Thermal Performance of Building Envelope in Very Hot Dry Desert Region in Egypt (Toshky Region)

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ABSTRACT

Toshky region is a desert region located in the south east of Egyptian western desert at the Tropical Cancer (23.5^{o}N). The following features characterized this region during the summer season; aridity, high summer day time temperatures reaches to above 40^{o}C for about 6 hours, large diurnal temperature variation, low relative humidity, and high solar radiation reaches to about 1100W/m^{2} on horizontal surfaces. In such climate thermal human comfort is crucial to provide the reasonable environment for the people. As the building envelop has a major role in saving comfort for people and improve the consumption of energy in building. So this study is interested in studying the thermal performance for some building constructed from different building materials as; Nobaa sandstone, hollow clay brick, light sand block, and hollow and insulated bazelt blocks. The external climatic conditions and the temperature distribution inside the wall construction and the indoor air temperature were measured. The result shows that using Nobaa sandstone alone in building is not adequate with the external climatic conditions of this region. But using building materials with specific thermal characteristics, and using thermal insulation led to reduce the heat flow through the walls and help the building to be suitable with its external environment conditions. The study also show that hollow clay brick and light sand block valid the lowest indoor air temperature, and the thermal performance of hollow bazelt blocks can be improved by using thermal insulation, Natural and forced night ventilation help the indoor environment to be within the thermal comfort.

KEYWORDS

Nobaa sandstone, thermal insulation, thermal comfort, Toshky region, nature ventilation

INTRODUCTION

Toshky region is a desert region located in the south east of Egyptian westran desert between 22 and 24 ^{o}N Latitude. The site of study is located at the Tropical cancer (23.5^{o}N) Latitude and at 31^{o}E longitude. This region is very hot and dry region; it is about 200m above sea level. In such climate thermal human comfort is crucial to provide the reasonable environment for people in this new community. The thermal response of building is defined as the reaction of the building envelop to some form of heat input and amount of internal loads. It depends mainly on the orientation, size, windows to wall ratio, also on the thermo-physical and optical properties of the building material, and on the external environmental conditions. In Egypt different field measurements and theoretical studies were carried out to investigate the thermal performance of the traditional houses under the effect of local external climatic conditions. The results of these studies showed that double walls, ventilated double walls improved the internal environmental conditions under the external climatic conditions of Cairo region (30^{o}N), Egypt [(1)]. Theoretical and experimental study was carried out to investigate the thermal performance of a pre-fabricated concrete flat in 15 May city, the results show that reasonable agreement between the theoretical and experimental indoor air temperature of the flat is achieved. Also shading devices, insulation materials and suitable orientation achieve a harmony building with environment [(2)]. The effect of building envelop on saving energy consumption in hot arid region was studied. This study illustrate that the (OTTV) method can be used to investigate the energy efficiency with an acceptable error in the results compared with simulation software programs. Also illustrate that new building materials such as smart glass, thermal insulation

materials, and new composite materials can be used to improve the thermal and energy behaviour of building in Egypt. Also the results showed that window ratio area plays an important role in the energy conserved in each facade [3]. Evaluating the external climatic conditions of Toshky region and evaluating the thermal performance of some traditional building built their, give us a picture view about the climate of Toshky which can be divided to three climatic periods as; the warm period start from November and continue till February, the hot and reasonable period start from March and continuo till the end of June and include October month, and the very hot and dry region include July, August and September. the study also show that Nobaa stone (50cm thick) in building alone is not perfable due to the high storage of it and high thermal mass and thermal conductivity of it [4-6] .Also the study reach to determine the upper limit of comfort zone in this region through the hot and very hot period, table (1). The effect of thermal insulation used in building envelop in very hot dry region; Toshky, were studied experimentally by using the technique of hot box to determine the U-value of the wall [7]. Other study by using the evaporative cooling was carried out on a prefabricated house in Toshky region during the hottest period and show that how the use of desert air conditioning moderate and improved the internal environmental conditions[8]. Also developed a new building material with three line defense of thermal insulation to valid the thermal comfort in building in Toshky region [9] were carried out. More theoretical and experimental study in different country was carried out to evaluate the thermal performance of building with different building envelope. The thermal performance of building and optimization the thermal insulation thickness in walls were studied [10]. The thermal performance of a vegetated cladding system on facade walls was also study [11]. Experimental approach to the contribution of plant – covered building envelops were study [12]. Also studying the effect of thermal mass walls to reduce building heating or cooling load regards as one of the most effective way where using massive building envelop components delay and flatten thermal waves caused by external temperature swings[13]. As building envelope regards as the main construction element which has an important role in the thermal performance of unconditioned building and also has important role in saving energy in conditioning building. So this study amid to study the thermal performance of building envelop (walls) of different system structure to reach to the best system suitable for the very hot and dry region of Toshky. This table shows that people in this regionhave the ability to live in higher temperature reach to 32^{o}C through the very hot period, which is due to their affecting with this very hot environment. Also the low relative humidity plays a significant role in the response with comfort in high temperature, where evaporating sweat led to balance between the people skin and the surrounding environment.

EXPERIMENTAL WORK

To valid the aim of this study 7 rooms of different building materials were built with internal dimension of 3.00 × 3.15 × 3.40m. The material used were local building material used in this region which called Nobaa sand stone, Hollow clay brick, hollow bazelt block, light sand blocks of thicknesses 40, 25, 30 & 40 cm respectively, 5cm expanded polystyrene was used as insulation material for ; insulate clay brick, insulated bazelt blocks, and insulated Nobaa sand stone. The description of the walls and their thermal characteristics are illustrated in table (2). To specify the effect of the wall only on the themal performance of the room's indoor air temperature, the roof of all the rooms was built from the same material and with good thermal insulation. The description of the roof and its thermal characteristics were illustrated in 1st report of the "Thermal Performance of Exposed Roofs and Walls for Test Rooms in Desert Area, TOSHKY Region" [14]. Figure (1) shows a photo for the test rooms in Toshky. Figure (2) shows the thermal insulation in room No.5 which built from hollow clay brick. Also figure (3) shows a photo of bazelt block with its three defense line of thermal insulation. For measuring the thermal performance of the walls, thermocouple of type T were installed in different position of the walls (the exposed wall surface, the interior wall surface, and inside the wall at the interface surfaces) and the indoor air temperature. All these thermocouple were connected to a scan thermometer instrument to measure and recorded the temperature. Thermo-hygrometer was also installing in the rooms to measure and recorded the indoor air temperature and humidity. The outdoor climatic factor (outdoor air temperature, the relative humidity, and wind speed and direction) were measured and the solar intensity were measured by SS-100 solar cell and recorded.

RESULTS AND DISCUSSION

Measurement for all the climatic factors and the thermal performance of all the rooms were recorded through different seasons to illustrate the thermal behavior of the rooms through the different climatic

period [14, 15]. Here we shall illustrate the very hot period in Toshky which is the critical and important period.

Figure (4) shows the hourly variation of the outdoor air temperature and the solar intensity on the horizontal and vertical west direction for Toshky region through 21-24 July 2009. The figure shows that the outdoor air temperature which reaches to maximum value of about 42°C at 15 pm and reduce to reach a minimum value of about 24°C at 5am with arrange of 18°C. The outdoor air temperature still over 30°C for 18 hours, which is 2/3 of the day hours and this case the thermal load and increase the heat stress on occupation. With this severe climate in July the very hot period the building envelop without any passive means can't valid the thermal comfort.

Figure (5) shows the hourly variation of the dry and wet air temperature and the solar intensity on the horizontal and vertical west wall, for Toshky region through 13-16 August 2009. The figure shows that the outdoor air temperature which reaches to 39°C as maximum temperature and reduce to reach 23°C as minimum value with range of 16 °C. Also the outdoor air temperature still over 30°C for 16 hours, which is 2/3 of the day hours and this led to the increase of heat stress on the occupation. This high range between the maximum and minimum value of the outdoor air temperature helps the roof and walls to loss a big part of their heat storage through night. The figure also shows that the outdoor wet bulb temperature has the same behavior of the outdoor dry bulb temperature and reaches to about 34°C as a maximum value. This means that there is a little high in the relative humidity which moderates the external environmental conditions of the region.

Table 1. Maximum, minimum and mean temperature and the upper limit for thermal comfort in Toshky region.

Temperature	Month					
	May	June	July	August	September	October.
Maximum	40.8	40.6	43.5	46.5	43.5	40
Minimum	25	26	27	28	26	25
Mean	32.9	33.3	35.3	37.3	34.8	32.5
Upper Limit for Comfort	30.4	30.4	31.8	32.8	31.5	30.3

Table 2. The walls description of the test rooms built in Toshky region and their thermal properties and characteristics.

No.	Building materials used	Thickness	Thermal Conductivity	U-Value	R-Value
		cm	W/m °C	W/ m² °C	m² °C/W
1.	Nobaa sand stone	40	1.5	2.087	0.479
	Internal plaster	2.5	0 .727		
2.	External plaster	2.5	0.5	1.339	0.747
	Hollow clay brick	25	0.727		
	Internal plaster	2.5	0.5		
3.	External plaster	2.5	0.727	1.299	0.769
	Hollow bazelt block	30	3.5		
	Internal plaster	2.5	0.727		
4.	External plaster	2.5	0.727	0.685	1.46
	Light sand block	40	0.33		
	Internal plaster	2.5	0.727		
5.	External plaster	2.5	0.727	0.433	2.309
	Hollow clay brick	12.5	0.5		
	Thermal insulation	5	0.032		
	Hollow clay brick	12.5	0.5		
	Internal plaster	2.5	0.727		
6.	External plaster	2.5	0.727	0.2009	0.498
	Insulated bazelt block	30	3.5		
	Internal plaster	2.5	0.727		
7.	Nobaa sand stone	35	1.5	0.433	2.309

The increase in relative humidity is due to the raise of water in front of the High Dam and flow of it in to the Toshky low ground. The figure also show that the solar intensity reach to about 1000 & 850 W/m^2 on the horizontal surface and the west wall direction, and the solar intensity still above 850 W/m^2 for 6 hours and this led to the high thermal stress on the occupation. To investigate the effect of wall construction systems on the indoor air temperature, 4 rooms of different wall structure (Nobaa sand stone, Holly clay brick, light sand block and bazelt block) were study, taking into consideration that the room must be closed without any natural/ forced ventilation, these study show in Fig. (6). The figure shows the hourly variation of temperature distribution indoor air temperature of rooms constructed from Nobaa sand stone, Holly clay brick, light sand block and bazelt block in Toshky region through 21-24 July 2009 without natural ventilation (closed case). The figure also show the hourly variation of the outdoor air temperature which reach to 42^{o}C as a maximum value and decrease to reach 24 ^{o}C as a minimum value with a range of 18^{o}C . the figure shows that the indoor air of room built from Nobaa sand stone (40cm thick) give the highest value and its vary between 36 and 37.8^{o}C far away from the upper limit of thermal comfort in this month (32.8 ^{o}C) .

Figure 1. Photo for the test rooms in Toshky

Figure 2. Photo of room built from double layer of hollow clay brick and thermal insulation in between

Figure 2. Photo of bazelt block With three lines thermal insulation

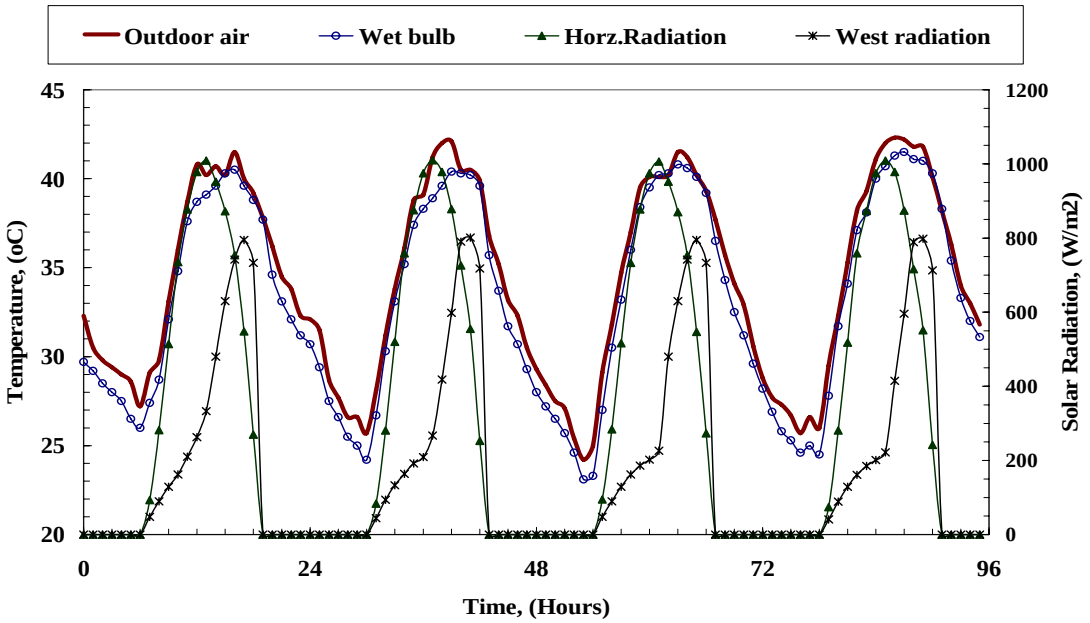

Figure 4. The hourly variation of the outdoor air temperature and the solar intensity on the horizontal and vertical west direction for Toshky region through 21-24 July 2009.

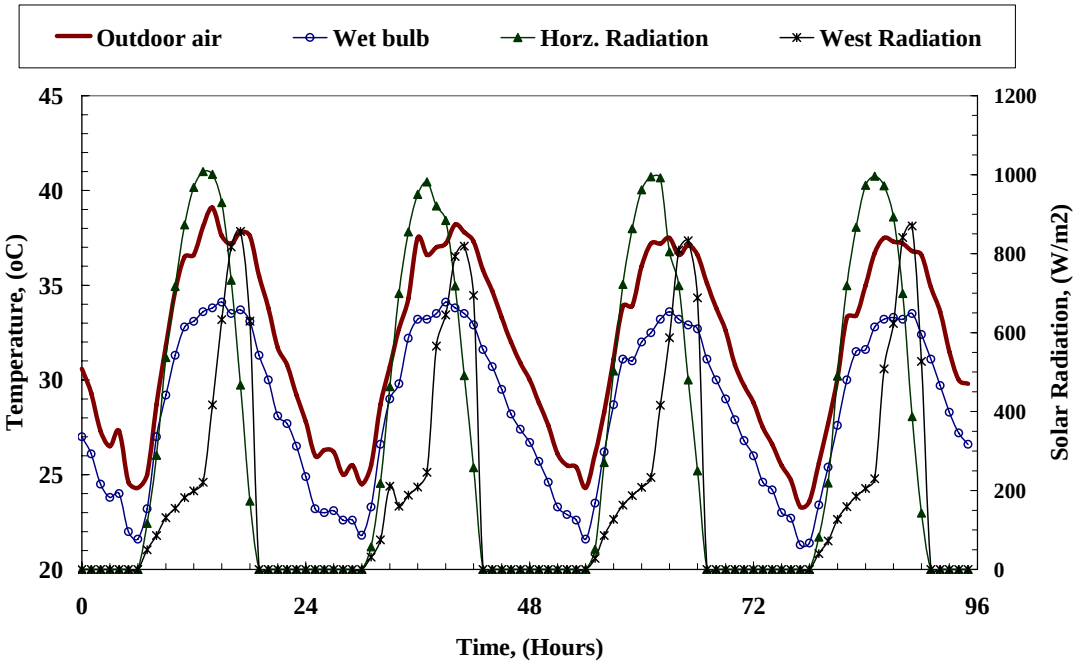

Figure 5. The hourly variation of the dry and wet bulb air temperature and The solar intensity on the horizontal and vertical west wall, For Toshky region through 13-16 August 2009.

This indicate that Nobaa sand stone didn't able to stop the flow of heat through wall due to its high thermal heat store capacity to store heat. The figure also show that light sand block (40cm) give the lowest indoor air temperature value which nearest the upper limit of thermal comfort in this month. Clay brick (25cm thick) and bazelt blocks (30 cm thick) have approximately the same behavior and reach a maximum value of about 35.6 and 35.8 ^{o}C. From the figure we note that the mean outdoor air temperature was about 34.3^{o}C, i.e bigger than 30^{o}C and so all building materials without helping passive means didn't able to valid thermal comfort[16] , and so insulation materials and passive means can helping building to be near or within the comfort zone. To illustrate the effect of the natural ventilation during night the same 4 rooms are measured taking into consideration that, the windows were opened through night time and early hours of the day (opened case), Figure (7) shows the results. Figure (7) shows the hourly variation of indoor air temperature of rooms constructed from different materials (Nobaa sandstone, Holly clay brick, light sand block and bazelt block) in Toshky region through 13-16 August 2009. The figure also show the hourly variation of outdoor air temperature which reach to maximum value about 39^{o}C. The figure shows that the indoor air temperature of room built of Nobaa sandstone (U-value of 2.087 W/m^{2o}C) give the highest value of about 36.5 ^{o}C compared to the other rooms, i.e. Nobaa sandstone alone falls to valid thermal comfort . Also the figure show that hollow clay brick, light sand block and bazelt block have approximately the same value through the day time and they nearest to the value of the upper limit of thermal comfort in that month (32.8^{o}C), while through night and early hours of the day and with the effect of natural ventilation, the indoor air temperature lay in the range of thermal comfort. We can notes also that the indoor air temperature is over 30^{o}C , this related to that the outdoor air temperature still over 30^{o}C for 16 hours, which is 2/3 of the day hours. To illustrate the thermal performance of wall and the effect of insulating materials on damping the heat and flatten the indoor air temperature, the temperature distribution inside south wall of room constructed from insulated clay brick (Figure 2) is discussed. Figure (8) shows the hourly variation of temperature distribution inside the south wall of room constructed from insulated clay brick and also the indoor air temperature of the room in Toshky region through 13-16 August 2009. The figure shows that the outdoor air temperature which reaches to 39^{o}C as maximum temperature and reduce to reach 23^{o}C as minimum value with range of 16 ^{o}C. The figure shows that the exposed south wall has the same thermal performance of the outdoor air temperature and reaches a maximum value of about 38^{o}C at noon (13.00pm summer time in Egypt). The effect of solar radiation is not appear, where Toshky is on 23^{o}N and at this latitude the solar altitude angle in this month is high, so the effect of solar radiation is low, also the light colour not absorb the solar radiation. The figure also show that the inside surface of the first layer of the wall before insulation layer decreased by about 3^{o}C from the exposed surface and with 6 hours time lag. Also the outside surface of the second layer of the wall after insulation layer decreased to be about 33.8^{o}C and with 2hours time lag from the first layer. The interior south surface decreased by about 5^{o}C from the exposed south surface and with time lag about 8 hours. The figure shows the important of using thermal insulating materials in reducing the flow of heat inside the wall and this clear in the thermal performance of the interior south surface and the outside surface of the second layer of the wall after insulation layer where they approximately the same. The figure also show the variation of the indoor air temperature , which nearest to the upper limit of thermal comfort in day time and inter the themal comfort zone in night and early hours of the day, due to the helping of the nature night ventilation. Figure (9) shows the hourly variation of indoor air temperature of rooms constructed from different insulated materials (insulated Nobaa sandstone, insulated clay brick and insulated bazelt block) in Toshky region through 13-16 August 2009. The figure also shows the hourly variation of outdoor air temperature which reach to maximum value about 39^{o}C. The figure illustrate that the indoor air temperature of room which built from insulated Nobaa sand stone is still valid the high temperature, while the indoor air temperature of rooms built from insulated clay brick and insulated bazelt block are nearest to each other through day time and through night the indoor air temperature of insulated clay brick becomes better, this is due to the ability of insulated clay brick (less mass) to loss part of its stored heat quickly than the insulated bazelt block (heavy mass). The used of insulated materials is appeared on the behavior of the interior surface where the presence of insulated materials help in damping the heat through its passage from outside surface to the interior surfaces. The effect of natural ventilation is appear clear in these rooms other than the uninsulated rooms [15], where some hours valid temperature less than 30^{o}C. This is a good indicator that nature ventilation with the use of insulating materials help the rooms to valid the thermal comfort through this very hot period.

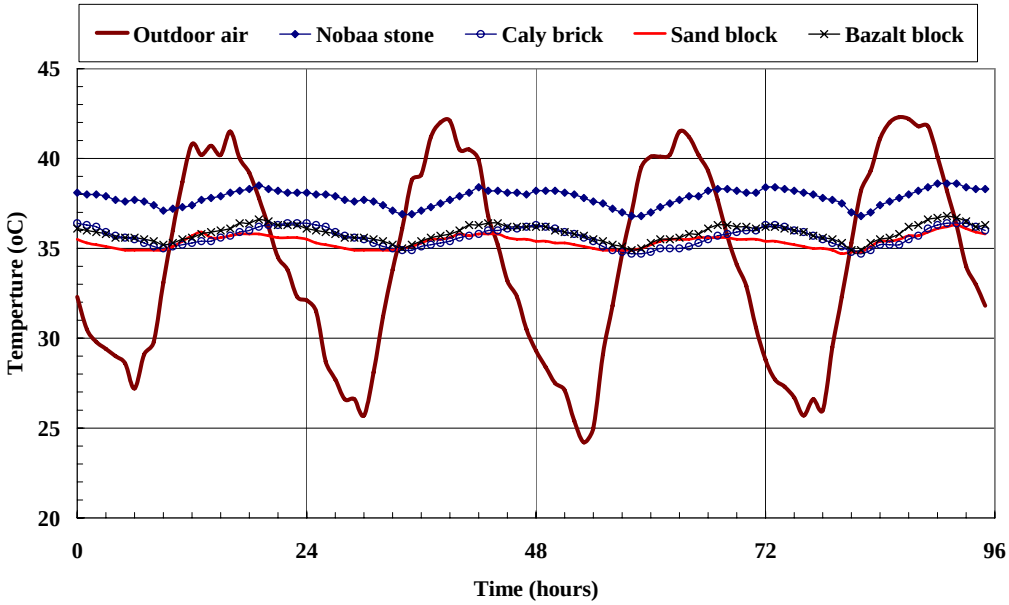

Figure 6. The hourly variation of indoor air temperature of rooms constructed from different building materials in Toshky region through 21-24 July 2009.

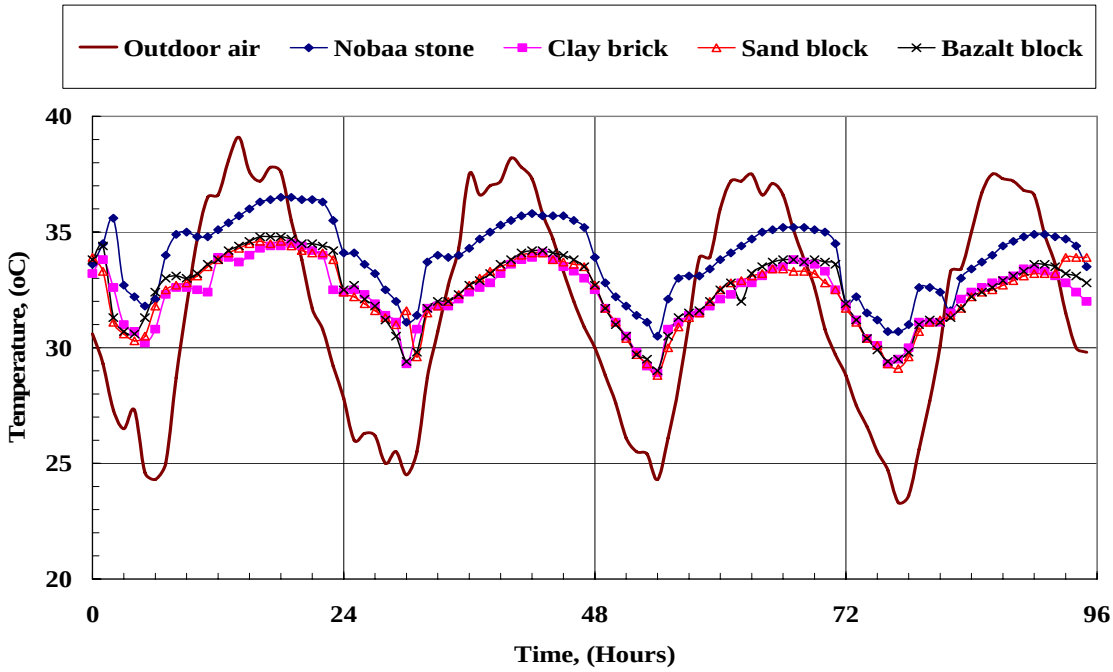

Figure 7. The hourly variation of indoor air temperature of rooms constructed from different building materials in Toshky region through 13-16 August 2009.

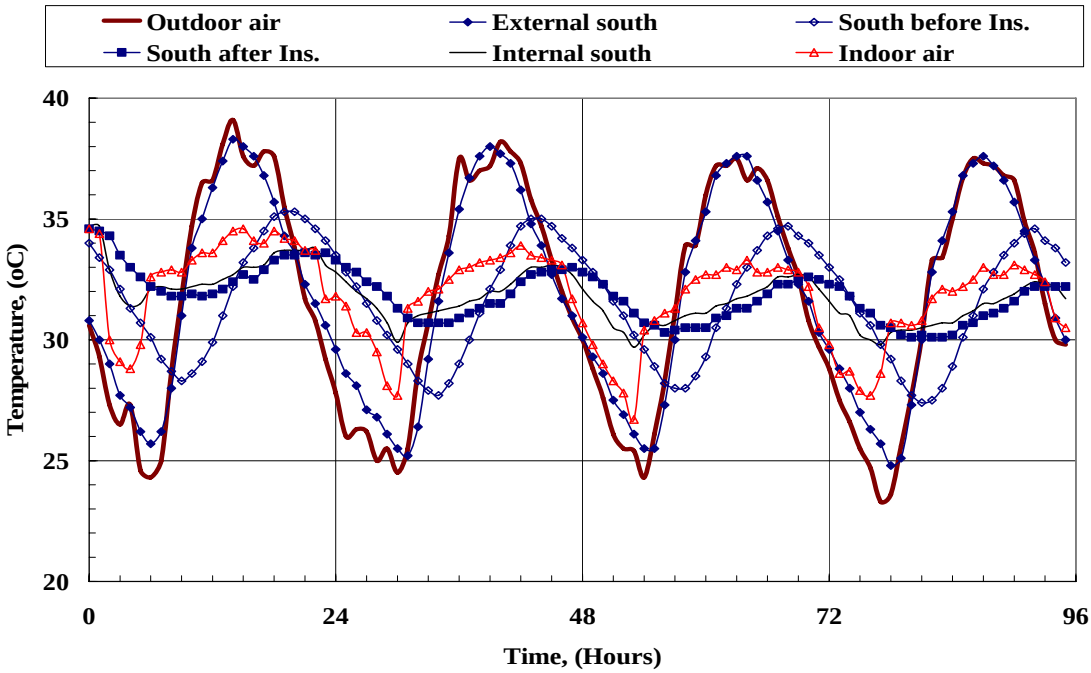

Figure 8. The hourly variation of temperature distribution inside the south wall of room constructed from insulated clay brick and also the indoor air temperature of the room in Toshky region through 13-16 August 2009.

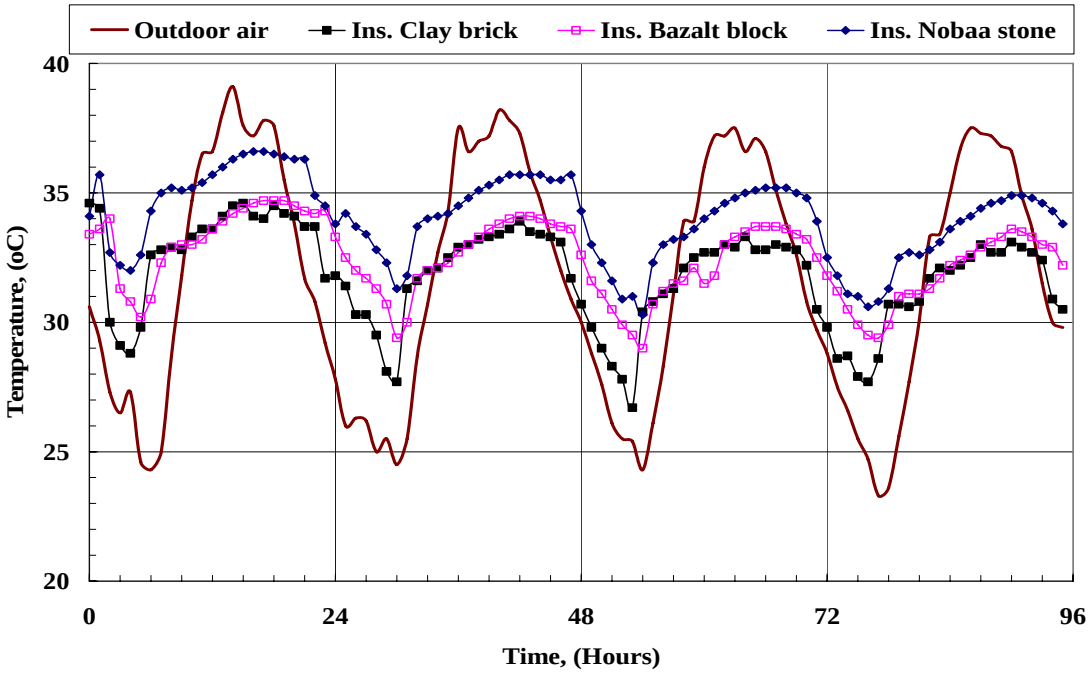

Figure 9. The hourly variation of indoor air temperature of rooms constructed from different insulated building materials in Toshky region through 13-16 August 2009.

To illustrate the effect of natural ventilation duration time room constructed from hollow clay brick is chosen to see this by varying the time of ventilation as shown in Figs. (10, 11), where in figure (10) the ventilation is from 22pm to 6 am and in figure (11) the ventilation is from 20 pm to 8 am. Figure (10, 11) show the hourly variation of indoor air temperature of room constructed from hollow clay brick (25cm thick) in Toshky region through 13-16 & 17-20 August 2009. The figures also show the hourly variation of outdoor air temperature which reach to maximum value about 38^{o}Cas a maximum value and with a range of 15^{o}C. The figures show that the outdoor air temperature still over 30^{o}C for about 16 hours. The effect of natural ventilation is appear on the indoor air temperature through night and early morning of the day, where most of the indoor air temperature lies in the comfort zone . From the figures, we show that by increasing the natural ventilation period from 20 pm to 8am the maximum and minimum indoor air temperature decrease. So the increase in natural ventilation hours improve the indoor air temperature and let it be in the comfort zone.

CONCLUSIONS

The results of this investigation show that:

1. the climate of Toshky which can be divided to three climatic periods as; the warm period start from November and continue till February, the hot and reasonable period start from March and continuo till the end of June and include October month, and the very hot and dry region include July, August and September.
2. The outdoor air temperature still over 30^{o}C for 16 hours, which is 2/3 of the day hours and this led to the increase of heat stress on the occupation.
3. The solar intensity reaches to about 1000 W/m^2 on the horizontal surface, and still above 850 W/m^2 for 6 hours which increase the thermal stress on the occupation.
4. Nobaa sand stone in walls alone falls to valid thermal comfort due to the high storage, high thermal mass and thermal conductivity of it.
5. Hollow clay brick, light sand block and bazelt block have approximately the same value through the day time and they nearest to the value of the upper limit of thermal comfort.
6. Light colour help in decrease the direct share of solar radiation on heat gain through walls.
7. Increasing the natural ventilation period from 20 pm to 8am led to reduce the maximum and minimum indoor air temperature. So the increase in natural ventilation hours improve the indoor air temperature and let it be in the comfort zone.
8. Using fan help in increasing the draw of the moderate outdoor air inside the rooms.

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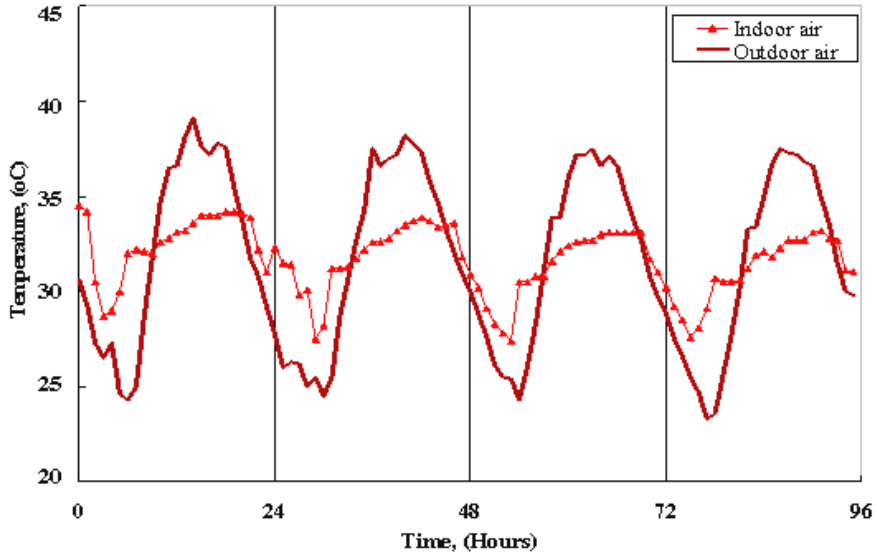

Figure 10. The hourly variation of indoor air temperature of room constructed from hollow clay brick in Toshky region through 13-16 August 2009, opened case from 22pm to 6am.

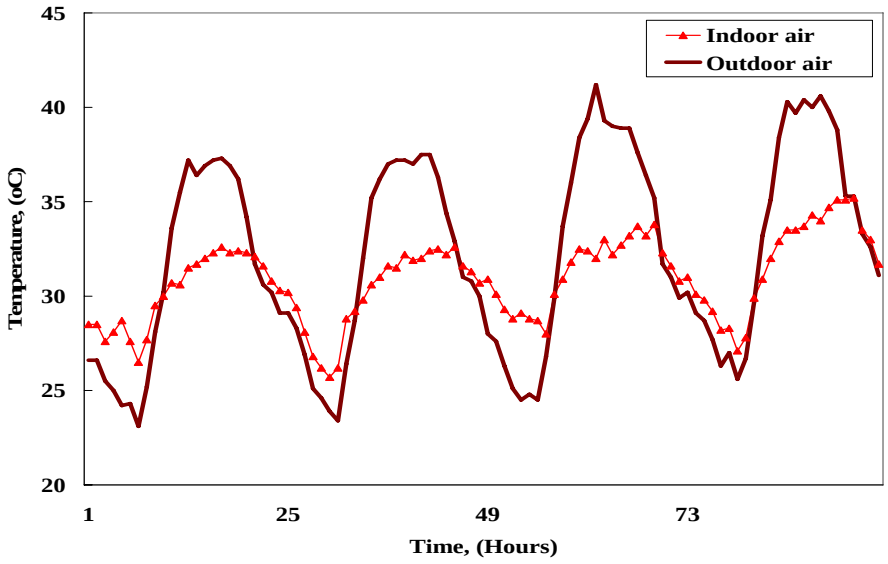

Figure 11. The hourly variation of indoor air temperature of room constructed from hollow clay brick in Toshky region through 17-20 August 2009, opened case from 20pm to 8am).

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