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The Effect of Outdoor Air Temperature on the Thermal Performance of a Residential Building

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***Abstract*—This paper gave an account on the field measurements of the outdoor air temperature on a typical residential building in Tripoli, Libya. The outdoor air temperatures were measured at two distinctive heights for 45 days.**

Sensors were located in and outside the building to record the temperature, humidity and electricity consumption from 5th July to 18th August, 2013. The temperature readings for the four facades were taken every two hours throughout the day on the walls, window glazing and the roof surfaces using infra-red cameras.

The influence of the outdoor air temperature due to the sun on the building facades was examined and compared with the walls, glazing and roof surfaces of the building. The type of building materials used, the design form adopted, orientation of the building, and the climatic period under consideration greatly influences the amount of outdoor air temperature that the building and its fabrics can absorb, store and dissipate both internally and externally.

Keywords—Air temperature, Climatic change, Libya, Residential building, Thermal performance.

I. INTRODUCTION

In recent times, modern architecture often adopted in most of our cities particularly in Libya, often over concentrates on aesthetics than the adoption of energy conscious designs. Modern building designers have stepped away from simple vernacular designs towards designs characterized by heavy energy consumption both in terms of their construction methodology and maintenance culture. This had led to many of such residential buildings providing poor quality indoor and outdoor environment that require huge amount of energy to run air conditioning, extractors among others [1]. This usually influences the thermal comfort and energy consumption and carbon emissions within the built environment in such regions. Due to the impact on climate change, there is a growing need for building service engineers and designers to design buildings which do not only provide comfort for the occupants but also minimize the consumption of fossil fuels and its resultant greenhouse gas emissions in the process of heating and cooling [2].

Again, most residential buildings in hot rid regions such as Libya experiences high cost of energy usage in cooling due to the predominant use of materials such as blocks which are of low thermal mass in construction and extensive use of glazing [3]. Principally, the hot and humid nature of the climate in such regions makes the climatic conditions largely fall outside the human comfort zone which in most cases demands cooling with air conditioners. The construction of most residential buildings in Libya often employs bricks of high thermal mass value. This is contrary to other countries in the tropics where sandcrete blocks of low thermal mass are mostly used [3]. Also, the current movement and choice of glazing as an element for wall cladding and windows without regards to local climatic conditions has often increase the thermal energy consumption both in and outside the building.

Moreover, there is little research on the thermal performance of buildings arising out of the use of these materials in relation to the effect of the outdoor air temperatures dynamics on the building in this part of our world. The aim of this paper is to explore the effect of the outdoor temperature on the thermal performance of a typical residential building located in Tripoli in Libya.

II. THERMAL CHARACTERISTICS OF RESIDENTIAL BUILDINGS IN HOT ARID REGIONS

Building designs and user characteristics

A residential building can be made more energy efficient basically by relating its facades to the sun and outdoor air movement. Furthermore, spaces that require cooling very often need to be located on the northern facades. A building that outstretched along its east-west axis would have its longer south facades subjected to the highest heat gain during winter and its shorter east and west elevations to a maximum heat gain in summer time. Consequently, a building that elongates along that direction is considered to be the largely efficient shape in all climates for minimizing the heating requirements in winter and cooling in summer [4]. In addition, the behaviour of occupants also sometimes influences the effectiveness of building designs in use and thus user demands and characteristics must be taken into account. User patterns and the time of occupation in a domestic or residential building might also influence the design and energy requirements of the individual rooms in the building.

On the other hand the relevance and significance of building structure and its characteristics has been extensively studied. For instance whilst [5] found the effect of building regulations on building energy use, [6] studied and suggest that energy performance regulations of buildings have been successful in conserving energy in the case of the Netherlands. However [7] argues that nonetheless, any variations in the energy consumption in residential buildings still remain a huge task for residences with similar characteristics. The above therefore indicates that the energy consumption pattern in buildings is largely influence by the building design, the users and the outdoor environment characteristics.

Building designs and openings

The design of openings in hot dry climates is governed by two requirements [8]: Thus smaller and high level openings are desirable for day time and larger openings for sufficient ventilation during the night periods. The solar heat gain in residential buildings can be reduced in proportion to that of the heat loss through the amount of window area allowed within the building. It has been recommended that a glass area of 0.06 of the total usable floor area of the room must be satisfactory for proper lighting in hot dry regions [9]. Also, recessing windows particularly glazing windows in order to keep them shaded even though an old fashion of design strategy, it's considered the best design mechanism [10]. Generally, the area of the window determines the amount of sunlight that enters the room, but the shape and position of the window identifies the spread [11] of the sunlight and the time the indoor temperature will rise up.

Building designs and roofs

In designing residential buildings roof in hot climate, the most important consideration is its reflectivity. Shade can be achieved by using a double roof with a layer of air between or by covering the roof surface with hollow bricks. Insulating materials such as fibreglass and lightweight blocks are often used. Using the specific materials required for such a solution is likely to increase the cost of the building beyond the means of most of the population particular in Libya. However, growing a roof garden might significantly reduce the roof temperature and it can also be used by the residents as a recreational space. Soil is an excellent heat insulator, and moreover plants can offer shade. Plant life also transpires and cools the air in contact [12] with the building. Flat roofs receive continual solar radiation during the day, at a rate that increases from the early mornings and decreases in the late afternoon due to the changes in solar intensity as well as the angle of the sun.

Outdoor air temperature and thermal performance of buildings

The thermal performance of domestic buildings is affected by a number of factors that includes outdoor air temperature and the orientation of the building. The amount and intensity of the outdoor air temperature and the façades that faces the air determines the amount of energy the building and its fabrics absorbs. Modern day designers have resorted to the use of a wide range of technologies to reduce the amount of energy that buildings need for cooling. One such method is the early cooling system technology. This involved natural methods such as breezes flowing through windows, water evaporating from trees and fountains, as well as large amounts of stone and earth absorbing daytime heat. These ideas although developed over the years as an integral part of building designs, designers can eliminate the need for mechanical cooling or at least reduce the size and cost of the equipment. The two most important ideas in any passive cooling design are the elimination of unwanted heat gains and the creation of cooling. In summer periods, various sources of heat gain have to be dealt with, including direct solar radiation from outside and internal gains from inside the building through the building fabrics.

III RESEARCH APPROACH

The case study domestic building which was built in 1999 has a rectangular plan with two storeys and a total height of 8.00 m. It has a ceiling height of 3.50 m and a ground floor of 1.00m above street level. Most of the structural elements were concrete with 20 x 40 x 20cm internal and external concrete block walls covered with 1-2cm mortar. More over the roof was constructed with reinforced concrete. The floor area is approximately 700 m^2 for the ground floor; which includes two flats, each of which has two bedrooms, two living rooms and a kitchen. The first floor is divided into two flats, each of them having three bedrooms, two living rooms, a kitchen and three bathrooms. The building is being used as a multifamily residence and the northern, southern, eastern, and western facades are shown in figure 1 to 4.

Figure 1: Northern façade of the building

Figure 2: Southern façade of the building

Data was gathered through sensors located in and outside the building to record temperature, humidity and electricity consumption between 05/07/2013 to 16/08/2013. The temperature readings for the four facades were taken every two hours throughout the day on the walls and window glazing for each floor using infra-red cameras. The various thermal properties were collected and analysed using a dynamic computer simulation model to investigate the potential influence of temperature changes to the building over the period of the study.

The outdoor air temperature for a period of 45 days was studied continuously out of which three days was chosen and studied in details. These days were 9th and 21st of July and on the 8th day of august 2013. The 9th and 21st days had the minimum and highest temperatures whilst the 8th august had the median temperature. The results are shown in figure 5 and 6. Each of the four facades of the building was also segmented into three elements of study: namely, the ground and first floor walls, window glazing and the roof surface.

Figure 3: Eastern façade of the building

Figure 4: Western façade of the building

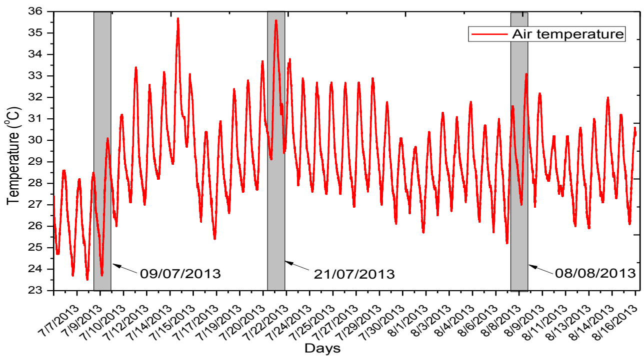

Figure 5: The 45 days outdoor air temperature.

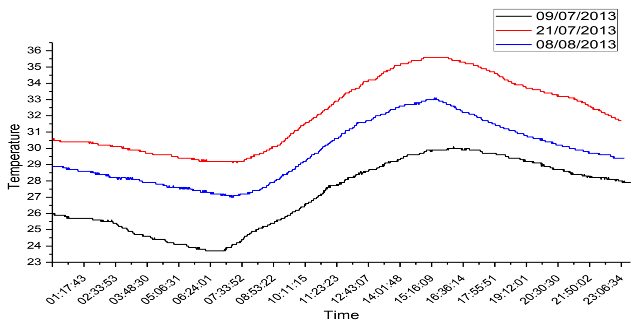

Figure 6: The 3 day's average outdoor air temperature of the building.

IV. ANALYSIS AND RESULTS

Figure 7 and 8 shows the north and southern façades for the whole period of the study and the temperatures for the entire northern facade are in harmony but increasing and decreasing by the same amount in relation to the outside air temperature. Moreover, the results also indicate that the outdoor air temperature was generally higher than the walls temperature. However, a more diverse pattern was observed in the results from the southern façade which shows a small difference up to 1°C between the ground floor glass and the other elements of the building while the outside temperature in general was below all of them.

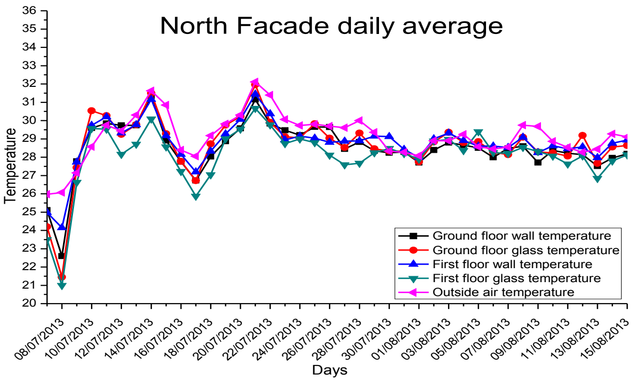

Figure: 7. the temperature for the 45 days study for the northern façade.

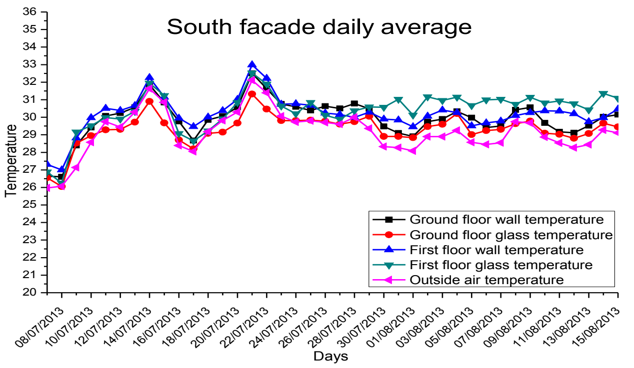

Figure: 8. the temperature for the 45 days study for the southern façade.

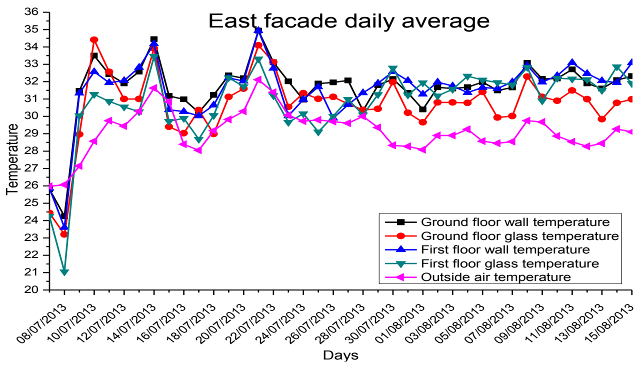

Figure: 9. the temperature for the 45 days study for the eastern façade.

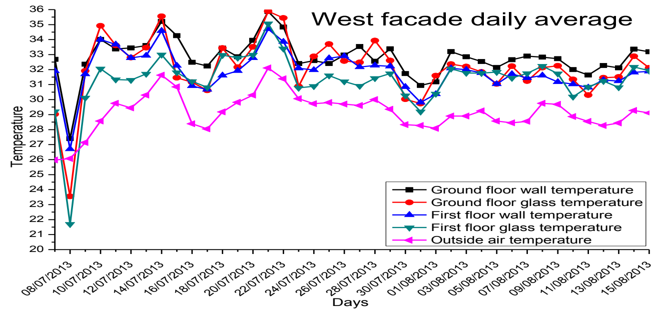

Figure: 10. The temperature for the 45 days study for the western façade.

In the case of the western façade, there was some difference in both ground and first floor glass temperatures. For instance, the first floor glass was having a lower temperature than the ground floor as well as the eastern façade due to the sun position, as shown in figure 10. Also, figure 11 shows a vast difference between the outdoor air temperature and the roof surface temperature for the 45 days of the study.

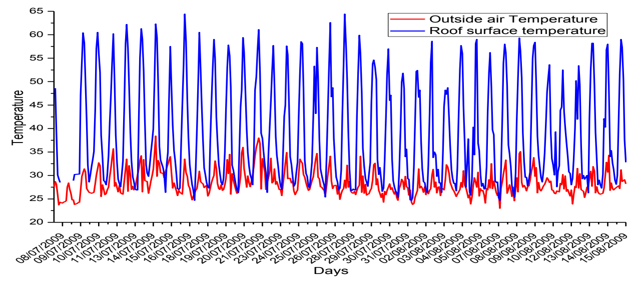

Figure: 11. Roof surface temperature for the 45 days of the study

The relationship between the average walls, glass, roof surface and the outdoor air temperature for the northern and southern facades

On the 9th of July, 2013, both north and south facades temperature patterns were all consistent with the external outdoor air temperature except the east and west façades as shown in figure 12. As early as 4:00 am in the morning the walls temperature starts to increase until mid-day where it reached 44°C. This was due to the sun position which was directly facing the western façades and this continued until mid-night. The roof surface also starts absorbing heat as early as 8:00 am till it reached 62°C at 14:00 hrs.

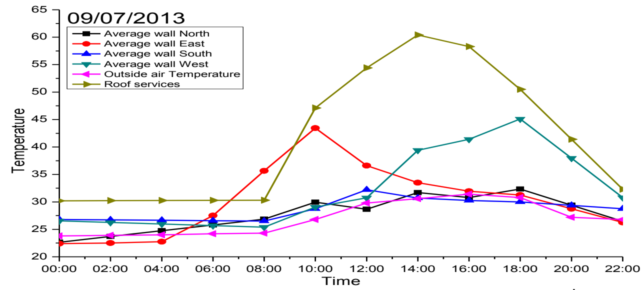

Figure.12. Average wall temperature on the 9th July, 2013 for all facades

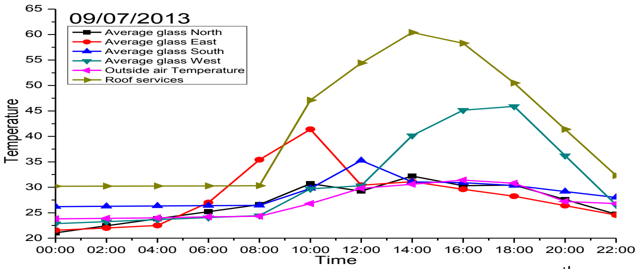

Figure.13. Average glass temperature on the 9th July, 2013 for all facades

Contrary, on the 21st July and 8th August, 2013 saw both north and south façades being in harmony with the outdoor temperature following an increase and decrease in both eastern and western facades at the same time of the day. Whilst the wall temperature starts increasing at 10:00 am with a temperature of 48°C on the 21st July, 2013, that of 8th August started as early as 6:00 am and reached a peak of 52°C. On the other hand, the glass temperature reaches its peak of 45 °C at 18:00 hrs whilst the roof surfaces reached its peak of above 60°C between 14:00 hrs and 16:00 hrs as shown in figure 14 to 17.

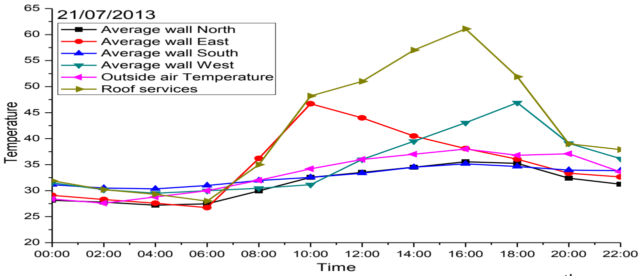

Figure.14. Average walls temperature on the 21th July, 2013 for all facades

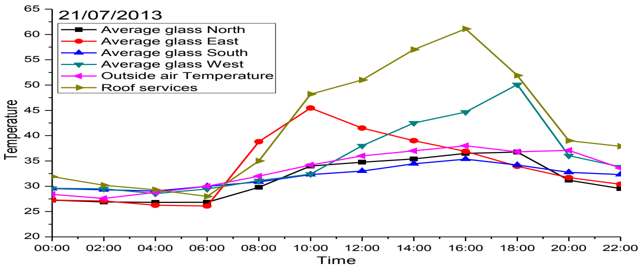

Figure.15. Average glass temperature on the 21th July, 2013 for all facades

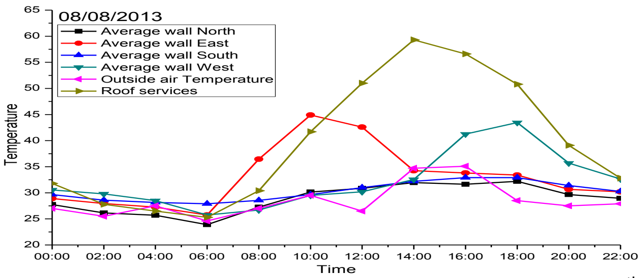

Figure.16. Average walls temperature on the 8th august, 2013 for all facades

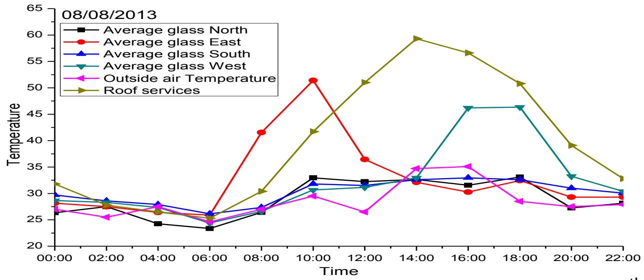

Figure.17. Average glass temperature on the 8th august, 2013 for all facades

The relationship between the average walls, glass roof surface and the outdoor air temperature for the Eastern and Western facades

Whilst the eastern façade temperature start to rise at 10:00 am to a peak of 44°C at 12:00 noon and start to drop, the western facades temperature start to rise at rather 12:00 noon to reach a peak of 46°C at 18:00 hrs. Moreover, the roof surface temperature rises alongside that of the eastern façade and until 14:00 hrs to a temperature of 62°C and drops down along with the western façade as shown in figure 18 to 21. On the 21st of July, it could be seen that the eastern façade temperature jumped from almost 22°C to reach 48°C within four hours period from 06:00 am to 10:00 am and began to fall down gradually. Furthermore, on the western façade, from mid night until 10:00 am the temperatures was fairly stable and starts to increase gradually until it reaches a peak of 50°C at 18:00 hrs.

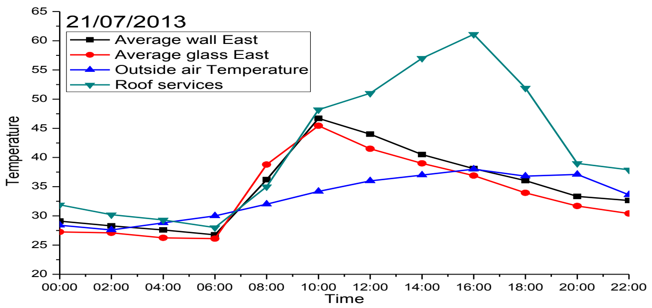

Figure.18. Average wall and glass temperature on the 21th July, 2013 for eastern façade

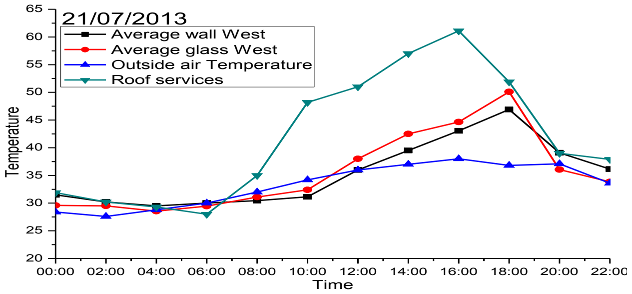

Figure.19. Average wall and glass temperature on the 21th July, 2013 for western facade

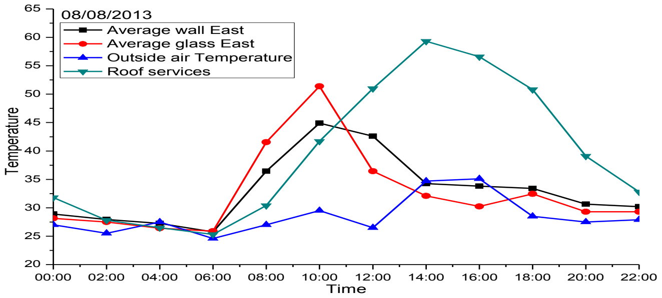

Figure.20. Average wall and glass temperature on the 8th July, 2013 for eastern facade

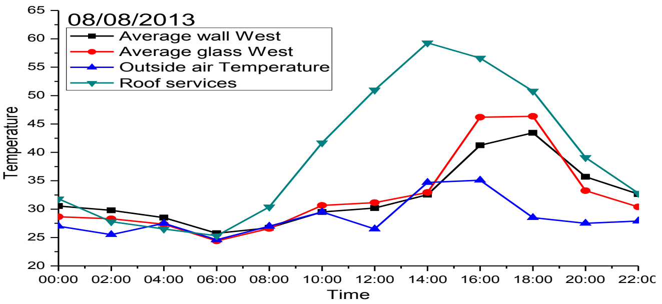

Figure: 21. Average wall and glass temperature on the 21th July, 2013 for western facade

However, it falls drastically within two hours to a similar level to that of the other facades. As usual, the roof surface temperature rises with the eastern façade and drops with the west façade recording a temperature value of about 60°C. This was completely different from the combine effect of both east and west façades although the outdoor air temperature was unstable, the wall and glass temperature on the eastern facade as at 06:00 am starts to increase until it reaches a peak of 52°C, at 10:00 am. It then starts again to decrease gradually until 14:00 hrs when the western façade also starts to increase to about 46°C at 18:00 hrs. Moreover, the roof surface was slightly different in the eastern façade as the outdoor air temperature rises before the roof surface temperature which is unusual as shown in figure 18 to 21.

Comparative study of all the four facades for the three days peak periods

In order to understand the effect of the temperature on each faced, a comparative study of the results was done. Figure 22 to 24 below shows the results of the three days for the northern façade. The temperature were stable for the three days period but usually start to rise at 08:00 am. As the outdoor air temperature rises through the different days, the roof surface temperature also follows a similar pattern on each day and reaches similar temperature values.

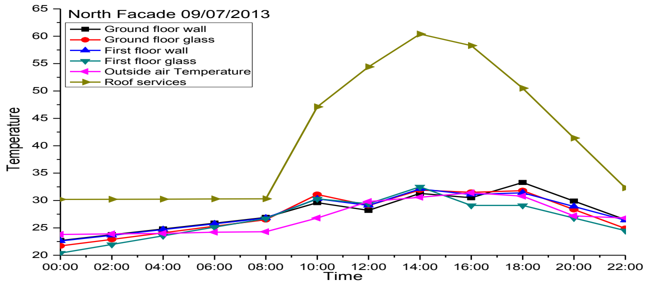

Figure: 22, Values for 9th July, 2013 for the Northern façade.

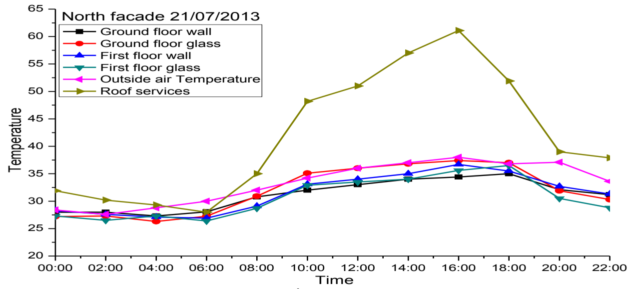

Figure: 23, Values for 21th July, 2013 for the Northern façade.

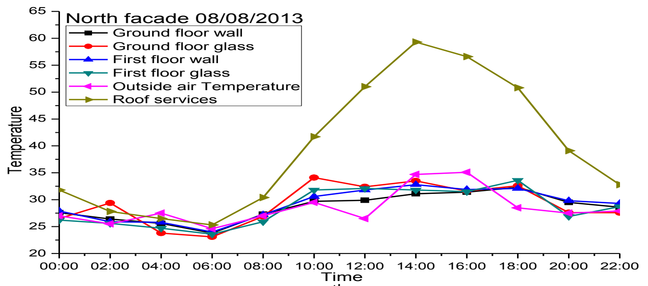

Figure: 24, Values for 8th August, 2013 for the Northern façade.

Figure 25 to 27 shows the average of all walls and glass for the southern elevation in comparison with the roof and outdoor air temperature. As can be seen on the 9th of July the south façade was stable and in harmony with the outdoor air temperature, while the roof surface at 14:00hrs reached a peak value with more than 30°C.

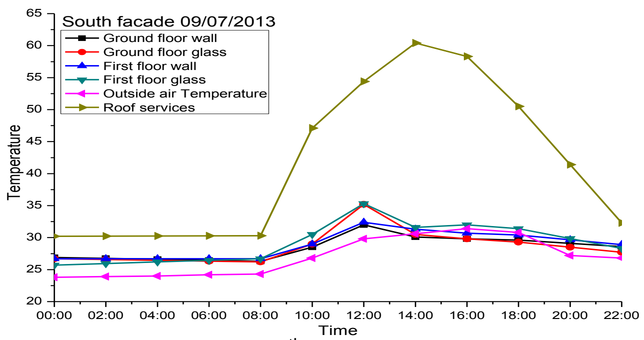

Figure: 25, Values for 9th July, 2013 for the southern façade.

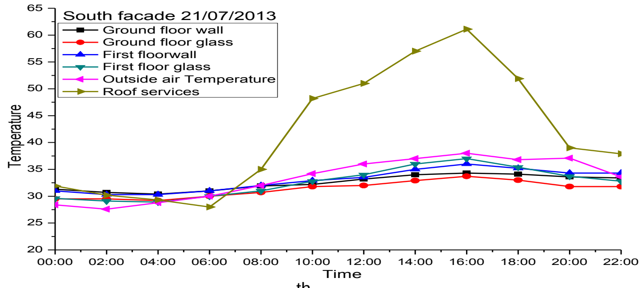

Figure: 26, Values for 21th July, 2013 for the southern façade.

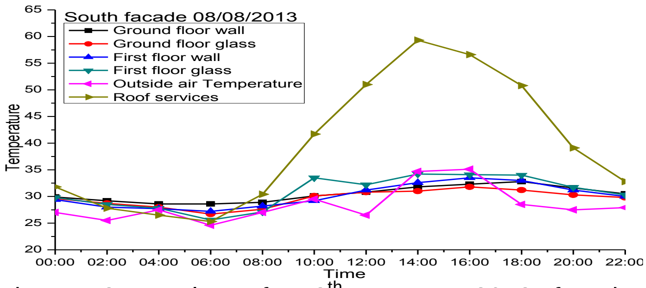

Figure: 27, Values for 8th August, 2013 for the southern façade.

The results as shown in figure 28 to 30 indicate that at 06:00 am, the walls, glass and roof within the eastern façade start to absorb heat. This was due to the sun rays that hit the façade from the sunrise until 10:00 am. Furthermore, after 10:00 am the walls and glass start to cool down, while the roof continues to absorb the heat until 14:00 hrs when the sun moves from the vertical position over the building.

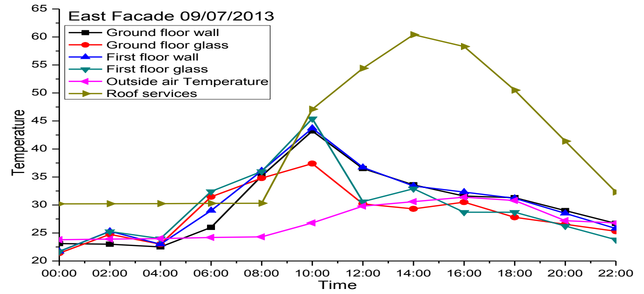

Figure: 28, Values for 9th July, 2013 for the eastern façade.

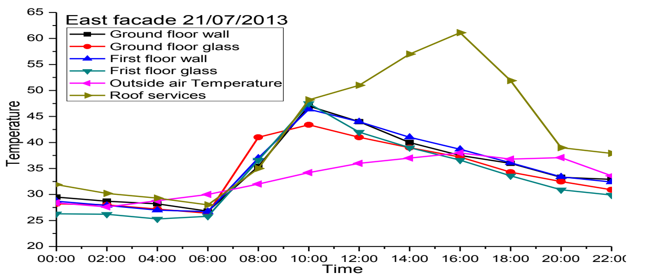

Figure: 29, Values for 21th July, 2013 for the eastern façade.

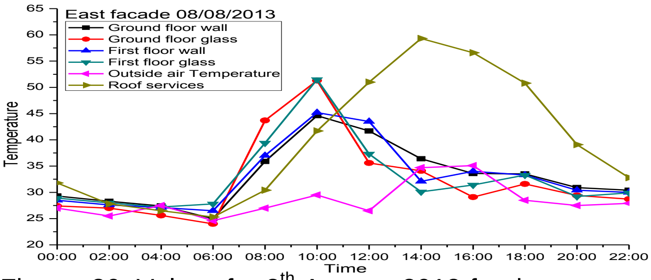

Figure: 30. Values for 8th August, 2013 for the eastern façade.

The behaviour of the western façade as shown in figure 31 to 33 is completely opposite to that of the eastern façade after midday when the sun starts to hit the western façade. This façade starts to heat up until sunset at 18:00 hrs at which time the wall and glass temperatures meet with the roof surface temperature and cool down together, the heat are the transferred into the inside of the building or rooms located at those facades. As it could be noticed that the first floor temperatures rises at night while the ground floor spaces in the eastern view also start to heat up until midday. The spaces on the western side start to heat after 16:00 hrs due to the time lag for the heat transfer from the outside to the inside of the building through the bricks and glass.

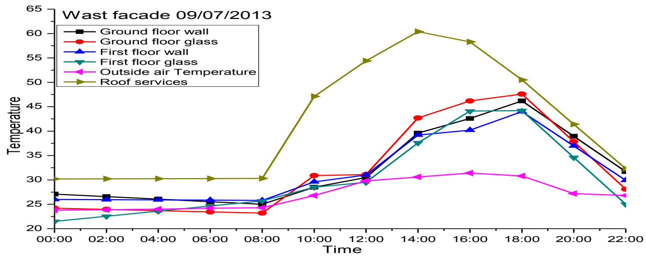

Figure: 31, Values for 9th July, 2013 for the western façade.

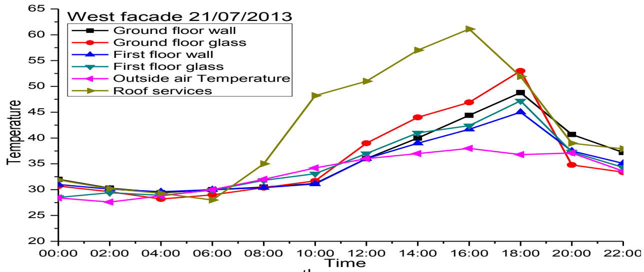

Figure: 32, Values for 21th July, 2013 for the western façade.

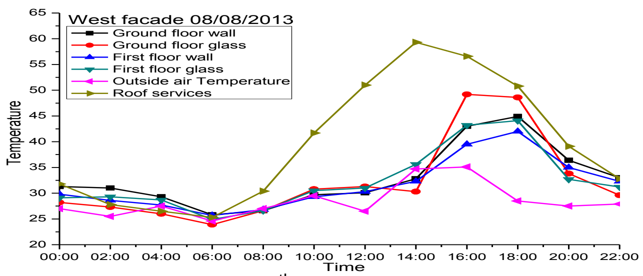

Figure: 33. Values for 8th August, 2013 for the western façade.

One of the main problems causing overheating is the absorption of solar radiation by the roof surface as can be seen in figure 34. In the middle of the day the roof surface temperature reaches 65°C and the difference between the day and night temperature approaches 30°C. However it should be noted that on the 9th of July the outdoor air temperature and the roof surface temperature were stable until 08:00 am, and after that the outside temperature starts to rise gradually until it reaches a peak of 65°C at 16:00 hrs and then begins to drop gradually. The roof surface temperature having jumped to 62°C within 6 hours became 32°C above the outside temperature. The same situation was repeated on the two other days, i.e. the 21st of July and the 8th of August.

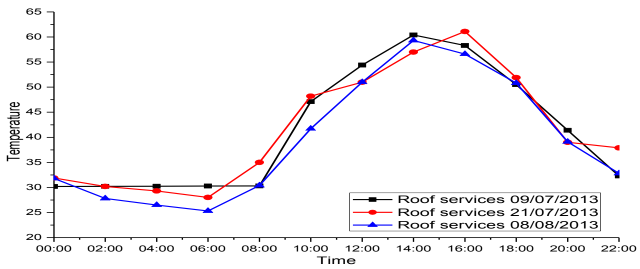

Figure: 34. Roof temperature for the three days

V. CONCLUSIONS

From the findings, location and orientation of a building are important factors in determining the amount of energy absorption, and loss through the building fabrics. Thus, the orientation, building form, fenestration and construction materials employed in the building contributes greatly to the energy absorption pattern of the building. As a general rule, for any given volume of building to be heated, the smaller the exposed envelope area, the lower the heat loss or gain. Hence, building form is an important factor influencing heat gain through the whole building, as cooling energy consumption has a significant influence on energy use. The thermal characteristics of a typical building in the case of Tripoli are largely influenced by design decisions which consequently have a major role to play in the design of energy efficient and comfortable buildings.

The use of suitable thermal mass and thermal insulation devices such as external and internal solar film devices as argue by [1] is important for heat absorption, reduction and efficiency. From the findings, there are a lot of heat gains during summer periods in Tripoli and the heat absorption pattern increases during such periods through the walls and other openings. The findings again, point to the fact that the adoption of bioclimatic architecture is one of the best energy saving measures that can reduce the energy factor of buildings in Tripoli. Also, passive solar design adoption is another surest way of minimising the thermal effect of the outdoor air temperature on buildings. This will minimize and utilize heat gain from the sun as well maximizing heat dissipation in the buildings.

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