NUMERICAL INVESTIGATION OF NATURAL VENTILATION IN A ROOM THAT INTEGRATED WITH SOLAR CHIMNEY OF METAL FOAM ABSORBER

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Abstract

In this paper, Numerical investigation of the influence of inserting the metal foam to the solar chimney to induce natural ventilation in the test room is analyzed in this work. Two types of solar chimneys which without insertion of metal foam absorber and with insertion of metal foam absorber are designed with dimensions of length × width × air gap (2 m × 1 m × 0.3 m) and size of the test room (1.5 m × 1.5 m × 1 m). Four incline angles are tested (30°, 45°, 60°, 90°) for each chimney and two length of tower inlet (30 cm, 40 cm). ANSYS FLUENT program (version 14.5) used to simulate this model and solve the governing equations by finite volume technique. The results showed that the air flow velocity at the outlet of ventilation solar chimney increases of the model with copper foam absorber about 33% from the model without copper foam absorber at constant inclination angle, therefore this gives indication of the important of insertion the copper foam as an absorber media in the ventilation solar chimney.

Keywords: Solar Chimney, Low-Energy House, Ventilation, Metal Foam, Porous Media, ANSYS FLUENT

I. Introduction

Solar energy is one of the potential alternative energy sources, is particularly attractive because it is renewable, nonpolluting and widely available on-site. Solar energy is being used for many purposes, such as electricity generation, refrigeration and air-conditioning applications. Solar chimneys are one kind of renewable energy technologies, which enhance the natural ventilation of buildings.

Ventilation is the process of supplying and removing air by natural or mechanical means to and from any space. Indoor air quality can be improved when proper ventilation procedures are followed. These procedures remove some of the air with pollutants and dilute the remaining pollutants with acceptable outside air. Ventilation air is a part of the supplied air from outdoors plus any recirculated air that has been treated [XI]. Ventilation is one of the significant options for supplying...
buildings thermal satisfactory. The increase realization of the energy utilize impacts on environment and cost, utilization of natural-ventilation has increasingly become a desirable technique for lowering energy utilize, price and for producing acceptable interior environmental condition and keeping a healthy, relaxation, and constructive interior climate instead of the more common method of mechanical ventilation usage [V]. Thermal buoyancy is sometimes referred to as the stack effect or the chimney effect. Because of the difference in density, pressure differences will be created, and that lead to pull air in and out of a building through special ventilation openings [II].

Many numerical and theoretical investigations that were carried out to cover the uses of the solar chimney in ventilation with similar geometries and operating principles.

[XIV] developed the applicability of analytical parameteric for studding solar chimney roof combined with spread sheet as a wind cooling cavity using computer program. This paper presents a description of detailed and sizing of such system. Space between the external glazing of solar chimney and the external leaf is optimized. The proposed solar chimney roof is capable to generate maximum air velocity is about 1.1 m/s and an air flow rate up to 1.6 kg/s derived in the chimney at a mean incident solar radiation of 850 W/m². The average mass flow rate is create as 1.3 kg/s at velocity of air in the chimney about 0.9 m/s and incident solar radiation 575 W/m². The cooled cavity can produce a mass flow of 0.35 kg/s at a speed of wind 4.0 m/s. The system may be integrated with a stand-alone building or with a group of buildings. It is however, suitable to be used to more than one floor construction.

[XIII] predicted the natural ventilation in buildings by SC alone, where a computer model was developed. The simulation program was based on the solution of 3-D steady, at laminar conservation equations of mass, momentum and thermal energy with a suited set of boundary conditions. The equations were discretized by finite difference formulation and solved by the marker and cell scheme (MAC) scheme. Results showed that the solar chimney alone can induce a sufficient ventilation rate for ensuring peoples thermal comfort, with outdoor temperature below 37 °C.

[VI] presented a mathematical model for computing the cooling performance of a wind tower in a dry and hot district, Yazd, in Iran. In this work, the influences of parameters such as the temperature of output and input air, the quantity of water vaporization, selection of the materials used in the wind tower walls, tower height, the relative humidity and velocity of the wind were investigated. A computer program that employments an iterative solution process was constructed with language C++ to solve the governing energy equations. At the peak of the cooling system performance, temperatures of air is capable to decreasing by 10–15 °C dependent on climate and environment conditions. In the height 2 m of the tower, temperatures of air is reduction (8–12 °C) when sprayers are separated uniformly through it. The consumption rate of water is about 0.025 kg/s and the rate of output cooling is approximately 100 kW, without consuming any fuels or using mechanical force.

[I] conducted a numerical and analytical study for the effect of SC inclination angle on the indoor flow pattern and ventilation ratio. FEM simulation by ANSYS.
was used to predict the flow pattern. Results of simulation were compared with the published experimental results. A mathematical model was built for an overall energy balance through SC and then solved iteratively by program language. Results showed that the optimum mass flow rate of air through SC achieved between (45 to 70 degrees) at 28.4 latitude. Also, a correlation to predict the ventilation ratio that was developed, with condition of solar intensity approximately 500 W/m², and width range of chimney at (0.1-0.35) m. All results of correlation were acceptable with different inclination angles.

[XII] studied numerically the indoor thermal comfort and natural ventilation via frugal combine airflow of multi zone by using the software of COMIS-TRNSYS (Madison, WI, USA). This paper improves thermal ventilation multi-zone model which an integration of solar chimney and cooling tower of direct evaporative in Egypt. The findings show that the indoor temperatures decreases about 10°C to 11.5°C less then outdoor temperatures due using integrated system reacts with climate situation and room environment. The results show that the minimum air change per hour is 2 ACH which achieved the minimum requirement of ACH without coefficient of pressure. Under the influence of solar radiation only, the system is applicable to generate 130.5 m³/h.

[X] studied three different materials of cooling pad as Coconut coir, Vetiver, Straw and Cellulose which using a system containing of an Evaporative Cooling Cavity (ECC) and a Solar Chimney (SC). The influence of parameters of main geometric on the performance of system has been considered. Also, the ability to achieve the requirement of thermal comfort of persons has been studied. The result shows that the cellulose cooling pad which gives higher efficiency which saturated efficiency 47.5% at velocity of air 0.10 m/s. It showed that the higher evaporation of water into air due greater wetted surface area and higher velocity causes less contact time for evaporation of water.

[XV] investigated of low energy technique for natural ventilation driven by solar chimney integrated with evaporative cooling to provide appropriate thermal comfort in a house space. Computational fluid dynamics (CFD) method used for simulation of house space system via ANSYS Fluent. The Zhang model was combined with the noval model of system in computational fluid dynamics (CFD) model for prediction the performance of overall and local thermal comfort space. A region placed in Riyadh was selected for dry and hot weather and 14 h and 17 h hours were chosen for representation. The result shows that when using a comfort scale changing from very comfortable at +4 to very uncomfortable at -4, the thermal comfort level of 1.42 at 14 h and 1.96 at 17 h. Wherefore when used the novel system, it noticed that the overall thermal comfort is improved significantly. Energy savings getting 10% are recording through all hours.

From the previous studies, it is concluded that the passive solar chimney effect can be used in different modes, like heating, cooling, and ventilation. All modes depend on the effect of buoyancy force generated. That force (buoyancy) impacts the quantity of air volume flow rate which ventilated by the solar chimney and cooled via evaporative cooling, so employing the heat absorber media leading to
increase heat transfer and temperature difference which in turn leads to increase buoyancy force.

The efficiency of air solar chimney is usually low and the main problems of solar chimney is a low value of heat transfer coefficient and thermal capacity of air, the reason for these problems to the physical properties of air. Also, the heat losses from solar chimney are high about 55% from the incident solar radiation, which reduces the performance of solar chimney [VII]. In the present work, Highly effectual techniques have been utilized in the preceding researchs for thermal-performance improvement that include the procedures of decreasing the losses of heat in the solar chimney. It include of insertion of porous media in flow passage of solar chimney as an absorber plate is a passive method which gives a high heat transfer rate as shown in figure 1. Metal foams are usually porous media with low density and novel structural and thermal properties. Metal foam is presently the most popular heat sinks utilized material. It has a comparatively high heat conduction that, is light, is relatively low price, and resistant to corrosion. The solar chimney with absorber of metal foam was carried at weather conditions of Baghdad-Iraq and compared with the solar chimney of conventional flat plate absorber.

Fig. 1: 3D Model of test room with ventilation solar chimney

II. Numerical Simulation

A physical model and numerical simulation depict the computational model that depends on the governing equations (GE), to describe the fluid flow, heat transfer and heat storage in different modes. Two computational models are constructed, one for heating, and the other one for ventilation mode. Heating and ventilation modes, both are almost common in description of the physical model and numerical solution. Both modes consist from steady state part to describe the heat transfer and fluid flow behavior for airusing ANSYS FLUENT version (14.5). Other part, present the transient heat storage in the combined material for solid and liquid of mushy zone.
i. Geometry

The geometry models created in SOLIDWORKS, version 2016 consists of solar chimney, test room, absorber flat plate and cooper foam absorber. The size of test room is (1m*1.5m*1.5m) and the size of solar chimney is 2m length, 1m width and 0.30m depth. The thermal insulation was made from fiber glass and the thickness is 3cm. Figure 1 shows a physical geometry of the system used in this work.

![Physical geometry of the system](image)

**Fig. 1:** Physical geometry of the system.

**Fig. 2:** Schematic diagram of the model with porous foam.

ii. Governing Equations

To obtain a mathematical simulation for steady state, free convection heat transfer in ventilation of solar chimney, several assumptions have been made:

- Three-dimensional of conservation equations.
- Steady state Incompressible flow.
- Conduction three-dimensional heat transfer through glass cover and absorber plate.
- Air flow in the channel has been considered turbulent according to the value of Rayleigh number.
- The Boussinesq approximation was used to account for the density variation.
- All properties are evaluated at an average temperature.
A key modeling equations in FLUENT for fluid flow and heat transfer in solar chimney from free convection were the conservation of mass, momentum, energy and the equation of turbulence. They can be written in Cartesian tensor form as:

**Continuity Equation**

The continuity equation can be written as

\[ \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 \]  

(1)

**Momentum Equation**

The momentum equation can be formulated as

\[ \nabla P = -\frac{1}{\rho_0} \nabla P + \frac{\mu}{\rho_0} \nabla^2 \mathbf{v} + \frac{g}{\rho_0} [1 - \beta (T - T_0)] \]  

(2)

**Energy Equation**

The energy equation can be formulated as

\[ \nabla \cdot \mathbf{v} T = \alpha \nabla^2 T \]  

(3)

Where

\[ \alpha = \frac{k}{\rho C_p} \]  

(4)

iii. Turbulence Model

The Standard k-ε Model

In Fluent, the standard k-epsilon (k-ε) model is the most widely used because of its robustness and is therefore valid only for fully turbulent flows, precision and relatively its low cost in computation time. This model is an example of two-equation models; turbulent kinetic energy and dissipation rate are obtained from the following equation [III].

\[ \nabla \cdot (\rho \mathbf{v} \mathbf{k}) = \nabla \cdot \left[ (\mu + \frac{\mu_t}{\sigma_k}) \nabla \mathbf{k} \right] + C_{d1} \mathbf{k} - \rho \varepsilon \]  

(6)

\[ \nabla \cdot (\rho \mathbf{v} \mathbf{\varepsilon}) = \nabla \cdot \left[ (\mu + \frac{\mu_t}{\sigma_\varepsilon}) \nabla \varepsilon \right] + \rho C_{d1} \mathbf{k} - \rho C_{d2} \frac{\varepsilon^2}{k + \varepsilon} + C_{d3} \frac{\varepsilon^2}{k + \varepsilon} \]  

(7)

**iv. Mathematical Model Porous Media**

In the present work, using copper foam as absorbing media is novelty work in the solar chimney for ventilation. Therefore, it required an appropriate mathematical model to deal with the porous media as absorber media and with heat transfer as convection and conduction and radiation in ANSYS fluent software. The porous jump is the suitable technique can be utilized to the forming this model because, The
thickness of the porous metal foam is small compared with the length of the porous metal foam [XIII]. These mathematical models can explain the physics of air movement through the pore structure and react with it.

The additional source $S'$ was added due to add a pore model in mathematical model of the momentum equation;

$$\tilde{S} = -(\frac{\epsilon}{\alpha} \tilde{V} + C_f \frac{1}{2} \rho |\tilde{V}| \tilde{V})$$

(6)

The first term in the equation (6) is the Darcy term and the second term is the Forchheimer (or inertia resistance) term, metal foam resistances to the flow of air where $\alpha$ and $C_f$ are the permeability and the inertial drag factor respectively, of the metal foam. They are calculated by the following [VIII];

$$\alpha = 0.00073 (1 - e)^{-0.224 (\frac{e}{d_p})^{-1.11 (d_p)^2}}$$

(7)

$$C_f = 0.00212 (1 - e)^{-0.132 (\frac{e}{d_p})^{-0.163}}$$

(8)

Where $e$, $d_f$ and $d_p$ are porosity of the porous copper foam, the ligament diameter and the pore diameter respectively.

The effective thermal conductivity $k_{eff}$ is estimated as the volume average of the conductivities of solid and fluid porous material which are denoted by [IX];

$$k_{eff} = \varepsilon k_f + (1 - \varepsilon) k_s$$

(9)

v. The Discrete Ordinate (DO) Model

The discrete ordinate model used to solve radiation heat transfer. This model only deals with semitransparent surface and very wide ranges of optical thickness.

The radiative transfer equation (RTE) for an absorbing, scattering medium and emitting in the direction $s$ at the position $r$ is express as following; [IV]

$$\frac{dI(r,\hat{s})}{ds} + (u + \omega_s) I(r,\hat{s}) = \alpha u + \omega_s \int \Phi(r,\tilde{s}) d\Omega$$

(10)

Where;

$I(r,s)$ is the solar radiation intensity

$(\sigma)$ is Stefan - Boltman constant.

$(n)$ is the refractive index,

$(a)$ is the coefficient of the absorption,

$(\sigma s)$ is the coefficient of the scattering,
vi. Computational Model

CFD Model Setting and Parameter

For the present work a second – order upwind scheme was used formomentum and energy equations, standard simple was used for pressure. Under – relaxation factors were used, 0.3 for pressure, 1 for density, 1 for body forces, 0.7 for momentum equation and 1 for energy equation. A flowsolution is considered to have converged after all equation residuals have been reduced to 1000-800 for energy equation and 1000-400 for continuity equation, they required (1200 – 1400 ) iterations in models (I) and (II) as shown in Figure 3. The flow solution is considered to have converged after all equation residuals have been reduced to 1000-700 for energy equation and 1000-300 for continuity equation, they required (1200 – 1250 ) iterations in this model as shown in Figure 3.

Fig. 3: ANSYS FLUENT Iteration of The work

Meshing

An acceptable mesh is crucial in reaching a correctly converged solution that captures all the key parameters of a simulationusing ANSYSFLUENT. For the current simulation, enough nodes are needed to be placed near the boundaries to capture boundary layer flow, as well as the temperature gradient. Too many nodes in the system may increase the computational resources and timewithout providing additional resolution. For these two reasons, a mesh fine enough to accurately capture the appropriate details of the fluid flow and heat transfer is required. From many practical tests as spacing of element of ( 0.1cm ) was enough to accurately capture the appropriate details of the fluid flow and heat transfer for all tests, Figure 4 shows the mesh generated in this work.
Boundary Conditions

The associated boundary conditions necessary to complete the formulation of the present work was shown in table 1:

**Table 1: Thermal Boundary conditions of the physical model**

| Boundary         | Type           | Parameter value          |
|------------------|----------------|--------------------------|
| Tower inlet      | Pressure inlet | $T= T_a, P=1$ atm.       |
| Chimney outlet   | Pressure outlet | $T= T_a, P=1$ atm.       |
| Absorber plate   | Wall           | Convection + radiation   |
| Glass roof       | Wall           | Convection + radiation   |
| Room             | Wall           | Fixed heat flux          |

Material Properties in Fluent

The materials properties that are used are summarized in Table 2 and shown in figure 5.
Table 2: Physical properties of materials

| Physical property          | Absorberplate | Glassroof | Insulation | Air          |
|----------------------------|---------------|-----------|------------|--------------|
| Density kg/m³              | 8978          | 1900      | 700        | Boussinesq   |
| Specific heat J/kg.K       | 381           | 837       | 2310       | 1006.43      |
| Thermal Conductivity W/m.K | 387.6         | 0.91      | 0.137      | 0.0242       |
| Viscosity kg/m.s           | -             | -         | -          | 1.7894e-05   |
| Refractive index            | 1             | 1.562     | 1          | 1            |

Fig. 5: Schematic diagram of the physical domain.

Operating Conditions

The operating pressure selected for the present work is 101.325Kpa, the reference pressure location were \((x = 0 \text{ m}, \ y = 0 \text{ m})\), and the gravity components for inclined channel or vertical channel was \((x = 0 \text{ m/s}^2, \ y = -9.81 \text{ m/s}^2, \ z = 0 \text{ m/s}^2)\). Table (3) shows the properties conditions of the porous metal foam.

Table 3: Properties conditions of the porous metal foam.

| Pores per inch (PPI) | Porosity (p) (%) | Permeability (K)(m²) | Inertial Coefficient (C) |
|----------------------|------------------|----------------------|--------------------------|
| 10                   | 0.93             | 7.859 x 10⁻⁸         | 0.17                      |

For the physical properties of air, the Boussinesq model was used for density in the present work

\[
\rho = \rho_0 [1 - \beta (T - T_0)]
\]

(11)
where: $T_o$ is taken as the inlet temperature that $\rho_o$ is the density at $T_o$, $\rho$ is the density at $T$, and $\beta$ is the thermal expansion coefficient.

III. Results and Discussion

Two identical rooms with ventilation solar chimney are studied numerically and analyzed to examine the impact of using metal foam absorber plate to the solar chimney. The numerically studies are established for selected days numerically to examine the thermal performance of the designed solar chimney and the impact of using metal foam on the heat transfer characteristics, also, effect of used solar chimney for ventilation of the room and quantity of air change per hour ventilated. The thermal performance of solar chimney as well as investigating the effect of different inclination angles ($30^\circ$, $45^\circ$, $60^\circ$, $90^\circ$) and different area of tower inlet was investigated. The parameters that was investigated: temperature of mean absorber plate, mean air temperature inside the solar chimney gap, outlet air temperature, absorber wall temperature, air temperature distribution in the mid space of the gap, mean exit air velocity, air volume flow rate, ACH (air change per hour), chimney thermal performance as well as useful energy for different chimney inclination angles.

III.i. Temperature Distribution

The variation of the mean temperature absorber plate for the two chimneys without and with metal foam insertion presents in figures (6 a-h), with time at chimney inclination angle ($30^\circ$, $45^\circ$, $60^\circ$, $90^\circ$) respectively for different dates. The minimum value of absorber plate mean temperature with metal foam and for without metal foam are ($63$ and $106$) $^\circ$C at a tilted angle equal $60^\circ$. It clear that the temperature of metal foam absorber plate is lower when it compares to the temperature of absorber plate without metal foam. The airflow across the metal foam absorber plate caused a decreasing in the mean absorber plate temperature, because the air is passed over, through and lower the metal foam plate while without metal foam the air is passed upper the absorber plate only. The maximum mean plate temperature variance that obtained between the chimneys attained to $6^\circ$C at $30^\circ$, $8^\circ$C at $45^\circ$, $13^\circ$C at $60^\circ$ and $21^\circ$C at $90^\circ$ chimney inclination angle. It can be noticed that the maximum mean plate temperature difference increased as the chimney inclination angle is increased. That the maximum temperature of absorber plate is established at $60^\circ$ incline angle.

III.ii. Air Temperature Distribution

Figures (6 a-h) shows the variation of the mean air temperature through inside the chimney gap for both solar chimneys without and with insertion of metal foam, for various chimney inclination angle and different dates. highest temperature of air flow for the chimney without insertion of metal foam attained to $36^\circ$C for $60^\circ$ and $35^\circ$C for $45^\circ$ and $33^\circ$C for $30^\circ$ and $29^\circ$C for $90^\circ$, although with the insertion of metal foam the solar chimney produces air flow with temperatures of $42^\circ$C for $60^\circ$ and $39^\circ$C for $45^\circ$ and $38^\circ$C for $30^\circ$ and $32^\circ$C for $90^\circ$. The variation of outlet chimney air temperature present in figures (6 a-h) for different inclination angles for each solar.
chimney without and with insertion of metal foam. The maximum temperature value of the outlet air for the chimney without insertion of metal foam rise to 35°C for 60° and 34°C for 45° and 32°C for 30° and 29°C for 90° and for the solar chimney with insertion of metal foam the temperatures of outlet air are 41°C for 60° and 38°C for 45° and 37°C for 30° and 31°C for 90° for the periods of time in between 12:00 PM at maximum heat flux 900 W/m². It is clear that the outlet air temperature for solar chimney with metal foam insertion higher from solar chimney without metal foam insertion at any inclination angle. The value of the outlet chimney air temperature at 60° incline angle gives the maximum difference of 6°C between the chimney of without and with insertion of metal foam.

![Diagram](https://via.placeholder.com/150)

a- Conventional ventilation chimney $\theta=90$

![Diagram](https://via.placeholder.com/150)

b- With Copper foam absorber $\theta=90$
c- Conventional ventilation chimney $\theta=60$

d- With Copper foam absorber $\theta=60$

e-Conventional ventilation chimney $\theta=45$
f- With Copper foam absorber $\theta=45$

g- Conventional ventilation chimney $\theta=30$

h- With Copper foam absorber $\theta=30$

Fig. 6: Temperature counters conventional and with copper foam at different angle.

III.iii. **Air Streamline and Velocity**

Figures (7 a-h) presents the variation of the mean air velocity for the chimney without insertion of metal foam with different chimney inclination angles and
selected dates. As shown in Figures (7 a-h) that the mean air velocity is increased as
the tilted angle increased this can be attributed to the fact that with increase the tilted
angle of solar chimney the reversed flow that induced by natural convection at the
upper section of the chimney plate become less effective and weak cause the air
velocity to increase.

Figures (7 a-h) conduct The variation for the mean air velocity for the two
chimneys without and with insertion of metal foam, for chimney inclination angle
(30°, 45°, 60°, 90°) respectively for different dates. It clear that the air velocity with
insertion of metal foam is higher than for without metal foam solar chimney. The
maximum values of solar chimney mean air velocity without insertion of metal foam
are 0.6m/s for 60° and 0.5m/s for 45° and for solar chimney with insertion of metal
foam the mean air velocity are 0.9m/s for 60° and 0.8 m/s for 45° at maximum heat
flux 900 W/m².

The disturbance that made by existence of metal foam, additionally the
increase in the surface-area lead to increase heat transfer among the surface area with
the moving fluid (air) inside chimney from the room. That cause a higher air velocity
at the exit and increasing in the ventilation rate that the enhancement can be
conducted from the insertion of metal foam.

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![Diagram](image1)

a-Conventional ventilation chimney θ=90

![Diagram](image2)

b- With Copper foam absorber θ=90

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c- Conventional ventilation chimney $\theta=60$

d- With Copper foam absorber $\theta=60$

e- Conventional ventilation chimney $\theta=45$
Fig. 7: Streamline of air velocity for conventional and with copper foam at different angle.

f- With Copper foam absorber $\theta=45$

g- Conventional ventilation chimney $\theta=30$

h- With Copper foam absorber $\theta=30$
III.iv. Area of Tower Inlet

Figures (8i-ii) shows the variation of the mean air velocity for the chimney with insertion of metal foam with for different width of tower inlet (30 cm and 40 cm). As shown in Figures (8 i-ii) that the mean air velocity is decreased as the area of tower inlet increased, this can be attributed to the fact that with decrease the the area of tower inlet of the room, the ventilated flow (velocity of air) through solar chimney is increase. Figures (8 i-ii) conduct the variation for the mean air velocity for the two chimneys with insertion of metal foam, for chimney inclination angle 45° for different width of tower inlet (30 cm and 40 cm). The maximum values of solar chimney mean air velocity with insertion of metal foam are H=30 cm and 0.8 for H=40 cm for same chimney angle 45° and at maximum heat flux 900 W/m².

![Image](image1)

i- With Copper foam absorber θ=45 H=30 cm

![Image](image2)

ii- With Copper foam absorber θ=45 H=40 cm

Fig. 8: Stream line of air velocity for copper foam at different tower inlet area.

III.v. Air Change Per Hour (ACH)

The air change per hour ACH variation for the two chimneys without and with insertion of metal foam shown in figure 8, for chimney inclination angle (30°, 45°, 60°, 90°) respectively for different dates. The maximum value of the air change per hour without insertion of metal foam solar chimney reaches 280 1/hr for 60°, 230 1/hr for 45° at maximum heat flux 900W/m² and for with insertion of metal foam solar chimney the air velocity are 450 1/hr for 60° and 380 1/hr for 45° at maximum heat flux 900W/m². As shown in the figure 8 that present the ventilate rate and the ACH the general trends are similar with the air velocity
distribution. That the (volume flow rate) and ACH are directly proportional to the air velocity which greatly effect by its value. It clear that the ACH (air change per hour) greater for solar chimney with insertion of metal foam compared with the solar chimney without insertion of metal foam.

![Graph showing ACH vs inclination angle]

**Fig. 9:** Air change per hour (ACH) for the room with ventilation solar chimney

**V. Conclusion**

The room with ventilation solar chimney has been analyzed numerically to conduct natural ventilation and investigate the enhancement in the characteristics of heat transfer and the solar chimney thermal performance that was achieved by integrating the copper foam absorber plate in the solar chimney. This study is carried out on two solar chimneys with insertion of metal foam and without metal foam under maximum heat flux. The following conclusions are obtained from the present work are:

i. The mean plate temperature with copper foam absorber is higher than model of without copper foam absorber.

ii. The air temperature with copper foam absorber is higher than model of without copper foam absorber.

iii. The air flow velocity at the outlet of ventilation solar chimney increases of the model with copper foam absorber about 33% from the model without copper foam absorber at constant inclination angle, therefore this gives indication of the important of insertion the copper foam as an absorber media in the ventilation solar chimney.

iv. Air change per hour (ACH) that the highest values obtained in the model with copper foam absorber then the model without copper foam absorber at any inclination angle.

v. The enhancement that achieved by the existence of metal foam is decreased as the chimney inclination angle is decreased.
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