Urban Materials and Colours – as a Mitigation Option

“If you force me to pick one colour, it’d be Black... It covers up the things inside of me that I don’t want to be known. Well, for the same reason, black is the colour I hate, too...”

― Gosho Aoyama (2004)

7.1. Introduction

Rapid urbanization is occurring across the planet. This extensive urban expanse is increasingly replacing the natural surface by more anthropogenic ones. For example, the mounting predominance of urban material such as asphalt and concrete is across the global landmass. The gradual shift to urban materials is altering the surface properties of earth and is resulting in development of the phenomenon of Urban Heat Island (UHI) (Weng et al., 2004). Each city is distinctive with its unique characteristics that influence UHI development; such as type of urban material used, proportional cover of built-up and vegetation, demography and climate to mention but a few. However, irrespective of their geographical settings the cities of the world display some similarities with respect to development of this phenomenon (Vez et al., 2000).

As discussed in Chapter 1, there are several factors that contribute to development of UHI. These factors are broadly covered under urban morphology (Torok et al., 2001), anthropogenic factors (anthropogenic heat and urban air pollution) (Rizwan et al., 2008), urban landscape (Buyantuyev and Wu, 2010), urban material and urban fabric (Chudnovsky et al., 2004). Of these the urban fabric and material have more direct implications for Surface UHI or SUHI than other types (Canopy layer and Boundary layer). The SUHI analysis deals with the UHI exhibited by earth surface rather than its manifestation in atmospheric domain.

Urban fabric is inimitable from non-urban materials with respect to radiative and thermal properties. Thermal property of the material refers to its characteristic which determines its reaction to excessive heat or heat fluctuations. Thermal capacity of the material is an inherent property decisive aspect for balancing the solar energy budget. It determines the ability of the material to store heat (Gartland, 2011). Radiative property
is largely determined by albedo or solar reflectance and emissivity. All these factors are crucial determinants of the fate of solar energy reaching the earth’s surface; through reflection, emittance and absorption (Arnfield, 1982; Voogt and Oke, 2003). Development of UHI is thus highly dependent on interplay of these factors. For materials that are thin, roofing for instance, reflectance and emittance are more important. In contrast to this for thicker structures such as pavements, thermal capacity holds more relevance in determining the progression of UHI.

UHI development is not only contingent upon the material type but also gets influenced by the material color (Radhi et al., 2013). For instance, experiments have been conducted which point out that cool-coloured coatings (such as white) are around 10°C lesser in temperature than standard black coating (EPA, 2012). This is because albedo is crucial factor of surface heat budget, which in turn governs the formation of UHI in urban areas. Since most of sun’s energy radiant on earth falls in visible spectrum, albedo thus becomes mutually related with a color of the material. Light surfaces tend to have higher solar reflectance as compared to darker objects (Sailor, 2006). Hence, along with material type, the material colour is also a crucial determinant of UHI growth in the area.

In spite of the plethora of literature and work that is available on process of development and measurement of UHIs, little work is found on extensive analysis pertaining to the causal factors; except changing land use land cover patterns. In general there is a dearth of work on role of urban material and colour in developing UHI in the city. This chapter aims at contributing in the understanding of the role of urban materials in UHI development, which behaves as the very backbone of urban structural existence.

**7.2. Objectives**

The objective of this chapter is to examine the thermal response of various urban fabrics (with respect to material and colour). The purpose was to characterise thermal behaviour of various urban fabrics with respect to seasonal and diurnal variations and also to analyse differential thermal response of building paint colours. Since urban areas are predominantly covered with such construction materials, thus a stronger knowledge base on these materials could offer opportunities for effective mitigation of UHI through moderation of usage of urban materials.
7.3. Methodology

To achieve the above discussed objectives, an inter-comparison of different urban surface materials and colours based on their thermal responses was performed (Figure 7.1).

![Methodological framework diagram]

**Figure 7.1: Methodological framework**

This work attempted to inspect how use of different colours in urban structures can either promote or mitigate SUHIs. Non-contact infrared thermometer was used to take LST measurements.

The procedure of data collection was repeated during four main seasons that city experiences, viz., Spring, Summer, Autumn and Winter. For spring first week of March was chosen when average temperature for the 6 day study period was 18°C and the average wind speed was 8km/h. The summer survey was carried out during hot month of June with 32°C (average temperature) and wind speed of 13km/h. October month was selected to accomplish autumn season study, when the climatic conditions were relatively calm with average wind speed of 4km/h and the average temperature of 26°C. Finally study during late December served the objective of covering winter season for study. The average temperature during this week was 12°C and the wind speed was 3 km/h. Monsoon season was dropped from the study plan as during this season it rains very heavily and it is not possible to conduct survey also this could have led to discrepancies in collected data. The observations were taken during four different
seasons (March, June, October and December) for six consecutive days. Four readings were taken each day at an interval of six hours each (just as in previously mentioned case). Thus a total of 112 readings were taken for each object and each colour.

Table 7.1: Details of materials and colours studied, reasons for their selection and their spatial connect with the city

<table>
<thead>
<tr>
<th>Urban material</th>
<th>Names</th>
<th>Reasons</th>
<th>Spatial connect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban material</td>
<td>Plastic</td>
<td>Plastic dominant in slum areas, which are already vulnerable to UHI impacts</td>
<td>Slum areas, where they use plastic sheets to cover the roofs</td>
</tr>
<tr>
<td></td>
<td>Solar panel</td>
<td>Expected to be more abundant considering NAPCC’s Solar Mission</td>
<td>Government buildings in and around central Delhi</td>
</tr>
<tr>
<td></td>
<td>Brick</td>
<td>Material most dominantly used in construction</td>
<td>Most of the residential areas across the city</td>
</tr>
<tr>
<td></td>
<td>Metal</td>
<td>Heavily used urban material (such as foot-over bridges)</td>
<td>Railway stations and railway lines, industrial areas of Narayana, Mayapuri, Moti Nagar</td>
</tr>
<tr>
<td></td>
<td>Glass</td>
<td>Predominant and relatively typical material to city buildings (offices in specific)</td>
<td>Business hub in central Delhi (such as Connaught Place)</td>
</tr>
<tr>
<td></td>
<td>Porcelain tile</td>
<td>Tourists and religious places in the city</td>
<td>Tourists and religious places in the city</td>
</tr>
<tr>
<td></td>
<td>Sandstone</td>
<td>Dominant material in older buildings</td>
<td>Monuments such as Red Fort</td>
</tr>
<tr>
<td></td>
<td>Grass lawn</td>
<td>Provides for cooling option and can be easily incorporated in planning</td>
<td>New Delhi area around embassies and the parliament, golf courses, Chanakyapuri</td>
</tr>
<tr>
<td>Urban colour</td>
<td>Blue</td>
<td>To look out for colour option best suited for UHI mitigation</td>
<td>Roof of most of the metro stations</td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>To look out for colour option best suited for UHI mitigation</td>
<td>To look out for colour option best suited for UHI mitigation</td>
</tr>
<tr>
<td></td>
<td>Black</td>
<td>To look out for colour option best suited for UHI mitigation</td>
<td>Government quarters in cantonment area and other areas</td>
</tr>
<tr>
<td></td>
<td>Red</td>
<td>To look out for colour option best suited for UHI mitigation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>White</td>
<td>To look out for colour option best suited for UHI mitigation</td>
<td></td>
</tr>
</tbody>
</table>

In-situ experimental set-ups were established to take measurements for urban material and colour (Table 7.1):

Urban colour – A set of observations were made for different colours for concrete blocks of same shape, size and composition so as to study the effect of colour on same material. The colour selection was done based on their common occurrence and usage. The colours hence used for study were blue, green, red, black and white.

Urban material – Another experimental setup comprising of different urban materials including plastic, solar panel, brick, metal, glass, porcelain floor tile, sandstone and grass lawn, was observed to study their thermal variations over time in a manner similar to previous one.

7.4. Results

The results section has been subdivided into materials and colours, to study the seasonal and diurnal variations exhibited. These sections have been discussed in three subsections; the seasonal analysis, the diurnal analysis and the comparative analysis. The LST data collected for the first objective (land use land cover), was used for validation of satellite derived LST values. This part has been explained and discussed in previous chapter (Chapter 5).

7.4.1. Materials

7.4.1.1. Seasonal Analysis

An average for seasonal observations was computed for each material. Maximum temperature is observed for summer season of June month and minimum for winter season of December month (Figure 7. 2). The surface and materials, illustrate a rhythmic pattern where temperatures initially increase moving from spring (max~20°C) to summers, reaching the peak (max~48°C). The temperatures then start falling with advent of post-monsoons (max~32°C) and finally touching the lowest values during winters (max~15°C).

Plastic was one material that consistently had highest or second highest temperature during all the seasons. Plastic experienced 20.25°C during spring (March), which increased to 45.98°C in summer month of June. In October month of post-monsoon, temperature again fell down to 26.55°C; further declining to 13.69°C in December month experiencing the winters.
Opposite to behaviour of plastic was grass that consistently illustrated low temperatures all around the year. Grass exhibited highest temperatures (=35.21°C) during summer season, and relatively lower temperatures during post-monsoon (=22.30°C) and spring (=17.25°C). The lowest temperature (11.57°C) of all the observations was demonstrated by, grass in winter month of December.

Brick exhibited second highest temperature across the seasons. Highest temperature for brick was around 40°C during June followed by 26°C and 21°C during October and March respectively. Lowest temperature was observed in December (~15°C).

All other materials had temperature lying between 37°C (June) and 12°C (December). For June, these materials had temperature range of 35°C (glass) to 37°C (sandstone). The range was 24°C (glass and tile) to 28°C (metal) for October and, 11°C (tile) to 15.5°C (metal) for December. Metal had highest temperature during October and December. During March, brick had highest temperature (20°C) and the temperature range for materials other than plastic and grass was 17°C (tile) to 20°C (brick).

**Figure 7.2:** Seasonal trend of thermal behavior of different urban materials (an average of day-night temperatures)

**7.4.1.2. Diurnal Analysis**

The temperature for different materials increased from t1 (09.30-12.30 hours) to t2 (14.30-16.30 hours) with the progression of day and dropped moving from t2 to t3.
(21.30-00.30) and from t3 to t4 (02.30-04.30 hours). All the materials exhibited more or less similar patterns during different seasons. However, variation was observed in absolute temperature values indicating differential response of materials to temperature stimuli more specifically during t1 and t2 (Figure 7.3).

During summer (June) for instance, plastic showed 48ºC during t1 that increased to 51ºC during t2, falling then to 44ºC (t3) and finally reaching 40ºC during early dawn t4. Other materials too exhibited the same trend of increase in temperature from t1 to t2 and then fall from t2 to t3 and then t3 to t4. At t1 brick was hottest (51ºC), followed by solar panel (50ºC), metal (47ºC), sandstone (44ºC), glass (44ºC), tile (39ºC) and the coolest was grass (40ºC). The temperature for all materials rose during t2; when plastic and brick was hottest (52ºC), followed by solar panel (50ºC), metal and sandstone (47ºC), then glass (44ºC) and tile (44ºC) and again the coolest was grass (38ºC).

During winter (December), the diurnal temperature pattern was same for all materials but their orders differed. Metal was found to be hottest during t1 with 24ºC that was followed by solar panel (21ºC), plastic (20ºC), brick (19ºC), glass (18ºC), sandstone (17ºC) and grass (14ºC). Tile (13ºC) demonstrated to be coldest material during t1. During t2, temperature for all materials increased slightly from 1-3ºC for all the materials. Materials exhibited a drop in temperature during night (t3) with solar panel showing the maximum fall (drop of 14ºC). A fall of 12ºC was observed for metal, glass and brick, followed by plastic (10ºC), sandstone and tile (7ºC) and least decline were noted for grass (6ºC). A further decrease of 1-2ºC was observed for all the materials during t4.

The diurnal pattern of temperature was similar during spring season (March) as well. During t1, solar panel was hottest with 30ºC while grass and tile were coolest with 20ºC. Other materials had temperature within range of 21ºC and 26 ºC. The temperature for solar panel remained unchanged during t2, while it increased for other materials. From t1 to t2, the temperature for plastic increased by 5ºC. Brick and tile became hotter by 4ºC during t2. For glass, grass and metal a 2ºC increase was noticed, while temperature for sandstone increased by 1ºC.

Post-monsoonal temperature pattern demonstrated striking similarity with that of other seasons. For t1, grass was found to be coldest (28ºC) while metal was hottest (37ºC). Brick and solar panel were second to metal with 35ºC, followed by plastic (34ºC), glass
(33°C), sandstone (32°C) and tile (31°C). At t2, elevated temperatures were in following order; metal (50°C), solar panel (45°C), brick (41°C), grass (32°C), plastic (35°C), glass (35°C), tile (33°C) and sandstone (32°C). From t2 to t3, a tremendous fall in material temperature was observed. Maximum decrease of 34°C was noted for metal, decreasingly succeeded by solar panel (31°C), brick (25°C), glass (22°C), grass and tile (17°C for each), plastic (15°C) and sandstone (13°C). Materials witnessed a further fall of 1-3°C in temperature from t3 to t4.

The diurnal pattern was almost the same for all materials in all the seasons, but drastic variations were observed in absolute change in temperature for different materials and different seasons as well. Metal, solar panels and glass show relatively high day surface temperatures. Metal reached highest values of 50°C during summer days, falling down through 47°C in post-monsoon to 22°C in winters and again increasing gradually through 24°C in spring. Solar panels and glass followed same trend with 47°C, 45°C, 21°C, 29°C, and 44°C, 35°C, 21°C, 26°C during June, October, December and March respectively. Grass lawns exhibit consistently low temperatures throughout the year (both day and night) and can thus be good for mitigating UHIs; Day: 41°C, 32°C, 15°C, 22°C; Night: 28°C, 17°C, 9°C, 14°C.

7.4.1.3. Comparative analysis

Brick show temperatures higher than other materials during day (~50°C) which fell down at night (~30°C) during summer season. The trend for post-monsoon was also similar to that of summer month with high values of up to 40°C and lower values approximately equal to 18°C, that could be as low as 10°C during winter season. Day and night thermal pattern for brick remained same during spring season of March (Figure 7.4). However, the temperature variation with respect to other materials is not considerable at night time. Metal displayed trends more or less similar to brick. It exhibited high temperature during day and tend to cool down at night. Porcelain tile recorded lower daytime temperature (~42°C in summers) when compared with brick (~52°C), plastic (~51°C) or metal (~47°C) throughout the seasons. At night, porcelain tile cools down up to the level of these materials viz., brick and metal. This behaviour indicates that, the tile has potential to store heat for longer period. Lesser heating of tile (as compared to brick, metal and plastic) during daytime comes as a result of white reflective surface of the tile that helps reflect major portion of the incident radiation.
Figure 7.3: Boxplots showing diurnal variation for different materials during; (a) March, (b) June, (c) October, and (d) December
Solar panel exhibited atypical behaviour with very high or highest daytime temperatures (up to 50°C in summers and 21°C in winters) and the lowest night time temperatures (~28°C in summer and 6°C during winters) across the different seasons. In spite of highest day time temperatures, these are not causative of UHI in the city, as the energy these absorb is channelized for some useful purposes (such as heating, lighting etc.) rather than becoming a contributing factor for UHI development. And at night also, these materials radiate minimum heat, indicating their candidature as UHI mitigation option.

Glass had moderately high day temperature (up to 44°C in June and 35°C in October) and one of the lowest at night time (28-30°C in June and ~18°C in October) during summer and post-monsoon season. In winters and spring, glass exhibited day observation on the higher end (22-32°C), while night time records were moderate to low (8-12°C).

![Figure 7.4: Overall comparison of different urban materials, at different timings of the day during different seasons](image)

In month of June, plastic sheet is one material that exhibited highest temperatures through all the four timings of both day (~50°C) and night (~40-45°C). Similar trend was followed by plastic in October with day temperatures reaching up to 35°C and at
night it touched approximately 20°C. During the colder month of December, plastic had moderately high day temperatures (~20°C) but at night it experienced somewhat lower temperatures (7-9°C). Plastic showed not much variation in temperatures as compared to other materials in March and appeared to be in transition of reverting back to the summer pattern.

Sandstone had moderately high to very high day time temperatures during summer (~48°C) and post-monsoon month (~32°C). The day temperatures for December (up to 20°C) and March were low to moderately high (~22°C). Night time thermal behaviour of sandstone was not very congenial especially during winter season as sandstone displayed highest temperature among all the materials during winter nights (~12°C). Even during summer nights, sandstone illustrated highest temperature (~34°C).

Grass had relatively lower temperatures as compared to other objects throughout day and night during all the seasons. Maximum day temperatures for grass were reached during summer (40°C) and minimum were obtained during winter season (~15°C). At night maximum value was recorded for summer (~28°C) which was 12°C lower than daytime. And minimum night temperature for grass was in winter season (~7°C).

7.4.2. Colours

7.4.2.1. Seasonal analysis

For all the colours, an average for their seasonal observations was computed (Figure 7.5). Summer season recorded maximum temperature and minimum was observed for winter season. The colours, demonstrated a rhythmic pattern with spring temperatures increasing from spring (max~22°C) to the peak in summers (max~44°C). The temperatures were then observed to fall with commencement of post-monsoons (max~30°C) and finally touching the lowest values during winters (max~15°C).

Black was the colour that consistently had highest temperature during all the seasons. Black colour recorded 21.07°C during spring (March), increasing to 43.39°C in summer (June). During post-monsoon, temperature again fell down to 28.89°C; further diminishing to 14.72°C in winters of December month.
White exemplified a behaviour that was entirely opposite to that of black. It consistently recorded low temperatures all around the year. White exhibited highest temperatures (≈37.45°C) during summer season, and relatively lower temperatures during post-monsoon (≈25.34°C) and spring (≈18.40°C). The lowest temperature (13.33°C) of all the observations was demonstrated by white in winter month of December.

7.4.2.2. Diurnal analysis

The temperature for all the colours was found to increase with the progression of day from t1 (09.30-12.30 hours) to t2 (14.30-16.30 hours) and a drop was observed from t2 to t3 (21.30-00.30) and then from t3 to t4 (02.30-04.30 hours). The pattern was similar for all the seasons and all the colours (Figure 7.6). However, variation was observed in absolute temperature values giving rise to differential manifestations of colours on more specifically on daytime (t1 and t2) UHI when inter-colour temperature variation was maximum.

In March for instance, maximum temperature for black was up to 26°C during t1, while blue and green was 25°C each, red was 24°C and white was as low as 20°C. During t2 the values for each rose; 32°C for black, 31°C for blue, 30°C for red and green each and 26°C for white were observed. At night (t3) the colours started to cool off coming down to 15°C±0.3. The cooling continued during t4, with all the colours in range of 13°C±0.45.
During the hot month of June, maximum values were observed for all the colours. Black was 57°C during t1, and achieved its maximum (60°C) during t2, beginning to cool during t3 (33°C) and finally reaching minimum (28°C) during t4. During t1, blue, green, red and white were 56°C, 54°C, 51°C and 44°C respectively. These eventually increased to 57°C, 57°C, 54°C and 47°C in t2. During t3, the colours began to cool down and reached 32°C±0.5. Cooling continued further in t4 and all the colours recorded temperature in range of 27-27.3°C.

As compared to summer month, the temperatures started falling down with commencement of post-monsoon (October) season. Temperatures for blue, green, red, white and black were 40°C, 40°C, 39°C, 35°C and 41°C during t1. These increased to reach maximum (44°C, 43°C, 41°C, 36°C and 45°C respectively) during t2. At night (t3) colder readings were observed in range of 17-17.5°C that additionally fell to 14°C±0.2.
With approaching of winter season (December), maximum temperatures declined to even greater extents. During t1, blue, green, and red had 18°C, while white and black recorded 15°C, and 19°C respectively. The colours turned hotter with approach of t2; with black and blue being 23°C, green, and red being 22°C, while white was 20°C. At t3, the temperature dropped to a range of 10-10.6°C. The range further reduced to 7-8°C during t4.

7.4.2.3. Comparative analysis
Black, blue and green exhibited relatively higher day surface temperatures (both t1 and t2). Black was highest during all the seasons specifically during day. White was one colour that had lowest temperature during day throughout the seasons (Figure 7. 7). At night all colours were more or less equally hot with slight variations of ±0.5°C.
Figure 7.7: Overall comparison of different colours, at different timings of the day during different seasons

7.5. Conclusion

Various urban fabrics contribute differentially to development or mitigation of UHI. Building materials specifically plastic, porcelain tile and sandstone exhibit high temperature in night throughout the year indicating their contribution in augmenting ‘Nocturnal UHI’. The temperature for all these materials ranges between 7°C (for t4 during winter season) and 52°C (for t2 during summer season). High thermal capacity of these construction materials is responsible for such a phenomenon. Materials such as metal (47°C, 50°C, 22°C, 24°C in June, October, December and March respectively), solar panels (47°C, 45°C, 21°C, 29°C in June, October, December and March respectively) and glass (44°C, 35°C, 21°C, 26°C in June, October, December and March respectively) show relatively high day surface temperatures establishing their higher contribution in development of ‘Diurnal UHI’. Metals have low thermal emittance and also these materials have high thermal conductivity which results in higher daytime temperatures. In summer season (June), plastic had relatively (as compared to other materials) higher temperatures both during day (51°C) and night (40°C). It is thus conducive in progression of ‘Seasonal UHI’. Grass lawns have low temperatures throughout the year (both day and night); Day: 41°C, 32°C, 15°C, 22°C; Night: 28°C,
17ºC, 9ºC, 14ºC in June, October, December and March respectively. Grass lawn thus extends itself as a relatively mitigating agent for nocturnal and diurnal as well as seasonal UHIs in the city. The annual mean satellite temperature (daytime) for grass lawns (Delhi golf course) was found to be around 32ºC-33ºC. As we move from grass lawn to mosaic landscape (well distributed built-up and green cover), the temperature increased to a range of 33ºC-34ºC. Whereas in the Old Delhi Railway Station area, that is dominated by metal, exhibited temperature in range of 37ºC-39ºC. Considering the business hub of Connaught Place, that is manifestation of glass covered buildings, the temperature varied from 36ºC-38ºC. Though all the locations discussed here are present in vicinity to each other, but vary greatly in their surface temperature ranges owing to presence of differential urban materials. The presence of grass lawn in between the built-up area could mitigate the UHI from 2ºC to 5ºC in contrast to all built-up area. The metal and brick dominated industrial sites of Anand Parbat illustrated temperature ranging from 38ºC to 40ºC. The residential block of Mahavir Enclave (Dwarka) that is predominantly represents brick, had temperature varying from 35ºC-36ºC.

UHI intensities also vary with difference in colour of urban fabric. White paint exhibits minimum temperature throughout the year. It could mitigate up to 4ºC during December, 6ºC during March, 13ºC during June and 6ºC during October. Red colour was found to be better than blue, green and black for mitigating surface heat. In general use of bright or light colours can have mitigating impact on UHI as such surfaces have higher solar reflectance as compared to darker materials..

Various urban fabrics and colours contribute differentially to the development or mitigation of UHI. Controlling the two contributing factors thus holds potential for combating the UHI development. For instance, incorporating more green spaces in planning and using white roofs can help decrease the surface temperatures and can thus serve as one of the many mitigation options for UHI in the cities.