A Computational Approach for Attic Space Designing

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ABSTRACT

The present study deals with the simulative results for the natural convection inside the trapezoidal shape enclosure for various Grashof Numbers. The problem has been characterized with the uniform temperature of walls while steady state condition has been formulated with the laminar air flow at Pr. = 0.7 and with no slip condition on wall. Grashof number varies from 10^4 to 10^6. ANSYS 18.1 has been used for the computational simulation.

Keywords - Attic Space, Natural Convection, Rectangular Enclosure, Trapezoidal Enclosure, Triangular Enclosure,

I. INTRODUCTION

With the increase in demand for the energy, development of the energy efficient building has been considered consciously by the societies. It enlighten the views of architects and builders on human comfort. Most of the complex heat transfer inside a building includes attic space in comparison to the rest of the building. Due to the effect of attic space in increasing or decreasing temperature, designing of attic space plays an important role.

Nomenclature

Dimensionless Numbers

Gr	Grashof Number
Nu	Nusselt Number
Pr	Prandlt Number

Greek Symbols

β	Coefficient of thermal expansion
θ	Dimensionless temperature

Physics Constants

g	Gravitational Constant
H	Altitude of physical domain
h	Convection coefficient

k	Thermal Conductivity of fluid
L	Length of the bottom wall for present study domain; Length of heater for reference study
L_H	Total length of hot wall/s
P	Pressure of fluid inside enclosure
S	Length of the top wall for present study;
	Distance between center axis and mid-point of the heater located in reference study
T_H	Temperature of hot wall
T_L	Temperature of cold wall
U; V	Velocity of Air
W	Length of the half of bottom wall in reference study

Corcione [1] has studied the Natural convection in an air filled rectangular enclosure heated from below and cooled from above for a variety of thermal boundary conditions at the sidewalls. They found the Numerical results for different values of both the height ratio of the enclosure and the Rayleigh number. Saravanan et al. [2] investigated the Buoyancy-driven convection in a square cavity with localized bottom heating and symmetrical cooling from the vertical walls in the presence of magnetic field was studied numerically. It was found that the overall heat transfer gets intensified or subsided for an increase in the source length depending on whether it is isothermal or is flux. Cheikh et al. [3] experimented natural convection in a square enclosure with localized heated from below and cooled from above for a variety of thermal boundary conditions at the top and sidewalls. Corvaro and Paroncini [4] analyzed natural convection in square cavities heated with a discrete heater from below and cooled by sidewalls. A. Dalal et al. [5] state that natural convection occur in the vicinity of tilted square cylinder in the range of ($0° \leq \theta \leq 45°$) inside an enclosure having horizontal adiabatic wall and cold vertical wall figure out by cell-centered finite volume method, which is used to reckoned two dimension Navier strokes equation for incompressible laminar flow. And taken the value of Rayleigh number is Ra= 105, Pr. = 0.71. G. De Vahl Davis [6] expresses that differentially heated side walls of square cavity are figure out for precise solution of the equations. It has taken the Rayleigh numbers in the range of 103 Ra106. Santhosh Kumar M.K. [7] had investigated rectangle enclosure under steady and transient state at different Rayleigh number. CFD analysis of natural convection was executed using varying properties and varying boundary conditions. Study concluded that Nusselt number is dependent on thermal conductivity and Rayleigh number of fluid while independent from value of viscosity and density of fluid.

H.C. Thakur and T. K. Bhattacharya [8] focused on the analysis of air flow pattern in a circular segment with the benchmark study of Chin Lung Chen and Chin Hsiang Cheng [9] at different Grashof number.in their study, result was being concluded with the statement that number of recirculating cell increases with the increase in Grashof number.

The literature review concerning natural convection in isosceles triangular cavity shows that this configuration was the object of experimental and numerous numerical studies [10]. Earlier, the flow and temperature patterns, local wall heat fluxes and mean heat flux rates were measured experimentally by Flack [11] in isosceles triangular cavities with three different aspect ratios. The cavities, filled with air, were heated/cooled from the base and cooled/heated from the inclined walls covering a wide range of Grashof numbers. Akinsete and Coleman [12] conducted a numerical study based on the finite-difference method on natural convection flow of air contained in a right-triangular cavity (half of the isosceles triangular cavity) with a cold base, heated inclined wall and insulated vertical wall. Numerical solutions were obtained for height base ratios ≤ 0.5 in conjunction with Grashof numbers varying up to a maximum value of 8000. Poulikakos and Bejan [13] reported a theoretical and numerical investigation of natural convection inside a right-triangular cavity with cold inclined wall, warm base and insulated vertical wall. The theoretical fluid flow and temperature fields were determined on the basis of an asymptotic analysis valid for shallow spaces with aspect ratios approaching zero. Another phase of the study focused on the temporal evolution of the velocity and temperature fields using various aspect ratios of the cavity.

The finite-element method was used by Holtzman et al. [14] to model the complete isosceles triangular cavity without claiming cavity symmetry. A heated base and symmetrically cooled inclined walls were considered as thermal boundary conditions for various aspect ratios and Grashof numbers. These authors performed a flow visualization study to validate experimentally the existence of symmetry-breaking bifurcations in one cavity of fixed aspect ratio. This anomalous bifurcation phenomenon was intensified by gradually increasing the Grashof number. The main conclusion drawn in this paper was that, for identical isosceles triangular cavities engaging symmetrical and non-symmetrical assumptions, the differences in terms of mean Nusselt number were about 5%.

1.1. Properties of Air

The density of the fluid for natural convection systems is often represented with the Boussinesq approximation. The Boussinesq approximation is used for computational problems of this type to simplify the formation of the coupled Navier-stokes equations. The approximation assumes that density variations are small in the fluid except in evaluating the buoyancy force (gravity multiplied by density). In general, the Boussinesq approximation is only valid when the temperature differences in the system are small (less than 28°C). Table 1 shows data for the properties of air used for the study of all enclosures in this paper.

Table 1-Properties of air

Properties	**Symbol**	**Values**
Gravitational acceleration	g	9.81 m/s^2
Density	ρ	1.0137 kg/m^3
Specific heat	c_p	1007.5 J/kgK
Thermal conductivity	k	0.02917 W/mK
Beta	β	2.87e-3 k^{-1}

II. ASSUMPTIONS, GEOMETRY AND GOVERNING EQUATION

Figure 1 provides the illustration of physical model to be use for numerical simulation considering following assumptions.

1. The flow of fluid is laminar and two dimensional.
2. Viscous dissipation is neglected.
3. Internal heat source or sink has not been introduced.
4. The fluid is Newtonian.
5. Compressibility effects is neglected.

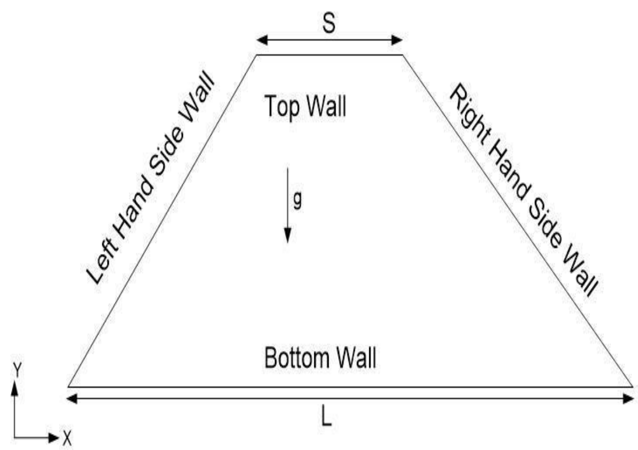

Fig 1: Physical Model

With an objective to find optimized attic shape, ratio for the length of the upper wall and lower wall alters from 0 (isosceles triangle) to 1 (rectangle), which is defined as S/L.

Figure 2 represents the structure of mesh for few of the attic shapes considered for the simulation. Area near the wall of the enclosure is dense for the structure of the mesh. Dense area of the mesh helps in formation of good quality boundary layer near the wall of the enclosure.

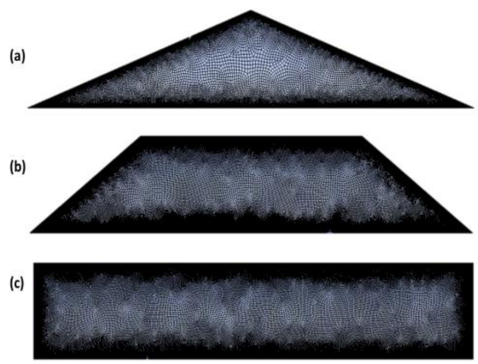

Fig 2 - Mesh for the physical domain (a) S/L = 0; (b) S/L = 0.5; (c) S/L = 1

The fluid properties are assumed to be constant except for the variation of density in the buoyancy term of the momentum equation, which is approximately by the Boussinesq approximation. The governing equations in dimensionless form may be obtained in the following form:

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0 \quad (1)$$

$$U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y} = -\frac{\partial P}{\partial X} + \frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2} \quad (2)$$

$$U\frac{\partial V}{\partial X} + V\frac{\partial V}{\partial Y} = -\frac{\partial P}{\partial Y} + Gr.\theta + \frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial X^2} \quad (3)$$

$$U\frac{\partial \theta}{\partial X} + V\frac{\partial \theta}{\partial X} + \frac{1}{Pr}\left(\frac{\partial^2 \theta}{\partial X^2} + \frac{\partial^2 \theta}{\partial Y^2}\right) \quad (4)$$

Dimensionless variables are defined by

$$X = \frac{x}{L}, Y = \frac{y}{L}, U = \frac{u}{v/L},$$

$$V = \frac{v}{\nu/L}, P = \frac{p}{\rho(\nu/L)^2}$$

$$\Pr = \frac{\nu}{\alpha}, Gr = \frac{g\beta L^3 (T_H - T_L)}{\nu^2}, \theta = \frac{(T - T_L)}{(T_H - T_L)} \qquad (5)$$

Boundary conditions associated with the above governing equations are given by

On hot wall, U = 0, V = 0 and θ = 1

On cold wall, U = 0, V = 0 and θ = 0

III. VALIDATION ANALYSIS

The present model is validated against the results of Saha et. al. [15]. An air filled triangular shaped enclosure has been considered. It has left wall at higher temperature and right wall at lower temperature. Additionally, discrete heating plate has been placed on bottom wall with a length given by "L". Validation exercise has been carried out for the fixed value of Rayleigh Number, S/W and L/W as 105, 0.5 and 0.4 respectively while aspect ratio changes from 0.2 to 1. Physical model for the enclosure is represented in figure 3.

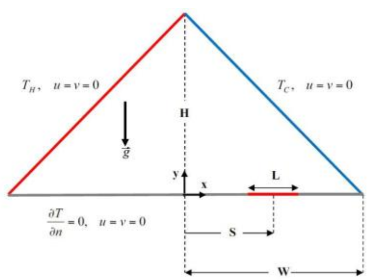

Figure 3: Physical modal for the validation of simulation in reference of Saha [15]

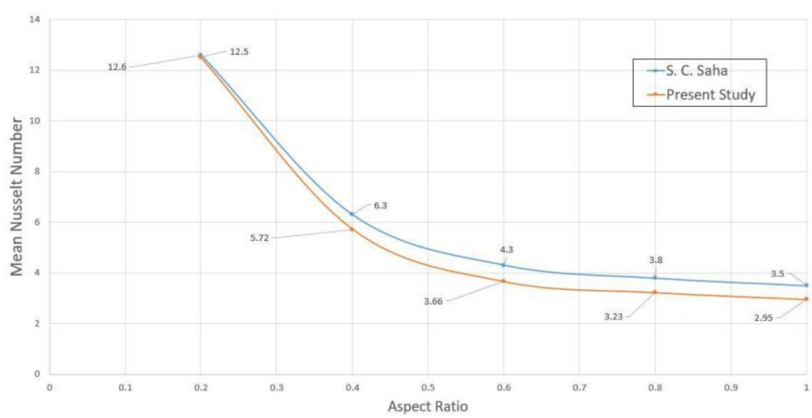

Figure 4: Comparison of mean Nusselt Number between present study and reference study by Saha [15]

Figure 4 shows that both studies follow the same pattern for the various values of aspect ratio. Validation has been concluded with the maximum error of +0.18. This validation study has been considered regarding the selecting parameters of characteristic length to be used for various calculations. In reference of [15], characteristic length has been considered as sum of length of left wall at high temperature and length of discrete heating element for Nusselt Number while it has been considered as altitude "H" (refer figure 3) for Rayleigh Number Calculations.

IV. RESULTS AND DISCUSSION

This section deals with the results in the form of streamlines, isotherm and value of the Nusselt number for the simulation of physical domain (figure 1). Simulation has been carried out at the different values of Grashof Number for the different values of S/L.

4.1. Flow Field Analysis

The problem has been investigated for the thermal analysis of natural convection flow inside trapezoidal shapes enclosure. The result of streamlines are illustrated in figure 5 for the Grashof number 10e4. From streamlines, it has been observed that clockwise rotational vortexes have been generated as a result of natural convection. With the increase in S/L, it has been also observed that the length of vortex generated has been increased due to increase in distance between hot and cold wall. The ow circulation inside the cavity begins when the hot fluid adjacent to left hand side wall rises above due to buoyancy forces and then circulated in a clockwise direction due to the inclination of side towards the right hand side. Consequently, the nature of streamlines does not change significantly with the increase in Rayleigh Number, refer Fig. 6 and Fig. 7. From the figure 8, it has been observed that the strength of the fluid increases with the increase in Rayleigh Number which also states that buoyancy force domination increases over viscous force.

4.2. Heat Flow Analysis

For the isotherm contours, the effect of Grashof number (Gr = 104, 105 and 106) and inclination angle of inclines wall (S/L ratio = 0.1 to 1.0) were examined. Isotherm lines represent the thermal field inside an enclosure. At low value of Grashof number, 104, pattern of isotherm is similar to the conduction as buoyancy driven convection is weaker. From the figure 5, it appears that isotherm lines are densely packed near to hot wall. With the flow of air in clockwise direction, isotherm lines from the top of the enclosure were disturbed providing variation in the range of temperature.

For Gr = 105 and 106, convection initiate dominating conduction for the heat flow which results in increasing value of average Nusselt Number and buoyancy driven flow while the nature for the isotherm remains same. Isotherm for the Grashof Number can be observed from the fig. 6 and fig. 7. Average Nusselt number plot has been represented in figure 9.

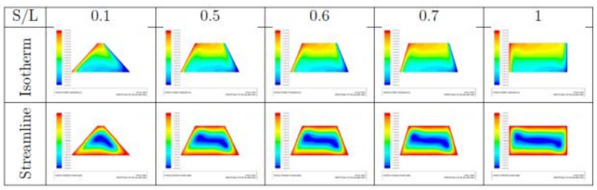

Figure 5: Isotherm and Streamlines for the various value of S/L at Gr. = 104

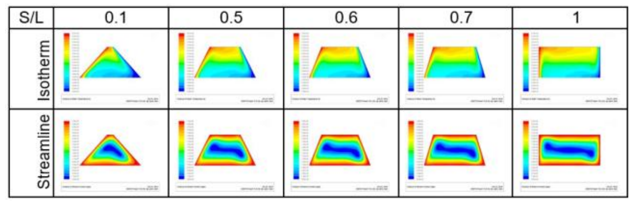

Figure 6: Isotherm and Streamlines for the various value of S/L at Gr. = 105

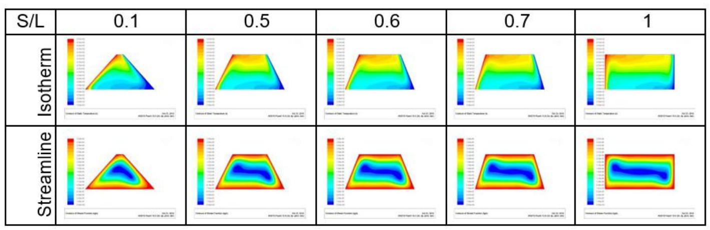

Figure 7: Isotherm and Streamlines for the various value of S/L at Gr. = 106

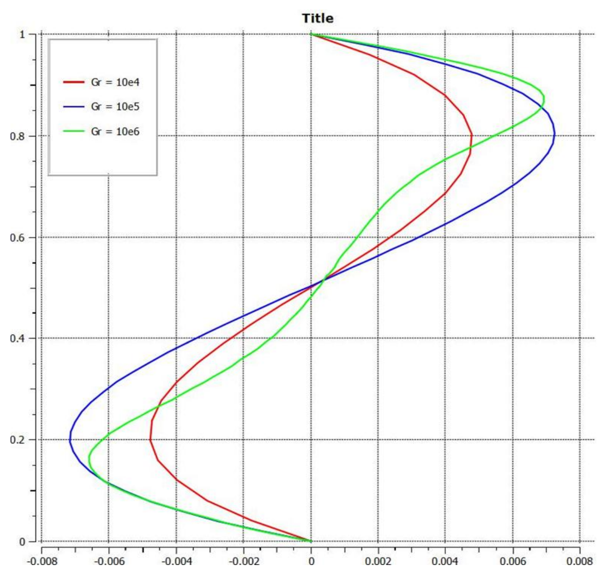

Figure 8: Value of velocity in center of domain along Y-axis

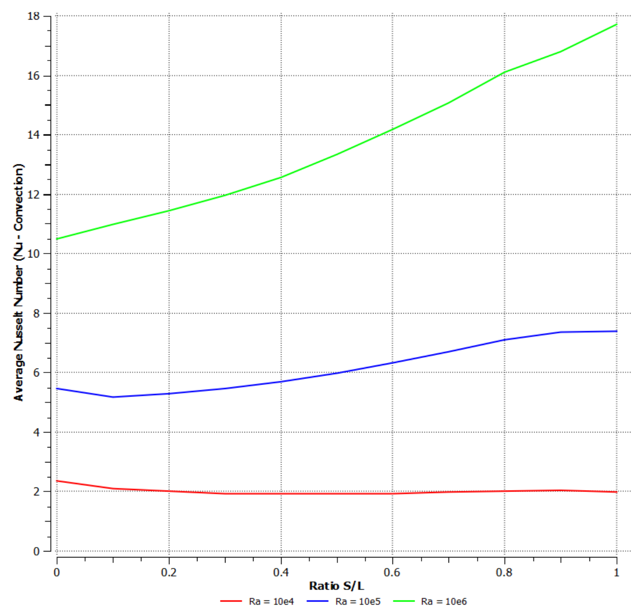

Figure 9: Value of Nusselt Number at Gr. = $10^4 – 10^6$

V. CONCLUSION

This section elaborates the finding of present study for the shape of trapezoidal under three different conditions at different Grashof Numbers.

- After a value of S/L ratio 0.3, value of Nusselt Numbers tends to constant at Gr. 10^4.
- Optimum shape for an attic space of a building can be considered with S/L ratio of 0.2.
- Regarding the aspect ratio to be considered for an attic space, we can refer the study conducted by Saha et. al. [15] and it has been also validated with the computation simulation that after 0.6 aspect ratio, value of Nusselt Number is not decreasing and tends to constant value.

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