# Prediction of House Walls Temperatures Subjected to Solar Energy in Northern Malaysia

Merdang Sembiring
Universiti Malaysia Perlis (UniMAP)
Email address: merdang@unimap.edu.my

***Abstract*. This study focuses on prediction of house walls temperatures, at Perlis Region, Malaysia, in which the house walls are striked by solar radiation from morning until sunset. The calculations in this study are just specialized for March month, due to at the time, Perlis Region is radiated by Solar Energy to be the highest during a year. The current design of the house walls in this study is quite simple. Four walls of the house with brick material, each face to the East, West, South and North, respectively. The variation of the ambient temperature, $T_{air}$, and solar heat flux incident, $q_{solar}$, on each of wall surface throughout the day is chosen for a typical day (day representation in March month) in 1-h interval. Heat transfer coefficient inside and outside walls are calculated. Influence of radiation to the sky is also to take part in this calculation. The interior of house is maintained at $T_{in}$ = 18°C at all times. In simulation, we applied the finite difference method to transient problems, where the solar heat flux incident, $q_{solar}$, at the walls change with the time as well as the position of the sun during its movement. In this case finite difference solution of transient problems requires discretization in time in addition to discretization in space. For simulation, we use Fortran Software to solve the problem with using** Gauss elimination method **iteration. For the values of Solar Energy hourly, which become input data in simulation, its values being converted from the monthly average Solar Radiation at Perlis Region [2], which have been collected during 26 years (from 1979-2005) by Station Metrology, Chuping, Perlis Malaysia.**

***Keywords* - Solar Energy, Position of Sun, House Walls, Heat Transfer, Numerical Solution, Walls Temperatures**.

## I. INTRODUCTION

Perlis is the smallest state in Malaysia, and it lies at the northwestern tip of the Malay Peninsula. Days are hot and windy. September to December is wet. Temperature varies little the year round, ranging from 21° C to 33° C, even though sometimes it arrives 36°C.

The direction of beam radiation, the position of the sun relative to the house walls (plane) and the geometric relationships between a wall of any particular orientation relative to the earth at any time, is shown in Fig. 1.

According to [1], the equation relating the angle of incidence of beam radiation, $\Theta$, and the other angle as shown in the Fig. 1, is:

$$\cos\theta = \sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma + \cos\delta\cos\phi\cos\beta\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega + \cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega \quad (1)$$

Meanwhile the equation of the angle of incidence of beam to the zenith angle of the sun, $\Theta_z$, is:

$$\cos\theta_z = \cos\delta\cos\phi\cos\omega + \sin\delta\sin\phi \quad (2)$$

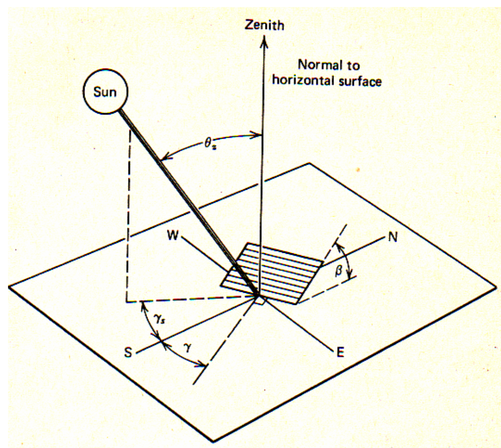


Fig. **1.** Zenith Angle, Slope, Surface Azimuth Angle And Azimuth Angle For A Tilted Surface.

From literature [2], the monthly mean daily extraterrestrial radiation ($H_o$) on a surface horizontal in absence of atmosphere, at Chuping, Perlis Region, is shown in the TABLE 1.

TABLE 1.
The Monthly Mean Daily Extraterrestrial Radiation ($H_o$) on Surface Horizontal in Absence of Atmosphere, at Chuping, Latitude 6°. 29' N, Perlis, Malaysia.

| *Month* | *Jan.* | *Feb.* | *Mar.* | *Apr.* | *Mei* | *Jun.* |
|---|---|---|---|---|---|---|
| *$H_o$ (MJ/m²)* | 33.23 | 35.33 | 36.99 | 37.27 | 36.31 | 35.50 |
| *Month* | *Jul.* | *Aug.* | *Sep.* | *Oct.* | *Nov.* | *Dec.* |
| *$H_o$ (MJ/m²)* | 35.71 | 36.62 | 36.87 | 35.64 | 33.61 | 32.46 |
| *Average :* | **35.46** | | | | | |

Still from the literature [2], we can also find the results of measurements of solar radiation at the surface of the earth (carried out by station Metrology Chuping, Perlis Region) as shown in TABLE 2.

These radiation measurements data, [are to be concern with effects of the atmosphere (atmospheric scattering by air molecules, water vapor, and dust; and also atmospheric absorption by $O_2$, $H_2O$, and $CO_2$)], have been tabulated from the measurements data from 1979 until 2005.

TABLE 2.
Mean Solar Radiation and Maximum Temperature, for average daily each month, Perlis Region, 1979 - 2005.

| **Month** | ***Mean Solar Radiation Ho*** (MJ/m2) | ***Max. Temperature T*** (C) | **Month** | ***Mean Solar Radiation Ho*** (MJ/m2) | ***Max. Temperature T*** (C) |
|---|---|---|---|---|---|
| Jan. | 18.50 | 33.0 | Jul. | 17.23 | 32.0 |
| Feb. | 19.72 | 34.7 | Aug. | 17.91 | 31.8 |
| Mar. | 20.29 | 35.0 | Sep. | 17.23 | 31.6 |
| Apr. | 20.08 | 34.3 | Oct. | 16.25 | 31.7 |
| May | 18.82 | 33.1 | Nov. | 15.42 | 31.5 |
| Jun. | 18.01 | 32.5 | Dec. | 15.80 | 31.4 |

Note : ***Ho*** = Monthly mean daily radiation results of measurement.

## II. ESTIMATION OF HOURLY RADIATION FROM DAILY DATA MEASUREMENT

The monthly average of daily solar radiation on horizontal surface as shown in TABLE 2 is not enough to become a basic data in practical, so it will be expanded in the form of hourly radiation ( $I$ ).
In this case we shall use the method that have been published by Collares-Pereira and Rabl (1979) [1].
They have presented the equation as followed,

$$\frac{I}{H_O} = \frac{\pi}{24}(a + b\cos\omega)\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - (2\pi\omega_s/360)\cos\omega_s} \text{ [J/m}^2\text{]} \quad (3)$$

Where the coefficients a and b are given by :
$a = 0{,}409 + 0{,}5016 \sin(\omega_s - 60)$
$b = 0{,}6609 - 0{,}4767 \sin(\omega_s - 60)$
with: $\omega$ is the hour angle in degrees for the time in equation, and $\omega_s$ is the sunset hour angle for the day at region chosen.

We notice that $H_O$ in "(3)," is average of the total radiation by measurement on a horizontal surface for Chuping, Perlis (latitude 6, 29 ºN) on daily average of each month in the year. For each hour in one day, based on the midpoints of the hour, the solar radiation on horizontal surface are estimated by the "(3),". These calculations can be repeated for each day representation of the month in a year. The result for March month is shown in TABLE 3.

TABLE 3.
Result of Calculation from Data Measurement (1979-2005), For Horizontal Solar Energy, Hourly, at Perlis Region, Latitude 6.29N.

| | ***March*** | | | | | |
|---|---|---|---|---|---|---|
| Time | 6 - 7 | 7 - 8 | 8 - 9 | 9-10 | 10-11 | 11-12 |
| *$I_h$ (MJ/m²)* | 0.240 | 0.830 | 1.481 | 2.099 | 2.583 | 2.848 |
| Time | 12-13 | 13-14 | 14-15 | 15-16 | 16-17 | 17-18 |
| *$I_h$ (MJ/m²)* | 2.848 | 2.583 | 2.099 | 1.481 | 0.830 | 0.240 |
| **Mean** | **1.680** | | | | | |

We mention that maximum of Solar Radiation Intensity arrived at surface of the earth, for Perlis Region, lies in March month. In the type of chart-line this intensity can be presented as shown in the Fig. 2.

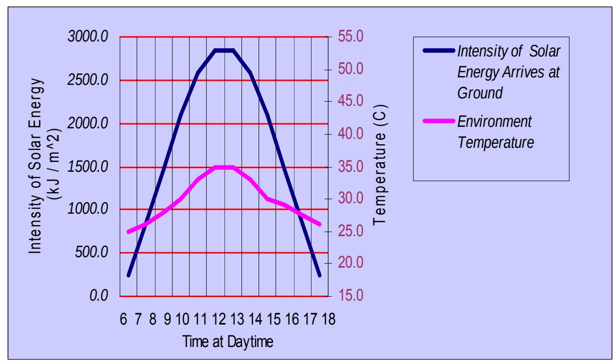


Fig. 2. Distribution of Solar Radiation Terrestrial and Environment Temperature Average, March Month, Perlis Region.

## III. ESTIMATION OF BEAM AND DIFFUSE RADIATION COMPONENTS OF HOURLY RADIATION.

In order to predict the performance of any solar conversion system, the diffuse and direct components of solar irradiation must be known on both a temporal and a geographic basic. In this study, the ratio between $I_d / I$ is estimated with using the correlation Orgill and Holland [1] in the form:

$$\frac{I_d}{I} = \begin{cases} 1.0 - 0.249\,k_t & \text{for } k_t < 0.35 \\ 1.557 - 1.84\,k_t & \text{for } 0.35 \le k_t \le 0.75 \\ 0.177 & \text{for } k_t > 0.75 \end{cases} \quad (5)$$

where $k_t$ is the ratio of total radiation to the extraterrestrial radiation for the hour, at Perlis region.
For March month, with using the "(5)," and based upon of data as shown in the TABLE 3., then the average of beam and diffuse components of hourly radiation can be calculated. It results are shown in TABLE 4.

TABLE 4.
Beam and Diffuse Components of Hourly Radiation, in Horizontal Surface, March Month, at Chuping, Perlis, Malaysia, Latitude 6, 29.

| Month March | $I_h$ MJ/m² | $k_t$ [2] | $I_b$ W/m² | $I_d$ W/m² |
|---|---|---|---|---|
| 6 - 7 | 0.240 | 0.393 | 55.59 | 11.07 |
| 7 - 8 | 0.830 | 0.451 | 167.65 | 62.90 |
| 8 - 9 | 1.481 | 0.504 | 259.03 | 152.36 |
| 9-10 | 2.099 | 0.547 | 320.98 | 262.07 |
| 10-11 | 2.583 | 0.578 | 354.07 | 363.43 |
| 11-12 | 2.848 | 0.593 | 368.56 | 422.55 |
| 12-13 | 2.848 | 0.593 | 368.56 | 422.55 |
| 13-14 | 2.583 | 0.578 | 354.07 | 363.43 |
| 14-15 | 2.099 | 0.547 | 320.98 | 262.07 |
| 15-16 | 1.481 | 0.504 | 259.03 | 152.36 |
| 16-17 | 0.830 | 0.451 | 167.65 | 62.90 |
| 17-18 | 0.240 | 0.393 | 55.59 | 11.07 |

**Note:** $I_h$: Hourly Total of Solar Radiation
$I_b$: Hourly Total Beam of Solar Radiation
$I_d$: Hourly Total Diffuse of Solar Radiation

IV. TOTAL SOLAR RADIATION STRIKES THE HOUSE WALLS.

For March month in a year the position of sun, relative to the earth, can be described as shown in Fig. 3.
House walls absorb beam, diffuse and reflected components of solar radiation, can be calculated as followed.

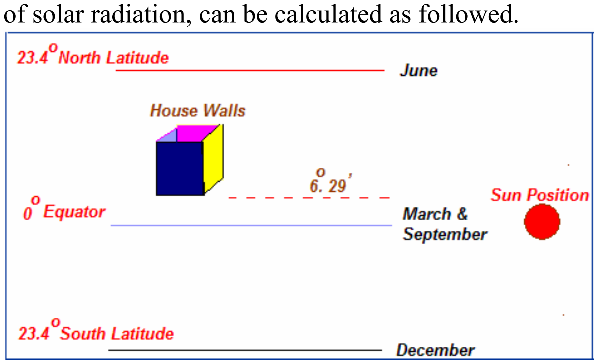


Fig. 3. Sun Position Relative To The House Walls In Terre.

By definition:

$$R = \frac{total\ radiation\ on\ a\ wall\ surface\ (I_T)}{total\ radiation\ on\ a\ horizontal\ surface\ (I)}$$

Then, the total radiation on a tilted surface can be written as:
$I_T = R\, I_H$

A wall tilted at slope ß = 90° from the horizontal has a few factor to the sky given by (1 + cos ß) / 2 = 0.5. We assume the diffuse solar radiation is isotropic, with symbol $R_d$. Then, the wall has a few factor to the ground of (1 – cos ß) / 2.
So, R could be rewritten as:

$$R = \frac{I_b}{I} R_b + \frac{I_d}{I_b}\left(\frac{1+\cos\beta}{2}\right) + \left(\frac{1-\cos\beta}{2}\right)\rho \qquad (6)$$

Where, $R_b = \dfrac{\cos\,\theta}{\cos\,\theta_z}$, and $\rho$ = reflectance of total solar radiation to the surrounding.

Results of calculation for the total solar radiation strikes the house walls for March month, at Perlis Region, is given in Fig. 4.

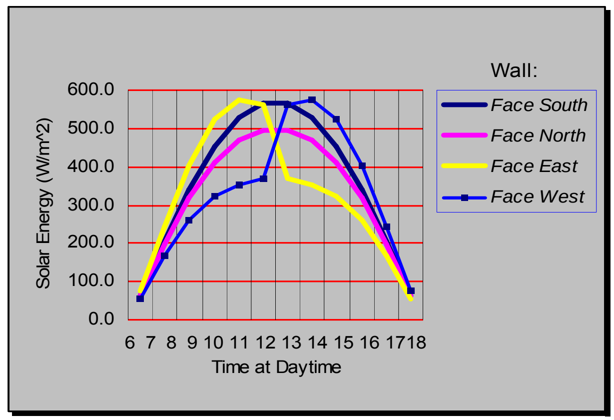


Fig. 4. Solar Energy Strikes House Wall ($I_T$), Function Of Time and Face Of The Wall.

V. PREDICTION OF HOUSE WALLS TEMPERATURE.

The simulation in transient problem for prediction of house walls temperature, throughout the day in March month for each alteration of parameters in 1-h interval, takes some assuming as follows.

a) Heat transfer is one-dimensional since the exposed surface of the wall is large relative to its thickness, and thus the corner effects were negligible.
b) Heat transfer by radiation, between walls and sky is function of time in a day, is taken for considering.
c) The variation of the ambient temperature, $T_{air}$, and solar heat flux incident, $q_{solar}$, on each of wall surface throughout the day is also taken for considering.
d) Thermal conductivity is constant.
e) The average combined heat transfer coefficient between wall and outer ambient, and also between wall and interior are taken to be constant; its values are: $h_{out}$ = 10 W/m².°C and $h_{in}$ = 5 W/m².°C, respectively.

For a general node *m* and *implicit method*, the finite difference formulations are expressed as:

$$\sum_{All\ sides} Q^{i+1} + e^{i+1}_{element} v_{element} = \rho v_{element} c_p \frac{T_m^{i+1} - T_m^i}{\Delta t} \quad (7)$$

Where $T_m^i$ *and* $T_m^{i+1}$ are the temperatures of node *m* at times $t_i = i\Delta t$ and $t_{i+1} = (1+i)\Delta t$, respectively.
$T_m^{i+1} - T_m^i$ represents the temperature change of the node during the time interval $\Delta t$ between the time steps *i* and *1 + i*.

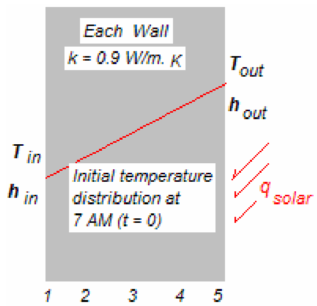


Fig. 5. The Nodal Network For The Wall Discussed.

The nodal spacing is given to be Δx = 2.5 cm, and thus the total number of nodes along the wall is:

$$N = \frac{L}{\Delta x} + 1 = \frac{10}{2.5} + 1 = 5$$

The node 1 is on the interior surface of the wall and node 5 is on the exterior surface, as shown in **FIG. 5**. Nodes 2 through 4 are interior nodes. Radiation heat transfer between walls and the sky at $T_{sky}$ may be calculated from

$$q_{rad} = \varepsilon \sigma A (T^4 - T_{sky}^4) \quad (8)$$

with $T_{sky} = 0.0552\ (T_{out})^{1.5}$ (9)

where ε = 0.8, σ = 5.669 x $10^{-8}$, and T with $T_{sky}$ in degrees Kelvin. Convection and radiation on inner side of the wall are negligible.
So, following Eq. 7, the transient energy equation for node 1, can be written as

$$h_{in} A (T_{in} - T_1^{i+1}) + k A \frac{T_2^{i+1} - T_1^{i+1}}{\Delta x} = \rho A \frac{\Delta x}{2} c_p \frac{T_1^{i+1} - T_1^i}{\Delta t} \quad (10)$$

Similarly, for node 5 with the radiation boundary condition, the transient energy equation may be written

$$h_{out} A (T_{out}^{i+1} - T_5^{i+1}) + \alpha q_{solar}^{i+1} A + k A \frac{T_4^{i+1} - T_5^{i+1}}{\Delta x} + \varepsilon \sigma A [(T_5^{i+1} + 273)^4 - (T_{sky})^4] = \rho A \frac{\Delta x}{2} c_p \frac{T_5^{i+1} - T_5^i}{\Delta t} \quad (11)$$

For the other three nodes the general expressions are written

$$k A \left(\frac{T_m^{i+1} - T_{m+1}^{i+1}}{\Delta x}\right) + k A \left(\frac{T_{m-1}^{i+1} - T_m^{i+1}}{\Delta x}\right) = \rho A \frac{\Delta x}{2} c_p \frac{T_m^{i+1} - T_m^i}{\Delta t} \quad (12)$$

with *m* can be changed become interior nodes number 2, 3 and 4, respectively.

From Eq. 10 through 12, the nodel equations may be written in form as

$$\begin{aligned} a_{11} T_1^{i+1} + a_{12} T_2^{i+1} + \ldots + a_{1N} T_N^{i+1} &= b_1 \\ a_{21} T_1^{i+1} + a_{22} T_2^{i+1} + \ldots &= b_2 \\ a_{31} T_1^{i+1} + \ldots &= b_3 \quad (13) \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots & \\ a_{N1} T_1^{i+1} + a_{N2} T_2^{i+1} + \ldots + a_{NN} T_N^{i+1} &= b_N \end{aligned}$$

Where $T_1$, $T_2$,.., $T_5$ are the unknown nodes temperatures.

Using Gauss Subroutine [4], in Gauss elimination method the matrix notation are arranged in array N x (N + 1) as

$$\begin{bmatrix} a_{11} & a_{12} & \ldots & a_{1N} & a_{1,N+1} \\ a_{21} & a_{22} & \ldots & a_{2N} & a_{2,N+1} \\ a_{31} & & \ldots & a_{3N} & a_{3,N+1} \\ \ldots\ldots & \ldots\ldots & \ldots\ldots & & \\ a_{N1} & a_{N2} & \ldots & a_{NN} & a_{NN,N+1} \end{bmatrix}$$

where matrix column toward N+1 is column of equations constants. In this study the number of node is N = 5.
Gauss elimination method is widely used for solution a transient analysis [3], where the new values of the node temperature $T_N$ for the next iteration are always calculated using the most recent values of $T_j$, which are the nodel temperatures around $T_N$. In this simulation, the properties of brick wall have been taken as: $c_p$ = 790 J/kg.C, ρ = 1920 kg/m$^3$ and k = 0.9 W/m. K.

## VI. RESULTS AND DISCUSSION.

The matrix coefficients are calculated by using the values of $I_T$ (see Fig. 4.) which are taken for an interval time 1 – hour, and these values become the values of $q_{solar}$ to be constant at the same interval time. Then by using Gauss Subroutine [4], a computer solution has been performed with Δt = 900 s. First, for the wall face South some results of calculation are shown in TABLE 5.

TABLE 5.
Evolution of Inner and Outer Wall Temperatures, For House Wall Face South, Function of Solar Energy Strikes The Wall and Time.

| Time | Solar Energy arrives at Horizontal Surface | Solar Energy arrives at Vertical Surface | Temperature Outer Wall | Temperature Inner Wall |
|---|---|---|---|---|
| | $I_H$ | $I_T = q_{solar}$ | $T_{o,w}$ | $T_{i,w}$ |
| O'clock | W/m$^2$ | W/m$^2$ | $^o$C | $^o$C |
| 6 - 7 | 66.67 | 62.69 | 17.74 | 17.93 |
| 7 - 8 | 230.56 | 203.78 | 22.43 | 17.24 |
| 8 - 9 | 411.39 | 340.03 | 31.05 | 23.58 |
| 9-10 | 583.06 | 451.75 | 37.42 | 28.13 |
| 10-11 | 717.50 | 527.04 | 43.12 | 32.08 |
| 11-12 | 791.11 | 564.95 | 46.60 | 34.57 |
| 12-13 | 791.11 | 564.95 | 46.97 | 35.08 |
| 13-14 | 717.50 | 527.04 | 44.23 | 33.59 |
| 14-15 | 583.06 | 451.75 | 39.28 | 30.67 |
| 15-16 | 411.39 | 340.03 | 34.71 | 27.93 |
| 16-17 | 230.56 | 203.78 | 28.82 | 24.33 |
| 17-18 | 66.67 | 62.69 | 21.80 | 19.98 |

The evolution of these inner and outer wall temperatures, are plotted in Fig. 6. We see that the maximum temperature of the wall is happened at 12.30 o'clock.

For the wall which face North, the evolution of inner and outer wall temperatures are shown in Fig. 7. Its can be seen that its form look like the temperature evolution in wall face South, but its values less than them which face South. These differences happened due to the position of sun relative to the both of the walls are not same one to another (see Fig. 3).

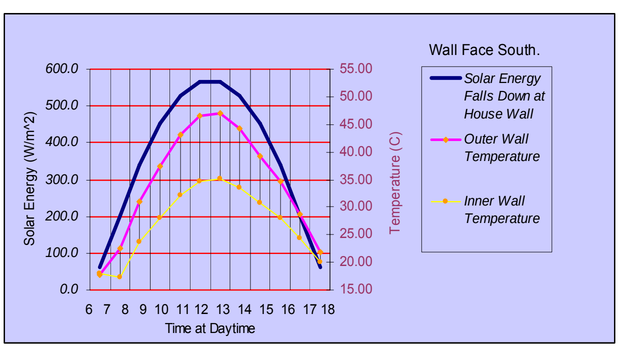


Fig. 6. Evolution Of Inner And Outer Wall Temperatures, Function Of Solar Energy Strikes The Wall Face South, March Month, Perlis Region, Malaysia.

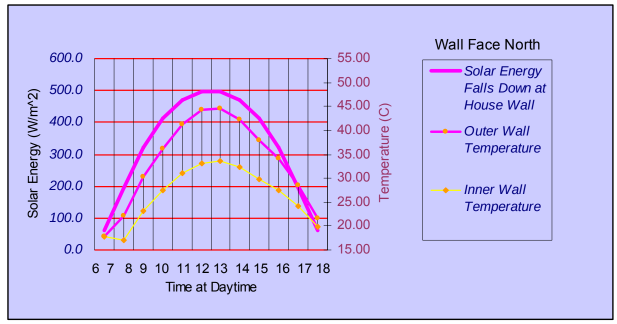


Fig. 7. Evolution Of Inner And Outer Wall Temperatures, Function Of Solar Energy Strikes The Wall Face North, March Month, Perlis Region, Malaysia.

Evaluating for same day for the walls face East and face West, are given in Fig. 8 and Fig. 9, respectively. Here the evolution of solar energy strikes the walls, not in form sinusoidal like the walls face South and face North.

Especially for the wall face East, the three of direct, diffuse and reflected components of solar energy strike the wall during half day in the morning. In the afternoon, start at 12 o'clock, direct solar energy not strikes the wall anymore and just diffuse and reflected of solar energy arrive on surface of the wall. Around 11.30 o'clock in the morning, the outer wall temperature face East obtains maximum temperature to be 46.43 $^o$C.

On the contrary, what taking place in the morning for wall face East, that phenomenon happened to the wall face West in afternoon. The outer wall temperature for wall face West become maximum temperature around at 13.30 pm and achieves 46.80 $^o$C (see Fig. 9), slight above maximum temperature of wall face East.

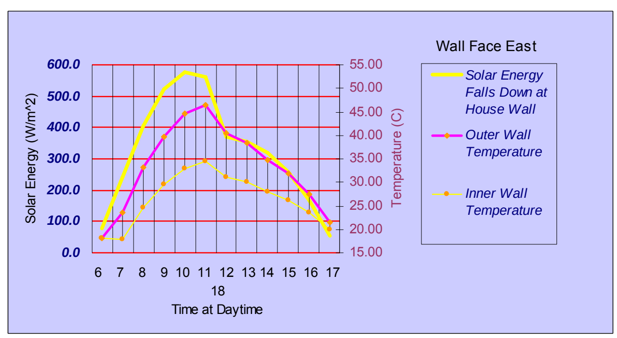


**Fig. 8.** Evolution Of Inner And Outer Wall Temperatures, Function Of Solar Energy Strikes The Wall Face East, March Month, Perlis Region, Malaysia.

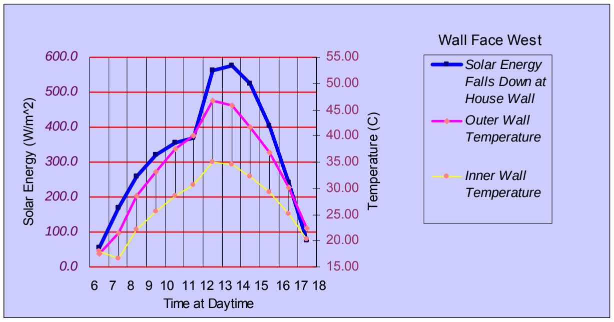

Fig. 9. Evolution Of Inner And Outer Wall Temperatures, Function Of Solar Energy Strikes The Wall Face West, March Month, Perlis Region, Malaysia.

In FIG. 10, it is shown the comparison of evolution of inner walls temperatures (each for wall face South, North, East and West, respectively) along daytime, for number day 17 on March month, in Perlis Region, Malaysia. It can be seen that all temperatures of the inner house walls at sun set nearly the same, around 20$^o$C, where the outer house walls achieve around 22$^o$C. This happened due to solar energy strikes each of the walls just function of diffuse and reflected components of solar energy, in which these values are nearly in the same for each of the wall.

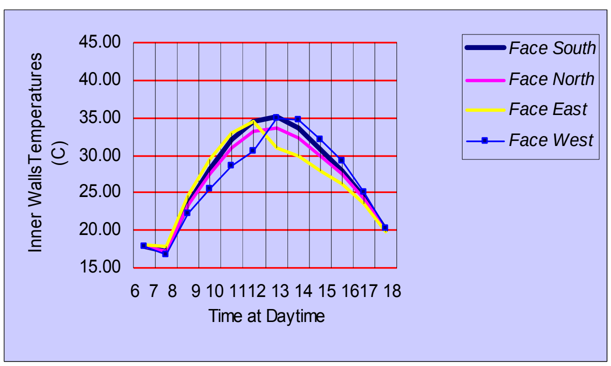

Fig. 10. Evolution Of Inner Wall Temperatures, Function Of Face Of The Wall, March Month, Perlis Region, Malaysia.

## VII. CONCLUSION

Total solar energy radiation arrives in earth surface is a function of sun position on its orbit. Its value can be best illustrated by taking specific situations, par example for region Perlis at Chuping with latitude 6, 29 $^o$N. It is seen from TABLE 3, that for horizontal surface in the earth, the maximum solar radiation intensity is lie in March month, with the top hourly intensity is 2.848 MJ/m$^2$. The top intensity decreases by around 0.3-0.5 MJ/m$^2$ hourly, follows the time to the next in the morning or to the afternoon in a whole day. With the position of the sun in March month as shown in Fig. 3, the solar energy strikes house wall ($I_T$) are function of time and face of the wall. For comparison, maximum solar energy strikes the house walls face South, North, East and West are: 564.95 W/m$^2$ (at 12.00 p.m.), 495.75 W/m$^2$ (at 12.00 p.m.), 575.36 W/m$^2$ (at 11.30 a.m.) and 575.36 W/m$^2$ (at 13.30 p.m.), respectively. Noting that for this calculation, the diffuse surrounding reflectance ($\rho$) is taken to be 0.3 along day.

Essentially the material of house walls in the study consist of one basic element of brick, as shown in Fig. 5. In function of time and face of the wall, solar energy strikes the house walls during the day. A brief comparative result of simulation is given as followed.

Results show that the inner and outer walls temperatures are increasing with the increasing of the solar intensity, and also on the contrary if the solar energy intensity become decrease. From the graph observation, the value of wall temperature between wall face North and face South shows only a slight differences for each time being. But for the wall face East compared with wall face West shows that wall temperature for each time being is quite differences. In the morning until 12 o'clock, the wall temperature is smaller for the wall face West compared with wall face East. But after 13 o'clock in the afternoon the contrary will be happened. The maximum wall temperature face East arrives 33.04 $^o$C at 11.30 a.m. Whereas for wall face West, the maximum temperature arrives 34.98 $^o$C at 14.30 p.m. In general the evolution of inner wall temperature can be seen in the Fig. 10, for the interior of the house is maintained at temperature equal 18 $^o$C.

Decreasing wall temperature of house.
The temperature of house wall can be decreased by:

(i) decreasing the solar energy strikes house wall. This may be done by using or installing screen in front of house wall, then solar energy can be avoided strikes directly to the house wall.
(ii) choosing the conductivity of wall material be smaller.
(iii) improving heat transfer coefficients from the wall surface to the surrounding.
(iv) improving the diffuse surrounding reflectance.
(v) increasing the layer of the wall.

Therefore, the program can be used to calculate of heat transfer rate through the each of entire house wall, wherever the façade of the wall, even through whatever the composite form of the wall. More far we can estimate the cooling load for one family household par example. Of course, the result not so precisely since we assumed the temperature within the wall to vary in one dimension only and ignored any temperature change in the two dimension.
But due to the exposed surface of the wall is large relative to its thickness, the model of program can be used in practice to obtain satisfactory results.

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