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Passive solar heating of a space

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Abstract: *An experimental investigation for solar chimney performance used as a heating source in Iraqi environmental condition has been done. Experimental room adopted under certain scale to (2.5×1.29×1.07) m, the studying model equipped with a solar collector 40° inclination angle south facing. The results were taking through January and February at different locations in test zone. The results showed that adopting walls towards sun light will improve the stored energy. Improving heat energy helps to make more motive force to flow air inside supposed building.*

Keywords: *Natural ventilation, Solar chimney, Passive heating, Similitude.*

I. Introduction

Home windows, walls, and floors can be designed to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer. This is called passive solar design or climatic design. Passive solar technique is one of the most effective methods used for space heating. It can greatly increase the energy efficiency of a building and can supply 100% of a home heat in many cases. Passive solar houses include a wide variety from those heated almost entirely by the sun to those with south facing windows that provide a fraction of the heating load. One of the most common designs of the solar passive techniques which are incorporating a thermal storage and delivery system called a trombe wall. The trombe wall is a smart device for collecting and storing heat from the sun during the day time and releasing heat into a building space during the night. However, the application of a trombe wall is restricted because of its visible black-matt surface of the blackened massive wall underneath the clear glass [1].

II. Literature Review

Solar chimneys have been studied by a number of researchers and for different applications including natural ventilation of buildings, power generation, etc. For example, **Khedari et al. (2000) [2]** conducted experiments on a school building installed with two roof solar chimneys, a modified Trombe wall, a Trombe wall and a metallic solar wall to determine their combined effects on thermal comfort. The building had a volume of 25m^3 and 27 different positions were measured to obtain the interior air temperatures and speeds. Results showed that with a combined surface area of 6m^2 to 9m^2, the temperature difference between the interior and ambient was 3^{o}C, lower than the 6^{o}C obtained without any ventilation. The air change per hour averaged 15ACH while the air speed within the room ranged between 0.02m/s to 0.09 m/s. Although results did not satisfy thermal comfort, it gave the possibility of combining various solar chimney designs to achieve better performance. **Chenet al. (2003) [3]** conducted experiments on a single wall heated Plexiglas solar chimney, 1.5m in height and 0.62m wide, with uniform heat flux in laboratory conditions. The theoretical solution obtained from pressure losses balancing was only reasonable for narrow solar chimney's depth and small inclination angle. Along the stack height, temperature generally increased with height. Across the varying chimney depth (0.20m and 0.40m) under different heat flux (400W/m^2 and 600W/m^2), air temperature dropped as it moved away from the heated surface before increasing slightly at the opposite surface due to radiation; mass flowrate increased for both increasing solar chimney's depth and heat flux (no optimal depth). However, both the temperature and velocity profiles were fairly uniform across the 18 chimney width. Furthermore, the optimal inclination angle was determined to be 45^o. **Bunnag et al. (2004) [4]** investigated the influences of the tilt angles (15^o, 30^o, 45^o, 60^{o}and 75^o), air gaps (0.14m and 0.19m) and heat flux (262W/m^2, 408W/m^2 and 574W/m^2) on the convective heat transfer coefficient of a roof solar collector measuring 1.00m wide by 1.50m long under steady state condition. Results showed that the temperature difference between the heated and unheated surfaces remained almost constant with different values of heat fluxes. Furthermore, increasing the heat fluxes or decreasing the tilt angles increased the air temperature. These results were further correlated and non dimensionalized as relationships between Nusselt number, Rayleigh number and Reynolds number. **Zhai et al. (2005)[5]** placed electric heating plates at the bottom of a wooden solar chimney measuring 1.5m height and 0.5m width with depth varying from 0.1m to 0.5m. Six thermocouples were placed on the surface of the bottom plate and within the chimney respectively while the air speed of the inlet and 20 outlets were also measured. In addition, a mathematical model based on energy balanced was derived. Results showed that air temperature increased along the height of the solar chimney before dropping off at the outlet. Furthermore, air temperature decreased along its depth away from the heating wall before increasing at the outer wall. In addition, air temperature and airflow rate were found to increase with radiation intensity. Lastly, no optimum channel depth was found; however the optimum tilt angle was found to be 45^o. **Burek and habeb(2007) [6]** have carried out an experimental study of a vertical channel simulating a solar chimney and a Trombe wall. The vertical channel had transparent cover and an absorber plate, matt black painted. The vertical channel was opened at both ends, and its dimensions were: 1.025 m length, 0.925 m wide and variable depth, 0.02m-0.11 m. Heat input to the absorber plate was supply by electrical means, 200-1000 W, in steps of 200 W. The principal results from the data showed the mass flow rate through the channel was a function of both the heat input and the channel depth, and the thermal efficiency of the system was a function of the heat input, and not dependent on the channel depth. **Sakonidou et al.(2008) [7]** have been developed a mathematical model to determine the angle that maximizes natural air flow inside a solar chimney used daily solar irradiance data on horizontal plane at a site. The solar irradiation absorbed by the solar chimney of varying tilt angle (30^o -60^o) degree and height ranged (1 -12) m with gab depth of (0.11) m and with 0.74 m width and aspect ratio (1/10) used the CFD calculation to compute the temperature and velocity of the air inside the chimney as well as the temperatures of the glass cover and the black painted absorber. The theoretical predictions are in satisfactory agreement with experimental measurements from a 1m chimney operated at different inclinations .For both chimneys ,it is clear that the higher velocities are achieved at 60^o while as the higher temperatures were at 30^o. **Susanti et al. (2008) [8];** built a full scaled cavity roof to examine the influences of heat production from the upper surface (50W/m^2, 75W/m^2, 100W/m^2, and 150W/m^2) on the temperature and velocity profiles within the solar chimney. The temperatures of the upper and lower surfaces increased along the height while the temperature dropped across the solar chimney's depth, reaching a constant value near the unheated lower surface. In addition, the velocity profile rose across the depth, hitting a maximum before dropping again. Furthermore, both the temperature and velocity were found to have a direct relationship with the heat production. The effects of the inclination angle were not significant on the temperature profile but a steeper inclination was recommended for a higher velocity profile. Lastly, restricting the inlet and outlet of the solar chimney increased the air temperature but reduced the air speed. **Nouanegue and Bilgen (2009) [9]** studied numerically the conjugate heat transfer of solar chimney system for heating and ventilation of dwelling. Conservation equations are solved by finite difference method .The basic governing parameters was: the Rayleigh numbers ranged from $5*10^8$ to 10^{11}, the Prandtle number, Pr = 0.7, the chimney aspect ratio, A=H/L ranged from 6 to 15, where, (H) presents the chimney's height and (L) presents its gap. The results showed that the surface radiation modifies the flow and temperature fields, affects the Nusselt number and the volume flow rate, both in a positive way, and improves the ventilation performance of the chimney. **Haghighi & Maerefat (2014) [1]** studied numerically natural ventilation of a room which uses solar chimney as a heating source to determine the effects of sizes of air gap, openings and environmental ambient condition on air change per hour (ACH) and indoor air temperature. As a result, it was found that the maximum ACH can be achieved when the air gap size was 0.2m. Therefore; it was concluded that the use of solar chimney with outlet size of less than 0.3m can provide thermal comfort and avoid undesirable vertical temperature gradient.

III. Experimental Work

The outdoor experimental study conducted at Baghdad on the roof of laboratory building in Technical Collage of Baghdad (9 m) height for a building latitude and longitude 33° north and 44° east, facing south in vertical position.

3-1 Design of Room Model:

There were some assumptions for the calculations such that neglecting any heat transfer to the air by radiation; clean room is to be considered, and similar thermal conditions existed in the model and prototype. A suitable scale factor to find the dimensions of the model is assumed to be 3:1, let the dimensions of the room under study be (7.5m×3.87m×3.21m). Since the scale factor is 3 then the dimension of model is (2.5m× 1.29m × 1.07m) as shown in figure 1.

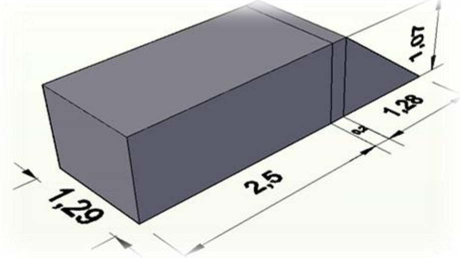
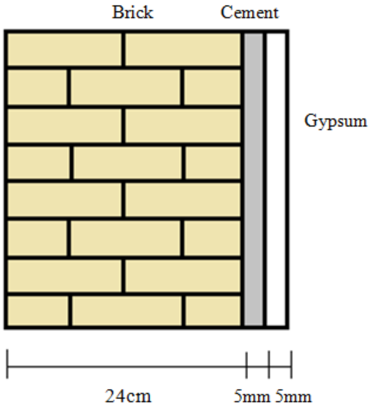


Figure 1: Schematic view of the *model.*

The reduced scale model used in this study is made of wood 18mm thickness with a thermal conductivity about ($0.522\, W/m°C$) which was selected after similitude it with the prototype over all heat transfer coefficient and this type of wood was the nearest to the calculated value ($0.556\ W/m°C$). The wood wall of the reduced model was connected by screw on an iron frame.



$$U_{model} = U_{prototype}$$

$$U = \frac{1}{\frac{1}{h_i} + \sum \frac{\Delta x}{k} + \frac{1}{h_o}}$$

$$h_i = 8.7 \frac{W}{m^2\, ℃}$$

$$h_o = 29.7\ \frac{W}{m^2\, ℃}$$

$$k_{brick} = 0.72 \frac{W}{m\, ℃} \&\ \Delta x_{brick} = 24cm$$

$$k_{cement} = 0.72 \frac{W}{m\, ℃} \&\ \Delta x_{cement} = 5mm$$

$$k_{gypsum} = 0.81 \frac{W}{m\, ℃} \&\ \Delta x_{gypsum} = 5mm$$

$$U = 1.63\ \frac{W}{m^2\, ℃}$$

$$U_{model} = \frac{1}{\frac{1}{h_i} + \frac{\sum \Delta x}{k_{wood}} + \frac{1}{h_o}}$$

$$k_{wood} = 0.556\ \frac{W}{m\, ℃}$$

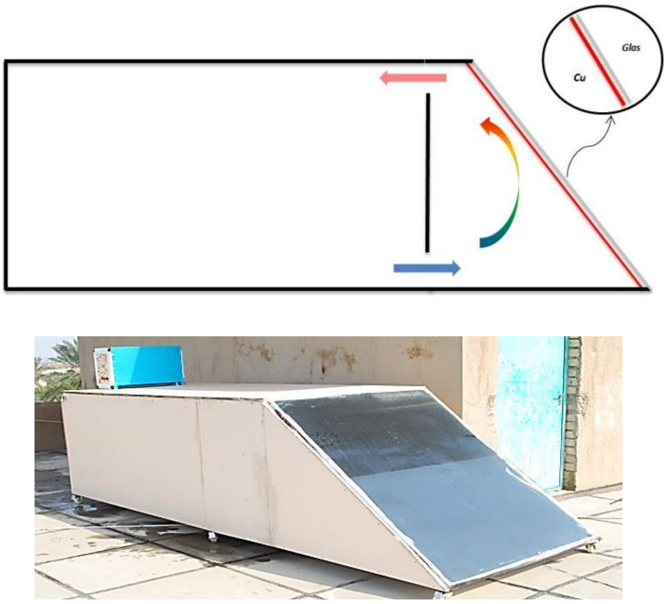


Figure 2: The reduced scale model.

The study model was closed to the environment and connected with solar chimney on the south wall as shown in figure 2, the cold air in the space enter to the solar chimney from the bottom. The cold air absorbed the heat which transferred by convection from the absorber plate and return to the space from the top.Twelve place temperature measurement measured by data logger as shown in figure 3. The absorber plate temperature measured at the center of plate by T9 sensor, as well as the wall temperature at the center of each wall of the model by (T1, T2 and T4). The air temperature measured at 10cm distance from each wall. T11 and T12 sensors was used to measure the air temperature near the east and west walls respectively. The air near the roof and floor was measured by T10 and T6, while T7 used to measure the temperature at the center of room.

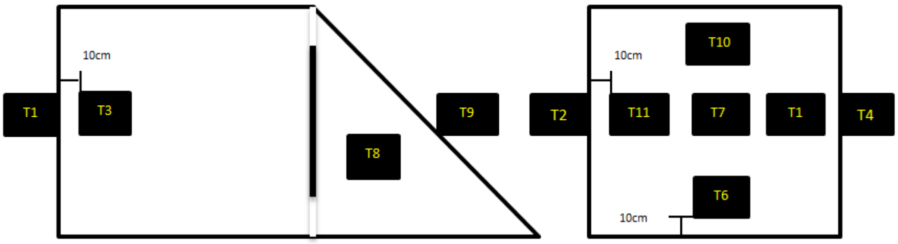


Figure 3: Temperature places measurements in the model.

3-2 The Absorber Plate

The absorber plate can be made of different cross-sectional shapes such as, the circular and flat plate configuration. The aluminum, concrete, copper, and iron is the most common materials used .The present chimney's plate was made of copper. In order to absorb enough solar radiation the surface of the solar chimney (plate wall) painted matte black. The dimensions of the plate were (0.1 cm thick, 1.68 m length, 1.29 m width) with inclination angle 40° as shown in figure 4.

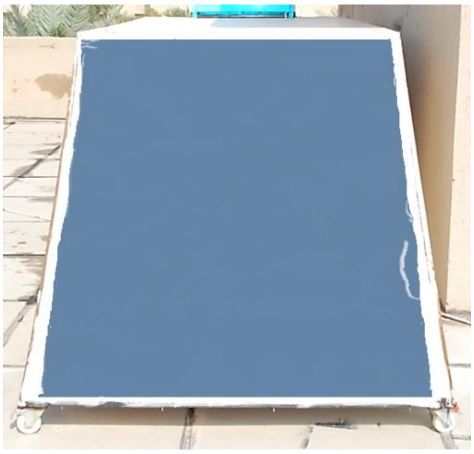


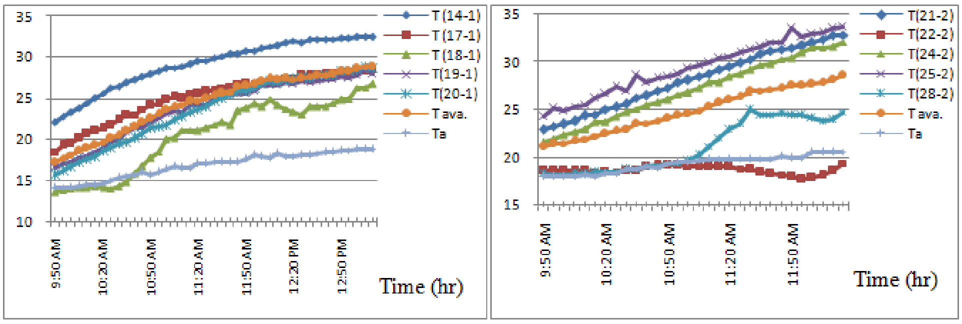
Figure 4: *solar chimney.*

3-3 The Glass Cover

A commercial glass panel of 4 mm thickness fitted in iron frame was used to cover the absorber plate. The cover dimensions were 1.68 m length and 1.29 m width. The purpose of using a glass cover was to decrease convection heat losses from the absorber plate end.

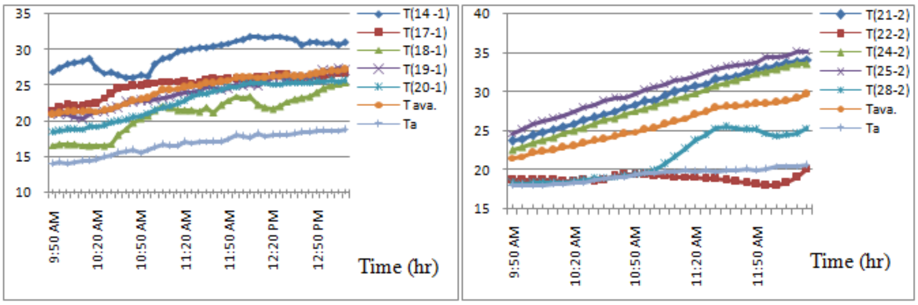
IV. Results And Discussion

The solar radiation data from 9:00am to 2:00 Pm for months (January and February) with an average solar irradiation of (44-190) W/m^{2}which were provided from meteorological Baghdad Station. The heating loss in the space which is represented by the heating load found to be equal to 220 W, while the heat added to the space from the absorber plate is 522 W. So that the heat added to the space is enough to heating the room, as it is greater than the heating load twice. Figure 5 shows that the maximum temperature difference between the north wall and the ambient temperature was 10 °C in January and 8°C in February, 33.7°C was the maximum temperature obtained in the north wall with 184.33W/m^2 solar radiation. In the center of the model 9°C temperature difference obtained and 35.2°C was the maximum value with 184.33W/m^2 solar radiation as shown in figure 6. Figure 7reveals the air take an amount of heat from absorber plate which was enough toincrease its temperature to 12°C in January and 10°C in February in the sunny days.



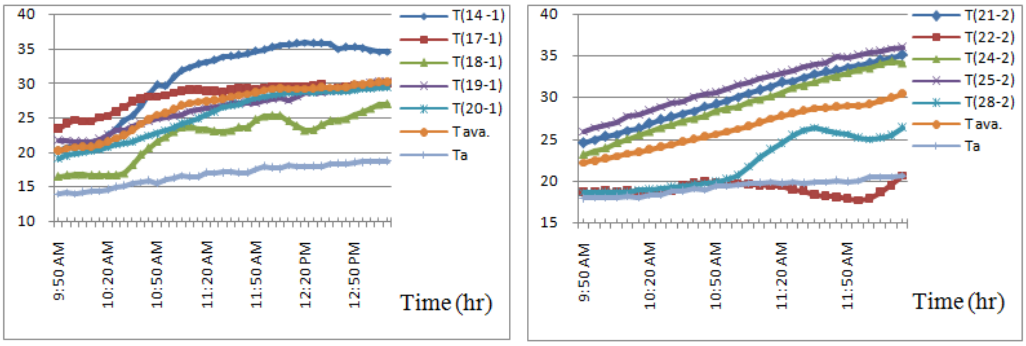
Temperature (°C

Figure 5: Temperature at a distance 10cm from north wall in for some daysJanuary and February.



Temperature (°C

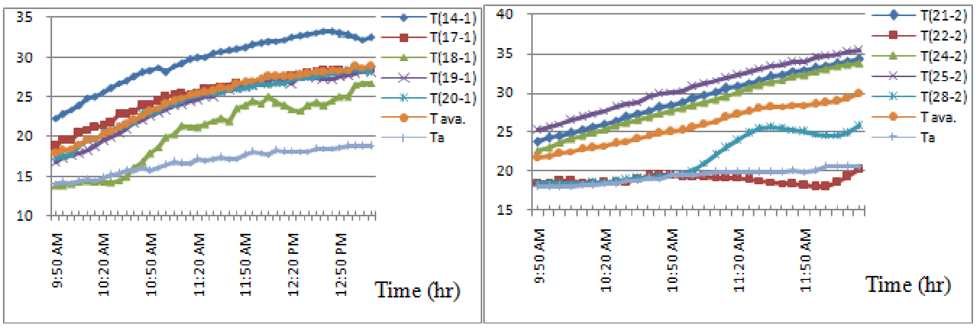
Figure 6: Temperature distribution the center of room in January and February.



Temperature (°C

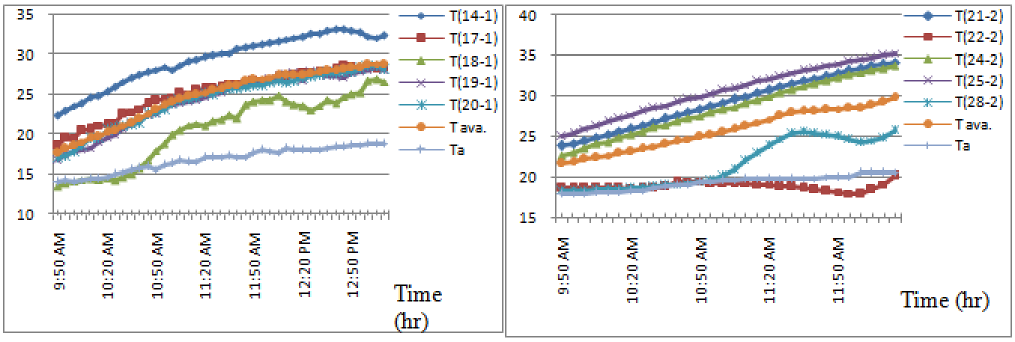
Figure 7: The temperature of air after the absorber plate in January and February.

Figures 8&9 show the temperature distribution in the east and west walls and illustrate that the air temperature riseat a constant rate with the rising of outside air temperature. The maximum temperature difference obtained was 10°C for the two walls.For the east wall, the maximum temperature obtained was 32.5°C in January and 35.4°C in February, while for the west wall was 32.4°C in January and 35.3°Cin February.



Temperature (°C

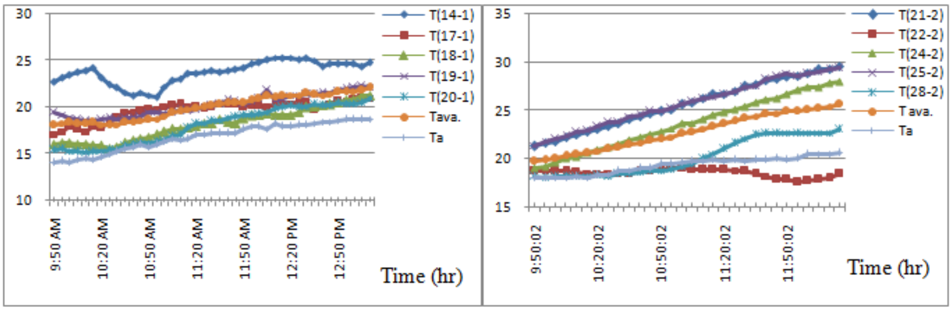
Figure 8: Temperature at a distance 10cm from east wall for some days in January and February.



Temperature (°C

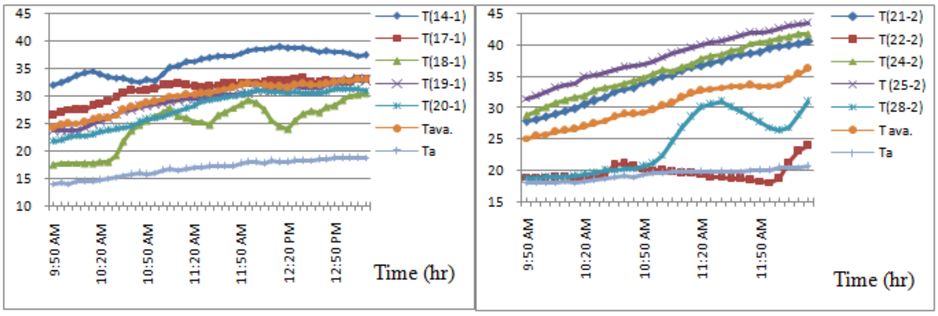
Figure 9: Temperature at a distance 10cm from west wall for some days in January and February.

Figures 10&11are exhibits the temperature distribution in the floor and the roof of studying model. The temperature difference in the floor approach to 6°C and reach to 9°C in the sunny days. The maximum temperature difference in the room was between air in the roof and outside air temperature, (19&23) °Cwas the maximum temperature difference obtained in the roof for January and February respectively. Figure 12 shows the temperature distribution inside the room.



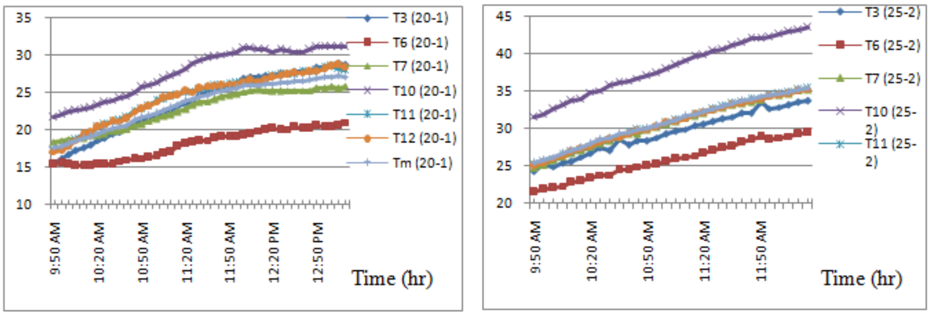
Temperature (°C

Figure 10: Temperature at a distance 10cm from the floor for some days in January and February.



Temperature (°C

Figure 11: Temperature at a distance 10cm from the roof for some days in January and February.



Temperature (°C

Figure 12: Temperature distribution inside the room for January and February.

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V. Conclusion

An experimental investigation for solar chimney performance used as a heating source has been done for (2.5 × 1.29 × 1.07) m model. The solar chimney added to the model to provide the heat that needed to cover the heating load. The concluded results showed an increasing in heat adding for supposed building by sun light with the time and the maximum value of heat was 522 W, while the heating load for the model was 220 W. So that the heat amount supplied to the model reach to the double value of heating load. The maximum temperature difference obtained between the north wall and the outside temperature was 10 °C in January, and the same difference was obtained for the east and west walls. At a distance of 10 cm from the floor 9°C temperature difference was reached, while the temperature difference of the roof for the same distance was in the range of (19-23) °C. The air temperature in the back side of the absorber plate was heated by 12°C in January sunny days. The air temperature in the center of the model was reach to 9°C more than the outside temperature.

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