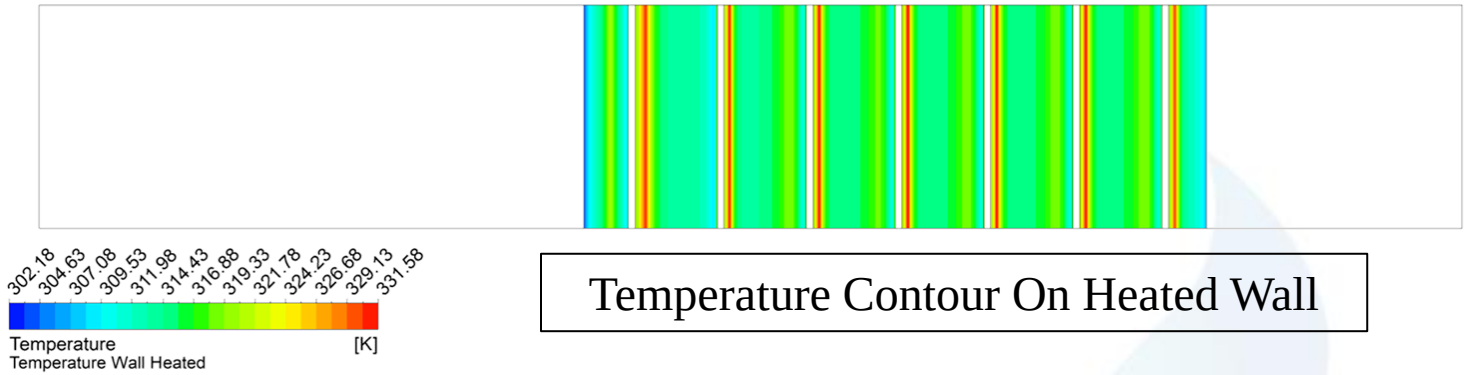


Temperature Contour Of Air

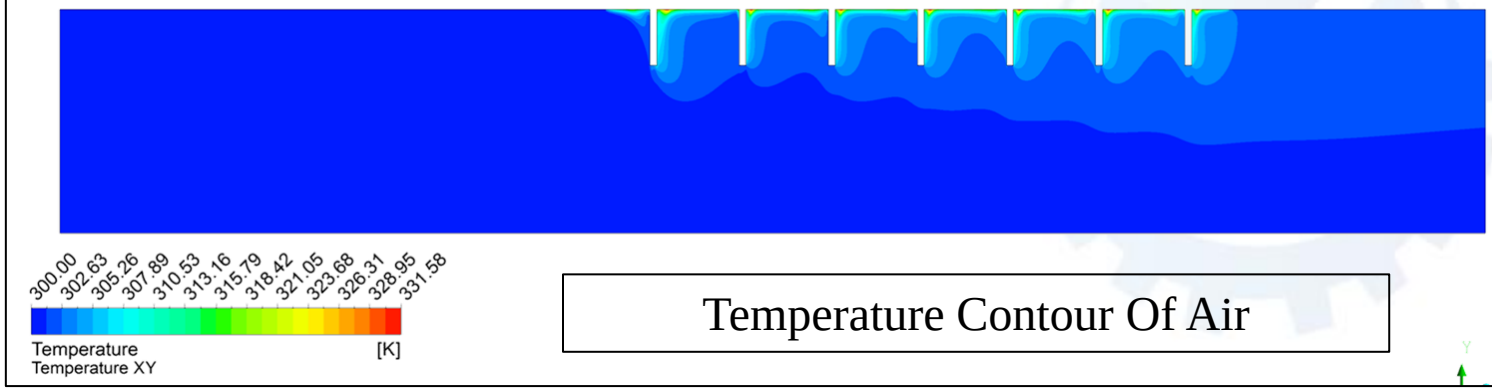


Results & Discussions (With Ribs)

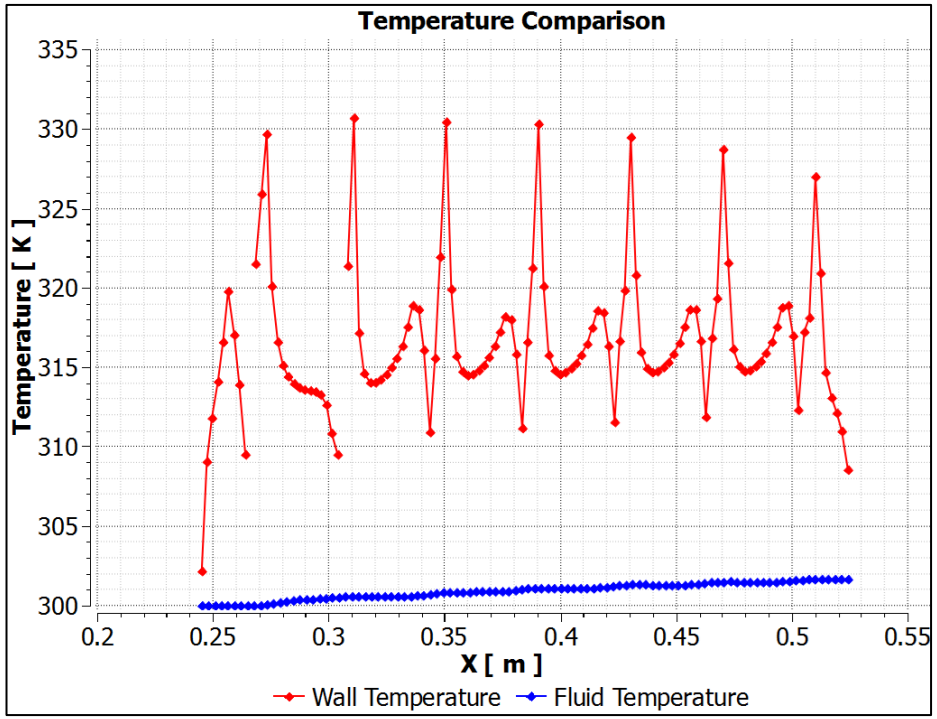
- In the presence of ribs, the average wall temperature was predicted as 316.6K and the bulk temperature was calculated as the average of inlet and outlet temperature (300.65K).
- This gives the convective heat transfer coefficient of 62.7W/m2-K and Nusselt number of 80.0 at the heated wall.
- The chart shows the temperature variation along the heated wall and the line passing through the center. (y=10mm)



Temperature Contour On Heated Wall

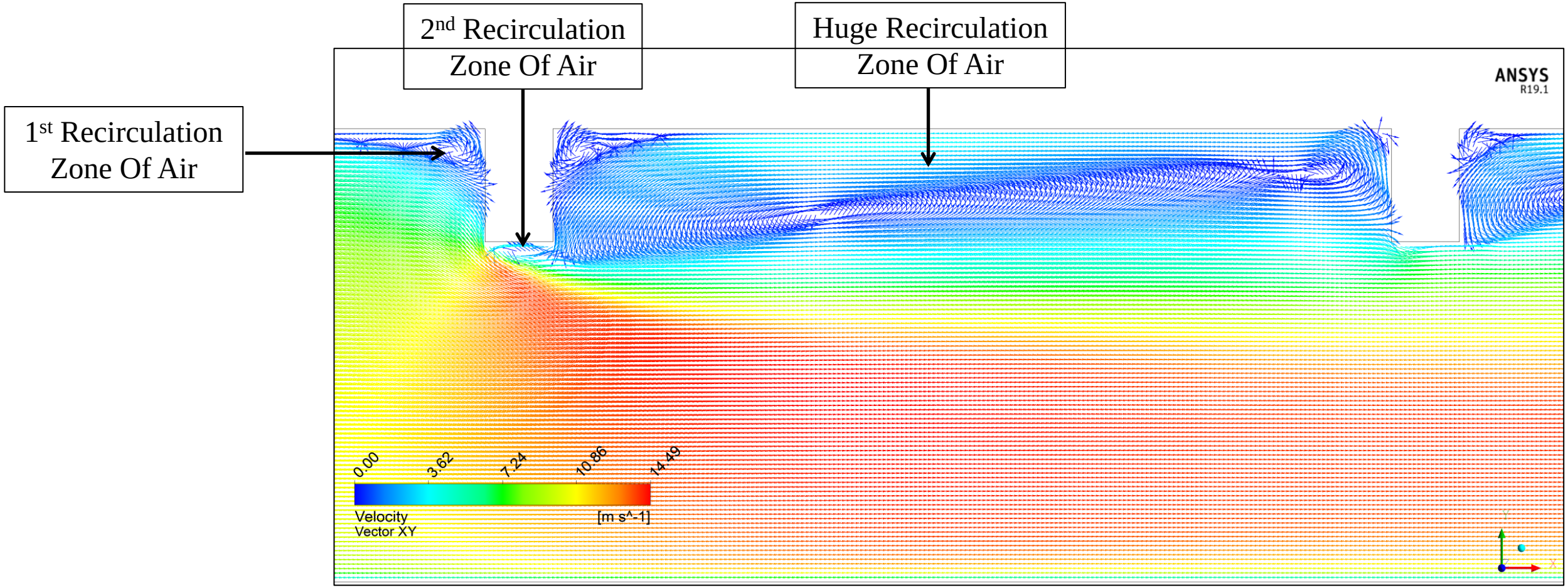


Temperature Contour Of Air



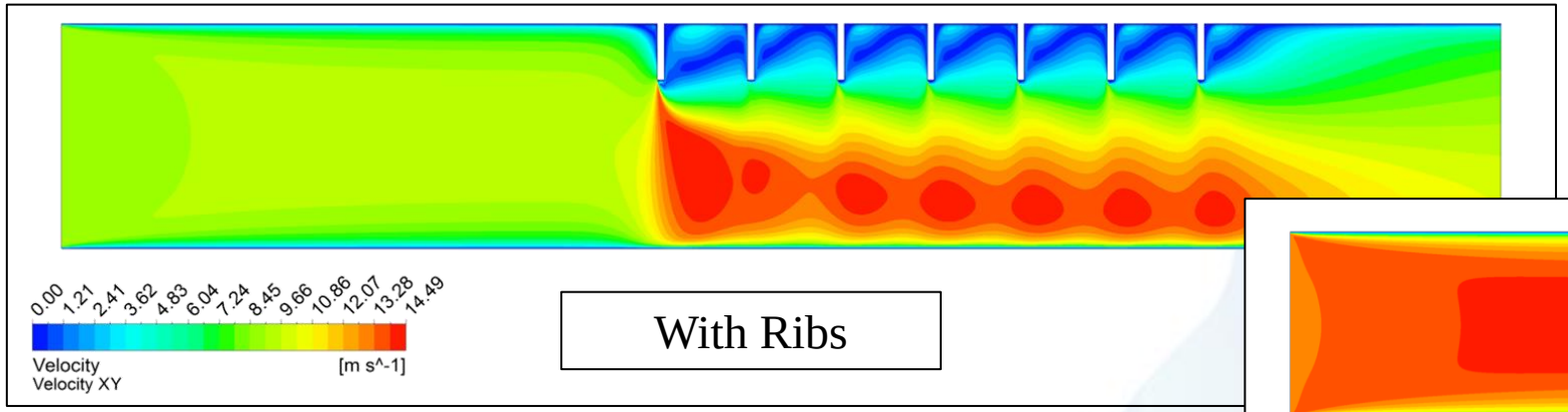
Results & Discussions (With Ribs)

- In the presence of ribs, recirculation zones are appeared upstream, downstream and above the rectangular roughness.
- The 1st recirculation zone appears before the ribs when the flow separation takes place.
- The 2nd recirculation zone appears above the ribs where the fluid velocity increases more than 150% of the inlet velocity.
- The 3rd recirculation zone appears downstream the ribs where flow reattachment takes place after separation. There is another small recirculation zone at the bottom of the ribs.

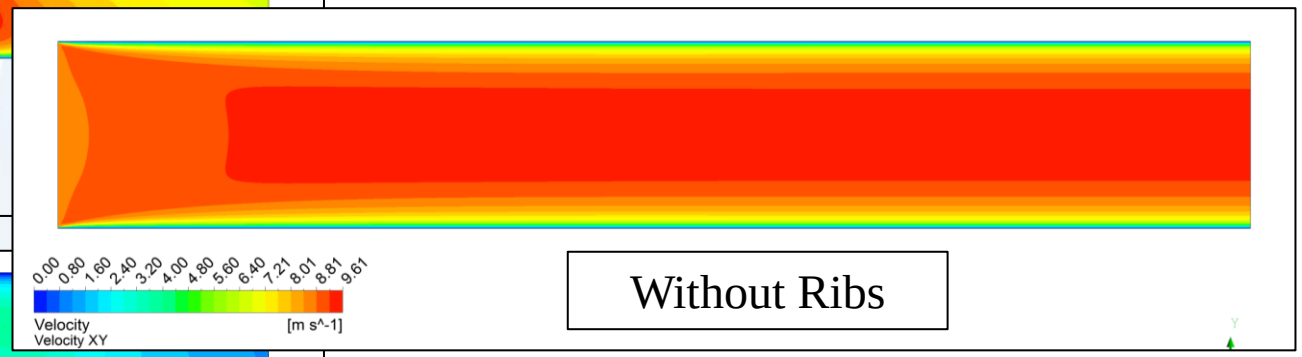


Results & Discussions (Comparison Between Smooth & Roughened Duct)

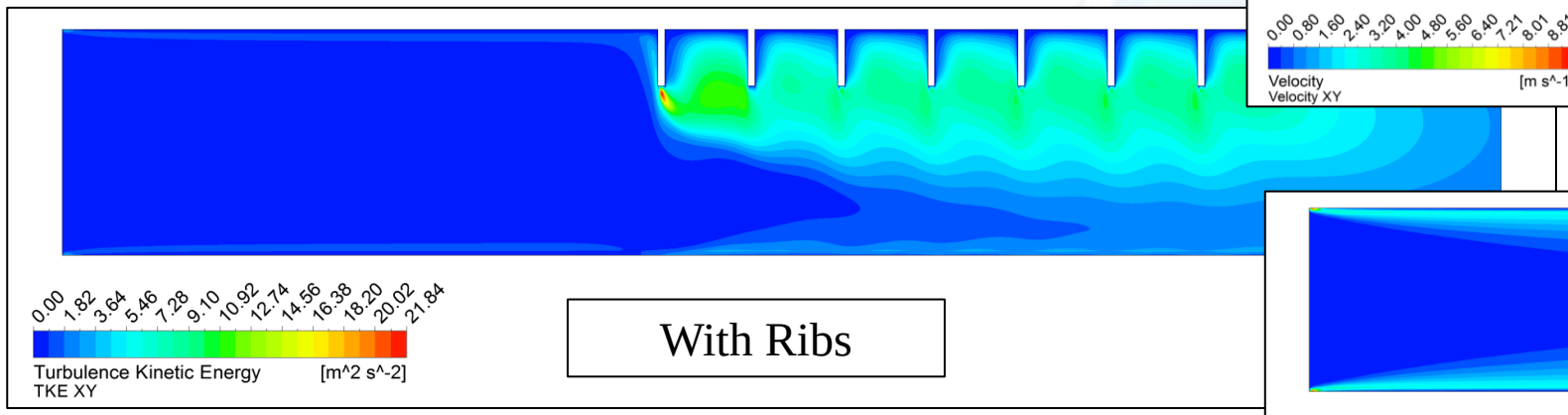
- The velocity has increased by 150% in the region where ribs were attached to the heating surface.
- The turbulent kinetic energy has also increased significantly due to application of ribs which resulted into enhancement in heat transfer.



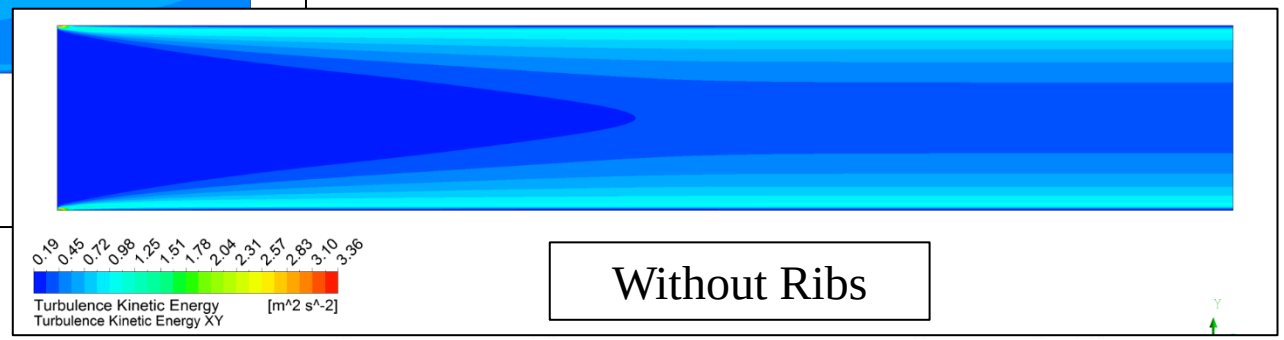
With Ribs



Without Ribs



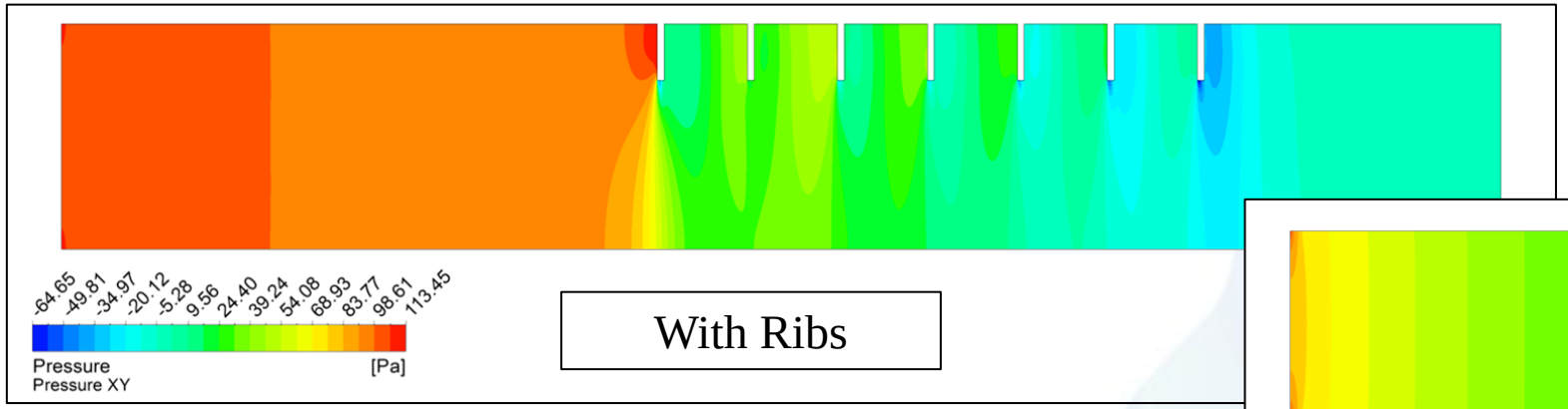
With Ribs



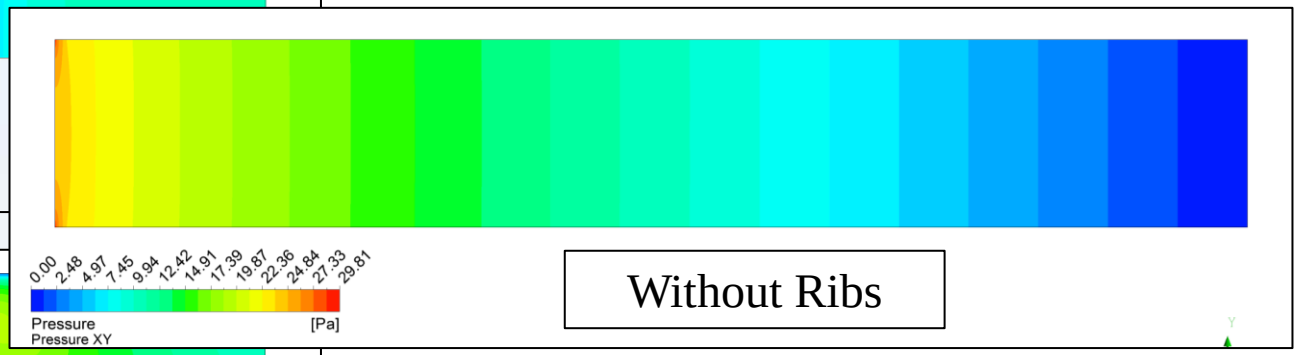
Without Ribs

Results & Discussions (Comparison Between Smooth & Roughened Duct)

- The pressure drop has increased when the artificial roughness was attached to the heating surface.
- The turbulent intensity has also increased significantly due to application of ribs which resulted into enhancement in heat transfer.



With Ribs



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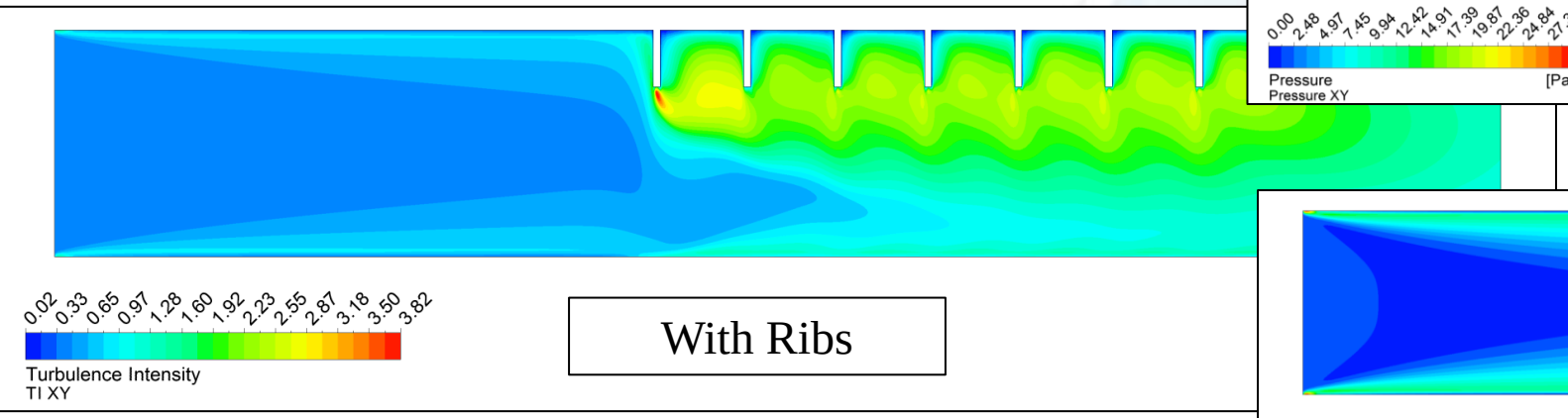
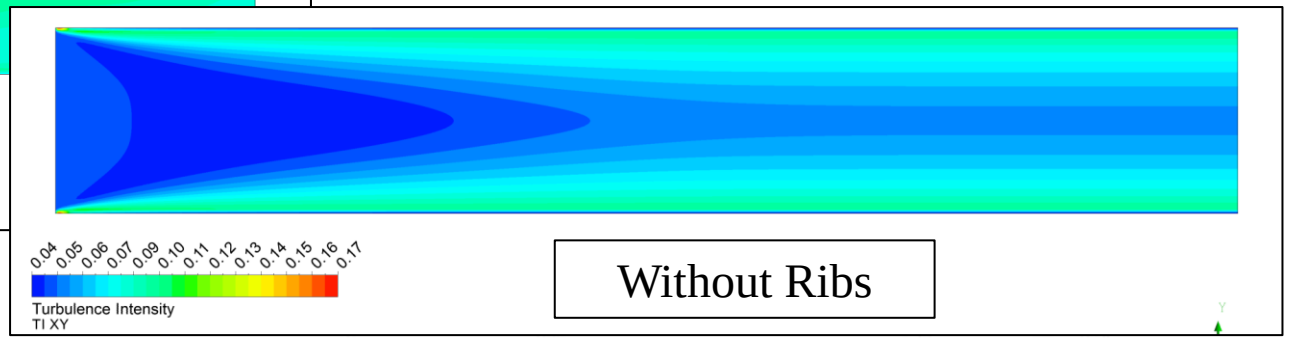


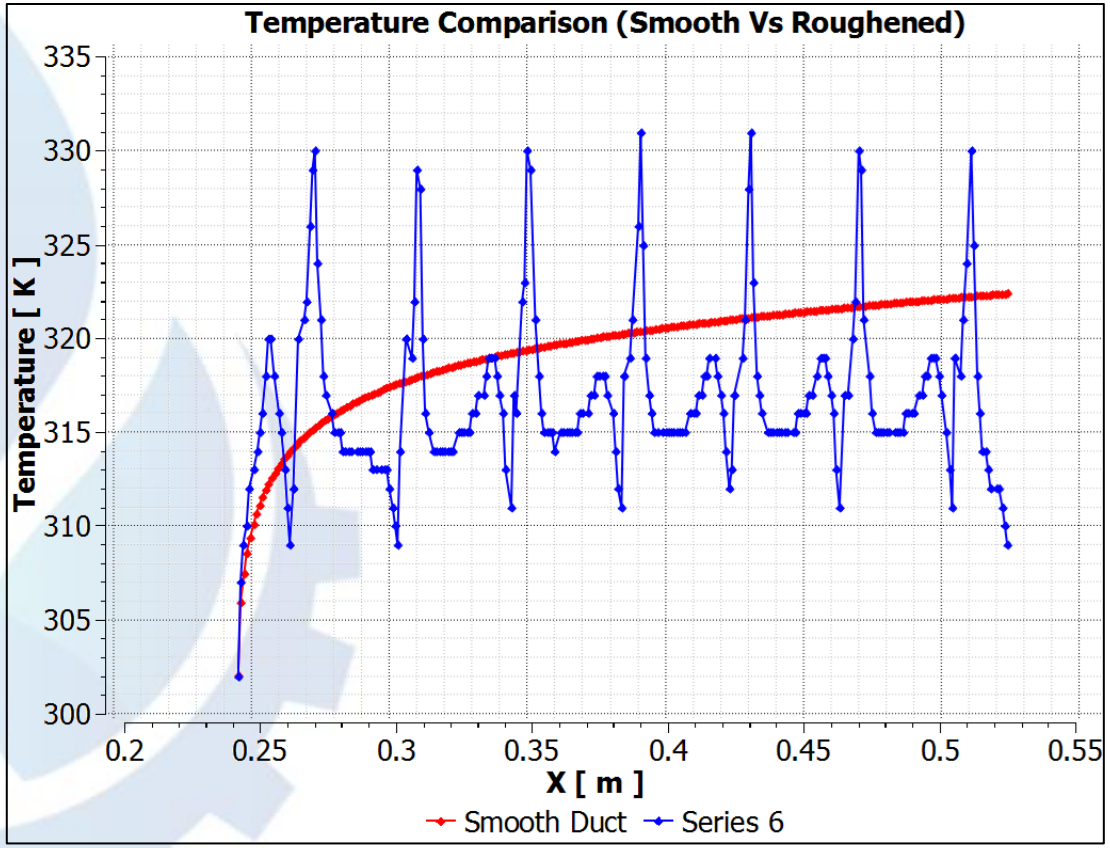
With Ribs



Without Ribs

Conclusion

- In the present case study, the solar air heater with artificial roughness was simulated using ANSYS Fluent software in steady state mode.

- It was found that after applying artificial ribs to the heating surface the heat transfer was increased by 1.2 times however the pressure drop also increases significantly.

- The thermal hydraulic performance can be optimized by reducing the height of the ribs which is not done in this case study as its main purpose was to simulate and check the effect of ribs on the heat transfer mechanism.