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Reducing Solar Heat Gain from Inclined Buildings' Roof by Using Radiant Barrier System

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Presentation outline

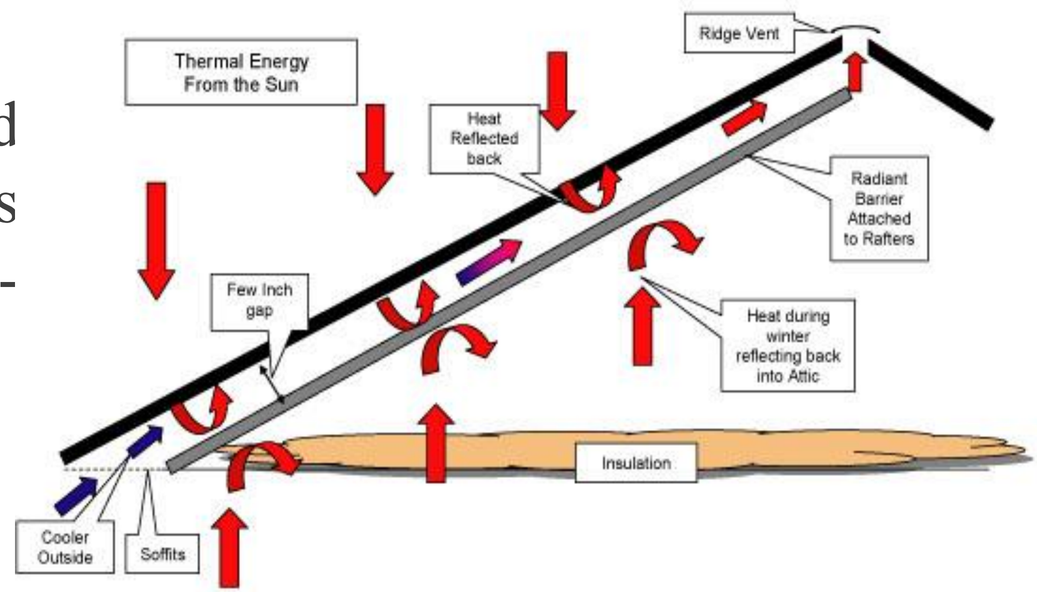
- Introduction
- Problem definition
- Governing Equations
- Use of COMSOL Multiphysics
- Parametric Study
- Results
- Conclusions

Introduction

- Energy conservation in buildings is one of the most significant areas of study.

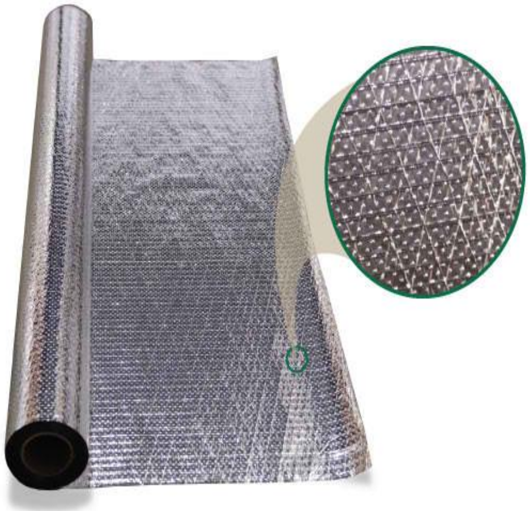
- Radiant Barrier System (RBS) is a thin low emissive layer equipped to buildings' roofs that reduces the amount of heat passed trough the roofs.

- The model considered heat transfer modes interacted with fluid-flow.



Introduction

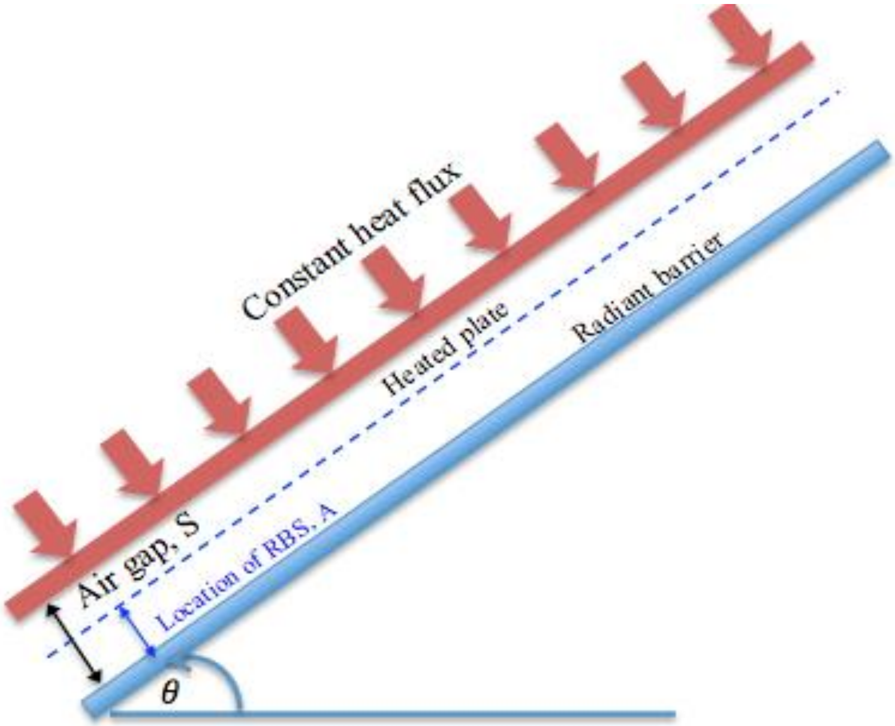
- **Radiant Barrier Features and Benefits:**
  - Reduces utility bills and save energy
  - Improves comfort in building structure
  - Improves air conditioning and heating performance up to 50%
  - Permeable, does not trap moisture
  - Improves efficiency of existing insulation



Problem Definition

- The study produced simulated model of natural convection in an inclined rectangular channel open ended (inclination angle = 15 degrees).

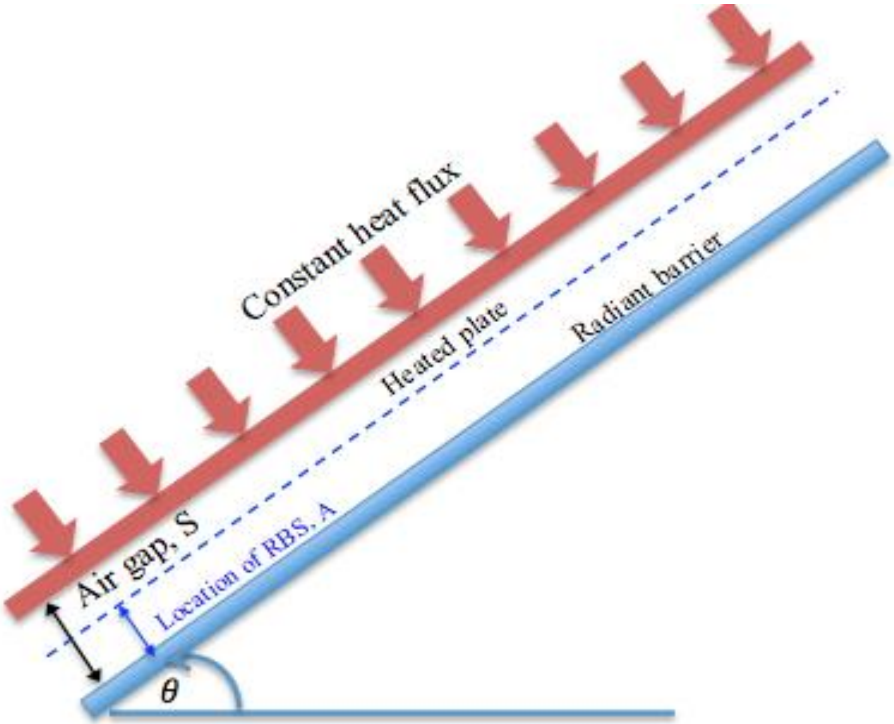
- The air is driven naturally be the variation in density due to the exposed uniform constant heat flux to the upper plate:190.5 , 285.7, 380.9 and 472.6 W/m^2.



Problem Definition

- The inner side of the lower plate is equipped with Radiant Barrier (RB).

- This shows that the model is a combination of three modes of heat transfer "conduction, convection and radiation" interacted with fluid flow "air".



Governing Equations

The most important governing equations are continuity, momentum, and energy equations:

- Continuity equation : $\nabla.(\rho u) = 0$
- Momentum equation : $r u.\nabla u = -\nabla p + \nabla.\left(m(\nabla u + (\nabla u)^T) - \frac{2}{3} m(\nabla.u)I \right) + F$
- Energy conservation : $r C_p u \nabla T = \nabla.(k \nabla T)$

Where,

r : air density (kg/m^3)

u : velocity vector (m/s)

p : pressure (Pa)

m : dynamic viscosity (Pa.s)

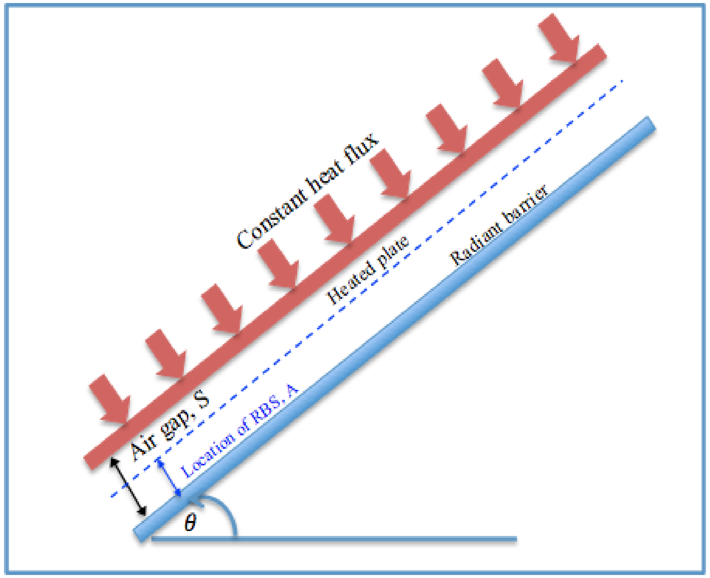
F : body force vector (N/m^3)

C_p : specific heat capacity at constant pressure (J/kgK)

T : absolute temperature (K)

Considered Assumptions:

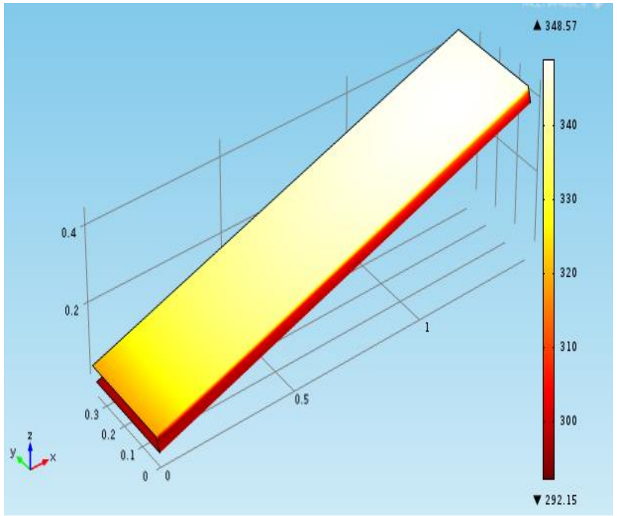
- Steady state model.
- Three-dimensional model.
- Incompressible flow.
- Plates with constant properties.
- Inlet temperature of 26^{o}C.
- Boussinesq approximation.



- Heat is transferred from the lower plate to the room by radiation only.
- The emissivity of radiant barrier is 0.02.
- The emissivity of the upper plate is 0.903.

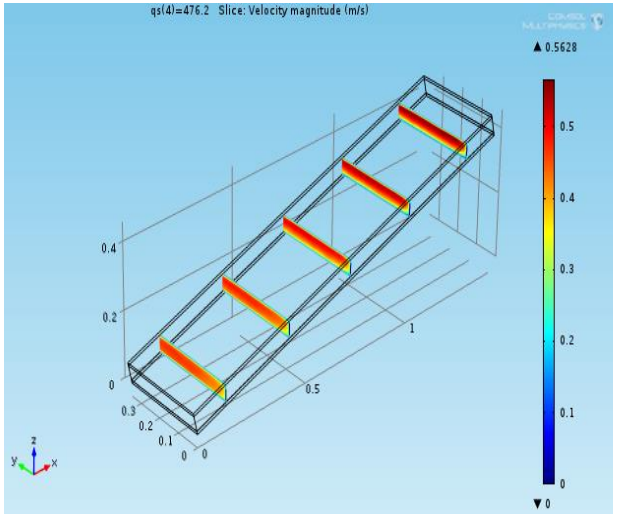
Use of COMSOL Multiphysics

- Non-isothermal fluid flow, laminar flow is used in this study.
- To involve the radiation in the model, surface-to-surface radiation option is used.
- The upper plate is exposed to a constant uniform heat fluxes.
- The depth of the plate is cut to half and a symmetric boundary condition is used.



Use of COMSOL Multiphysics

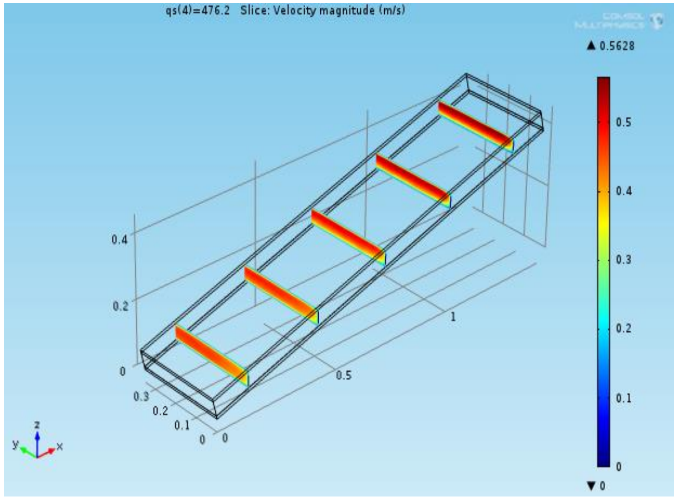
- The heat is transferred from the lower surface of the upper plate to the channel by convection and radiation.
- The transmitted heat is discharged to the ambient by radiation "surface-to-ambient radiation".
- Open boundary condition is applied to the inlet and the exit of the channel since they are exposed to the atmospheric air.
- The density of the air varies inside the channel, so volume force option is applied to express the effect of body force.



Parametric Study

- **Case 1:**

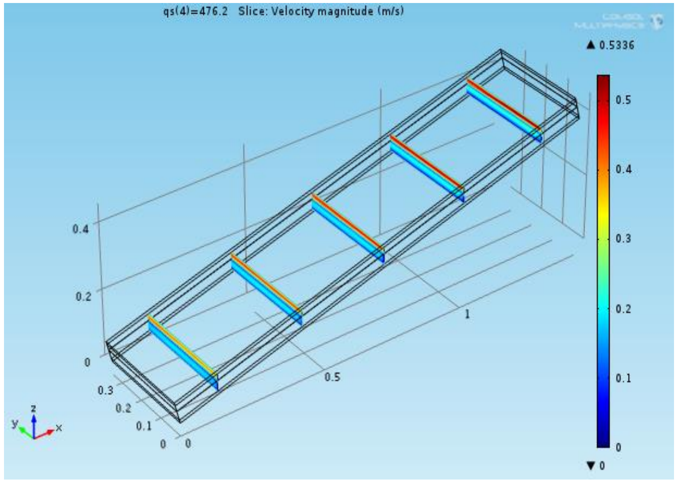
Studying the effect of RB equipped to buildings' roof compared to regular roof



- **Case 2:**

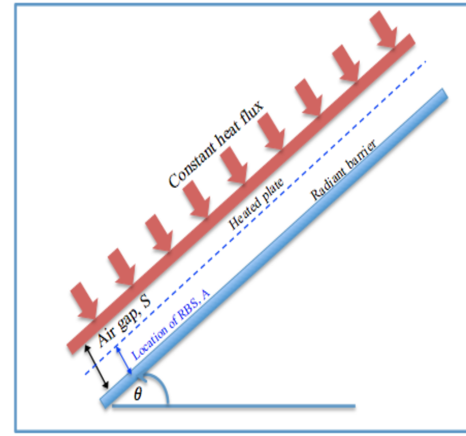
Studying the effect of varying RB locations along the channels' air space:

A = S/5, 2S/5, 3S/5 and 4S/5



Results

Case 1



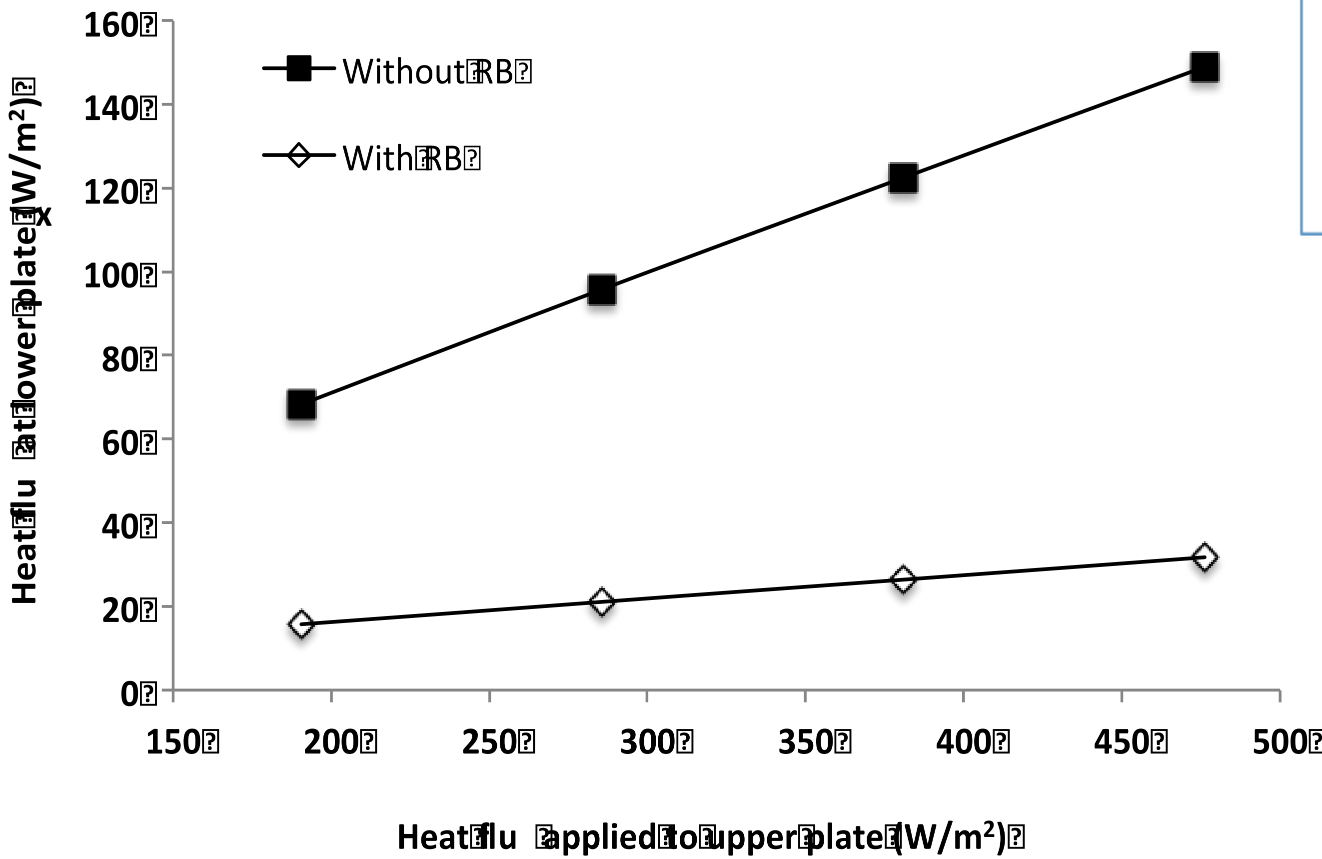
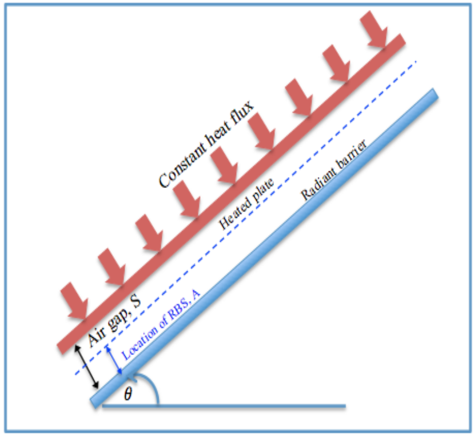


Figure 1: Heat flux passed through the channel for different heat fluxes applied on the upper plate

Case 1



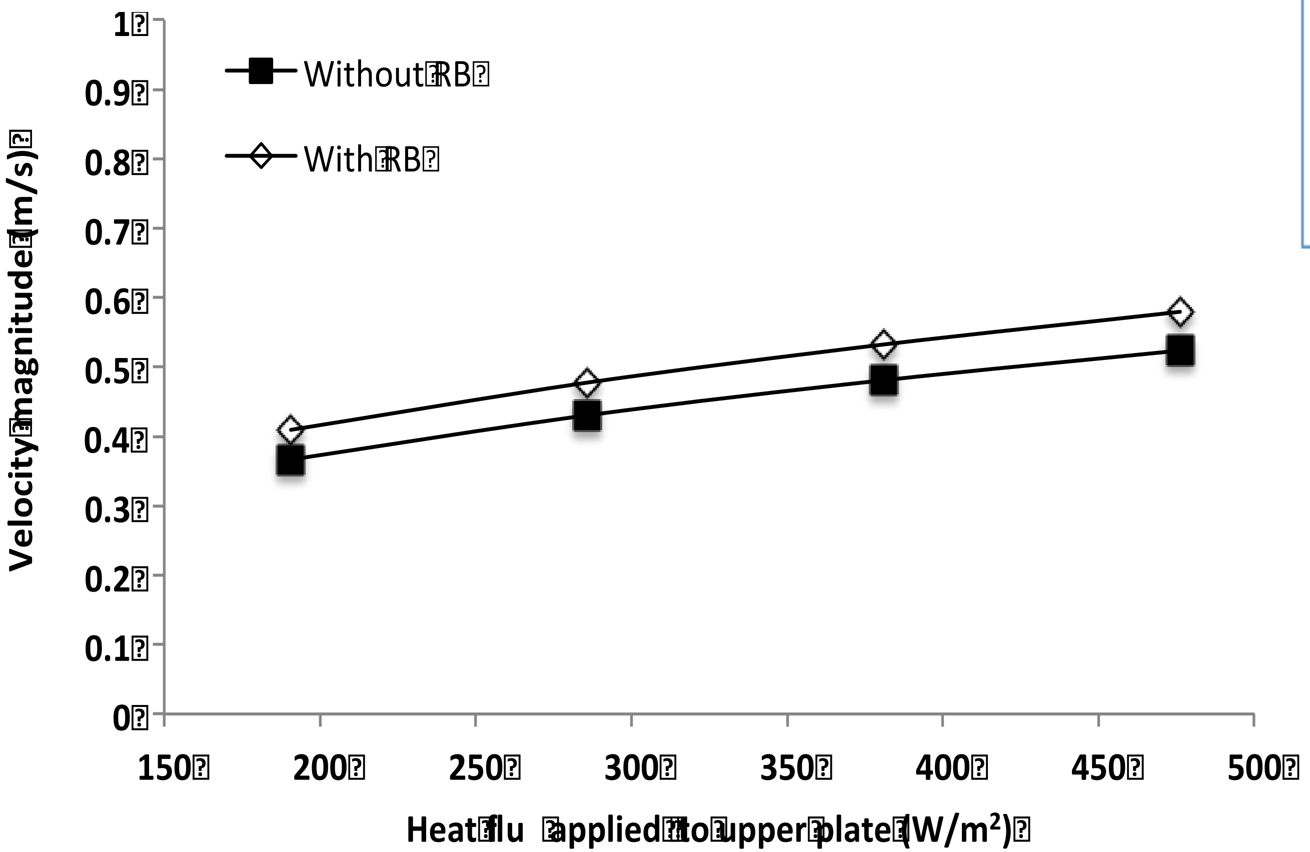
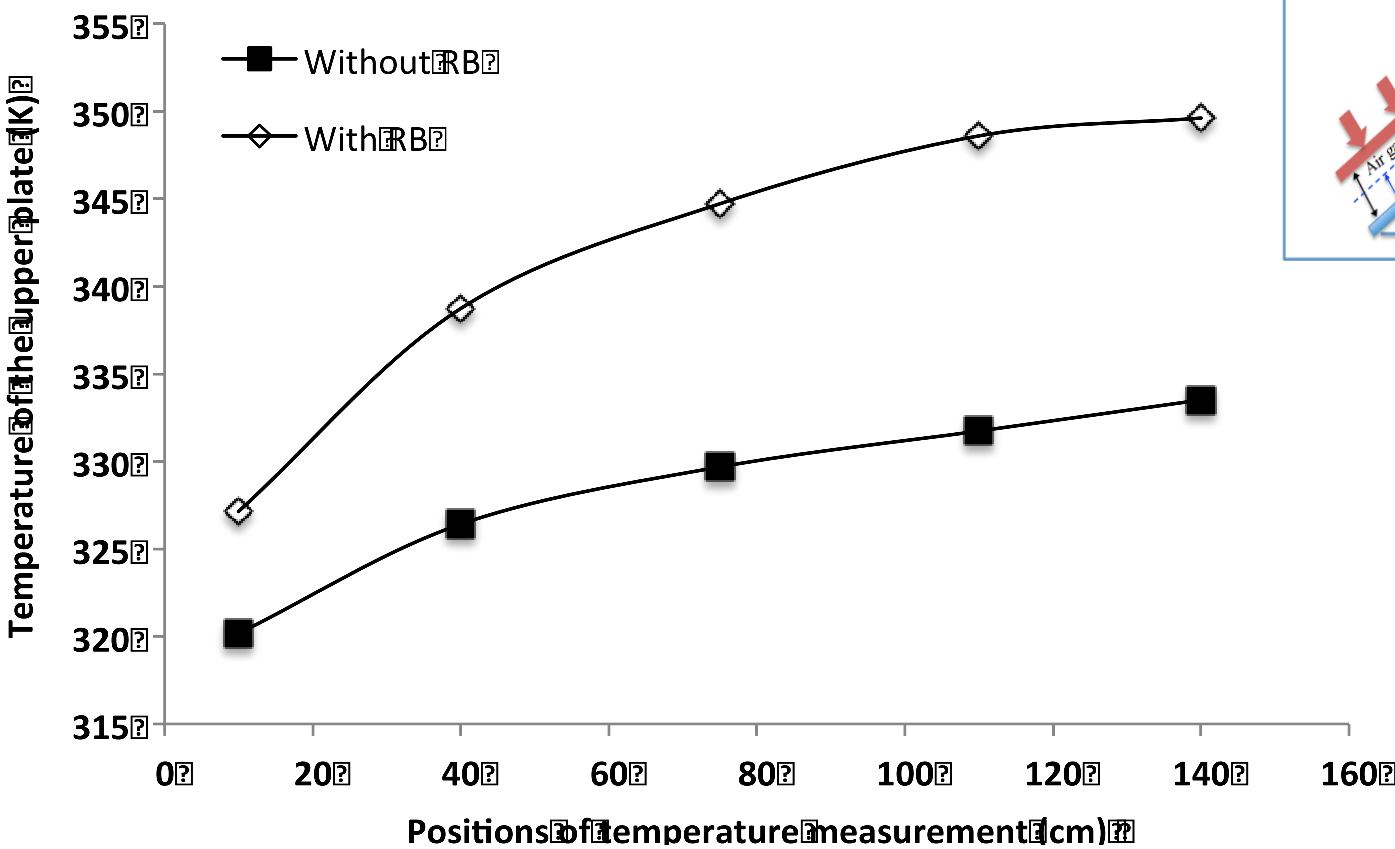


Figure 2: Velocity magnitude at the exit of the channel for different heat fluxes applied on the upper plate

Case 1



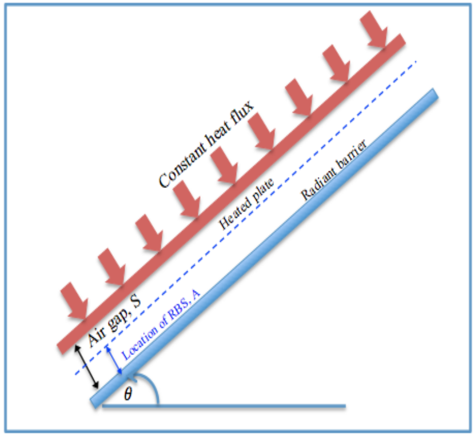
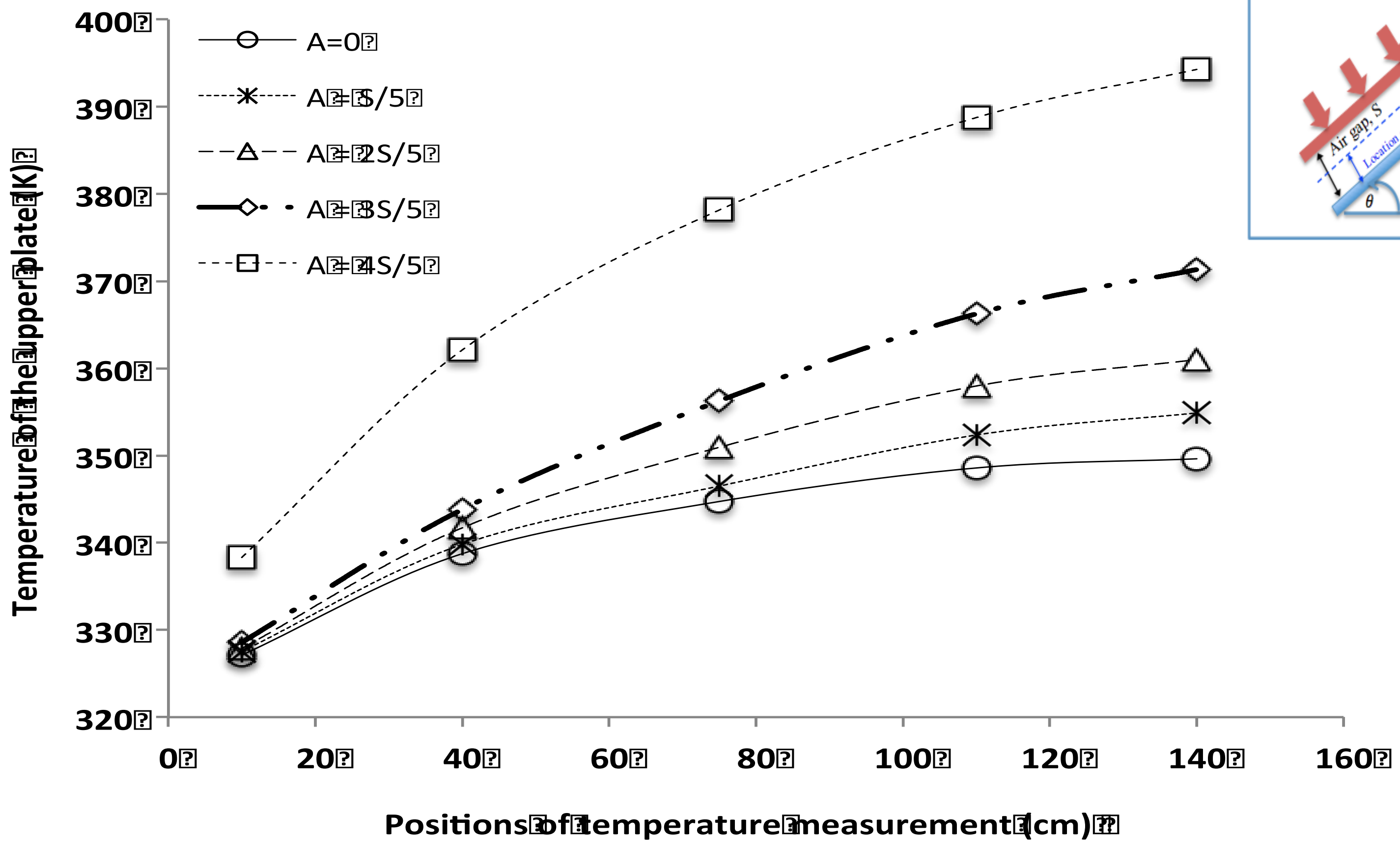


Figure 3: Upper plate temperature distributions along the channels' length for heat flux of 190.5 W/m^2

Case 2



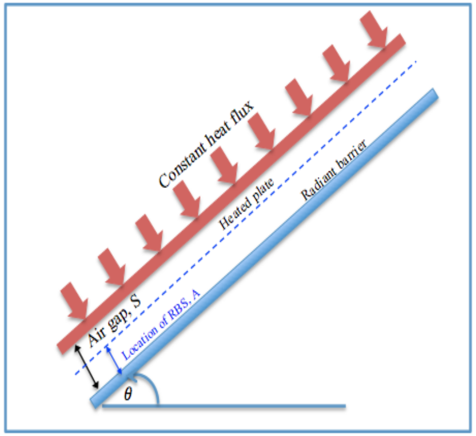
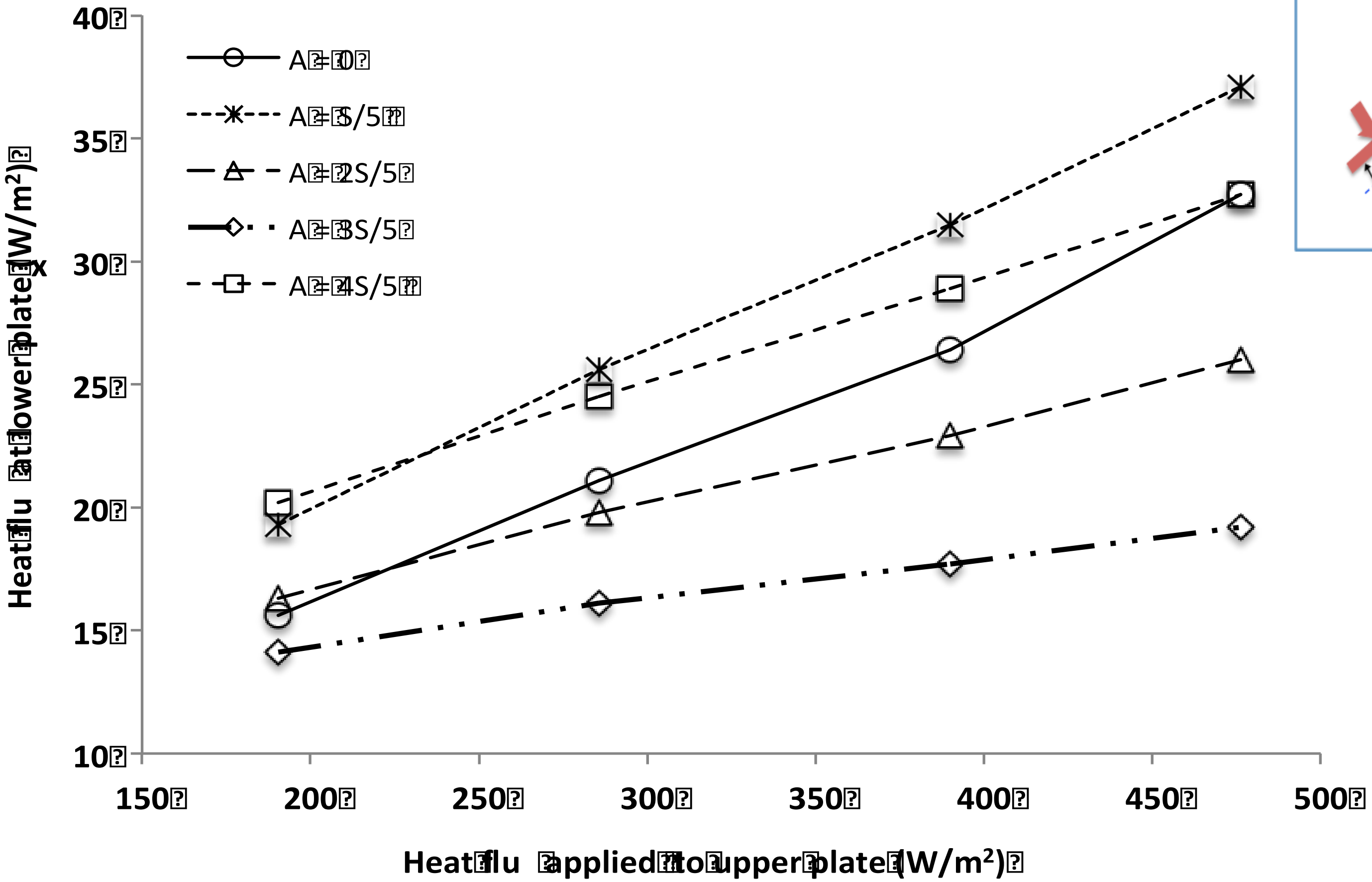


Figure 4: Upper plate temperature distributions along the channels' length for heat flux 190.5 W/m^2

<u>Case 2</u>



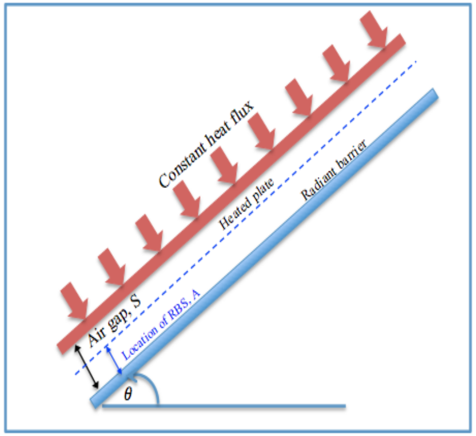
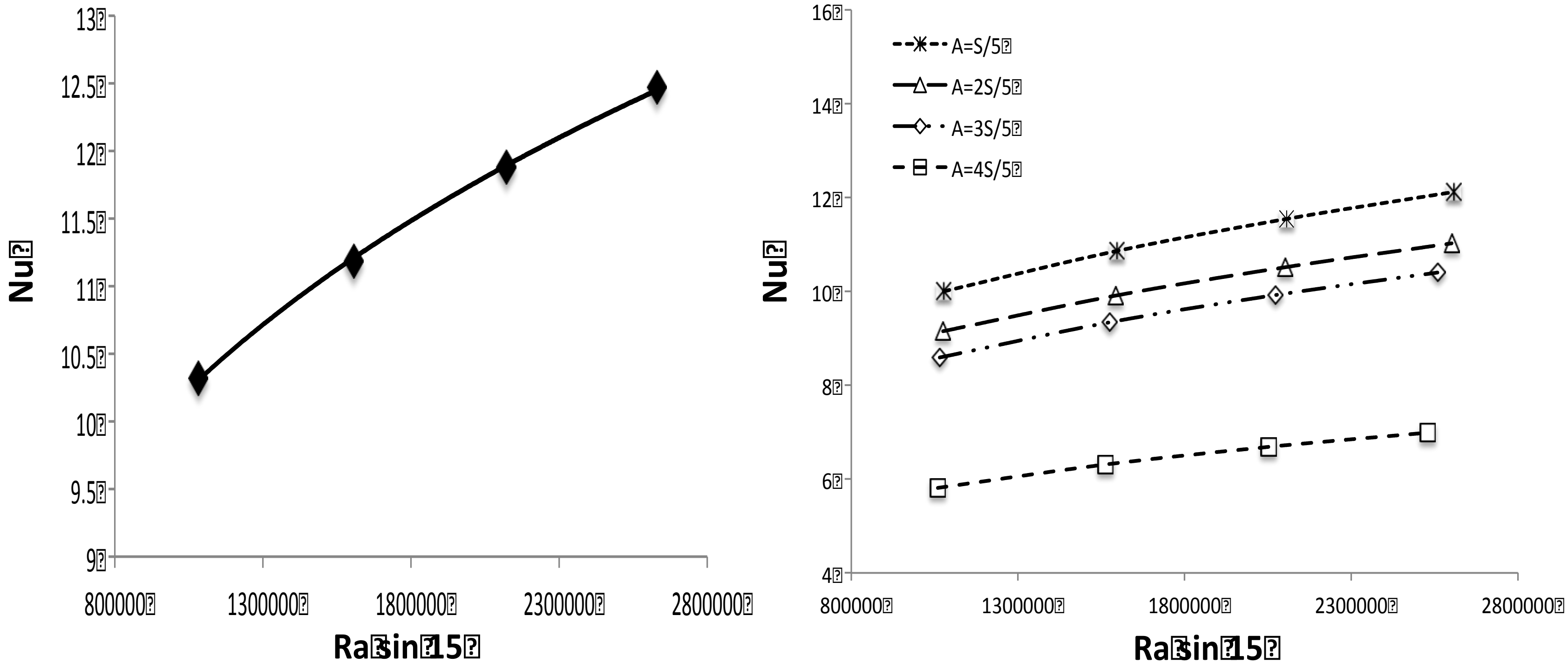


Figure 5: Heat flux pass through the channel for different applied heat fluxes on the upper plate

Case 2



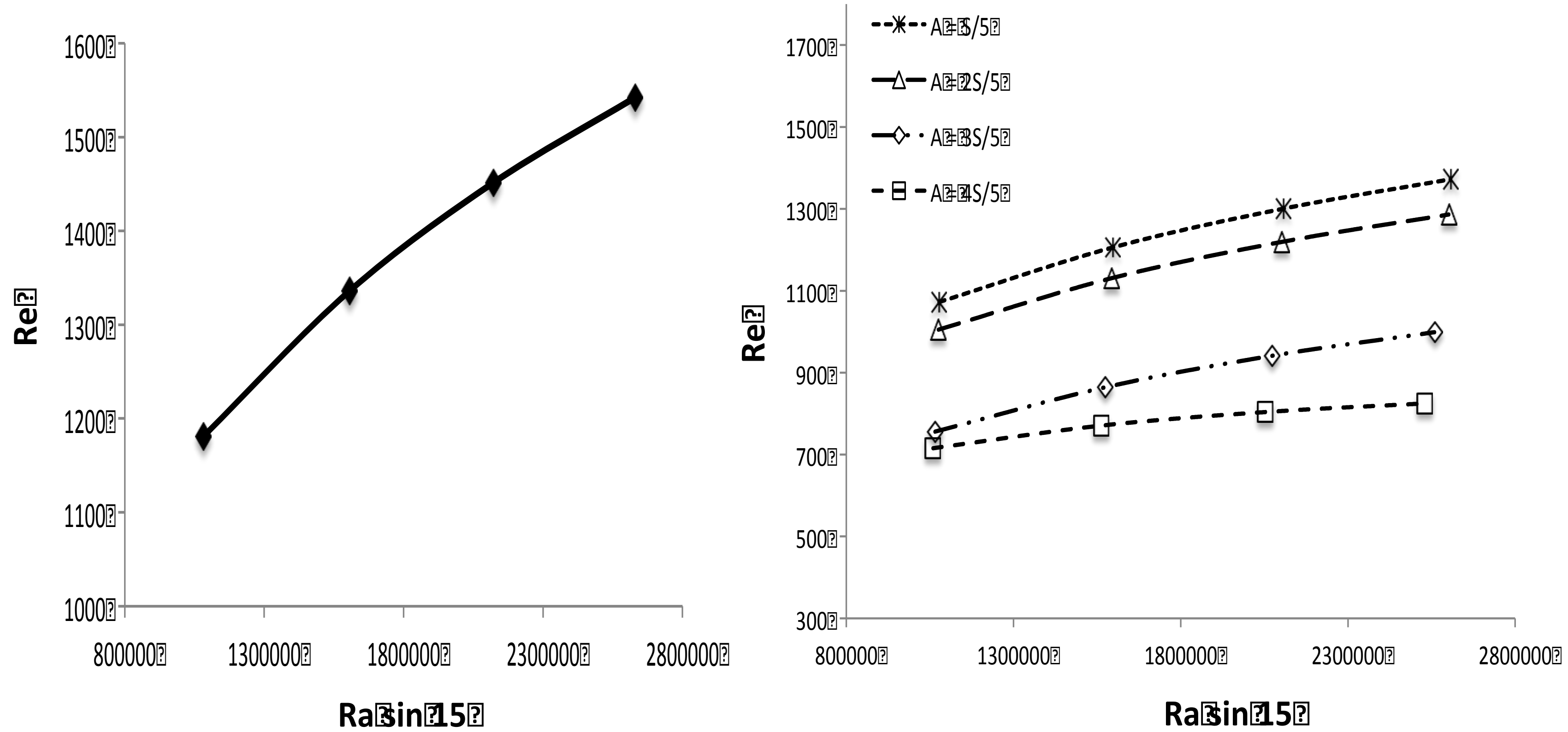
(a) (b)

Figure 6: Nu versus Ra sin 15: a) RB at the surface of the lower plate b) different RB locations

Table 1. Summary of Nu correlations for different RB locations

RB Location, cm	Correlation
0	$Nu = 0.5354(Ra\ \sin 15)^{0.2128}$
S/5	$Nu = 0.4888(Ra\ \sin 15)^{0.2172}$
2S/5	$Nu = 0.491(Ra\ \sin 15)^{0.2182}$
3S/5	$Nu = 0.4156(Ra\ \sin 15)^{0.2182}$
4S/5	$Nu = 0.3073(Ra\ \sin 15)^{0.2119}$

Case 2



(a) (b)

Figure 7: Re versus Ra sin 15: a) RB at the surface of the lower plate b) different RB locations

Table 2. Summary of Re correlations for different RB locations

RB Location, cm	Correlation
0	$\mathrm{Re} = 18.078(Ra\ \sin 15)^{0.3009}$
S/5	$\mathrm{Re} = 22.072(Ra\ \sin 15)^{0.2789}$
2S/5	$\mathrm{Re} = 20.644(Ra\ \sin 15)^{0.28}$
3S/5	$\mathrm{Re} = 9.0498(Ra\ \sin 15)^{0.3191}$
4S/5	$\mathrm{Re} = 73.288(Ra\ \sin 15)^{0.1646}$

Case 2

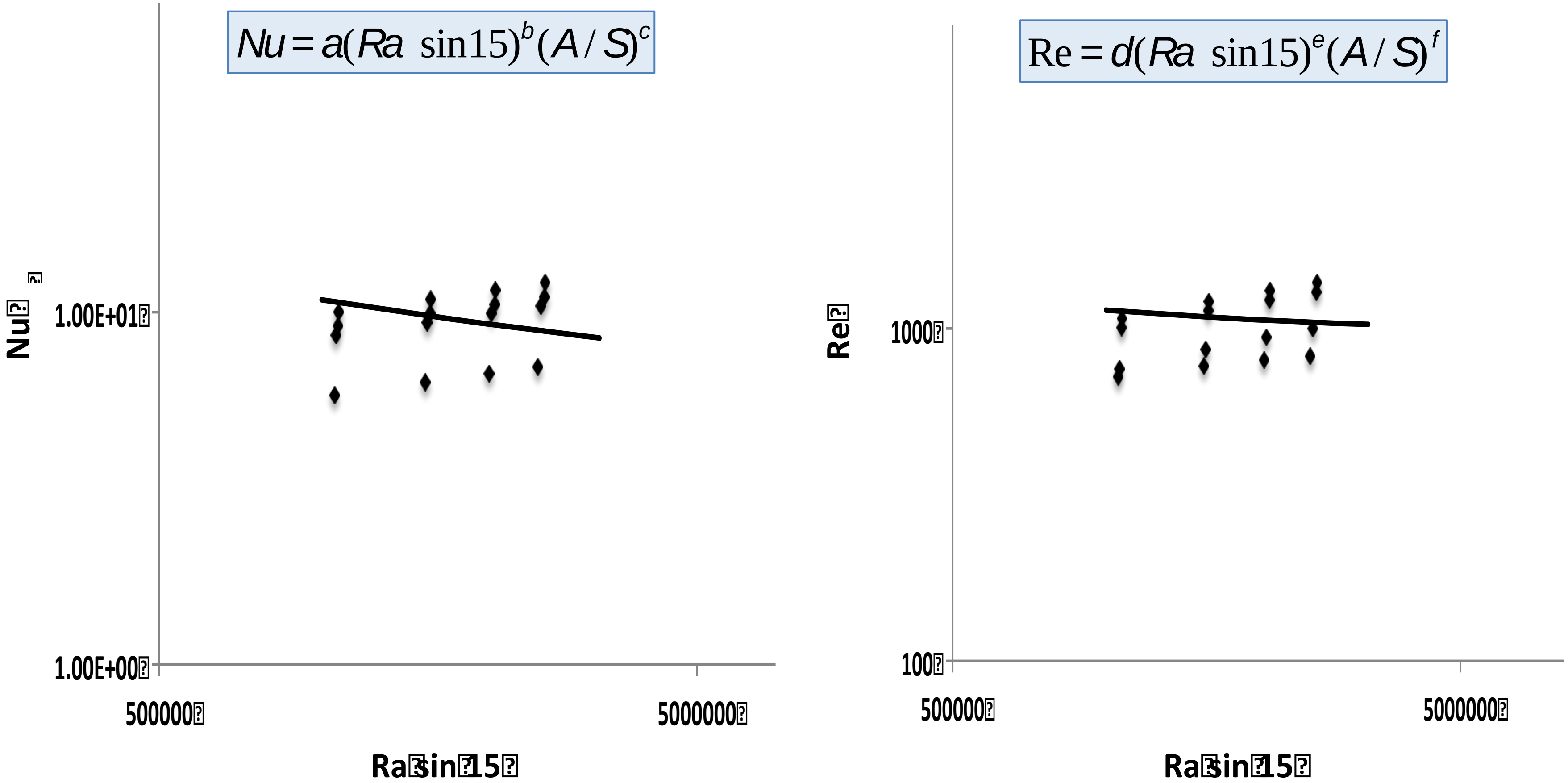


Figure 8: Correlation of Nu and Re versus Ra sin 15 for various RB locations

Correlations

Nusselt Number Correlation:

$$Nu = 1.3968(Ra\ \sin 15)^{0.1156}(A/S)^{-0.2803}$$: A = S/5, 2S/5, 3S/5 and 4S/5

The achieved correlation are valid in the range of $1 \times 10^6 < Ra \sin 15 < 2.5 \times 10^6$ and $6 < Nu < 12$.

Reynolds Number Correlation:

$$Re = 15.953(Ra\ \sin 15)^{0.273}(A/S)^{-0.3068}$$: A = S/5, 2S/5, 3S/5 and 4S/5

The data are achieved for the range $1 \times 10^6 < Ra \sin 15 < 2.5 \times 10^6$ and $700 < Re < 1300$.

Conclusions

- It was found that RB blocked 77% of the heat passing through the channel in gypsum board roof.

- Locating RB in the middle of the channel provided a maximum reduction in the heat flux passing through the channel.

- When heat flux of 190.5 W/m^2 is applied to the top plate, 24% reduction in passing heat is achieved.

- While applying heat flux of 472.6 W/m^2, 44% reduction in the passing heat is achieved compared to standard case when RB was located on the lower surface.

Thank you