Building Roofs in Sudan

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Abstract. Buildings forms in the hot dry region of the tropics had evolved gradually by process of trial and error, using techniques and available materials. The traditional building construction in the hot dry tropic is of massive loadbearing walls and thick roofs. These two elements have a considerable heat storage capacity. The heavy structure absorbs heat during the day and released it gradually during the day whenever external or internal temperatures are lower. They also modify the temperature fluctuation and keep the interior comparatively cooler. The performance is satisfactory up to certain extent.

1. Introduction
With the development of building forms and functions and the use of new building materials, it is becoming very important to understand the thermal performance of the building and suitability of the new materials to the local conditions. This can only be achieved by the proper understanding of the local domestic factors and their effect on the performance of the building and the materials. Unfortunately, this has not been taken into consideration and many examples had been based on forms developed in the temperate zone for cooler climates and in area were people and designers are familiar with the climatic conditions and new building products and their performance under the local conditions. Method of construction and maintenance costs is major items to be taken in consideration during the design stage as many are not familiar with the system and the required skills especially with the new technology and air conditioning systems [1,2].

The design approach in the hot dry regions has been greatly influenced by western trend towards international architectural style which is the result of the advances in building techniques and the increase in industrializations. Many examples and forms based on these systems can be seen in the hot dry region. The demand for these types of buildings for housing is increasing as a result of the cultural, social and economic changes also the increased demand for public facilities such as hospitals, educational facilities, commercial, and government buildings. People are becoming more concerned about their image, comfort and performance of buildings, and also about the use of new materials and the construction cost.

The roof of the building in the tropics is the part of the building mostly exposed to the highest solar radiation intensity and high air temperature. That makes the roof an important part of the building to assess its performance and to examine the type of the materials and method of construction. This is to ensure that it satisfied the requirement and provided the safety and comfortable healthy conditions and shelter from the sun and the rain. The roof design should allow for additional floors and a terrace for social functions and support other utilities, which is a requirement in most cases.

The design of the roof in the tropics has to prevent the excessive heat from reaching the inside of the building and provide comfort for the occupants of the building during the day hours and cooling the structure during the night. The excessive solar heating during the day may cause rapid deterioration to the roofing materials. The concrete structure, which is the most common type of roof in urban area, can provide thermally uncomfortable conditions unless it is well treated and protected and insulated to reduce the effect of the
intensive solar heat. The intensive solar heat and the long exposure to solar radiation through most of the day hours can cause the breakdown of the protecting roofing layers. In case of light roofs, the excessive heat and cooling effect during the night can cause damage as a result of the movement of the metal sheets which due to the expansion and contraction. This action can create leaking during wet days and possible distortion to the steel structure. Therefore, an experimental work for some types of roofs which had been practiced in Khartoum, (Sudan) was carried out in a model building Figure 1. Khartoum was chosen as it is in the hot dry zone (latitude 15 30 and longitude 32 30) It is an example with large diurnal variation in temperature, high radiation intensity, and little rainfall Intensity.

Design of the roof has to be studied carefully to avoid any troubles in the future. It is the most important element of the building structure. It should be designed to absorb limited solar energy and reradiate minimum to the interior of the building during day time and allow its re-radiation to the sky during the cool night time. Light metal roofs, zinc, or aluminum sheets are extensively used in low cost housing. The material and the method of construction is simple and less expensive compared to other types of roofs but it is extremely uncomfortable due to the high intensity of heat during the day hours. People used some sort of ceilings or paint the top with light colour to improve the conditions. Figure 1 shows the performance of bare reinforced concrete roof slab compared to two treated concrete slabs during a week period.

2. Experiment

An experimental work for some types of roofs which had been practiced in Khartoum, (Sudan) was carried out in the model building as shown in Figure 2. Khartoum was chosen as it is in the hot dry zone (latitude 15 30 and longitude 32 30) It is an example with large diurnal variation in temperature, high radiation intensity and little rainfall Intensity.

The model was constructed with red bricks walls and reinforced concrete slab for the roof. The testing was to find out the effect of certain climatic factors on most selected common types of finishes on a reinforced concrete roof slabs Figure 3. The instruments used for the experiment had been chosen for their dependability in the hot dry tropical conditions and the unavoidable penetration of dust.

They consisted of probe type thermistors to measure the internal temperature of the room and the external air temperature and disc type for surface fixed to upper and lowers surfaces. All these thermistors were connected to Grant Recorders which were recording temperature directly on a chart.
Figure 1. the performance of bare reinforced concrete roof slab compared to other two treated concrete slabs during a week period.

A solar meter was used to measure the total solar radiation on the horizontal surface. The measurements of the velocity of the air over the surface were measured by electronic anemometer.

All the instruments used were regularly checked and the first stage of the tests was to find out the effect of natural ventilation maintained to ensure that they worked according to the required accuracy. The connections to the instruments are checked regularly on the thermal comfort of the space and the extent of the roofing material on that comfort condition. The experiment started on the month of May which was considered to be the hottest month of the year. During that period reading were recorded for the following conditions; Figure 3.

The 100mm reinforced concrete roof was tested with applying the following treatments on the upper and lower surface of the model roof of the building:

2.1 White wash or light colour Figure 3.1
2.2 75 mm thick layer of white gravel + two layers of roofing felt (Ruberoid) Figure 3.2
2.3 Two layers of roofing felt and 50 mm insulation (polystyrene) boards Figure 3.3
2.4 Two layers of roofing felt (Ruberoid) and khafgi mix Figure 3.4
2.5 Corrugated galvanized iron (C.G.I) sheets for shading with air space in between for ventilating the inner space. Figure 3.5,

2.6 Hollow tiles + roofing felt (Ruberoid) + cement, sand screed + white wash on top Figure 3.6

The hollow concrete roof tiles which had been practiced in the Sudan since 1965 and the performance was also tested for comparison Figure 3.6. The results of the experiment showed some variation in the performance of some types of roofs which are generally used in most regions of Sudan.

3. Results and discussions

The results of the experiment are in agreement with some findings in the literature of other works as shown below:

3.1 The reinforced concrete roof slab which is becoming very common without any insulation. It is thermally uncomfortable as it radiates a lot of heat to the interior of the building. This is becoming common because of the availability of the material, cheap to construct and it forms the base for any additional floors. It is fire resistant and the roof is sometimes used for storage, supporting water tanks and air conditioning machine. Many use the roof as terrace for sleeping and for recreation.

3.2 To reduce the thermal capacity of the reinforced concrete roof slab, the top surface of the experimental building was painted white or light colour paint to reflect a large percentage of the solar heat or applying white cement tiles. The internal air temperature dropped from 47.7 deg C to 27.2 deg C.

3.3 Using 50mm insulating material (polystyrene sheets) above the reinforced concrete slab and two layers of roofing felt (Ruberoid), the internal temperature dropped from 47.5 deg C external air temperature to 26.5 deg C internal air temperature. When it was painted white wash or fixing the insulation to the lower surface of the slab the internal air temperature dropped to 25.2 deg C. The above experiment was repeated using a layer of 50 mm thick of white gravel; the result was the same, no noticeable effect on inner temperature.

3.4 Applying 100mm of Khafgi mix (mix of crushed red bricks + lime + sand+ cement+ water and left for three days) then applied over two layers of roofing felt on the reinforced concrete slab. The internal air temperature dropped from 40.8 deg C to 32.6 deg C.

3.5 Shading the reinforced concrete roof slab using galvanized metal sheeting (zinc) with an air gap in between to allow air to pass through to remove the hot air. The inner air temperature dropped from 41.8 deg C to 29.2 deg C. When ceiling was added to the inner, air temperature dropped to 31.0 deg C.

3.6 Hollow tile roof which is more economical as it does not need shuttering system was used for the experiment with sand cement screed and white wash paint on the top. The inner air temperature dropped from 42.5 deg C to 32.0 deg C.
Figure 2. Experiment Model Room (Brick Walls and Reinforced Concrete Roof)

Figure 3. Typical Section of the Experiment Roof
Performance of the roofs. People in the tropics use imported building materials without proper assessment which could be not appropriate for the hot dry tropical climates and may deteriorate quickly as a result of surface temperature fluctuation. This action is getting more important with the introduction of air conditioning systems.

The bare reinforced concrete roof offered very little resistance to the external climate in Khartoum. The diurnal range was the higher in the range of 10 deg C and the maximum internal air temperature was higher than the corresponding external air temperature. The effect of the treatment on the roof surface applying different type of finishes during two consecutive days showed different temperature profile as in figure 4.1 and 4.2.

Using a light steel shading for the reinforced concrete, roof which can be designed to be folded or rolled to allow the heat gained to cool down the structure during the night hours.

Applying a white reflecting paint or white wash to the external surface resulted in a considerable improvement; it reduced the external surface temperature and the diurnal range and delayed the time of peak temperature. The main problem with white wash it remains effective as long as it is in a clean condition. When the khafgi was applied with white finished top there was delay of the peak temperature of about 5 to 6 hours and reduction of the internal temperature.

A 100mm layer of white gravel over the concrete roof slab improved the thermal efficiency of the roof. It maintained a lower temperature, minimum diurnal range and delayed the time of the maximum internal temperature similar to the heavy roof construction. Its disadvantage is the weight and the restriction of using the roof surface for any other activity.

Light metal steel roofs (zinc or aluminum sheets) with fiberboard ceiling, achieved a good reduction in maximum temperature and diurnal variation but with very short time lag. The internal temperature followed the external temperature fluctuation very closely. Ventilating the roof/ceiling space had little effect; it had small reduction of the maximum internal air temperature.
The concrete hollow tiles or precast units, aerated or insulated reduce the heat gain and they can also be treated on the top with white paint or white cement tiles. This treatment may reflect large percent of the incident solar heat. The system is economical as it does not need full shuttering system.

4. Conclusion
The experimental work on the thermal performance of roofs in the hot dry regions showed that it can be improved by one of the following methods:

4.1 Applying a white coat of paint or high reflecting material or bright metallic sheets to the external surface of the roof or using white cement tiles with air space for ventilation, this treatment may reflect about 80% of the incident heat and cooling the structure by emitting long wave radiation during cool nights.

4.2 Using double roof system and allowing the shaded roofs construction lose its gained heat to the cool night sky by folding or rolling away the shading device during the night hours. The shading device might be a metal sheets.

4.3 Using 50mm thick thermal insulating material sheets above or below the concrete slab +water proofing layers of felt + an average of 100mm thick lightweight concrete.

4.4 Light weight hollow tiles with 50mm reinforced concrete above +water proofing layers of felt + white cement tiles supported on blocks.

4.5 Light metal sheets (zinc or aluminum) over the reinforced concrete slab with ventilated space in between. To improve the thermal efficiency, the metal can be painted white.

4.6 Generally heavy constructed roof can delay the time for thermal heat to reach the inner space.

In all cases frequent maintenance to prevent accumulation of dust and dirt and repairing any damages or cracks will keep the efficiency of the roof for longer time.

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