LOW COST HOUSE MODEL WITH MODERATE INSIDE TEMPERATURE USING NATURAL VENTILATION +

Mahmmod Aziz Muhammed *

Abstract:

A low cost house model with a certain spatial scale was constructed in order to inspect its performance against the hot weather of summer season in Iraq. The materials used are wood and aluminum with a small glass window on each side. The natural ventilation, that was applied in order to decrease the inside temperature, made use of the damp ground of the outside park. The ventilation was speeded up using a solar collector which was also a low cost constructed collector that uses empty soft drink cans coated with a special dye.
The experiment was made in July between 9:00 to 15:00 in order to ensure high ambient temperature. Results obtained showed a maximum difference of 10°C between ambient and inside temperature which is accepted considering no air conditioning devices were used with so limited air steam flowing through the inside space of house model.

Key words: house model, natural ventilation, solar collector, temperature difference.

نموذج بيت واطئ الكلفة ذو درجة حرارة داخلية معتدلة باستخدام التهوية الطبيعية

محمود عزيز محمد

المستخلص :

نموذج بيت قليل الكلفة قد تم تصنيعة بمقياس بعدي خاص لغرض اختبار ادائه في الطقس الحار خلال موسم الصيف في العراق. المواد المستخدمة هي الخشب والالمنيوم مع شباك زجاجي على كل جانب. التهوية الطبيعية المارة خلال فضاء البيت لغرض خفض درجة الحرارة استفادت من رطوبة ارض الحديقة الخارجية. تم تعجيل تيار الهواء المار في فضاء البيت عن طريق استخدام مجمع شمسي والذي هو الاخر تم تصنيعة من مواد رخيصة غير مكلفة وهي عبارة عن عبوات الاشربة الغازية الفارغة والمطلية بطلاء خاص.

تم اجراء التجربة في شهر تموز بين الساعة 9:00 و15:00 من اجل ضمان درجة حرارة خارجية قصوى. النتائج التي تم الحصول عليها بينت فرق عام في درجات الحرارة بين داخل وخارج البيت وصلت الى 10°م وهذا الفرق يعتبر مقبولا اذا اخذنا بنظرالاعتبار عدم استخدام اي وسيلة لتكييف الهواء المار في حيز البيت والذي كان تياره محدوداً جداً.

كلمات الدلالة: نموذج بيت, تهوية طبيعية, مجمع شمسي, فرق درجات الحرارة

+ Received on 30/1/2013 , Accepted on 23/1/2014
* Lecturer / Technical Institute / Aumara

Nomenclature :

$\dot{Q}$ = The rate of heat transfer (W)
$\dot{m}$ = Air mass flow rate (kg/s)
C = Specific heat of air (J/kg.K)
T_{wind} = wind temperature (ºC)
T_{home} = inside space temperature (ºC)
T_{in} = inside surface temperature (ºC)
T_{out} = outside surface temperature (ºC)
ρ = Density of air (kg/m^3)
V = velocity of air (m/s)
A = cross sectional area of air inlet (m^2)
r = radius of inlet pipe (m)
k = thermal conductivity (W/m.K)

Introduction :

Hot weather during the long summer season in Iraq since ancient ages laid emphasize on the need for serious thinking to build comforting houses in term of thermal insulation and natural ventilation that furnishes moderate indoor temperature.

At those times, thoughts were so primitive that the building materials were clay, hey, stems of date trees, etc. As time passed, new building materials with better thermal properties such as; gypsum stones, sandwich panels, polystyrene boards, polyurethane boards, polyisocyanurate, compressed wheat straw, epoxy, Rock and slag wool, etc were used so that those primitive ones became no longer in use as they are not suitable for decoration of modern building styles [1].

On the other hand, for reason of high strength and beautiful decoration, tones of concrete and steel as well as considerable number of glass sheets are used in building even though those materials have bad thermal properties in such away serious and detailed studies and researches especially in those countries with extreme weather such as Iraq are needed in order to achieve suitable designs and materials. The stunning multistory houses which are furnished with beautiful decoration and sophisticated techniques of building style feel so hot in summer (and so cold in winter) that demand hundreds of kilowatts of energy to maintain comforting indoor temperatures during the long-day hours [2].

This big amount of energy consumed in modern houses costs so much that the total cost of those houses are increasing continuously. On the other hand, the big amount of electrical energy consumed reflected negatively on the local increasing temperature levels because of the enormous amount of fuel burned which in its turn results in huge amount of greenhouse gases. Heat rejected by heat exchangers of air conditioners also plays a significant role in pushing the weather of Iraq to extremities and converting it to desert in worrying and alarming rate [3].

In addition to materials used in building and how efficient they are in maintaining comforting indoor temperature, one should think of the natural ventilation that can be optimized in order to maintain a relatively constant temperature with very low energy consumption level. Such optimization can be achieved applying simple building design that ensures good airflow through the building space. In addition, the damp ground and hot sun can be used in combination in order to reduce air temperature and speeding up airflow respectively.

Based on the brief explanation above, it can be concluded that thinking of new, low cost building style that ensures good thermal insulation and low energy consumption is becoming one of paramount important issues one can think of and should be given high priority. This building style shall not focus only on decoration and out looking appearance; rather it should focus on thermal insulation, unblocked-natural ventilation and low indoor temperature using natural approaches. With this, it should be emphasize that this research has no concern with building style and techniques used for such style; rather its main concern is the heat transfer system which is built using low-cost, simple materials with zero electricity consumption.

House Model :

In this research, a simple model of residence house was made using simple, low-priced materials. The house was made applying a certain scale (1:10) in order to ensure theoretical calculations that can be compared to actual ones. The materials used are a combination of blocks and sheets of wood and aluminum. The thermal properties of this combination can be compared to the thermal properties of the existing house walls (those walls are usually built from burned clay bricks, cement and gypsum plasters). In addition, some empty soft drink cans that usually got their way to garbage were used as a solar collector at the roof of house after applying a thin layer of black coat and fine grains of sand on their surfaces. This collector plays a significant role in speeding up the air stream inside the house. The selection of empty cans was deliberately made since the heaps of rubbish spread widely around our everyday environment. Figure (1) represents a photographic picture of our model which was installed at the house mini garden.

In figure (1), one can see two pipes; the first one is for the wind that will pass through a long underground passage before it gets inside the house. The other one (which is attached to the solar collector) is for escaping the hot air that got trapped inside the collector. The direction of flowing wind should be considered so that the wind entrance will face the direction of wind and the other pipe (exit pipe) will be in parallel with wind direction. This arrangement also helps speeding up the flow of air inside the house and hence reducing the indoor temperature. Reversing the directions of both pipes will increase the indoor temperature which is necessary in winter to keep a comforting temperature inside the house. See Figure (2) below.

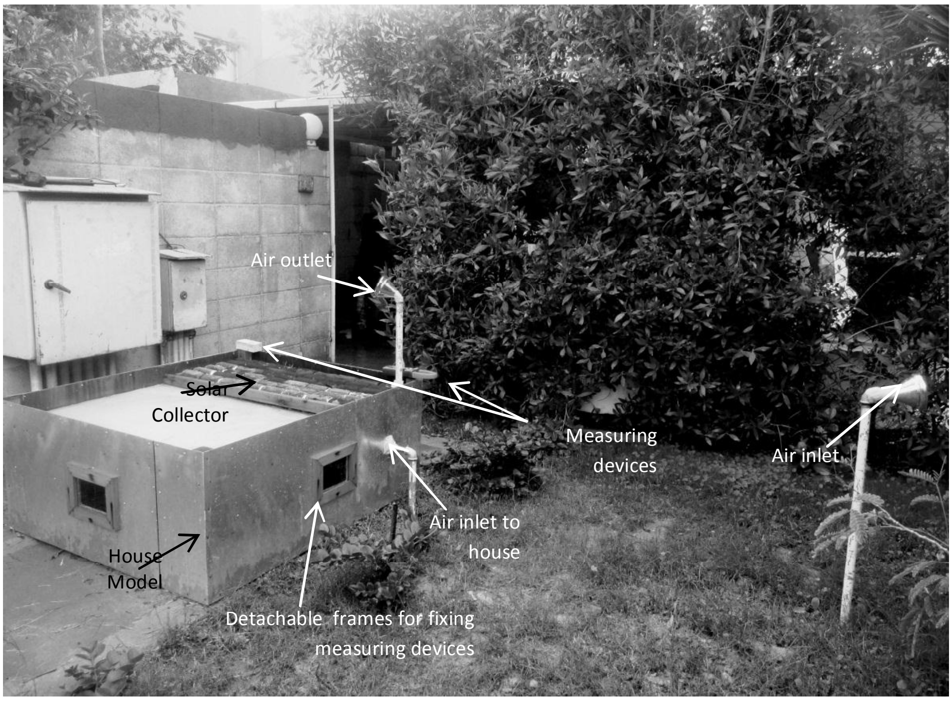

Figure (1): Photographic picture of the house model installed at the outside park

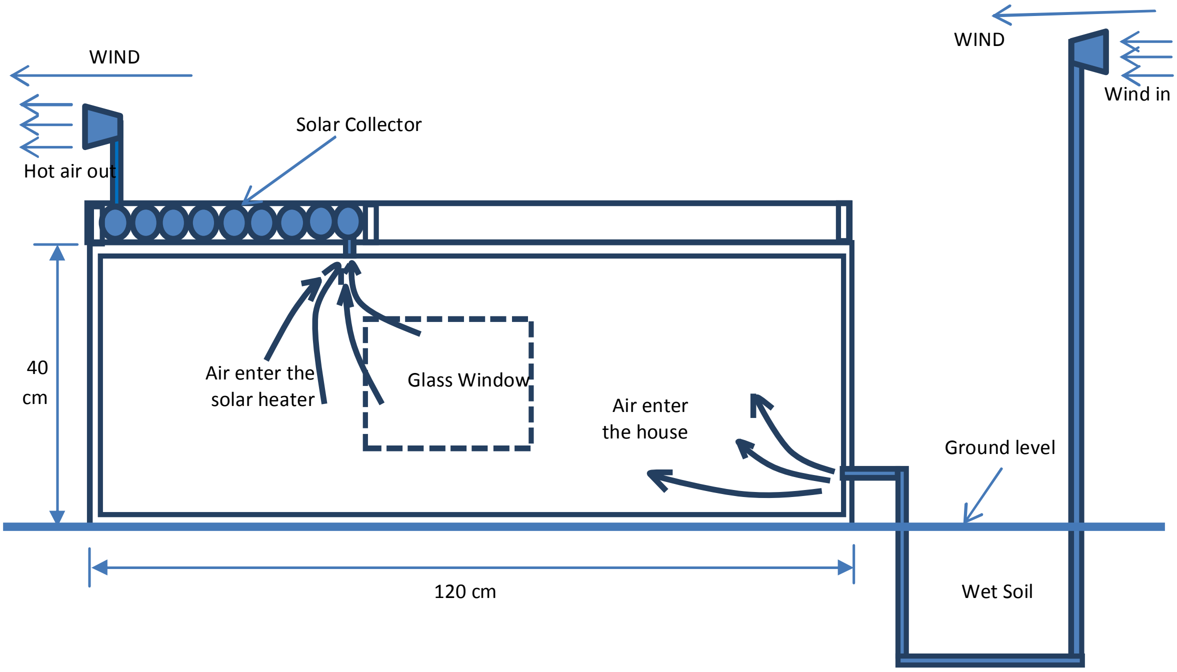

Figure (2): The side view of house model in which the circulation of air inside the house in accordance with wind direction is shown.

Basic Theory :

Before getting through the details of basic theory that governs the calculations, the following scientific axioms which cast the governing equations should be considered:

- The temperature of damp earth depends on the depth of the ground or alternatively on the negative distance from the ground surface. The deeper the distance is the lower the temperature of soil will be. The underground water (depending on Geographic locations) will also help in decreasing the temperature drastically [4].

- The temperature of air passing through a pipe (good conductor of heat) depends on the temperature of the wall and the length of pipe. The lower the temperature of wall and the longer the pipe is, the lower the temperature of air will be [4].
- Hot air rises to higher positions because of its low density so that cold air will replace its position. This phenomenon is called free convection [5].
- The amount of heat from sun can be optimized by means of using blackened, rough surfaces as roughness reduces reflection of sun radiation incident and the black color is to increase the absorption of heat [6].

The application of the first axiom was achieved by shaping the air inlet in a multi U-shaped pipe which is buried in the wet soil of the park at a depth of 50 cm. a schematic drawing of the inlet pipe is appeared in Figure (3).

The second axiom makes use of the snaky shape of pipe which was resulted in a buried length of 6.8 m and total length (including the partially buried pipes) of 7.5 m. This length has resulted in a temperature drop between the air entering the pipe and air entering the house of about 10-13^{o}C (see results and discussions).

A hole at the celling of the house model was made in order to allow the air inside the house to escape through the solar collector which is always filled with hot air. Accordingly the hot air will leave the collector and be replaced by the house air which becomes hot too and so on. This was the application of the third axiom.

The forth axiom explains why the empty cans were coated with a black color and made rough with grains of sand. This ensured rapid heating of air following inside the collector.

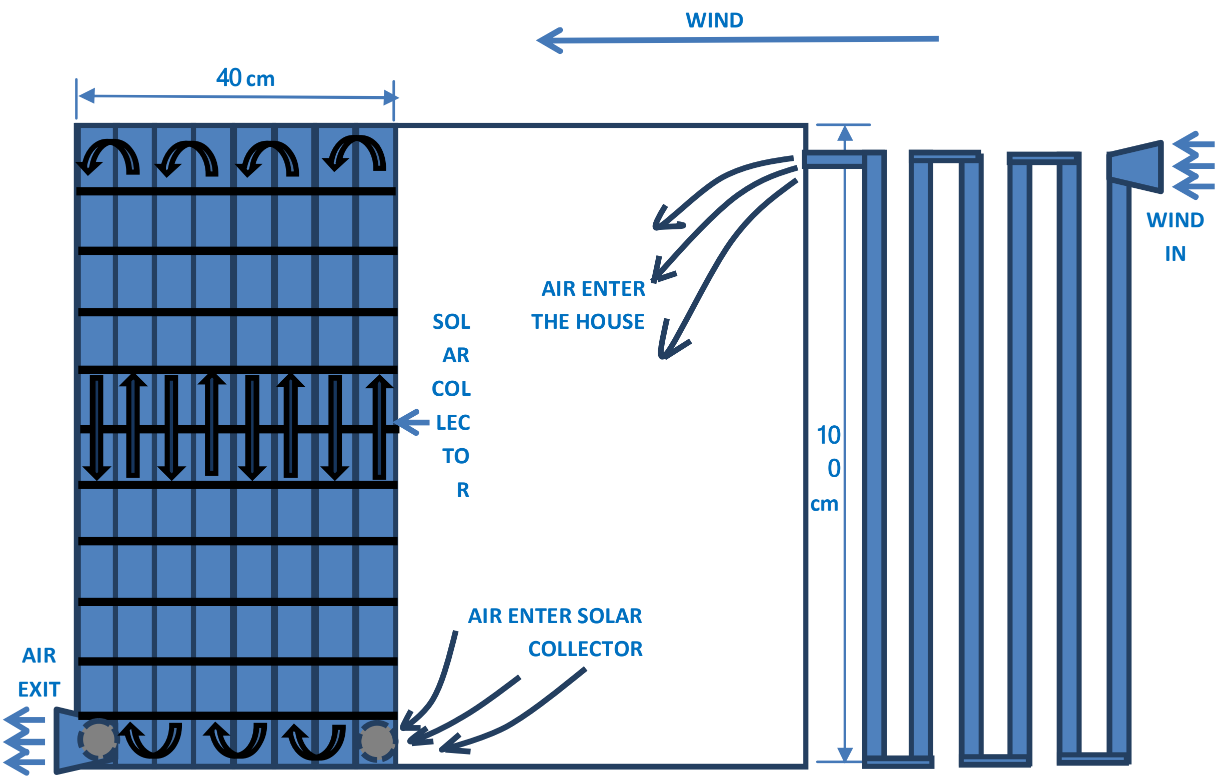

Figure (3): Top view of house model in which the inlet buried pipe with a total length of 7.5 m is shown

Before proceeding with calculations, two points regarding the circulation of air through the house should be made clear:

1. The inlet diameter of underground pipe (which is equal to inlet and outlet diameters of solar collector) is 19 mm. This diameter was selected after several attempts to achieve relatively high speed of air (approx. 2 m/sec). Larger diameters resulted in lower speed and the same thing can be said when the number of U-shaped elbows increased. More details about optimized airflow through pipes can be found in [7].
2. The solar collector is made with eight rows of air passages as shown in figure (3). Increasing the number of air passages will result in a lower efficiency of solar collector. This fact was proven by the work of [8].

For analytical calculations, the following equations were applied:

- The equation used to estimate the heat loss from inlet air through inlet pipe is [9]:

$$\dot{Q} = \dot{m}c(T_{wind} - T_{home}) \tag{1}$$

Note that:

$$\dot{m} = \rho VA \tag{2}$$

In general, all space temperatures were measured using thermometers. For surface temperatures, thermocouples were used. The velocity of air was measured using a fan meter which was placed at the entrance of air to the house. Fixing the fan meter at the exit of air (the hole connecting the inside of house to solar collector) is also possible. Figure (4) shows the devices used for measuring temperatures and air speed through the model.

(a) (b) (c)

Figure (4): Measurement devices (a) thermocouple for surface temperatures (b) fan meter for measuring air velocity (c) thermometer for space temperatures

Other parameters appeared in equation 1 and 2 were taken from tables found in handbooks or estimated using special dimension (such as the cross sectional area of inlet pipe).

- The equation governing the heat load entering the house through walls, roof and windows is [9]:

$$\dot{Q} = \dot{Q}_1 + \dot{Q}_2 \tag{3}$$

Heat transfer through house walls and ceiling excluding the glass windows ($\dot{Q}_1$) is:

$$\dot{Q}_1 = \frac{T_{wind} - T_{home}}{\frac{1}{h_{wind}\,A_1} + \frac{L_1}{k_1 A_1} + \frac{L_2}{k_2 A_2} + \frac{1}{h_{home}\,A_2}}$$

And the heat transfer through glass windows ($\dot{Q}_2$) is

$$\dot{Q}_2 = \frac{T_{wind} - T_{home}}{\frac{1}{h_{wind}\,A_3} + \frac{L_3}{k_3 A_3} + \frac{1}{h_{home}\,A_3}}$$

The schematic diagram for the series of heat resistances is shown in Figure (5) below:

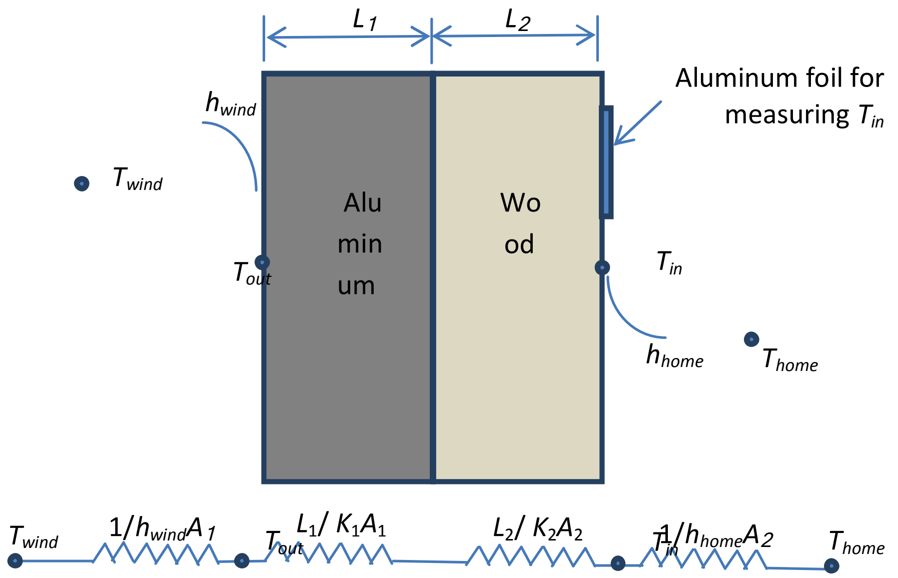

Figure (5): Schematic diagram of thermal resistance series through the house wall

Notice that heat transfer by radiation was ignored for the following reasons:

1. The outside surface of the model is so bright that the portion of heat radiation reflected is far higher than the portion absorbed through the wall.
2. Local wind in Iraq during summer mostly has a range of speed of 20-35 km/hr (especially during the days the experiment was made). During such environment, convective heat transfer will be dominant; hence radiation heat transfer can be ignored with disregarded error [9].

Calculations and Results :

In order to do the calculations, the following empirical data was taken from [10] while the spatial data such as areas and air velocity were measured. Nevertheless wind speed was taken from weather forecast websites which are available on the World Wide Web. :

Average wind velocity (V_{wind}) = 25 km/hr = 7 m/s
Convective heat transfer coefficient (h_{wind}) = 100 W/m^2.k
Convective heat transfer coefficient (h_{home}) = 10 W/m^2.k
Thermal conductivity for aluminum sheet (k_1) = 30 W/m.k
Thermal conductivity for wood sheet (k_2) = 0.147 W/m. k
Thermal conductivity for glass (k_3) = 0.96 W/m. k
Thickness of Aluminum wall (L_1) = 0.002 m
Thickness of Wood wall (L_2) = 0.004 m
Thickness of glass window (L_3) = 0.002 m
Specific heat for air at an average temperature of 40°C = 1000 J/kg. k
Density of air at a range of temperature 20 – 40 ^{0}C = 1.12 kg/m^3
Diameter of air inlet (d) = 0.019 m
Cross sectional area of air inlet = $\pi d^2/4$ = 0.00028 m^2
Velocity of air inside air inlet = (1.89 – 2) m/s
Mass flow rate of air = 0.000952 kg/s
Area of outside layer (aluminum layer)
A_1 = (1.2*2+1*2)0.4 + (1.2*1) – (0.15*0.15)4 = 2.87 m^2
Area of inside layer (wood layer) $A_2 = A_1$ = 2.87 m^2
Area of glass windows (A_3) = 4(0.15*0.15) = 0.09 m^2

The main temperature (T_{wind}, T_{out}, T_{in}, and T_{home}) are considered variables against day hours. These variables are listed in table (1) below:

Table (1): List of main temperatures against day hour (air inlet is open)

Day hour	T_{wind} (°C)	T_{out} (°C)	T_{in} (°C)	T_{home} (°C)
9:00	38	40	31	28
10:00	41	48	35	31
11:00	46	52	40	33
12:00	48	55	42	34
13:00	49	56	47	38
14:00	50	59	49	39
15:00	51	60	50	40

These values are shown in Figure (6). Note that three hours before noon and three hours after noon were selected to be the base of the calculations as those temperatures are considered to be the hottest ones during which hot weather felt severe. Also note the fluctuation in data which was caused by measurement error and/or the location where the model was installed. In general, it can be said that an ascending tendency of afternoon temperatures occurred where peak occurs at 15:00.

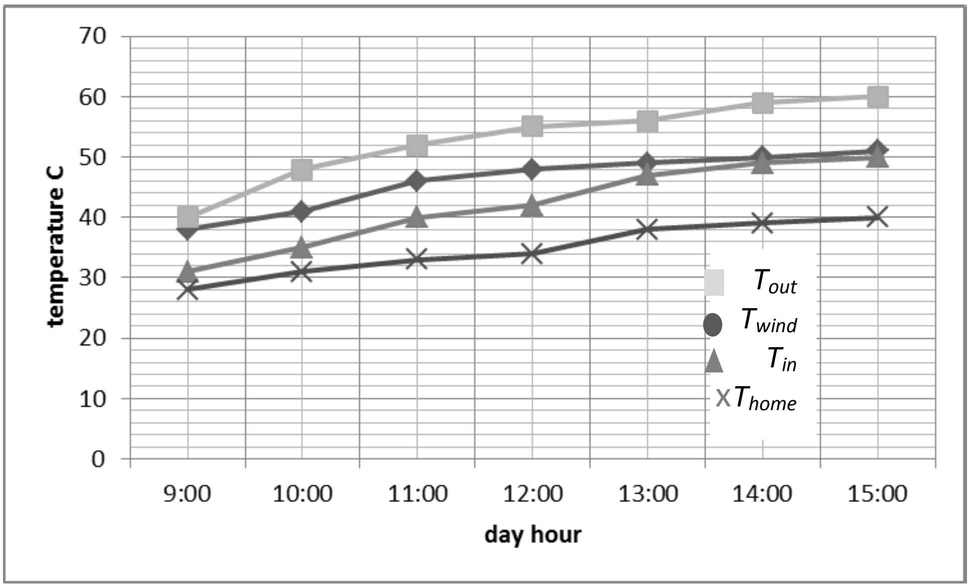

Figure (6): The relation between main temperatures and day hour (air inlet is open)

The average difference between T_{wind} and T_{home} is 10°C. This difference was achieved naturally by means of air passing through an underground pipe. The effect of this stream of air can be observed by closing the air inlet and measuring the same temperature values in a different day and the results are shown in table (2) below:

Table (2): List of main temperatures against day hour (air inlet is closed)

Day hour	T_{wind} (°C)	T_{out} (°C)	T_{in} (°C)	T_{home} (°C)
9:00	36	38	34	31
10:00	38	41	37	35
11:00	40	44	39	38
12:00	44	48	42	43
13:00	47	55	46	49
14:00	49	58	48	50
15:00	50	62	50	53

The curves for those temperature values against day hours are shown in Figure (7) below:

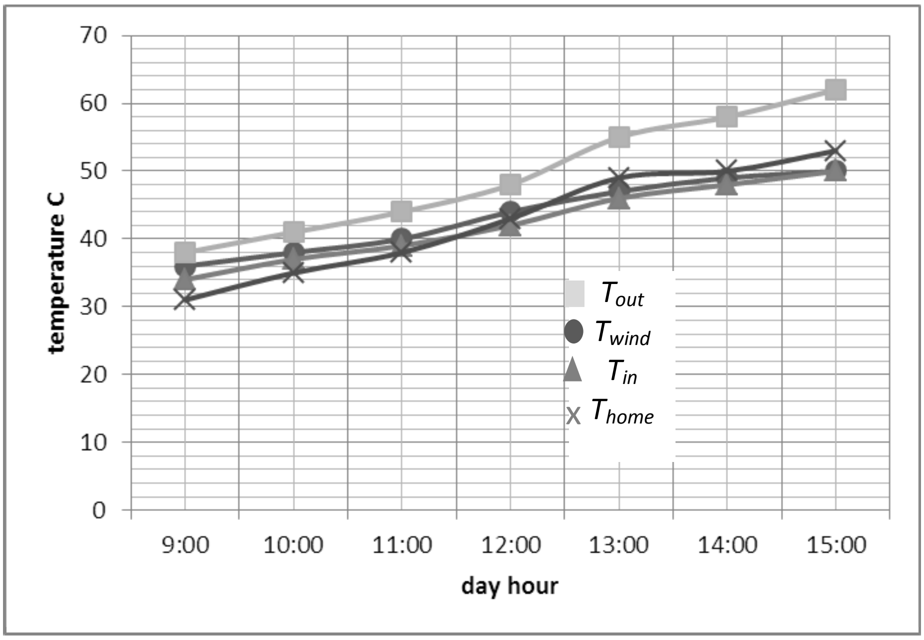

Figure (7): The relation between main temperatures and day hour (air inlet is closed)

The difference obviously reduced to at most 5 degrees and then the inside temperature jumps above the outside temperature during afternoon hours.
The amount of heat passes through the outside boundaries and the heat loss from the air passing through underground pipe can be studied. Both heat calculations based on the values of main temperatures appear in table (1). The gain of heat can obtained applying equation (3) and the loss of heat can be obtained applying Equation (1). The values of both heat amounts are listed in Table (3) below.

Table (3): Values of heat gain and heat loss against day hour

Day hour	Heat gain (Watts)	Heat loss (Watts)
9:00	47.198	9.52
10:00	47.198	9.52
11:00	61.357	12.376
12:00	66.077	13.328
13:00	51.918	10.472
14:00	51.918	10.472
15:00	51.918	10.472

For reason of comparing heat amounts with each other, those values have been drawn against day hours and shown in Figure (8) below:

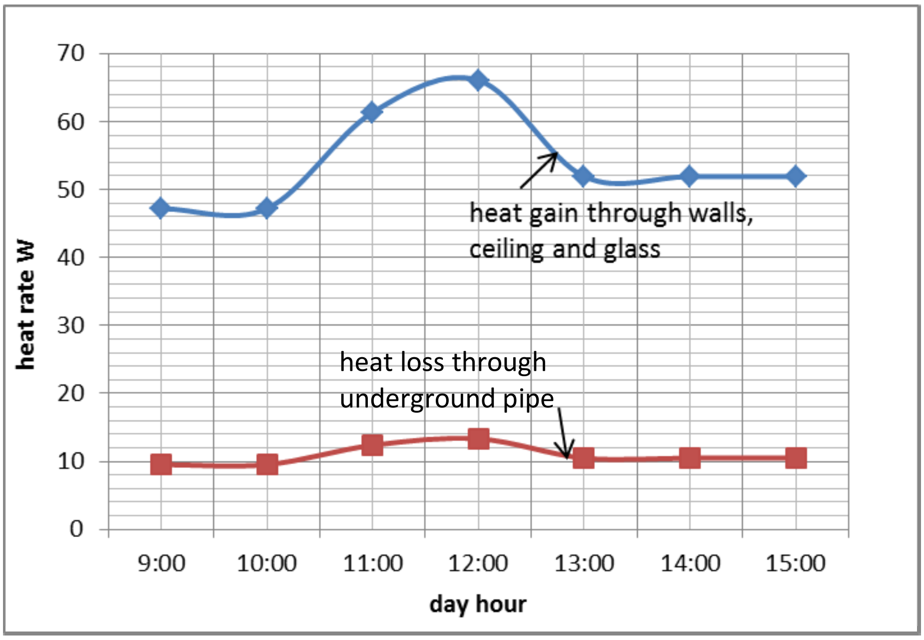

Figure (8): Heat gain and heat loss against day hours

Conclusions and Suggestions :

- The maximum temperature difference between inside and outside the house was 10°C which is not so optimistic because such difference can be achieved in open shadow. However, considering that the inside space was absolutely closed but from the small inlet and outlet (0.00028 m^2) and the metal outside layer that surrounding the house, a temperature difference of 10°C is accepted. Table (2) and Figure (7) prove this fact.
- The temperature of outside layer (aluminum layer) during all day hours exceeds outside temperature. Accordingly most of heat was reflected outside but a small amount which appeared in column 2 in Table (3). In fact, this amount represent the last term in equation (3) (i.e. the convection heat between inside and home temperatures).
- During the test, no fan was used for speeding up stream of air inside the house. Doing so is expected to increase the amount heat rejected outside the house and hence increasing the temperature difference between inside and outside the house.

The following ideas are suggested:

- Using a small, low electricity consumption fan inside the house is expected to result in decreasing the inside temperature remarkably.
- Using double wood layer is expected to decrease the inside temperature.

The above suggestions hopefully can be attempted by researchers who will add to their ideas and/or modifications.

References :

1. Masine Md. Tap, Haslinda Mohamed Kamar, Abdul Kadir Marsono, Nazri Kamsah, "Simulation of Thermal Comfort of a Residential House", International Journal of Computer Science, Vol. 8, PP: 200-208, DOAJ , 2011, (IVSL).
2. Thormark Catarina, "Environmental analysis of a building with reused building materials", International Journal of Low Energy & Sustainable Building, Vol. 1, Lund University, 2000 (IVSL).
3. Kharrufa, S.N. and Adil, Y., "Roof pond cooling of buildings in hot arid climates", Building and Environment Journal, Vol. 43, pp:82-89, Elsevier , 2008 (IVSL).
4. Zhang Chenghu and others, "Temperature Field and Heat Transfer Analysis of Underground Buried Pipe", 2011 Third International Conference on Measuring Technology and Mechatronics Automation, Vol. 3 PP.636-639, IEEE, 2011 (IVSL).
5. Frank P. Incropera, and others, "Fundamentals of Heat and Mass Transfer", John Wiley &Sons, USA, 2002.
6. Chang, T.P. , "The Sun's apparent position and the optimal tilt angle of a solar collector in the northern hemisphere", Journal of Solar Energy, Vol. 83, PP. 1274-1284, Elsevier, 2009 (IVSL).
7. Ruth M., and others "Numerical Prediction of Air Flow in a Sharp 90° Elbow" Seventh International Conference on CFD in the Minerals and Process Industries CSIRO, Melbourne, Australia 9-11 December 2009.
8. Mahmmod A., "The Effect of Using Baffles on the Performance of Solar Heater Having Granulated Carbon Layer", Master Thesis, Gadjah Mada University, Indonesia, 2000.
9. J. P. Holman, "Heat Transfer", McGraw-Hill Co., USA, 2006.
10. Warren M. Rohsenow and others, "Handbook of Heat Transfer", McGraw-Hill Co., USA, 1998.