Journal of Engineering Sciences, Assiut University, Vol. 40 No 6 pp.1661-1677 - November 2012

IMPROVEMENT OF NATURAL VENTILATION IN BUILDING USING MULTI SOLAR CHIMNEYS AT DIFFERENT DIRECTIONS

Soubhi A. Hassanein[1] and Waleed A. Abdel-Fadeel [2]

[1,2] Assistant Professor, Department of Mechanical Engineering, Aswan Faculty of Energy Engineering, South Valley University, Egypt

[1] Corresponding author. Tel: +20 1141480210, Fax: +20 97 3481235,
E-mail address: soubhi_a@yahoo.com, P. O.: 81528 Aswan, Egypt.

(Received March 26, 2012 Accepted September 29, 2012)

ABSTRACT

The solar chimney is a simple and practical tool that is applied to enhance space natural ventilation. This paper reports an experimental work to investigate effects of number of solar chimneys, chimney height, air gap width, and chimney orientation on natural ventilation in a space. Temperatures and velocities profiles were recorded through both chimney channel and room connected to channel under different parametric conditions. The results show that improvement in natural ventilation could be achieved using multi solar chimney. Also, using one, two, or three chimneys could reduce the room center temperature by 6%, 10%, and 12 % respectively, and using two and three chimneys instead of one chimney increased ventilating flow rate to 13% and 33% respectively.

Keywords: Improvement; Natural ventilation; multi-solar chimney; Experimental.

1. Introduction

A solar chimney is a natural draft device which utilizes solar radiation energy to build up stack pressure, thereby driving airflow through the chimney channel by converting thermal energy into kinetic energy of air movement. A primary strategy for cooling building without mechanical intervention in hot climate is to promote natural ventilation. With ambient air temperatures almost between 42-49 ^{o}C during over heated period in hot and dry condition as Aswan city. Direct ventilation is not recommended due to undesirable body heat gain by convection. This problem can cause thermal discomfort for building occupants. Solar energy has a number of different applications such as ventilation, passive solar heating and cooling of buildings, solar energy drying, and power generation.

During the last two decades, increasing awareness of greenhouse gas emissions and the need for effective, efficient and ecologically sound building ventilation has led to renewed interest in solar chimneys. In recent years, a number of experimental, numerical and theoretical investigations have contributed to the current understanding of solar chimneys. The effects of solar chimney height, solar absorptance of the absorber wall, solar transmittance of the glass cover and the air gap width are investigated by Lee and Strand [1] under various conditions. The effects of chimney inclination angle on number of air changes per hour and indoor flow pattern , and also chimney inlet size and width were numerically and analytically investigated by Bassiouny and Korah [2, 3]. An experimental investigation was done by Burek and Habeb [4] to investigate heat transfer and mass flow in thermo-syphoning air heaters, such as solar chimneys and trombe walls. Experiments were carried out by Chen et al [5] using an experimental solar chimney model with uniform heat flux on one chimney wall with a variable chimney gap to height ratio. A simple and useful tool to study energy performance of different ventilated facades typology was done by Balocco [6]. Several modeling tests were carried out by Coussirat et al. [7] on a well documented experimental test case taken from open literature in order to obtain a suitable model for the double glazed facades. A commercial CFD package was used by Guohui Gan [8] to predict buoyant air flow and flow rates in the cavities.

Thermal performance of a solar chimney for natural ventilation was experimentally investigated by Arce et al. [9]. The experimental model was implemented on full scale and real meteorological conditions. A parametric analytical study of roof solar chimney coupled with wind cooled cavity using spread sheet computer program has been presented by Aboulnaga [10]. A low energy consumption technique to enhance passive cooling and natural ventilation in a solar house, using a system consisting of a solar chimney and an evaporative cooling cavity has been proposed by Maerefat and Haghighi [11]. A numerical study is presented by Giabaklou, and Ballinger [12] to demonstrate the passive evaporative cooling system efficiency and air flow rate through building.

There have been relatively few reports of detailed measurements using multi solar chimneys. So, the present research was directed to study the effect of multi solar chimneys at different directions on natural ventilation. In this work, experiments were carried out using a solar chimney experimental rig under actual outside operating conditions (hot and dry) of Aswan city at South Egypt. Air temperature and velocity for different chimney parameters (height, gap, orientation, and numbers) were measured to provide further understanding of the ventilation performance of solar chimney.

2. Experimentation

Figure 1 shows schematic view of the solar chimney test rig. It is composed of three chimney channels connected to a room of dimensions (1.5 m length × 1.5 m width × 1.5 m height) . The three chimneys are connected to the room at different positions. The first is at east (2000 mm height × 300 mm length × 200 mm wide). The second is at south (2000 mm height × 300 mm length × 300 mm wide). The third is extended from the top of the room upwardly, by (500 mm height × 300 mm length × 200 mm wide) as shown in Fig. 1. Figure 2 shows a photo of the solar chimney test rig. The room has an inlet opening of 300 mm × 300 mm through inlet door used for fixing temperature and velocity instruments inside the room. Each chimney channel consists of four faces three of them are from glass of 6 mm thickness, and the fourth face is the absorbing surface made from stainless steel sheet (6 mm thick) which is painted black to behave almost as a black body. Figure 3 shows an illustration of the east and south solar chimney positions. The solar chimney in the south position has one moving plate face to control the air gap. All absorbing surfaces of the three chimneys were insulated to minimize heat loss. The test rig was instrumented to measure both air temperature and velocity through the chimney and room, using digital air velocity and temperature instrument as shown in Fig. 4. It has the capability to be connected to a computer and/or a printer for accessing data and printing it. The specifications of the air velocity and temperature are listed in Table 1. All measurements were carried out from 7 am to 7 pm.

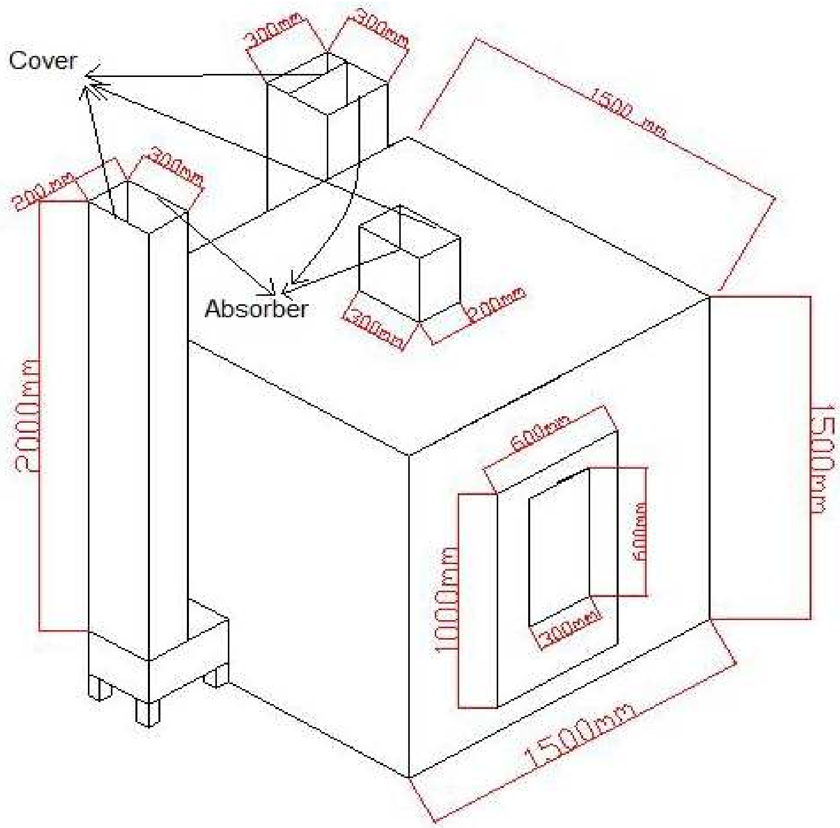
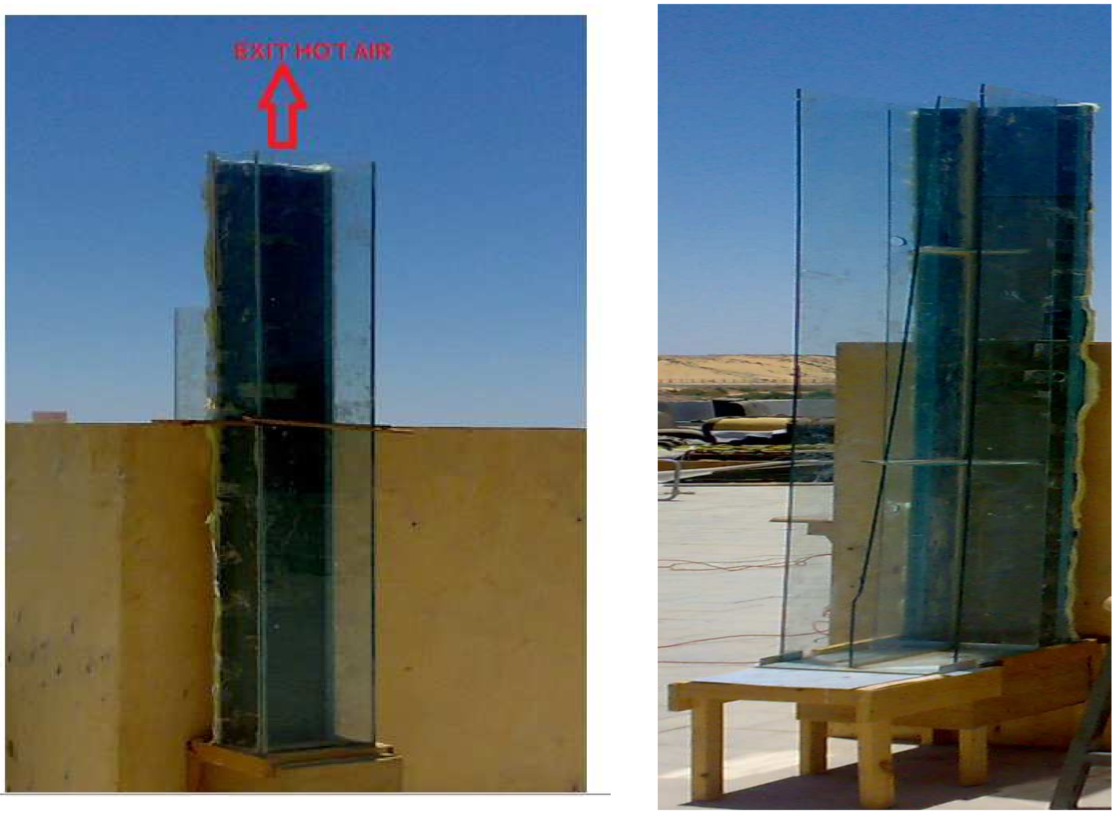


Fig. 1 Schematic view of the solar chimney experimental system.

Fig. 2 Photo of the solar chimney experimental system.



a- solar chimney facing east direction b- Solar chimney facing south direction

Fig. 3 a, b Illustration of the chimney position

Fig. 4 Digital air velocity and temperature instrument.

Table 1 Specifications of the motive air Thermo-Anemoter air meter unit.

Measured quantity	Velocity	Temperature
Range	0.2 – 25 m/s	-20 to 60 ^{o}C
Accuracy	($\pm$ 2% + 0.2)	$\pm$ 0.8 C
Resolution	0.1 m/s	0.1 C

3. Experimental results and discussions

In this part, the obtained experimental results will be comprehensively discussed. The results include the temperature and velocity distribution across the chimney at different heights, air flow rate along the chimney height and across the air gap, and the effect of the number chimneys and orientations on natural ventilation. Finally a comparison between flow through chimney when connected and disconnected to room has been done.

3.1 Temperature distribution across chimney height

Figure 5 shows temperature versus distance across the chimney from absorbing surface for 1m height from chimney inlet. The experiment leading to this figure was performed on June 29th ,2011 while the average ambient temperature was about 44.5 ^{o}C. It could be seen from the figure that the temperature decreases as the point is far from the absorbing surface till reaching a certain value, and then, it increases after that. This means that the cover temperature was greater than the air temperature (but less than the absorber temperature). This could be attributed to radiation heat transfer from the absorber plate to the cover plate. Similar observations have been made by [4].

Figure 6 shows the temperatures along the channel height for chimney at the south position for 200 mm air gap. The experimental results leading to this figure was performed on June 30th ,2011 while the average ambient temperature was about 41.5 ^{o}C . It could be seen from the figure that the air temperature increases along the chimney height. This is due to the fact that the longer chimney air channel provides a longer path for the convective heat transfer between the absorber wall and the air.

It is to be noted that figures 5 and 6 show average values of temperature of 52.8 ^{o}C and 45.7 ^{o}C respectively at a height of 1m and an air gap width of 200 mm for the south-facing chimney. The difference in results is attributed to the different meteorological conditions during performing the two experiments including ambient temperature as well as solar flux and wind velocity.

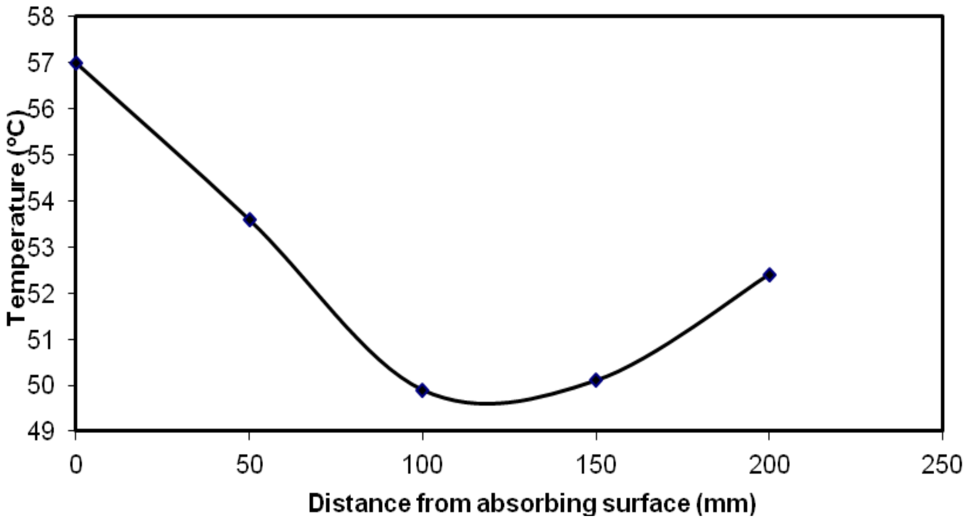


Fig. 5 Typical profile of air temperatures across the chimney channel depth at the south position of 1 m height for 200 mm air gap width (on June 29 th ,2011) .

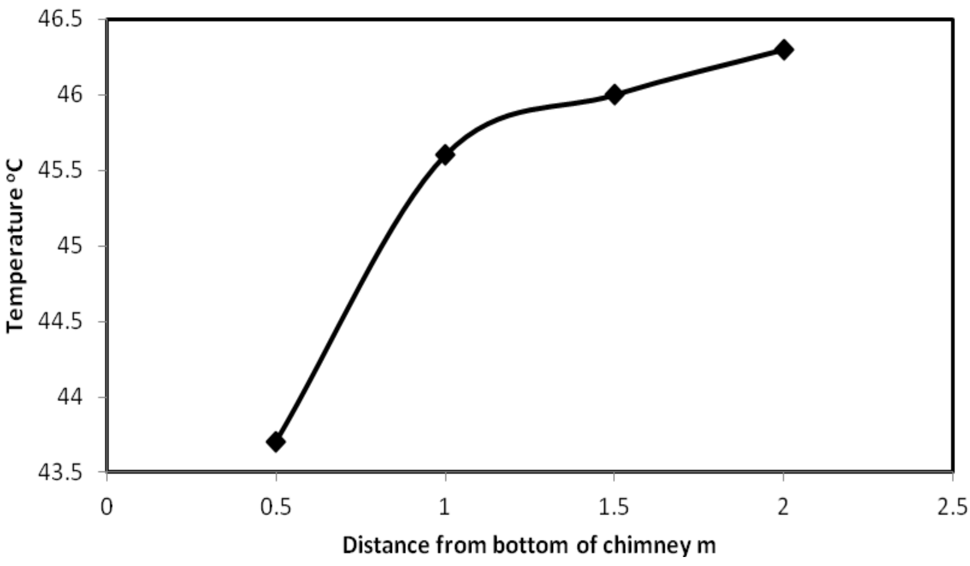


Fig. 6 Air temperature along the channel height for chimney facing south position for 200 mm air gap width (on June 30th ,2011).

3.2 Velocity distribution across chimney height

Figure 7 shows the average velocity versus distance from bottom of chimney at the south position for 200 mm air gap. It could be seen from the figure that the average velocity increases along the channel height, which could be attributed to converting thermal energy gained by air as it passes over the absorbing plate to kinetic energy.

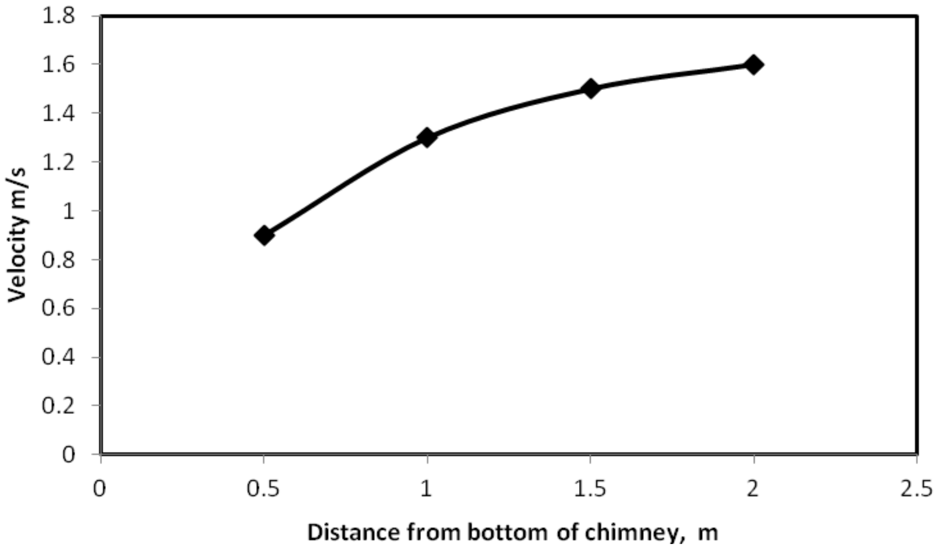


Fig. 7 Air velocity along channel height for chimney at south for 200 mm air gap width.

3.3 Air flow rate across chimney height

Figure 8 shows the average air flow rate along the channel height for chimney at the south position for 200 mm air gap. It could be seen from the figure that the flow rate increases along the chimney height.

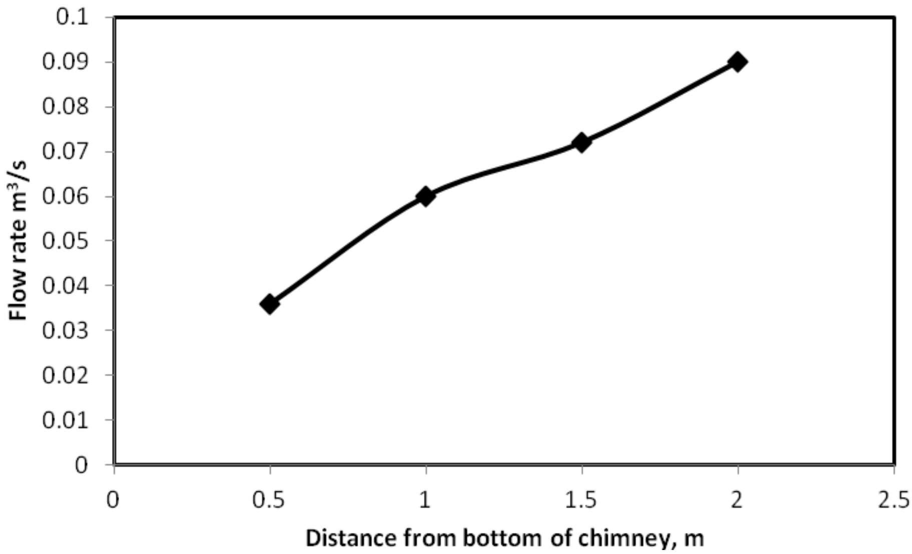


Fig. 8 Air flow rate along channel height for chimney at south for 200 mm air gap width.

3.4 Air flow rate across chimney gap

Figure 9 shows the flow rate versus air gap width at different values of distance from the bottom for the chimney at the south position. It could be seen from the figure that the flow rate is slightly reduced for higher air gap widths, indicating that a smaller air gap enhances slightly the natural ventilation flow rate. This could be attributed to that decreasing the air gap makes the bulk air more affected by the absorbing plate and thus having a higher temperature than the air close to the glass cover which leads to an increase in the air velocity. However, the increase in air flow rate for different air gab widths values is almost negligible and the air gap width does not have much effect on the performance of the chimney as the other design parameters. Also it could be seen from the figure that the flow rate increases with chimney length above the bottom. Finally, it could be seen that the effect of chimney height is more pronounced than that of air gap width on natural ventilation.

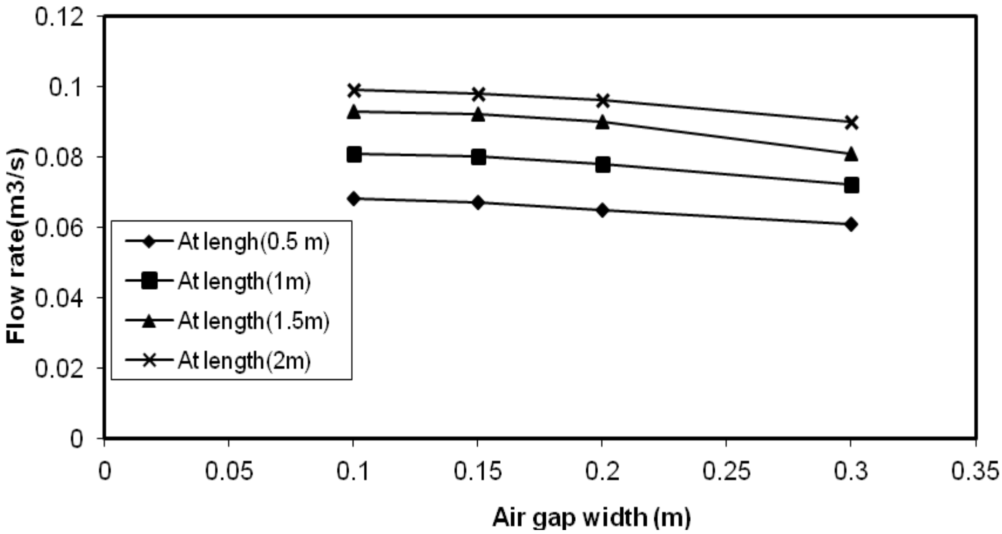


Fig. 9 Flow rate versus air gap width at different channel heights for chimney facing south.

3.5 Effect of number of chimneys

Figure 10 shows the variation of temperature at the center of the room with time for multi chimneys of 200 mm air gap width and that without chimneys. It could be seen from the figure that the transient temperature at the center of the room is lower with increasing the number of chimneys, and that the center temperature of the room without chimney is the highest one. This could be explained by that increasing number of chimneys makes the room more ventilated which means that the air is more mixed, homogenous and give temperature lower than that for lower number of chimneys. Finally, it could be seen that at one o'clock in the afternoon using one chimney could reduce the room center temperature by 6%, also using two chimneys could produce a reduction in temperature of 10%, and when using three chimneys the reduction in temperature could reach 12 % compared with case without chimneys. Looking at Fig. 10 it could be concluded that using multi solar chimneys as that of the present configuration one chimney at east ,another at south, and the last above the room enables tracking sun that makes temperature most of the time almost uniform.

Figure 11 shows the transient flow rate through the room using multi chimneys of 200 mm air gap. It could be seen that for most of the time the ventilation flow rate is higher using more chimneys. This could be explained by considering the chimney as a pump, and the multi chimneys as pumps arranged in parallel. So, increasing the number of chimneys increases ventilation flow rate. Finally it could be seen that at one o' clock in the after noon using two chimneys could increase ventilating flow rate by 13%, and increasing number of chimney to three could increase ventilating flow rate by 33%.

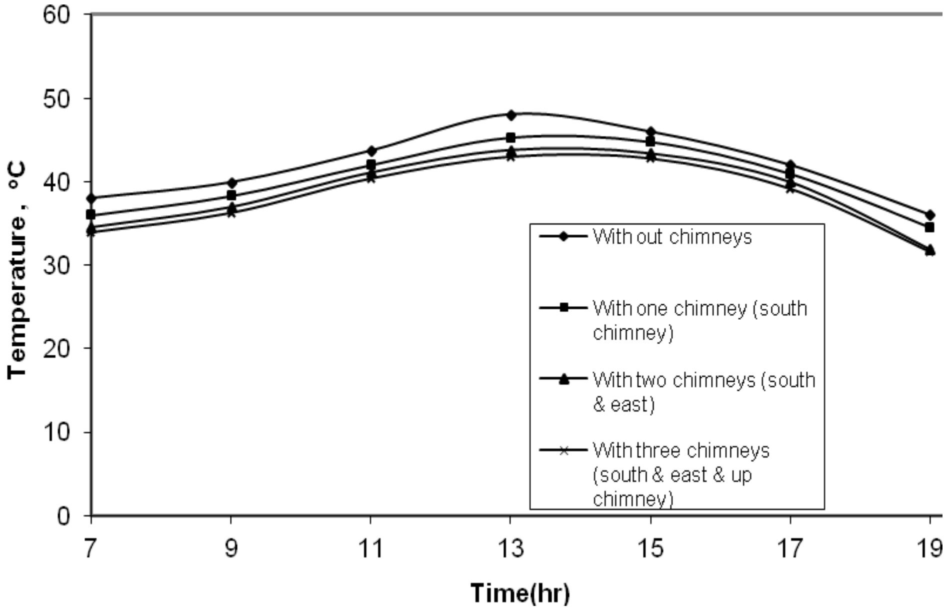


Fig. 10 Temperature at center of the room versus time with multi chimney of 200 mm air gap width and without chimney.

Figure 11 shows the transient flow rate through the room using multi chimneys of 200 mm air gap. It could be seen that for most of the time the ventilation flow rate is higher using more chimneys. This could be explained by considering the chimney as a pump, and the multi chimneys as pumps arranged in parallel. So, increasing the number of chimneys increases ventilation flow rate. Finally it could be seen that at one o' clock in the after noon using two chimneys could increase ventilating flow rate by 13%, and increasing number of chimney to three could increase ventilating flow rate by 33%.

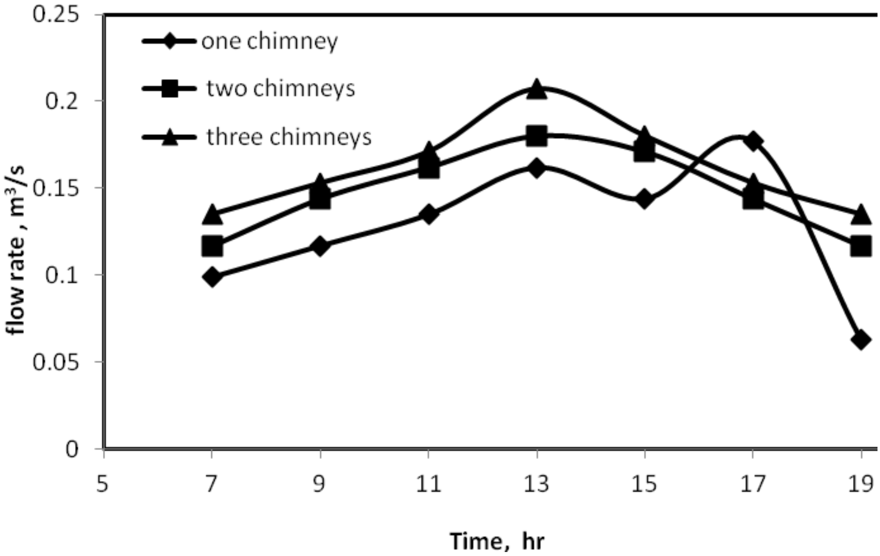


Fig. 11 flow rate through room versus time using multi chimneys of 200 mm air gap width.

3.6 Effect of chimney orientation

Figure 12 shows air velocity at outlet from the chimney under different orientations for 200 mm air gap width. It could be seen from the figure that the chimney at the east has higher velocity from 7 am to 11 am and this could be explained by the solar azimuth angles are in east direction. With respect to chimney at south it could be seen that the air has a higher velocity in duration of time from 12 am to 5 pm where the sun rays are in the south direction. With respect to the chimney above the room it is noted that it has higher velocity in the time duration of 5pm to 7 pm and this could be explained by that the absorbing surface of this-chimney was facing the west direction. Finally, the figure shows that the maximum values occur at the south direction chimney.

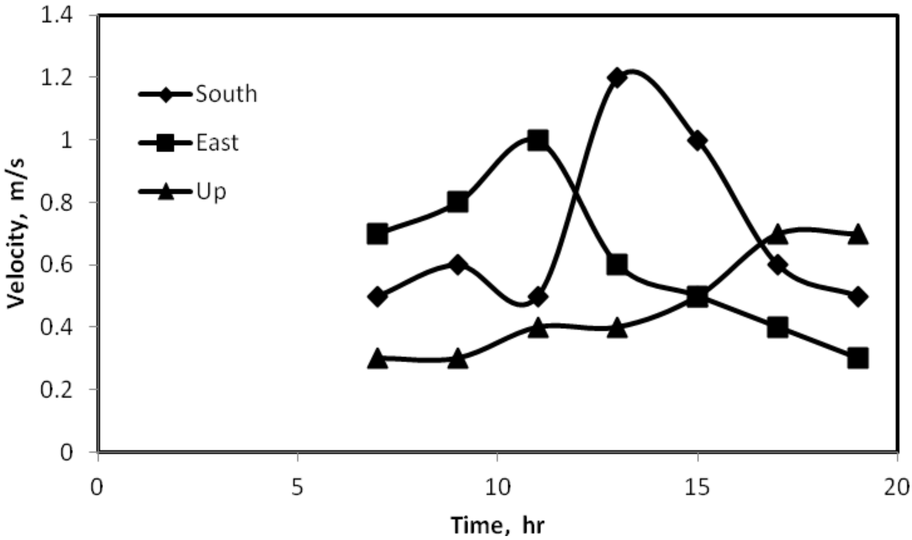


Fig. 12 velocity at chimney exit under different orientations for 200 mm air gap width.

3.7 Characteristics of separated chimneys

In this section ventilation characteristics for one chimney alone (oriented east), is examined. The results are compared to the case when the chimney was connected to the room.

3.7.1 Velocity distribution along the chimney height

Figure 13 shows the average outlet velocity versus time at different heights for 200 mm air gap chimney at south when disconnected from the room. It could be seen from the figure that the velocity increases with time and this is due to increasing temperature with time. Also it could be seen from the figure that as the height of the chimney increases the velocity is increased, which could be attributed to the conversion of thermal energy gained by air as it passes over the absorbing plate to kinetic energy.

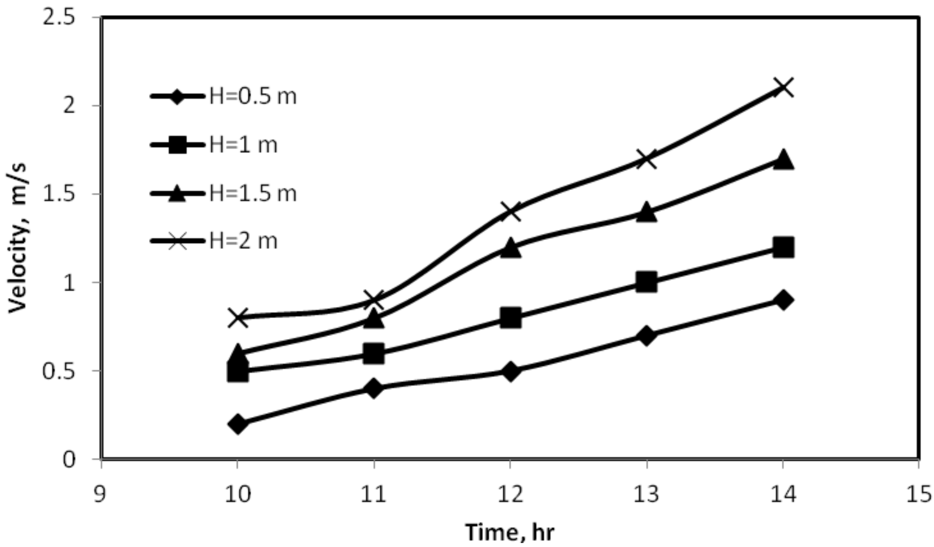


Fig. 13 Average air velocity versus time at different heights for 200 mm air gap width chimney at the south.

3.7.2 Temperature distribution along the chimney height

Figure 14 shows the average outlet temperature versus time for various chimney heights for 200 mm air gap chimney facing the south when chimney is disconnected from the room. It could be seen from the figure that the temperature increases with time and this could be explained by the increase in ambient temperature with time. Also, it could be seen from the figure that as the height inside the chimney is increased the temperature will increase. This could be attributed to thermal energy gained by air as it passes on the absorbing plate.

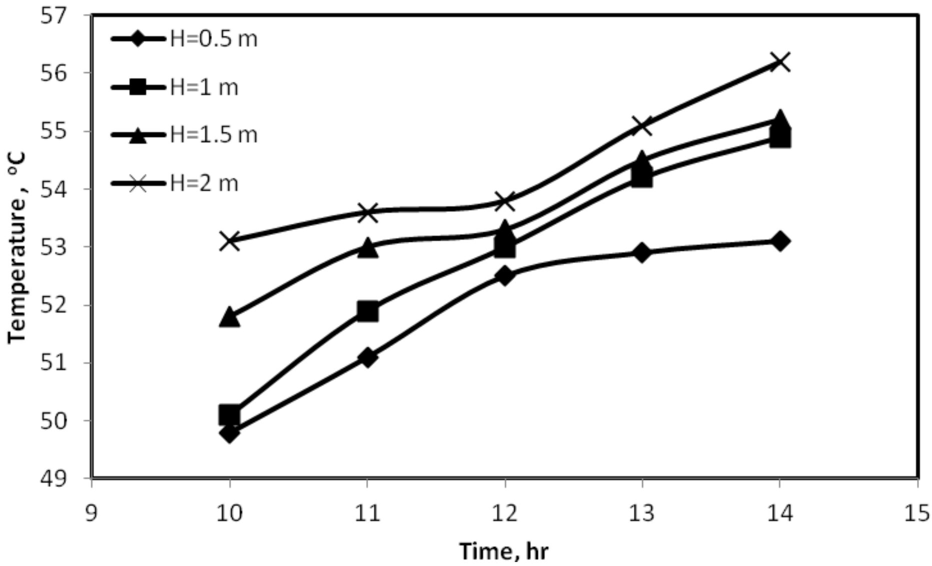


Fig. 14 Temperature versus time at different heights for 200 mm air gap width chimney facing the south.

3.7.3 Comparison between the ventilation characteristics for chimney alone and chimney connected to the room

Figure 15 shows the velocity at outlet from the chimney versus time for both cases of chimneys connected to and disconnected from room. It could be seen from the figure that for most of the time the outlet velocity for connected chimney is larger than that for disconnected chimney. This could be explained by that the room connected to chimney acts as an orifice in pipe and this will increase the air velocity into the chimney.

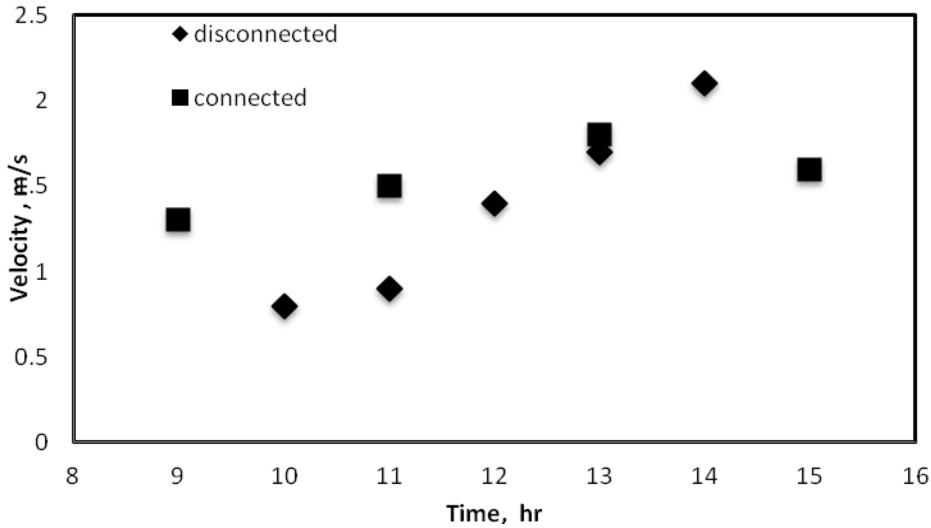


Fig. 15 Velocity at outlet from chimney versus time for both connected and disconnected chimneys to room.

4. Conclusions

The following conclusions could be drawn:

1-Chimney height, chimney gap, orientation, and number of chimneys have influence on the natural ventilation.

2-For large value of the chimney height and number of chimneys facing south and low values of air gap width the building's natural ventilation is relatively high.

3-The effects of chimney height, number of chimneys and orientation are more pronounced on natural ventilation than the effect of chimney air gap.

4- Using one, two, and three chimneys reduces the room center temperature by 6%. 10%, and 12% respectively..

5- Using two chimneys could increase ventilating flow rate by 13% , and increasing chimney number to three increases ventilating flow rate by 33%.

6-Using multi solar chimneys as the configuration given in the present study : one chimney facing the east , another facing the south, and the last above the top of the room caused taking the advantage of tracking the sun which lead to almost uniform temperature most of the time as shown in Fig. 10 for three chimneys.

7-It could be concluded that ventilation flow rate through chimney connected to room is more than that for chimney disconnected from the room.

5. References

[1] Lee Kwang Ho and Strand R. K. " Enhancement of natural ventilation in buildings usings a thermal chimney" Energy and Buildings 41 (2009) 615-621.

[2] Bassiouny Ramadan and Korah Nader S. A. "Effect of solar chimney inclination angle on space flow pattern and ventilation rate" Energy and Buildings 41 (2009) 190-196.

[3] Bassiouny Ramadan and Korah Nader S. A. "An analytical and numerical study of solar chimney use for room natural ventilation" Energy and Buildings 40 (2008) 865-873.
[4] Burek S.A.M. and Habeb A." Air flow and thermal efficiency characteristics in solar chimneys and trombe walls" Energy and Buildings 39 (2007) 128-135.
[5] Chen Z.D., Bandopadhayay P., Halldorsson J., Byrjalsen C., Heiselberg P., and Li . Y. "An experimental investigation of a solar chimney model with uniform wall heat flux" Building and Environment 38 (2003) 893-906.
[6] Carla Balocco "A simple model to study ventilated facades energy performance" Energy and Buildings 34 (2002) 469- 475.
[7] Coussirat M., Guardo A., Jou E., Egusquiza E., Cuerva E., and Alavedra P. "Performance and influence of numerical sub-models on the CFD simulation of free and forced convection in double-glazed ventilated facades" Energy and Buildings 40 (2008) 1781-1789.
[8] Guohui Gan "Simulation of buoyancy-induced flow in open cavities for natural ventilation" Energy and Buildings 38 (2006) 410-420.
[9] Arce J., Jimenez M. J., Guzman J. D., Heras M. R., Alvarez G., and Xaman J. "Experimental study for natural ventilation on a solar chimney" Renewable energy 34 (2009) 2928-2934.
[10] Aboulnaga M. M " A roof solar chimney assisted by cooling cavity for natural ventilation in buildings in hot arid climates: an energy conservation approach in Al-Ain city" Renewable energy 14 (1998) Nos 1-4 PP 357-363
[11] Maerefat M., and Haghighi A.P. " Natural cooling of stand alone houses using solar chimney and evaporative cooling cavity" Renewable energy 35 (2010) 2040-2052
[12] Giabaklou Z., Ballinger J. A. " A passive evaporative cooling system by natural ventilation" Building and environment 31 Nos 6 (1996) 503-507

التحســـين في التهوية الطبيعية لمبنى مستخدما اكثر من مدخنه شمسية في اتجاهات مختلفة

المدخنة الشمسية هي اداة بسيطة وعملية تستخدم لتحسين التهوية الطبيعية . هذا البحث يحوى دراسة عملية لتأثير عدد المداخن الشمسية وكذلك ارتفاع وعمق المدخنة واتجاهها على التهوية الطبيعية خلال المدخنة. في هذا البحث تم قياس درجات الحرارة وكذلك سرعات الهواء خلال المدخنة والغرفة المتصلة بها.

وقد اظهرت نتائج هذا البحث حدوث تحسن فى التهوية باستخدام اكثر من مدخنه فى اتجاهات مختلفة. حيث وجد عند الساعة الواحدة ظهرا أن درجات الحرارة تقل بنسبة 6، 10 ، 12 % عند استخدام عدد 1، 2 ،3 مدخنة الأولى في اتجاه الشرق والثانية فى اتجاه الجنوب والثالثة مركبه اعلى الغرفة فى اتجاه الغرب على الترتيب. وكذلك وجد ان معدل السريان يزداد بمعدل 13 ، 33 % باستخدام مدخنتين وثلاثة مقارنه بالسريان لمدخنة واحدة.