# STUDY OF A PASSIVE SOLAR WINTER HEATING SYSTEM BASED ON TROMBE WALL

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## ABSTRACT

In buildings for heating and cooling purpose use a large amount of non renewable energy. Now a day's renewable energy such as solar energy is a suitable solution for reduce the excess use of non renewable energy. Passive solar systems do not use the mechanical or electrical equipments to store and transfer the thermal energy. Trombe wall is a passive solar system and it is based on the natural conduction, convection and heat storage. This works contains numerical study on the passive solar winter heating system. Study the distribution of temperature in wall, living space of room and the effect of outlet position in a system. Analysis can be done for 2-D model and Present work involves natural ventilation and convective mode of heat transfer. Results shows that temperature distributions depend up on the quantity of heat flux gain by Trombe wall and positions of the outlet also affect the performance of the system.

## INTRODUCTION

The earth's atmosphere receives vast amount of solar energy everyday and before it reaches the planet's surface majority of it is reflected back into atmosphere by clouds. The energy demands of the world might be met if a very small amount of the sun's energy is captured very effectively. The process of capturing and utilizing the solar energy is of two types via passive and active solar energy system. The passive solar energy system is of prime importance since it does not involve the use of mechanical devices. In order to transfer and collect solar energy no devices are used in this method. The ability to redistribute and store heat depends on the thermal mass and orientation. The energy consumption by the building is minimized by emphasizing on the architectural design approaches by using the day lighting design and thermal mass instead of depending mainly on fans, lighting system and various other equipments. The method of flow of thermal energy through the building by natural means such as conduction, convection and radiation without any external power is known as passive heating or cooling system. Direct gain passive systems, indirect gain passive systems and isolated gain passive systems are three mostly used types of passive systems. This type of systems is one of the earliest applications of indirect gain systems. They were first projected and developed by a French engineer Felix Trombe and later they were used in different buildings by Jacques Michel. Therefore, these systems are generally called as either Trombe Wall or Michel-Trombe Wall. Trombe wall consists of a south facing glazing and a concrete masonry wall the exterior of which must be a dark color. The glazing admits the sunlight during the day and in a way it also prevents the heat losses at night. Solar heat is captured and trapped by the glass and later it is absorbed by the Concrete wall. It is transferred to the living space by radiation and convection.

## PHYSICAL MODEL AND MATHEMATICAL FORMULATION

Winter heating Models are utilized for analysis and it consists of a concrete wall, glass, inlet vent and outlet vent and air space between glass and wall. The geometry is described using Cartesian coordinate system. 'A' represents origin for the physical model and the positive direction is considered along the x-axis while the positive direction is considered along the y-axis. In winter heating system the inlet vent J is provided near the bottom of the glass and outlet vent K at top of the right side wall. IA represents the glass, BCGF represents the concrete wall, P and Q represents top and bottom interior openings of concrete wall respectively. In this system Q opening closed. CDEF represents the living space. The total length of the model represented by L and height of the model represented by H and 2D analysis is conducted. The Figure 1 shows physical model of the winter heating system. The dimensions of the model are tabulated in table 1

**Table1: Trombe wall model dimensions**

| Parameters | Dimensions (m) |
|---|---|
| Concrete wall width | 0.3 |
| Concrete wall height | 2.4 |
| Room length | 3 |
| Room height (H) | 2.4 |
| Glass thickness | 0.06 |
| Air space | 0.1 |
| width of opening | 0.1 |

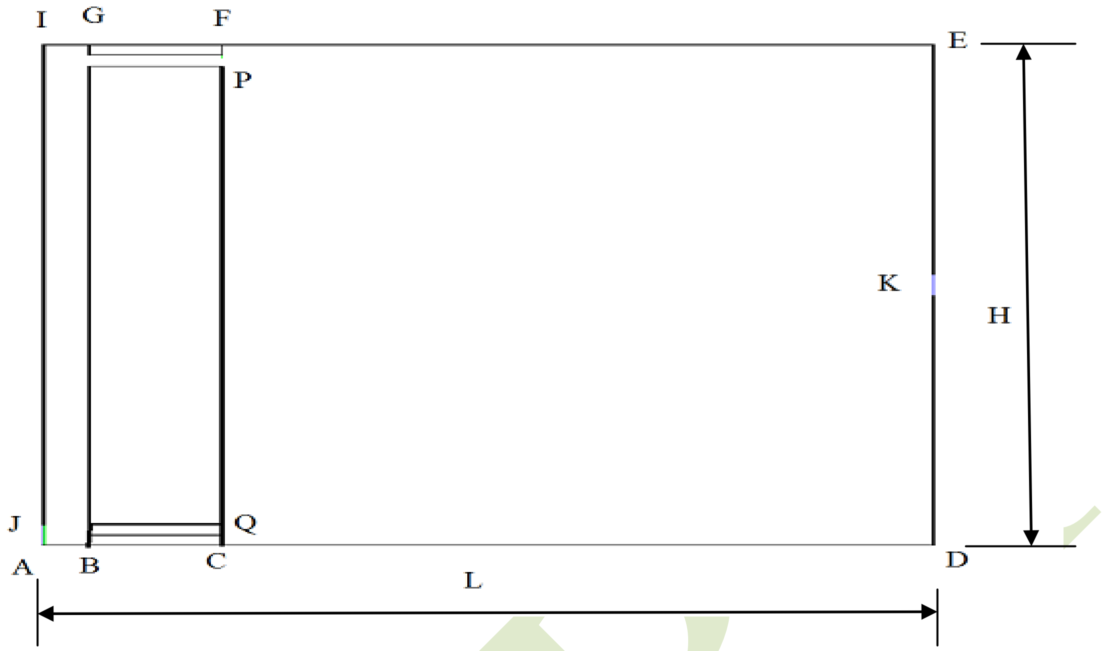


**Fig1: physical model for winter heating system in 2D**

## ASSUMPTIONS

The buoyancy effect is considered, Steady state is considered, and Radiation mode of heat transfer is negligible. For concrete wall, glass and air which properties like density, specific heat and thermal conductivity were considered to be constant.

## GOVERNING EQUATIONS

The partial differential equations expressing the conservation of mass, momentum, energy, turbulence kinetic energy and turbulence kinetic energy dissipation rate represent the governing equation for the present problem

## GOVERNING EQUATIONS IN 2D

**Continuity equation**

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1)$$

**X-direction momentum equation**

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\nu\nabla^2 u \tag{2}$$

**Y-direction momentum equation**

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\nu\nabla^2 v-g[1-\beta(T-T_1)] \tag{3}$$

**Fluid energy equation**

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\nabla^2 T \tag{4}$$

**Heat conduction equation in the thermal storage wall**

$$\nabla^2 T_w=0 \tag{5}$$

**System of non-dimensionalization**

For non-dimensionalization, we define the dimensionless variables as follows:

$$X=\frac{x}{L},Y=\frac{x}{L},U=\frac{uL}{\nu},V=\frac{vL}{\nu},P=\frac{p+\rho gy}{\rho\left(\frac{\nu}{L}\right)^2},\theta=\frac{T-T_1}{L\left(\frac{q}{k}\right)} \tag{6}$$

**Equations in dimensionless form**

$$\begin{aligned}
&\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}=0\\
&U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial Y}=-\frac{\partial P}{\partial X}+\nabla^2 U\\
&U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial Y}=-\frac{\partial P}{\partial Y}+\nabla^2 V+\frac{R\mathrm{a}}{Pr}\theta\\
&U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\frac{1}{Pr}\nabla^2\theta\\
&\nabla^2\theta_w=0
\end{aligned} \tag{7}$$

$$Ra=Rayleigh\ Number=\frac{g\beta\left(\frac{qL}{k}\right)L^3}{\nu\alpha}$$

$$Pr=Prandtl\ Number=\frac{\nu}{\alpha}$$

## BOUNDARY CONDITIONS

The hydrodynamic boundary conditions are no-slip conditions on all the rigid wall surfaces and atmospheric pressure at the openings on the external walls. The thermal boundary conditions are as follows:
Air entering the enclosure through an opening on the external wall is assumed to be at $T_1$. Air leaving any opening on an external wall is assumed to obey the zero gradient condition, i.e.,$\frac{\partial T}{\partial x} = 0$. On the vertical side of the thermal storage wall exposed to solar radiation, the interface condition is:

$$q_s = k\,\frac{\partial T}{\partial x} - k_w\,\frac{\partial T_w}{\partial x}$$

The above interface condition states that the solar radiation flux $q_s$ is partly conducted into the air in the chimney (first term on the right hand side) and partly into the thermal storage wall (second term on the right hand side). Here it should be noted $q_s$ is the net (or effective) solar radiation flux that remains after passing through the glazing. This flux falls on the side of the thermal storage wall exposed to the sunlight side. The other vertical surface of the thermal storage wall is in communication with the room air and does not receive any flux from external side. Hence the interface condition for this surface becomes:

$$k_w\,\frac{\partial T_w}{\partial x} = k\,\frac{\partial T}{\partial x}$$

All other surfaces of part surfaces, horizontal or vertical are assumed to be adiabatic, i.e., on these walls:$\frac{\partial T}{\partial n} = 0$, where $n$ represents either $x$-coordinate or $y$-coordinate, as the case may be. The thermal boundary conditions give rise to another dimensionless parameter, namely, $k_w/k$. This is the thermal conductivity ratio of the wall to that of air. After non-dimensionalization, the interface conditions become:

$$1 = \frac{\partial \theta}{\partial X} - \frac{k_w}{k}\frac{\partial \theta_w}{\partial X}$$

on the radiation side of the thermal storage wall, and

$$\frac{\partial \theta}{\partial X} = \frac{k_w}{k}\frac{\partial \theta_w}{\partial X}$$

on the wall-room-air interface. The adiabatic conditions become:

$$\frac{\partial \theta}{\partial N} = 0$$

Where $N$ is either $X$ or $Y$.

Apart from the above we have number dimensionless geometrical parameters such as $H/L$.

## COMPUTATIONAL PROCEDURES TO SOLVE THE PROBLEM

Two software packages GAMBIT and ANSYS FLUENT version.6.3.26isused for create 2-D models. The models are created by using co-ordinate system and apply the mesh on the 2-D model in Gambit. Specified the boundary zones and types of continuum in Gambit and export the meshed model to fluent from the Gambit. Initially in Fluent read the gambit file and in which governing equations are used based on the control volume based discretization. Buoyancy effect considered because in this system buoyancy effect play a vital role, so activated the bossiness model. The pressures, density and temperature are deposit at the normal nodal points and velocity is found at the staggered nodes. Residual for all variables is$10^{-6}$. The CFD model used the basic settings are shown below table 2

**Table 2: Basic settings used in CFD model**

| Setting | Model | Reason |
|---|---|---|
| Density | Boussinesq approximation | To consider buoyancy effect |
| Energy | Activated | To consider heat transfer |

**Table 3: zones type with continuum Condition chosen**

| zone type | continuum condition |
|---|---|
| Concrete wall | solid |
| Room interior | fluid |
| Air space | fluid |

**Table 4: zones type with boundary condition chosen**

| zone type | boundary condition |
|---|---|
| glass | wall |
| Concrete wall | wall |
| inlet | pressure inlet |
| outlet | Pressure outlet |
| Roof | wall |
| Ground floor | wall |
| Wall openings | interior |

**Table 5: Under relaxation factor**

| | |
|---|---|
| PRESSURE | 0.3 |
| DENSITY | 1 |
| BODY FORCE | 1 |
| MOMENTUM | 0.7 |
| ENERGY | 1 |

## RESULTS AND DISCUSSIONS

The function of Trombe wall taken in this analysis is the attitude to use solar energy in order to decrease building energy required for heating. A result of the optimization analysis is show that it is Possible to decrease the environmental burdens and energy demand through Trombe walls. Many results are obtained by varying the quantity of heat flux and positions of outlet. Analyze the temperature distribution and velocity of air in the winter heating system. From the result understanding bouncy effect gives the fundamental driving forces. Low dense fluids have low gravitational force pulling them down, and will rise relative to high dense fluids.

**Outlet vents at the top position:** In winter heating system the outlet vent at the top position of the right side wall the heated air flows through air space, wall interior and distribute in living space it gives heating effect in day time . The inlet vent place at bottom of the left side of glass, the direction of flow of air is the fresh air is come from atmosphere through inlet and move upwards in air space and circulates in living space. Here this model has outlet position at top so there some chances of warm air quickly reach the outlet. Some times over heating happens when more heat flux gain by the wall. The temperature distribution and velocity plot as shows in below figures ‘2’ and ‘3’.

**Outlet vent at the middle position of the right wall:** In this model the outlet vent is present at middle position of right side wall. This system is better compared to top position vent system because the reason is the quickly escape chances of warm air is less comparatively. The temperature distribution and velocity plot as shows in below figures ‘4’ and‘5’.

**Outlet position at bottom:** In this system the outlet position at the bottom of the right side wall. Warm air circulates the living space and here warm air cannot escapes easily. This system is good compared both the system. The temperature distribution and velocity plots as shown below figures ‘6’ and ‘7’.

**Outlet vent at the top portion**

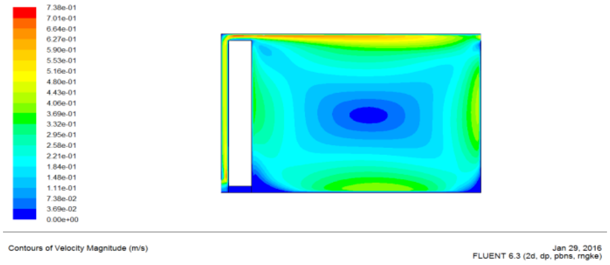


**Fig: 2**

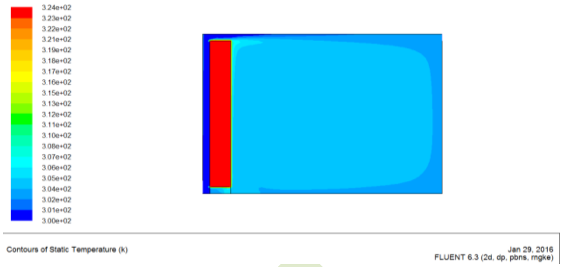


**Fig: 3**

**Out let vent at middle portion**

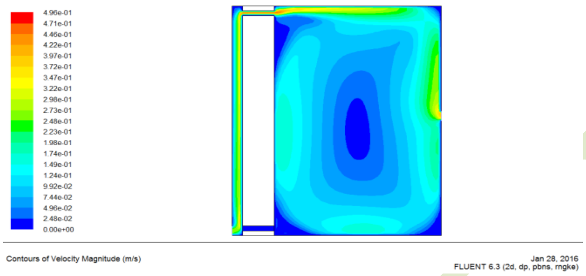


**Fig: 4**

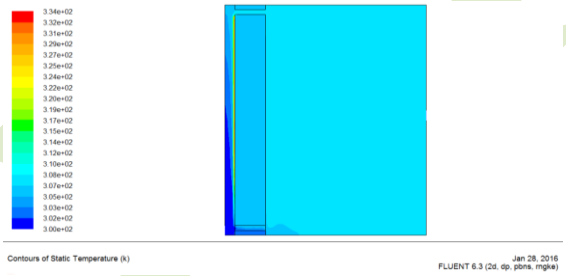


**Fig: 5**

**Out let vent at bottom portion**

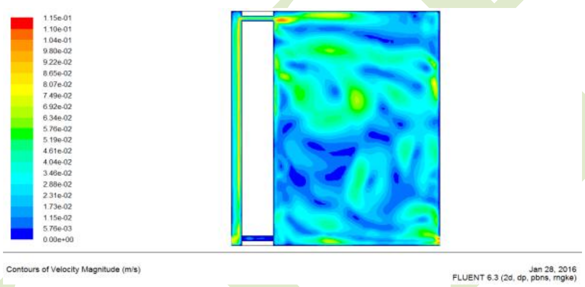


**Fig: 6**

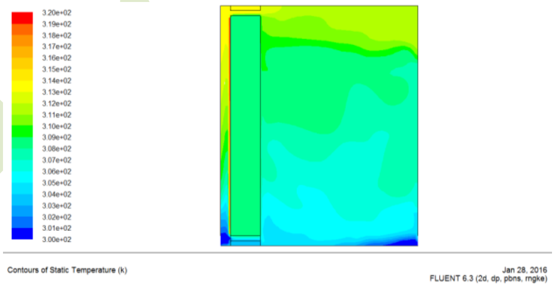


**Fig: 7**

## CONCLUSIONS

The study clearly shows that Trombe wall system can be an effective passive solar system from the view point of energy savings, indoor temperature comfort and sustainability assumed the proper configuration and maintenance. The principle of passive solar space-heating systems is the utilization of solar energy in the heating of buildings without the help of technology. The glass is should be south- facing in passive heating system because most of the solar gain is obtained through these glass. From the results of 2D analysis showed that the hot air entered the living space and it gives the heating effect. Temperature of the wall is directly proportional to the quantity of heat flux hits on the wall. In winter heating system the presence of buoyancy effect was seen heating effect on living space. The velocity of air in Trombe wall system is dependent on temperature of the wall and glass. The efficiency of the winter heating system can vary with the position of the outlet vent. In winter heating system the out let position at bottom is better compared top and centered.

## FUTURE SCOPE

Now a day's our main goal is to reduce fossil fuel use in living spaces, the future research should focus around this goal. The present analysis is carried out by considering a steady state, varying the position of inlet and out let vents, varying the quantity of applied heat flux on the wall .Further studies can be carried out considering the following factors.

- Varying the types of wall.
- Varying the thickness of wall
- Considering a transient effect.
- Considering the effect of radiation.

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