The Effect of Roof Colour on Indoor House Temperature In Case of Hadhramout, Yemen

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ABSTRACT
This study discusses on minimising indoor temperature in hot and dry climate by application of roof colours. The problem is that most architects today do not emphasized on the effect of the roof colour and its importance to reduce the indoor air temperature in the building design. No study so far is conducted to determine the reduction of indoor temperature using white roof colour in mud-brick houses as a case study in a hot and dry climate in Hadhramout, Yemen. The survey was conducted in two phases, first: measurements before painting with white colour for continuously four days’ and after painting with white colour for another four days’ period. The measurements of air temperature were taken at every 3 hours interval in a day on July 2011. The results obtained show that white colour is able to reduce the indoor air temperature from 0.1 to 2.3°C. The indoor surface temperature besides is decreases from 0.8 to 3.9°C, while the outdoor surface temperature has a high reduction ranging from 2.5°C at night to 22.8°C at noon. White roof colour has a significant effect in reducing the indoor air temperature due to the decrease on outdoor and indoor roof surface temperature as well as the indoor air temperature.

1. Introduction

This study discusses the effect of white roof colour (whitewash) to indoor house temperature. Due to exposure to direct sun light, the roof becomes the hottest element of the building envelope, which we should be take into account to minimize the heat gain. The building surface partly absorbs and reflects solar radiation. The absorbed part of solar radiation has an effect on surface temperature and indoor temperature of the building (Givoni, 1998). Suehrcke et al (2008) reported that about 1kw/m² of solar radiation falling on a roof surface during clear sky condition and from 20% to 95% of this solar radiation is absorbed. However, the effect on colour of building envelope to its indoor temperature is depended on various parameters such as building orientation, composition of the walls, windows and air ventilation system (Cheng et al., 2005). Heat flow through this roofs envelope is proportional to the difference of the temperature between indoor and outdoor surfaces (Brown and Dekay, 2001). A study in a roof temperature can provide significant solution to its indoor thermal condition (Zinzi and Agnoli, 2011).

Colour of wall and roof surface has a significant effect to the indoor air temperature (Givoni, 1994). Previous studies show that colour on the building envelope had a significant impact to the indoor thermal condition. Many studies carried out works on the effect of light colour on the building envelope to its indoor temperature. Bansal et al (1992) argued that a room painted with white colour has lower indoor air temperature than a room painted with black colour with about 6°C in summer and 4°C in winter. Another study by Cheng et al (2005) also indicated that building colour has significant effect on the indoor air temperature. The study reported that dark colour had more than 10-degree air temperature higher than white colour. The study also showed that the intensity of solar radiation plays the vital role as the dark colour has more heat absorption due to solar radiation. A study on passive solar cooling was conducted in arid climate by Amer (2006) the results of the study shows that indoor air temperature had about 6 °C lower than outdoor temperature for the roof painted with white colour.

A study on the effect of building colour to the outdoor and indoor surface temperature was carried out by Givoni (1994). The study analysed three types of roof thickness (7, 12 and 20 cm) and two different colours (grey and white). For grey colour with outdoor air temperature of 31°C the average external surface temperature recorded was 69°C whereas the indoor surface
temperatures affected by the thickness (7, 12 and 20 cm) of the roof were 45, 39 and 33°C respectively. For white colour with outdoor air temperature of 27°C, the average external surface temperature recorded was 27.5°C, while the indoor surface temperature for three different roof thicknesses were the same, which is 25.5°C. The study also reported that the diurnal average of external surface temperature of white colour was lower than the air temperature, which indicates that the radiant loss is higher than energy absorbed in the white roof. According to Givoni (1994) “This phenomenon of white roofs being at lower diurnal temperature than the ambient air, was observed repeatedly, with different roof types, even in midsummer in very clear days”.

One of the studies by Valentina Dessì (2011) investigated the effect of colour for several materials used for building construction and it is contribution in lowering surface temperature and to improve the outdoor condition. The study highlighted the differences of the materials from one to another such as thermal capacity, density and albedo. The study found that the surface temperature of thermally positive materials has similar to the ambient air temperature during the day and its surface temperature with shaded materials. Besides a study on the effect of urban albedo on global temperature was conducted by Akbary et al (2007) This study found that cool roofs have a potential impact in improving energy efficiency and to slow down the climate change. Whenever the albedo is higher, the surface temperature is lower, in spite of different physical features of the materials. A comparative study carried out by Doulos et al (2004) was analysing suitable materials to minimize ambient temperature in urban space for popular pavement materials. The study reported that these materials has higher average surface temperature than the average ambient air temperature except the materials with white colour that has temperature lower than ambient air temperature with about 1.5°C.

A study was conducted by Akbary et al (1992) to investigate the amount of energy savings on white colour surfaces, the study showed that the roofs with white colour decreases the use of air-condition by saving electricity 12kWh/day in energy and 2.3 kW in peak power. Roof and wall painted with white colour saved 50% of the electricity use in air condition. Parker et al (1996) in his experimental study on residential building in Florida found that 20% of electricity for air condition was reduced after applying white reflective roof coatings. Sixty eight percent of
solar radiation was reflected with an acrylic white elastomeric coating with 63% after one-year age of coating. The study showed that by white roofing system had an improvement in indoor thermal comfort. The other study conducted on the effect of white roof colour on cooling load also by Parker et al (1997) on seven retail shops. The result showed a saving of an average of 25.3% electricity in summer.

In 2011, a study on the effect of green roof and white painted roof colours to improve indoor thermal comfort was conducted in Malaysia, which has warm and humid climate. This comparative study between green roof and whiter roof colour aimed to identify which roof provides better indoor temperature. The result showed that both roofs had a significant cooling effect on the roof surface and indoor air temperature. The ability of green roof to minimize the indoor air temperature is slightly better than the white roof. This phenomenon is due to shade and evapotranspiration provided by green roof (Asmat et al., 2011).

Rosangela (2002) in his study found that the use of reflective white surface had the best performance and reduced the need of insulation. This significant drop in the temperature of upper air was due to the white tile concrete roof. Suehrcke et al (2008) summarized in his literature study that the use of roof reflective surfaces materials such as white colour had significant increase to the thermal comfort because of cooling loads reduction.

2. Methodology

2.1 Case study

2.1.1 Hadhramout climate

Hadhramout state (Map 1) is the largest state in Yemen. The climate of Hadhramout is different from one region to another due to variations of its topography, which consists of coastal areas, highlands plateaus and deserts. The climates is classified as hot and humid in coastal area in summer and moderate in winter while hot and dry in highlands plateaus in summer in contrast to cold and dry in winter. According to Al-Kharasani (2005) and Bilfkih (1997), Hadhramout valley is located under the effect of desert climate which hot in summer and cold in winter where the average maximum temperature ranges from 28°C to 31°C in winter and from 40°C to 43°C in
summer. While the average of minimum air temperature ranges from 9°C to 12°C in winter and from 22°C to 25°C in summer. Average monthly relative humidity in Hadhramout valley ranges from 30% to 46% during winter and from 25% to 35% during summer. Sunshine is usually between 8 to 10 hours throughout the year, and exceeds 11 hours in May, October and November. The rainfall is rare, only from 50 mm to 125 mm annually.

2.1.2 Building description

The study selected a roof in a single storey detached house in Tarim city, Yemen. It has a brown colour (natural colour of the mud) before it was painted with white colour. This roof covers a house, which consists of three rooms (Figure 1). The study selected one room located in the corner to investigate the effect of roof colour (whitewash roof) on surface temperature and indoor air temperature.

The room measurements are 3.90m × 5.04m × 3.45m (height) with an area of about 19.65m². It has East and South orientation. One side of the room oriented to the East with 74° degree inclination from the North while another side oriented to the south with 164° degree inclination from the north. The other two sides are interior walls inside the space. There are two windows with a total area of 2.0m² located on the south sidewall, and the door 2.0m² is located in the opposite wall.
There are 50cm width’s external and internal walls constructed from mud bricks with mud mortar from 2.5cm to 3cm and 1cm lime mortar plastered inside the interior sides. The mud roof has 24cm thick, with mud mortar 2.5cm plaster at the interior and 3 cm at the exterior of the flat roof, and 1cm lime mortar plaster at its interior. The floor finish is of 3-4 cm thick cement.

Figure 1: Building layout indicates the location of the room for the case study.

Figure 2: Building form.

Figure 3: A. Roof colour before painting and B. Roof after painting with white colour.

2.1.3 Data collection

The study carried out a survey from 30\textsuperscript{th} June to 7\textsuperscript{th} July continuously for 8 days. The reason for selecting this particular period is that it is within the hottest period of summer season during the year. It study expected to have a large effect of solar radiation on the roof surface and indoor air temperature. The study recorded measurements at indoor and outdoor of the room. The types of measurements are indoor air temperature, outdoor air temperature, indoor roof surface temperature
and outdoor roof surface temperature.

The study took measurements of air temperature and surface temperature in 4 days continuously with every 3 hours intervals. It took measurements in two phases, first: before painting the roof with white colour and after painting with white colour.

Measurements of air temperature were at high 110 cm from the ground level of the room. The study measured the outdoor air temperature using another sensor placed outdoor under the shade at 250 cm high from the ground level. The devices used to measure indoor and outdoor air temperature is EXTECH 45160 3in1, Thermo Hygro Anemometer (Figure 4) and CENTER 342 Temperature Humidity Recorder (Figure 5) respectively, while IRtek IR60 Infrared Thermometer was used to measure the surface temperature (Figure 6).

**Figure 4:** EXTECH 45160 3in1 Thermo Hygro Anemometer.  
**Figure 5:** CENTER 342 Temperature Humidity Recorder.  
**Figure 6:** IRtek IR60 Infrared Thermometer.

Limitation of this study is that this it did not carry out study on the amount of light reflectance or absorbed by the building surface but it is to give an idea of the ability of white colour (whitewash) in reducing the surface and indoor temperature.
3. **Result and Analysis**

3.1 **Temperature**

Figures 7 to 9 illustrates the results of air temperature taken from the survey in the line chart graphs. The X-axis represents the hours of the daytime when the study took air temperature data from indoor and outdoor, while the Y-axis represents the degree of air temperature in degree Celsius (°C).

The graphs illustrated that the outdoor roof surface temperature before and after painting with white colour started to rise up from the morning to reach the peak at 12 pm when the sun was perpendicular to the roof, and then start to decrease until at its lowest surface temperature at 6 am. The hottest roof surface temperature before painting was 62.6°C at 12 pm while the lowest was 20.5°C at 6 am, however, after painting with white colour the hottest temperature recorded was 40.1°C, while the lowest was at 17.9°C. In summary, the maximum surface temperature before and after was 62.6°C and 40.1°C respectively, while the minimum surface temperature was 20.5°C and 17.9°C respectively.

The average maximum difference recorded between outdoor roof surface temperatures before and after painting was 22.4°C and 17.2°C at 9 am and 3 pm respectively, while 5.2°C at 9 pm and 3.7°C at 12 am and 3 am respectively. The daily range (between minimum and maximum) of outdoor surface temperature before painting was 40.1°C, while after paint with white colour the daily range was 22.2°C this reduction was 19.9°C after painted with white colour.

From comparison of indoor roof surface temperature before painting to outdoor roof surface temperature after painting, it showed a reduction of outdoor roof surface temperature where all readings were recorded lower than indoor roof surface temperature except two reading at higher with a difference of 0.5°C. All the outdoor roof surface temperature after painting were recorded lower than those of indoor roof surface temperature except 4 reading at 12 pm and 3 pm warmest with an average temperature of 2°C. This is due to high intensity of solar radiation perpendicularly to the roof surface at noon.

Before painting, outdoor roof surface temperature had an average temperature of 15.4°C.
higher than indoor air temperature from 7.30 am to 5 pm, which was the period of the roof surface exposed to direct solar radiation during the daytime. It had lower than indoor air temperature with an average of 6.75°C from 5 pm to 7.30 am, when there was no occurrence of solar radiation. After painting, the outdoor roof surface temperature had average temperature of 8.7°C lower than indoor air temperature of the room except three readings at 12 pm, which had higher average temperature of 1.4°C.

The study compared also between indoor air temperature before and after painting. The results showed that after painting, the indoor air temperature had lower temperature than before panting ranging from 2.3°C to 0.1°C with an average of 0.85°C. The average outdoor air temperature before and after paint however was similar, which are 38.82°C before and 38.86°C after painting.

From analysis of indoor roof surface temperature it can be noted that before painting, indoor roof surface temperature had low temperature of 36.6°C at 6 am then increased until 12 pm and after that, it dropped again until 6 pm. Lastly, it rised to record highest temperature of 39.4°C at 9 pm. While after painting the indoor roof surface temperature had the highest temperature of 38.7°C at 3 pm. Then, the temperature started to drop down to record the lowest temperature of 34.2°C at 6 am. The study noted also that after painting, indoor roof surface temperature had ranged from 3.9°C to 0.1°C lower temperature than those before it was painted.

A comparison between outdoor roof surface temperature and outdoor air temperature before and after painting with white colour showed that before painting, the surface temperature was higher than outside air temperature from 7.30am to 5 pm. The surface temperature was however lower than outside air temperature from 5 pm to 7.30 am. The highest average temperature of outdoor roof surface during daytime was 9.7°C ranging from 3°C to 16.9°C, while the lowest average temperature of outdoor surface during nighttime was 5.84°C ranging from 1.3°C to 9.5°C. However, after painting all the readings of outdoor surface temperature was lower than outside air temperature with an average of about 10°C temperature lower during the day, ranging from 1.3°C to 12.5°C.
Figure 7: Outdoor roof surface temperature and outdoor air temperature before and after painting.

Figure 8: All tested parameters before and after painting.
4. Discussion

The analysis found that the high outdoor roof surface temperature is due to direct exposure to solar radiation, the hottest temperature was recorded when the sunbeam was perpendicular to the roof surface. This is due to distribution of the intensity from the sunbeam over a small area of the roof surface.

From the analysis of outdoor roof surface temperature before and after painting with white colour, a high reduction of the surface temperature of 22.2°C (35.5%) after painting is due to ability of white colour to reflect large amount of solar radiation to the ambience as well as low absorption of solar radiation.

The analysis also showed that indoor roof surface temperature before painting with white colour had recorded low temperature and then started to increase until 12 pm, and later dropped its temperature until 6 pm. Lastly, it increased to record highest temperature. These variations are because of changes in the outdoor roof surface temperature which ranging from 20.5°C early morning to 62.1°C at noon, with daily temperature range of 42.1°C. Low surface temperature at

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night is transferred through the roof slowly to reach indoor surface after 10 to 12 hours, which explain the drop of indoor surface temperature in the graph at 12 pm. While the extreme heat of outdoor surface at noon transferred to the indoor roof surface after 9 hours. The difference in time lag of heat transfer is because it is proportionally between the rates of heat transfer through building materials with the difference between the temperatures of the roof surface. However, after painting with white colour, the indoor roof surface temperature had recorded highest temperature at, and then the temperature started to drop to its lowest temperature at. The line graph has moved up and down showing a regular shape pattern. This is due to large differences occurred in the outdoor roof surface temperature before and after painted with white colour. The outdoor roof surface temperature has lower than the indoor air temperature of the room. The reason is only the room air temperature influenced the indoor roof surface temperature. This illustrated the similarity after painting in the line graph of indoor roof surface temperature and indoor air temperature.

5. Conclusion

The study concluded that after painting the roof with white colour, the indoor roof surface temperature recorded a large reduction, which in turn resulted in the reduction of heat transfer through the roof to the indoor. The reduction occurred in the amount of heat transmitted through the roof, which means that painting the roof surface with white colour has reduce improved indoor thermal comfort. The highest indoor roof surface temperature before painting occurred at night when the outdoor air temperature had dropped. It is possible to control this heat gain by enhancing the air exchange between indoor and outdoor.

6. References


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