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ON-SITE MEASUREMENTS OF THERMAL PERFORMANCE OF A RESIDENTIAL BUILDING IN A HOT-ARID REGION

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ABSTRACT

Many residential buildings in hot climates use a huge amount of energy to run the air conditioning in order to maintain comfortable conditions for the occupants. This study of a domestic building in Libya used detailed monitoring and analysis of the measured data with a view to devising a strategy for reducing energy consumption and carbon emissions.

Key words: building energy; architectural design; energy saving in building; overheating

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Introduction

Because of the impact on climate change there is a growing need for building services engineers and architects to design buildings which not only provide comfort for the occupants but also minimize the consumption of fossil fuels and resultant greenhouse gas emissions in the process of heating and cooling (1).

Architects have stepped away from simple vernacular designs towards designs characterized by heavy energy consumption both in terms of construction and operation. It is estimated that 50% of all energy resources consumed across our planet relate to operation and control of the indoor environment of buildings, which are heavily dependent on mechanical systems. The scale of this energy consumption represents a major problem facing the world, thus the need for energy conservation has become one of the main concerns for architects. However, many modern buildings in hot-arid areas are constructed with no consideration given to energy consumption, or their relationship with the climate. The use of new building technologies often results in failure to achieve thermal comfort, and consequently leads to an increase in energy consumption as mechanical cooling is needed, whereas many traditional buildings achieve comfort with little or no energy use.

Energy Consumption in Libya

Although Libya is an oil producing country, there is an energy crisis in Libya for the following reasons:

- Extensive use of conventional energy sources leading to their depletion, and the increase in the individual annual consumption of electrical energy.
- Most of the energy consumption is from relatively inefficient non-renewable sources, while the use of renewable sources is still in the foundation stages.
- Energy consumption is on the increase annually.

The growth in electricity generation in Libya amounted to more than 50% in the ten years from 2000 to 2010 (2), with total CO_2 emissions of around 60 million tonnes per year (55% due to oil and 45% due to Natural gas). One of the reasons consumption continues to rise is the low cost of electricity; RCREEE (3) showed that electricity consumption per capita in Libya is 6 times that in Morocco, while the price per unit in Morocco is 5 times that in Libya.

Background

Buildings, in addition to offering shelter and fulfilling aesthetic requirements, should provide conditions of comfort for their occupants. During summer in hot climate

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regions, buildings are exposed to high intensities of solar gain, which may result in over-heating, causing discomfort to the users. Under these conditions, cooling the building is very important. Cooling processes include a range of measures from simple natural cooling techniques such as solar gain control, evaporative cooling and natural ventilation, to mechanical systems, i.e. air conditioners (4).

Designers use a range of technologies to reduce the amount of energy that buildings need for cooling. Early cooling system technology 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 were developed over thousands of years as an integral part of all building designs and are known as "passive cooling". By engaging passive cooling techniques in new buildings, the designer can often eliminate the need for mechanical cooling or at least reduce the size and cost of the equipment. In this work we aimed to monitor the actual performance of an existing building, with a view to recommending techniques for improving conditions and reducing electricity consumption.

Methodology

This work presents part of a larger research program whose overall aim is to study the thermal performance of domestic buildings in Tripoli, with a view to offering design recommendations for reducing the cooling load and energy consumption.

The first part, presented here, consists of analysing monitored data from sensors located in and outside a residential building recording temperature, humidity and electricity consumption from 05/07/2013 to 16/08/2013. In addition, temperature readings for the four facades were taken every two hours throughout the day, for walls and glazing for each floor using an infra-red camera. In a later part of the work, detailed computer simulation of the thermal performance will be carried out in order to determine strategies to reduce the energy load.

Below follows an introduction to the climate of Tripoli and a description of the case study building.

Climatic Analysis of Tripoli City

Tripoli city lies on the far north of the continent of Africa overlooking the Mediterranean Sea. The ordinates of the city are latitude 32° 47" N and longitude 13° 04" E respectively. Tripoli is classified as a hot dry climate, this type of climate usually being found at latitudes between 20° and 35°, and the main shelter issue is overheating. The mean summer temperatures are around 25°C but can reach a maximum of 45°C; clear nocturnal skies can cool temperatures down as -10°C.

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Furthermore, the building studied is located in the city of Tripoli, which incidentally is only 21Km north of the area where the hottest air temperature ever was recorded, 58°C, (5). Table 1 shows the yearly average weather condition readings covering rain, average maximum daily temperature and average minimum temperature.

Table 1 : Ambient Conditions in Tripoli

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Record high °C	28	33	38	41	43	44	46	44	45	41	36	31
Average High °C	16	17	19	22	24	27	29	30	29	27	23	18
Average low °C	8	9	11	14	16	19	22	22	22	18	14	9
Record low °C	1	3	4	6	6	10	16	17	15	10	6	1
mm rainfall	81	46	28	10	5	0	0	0	10	41	66	94

The Case Study

The case study residential building has a rectangular plan and was built in 1999. The building is two storeys high with a total height of 8 m. The ceiling height is 3.5 m. The ground floor is 1m above street level and the roof has a sill of one meter. The floor area is approximately 700 m^2 for the first floor; this includes two flats, each of which has two bedrooms, two living rooms, two bathrooms, and a kitchen. The second floor is also divided into two flats, each of these having three bedrooms, two living rooms, a kitchen and three bathrooms. It is occupied as a multifamily residence and the ground and first floors are as shown in Figure 1.

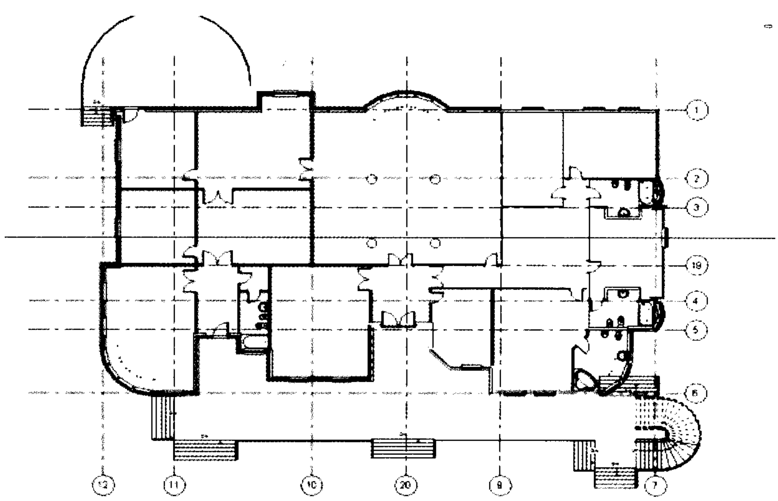

Figure 1 : Plan of the building

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Results and Analysis

A field study including temperature, humidity and electricity consumption measurements was carried out and results from the study were gathered and analysed. The building was monitored continuously for 45 days, and the results clearly showed that there were two peak days; in between these days there is a sharp drop in temperature, otherwise the average temperature range is between 27°C-33°C. Three typical days were selected for detailed study, the first being the peak day 21/07/2013, the second day having a low temperature (09/07/2013), and finally a mid-temperature day (08/08/2013). The outside air temperatures for the three days are shown in Figure 2.

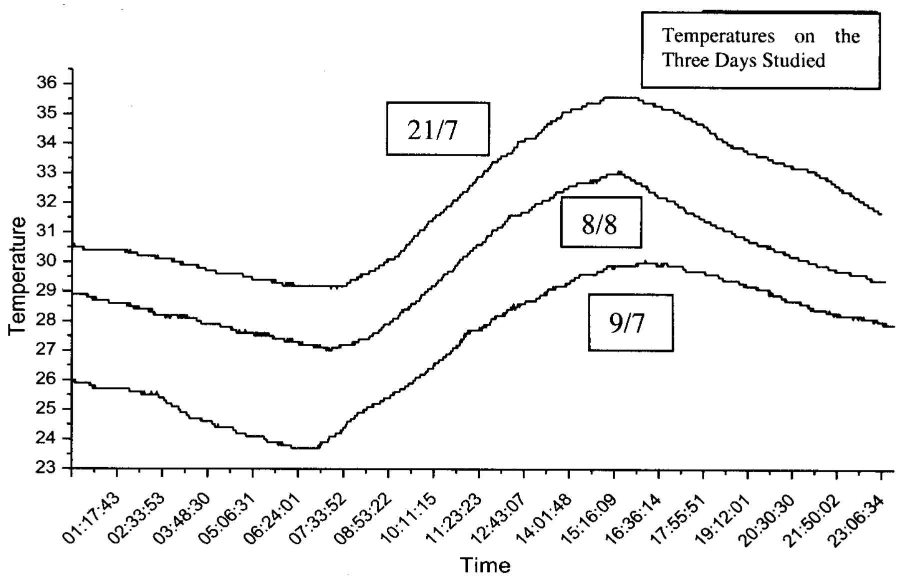

Figure 2 : Outdoor air temperatures for the days studied

Figure 3 shows the outdoor temperature and that in the main rooms on the 9th of July, when the external temperatures ranged between 24°C and 30°C. The shaded areas indicate when the air conditioning was operating. Note that rooms located on the ground floor, i.e. flat 1 and 2, have a fairly steady temperature, while the room located on the west side in flat 2 is almost one degree higher than the room on the east side in flat 1. Furthermore, in flat 3 the room temperature drops at approximately the same rate as the drop in external temperature early in the morning, and rises with the rise in external temperature; at 27°C the air conditioning is switched on and starts cooling. While the temperature initially drops by about 0.5°C in about 20 minutes, the average cooling rate in this period is about 1°C per hour, at the same time as the outside temperature is rising at about 1.5°C per hour. As soon as the A/C is switched off the temperature rises slowly as the direct sun is now away from that part of the building.

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As for the room in flat 4, (with no air conditioning), the temperature is stable at around 31°C and is higher than the outside temperature. It is located on the second floor and the west side.

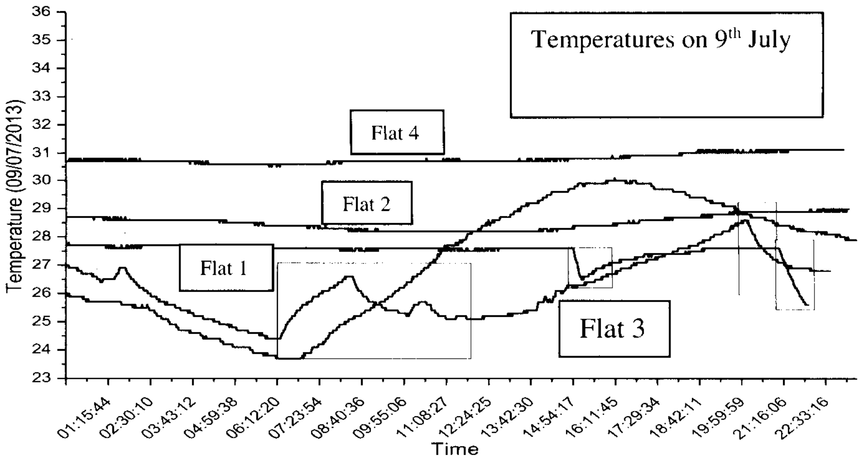

Figure 3 : Main room temperatures on the 9th July

Considering now the rather hotter day of the 21st of July, the room in flat 4 (West side, upper storey) is as usual higher than the other rooms with average temperature of 33°C to 34°C, and flat 2 (West side, lower storey) is stable at around 31°C (Figure 4). In flats 1 and 3 (East side, lower and upper) the rise and fall in temperature as a result of switching the air conditioning off and on can also be seen, and it is evident that even over a period of several hours, even as the air temperature is falling the air conditioning does not bring the temperature in flat 3 below 26°C. The temperature rises rapidly when it is switched off (over 3°C in 1 hour) against a rising outside temperature of around 30°C.

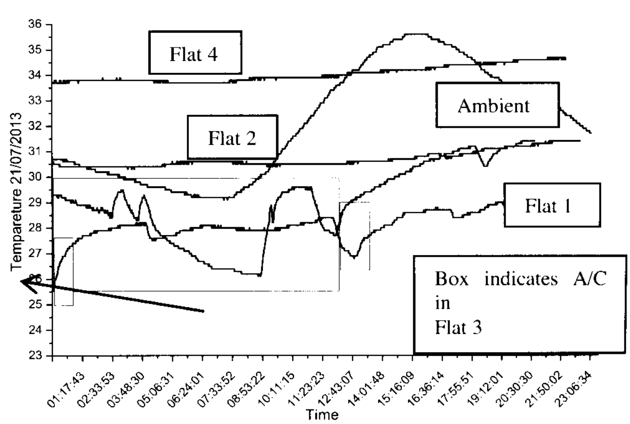

Figure 4 : Main Room Temperatures on 21st July. Box Indicates A/C in Flat 3.

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The upper storey suffers from high solar gain through the roof, which is not insulated. Figure 5 shows that the living room temperatures on the 9th of July for flats 1, 2 and 3 are on average between 27°C and 29°C, except in the living room in flat 1 where the peak day temperature in the late afternoon temperature dropped two degrees, while the living room in flat 4 is above the outside temperature at around 31°C.

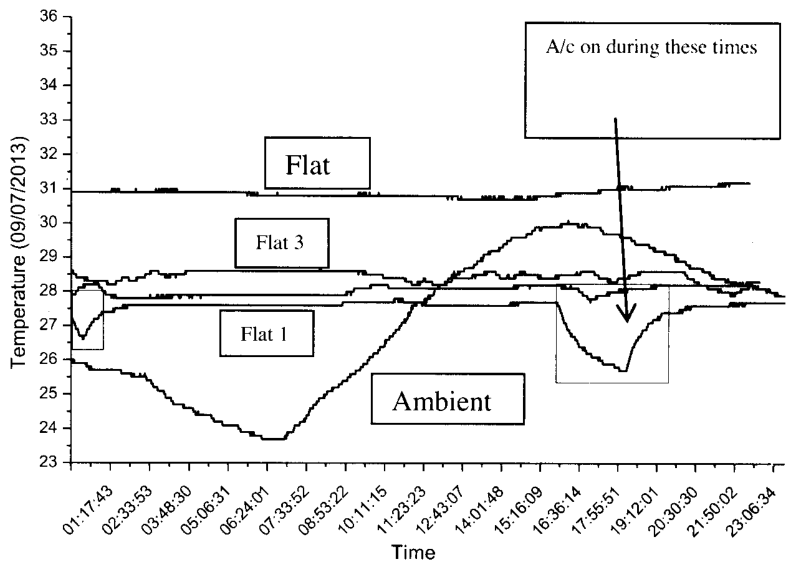

Figure 5 : Living room Temperatures for the 9th July

The last space studied is the kitchen, which is no less important than the rest of the flat elements as it is occupied for a large part of the day. Figure 6 shows the kitchen temperatures on the 9th of July for all flats, and it is clear that the kitchen in flat 1 is stable at slightly above 28°C, and falls to a minimum of around 26°C when the air conditioning is running, after which it rises to around 28°C once more; furthermore the temperatures in the kitchen in flat 3 were stable and reasonably low due to the fact that the air conditioning was running almost continuously. Note that the temperature climbs suddenly in the last hours of the day even though the external temperatures fall, due to the time lag and the air conditioning being switched off. As for the kitchen in flat 4, as before, the temperature is stable at around 32°C, and is higher than the temperature outside the building: note again that that the temperature is out of phase with the outdoor temperature by about 5 hours due to the time lag induced by the thermal mass of the building materials.

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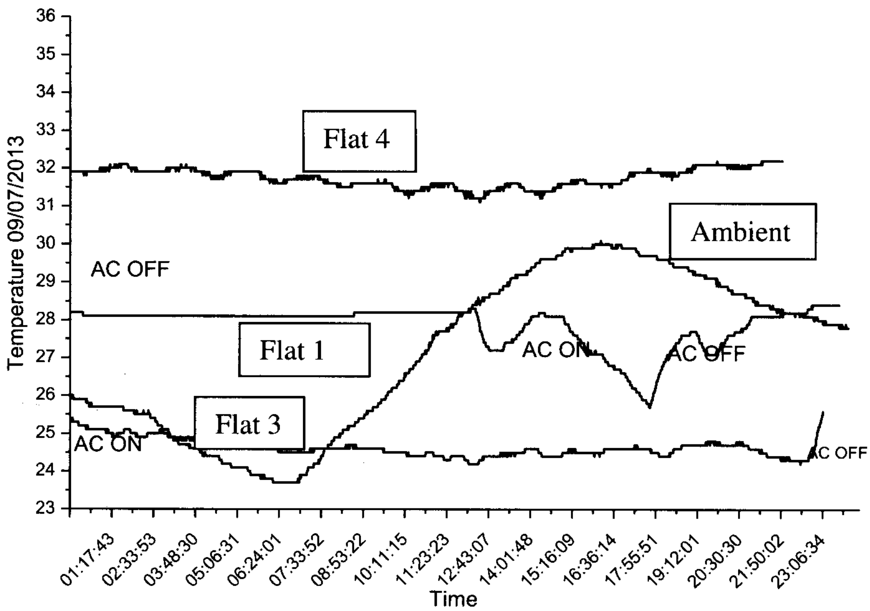

Figure 6 : Kitchen Temperatures for the 9th July

Figure 7 shows how the A/C plays a significant role in changing the temperature inside the kitchen and also shows how the temperature returns back to normal after switching it off. On the 21st of July the air conditioning in the kitchen of flat 3 was on until 4 am, however, after switching the AC off the temperature increased about 3°C and continued rising gradually until it reached 31°C, when the air conditioning was switched on and the temperature fell to around 28.5°C, while the outside temperature reached a peak of 35.5°C. Moreover when the A/C was switched off again the temperature increased to 32°C, and after running the A/C it fell to 28.5°C. Similar comments apply to the data for the 8th of August.

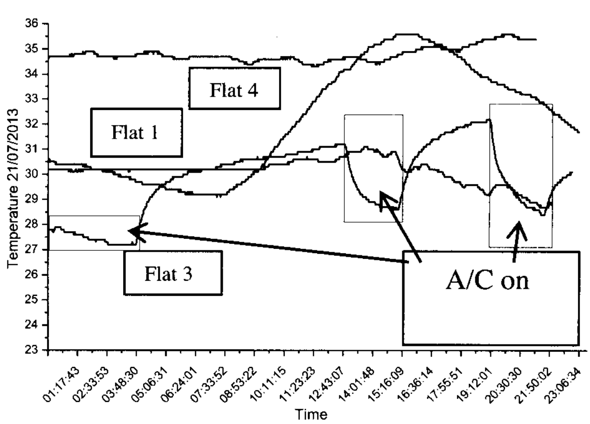

Figure 7 : Kitchen Temperatures on 21st July

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Figure 8 shows the relationship between the outside temperature and the temperature of the basement for the three days, and it is clear that the high thermal mass and lack of direct solar radiation enable the temperatures to remain steady in the basement.

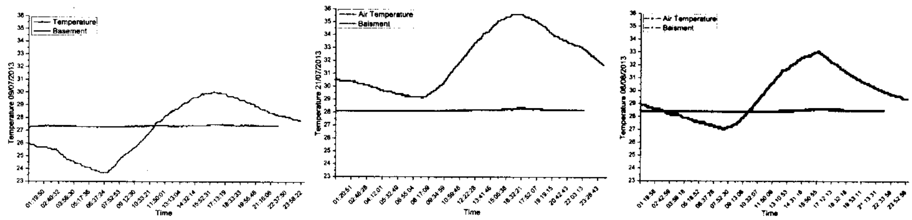

Figure 8 : Basement Temperatures on the Three Days.

Conversely, one of the main problems causing overheating is the absorption of solar radiation by the roof surface as can be seen in figure 9. In the middle of the day the roof surface temperature reaches 65°C and the difference between the day and night temperature reaches 30°C. However it should be noted that on the 9th of July the outside temperature and the surface temperature are stable until 8AM, and after that the outside temperature starts to rise gradually until it reaches a peak at 4PM and then begins to drop gradually, the roof surface temperature having jumped to 62°C within 6 hours, 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.

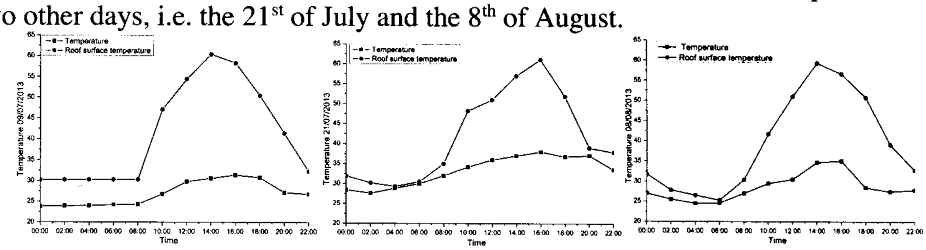

Figure 9 : Roof Surface Temperatures on the Three Days.

Discussion

The monitored readings show that the indoor temperatures achieved in the various rooms of the building relate directly to:

- The location of the room in relation to the position of the sun
- The vertical location of the room, .i.e. basement, ground floor or first floor
- The use of air conditioning

The indoor temperatures in the building are not simply based on the environmental conditions (air temperature, solar radiation) but are related to occupancy behaviour and the use of air conditioning. Such behaviour can be idealised in a computer model,

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but in the analysis of the monitored data from the building the actual human behaviour is not controlled and therefore the analysis is much more complex. Any design lessons learnt from the monitoring exercise must take into account the fact that control of the a/c units, for example, is not ideal. At times they may take the temperature below the comfort level, while at others the cooling power may be insufficient to drop the temperature down to acceptable values. Direct relationships between a/c use and temperature are therefore difficult to achieve and interpret. In an ideal building the size of the air conditioner would meet the maximum cooling demand, and would be infinitely variable to allow for lower cooling loads, but in practice, sizing and control of a/c units is far less precise.

Basement temperatures are fairly constant irrespective of the outside temperature; while outdoor temperature varied between 24 and 35°C, the basement temperature varied between 27 and 32°C. On the same days the living room temperatures ranged from approximately 24 to 33°C.

Conclusion

This part of the investigation focused on studying the thermal performance of the building, chiefly using the inside and outside temperature, and the on/off state of the air conditioner.

From the building measurements, it was confirmed that.

- Flats on the upper floor suffer the highest heat gains due to the fact that the roof surface is the most significant heat absorber in the building. Insulation for the roof should be targeted as a cost effective measure to reduce consumption.
- The energy used for air conditioning was substantial but because of the varied occupations of the rooms, was related only loosely to outside conditions.
- Flats located on the ground floor use the air conditioner during the day while the flats on the first floor use it more at night due to the time lag in heat transfer.
- The basement temperature is not significantly affected by the outside temperature, due to the fact that it is largely protected from solar gains.

In architectural terms, these findings point to the solar gain, rather than simple air temperature, as the principal driver of energy consumption in the region, and that insulating the roof and providing shading to the windows will have a substantial impact on the energy consumption. These measures can be applied to both new-build and retrofit work. This work will with software simulation to investigate the effect of a range of strategies for reducing the cooling load.

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