Urban heat island is contributing to change in temperature profile at both micro and macro levels. This document provides a brief introduction to the problem, its impact and possible options to mitigate and adapt to the situation thereby increasing the indoor thermal comfort.

Urban Heat Island Effect and Its Mitigation Strategies
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Chapter - 1: Urban Heat Island

Introduction
Over the past few decades, the world has experienced a sudden increase in migration. This migration is not only of number of people moving between continents and countries due to the advancement in the transportation but also in number of people moving from rural areas to urban areas. This is due to changes in the economy and work profile. From the Figure 1 it is clear that according to census 2011, 31.2% of India’s population is residing in urban areas. The decadal urban growth rate of India stands at 31% while rural urban growth stands at 12%, a decline of 6% in one decade.

![Urban and Rural Population India](image)

Figure 1 Urban and Rural Population India

Figure 2 illustrates that percentage of world population in urban areas during 2007 and the projected values for the years 2025 and 2050. From Figure 3 we can infer that if the trend of migration of people towards the urban areas increases, then by 2010 more than 50% of the world’s population will be living in urban localities.
Fig 2 Urban and rural population of the world, 1950-2050

Fig 3 Percentage of population in the urban areas
This increase of the urban population has also led to rapid changes in land use and land cover within cities. During recent years there are evidence of increased change in traffic congestion and pollution. These physical changes affect the quality of the environment, contributing to other phenomenon such as an increase in air temperature. Scientists have observed that air temperatures in densely built urban areas are higher than the temperatures of the surrounding rural country. This increase in temperatures within urban areas is known as the ‘urban heat island’ (UHI) phenomenon. According to Voogt (2005), UHI can be defined as “closed isotherms indicating an area of the surface that is relatively warm; most commonly associated with areas of human disturbance such as towns and cities. The temperature differences strongly vary on micro scale, both in rural and urban areas because of varying radiant load. For example, a concrete surface may have a different radiant load as compared to water in a lake. This could be observed both within the urban and the rural environment. But, the thermal characteristics of the overall urban terrain constitute a basic factor in creating the UHI effect which is not only observable at a micro level but also at the macro level.

**Causes of Urban Heat Island Effect**

Over the past decade UHI presence has been studied and documented in several cities around the world. As the name suggests, the cause of this phenomenon is an urban landscape in general, there are several bio-physical factors that contribute to its presence and spread. In a broader perspective every human being wants to live in a developed environment or an environment where there is an easy access to resources and their benefits. With the advent of technology and modern transportation systems, access to resources/benefits has become easier and such facilities have been achieved in many cities within the developed nations. However, ease of accessibility comes with the price of change in land use and land cover. In this case it is not only the monetary price that one has to invest to achieve such things but also other qualitative prices that one has to pay through the process. One such price is the quality of the living environment.

According to Golany (1996), during the early years of development of a city "the design without designer method was traditionally passed from one generation to another, versus our contemporary design style produced on drafting tables with little or no observation of the diversified natural forces acting on the field". The traditional method of planning would be to include environmental considerations within design. But, lack of such a process within methodology has led environmental scientists to look back and analyze various effects of natural and built forms within urban surroundings.

**1.2.1. Weather**

When we discuss UHI effect, we are essentially discussing a component of boundary layer, canopy layer or surface layer weather system. Similar to weather systems UHI effects have a strong relationship with weather parameters such as wind and cloud. In a smaller scale (individual building scale) experiment by Hall et al. (1999) many of the meteorological and climate characteristics were analyzed. The research demonstrated that aspect ratio, wind direction, wall thickness of buildings, presence of openings and surface clutter have significant effects on the heating and cooling of the surfaces, often altering them by orders of magnitude. The study of UHI in Athens by Mihalakakou et al. (2004) demonstrated that the high pressure ridge mostly favor heat island phenomenon whereas, intense northerly winds are responsible for its nonappearance.
1.2.2. Size and spread of the urban sprawl

According to Schiller and Evans (1996) “The ability to design with urban microclimates depends on architects’ and planners’ skills to identify significant variations in regional climate in urban areas, develop awareness of possible future modifications produced by changes in urban tissue and its potential during the process at different scales of applications”. City forms such as size, geometry and materials used in construction of urban spaces define UHI effects characteristics. For example two cities with ‘X’ amount of population but differing urban geometry, allocation of spaces and type of construction material used would have two entirely different UHIs.

Scherer et al. (1999) demonstrated this behavior and came up with criteria to effectively maintain natural ventilation within a city environment, reduce risks of hazards caused by wind, to help transport fresh air and reduce air pollution in sensitive areas and to reduce heat load while simultaneously reducing negative effects of frost and cold stress. These criteria were incorporated to help urban planners in addressing the issue of urban climate within their planning process.

Streutker (2003) analyzed presence of UHI in the city of Houston, Texas and quantified it in terms of spatial spread and magnitude. In this study, the author demonstrated that there is an inverse relationship in temperature profiles between urban areas and their surrounding rural areas. In a UHI study conducted by Mohan, Kandya and Bottripolu (2011) in NCR region of India, it was observed that urbanization of the NCR region make a difference in minimum night time temperature of areas over the years. In a comparative study between Safdargunj and Palam area of Delhi, it was found that prior to 1985, Safdargunj had a higher night time temperature but after 1986, Palam experienced a higher nighttime temperature with respect to Safdargunj as most of the area urbanization in Palam area took place only after 1986 with Asia’s largest residential colony Dwarka and major new international terminal at IGI airport. The causes for the increase of nighttime temperature and urban heat Island effects can be attributed to the less green area due to more build up area, higher density, less evapotranspiration and increased anthropogenic heat due to the number of vehicles on the road.

Fig 4 Causes of Urban Heat Island (Courtesy of J. Forkes, 2009)
1.2.3. Geometry

The geometry of a building or any built form is also an important constituent of the much larger UHI effect. Orientation and spacing of buildings also plays a crucial role in formation of urban heat islands. Dense high rise buildings and narrow streets can restrict air movement and trap heat thus building up hot spots. According to the study performed by Hoyano et al. (1999) on sensible heat flux from exterior surfaces of buildings it was demonstrated that difference between surface temperature and air temperature vary between 20-30 C during day and 5-10 C at night in summer and winter respectively. The study also showed that difference between roof and air temperature was around 14 - 25 C depending upon the time of the day. In yet another study by Lagouarde et al. (2004) using an airborne TIR camera, influence of time on UHI effect on a large scale was analyzed. In this study, first four plots were obtained over the city center at different dates and times and subsequent data from these plots were used to illustrate a dependence on sun illumination. From the results, all plots showed thermal 'hot spot' effect with maximum temperature observed when aiming at a surface opposite to the sun (with the sun behind). Also, the direction of the hot spot moved during the day and was consistent with the sun displacement.

1.2.4. Function of the city

Quality of life aspects such as energy use, water use and pollution have a bilateral relationship with the UHI effect. In their study, they demonstrated the effect of air circulation on air pollutants (especially oxidants) at various levels, thereby, establishing an indirect relationship between temperature and air pollution levels within the city. A study by Sarrat et al. (2006) also demonstrated similar results, establishing an indirect relationship between surface temperature and air pollution within an urban environment.

In spite of several studies related to quality of life it is very important for us to understand the effect of these variables with respect to UHI effect. The main reason is that even though some aspects of a particular variable may contribute to a decrease in UHI effect but they may still contribute to an increase in hazardous phenomena. A study by Taha (1997) demonstrated that the use of high albedo materials would lead to a significant reduction in ozone (decrease of 12%) and a decrease in population- weighted exposure to this pollutant. A similar study by Bretz et al. (1998) demonstrated that the use of high albedo materials would favor in the mitigation of the UHI, leading to a substantial decrease in energy demands. But in order to achieve high albedo within the urban settings, some form of synthetic material may have to be used as a coating to existing surfaces which might lead to other forms of health hazards. In some cases, the presence of vegetation, especially trees in the suburban neighborhood, may reduce the summer air conditioning demand. On the other hand, this dense vegetation canopy structure might intercept the incoming solar energy during winter months, thereby increasing the winter heating load (Simpson and McPherson, 1998).

1.2.5. Geography

The physical, human and environmental geography of a city including topography, rural surroundings and climate are some of the criteria that have been long studied in relation to UHI effect. These studies were carried out mainly because of two main reasons. First, these parameters could be effectively quantified using statistics and second, the collection and documentation of primary data was relatively straightforward. The primary parameter that defines much of urban space is its climate. The UHI phenomenon may vary with respect to the local climate, which is generally controlled by the geographic location of the city on
Earth. For example, the UHI phenomenon in a tropical climate may behave differently during different times than the UHI phenomenon in a non-tropical setting.

A detailed study of the climatic variation, using a city’s available climatic data and physical simulations of the thermal field in urban areas is presented in a study by de Assis and Frota (1999). In their study, they demonstrated that the design requirements for varying climatic regions during different seasons vary strongly and have to be taken into account before arriving at any mitigation strategies. Local topography and location of the main commercial and industrial sectors are also an important variable while analyzing the UHI effect. In the analysis executed by Kim and Baik (2005) near the borderline of Seoul, it was found that temperatures were relatively low in the city, except near the southwestern and southeastern borderlines where several warm cores were observed. These are the regions where urbanization is in progress and are pronounced by industrial complexes, highly commercialized complexes with high-story buildings and heavy traffic.

**Effects of UHI**

It is imperative to understand the UHI effect is evident in urbanized and urbanizing regions. This presence of UHI within such environment poses several threats to human life, plants, animals, regional climate and global climate patterns. These impacts can be broadly classified into two classes i.e. effect on climate and effect on living environment.

### 1.3.1. Impact on climate

The UHI phenomenon affects both the regional and the global climatic patterns (Golden, 2004). In a research conducted by Chin et al. (2005) using a three dimensional mesoscale model inferred that the urban canopy produces a nocturnal warming along the urban zone with a maximum value of 1.8 C and a corresponding hydrostatically induced negative pressure anomaly zone at a level of 10 m above the ground. On further analysis Chin et al. (2005) were able to identify that this warming is a result of weaker nighttime cooling within the urban canopy due to urban heat release at night. Furthermore, research by Ghiaus et al. (2006) arrived at a similar conclusion, stating that the UHI effect has a strong negative influence on natural ventilation potential.

Anthropogenic heat is one of the significant parameters that affects energy balance within urban surroundings ((Cenedese and Monti, 2003; Offerle et al., 2006). A drastic change in this parameter during both summer and winter has considerable impact on both local air circulation and latent heat flux which mainly contributes in evaporation and therefore rainfall. There have been several studies that have demonstrated the impact of UHI on weather leading researchers to speculate that UHI influences anomalies in rainfall patterns and lightning (Childs and Raman, 2005; Gedzelman et al., 2003; Rozoff et al., 2003). In a study by Lensky and Drori (2007) on cloud formation, they demonstrated that the temperature difference is greater for clouds that develop over more polluted and/or warmer surfaces than those resulting from smoke and urban pollution and/or urban heat island,. Furthermore, through a case study over Southeast Asia, Lensky and Drori (2007) were able to demonstrate that the difference in temperatures is around 1 - 6 C for tropical maritime clouds, 8 - 15 C for tropical clouds over land, 16 - 26 C for urban air pollution, and 18 - 39 C for clouds ingesting smoke from forest fires. Furthermore, from an experiment conducted by Mihalakakou et al. (2004) it was concluded that the daytime air temperature was a single input parameter that contributed between 24 and 31% of regional climate model's accuracy.
Therefore, based on the above results one can conclude that nighttime and daytime estimations of urban air temperature is one of the predominant input parameters on urban climatic conditions, thus emphasizing the importance of the heat island phenomenon.

1.3.2. Impact on Livable environment

According to the world health organization (WHO) anthropogenic warming claims more than 150,000 lives on an annual basis (refer Figure 4). According to Patz et al. (2005) these heat related mortalities can be classified into two broad divisions. First, direct heat related mortality and morbidity, and second a climate-mediated change on the incidence of infectious diseases. The primary is mortality caused due to considerable difference between temperature extremes especially between the mean and the maximum during a particular period. This has more effect during early summer months when people are in the process of getting familiar to higher temperatures. A sudden change in the temperature during these days instead of gradual increase might affect many who are less prepared for that change, especially old people. Such sudden increases in temperatures are termed as heat waves (Souch and Grimmond, 2004). These effects arise because of one or more meteorology-related factors such as an increase in the number of consecutive hot days, higher effective temperatures, increased humidity, stagnation, accelerated photochemical smog, pollutant emissions, and particulate formation (Taha et al., 2004). Such heat waves can cause severe thermal environmental stress leading to health impediment and increased mortality. The worst such effect was experienced by the people of Europe in the year 2003 which caused heat related mortality in tens of thousands and property damages in billions due to the subsequent forest fires (UNEP, 2004).

According to an Environmental protection Agency (EPA) study in 2003 and Samenow (2007), heat waves were much more severe in Western Europe than in countries to the east. The studies found that temperature deviations were generally higher for maximum, rather than minimum, temperatures. Of major European cities, Paris exhibited the greatest deviations where the temperature increased to more than 17 C. Even though the occurrence was a once in a lifetime event, according to the UN, projections indicate that such extreme changes may be quite common in future climate scenarios. As urban populations grow in the future, their vulnerability towards such heat-related mortality would also be likely to grow.

Apart from heat waves, another effect which is evident in our everyday life is the increase in pollution within urban centers. Even though the UHI phenomenon does not contribute to an increase in the air pollution, it does substantially contribute to its dispersion. The Department of Environment of Australia commissioned a study to analyze wind patterns and their effect on air pollutants in the Southeast Queensland air shed to analyze the significance of anthropogenic heat. From the results of their experiments by Khan and Simpson (2001) inferred that anthropogenic heat in urban areas can substantially affect the wind and temperature regime. Through their experiments they were able to demonstrate that the meteorological conditions have strong correlation with the extent and intensity of pollution. Furthermore, their model simulations identified clear patterns of pollutant movement within a strong sea breeze during the summer months. Some of their simulation results demonstrated that in scenarios where the onshore sea breeze is strong, then it would be capable of carrying pollutants as far as 100 km inland. If analyzed with relevance to the experiment carried out by Childs and Raman (2005) to realize the potential of bio-terrorism hazards, this projects a catastrophic scenario. The authors further state that if any biological attacks do coincide with such environmental conditions then the hazardous elements would travel to the entire city of Queensland and in some cases extend to neighboring cities. This scenario was validated after the September 11th attack, by Gedzelman et al. (2003) where they analyzed the dispersion of
debris (pollutants) after the attack within the city at various times of the day and night for four months.

In a research Taha (1997) demonstrated that mitigating UHI has a positive effect on mitigation of air pollution within that environment. In this study, the author analyzed the effects within Salt Lake City, Baton Rouge, and Sacramento using both mesoscale meteorological data and air quality modeling. The results of these simulations indicated that for these three cities a decrease of 1 - 2 C in the UHI effect would lead to a drastic decrease in air-pollution concentration.

Apart from heat related mortality, many prevalent human diseases are also linked to climatic fluctuations. This includes, cardiovascular mortality and respiratory illnesses due to heat waves, to alter the transmission of infectious diseases and malnutrition from crop failures. According to Patz et al. (2005), El Nino/Southern Oscillation (ENSO) has been found to be related to incidences of malaria in South America, rift valley fever in east Africa, dengue fever in Thailand, hantavirus pulmonary syndrome in the southwestern USA, childhood diarrheal disease in Peru and cholera in Bangladesh. The authors further state that “it is unclear at this stage whether global warming will significantly increase the amplitude of ENSO variability, but if so, the regions surrounding Pacific ocean and Indian ocean are expected to be most vulnerable to associated changes in health risks”.

There have also been instances of such heat fluctuations leading to an increase in tornadoes and wind storms. On one hand, in the USA, air mass temperature contrast leads to creation of a powerful jet stream in the upper atmosphere and this jet stream in turn provides wind shear.
which serves as a source of rotation for tornadoes (Halverson, 2006). On the other hand, in Europe, wind speeds have significantly increased over the second half of the twentieth century (Pryor et al., 2005). Even though the increase in wind speeds has lead to an increase in wind energy generation in certain regions, this effect has led to an overall increase in both the frequency and the amount of wind storms across Europe.

Another dimension of the effect of UHI can be felt in terms of the economy and the increase in consumption of both renewable and non-renewable energies. Guhathakurta and Gober (2007), found that during the summer months, especially during days when the UHI effect is at its relative maximum water consumption within Phoenix, Arizona increased by 60%. The authors demonstrated that for every 0.55 C increase in a census tract’s low temperature, average water use in single-family unit increased by 1.7% or 290 gallons per month. Furthermore, a similar increase in warmer temperature during the night would increase water use by 681 gallons. A similar study conducted by Rosenzweig et al. (2006) towards electricity consumption and the results demonstrated a strong association between higher temperatures and an increase in electricity demand.

1.3.3. Impact on Energy Consumption:

Urban heat island has made a direct impact on the amount of cooling energy consumption worldwide. Air conditioners are used very often in residential buildings, public places, industrial buildings and even cars to provide the thermal comfort during peak summers. In addition to the increased high energy demand, growing use of air conditioner has worsened the impacts of urban heat islands. Exhausting hot air from air-conditioners degrade the air quality in the surrounding atmosphere that affects the human health. Because of the growing urban population and increasing minimum temperature of the cities in summer, most of the energy consumed in India goes into air-conditioning and air cooling only (Fig. 6). A World Bank study (2008) estimated that demand of air-conditioners in India will rise from 4.7 million in 2011 to 48 million by 2031. Air coolers and fans will see an increase of 130 million and 735 million respectively between 2011 and 2031.

![Household Electricity consumption in India](Source: World Bank,2008)

According to World Bank energy report (2008) on India, an air-conditioner uses 1.88KW/hr energy per unit and every unit has 575 hrs operating time in a year. Air conditioners alone
will give an additional burden of 49928 GW/yr to power plants in 2031 which is equivalent to power generating capacity of 500MW power plants in a year. Increasing the temperature set point of the air-conditioner by 1oC will reduce the power consumption by up to 10 per cent and save 200 kg of carbon pollution.

**Summary**

Urban heat island (UHI) phenomenon has been observed all around the world in those cities which have seen rapid growth and urbanization. As more people move to cities “the economic engines of a country”, the land cover and land use will be subjected to change and due to which UHI phenomenon may increase and impact over society and environment. Various factors such as changing climate, urban sprawling, lifestyle of people, geometry and geography of the cities play a vital role in increasing the urban heat island intensity. UHI has an adverse impact over climate and livable environment both. UHI results in thermal discomfort, heat related health issues like asthma, heat stroke, lung disease and deterioration of air quality. Thermal discomfort can be counterbalanced by using more HVAC equipment which means more energy consumption in peak summers. Further chapters will investigate the numerous environmental friendly mitigation strategies to reduce the urban heat island effects.
Introduction

Urban heat Island mitigation strategies vary from providing natural vegetation to cool roofs and cool pavements. Different mitigation strategies are suggested by different experts in the field of urban planning, architecture, natural resource management and transportation. These mitigation strategies have an impact on both local and global climates. In addition to environmental benefits, these mitigation strategies also help in reducing the energy consumption for cooling and increase the thermal comfort of the poor people who suffer most in the heating summers.

This chapter talks about different mitigation strategies both for indoor environment of a building and outside environment. Trees and vegetation and green roofs will not only cool down the buildings itself but also provide a healthier atmosphere in the city. Other approaches like cool roof and cool pavements, passive ventilation and reduction of anthropogenic heat due to building appliances will provide more thermal comfort of building occupants. Local climate of the particular city should be taken into consideration before deciding the suitable mitigation strategy for urban heat island. Combination of complementary measures can prove to be more efficient techniques in reducing the urban temperature.

![10 Most Deadly Heat Events](Source: EM-DAT 2007)
Fig. 7: Schematic diagram of Urban Heat Island Mitigation Strategies Involving buildings (Melissa Giguere, 2012)
**Trees and Vegetation**

Trees and vegetation are simplest way to reduce urban heat island effects. Urban temperatures can be reduced up to a substantial amount by planting the trees which help in increasing the albedo of the surfaces. Planting of trees and vegetation has both direct and indirect contribution in reducing CO2 from the atmosphere (Giguere 2012). Trees directly reduce CO2 from the atmosphere as they use the carbon from the atmosphere in photosynthesis. Planting trees also reduces CO2 indirectly from the atmosphere as they help in reducing the demand for cooling, thus minimizing the burden of power plant in electricity production.

Akbari et al. (1991) showed that the amount of CO2 reduced due to indirect effect is considerably greater than the amount consumed directly in the photosynthesis of plants. Similarly, trees directly trap ozone precursors (by dry-deposition, a process in which ozone is directly absorbed by tree leaves), and indirectly reduce the emission of these precursors from power plants (by reducing combustion of fossil fuels and hence reducing NOx emissions from power plants) (Taha 1996).

Trees and vegetation improve the air quality through oxygen production, carbon capture and reducing the smog which builds up more in the rising temperature. Air quality also improves with the deposition and less production of air pollutants through power plants. Proper selection of trees around the buildings provides benefits in both summer and winter season. Deciduous trees obstruct the sunlight in the scorching summer and provide passage to enter sunlight into buildings in winter because they start losing leaves from autumn.

Trees and vegetation lower surface and air temperatures by providing shade and through evapotranspiration. Evapotranspiration word is made of two words evaporation and transpiration. Evaporation is the process in which water changes into the water vapor in an open atmosphere. Transpiration is the process by which water in plants is transferred as water vapor in the atmosphere. Shaded surfaces, for example, may be 11–25°C cooler than the peak temperatures of unshaded materials. Evapotranspiration, alone or in combination with shading, can help reduce peak summer temperatures by 1–5°C.

Trees and vegetation are most useful as a mitigation strategy when planted in strategic locations around buildings or to shade pavement in parking lots and on the streets. Researchers have found that planting deciduous trees or vines to the west is typically most effective for cooling a building, especially if they shade windows and part of the building’s roof.

**Green Roofs**

A green roof, or rooftop garden, is a vegetative layer grown on a rooftop. Green roof reduces the surface temperature by providing the shading like trees and vegetation and reducing the air temperature by evapo-transpiration mechanism. Green roofs can be cooler than air temperature while the conventional rooftops can be warmer up to 50°C. Green roof temperatures depend on the roof’s composition, moisture content of the growing medium, geographic location, solar exposure, and other site-specific factors\(^1\).

Green roofs can be installed on a wide range of buildings including industrial, public and private buildings but the high cost of construction and maintenance limits it to use. There are two kinds of green roof i.e. extensive and intensive. These are defined on basis of plant density and vegetation on the rooftop. Extensive green roofs are roofs having low vegetated

\(^1\) www.epa.gov
and uniformly distributed plants. These are designed to get maximum thermal and hydrological benefits with low dead weight. Plants used in extensive green roofing should be able to withstand in dry, hot and windy conditions without much maintenance. Extensive green roofing is less expensive in comparison to intensive green roofing and often inaccessible to the public.

Intensive green roof is like a conventional garden with all kinds of plants including trees and shrubs. They are designed to offer the energy saving with reduced rooftop temperature and provide a green environment to the building occupants. Load carrying capacity of the building should be properly assessed before applying this kind of roofing. Being heavy, these roofs require an additional structural support system to sustain the additional dead load and live load. These roofs require more landscape maintenance over the long term, infrastructure such as water collection system, irrigation and fertilization. Green roofs provide similar benefits as those by trees and vegetation including storm water management.

In Germany, Green space is used as a premium in urban growth to limit the urban sprawl and developers are often required to provide green roofs as a compensation of lost open space. (DDA Manual, 2007). Green roofs filter particulate matter from the air, retain and cleanse storm water and provide new opportunities for biodiversity preservation and habitat creation (Peck & Kuhn, 2003). In a study carried out by Peck and Kuhn (2003), it is estimated that 1,000-square foot (93 m2) green roof can remove about 40 pounds of PM (particular matter) from the air in a year, while also producing oxygen and removing carbon dioxide (CO2) from the atmosphere.

**Cool Roofs and Cool Pavements**

In most of the urban areas, roofs and pavements constitute almost 60% of the land surface area (Akbari et al. 2008). Most of the solar energy gets absorbed by these paved surfaces and roofs and then it is transmitted inside the buildings. Absorption of solar energy increases the roof temperature up to 70-80°C and thus increases the ambient air temperature of the surroundings. A dark colored roof absorbs more solar energy in comparison to the light color roof and thus remains at a relatively higher temperature. The higher the reflectivity and
emissivity of the roof material, the less likely it is to store the heat and radiate it back to the atmosphere or into the building through the walls and roof (Paroli and Gallagher, 2008; Synnefa, 2007).

The albedo of the roof plays an important role to keep the roof surface at low temperature. Different cooling materials are available in the market in the form of cool roof coatings, clay and concrete tiles, metal roofing, single ply membranes etc. But the selection of the material has to be done on the basis of the existing roof and microclimatic condition of the area. Berdahl and Bertz (1997) observed maximum 50K temperature difference between surface and ambient air for low albedo surfaces while for high albedo surfaces (such as roofs with white coating), this temperature difference was found to be only 10K. Most high albedo roofing materials are light colored, although surfaces which reflect a large portion of the infrared solar radiation but absorb some visible light can be dark colored and still having high albedos (Levinson et al 2005 a, b, Berdahl and Bertz 1997). Following table provides the albedo and emissivity of the different roofing materials.

Emissivity is property of the material to release or emit the solar energy. It is a function of surface condition and in case of a metal, degree of oxidation (Giguere, 2012). A material with a low emissivity is a better thermal insulator (Leibard and Deherde, 2005).

<table>
<thead>
<tr>
<th>Material</th>
<th>Emissivity Factor</th>
<th>Albedo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polished Aluminum</td>
<td>0.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Dirty Concrete</td>
<td>0.9</td>
<td>0.2</td>
</tr>
<tr>
<td>Dark Wood</td>
<td>0.95</td>
<td>0.15</td>
</tr>
<tr>
<td>Red Brick</td>
<td>0.9</td>
<td>0.3</td>
</tr>
<tr>
<td>Tarnished Copper</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>White Marble</td>
<td>0.9</td>
<td>0.6</td>
</tr>
<tr>
<td>White Paint</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>Plaster</td>
<td>0.9</td>
<td>0.9</td>
</tr>
</tbody>
</table>

(Source: Liebard and Deherde, 2005)

Highly absorptive and less emissive surfaces contribute to a greater extent in keeping the ambient air and the buildings on a higher temperature and thus indirectly increasing the cooling demands of the buildings. Increased load on the power plant in the summer period contributes into more CO2 emission and more polluted environment due to more smog formation in a warm environment. Akbari et al. (2008) estimate that retrofitting 100 m² (1000 ft²) of roof offsets 10 tons of CO2 emission.

Major problem with cool roof is reduction in reflectance with aging. Dirt and other pollutant will adhere to the roof surface and they will start losing their reflective property and hence they are less effective over time. Cool roofs should be recoated or washed on a regular basis to keep them dirt free. Another problem occurs with high albedo roofs when glazing of roofs creates the visual discomfort. So problem of glazing should be studied first especially for sloped roofs before applying these cool roofing techniques (Akbari, 2003).
Pavements cover almost 45% of the city’s surface area (USEPA, 2008b). Most of the paved street and parking lots are paved using dark asphalt which absorbs a lot of solar energy and hence contribute in increasing the urban heat island effects. Albedo of the pavement should be increased in order to minimize the buildup of heat in the pavement. Figure 7 summarizes the benefits obtained from four different kinds of roof cooling or energy efficiency techniques.

<table>
<thead>
<tr>
<th>Health Benefits</th>
<th>Cool Roofs</th>
<th>Green Roofs</th>
<th>Passive ventilation</th>
<th>Insulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Savings</td>
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<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td>Building Cooling</td>
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<td>City Cooling</td>
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<tr>
<td>Global Cooling</td>
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<tr>
<td>Low Maintenance</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Compatible with other environmental roofing strategies</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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Fig.9 Comparison of different UHI mitigation strategies

Akbari et al. (2008) estimate that permanently retrofitting urban roofs and pavements in the tropical and temperate regions of the world with solar-reflective materials would offset 44 billion tonnes of emitted CO2, worth $1.1 trillion at $25/tonne.

**Passive Ventilation**

Passive ventilation is the most cost effective technology to keep the buildings cool in summer heat. Before airtight houses and mechanical ventilation systems, people used to keep their houses cool using natural methods like windows for getting cool air, walls with air-vents and large solid masses absorbing the heat. These ideas were in use for thousands of years and became the integral part of the building design. Now these methods are called as passive ventilation techniques and we considered them alternative technology to “normal” mechanical cooling systems.

Passive cooling systems should be designed in such a way that they use the minimum or no mechanical energy to keep the buildings cool. Passive ventilation can be defined in two ways i.e. pressure system and buoyancy system. Pressure systems rely on positive pressure on the windward side of the building causing a lower pressure on the leeward side, in turn creating air movement through the building from the windward to the leeward side. There are design implications in that vents, windows and room layouts have to be positioned appropriately to ensure air movement is possible and in the right direction.
Wind tower, solar chimney or passive stack ventilation work on the buoyancy principle. Natural airflow, wind and the temperature differences in the indoor and outdoor air help to draw in fresh air and circulate it through the home. Hot air being lighter than cool air tends to rise and it helps in drawing cooler air into the buildings. A passive house is an extremely energy-efficient home in which a comfortable interior climate can be maintained without active heating and cooling systems.

**Reducing Anthropogenic Heat**

In a study conducted by Taha (1997), it was estimated that anthropogenic heat can contribute 20 to 30°C temperature increase in urban centers. Heat production by the building appliances and vehicles contribute in developing the urban heat island. Artificial lighting inside the building should be avoided as much as possible because halogen and incandescent bulb produce significant heat which is absorbed by the walls and materials present in the building. According to Solomon and Aubert (2004), 500W halogen bulb uses only 6% electric energy for lighting; the rest is converted into heat. Energy efficient fluorescent bulbs dissipate less quantity of heat. Photoelectric sensors can also be used to measure the natural lighting and to adjust the artificial light inside the rooms.

More use of public transportation system and less use of individual cars help in reducing the urban temperatures. Giguere (2012) found that a car consumes twice as much energy per passenger per kilometer as a train and four times more than a bus. Vehicle emissions also contribute to urban smog and global warming. (Watkins et al. 2007). Instead of petrol and diesel, use of CNG as a car fuel will also reduce the ambient air temperature and will also help in pollution control. Providing natural ventilation will reduce the use of air conditioners.

**Summary**

This chapter describes four mitigation strategies to reduce the urban heat island effects, but there are several other methods or combination of different technologies which can help in reducing the impact of extreme heat within an urban environment. Implementing these measures will not only help to reduce the energy demand during peak summer but will also
provide health and environmental benefits such as reduced mortality due to heat stroke, less CO2 emission, increased thermal comfort, reduced air pollution and hence less lung diseases.

In the next chapters, we will be focusing more on cool roofs and passive cooling techniques as roofs make a huge contribution in solar energy absorption and passive cooling techniques are the most economical solution to increase thermal comfort for the poor people in a developing country like India where most of the buildings are not thermally insulated.
References


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