HANDBOOK ON ACHIEVING THERMAL COMFORT WITHIN BUILT ENVIRONMENT

VOLUME I

TARU

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Executive Summary

Rapid urbanization and aspirational change is causing unplanned land use and land cover changes. Unplanned and unforeseen development are resulting in micro-climate changes which are evident in urban areas. The relative change (mostly increase) in urban temperature profile compared to its rural counterpart is termed as urban heat island effect (UHI). Such changes give rise to challenges associated with service deficiency, un-engineered built environment, public health, etc.

In India, according to the Indian Meteorological Department nine out of the last twelve years were amongst the twelve hottest years since 1901. Such temperature rise has led to an increase in need for space cooling. Further, increase in affordability and aspirations among urban residents has led to increased usage of air-conditioners especially among middle and high income households. This trend has led to increase in energy load during summers leading to power surge. On the other hand, urban poor live in congested areas and unenginneered buildings. The building elements of these houses comprise of tin sheets or asbestos cement sheets for roofs with limited ventilation or cooling facility. Such roofs increases the ambient room temperatures to uninhabitable conditions resulting in health impacts amongst its residents. This trend is likely to worsen over the coming years due to climate variability and climate change.

The use of inefficient technologies by urban poor and middle class is currently contributing to consumption/wastage of large amounts of water and energy. In India, one of the common coping mechanisms widely noticed among urban middle and lower class households (living in one or two storied buildings) is their preference to sleep on flat concrete roofs during summers in order to overcome the indoor heat build-up during evenings. Also, traditional and cost effective methods of roof cooling and passive ventilation include using white floor tiles on roof and painting roof with lime wash every year thereby increasing the solar reflectance and decrease the heat gain. Another common option is using desert coolers during low humidity periods. But with widespread use of electricity for cooling, these traditional methods have been neglected.

Surat and Indore lie in the transitional zone between humid south and arid north, and face extremely high temperatures during summers. Surat being a coastal city is also subjected to periods of high humidity. Increase in temperature combined with humidity has an impact on work productivity during day and decreased comfort level during evenings. This report aims to highlight urban heat islands, their impacts and possible mitigation strategies by considering case of Surat and Indore.

This report aims to aid urban managers, engineers, architects and designers who may consider using cool roofing and passive ventilation options within urban built environment. This report provides information on traditional methods, new technology, native practices and cost effective solutions for increasing the thermal comfort of high, middle and low income settlements.

List of Abbreviations

ACCCRN - Asian Cities Climate Change Resilience Network

Avg. Temp. - Average Temperature

CO_2 - Carbon dioxide

CRPV - Cool Roof & Passive Ventilation

IEC - Information, Education & Communication

IMC - Indore Municipal Corporation

NO_x - Nitrogen oxides

NOAA - National Oceanic and Atmospheric Administration

SMC - Surat Municipal Corporation

UHI - Urban Heat Island

ULBs - Urban Local Bodies

WHO - World Health Organisation

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CHAPTER 1: URBAN HEAT ISLAND

URBAN AND RURAL POPULATION IN INDIA

1.1 Introduction

Cities are growth centres, attracting people in the hope of a better life for themselves and their children. Today, almost 50% of the world's population resides in these urban centres demonstrating an unprecedented growth in number and size of cities. This trend of world urbanisation has deteriorated the urban environment and quality of life in cites.

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) effect. UHI can be demarcated as an area of the surface that is relatively warm compared to it's surrounding; most commonly associated with areas of dense human activity, such as towns and cities [1]. The temperature differences strongly vary at a micro level, both in rural and urban areas because of varying surface temperatures. For example, a concrete surface may radiate greater amount of heat 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.

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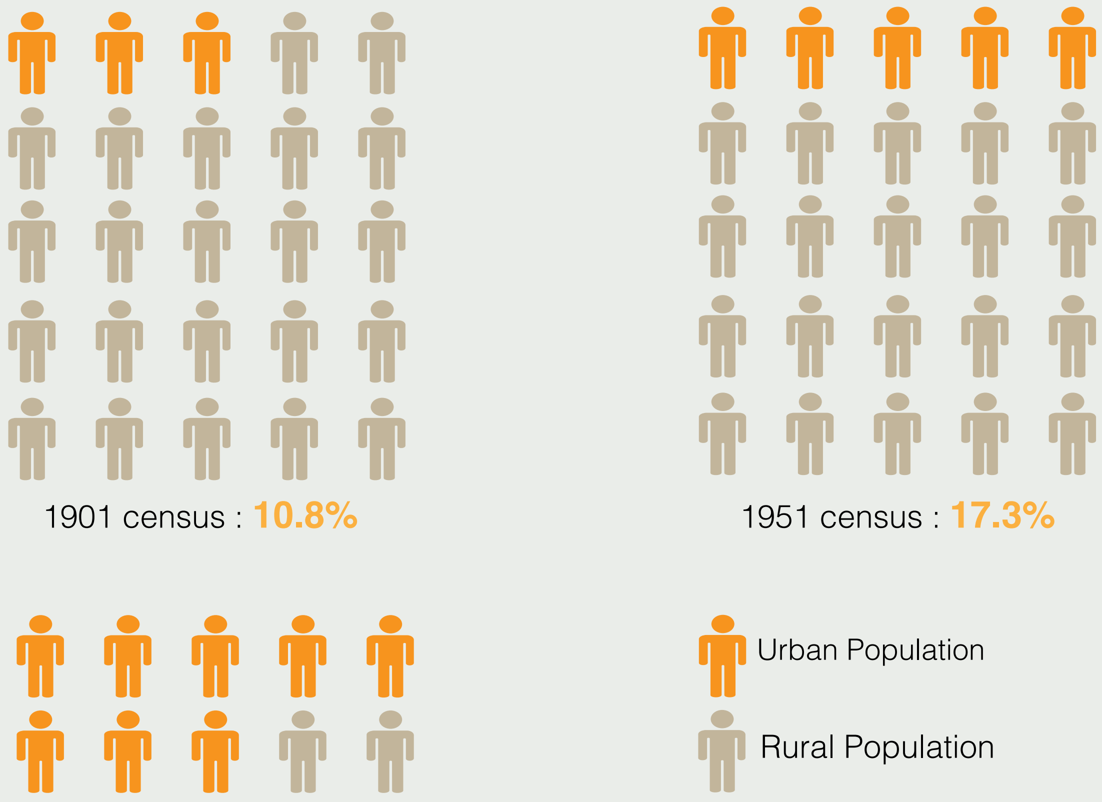
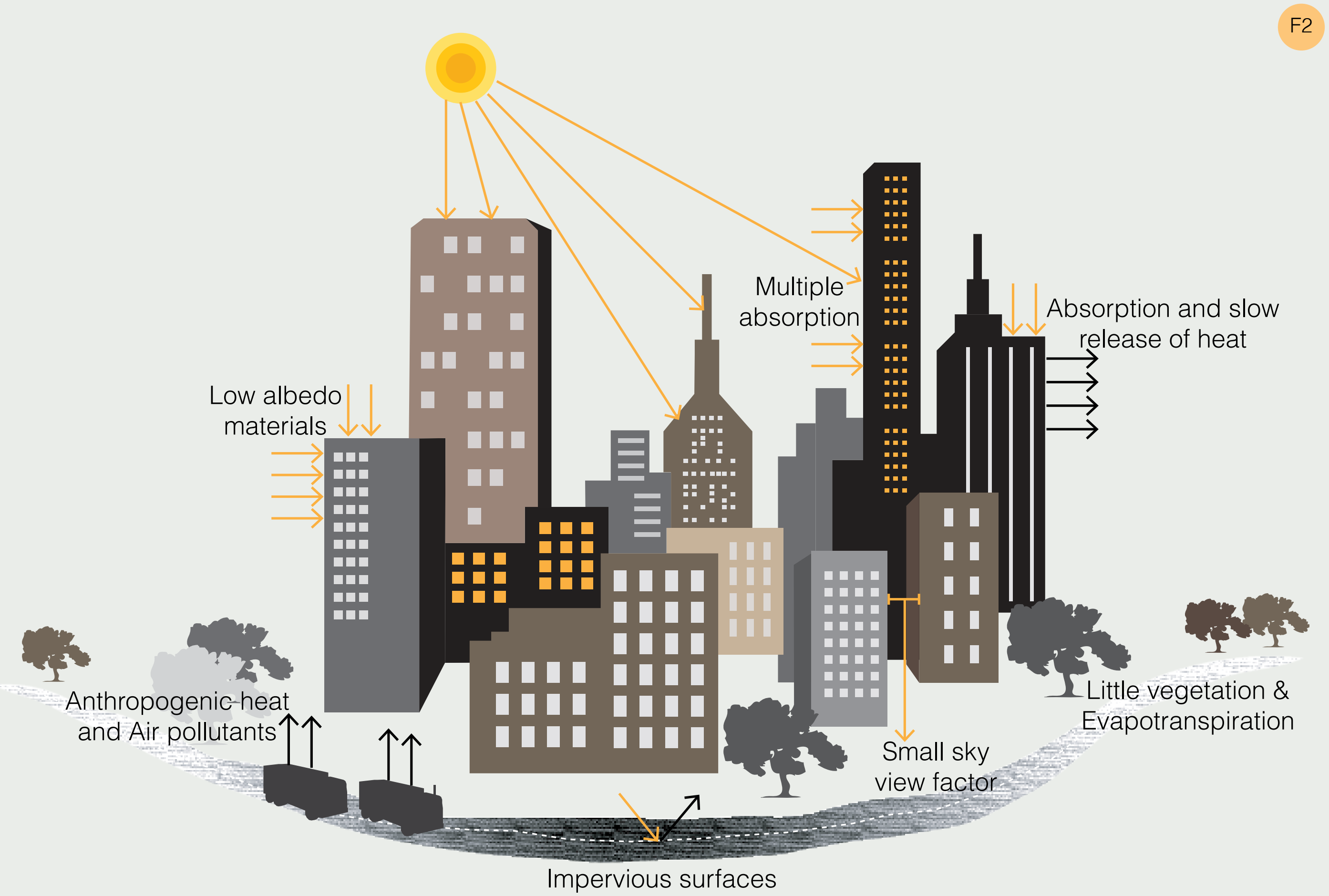


In India the phenomenon of migration and urbanization in last decade has lead to growth rate of urban population by 31%, while rural growth stands at 12%, a decline of 6% in a decade.

CAUSES OF URBAN HEAT ISLAND



*Air temperatures in densely built urban environment are higher than the temperatures of the surrounding rural areas. This increase in temperatures within urban areas is know as **"Urban Heat Island"** (UHI) phenomenon. The higher temperature is due to retention of heat by buildings, concrete surfaces and asphalt. Also air pollution and lesser vegetation contribute to UHI effect.*

1.2 Causes of UHI

In the recent past, UHI effect has been studied and documented in several cities around the world. Growing aspirations are bringing together financial institutions, researchers, entrepreneurs and services industry to the cities. Easy access to resources and innovative technology are leading to expansion of cities.

The heat gets trapped in impervious surfaces like concrete and asphalt, while disturbing the atmosphere above the city. While cities mostly have the highest concentration of pollution arising due to human activity, augmentation of heat and pollutants intensifies the urban heat island effect [2]

Several environmental factors like wind condition, humidity, precipitation, etc. play a crucial role in defining the UHI effect. Such factors are affected by increased population density and size of the city. While population density influences the land-use pattern within an urban area, there is a growing need to re-look at the traditional practices of planning. It is also predicted that in future climate change may increase the potential hazard of UHI effect [3].

1.2.1 Weather

UHI effects have a strong relationship with weather parameters such as wind and cloud. Research on thermal comfort in building demonstrates that building aspect ratio, wind velocity and direction, wall thickness of buildings, presence of openings and surface clutter have significant effect on heating and cooling of the surfaces, often altering them by orders of magnitude [4]. A similar study in Athens demonstrated that a high pressure ridge mostly favours heat island effect, whereas intense northerly winds are responsible for its nonappearance [5].

1.2.2 Spread of Urban Sprawl

“The ability to plan a development, while incorporating urban micro climatic conditions depends on an 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 design and ascertain its potential during the process at different scales of applications” [6]. City forms such as size, geometry and materials used in construction of urban spaces characterise UHI effects. For example two cities with similar population and area but differing urban geometry, allocation of spaces and type of construction material used would have two entirely different UHI effects.

Such behaviour has been demonstrated to come 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 [7]. These criteria were incorporated to help urban planners in addressing the issue of urban climate within their planning process.

In a UHI study conducted in NCR region of India, it was observed that urbanization of the NCR region makes a difference in minimum night time temperature of areas over the years. In a comparative study between Safdarjung and Palam area of Delhi, it was found that prior to 1985, Safdarjung had a higher night time temperature but after 1986, Palam experienced a higher night time temperature due to the massive residential development at Dwarka and a new international terminal of Indira Gandhi International airport. [8]. The causes for the increase of night time temperature and urban heat Island effects can be attributed to the less green area due to more built-up area, higher density, less evapotranspiration and increased anthropogenic heat due to the number of vehicles on the road.

1.2.3 Geometry

The geometry of a building is an important constituent of larger UHI effect. Orientation and spacing of buildings play a crucial role in formation of UHI. Dense high rise buildings and narrow streets can restrict air movement and trap heat thus creating hot spots.

A study measuring the amount of heat transferred through building surfaces demonstrated that the 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 the difference between roof surface temperature and air temperature was around 14-25°C depending upon the time of the day [9]. In yet another study, airborne Thermal Infrared camera was used to study the influence of time on UHI effect. The study illustrated dependence of UHI on sun illumination - maximum temperature of hot spots was observed at surfaces 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 [10].

1.2.4 Function of the city

Factors governing ‘quality of life’ such as energy consumption, water use and pollution have a bilateral relationship with the UHI effect. Air circulation has an effect on air pollutants (especially oxidants) at various levels, thereby, establishing an indirect relationship between temperature and air pollution levels within the city. A study also demonstrated similar results, establishing an indirect relationship between surface temperature and air pollution within an urban built-environment [11].

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 demonstrated that the use of highly solar reflective (albedo) materials would lead to a significant reduction in ozone (decrease of 12%) and a decrease in population weighted exposure to this pollutant [12].

A similar study also demonstrated that the use of highly reflective materials would favour mitigation of the UHI effect, leading to a substantial decrease in energy demands [13]. 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 health hazards. In some cases, the presence of vegetation, especially trees in the suburban neighbourhood, 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 [14].

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 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 effect may vary with respect to the local climate, which is generally controlled by the geographical location of the city on Earth. For example, the UHI effect in a tropical climate may have different spatial and temporal characteristics in comparison to UHI 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 has 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 [15]. Local topography and location of the main commercial and industrial sectors are also an important variable while analysing the UHI effect. A study performed in Seoul revealed that temperatures were relatively low in the city, except near the south-western and south-eastern borderlines where several warm cores were observed [16]. These were the regions where urbanization was in progress and were pronounced by industrial complexes as highly commercialized areas with high rise buildings and heavy traffic.

CHAPTER 2: IMPACTS OF URBAN HEAT ISLAND

2.1 Impact on Climate

The UHI effect affects both the regional and the global climatic patterns [17]. Anthropogenic heat is one of the significant parameters that affect energy balance within urban surroundings [18]. A drastic change in this parameter during both summer and winter has considerable impact on both local air circulation and transfer of latent heat, which mainly contributes in evaporation and thus rainfall. Several studies have demonstrated the impact of UHI effect on weather, which lead researchers to speculate that UHI influences anomalies in rainfall patterns and lightning [19] [20] [21].

A study on cloud formation 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 [22]. A case study over Southeast Asia, demonstrated that the difference in temperatures is around 1-6^{O}C for tropical maritime clouds, 8-15 ^{O}C for tropical clouds over land, 16-26^{O}C for urban air pollution, and 18-39 ^{O}C for clouds ingesting smoke from forest fires [22]. Furthermore, an experiment concluded that the daytime air temperature was a single input parameter that contributed between 24-31% of regional climate model's accuracy [5].

Therefore, based on the above results one can conclude that night time and day time estimations of urban air temperature is one of the predominant input parameters on urban climatic conditions. Thus, emphasizing the importance of the UHI effect.

2.2 Impact on Livable Environment

According to the world health organization (WHO) anthropogenic warming claims more than 150,000 lives on an annual basis. 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 [23]. The primary 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. 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 [24]. 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 [25].

Apart from heat waves, another effect which is evident in our everyday life is the increase in pollution within urban centres. Even though the UHI effect does not contribute to an increase in the air pollution, it does substantially contribute to its dispersion.

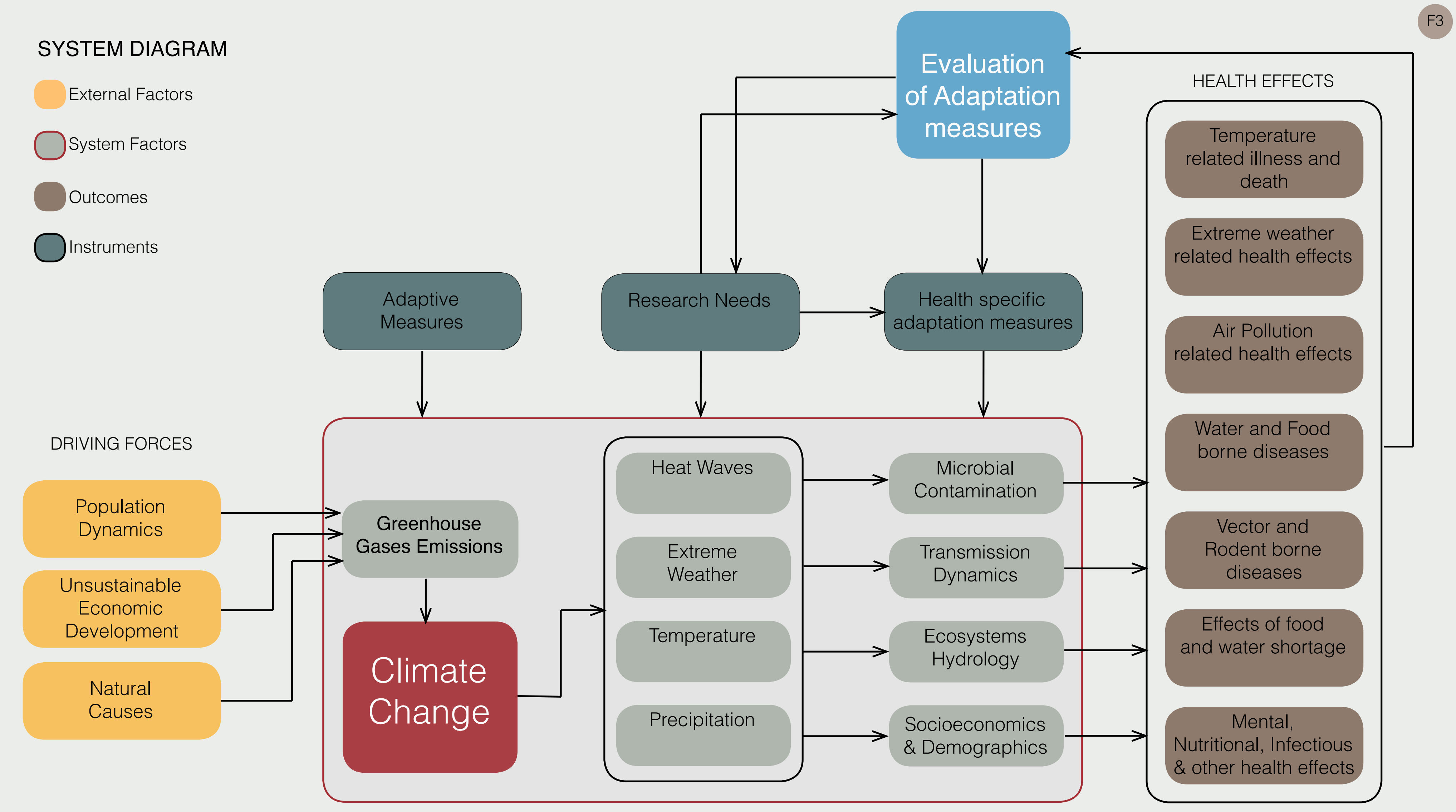
A study commissioned by the Department of Environment of Australia found that anthropogenic heat in urban areas can substantially affect the wind and temperature regime, while demonstrating that the meteorological conditions have strong correlation with the extent and intensity of pollution [26]. Furthermore, 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 kms inland. If analysed with relevance to similar experiments carried out to realize the potential of bioterrorism hazards, this projects a catastrophic scenario [19].

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 neighbouring cities. This scenario was validated after the September 11th attack, 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 [20].

A research demonstrated that mitigating UHI effect has a positive effect on mitigation of air pollution within that environment [12]. In this study, the author analysed the effects within Salt Lake City, Baton Rouge, and Sacramento using both meso scale meteorological data and air quality modelling. The results of these simulations indicated that for these three cities a decrease of 1-2^{O}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. The band of anomalously warm ocean water temperature (El Niño) and it's counterpart (La Niña) have been

CLIMATE CHANGE AND POSSIBLE HEALTH IMPACTS



Rapid urbanization and unsustainable growth are the major contributors to climate change. ***Extreme weather conditions directly impact human health and also contribute to increased mortality.***

Adopted from WHO [31]

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 south-western USA, childhood diarrheal disease in Peru and cholera in Bangladesh [23].

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 [27].

On the other hand, in Europe, wind speeds have significantly increased over the second half of the twentieth century [28]. Even though the increase in wind speeds has led 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. A study found that during the summer months, especially during days when the UHI effect is at its peak water consumption within Phoenix, Arizona increased by 60% [29]. A similar study towards electricity consumption demonstrated a strong co-relation between higher temperatures and an increase in electricity demand [30].

2.3 Impact on Energy Consumption

Urban heat island effect 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 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, change in aspiration, increased affordability and increasing minimum temperature of the cities during summer, most of the energy consumed in India goes into air-conditioning.

A World Bank study 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. The report also stated that in India an air-conditioner consumes 1.88KW/hr energy per unit and every unit has 575 hours operating time in a year. Air conditioners alone will give an additional burden of 49,928 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 1^{o}C will reduce the power consumption by up to 10 per cent and save 200 kg of carbon pollution [31].

HOUSEHOLD ELECTRICITY CONSUMPTION IN INDIA

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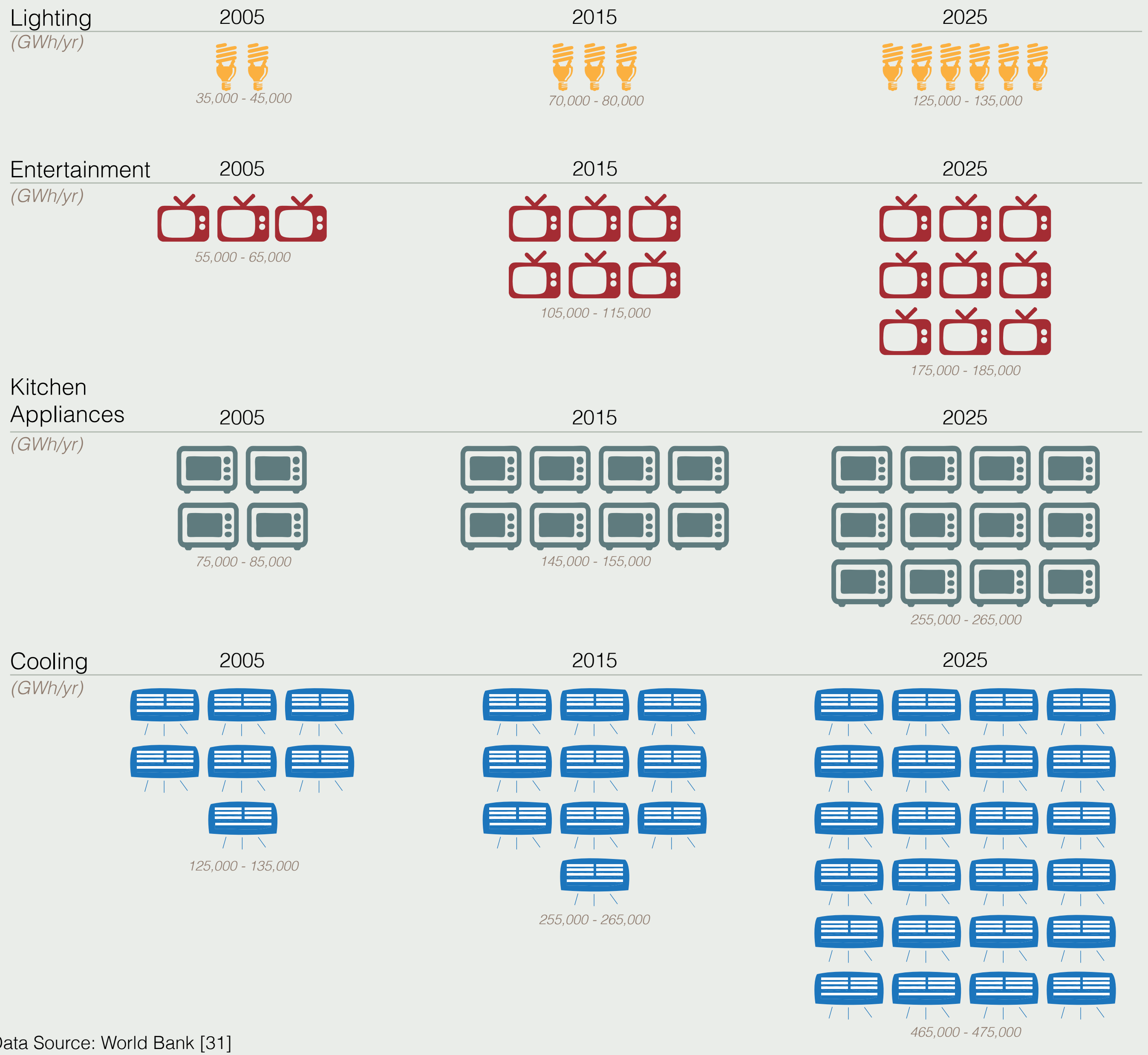

Data Source: World Bank [31]

Demand of Air conditioners i*n 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.*

CHAPTER 3: RESILIENCE STRATEGIES:
ROOF COOLING AND PASSIVE VENTILATION

3.1 Introduction

UHI mitigation strategies vary from providing natural vegetation to cool roofs and cool pavements. Different strategies are suggested by different experts in the field of urban planning, architecture, natural resource management and transportation. These strategies have an impact on both local and global climates.

In addition to environmental benefits, these strategies also help in reducing the energy consumption for cooling and increase the thermal comfort in buildings and slums during summers. This chapter discusses different such strategies both for indoor and outdoor environment of a building, like cool roof and cool pavements, passive ventilation, insulation, etc. Local climate should be considered before deciding the suitable mitigation strategy or combination of complementary strategies for dealing with UHI.

3.2 Trees and Vegetation

Trees and vegetation are simplest way to reduce UHI effects. Trees help in increasing the albedo of the surfaces. Planting of trees and vegetation has both direct (reduce CO_2 from atmosphere) and indirect (reduce energy consumption) contribution in reducing CO_2 from the atmosphere [32]. Other study revealed that amount of CO_2 reduced due to indirect effect is considerably greater than the amount consumed directly in the photosynthesis of plants [33].

Trees and vegetation improve the air quality and also lower surface and air temperatures by providing shade and through evapotranspiration. They are useful as a mitigation strategy when planted in strategic locations and use of appropriate species of plant around buildings and on the streets.

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3.3 Green Roofs

A green roof is a vegetative layer grown on a rooftop. Green roof reduces the surface temperature and provides shading, like trees and vegetation and reducing the air temperature by Evapotranspiration mechanism. Green roof temperatures depend on the roof's composition, moisture content of the growing medium, geographic location, solar exposure, and other site-specific factors [34]. Green roofs can be installed on various buildings like industrial, public and private. There are two kinds of green roof based on plant density and vegetation: 1. Extensive and 2. Intensive.

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 [35]. Green roofs filter particulate matter from the air and a study estimated that 93 m2 green roof can remove about 40 pounds (18.15 kgs.) of PM from the air in a year, while also producing oxygen and removing carbon dioxide (CO_2) from the atmosphere [36].

3.4 Cool Roofs and Cool Pavements

In most urban areas, roofs and pavements constitute almost 60% of the land surface area [37]. Most of the solar energy gets absorbed by these paved surfaces and roofs, increasing the roof and ambient air temperatures. A dark colour roof absorbs more solar energy in comparison to the light colour roof. The higher the reflectivity and emissivity of the roof material, the less likely it is to store the heat and radiate it back into the building through the walls and roof [38] [39]. The observed maximum 50^{O}K temperature difference between surface and ambient air for low albedo surfaces while for high albedo surfaces, this temperature difference was found to be only 1^{O}K [40].

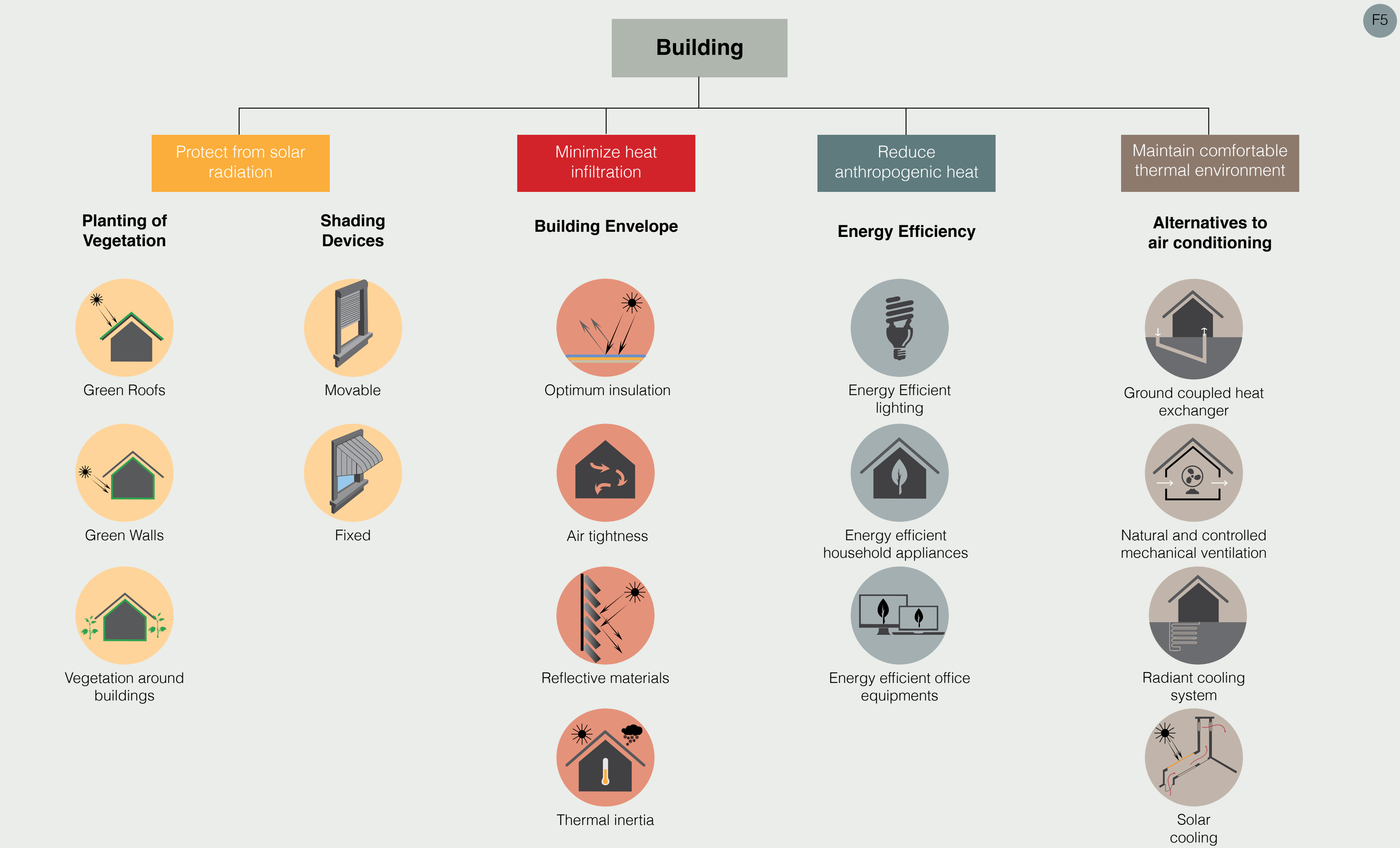
High absorptive and less emissive surfaces contribute in keeping the ambient air temperature high and thus indirectly increasing the cooling demands of the buildings. It was estimated that retrofitting with cool roof options, 100 m^2 of roof offsets 10 tons of CO_2 emission. They also estimated that permanently retrofitting urban roofs and pavements in the tropical and temperate regions of the world with solar-reflective materials would offset 44 billion tons of emitted CO_2, worth $1.1 trillion at $25/ton [37].

3.5 Passive Ventilation

Passive ventilation is the most cost effective means for achieving thermal comfort. Before airtight houses and mechanical ventilation systems, people used to keep their houses cool by regulating the air flow inside the building with the help of appropriately positioned window openings and thermal mass. These methods were traditionally part of the building design.

Passive cooling systems use the minimum or no mechanical energy to keep the buildings cool. Passive ventilation can be defined in two ways 1.Pressure system and 2.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. Hot air becomes light and rises up. The buoyancy system works on principle of removing this light hot air through ventilators in buildings.

SCHEMATIC DIAGRAM OF URBAN HEAT ISLAND MITIGATION STRATEGIES IN BUILDINGS



Adopted from Melissa Giguere [32]

T1 ROOF COOLING OPTIONS

	Solar Reflectance	Solar Emittance	Solar Reflective Index	Thermal Comfort	Life Expectancy	Types of Slope
Elastomeric Acrylic Coating (water based)	0.7 - 0.85	0.8 - 0.9	100 - 112	3 - 8 °C	6- 7 years	Low & Steep
Elastomeric Acrylic Coating (solvent based)	0.7 - 0.85	0.8 - 0.9	100 - 112	3 - 8 °C	7 - 10 years	Low & Steep
Cementitious Coating	0.7 - 0.85	0.8 - 0.9	100 - 112	3 - 6 °C	7 - 10 years	Low & Steep
Spray Polyurethane Foam	0.7 - 0.85	0.8 - 0.9	100 - 112	3 - 6 °C	5 - 7 years	Low & Steep
Heat Insulation Tiles	0.77	0.94	96	Good	50 years	Steep
Clay and Concrete Tiles	0.7	0.8 - 0.9	92 - 100	Good	50 years	Steep
Thermoset Membrane	0.7 - 0.8	0.8 - 0.9	92 - 100	Good	10 - 20 years	Low & Steep
Thermoplastic Membrane	0.7 - 0.8 (white) 0.4 - 0.6 (colour)	0.8 - 0.9	92 - 100	Good	20 - 30 years	Low
Modified Bitumen	0.6 - 0.75	0.8 - 0.9	69 - 93	Medium	10 - 30 years	Low
Metal Cool Roofing	0.5 - 0.7	0.8 - 0.9	55 - 85	Low to High	20 - 50 years	Low & Steep
Built-up Roofing	0.5 - 0.8	0.8 - 0.9	55 - 100	Medium to High	10 - 30 years	-
Extensive Green Roof	Low	Low	Low	High	5 years	Up to 40%
Intensive Green Roof	Low	Low	Low	High	10 - 15 years	Up to 4%
Roof Pond Cooling System	Low	Low	Low	2 - 4 °C	5 years	Low
Roof Mist Cooling System	High	Medium	High	2 - 5 °C	5 years	Low
Thatched Roof	Low	Low	Low	Medium to High	5 years	Steep

PASSIVE COOLING TECHNIQUES: ADVANTAGES AND LIMITATIONS

T2

	ADVANTAGES	LIMITATIONS
Earth Air Tubes	Ensures better indoor air quality and fresh air circulation for effective year round comfort	Needs access to additional land for running underground tubes
Wind Tower	Most effective in dry and hot climate	Not effective during early morning and late evening
Solar Chimney	Provide comfort by cooling the building structure at night	Not effective during summer day time
Passive Downdraft Evaporative Cooling	Beneficial in hot and dry weather	Not effective in very humid region
Orientation of the Building	Most economical solution	Site constraints in high density urban areas
Attic Ventilation: Whole House Fan	Most effective during early morning and late evening	Noisy if not properly installed
False Ceiling	Reduces the heat load on HVAC system, thereby reduces the energy costs	
Earth Berming	Very effective natural heat sink	Water seepage problems can occur
Rat Trap Bond Masonry	Cost effective alternative to conventional brickwork for better thermal and sound insulation	Building services like electrical, plumbing and drainage have to be planned in advance
Building Insulation	Also improves weather proofing and sound resistance.	Makes it difficult to fix heavy items on the insulated walls
Rammed Earth Walls	Very effective thermal mass - cool in summer and warm in winter	Not feasible for high rise buildings
Exterior Shading Devices	Least cost solution for cutting heat gain into the building	
Shading: Landscaping	Applicable in all weather conditions	Dense vegetation can make the air warmer near the building

BENEFITS OF COOL ROOFS

3.6 Benefits of Cool Roofs

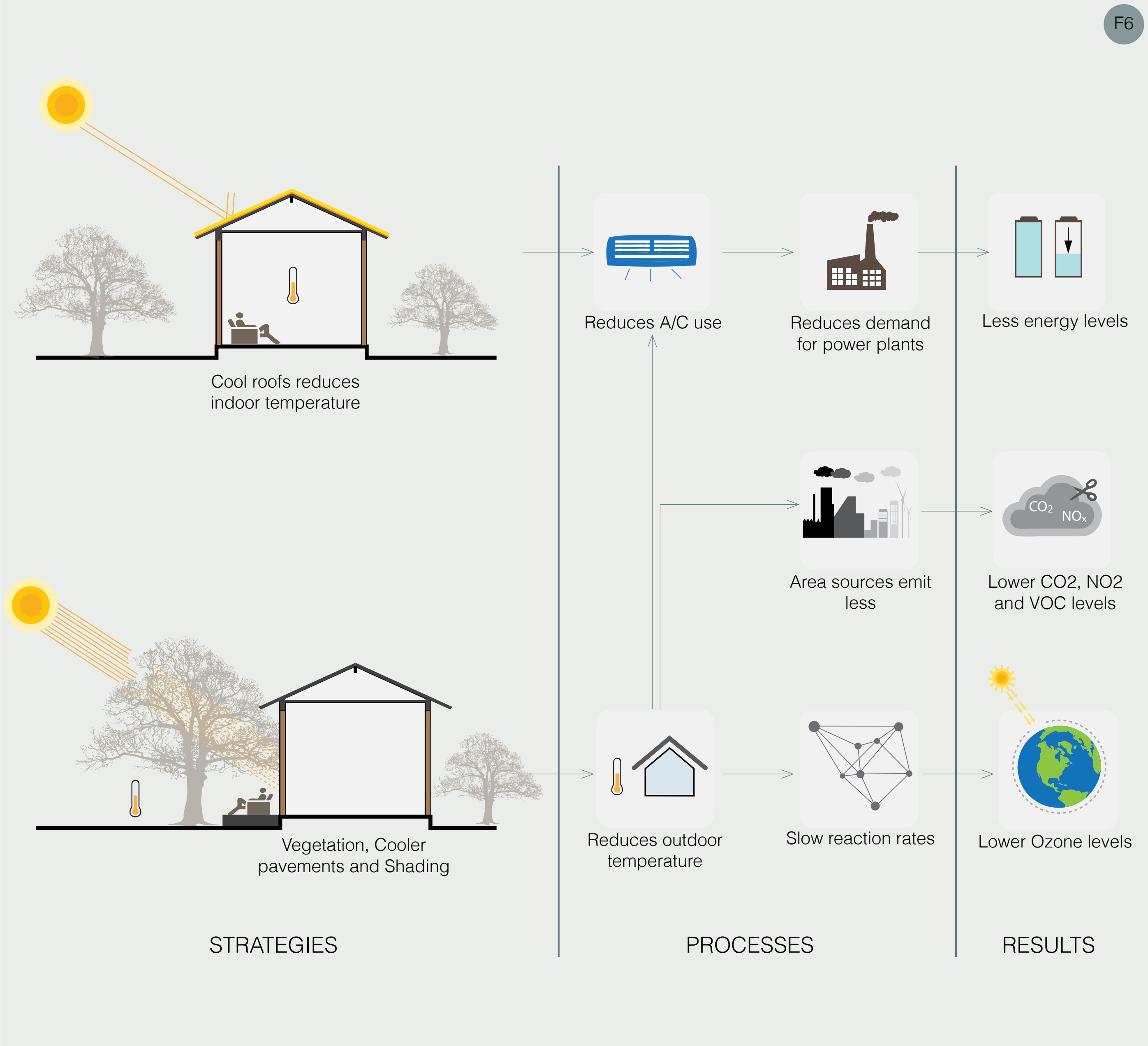
1. Climate Change Mitigation: Cool roofs directly reduce greenhouse gas emissions by conserving electricity for air conditioning therefore emitting less CO_2 from power plants. A study found that world-wide reflective roofing will produce a global cooling effect equivalent to offsetting 24 giga tons of CO_2 over the lifetime of the roofs [41]. This equates to $600 billion in savings from CO2 emissions reduction.

2. Urban Heat Island Mitigation: By immediately reflecting solar radiation back into the atmosphere and re emitting some portion of it as infrared light, cool roofs result in cooler air temperatures for the surrounding urban environment during hot summer months.

3. Reduced Smog: Smog is created by photochemical reactions of air pollutants and these reactions increase at higher temperatures. Therefore, by reducing the air temperature, cool roofs decrease the rate of smog formation. Ozone levels increase during chemical reaction of volatile organic compound and NOx in presence of heat.

4. Public Health Benefits: Lower ambient air temperatures and the subsequent improved air quality also result in a reduction in heat-related and smog-related health issues, including heat stroke and asthma.

5. Peak Energy Saving and Grid Stability: Because cool roofs reduce air conditioning use, the associated energy savings occur when the demand for electricity is at its peak. Therefore, use of cool roofs reduces the stress on the energy grid during summer months and helps avoid shortages that can cause blackouts or brownouts.



COMPARISON OF DIFFERENT UHI MITIGATING STRATEGIES

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	Cool Roofs	Green Roofs	Passive Ventilation	Insulation
Health	●	●	●	
Energy saving	●	●	●	●
Building cooling	●	●	●	●
City cooling	●	●	●	
Global cooling	●		●	
Low maintenance	●		●	●
Compatibility	●	●	●	●

3.7 Benefits of Passive Ventilation

1. Appropriate Technology: Natural Ventilation/Passive Cooling is mostly suitable in mild or moderate climate conditions, while optimising thermal performance of a building thereby minimising heat gain from external environment.

2. Economic gains: It is least expensive means of cooling at home compared to mechanical solutions like fans, air cooler and air conditioner.

3. Environment friendly: It has the lowest environmental impact. Passive cooling maximises the ability of the occupants to losE heat to natural sources of cooling.

4. Public Health Benefits: Passive ventilation techniques improve the air quality inside the buildings along with the other advantages like thermal comfort and high flow rate is possible when needed.

5. Energy Saving: These technologies save more energy in comparison to cool roof materials because they also improve day lighting along with the cooling of the buildings.

CHAPTER 4: URBAN HEAT ISLAND IN INDIAN CITIES: CASE OF INDORE AND SURAT

LAND SURFACE TEMPERATURE

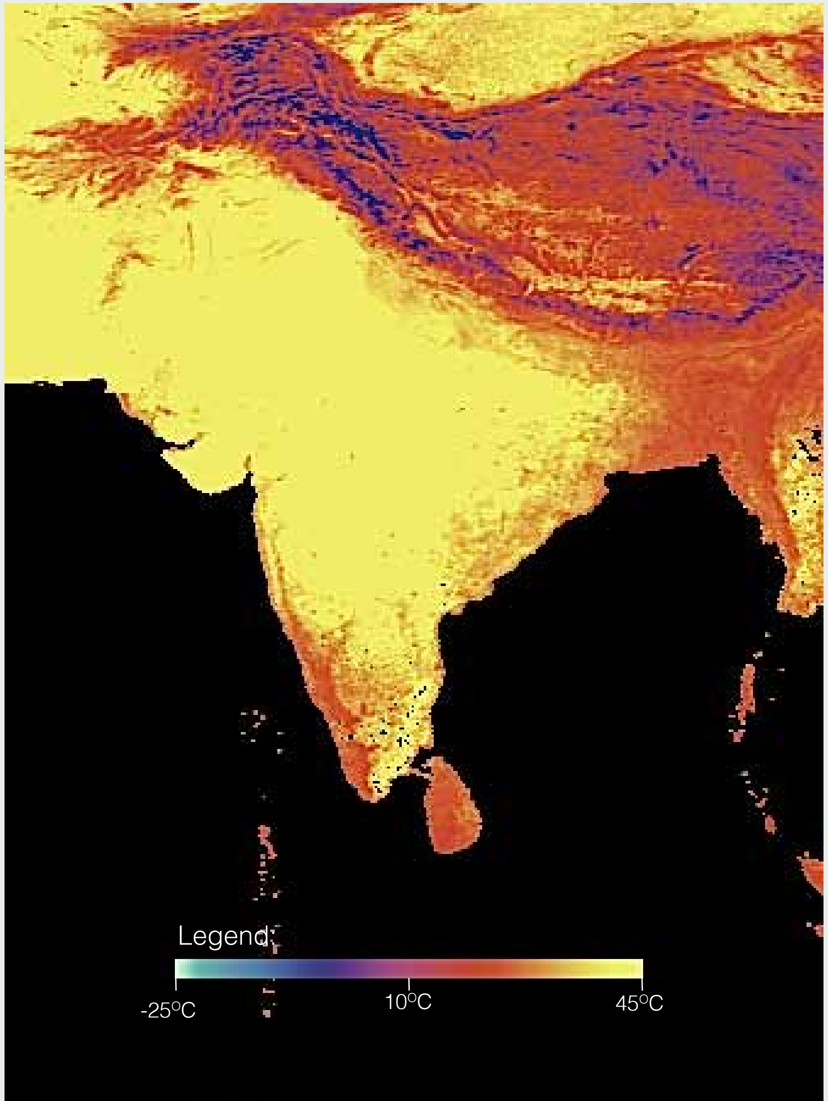
4.1 Overview

With the changing climate, Indian cities are also seeing the increase in summer temperature and heat waves. As a result India is not being able to meet its current energy demands considering the rapid growth in urbanization and population and it is estimated that India would see a two to threefold increase in demand by 2030. In spite of low per capita consumption, the increase in population combined with an increase in affordability and aspiration among residents has led to the increase in total energy demand. This drastic increase in energy demand creates a mis-match with supply of electricity, resulting in and frequent power cuts especially during summer. This impacts livelihoods and adversely affects trade and industry in urban areas.

4.1.1 Study Brief

This study identifies a set of cool roof and passive ventilation options in order to increase the thermal comfort level within buildings, with a focus on low income households. The identified technologies have been demonstrated over a set of 20 different type of buildings in Indore and Surat. A network of stakeholders including professionals, academicians and city, state and national authorities has been established. Information will be disseminated through workshops, conferences and other IEC material. The technologies demonstrated in the project will help in reducing space cooling loads and, in particular, benefit low-income households with limited capacity to invest in space cooling.They can also be used in industries and other commercial buildings where they can reduce electricity bills and improve productivity of workforce.

F8



Land Surface Temperature for the month of May 2013

Source: http://neo.sci.gsfc.nasa.gov [45]

Complete blackout in 17 states of India in July 2012 shows the glimpse of future energy crisis in India. A study by IISc Bangalore indicates an increase in temperature by 1.7-2°C in India by 2030 [42]. Indian cities have an average maximum temperature of 35°C and hence there is a need to address the UHI effect and reduce the energy consumption/demand arising due to space cooling needs. According to the 12th five year plan, India must increase its energy production by 6.5% annually from 2011 to cater to demand.[43]. To deal with energy crisis, government of different states can implement cool roof and passive ventilation technologies as energy efficient measure [44].

With the energy costs growing over years and expansion of urban heat islands of cities, there is a need for conserving energy, while improving thermal comfort of the residents. Energy efficient measures are one of the only possible solutions to reduce the growing demand-supply gap.

NOAA NATIONAL WEATHER SERVICE: HEAT INDEX

F9

Temperature °C

Relative Humidity (%RH)	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
40	27	27	28	29	31	33	34	36	37	38	41	43	46	48	51	54	58
45	27	28	29	31	32	34	36	38	39	40	43	46	48	51	54	58	
50	27	28	29	31	33	35	37	40	41	42	45	48	51	55	55		
55	27	29	30	32	34	36	38	41	43	44	47	51	54	58	58		
60	28	29	31	33	35	38	41	43	45	47	51	54	58				
65	28	29	32	34	37	40	42	46	48	49	54	58					
70	28	30	32	35	38	41	44	48	50	52	58						
75	29	31	33	36	40	43	47	51	53	56							
80	29	32	34	38	41	45	49	54									
85	29	32	36	39	43	47	52	57									
90	30	33	37	41	45	50	55										
95	30	34	38	42	47	53											
100	31	35	40	44	49	56											

Caution (Fatigue is possible with prolonged exposure and activity. Continuing activity could result in heat cramps)

Danger (Heat cramps and heat exhaustion are likely; heat stroke is probable with continued activity

Extreme Caution (Heat cramps and heat exhaustion are possible. Continuing activity could result in heat stroke)

Extreme Danger (Heat stroke is imminent)

NOTE: A 34°C temperature will feel like 41°C with a relative humidity of 55% (NOAA Heat Index Chart)

Source: National Oceanic and Atmospheric Administration [46]

4.2 INDORE: A Case Study

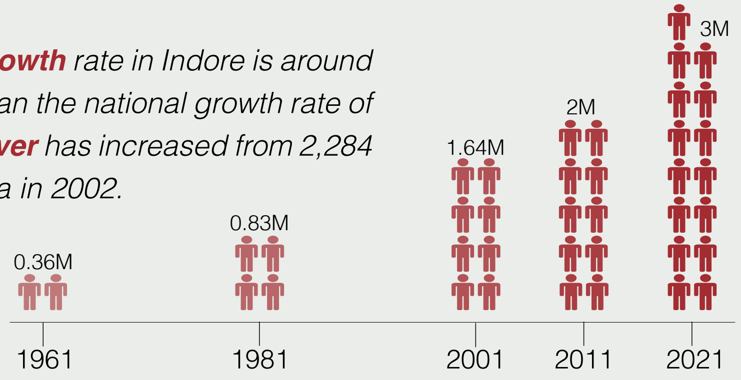
The population of the Indore increased from 57 thousand in 1911 to 16 lacs in 2011. Being an educational, medical and trade hub of Madhya Pradesh, Indore is seeing a lot of migration from rural areas. Population of Indore is expected to be 3 million by the year 2021 (IMC). With the increase of more built up area in the coming years and reducing the green area in the city, the problem of urban heat island is expected to intensify.

As 27% of the city's population live in slums, almost one third population of Indore city suffers from uncomfortable indoor environments due to overcrowded settlements, low ventilation and poor vegetation cover. Since most poor cannot afford space cooling devices beyond fans, nor the increasing costs of electricity, they are likely to be impacted the most.

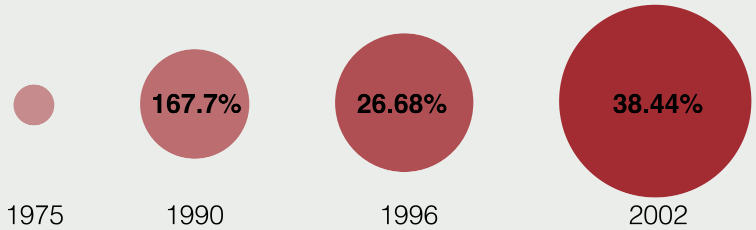
The future temperature predictions from 2021 to 2050 indicate that the minimum and maximum temperatures are likely to increase in the city, as compared to the minimum and maximum observed temperatures from 1960 to 1990. During near term, i.e. for the next three decades this increase may be of the order of 0.5-1°C in maximum temperature and around 3-4°C in minimum temperature. In later part of this century i.e. beyond 2040, the temperatures are likely to increase in the range of 2-4°C in maximum and minimum temperatures respectively.

F10

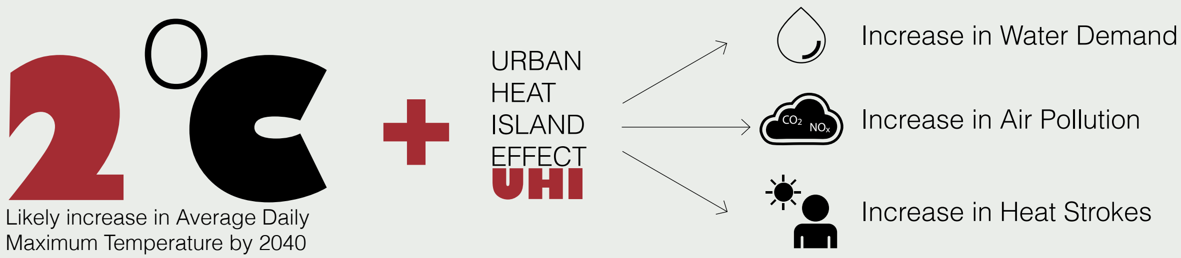
*Decadal **population growth** rate in Indore is around 40%, which is higher than the national growth rate of 22%. While the **land cover** has increased from 2,284 Ha in 1975 to 10,775 Ha in 2002.*



POPULATION GROWTH IN INDORE CITY



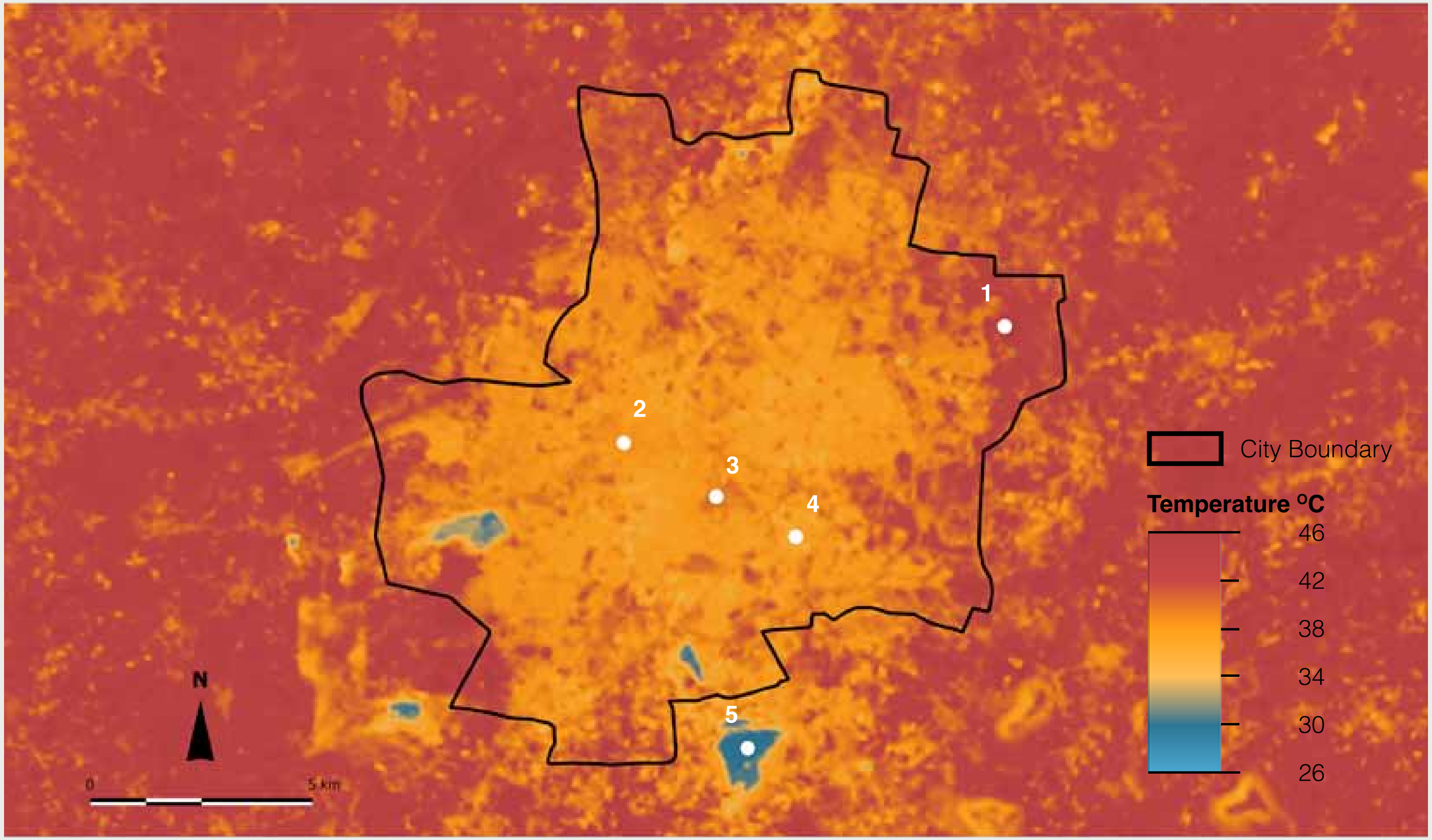
URBAN GROWTH OF INDORE CITY



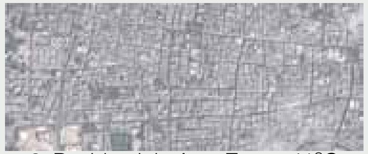
Data Source: CDP Indore [47]

INDORE: LAND SURFACE TEMPERATURE IMAGE

F11

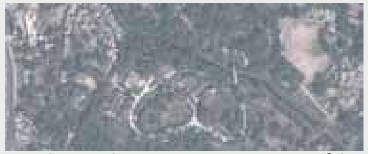


1. Open Land : Avg. Temp. 42°C



2. Residential : Avg. Temp. 41°C

3. Commercial : Avg. Temp. 43°C



4. Green Space : Avg. Temp. 39°C

5. Water Body : Avg. Temp. 39°C

The image shows the land surface temperature of Indore city captured in May 2013.

In the above image every pixel (cell) represents relative surface temperature of the city and its surrondings. Due to lack of vegetation (bare soil) in the month of May, the rural areas tend to radiate/exhibit more heat. One can also notice the considerably cooler water bodies.

Source: Imagery ©2013 Digital Globe, Map Data ©2013 Google, Landsat 8, TARU Analysis 2013.

4.3 SURAT: A Case Study

Surat is the 8th largest city in India. As per the census 2011, Surat has a population of 4.46 million. Many people migrated to Surat city due to the presence of huge textile and diamond industry. The city saw an unprecedented growth in the last four decades, recording one of the highest growth rates in the country and a 10-fold population rise over four decades.

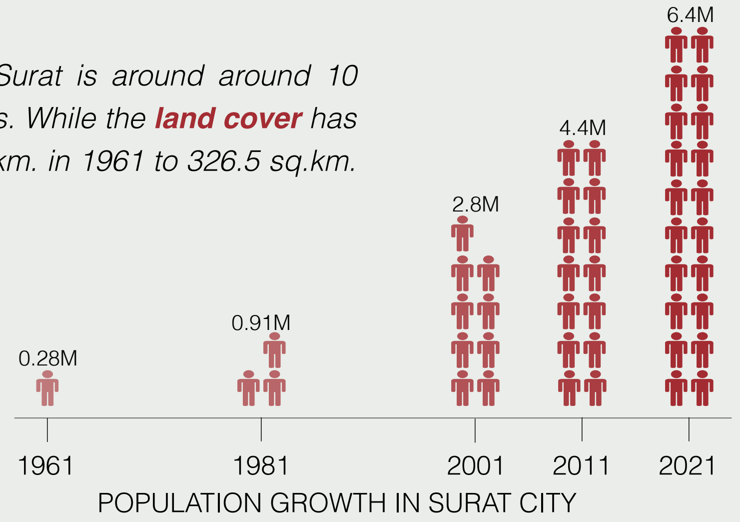
Prior to 1961, Surat's area was 8.12 sq. Km., while in 2009 it had expanded to 326.5 sq. Km. The population of Surat is expected to grow from 4.46 million (2011) to 6.4 & 8.5 million by 2021 & 2031. With the increase of more built up area in the coming years and reducing the green area in the city, the problem of urban heat island is expected to intensify.

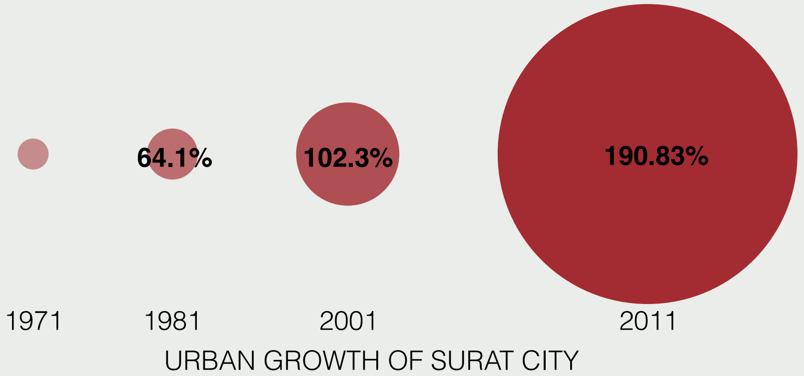
The future temperature predictions from 2021 to 2050 indicate that the minimum and maximum temperatures are likely to increase in the city, as compared to the minimum and maximum observed temperatures from 1960 to 1990. The results indicate that in the next few decades the minimum temperature may increase by around 3-4°C leading to the winter minimum temperature being around 20°C instead of the current 15°C. Further, the maximum temperatures are showing possible increases and may rise beyond 35°C. Since Surat is a coastal city, high relative humidity and increase in temperatures will decrease the thermal comfort of the city drastically.

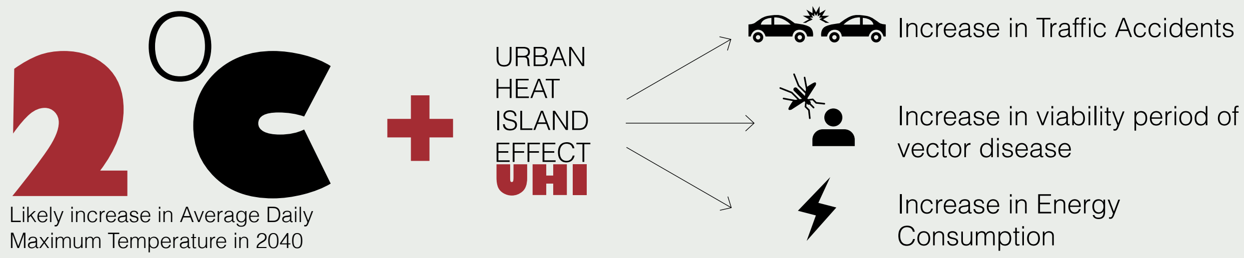
SURAT: DEMOGRAPHICS, URBAN GROWTH AND TEMPERATURE

F12

__Population growth__ in Surat is around around 10 fold in over four decades. While the __land cover__ has increased from 8.12 sq.km. in 1961 to 326.5 sq.km. in 2009.



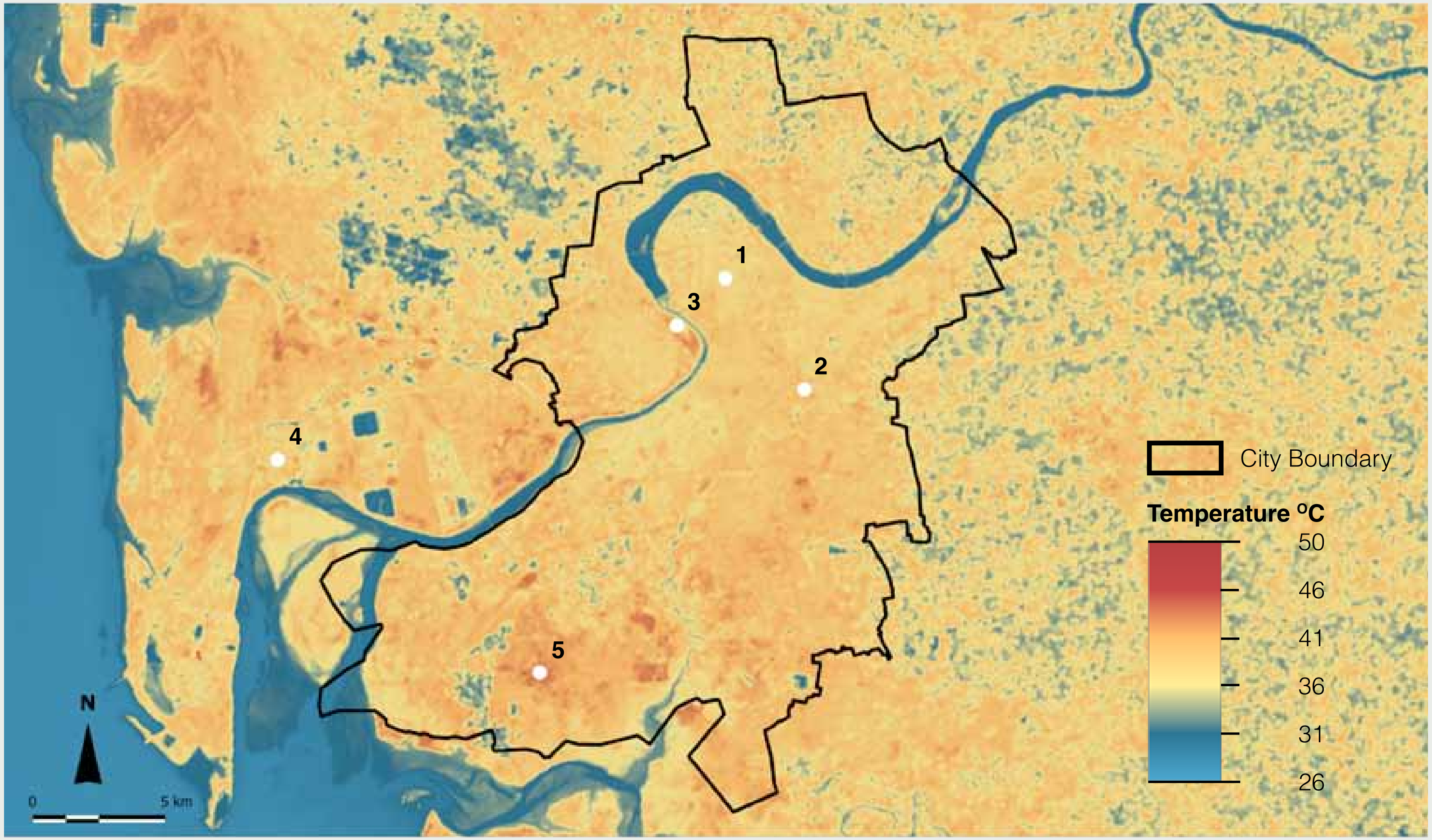




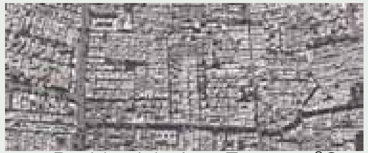
Data Source: CDP Surat [48]

SURAT: LAND SURFACE TEMPERATURE IMAGE

F13



The image shows the land surface temperature of Surat city captured in April 2013.



1. Residential : Avg. Temp. 37°C

2. Commercial : Avg. Temp. 39°C

3. River Bank : Avg. Temp. 39°C

4. Industrial Park : Avg. Temp. 38°C

5. Non Agricultural Land : Avg. Temp. 42°C

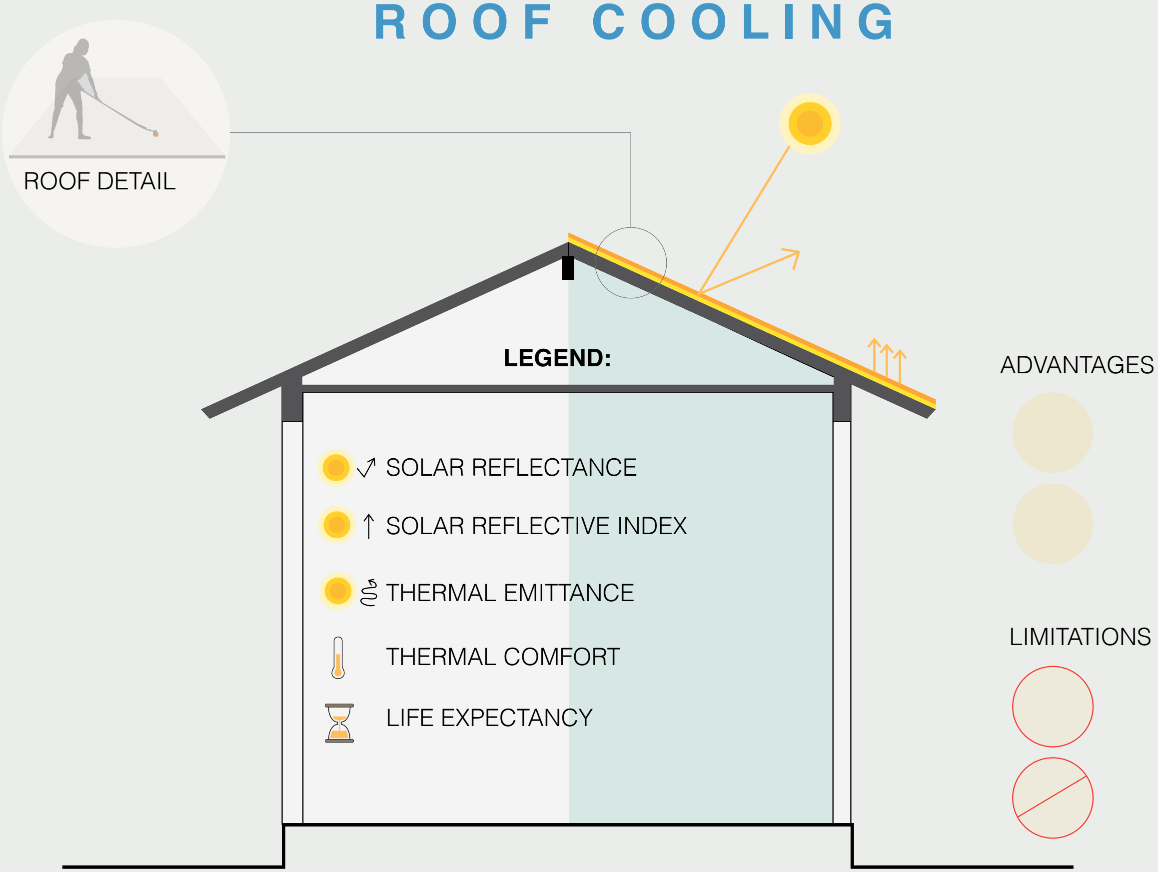
In Surat urban heat islands were evident in the South and South-East parts of the city. These areas in the last decade, have experienced rapid change in Land use and Land cover.

Source: Imagery ©2013 Digital Globe, Map Data ©2013 Google, Landsat 8, TARU Analysis 2013

CHAPTER 5 : THERMAL COMFORT OPTIONS

SECTION 5.1: ROOF COOLING

ROOF COOLING



APPLICATION PROCEDURE

Solar Reflectance: Fraction of sunlight which is reflected, expressed as number between 0 and 1. *

Thermal Emittance: Efficiency with which a surface cools itself by radiating heat to surroundings, expressed as a number between 0 and 1.*

Solar Reflective Index: Indicator of 'coolness' of roof, Clean White Roof SRI=100, Clean Black Roof SRI=0. *

Thermal comfort: Reduction in the indoor environmental temperature as compared to ambient temperature, will vary according to weather conditions and type of construction.

**Note: The values of Reflective Index, reflectance and emissivity are 'average' values observed for the product from among the various brands available.*

CONTENTS

ROOF COOLING

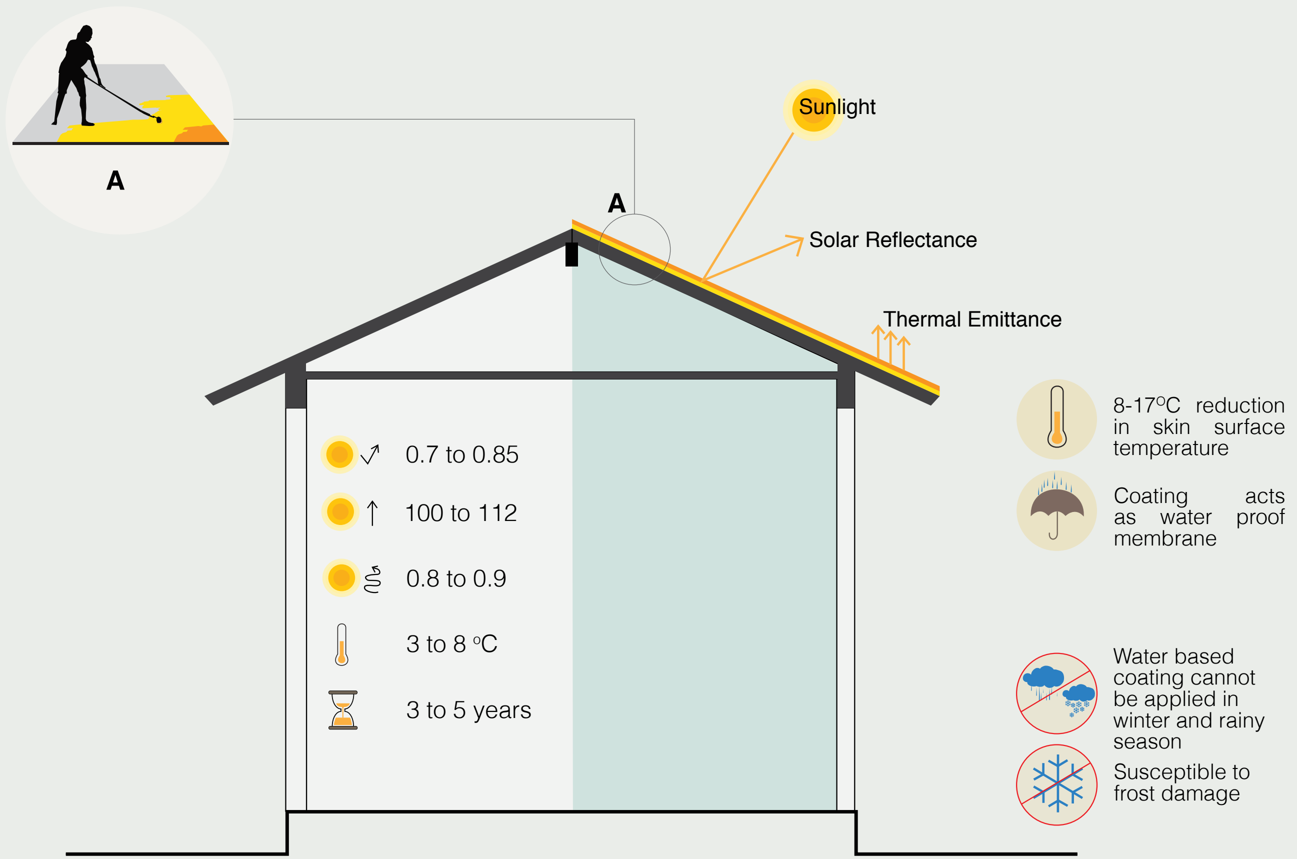
Cool roof coatings are applied to steep as well as low sloped roofs in good condition. Coatings can be field applied to both new roofs and existing roofs.

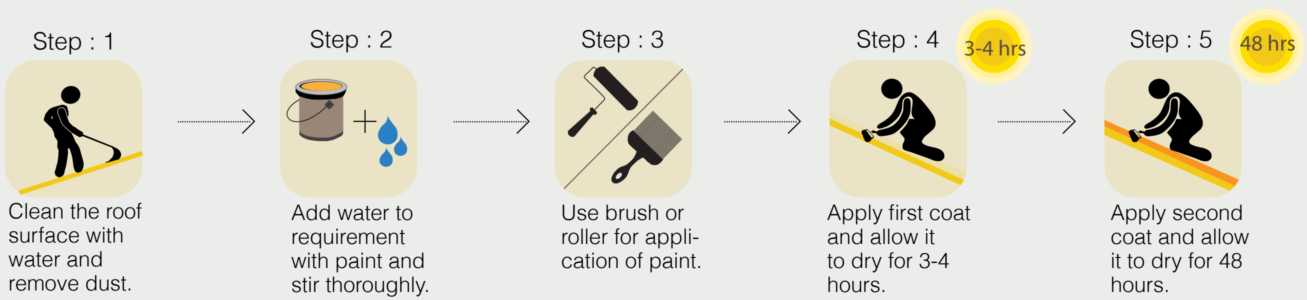
Reflectance in white/light coatings is achieved by pigments, such as titanium dioxide, in a carrier base, and is applied in several layers over a smooth surface.

Elastomeric coatings contain added polymers that make them less brittle and more adhesive to building surfaces. The acrylic resins cross link under UV exposure to lock in colour and lock out dirt. Elastomeric coating also enhances water proofing of roofs.

Acrylic coating is water based coating. Since the coating itself is not getting heated up, the roof and air below the roof will never get hot. Acrylic coatings are the most common, but others include urethane, silicone, Hypalon and other polymer-based coatings.

COOL ROOF COATING: ELASTOMERIC ACRYLIC COATING (WATER BASED)

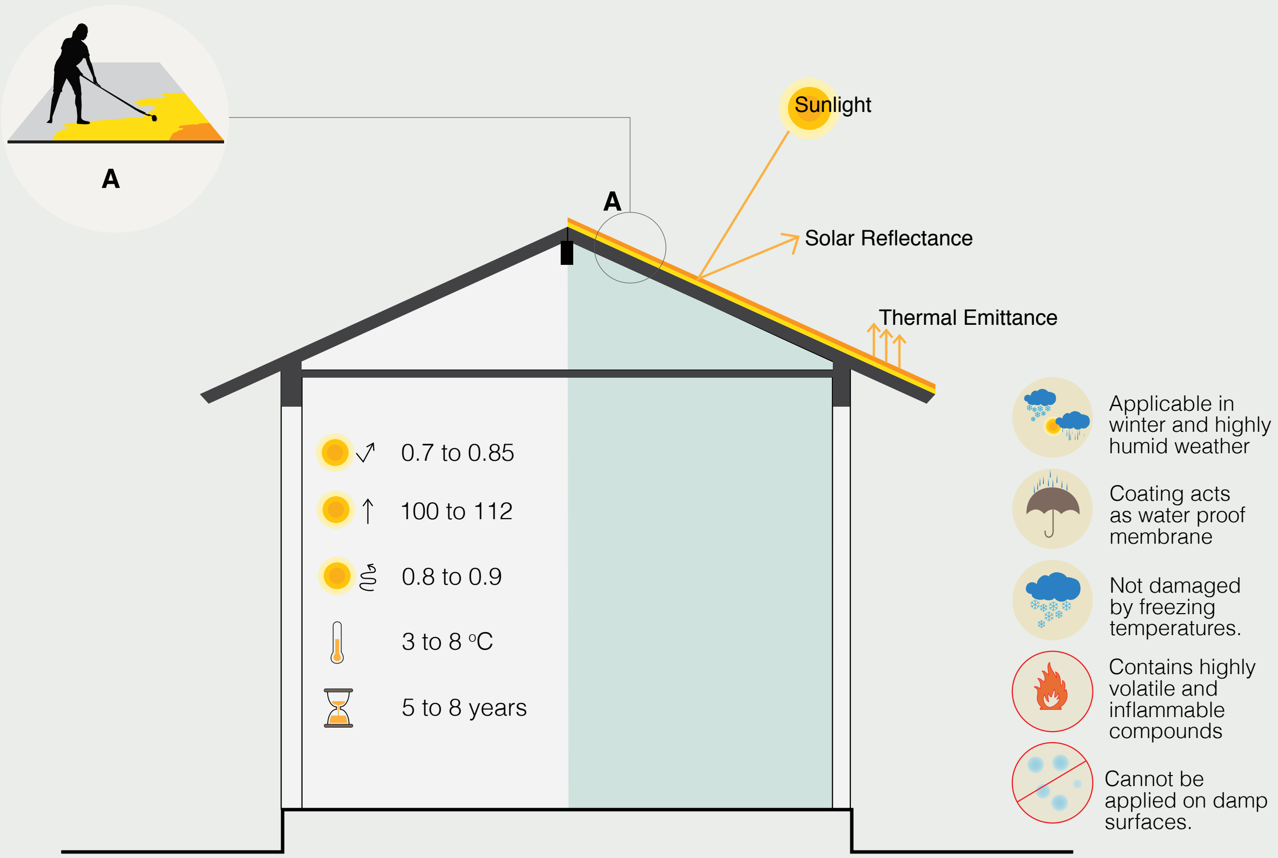


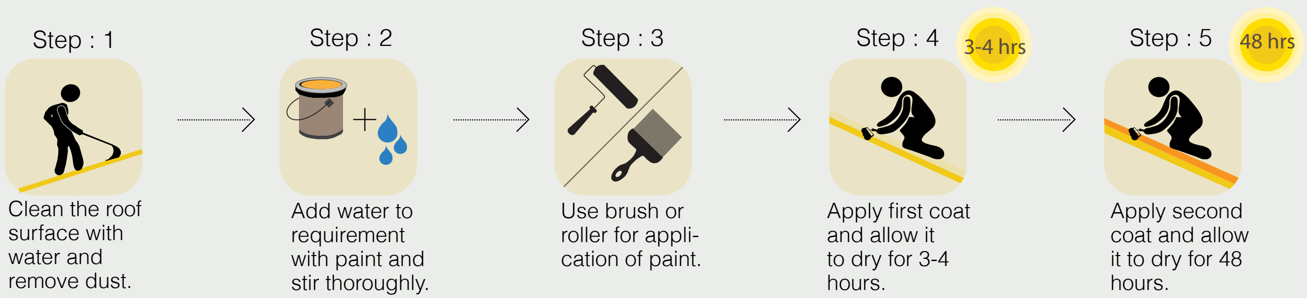


References:

1. Reducing Urban Heat Island: Compendium of Strategies, Cool Roof by EPA, USA.
2. DDC Cool and Green Roofing Manual by New York City Department of Design and Construction.
3. http://home.howstuffworks.com/home-improvement/construction/green/10-ways-cool-roof2.htm

COOL ROOF COATING: ELASTOMERIC COATING (SOLVENT BASED)





Elastomeric coating can also be classified according to the carrier i.e. solvent based coatings and water based coatings. Each one has its own merits and demerits, which should be kept in mind while deciding cool roof coating.

Solvent based Elastomeric coating provide better moisture resistance and offer much lower water vapour transition than water-based elastomeric coatings. The coating is highly impermeable and rust proof as it prevents penetration of moisture and oxygen.

This coating allows application on roof areas that retain water and are susceptible to ponding. It can also be applied on the sloped roof. Solvent based coatings will not freeze and will provide the applicator a longer working season. Also there is less risk of wash-off or humidity related curing issues.

References:
1. Reducing Urban Heat Island: Compendium of Strategies, Cool Roof by EPA, USA.
2. DDC Cool and Green Roofing Manual by New York City Department of Design and Construction.
3. http://home.howstuffworks.com/home-improvement/construction/green/10-ways-cool-roof2.htm

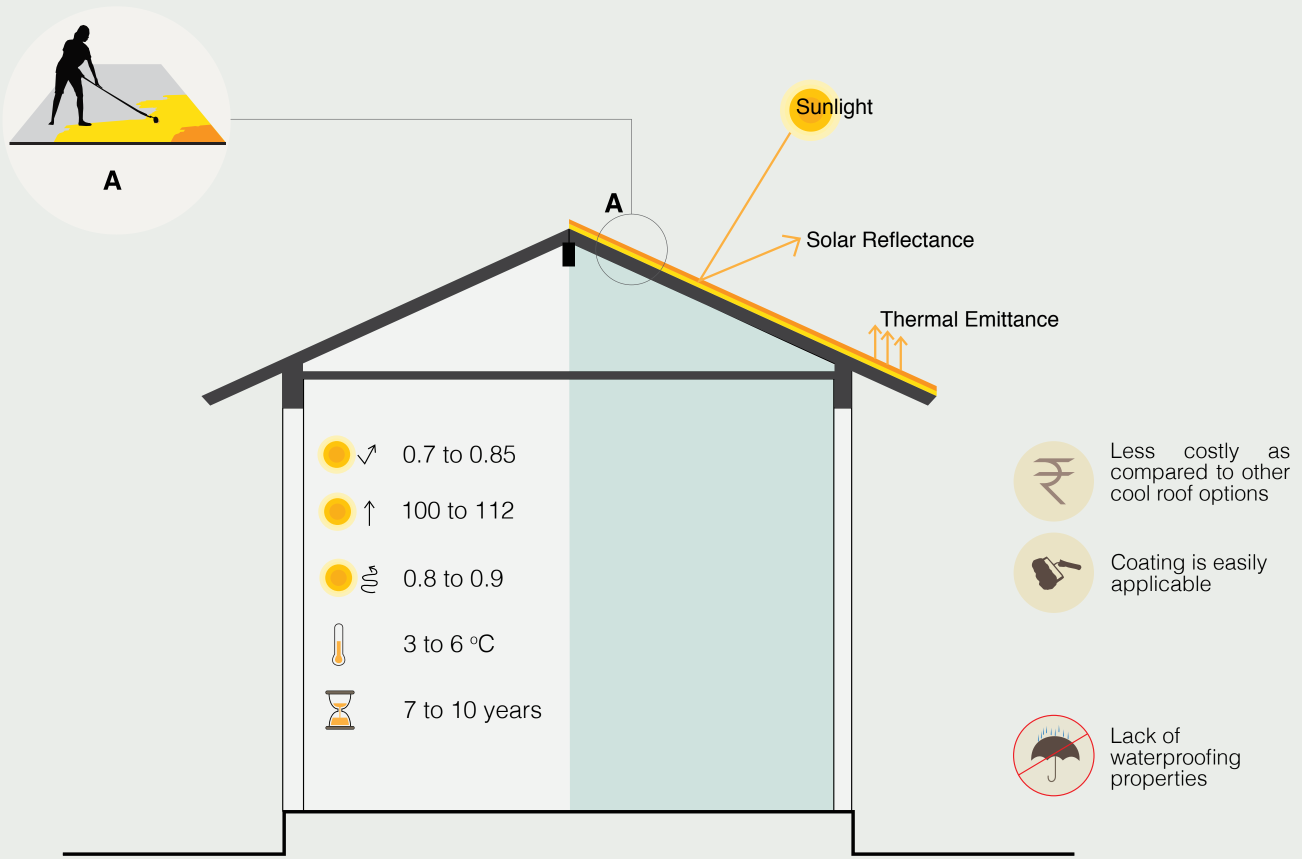
ROOF COOLING

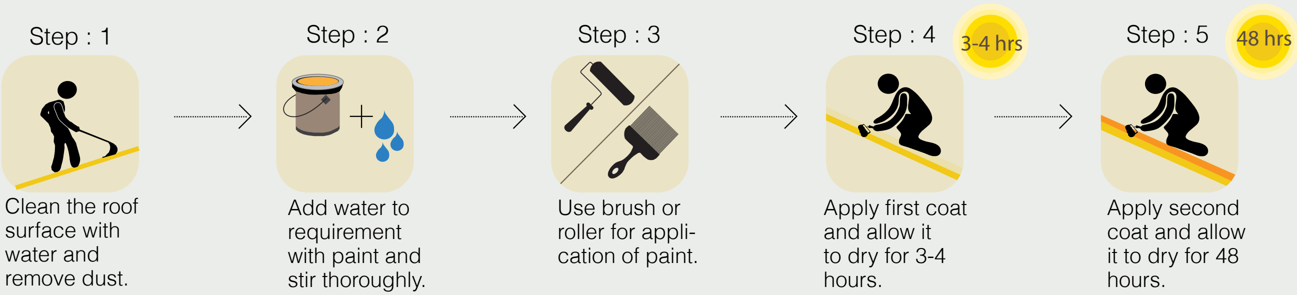
Cementitious coating is one of the most economical solutions in the cool roof market. Cementitious coating on the roof provides a highly reflective surface similar to elastomeric coating and can be applied to both low and steep roof slopes.

The main difference between elastomeric coating and cementitious coating is that elastomeric coating act as a waterproof membrane while cementitious coating should be applied over a roof surface that has already been thoroughly waterproofed.

Cementitious coatings are like very thick paints that can protect the roof surface from ultraviolet light and chemical damage, and also has a restorative feature.

COOL ROOF COATING: CEMENTITIOUS COATING

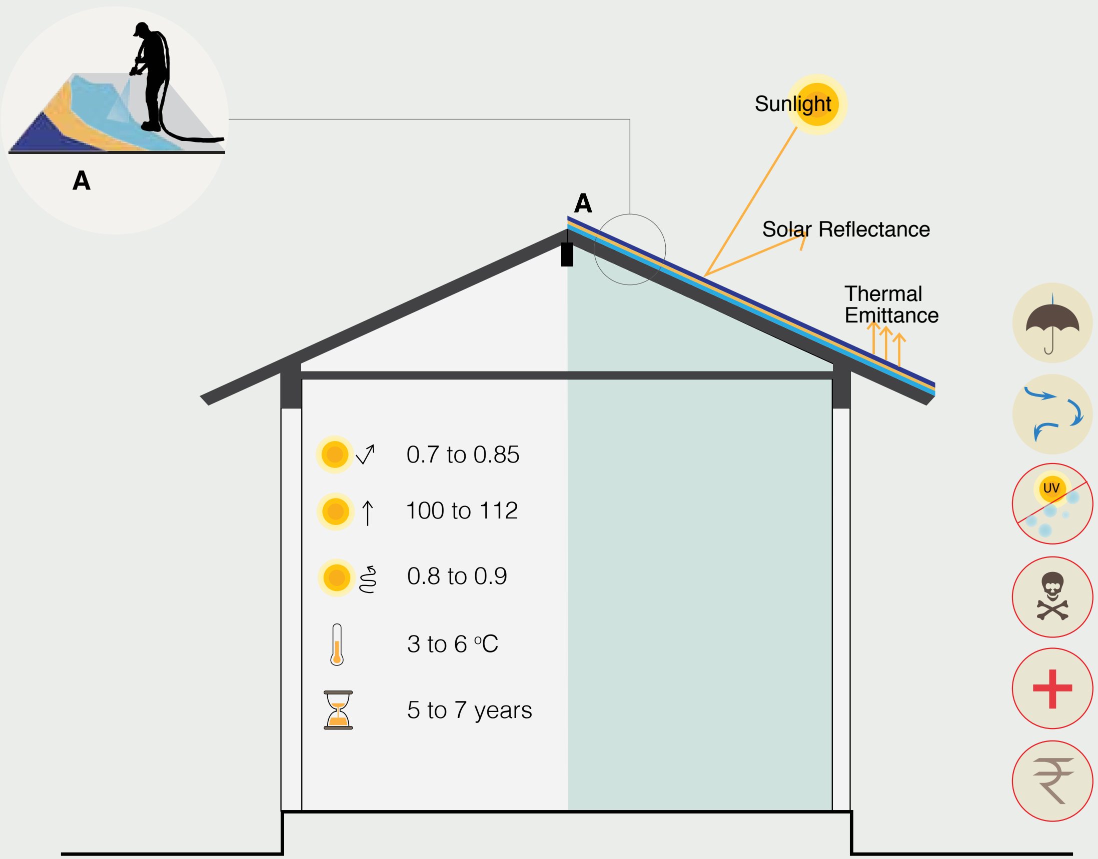




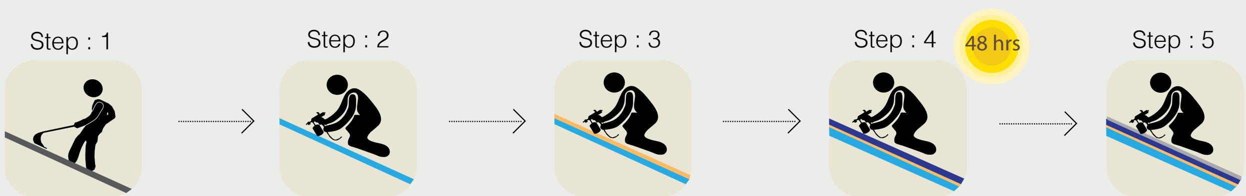
References:

1. Reducing Urban Heat Island: Compendium of Strategies, Cool Roof by EPA, USA.
2. DDC Cool and Green Roofing Manual by New York City Department of Design and Construction.
3. http://home.howstuffworks.com/home-improvement/construction/green/10-ways-cool-roof2.htm

COOL ROOF INSULATION: SPRAY POLYURETHANE FOAM (SPF)



- Extend life of roof by locking leakages
- Excellent resistance to air filtration
- Foam is susceptible to moisture and UV damage
- Toxic properties
- Health hazard during application
- More expensive than elastomeric coating



1. Clean the roof surface by removing debris and gravel.
2. Apply SPF with a minimum thickness of 1 inch.
3. Coat foaming surface with cool coating.
4. Apply second coat and let it dry for 48 hours.
5. Apply protective coating on top foaming surface.

Spray Polyurethane Foam (SPF) is a seamless "spray-in-place" insulation that are available as both open-cell (low density) and closed-cell (high density) plastic foam.. It has the most efficient insulating properties available.

SPF roofing systems are typically coated with light coloured reflective coatings to protect the insulation from damage caused by sun's UV rays, which reduces the amount of heat transported inside the building through thermal bridges.

SPF roofing systems are resistant to leaks caused by hail, wind driven debris and high wind blow-off. They are often used to recover an existing roof, which can eliminate the need to tear off as well as reduces the amount of construction materials in fillings. It can be applied on low and steep roof slopes.

SPF expand to almost 20 times to its original volume when applied on the roof surface. Proper safety gear should be used in application of SPF as there is high risk in exposure to toxic fumes during the spraying process.

References:
1. http://www.buildings.com/ArticleDetails/tabid/3334/ArticleID/14365/Default.aspx
2. http://www.conklin.com/content/products/rs/bospraypolyurethanefoam.cfm

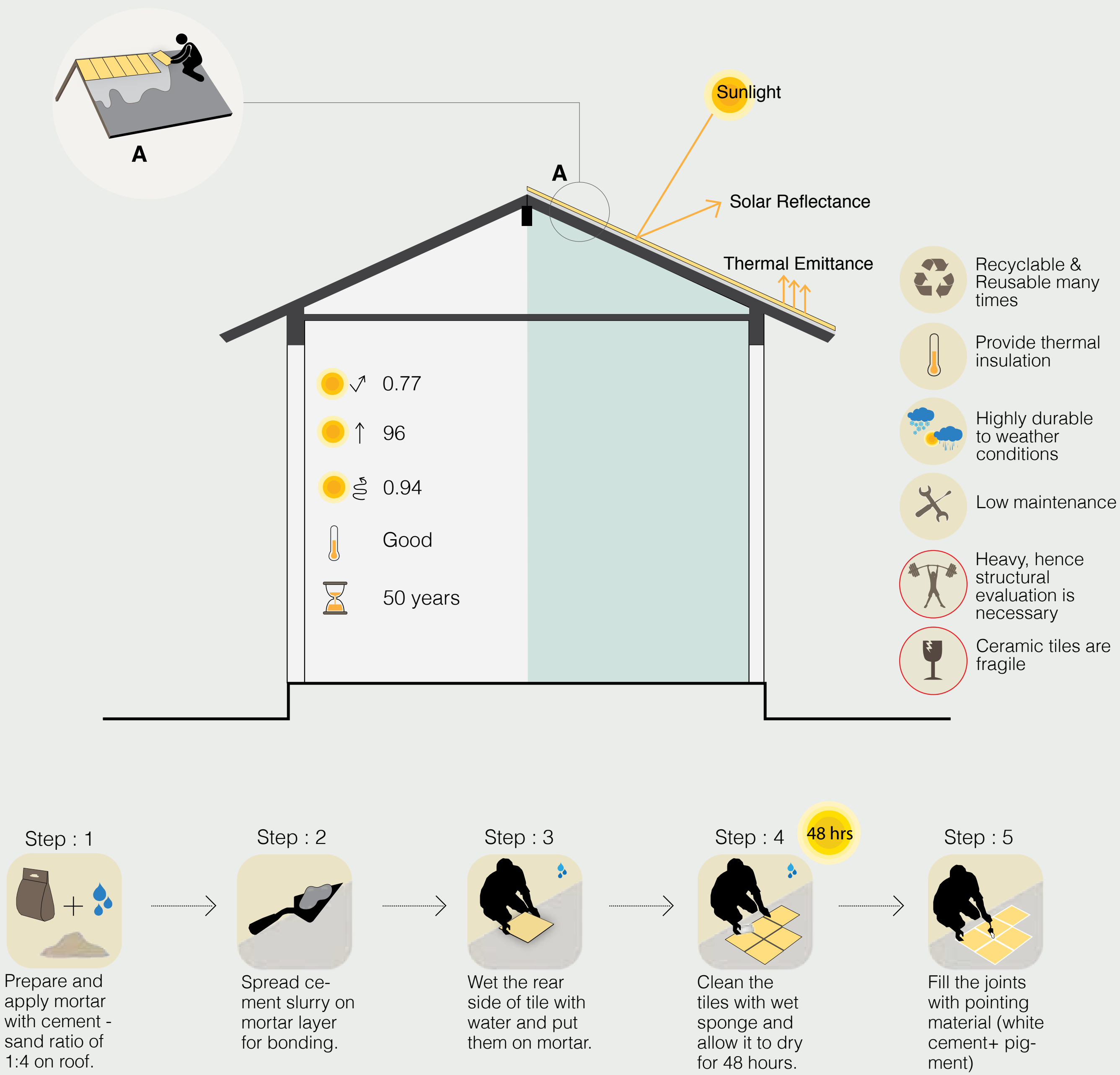
ROOF COOLING

Tile is a resilient material and is able to withstand hail, wind and fire. Heat Insulation Tiles are made from PCM (Phase Change Material) Technology. Micro encapsulated PCM's are leak proof and stable.

They are designed to control the flow of heat from roof and used as surface resistant, which provide 60% of saving in energy as compared to normal roofing.

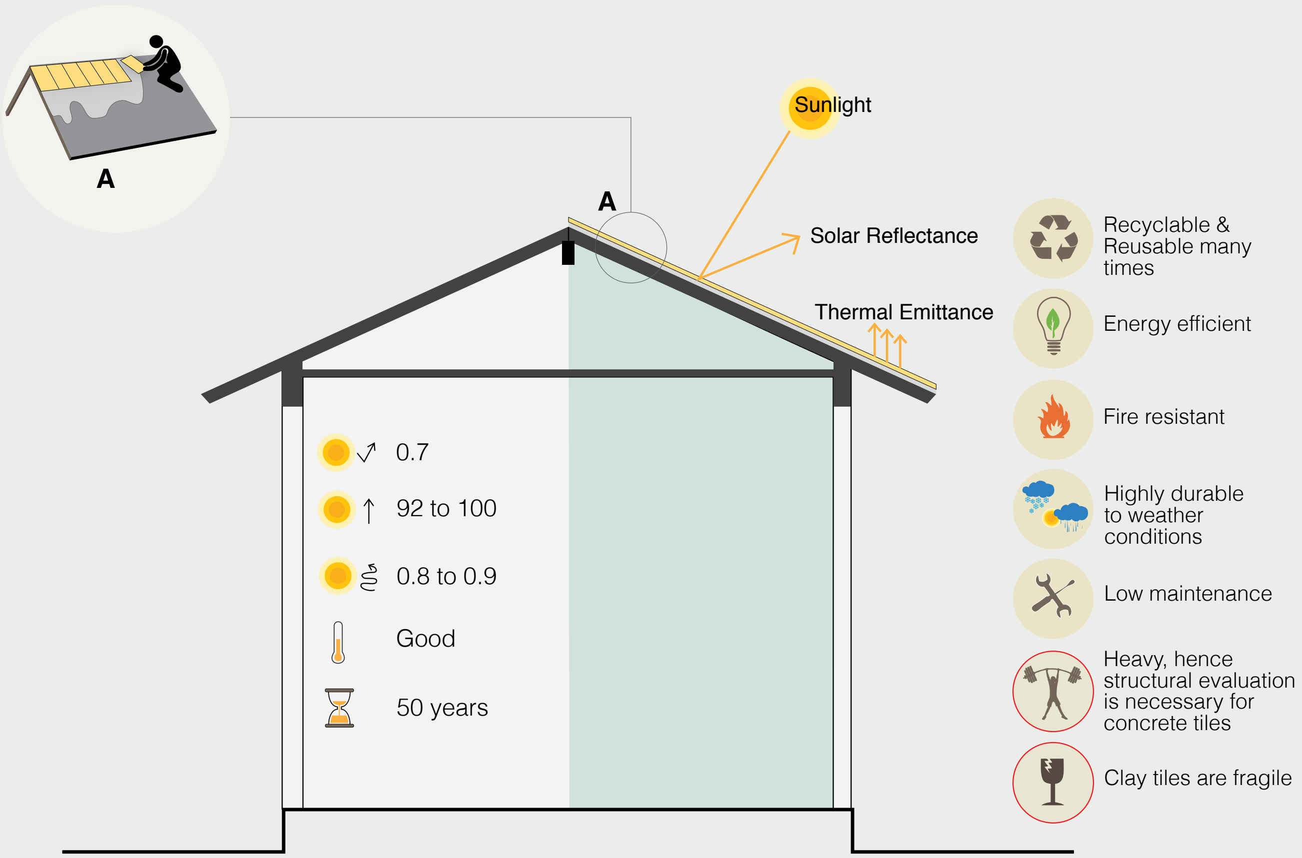
The external surface of the tiles is also designed to provide a smooth, glossy and 100% water resistant surface, which adds to its durability. Being fragile, standard maintenance of tile roofs such as painting or cleaning rain gutters or fireplace have to be done with care. Roof tiles is suitable for steep roof slopes.

COOL ROOF TILES: HEAT INSULATION TILES



References:
1. Reducing Urban Heat Island: Compendium of Strategies, Cool Roof by EPA, USA.
2. http://www.insulla.com/thermal insulation tiles features.php
3. http://home.howstuffworks.com/home-improvement/construction/green/10-ways-cool-roof2.htm

COOL ROOF TILES: CLAY AND CONCRETE TILES



Clay and slate tiles are made using locally available soil. The colour of the clay tile varies depending on naturally available chemical and minerals in the clay. Some varieties are naturally reflective and aid in achieving cool roof standards.

Tiles are glazed to provide water proofing. They are also coated to provide customized colours and surface properties. They are durable against fire and insects. Tiled roof has long life span and provides longest warranties in the roofing industry.

Concrete tiles have essentially all of the upsides of clay tile but with the added advantage of being available in more number of designs and styles. Concrete tiles have good thermal performance due to their relatively high emittance and high reflectance, especially the ones with smooth, light coloured finish.

Clay and Concrete tiles are suitable for steep sloping roofs.

References:
1. Reducing Urban Heat Island: Compendium of Strategies, Cool Roof by EPA, USA.
2. Roofing Material for sloped Roofs by Green Affordable Housing Coalition.
3. Guidelines for selecting Cool Roofs by U.S. Department of Energy.

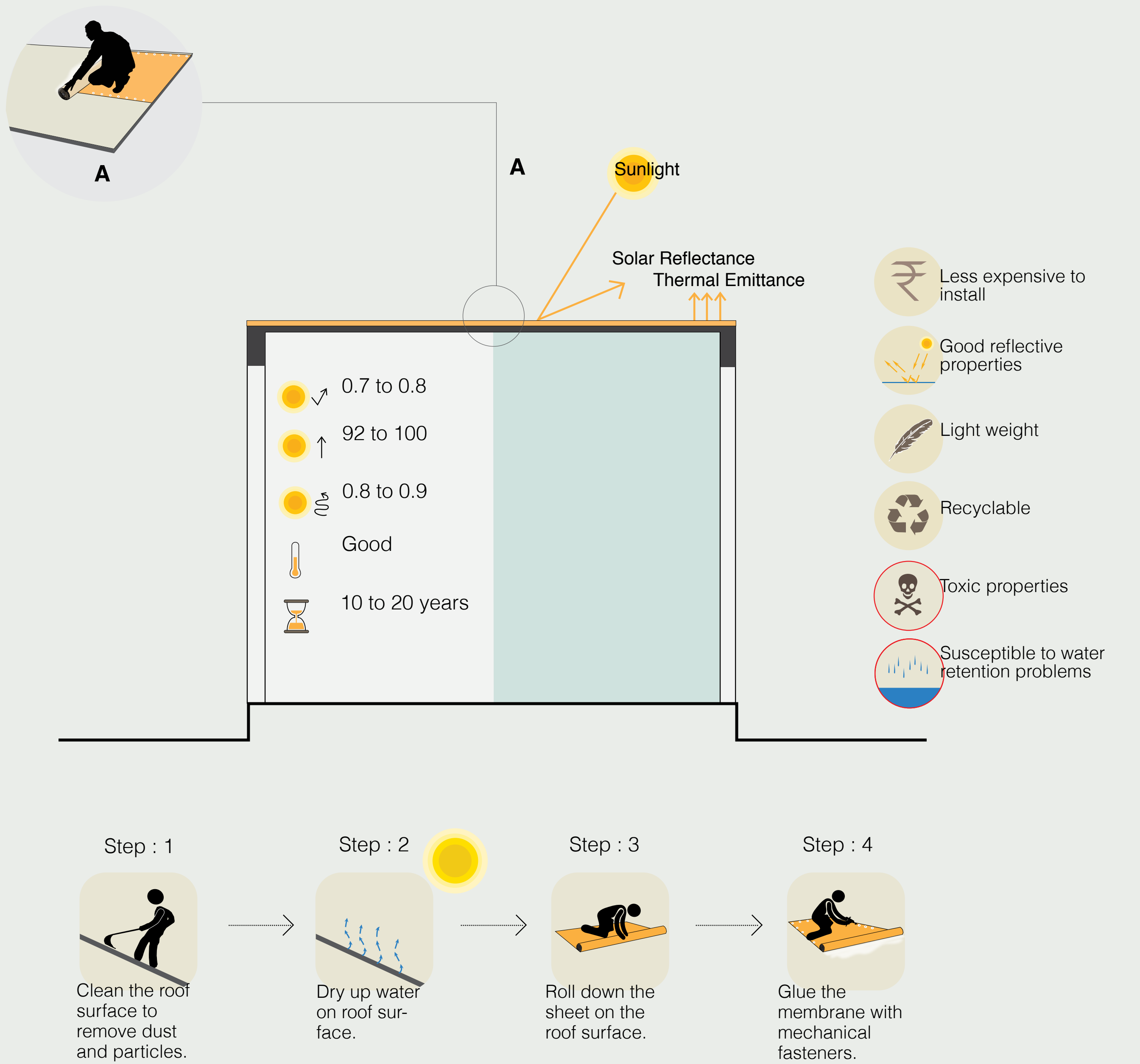
ROOF COOLING

Single Ply membranes are pre-fabricated plastic or vinyl sheets with solar reflective materials. The sheets are rolled onto the roof deck and then attached to the structure with combinations of chemical adhesives, mechanical fasteners, or ballast such as gravel or aggregates.

Thermoset membranes are made from synthetic rubber (elastomeric) polymer. Most common thermoset roofing membranes are Ethylene Propylene Diene Monomer (EPDM) and Chlorosulfonated Polyethylene (CSPE). The membranes do not require any coating as the product itself is integrated with cool roof properties.

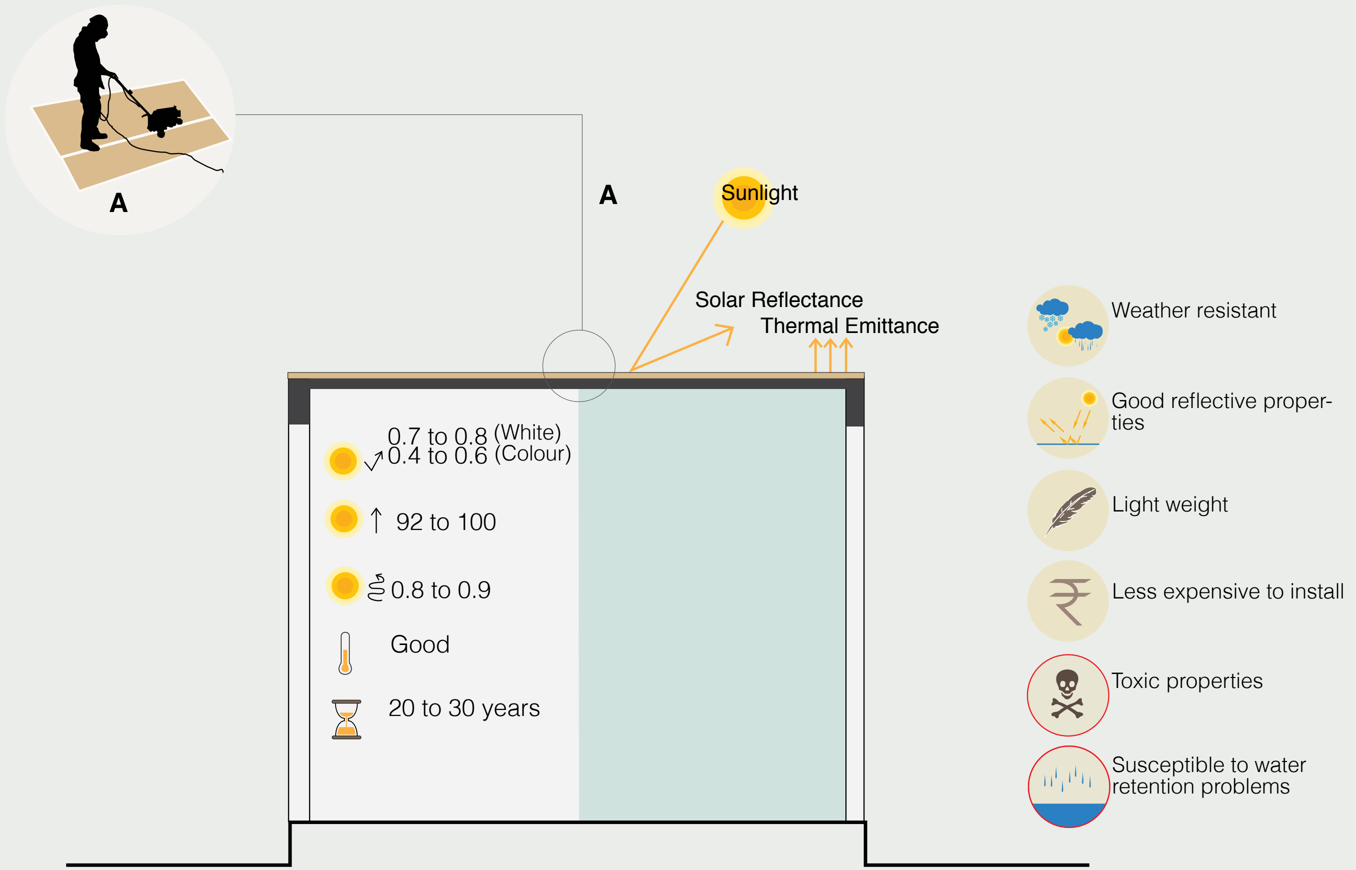
Thermoset membranes must be glued or taped together. Single ply membranes perform better than built-up roofs and can be installed on both low and steep roof slopes.

SINGLE PLY MATERIALS: THERMOSET MEMBRANES



References:
1. Reducing Urban Heat Island: Compendium of Strategies, Cool Roof by EPA, USA.
2. DDC Cool and Green Roofing Manual by New York City Department of Design and Construction.
3.Roofing Material for Cool Roofs by Green Affordable Housing Coalition.
4. http://home.howstuffworks.com/home-improvement/construction/green/10-ays-cool-roof2.htm

SINGLE PLY MATERIALS: THERMOPLASTIC MEMBRANES



Thermoplastic membranes are made from plastic polymers. Most common types among thermoplastic membranes are Polyvinyl Chloride (PVC) and Thermoplastic Polyolefin (TPO). They are suitable for low roof slopes.

Formulations and additives vary by type and manufacturer, for example, PVC membranes typically include phthalate plasticizers for flexibility, and TPO membranes sometimes require fire retardant additives.

Since the “single-ply” classification includes both light and dark coloured materials, hence products with high reflectivity should be selected for reducing heat island effect and energy savings purposes.

New single ply roof products are manufactured with self cleaning and mold resistant polymers to maintain solar reflectance.

References:
1. Reducing Urban Heat Island: Compendium of Strategies, Cool Roof by EPA, USA.
2. DDC Cool and Green Roofing Manual by New York City Department of Design and Construction.
3.Roofing Material for Cool Roofs by Green Affordable Housing Coalition.
4. http://home.howstuffworks.com/home-improvement/construction/green/10-ways-cool-roof2.htm

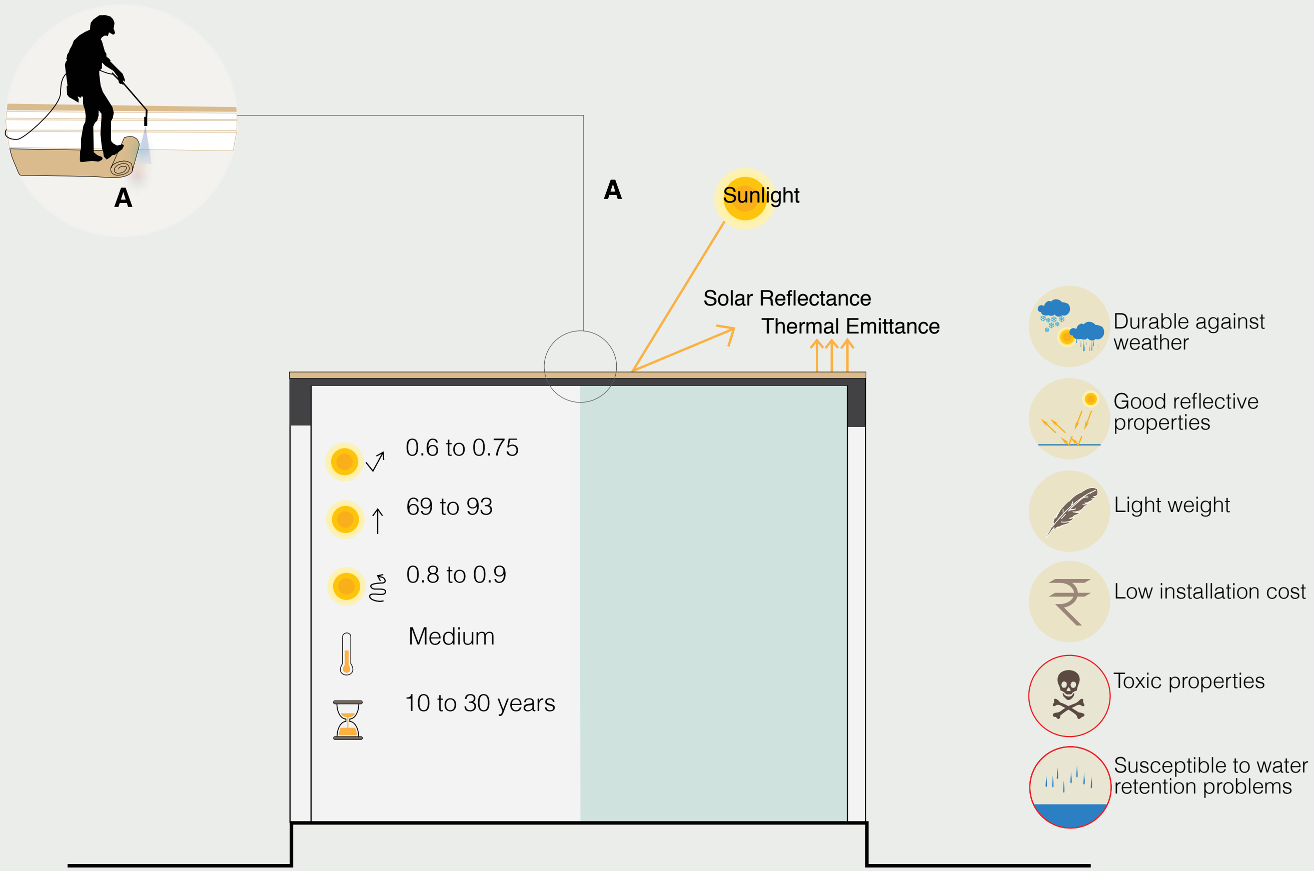
ROOF COOLING

Modified bitumen roof is one of the most common cool roof option for low sloped or flat roof. Modified bitumen roofing is an evolution of conventional asphalt roofing and is made from asphalt, combined with various solvents and modifiers. It is available in the form of membrane/sheets made of plasticized or rubberized asphalt, held together with rolled reinforcing fabric and fastened to the roof deck. The sheets are fastened either with heat application, where the seams are heated to form a seal or cold applied adhesive.

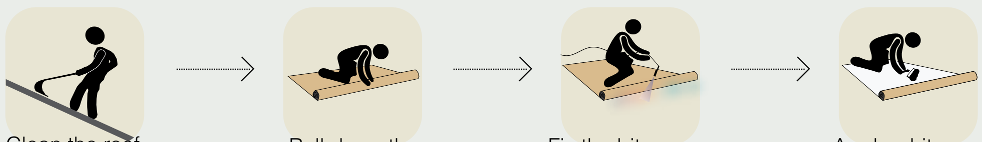
A modified bitumen sheet can also be used to surface a built up roof, which is called a "hybrid" roof.

In option to traditional bitumen, which is black or grey, modified bitumen surfaces can be pre coated at the factory to increase their cooling properties. Simple application of a white coating on the surface of the material can increase the solar reflectance to acceptable cool roof standards. The surface can also be made reflective with white granular surfaced bitumen or light gravel on bitumen.

SINGLE PLY MATERIALS: MODIFIED BITUMEN



Step : 1 | Step : 2 | Step : 3 | Step : 4



Step : 1 — Clean the roof surface to remove dust and other particles.

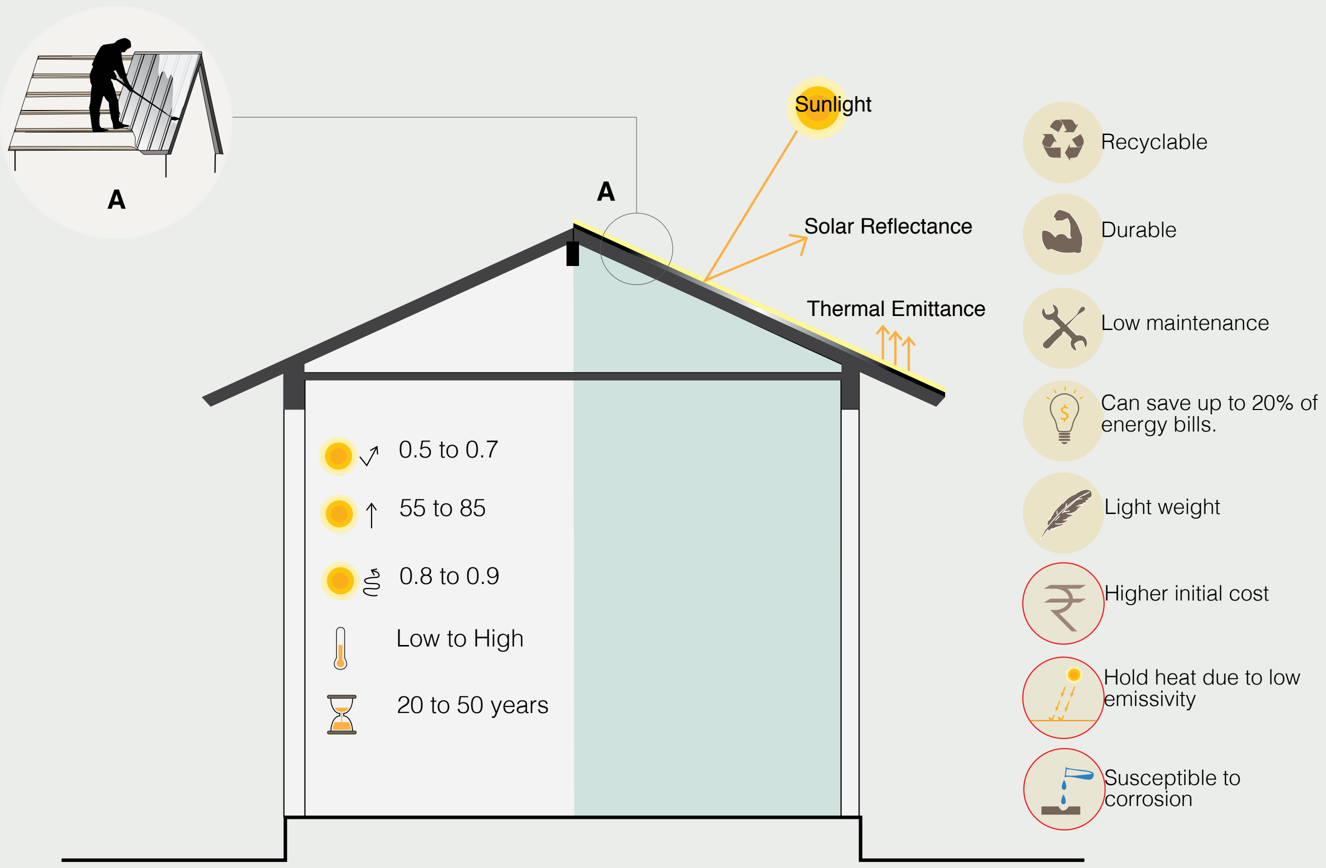
Step : 2 — Roll down the sheet on roof surface.

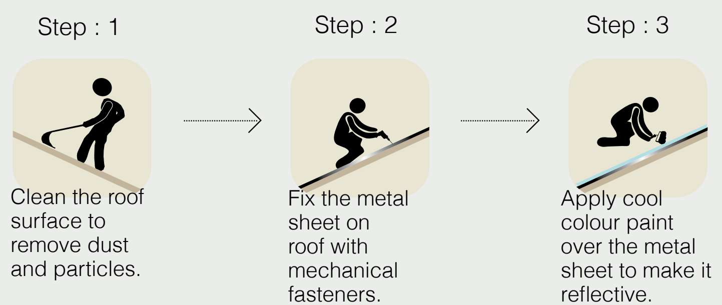
Step : 3 — Fix the bitumen sheet with cold adhesive or hot asphalt using torch down method.

Step : 4 — Apply white coating to make roof reflective.

References:
1. Reducing Urban Heat Island: Compendium of Strategies, Cool Roof by EPA, USA.
2. DDC Cool and Green Roofing Manual by New York City Department of Design and Construction.
3. http://home.howstuffworks.com/home-improvement/construction/green/10-ways-cool-roof2.htm

METAL COOL ROOFING





Unpainted metal roofs are generally reflective due to high solar reflectance but tend to hold heat due to low emissivity. Hence metal roof is more suited for steep sloped roof as compared to flat roof, as flat roof receive more sunlight throughout the day. A factory applied cool roof coating can improve the heat releasing properties of metal roof.

Due to its light weight metal roof is more suitable for retrofitting and in seismic zones.

Advantages of metal roofs like recyclable, durable, low maintenance, longer life and significant reduction in heating and air conditioning costs, makes life cycle cost of metal roofs attractive. Metal roofs are also available with natural metallic finishes, oven baked paint finishes, or granular coated surfaces.

References:
1. Roofing Material for Cool Roofs by Green Affordable Housing Coalition.
2. http://home.howstuffworks.com/home-improvement/construction/green/10-ways-cool-roof2.htm

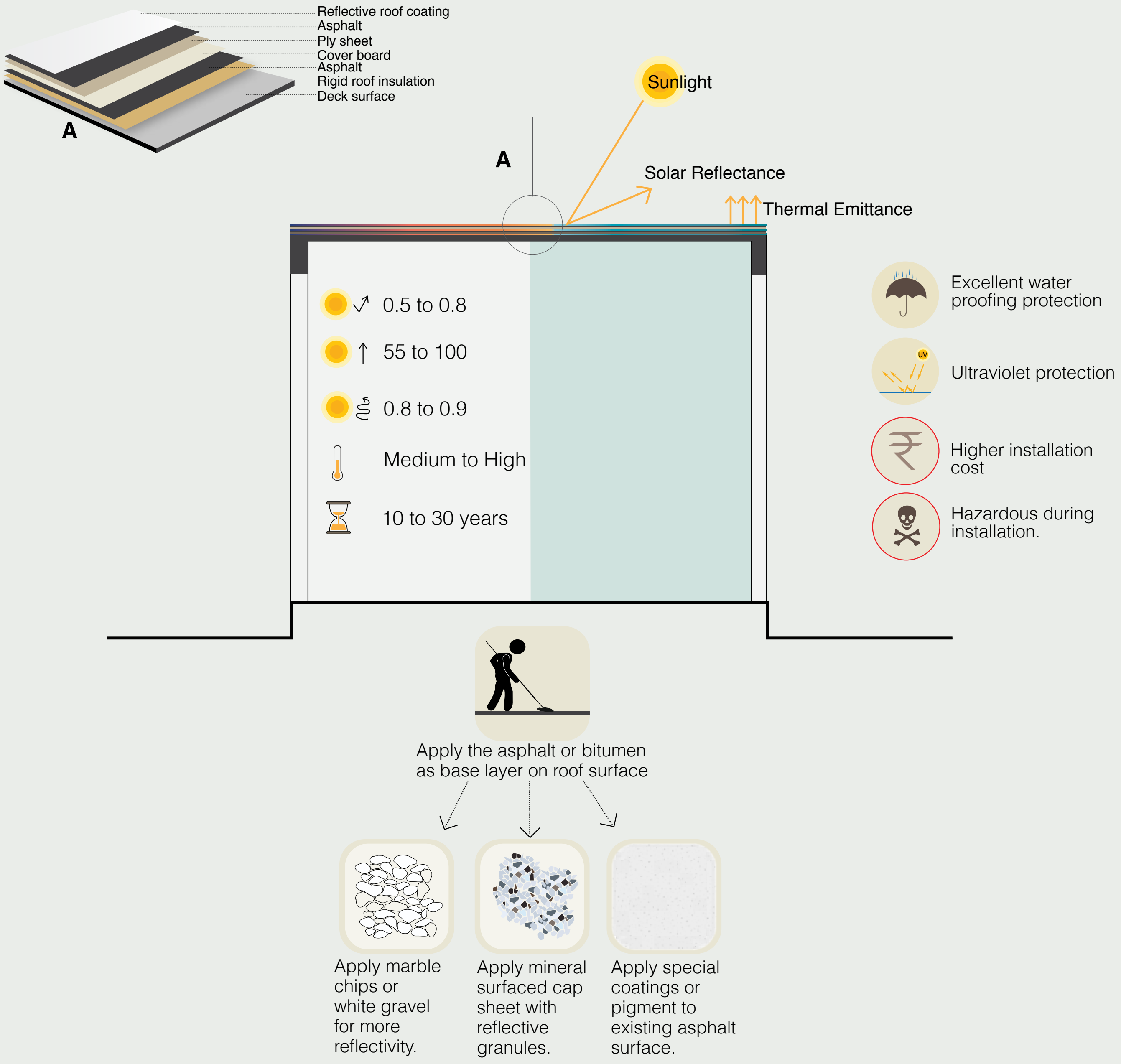
ROOF COOLING

Built up roofing (BUR) is the term for the old standard tar and gravel roof. It is easy to apply and repair and is inexpensive to install. It is among the commonly used roofing systems for flat and low sloped roofs.

Built-up roofing involves layering a base sheet of asphalt or bitumen with fabric, followed by a protective layer of gravel, mineral granules or some sort of aggregate rock. Bitumens provide the water proofing agents and adhesive properties of the system.

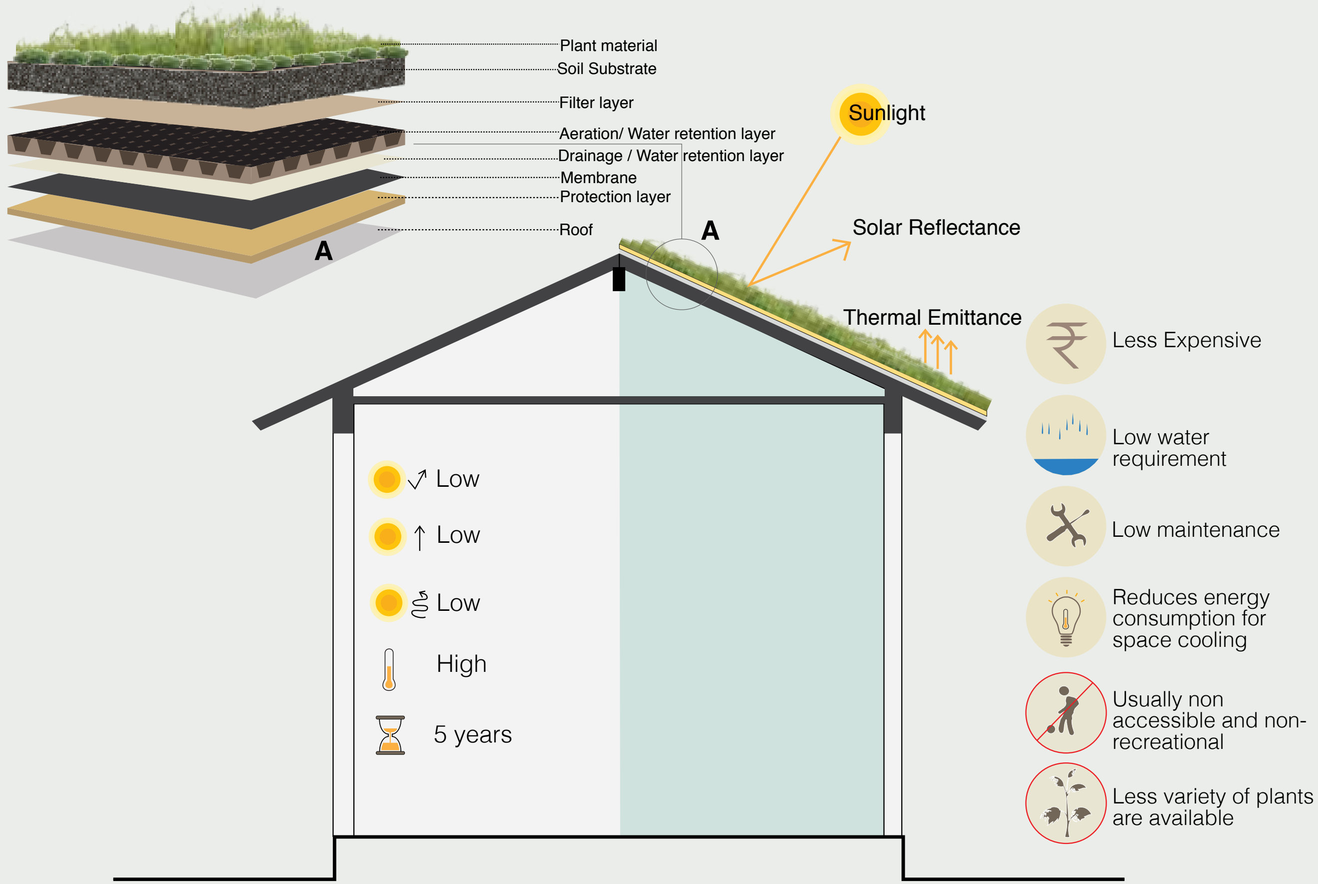
BURs have a low albedo so they must be finished with a reflective coating to achieve temperature reduction and realize energy savings. The surface layer can also be finished with white gravel or reflective marble chips to increase its solar reflectance

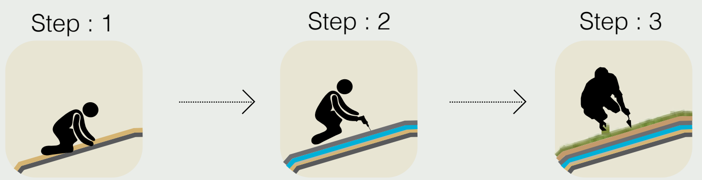
BUILT UP ROOFING (BUR)



References:
1. Reducing Urban Heat Island: Compendium of Strategies, Cool Roof by EPA, USA.
2. Roofing Material for Cool Roofs by Green Affordable Housing Coalition.
3. http://home.howstuffworks.com/home-improvement/construction/green/10-ways-cool-roof2.htm

COOLING ROOF WITH NATURAL MATERIALS: EXTENSIVE GREEN ROOF





Apply membrane and protection layer on roof surface.

Fix the aeration and drainage water retention layers.

Put the layer of plants on top of soil substrate and filter layer.

ROOF COOLING

Green roofs are vegetated roof surfaces, essentially roof tops covered partially or entirely with living plants. Green roofs provides thermal comfort inside the building along with the other environmental benefits like storm water management, aesthetic value and better air quality. Green roof shades the building from the direct sun light and reduce both the inside temperatures and surrounding air temperatures through evaporation and transpiration.

Extensive green roof includes a light weight system with low vegetation planted uniformly over the roof. Below vegetation is thin layer of soil (2 to 6 inches) or other mineral based mixture, a drainage system, a roof protection system and a water proof membrane. Roof slope up to 40% is suitable for extensive green roof.

The plant used in extensive green roof should be capable of withstanding hot, dry and windy conditions without much maintenance and must have the capacity to store water within their foliage. Plants like sedums, herbs, creeping perennials, al- pines, some wild flowers and grasses are few examples, which can be used for extensive green roof.

References:
1. Reducing Urban Heat Island: Compendium of Strategies, Cool Roof by EPA, USA.
2. DDC Cool and Green Roofing Manual by New York City Department of Design and Construction.

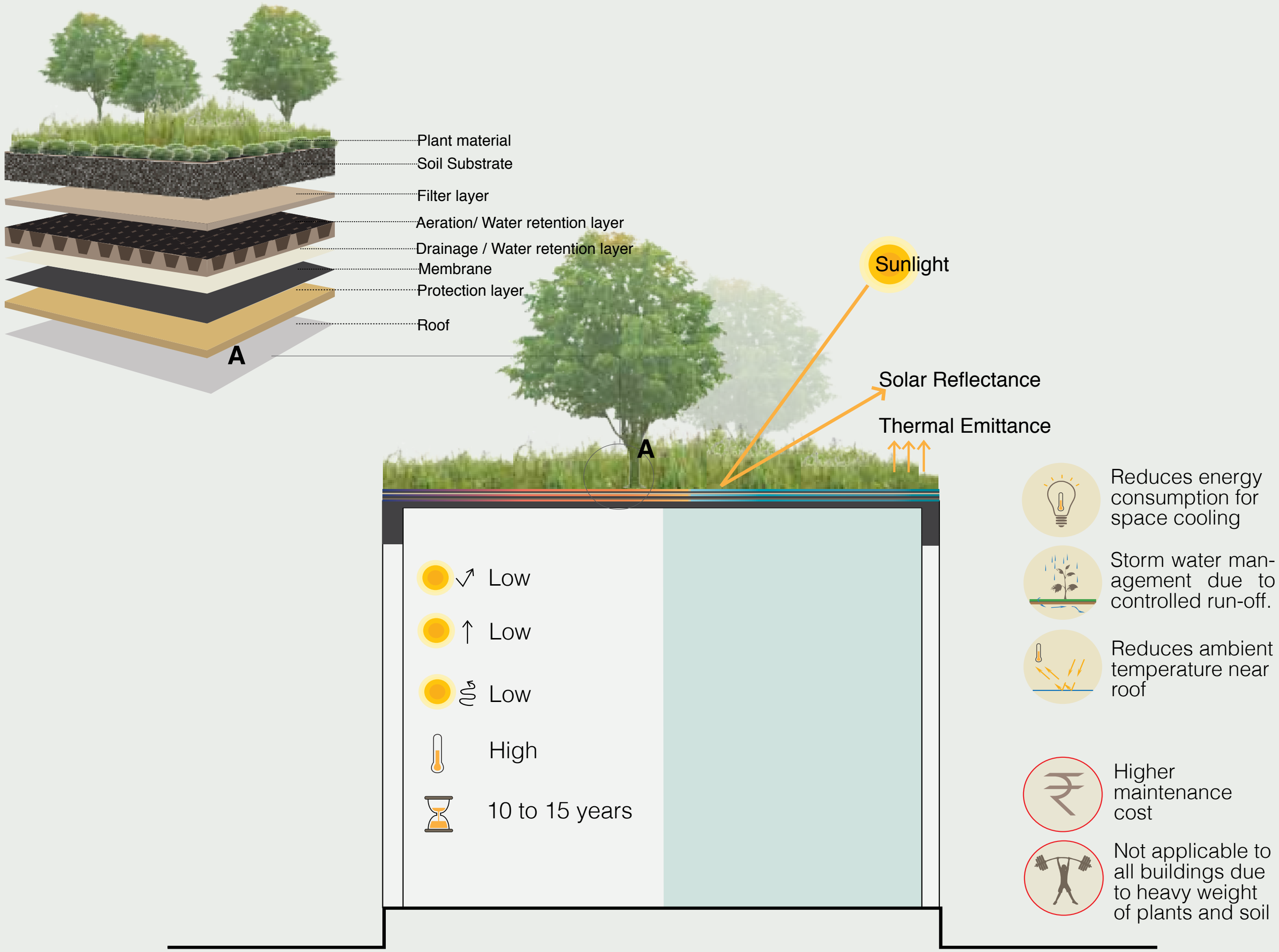
ROOF COOLING

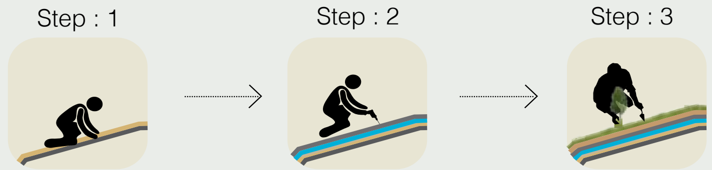
Intensive green roofs are like a garden on the roof with all kind of plants including trees and shrubs and are intended for human use.

Intensive green roof requires a reasonable depth (12 inches or more) of soil. It is heavy because of its depth and composition; the saturated weight load of an intensive roof ranges from 60 to 200 pounds per square foot. Costs for this type of green roof range widely depending on the actual soil depth, container types and amenities for public access. Such green roof is suitable for flat roof or roof with slope up to 4%.

Intensive green roofs generally require landscape maintenance, infrastructure such as a water collection system, irrigation, fertilization and provision for access and egress. Before applying intensive green roof, structural capacity of the building should also be investigated due to heavy weight of the plantations.

COOLING ROOF WITH NATURAL MATERIALS: INTENSIVE GREEN ROOF





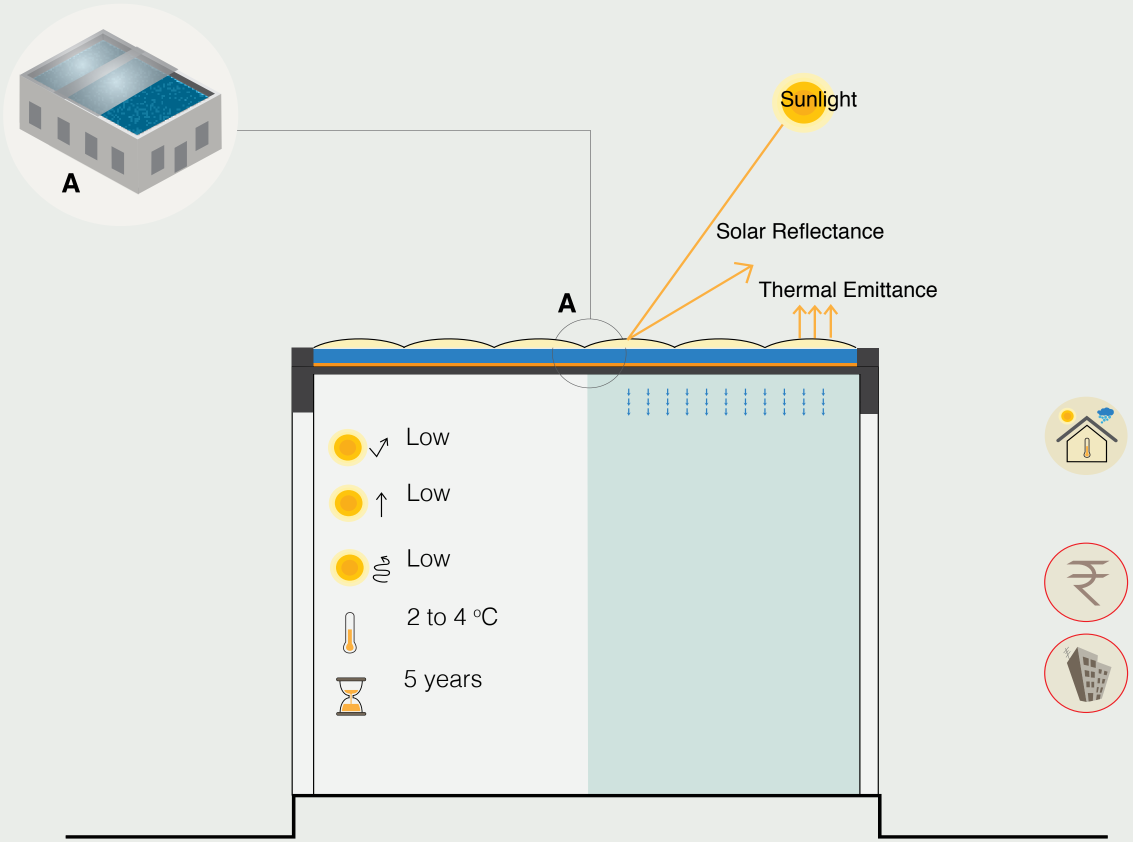
Apply membrane and protection layer on roof surface.

Fix the aeration and drainage water retention layers.

Put the layer of plants on top of soil substrate and filter layer.

References:
1. Reducing Urban Heat Island: Compendium of Strategies, Cool Roof by EPA, USA.
2. DDC Cool and Green Roofing Manual by New York City Department of Design and Construction.

ROOF POND COOLING SYSTEM OR RADIANT COOLING

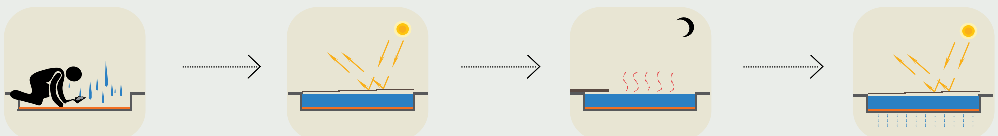


The system can be inverted during winters to heat the building

Additional cost of sliding insulated cover

Ineffective for multi-storey buildings, as spaces directly below the roof are benefited

Step : 1 — Step : 2 — Step : 3 — Step : 4



Step : 1 Make the roof slab water proof to prevent leakages.

Step : 2 Fill the roof with water and cover it with sliding insulating deck to prevent heating during day.

Step : 3 Expose the roof in night to cool the water.

Step : 4 The cooled water radiates coolness and acts like radiant cooling system during day.

ROOF COOLING

A roof pond cooling system uses stored water above the roof to mediate internal temperatures, usually in the hot desert climates. It is a passive indirect evaporative cooling system.

The system consists of an insulating material that can be moved over the roof of the building and is used to cover the pond. This system allows exposure of the thermal mass of roof i.e. water to the sky during night time, while during the day water is covered by an insulating layer to minimize heat storage in the thermal mass due to solar radiation. The evaporating water cools the building by conduction across the roof. Both indoor air and radiant temperatures decrease without rising indoor humidity

This kind of system can easily be used in residences and works very well in moderate, hot and dry climate. Flat slab or low sloped roof are appropriate for roof pond. In this kind of system, roof slab has to be water proofed enough to prevent the leakage of water.

References:
1. http://www.mcdberl.com/tech/Roof pond cooling system.pdf
2. Passive Cooling Technologies by Austrian Energy Agency.

ROOF COOLING

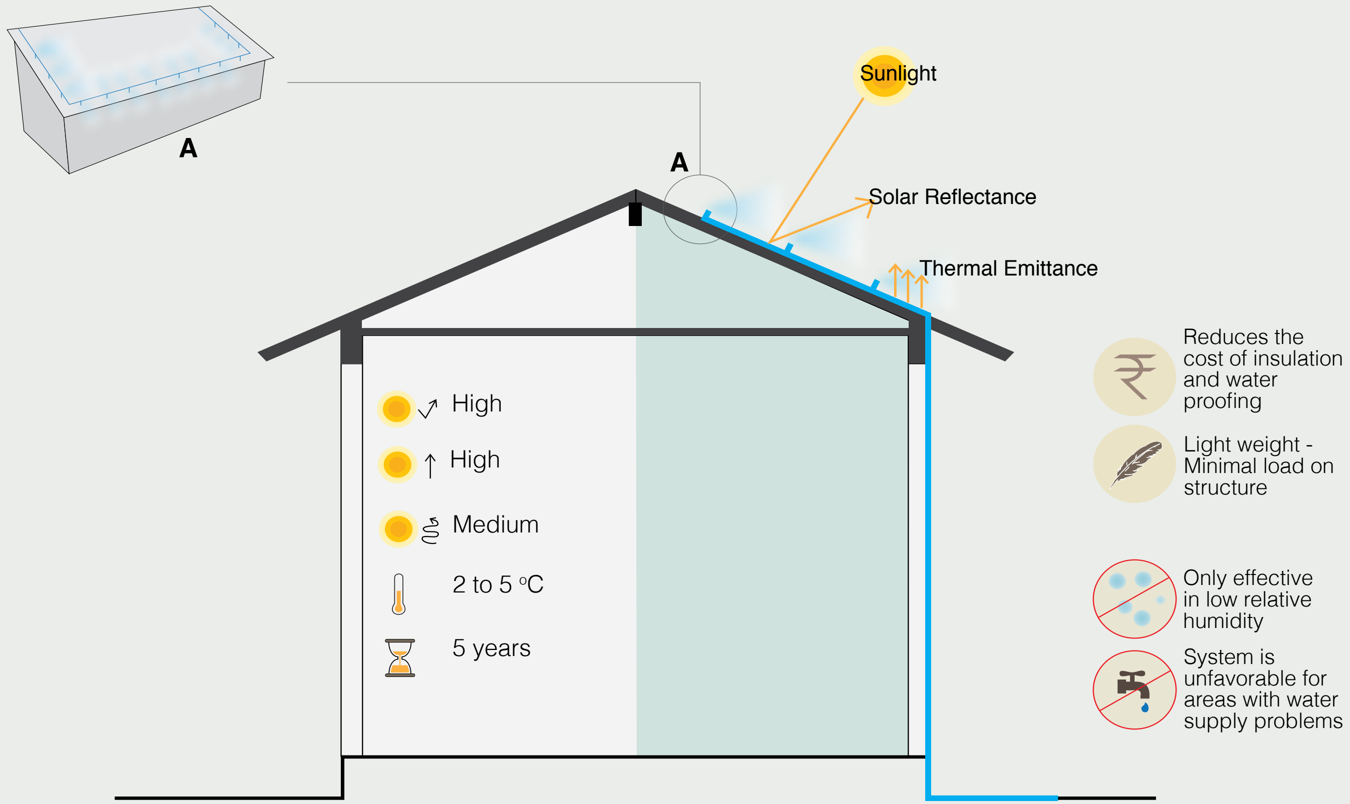
Evaporative cooling system, also called as roof mist cooling system reduces the roof surface temperature by spraying an extremely small amount of water across the roof. Spraying allows to cool the roof as the water evaporating from the surface captures the heat. This system works well in hot and dry climate as well as in moderate climate.

Cooling depends upon the amount of water evaporated rather than amount of water applied. The objective of a well designed evaporative roof cooling system is to spray appropriate amount of water on the roof, which will all evaporate.

If there is an excessive quantity of water, and it gets stagnated on the roof, the cooling action will be less efficient and the roof temperature will actually rise in those areas. This system is appropriate for both low and steep sloped roof.

References:
1. http://home.howstuffworks.com/home-improvement/construction/green/10-
2. Evaporative Cool Roofing: A Simple Solution to cut cooling costs, by Dick Abernethy.

ROOF MIST COOLING OR EVAPORATIVE COOLING SYSTEM

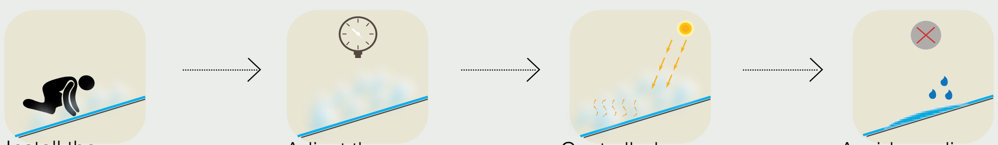


Step : 1 — Install the mist cooling system on the roof .

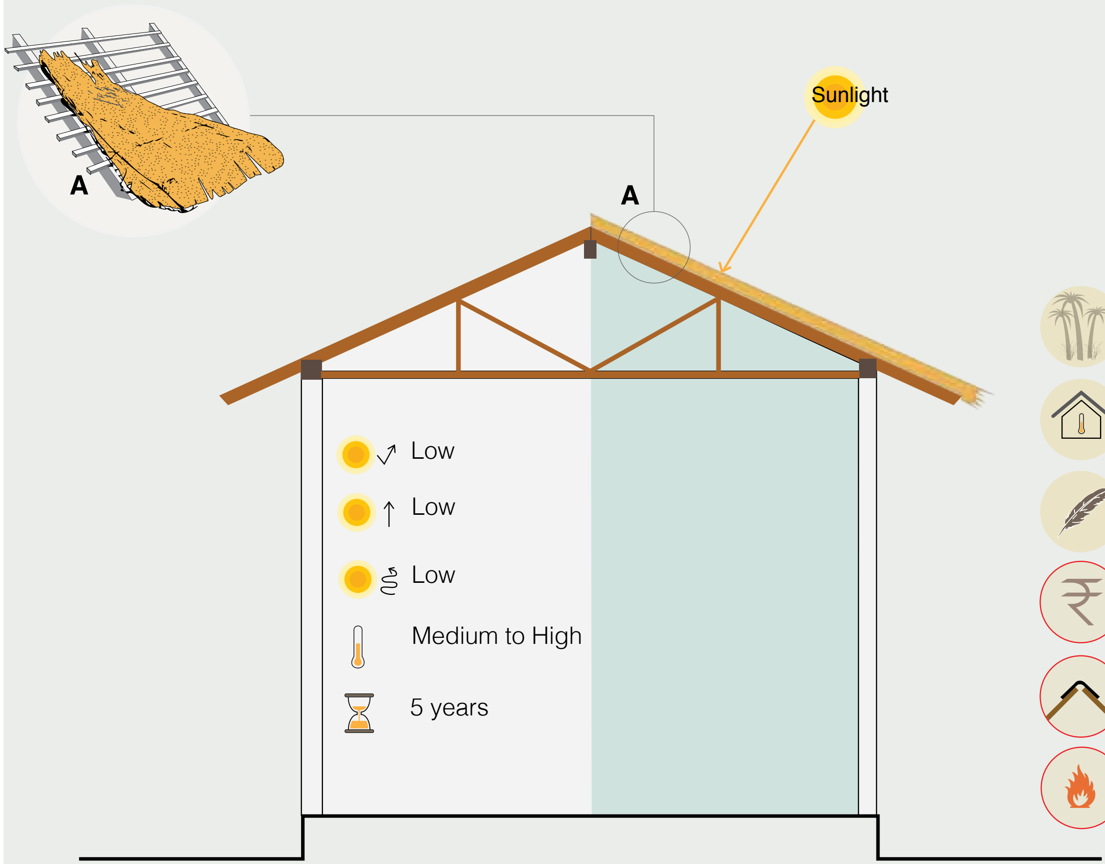
Step : 2 — Adjust the pressure of water to create mist environment.

Step : 3 — Controlled quantity of water is sprayed to ensure evaporation quickly.

Step : 4 — Avoid ponding of water on roof surface to prevent damage to roof.



COOLING ROOF WITH NATURAL MATERIALS: PALM THATCHING



- Materials are readily available
- High insulating capacity, maintains comfortable indoor temperature
- Light weight
- Comparatively expensive to hard materials
- Ridge is the weakest point of thatch roof
- Prone to fire risk.

Thatching is another way of roof construction using dry vegetation such as straw, water reed, wheat reed, palm leaves, coconut leaves, etc. It is a very old roofing method and has been used in both tropical and temperate climates.

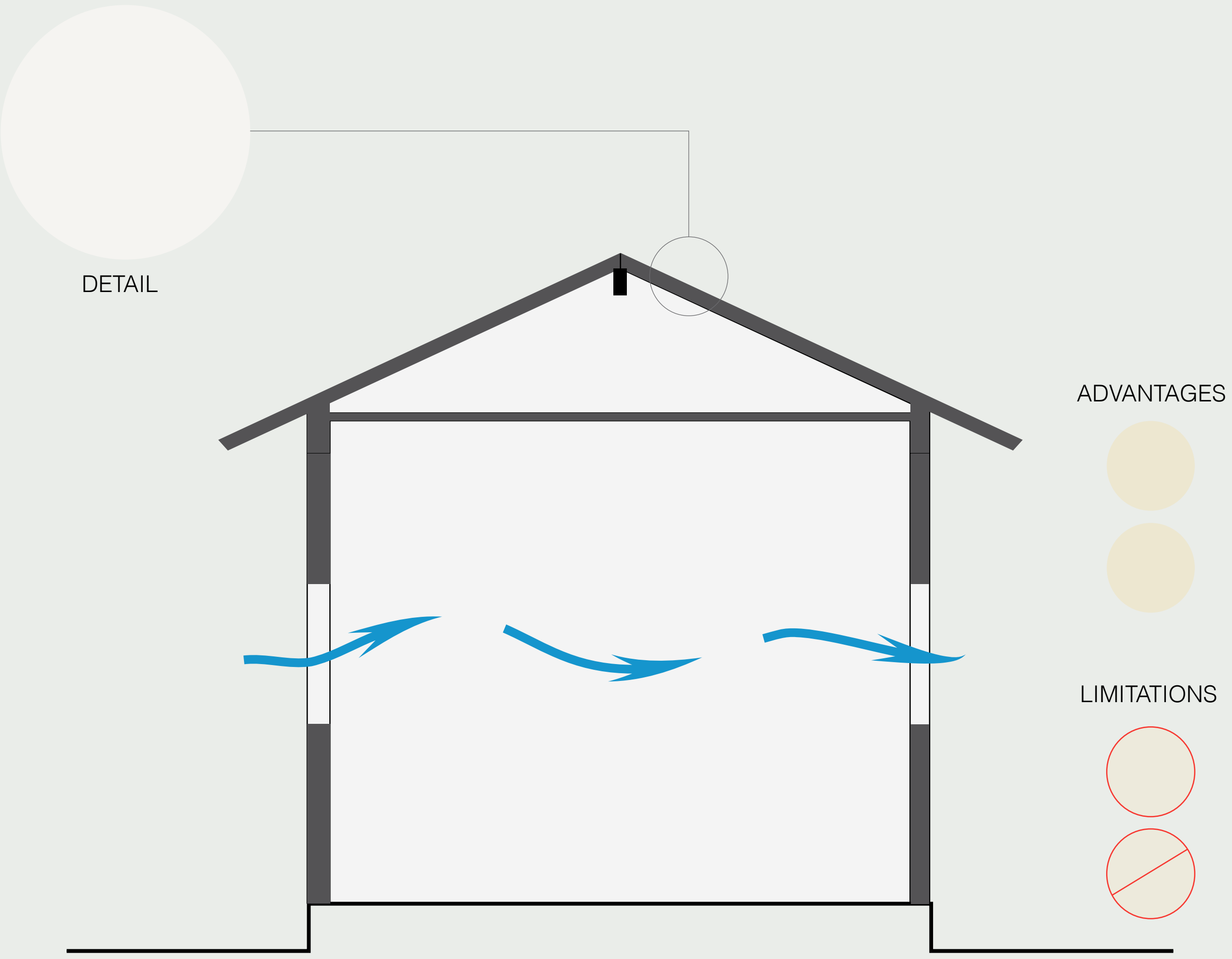
Maintained thatch also acts as a water proofing layer. Traditional deep thatched eaves will shed rainwater without the need for any down pipes or gutters. Thatch has a much greater insulating value than any other traditional roof covering. With the right choice of material and detailing, a well maintained thatched roof will keep a building warm in winter and cool in summer and has the added advantage of being sound proof.

A reed thatch with its strong quill like structure will allow greater air infiltration and heat loss than a long straw thatch where the straw is compacted by the action of threshing and is fixed fairly tightly against the roof.

References:
1. Energy Efficiency and Historic Buildings: Insulated Thatched Roofs by English Heritage.
2. http:// www.ehow.com/how 7259691 thatch-roof-palm-leaves.html
3. www.en.wikipedia.org/wiki/Thatching.

SECTION 5.2: PASSIVE VENTILATION

PASSIVE VENTILATION



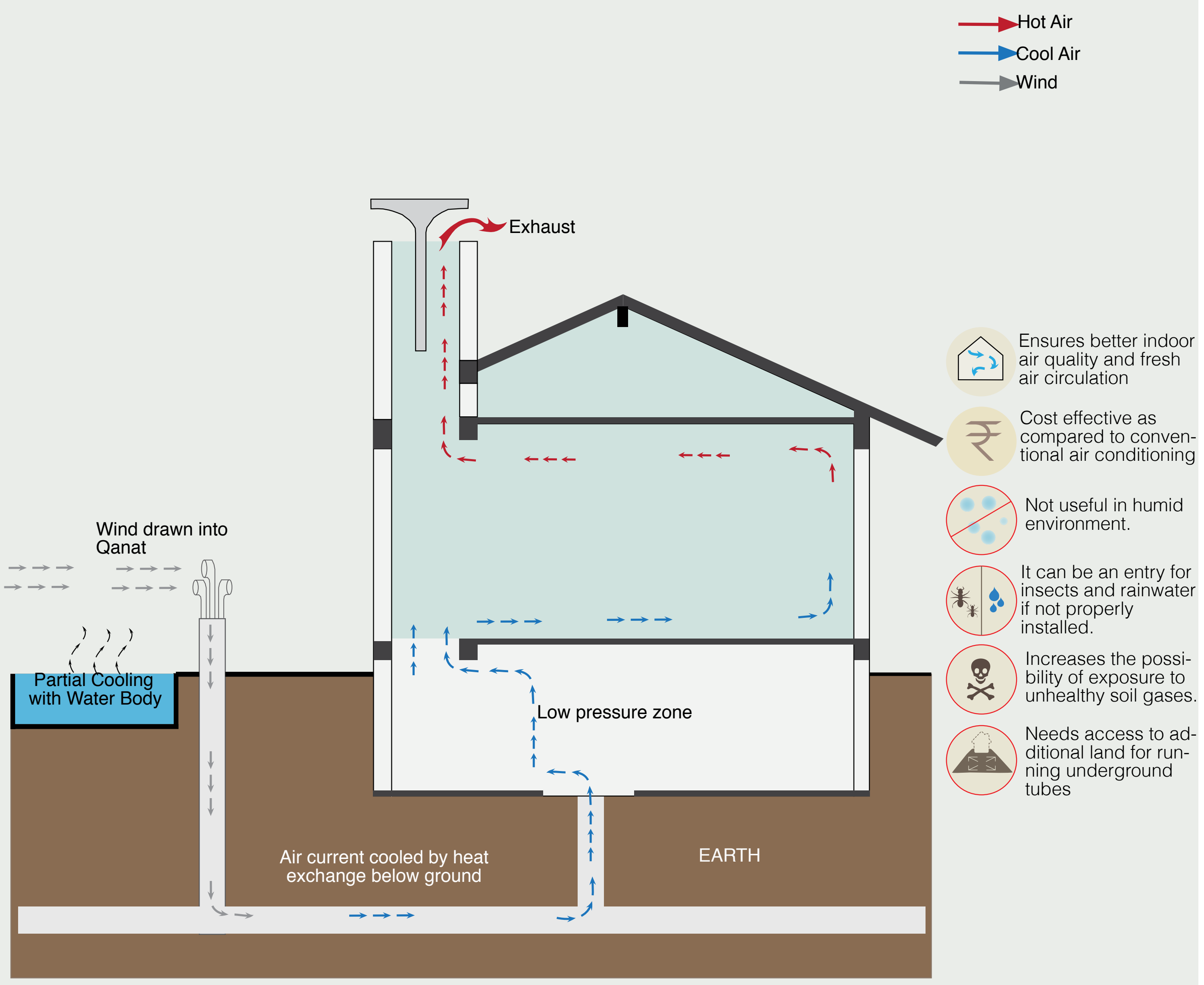
CONTENTS

PASSIVE VENTILATION

The use of earth as a heat sink or a source for cooling/heating air in buried pipes or underground tunnels has been a testimony to Islamic and Persian Architecture. At a depth of about 4 m below ground, the temperature inside the earth remains nearly constant round the year and is nearly equal to annual average ambient air temperature.

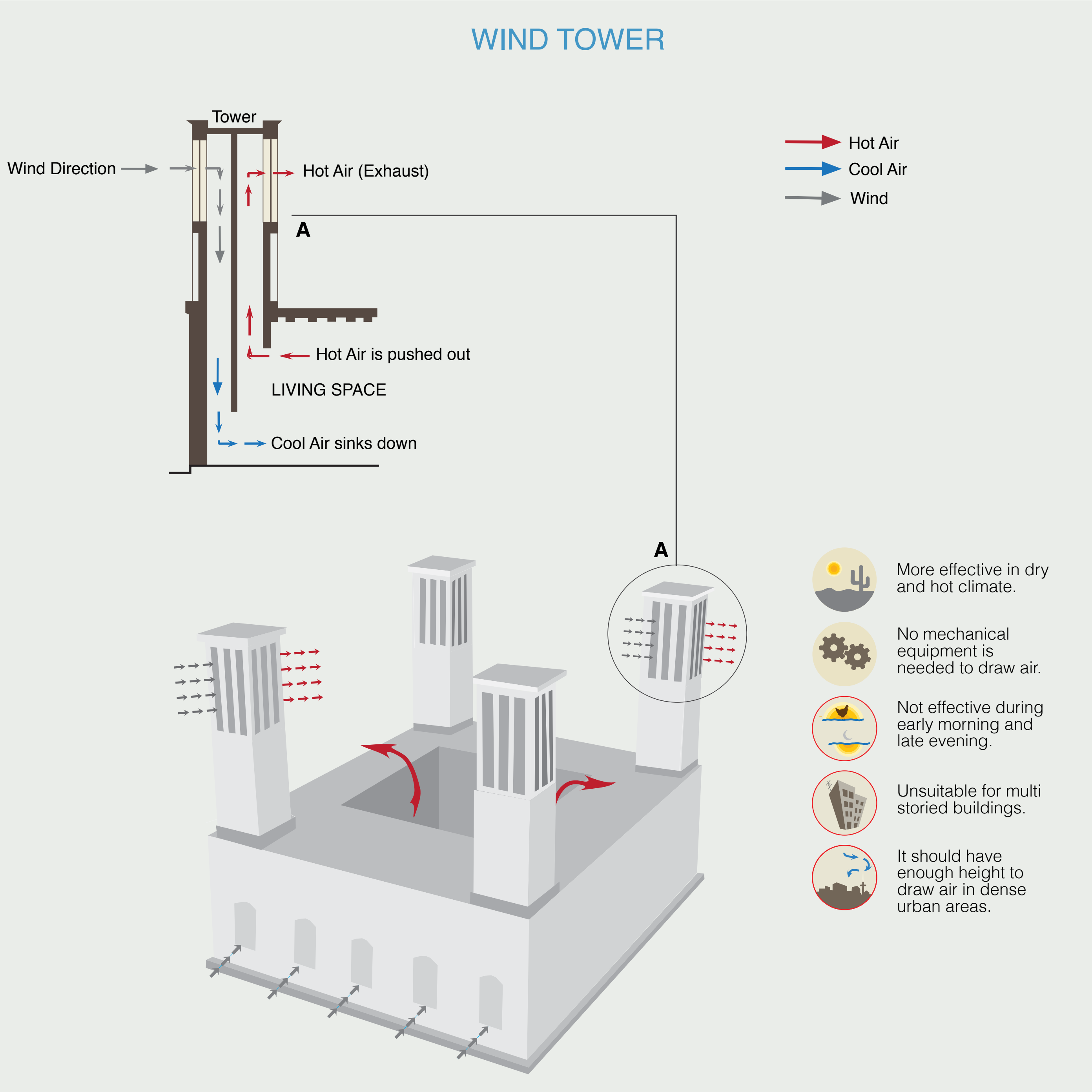
The air passing through a tunnel or a buried pipe at a depth of few meters gets cooled in summers and heated in winters. The length of the pipe is proportional to the area of the building that has to be air conditioned. The system can be designed as an 'open system', which draws outside air from a filtered intake or a 'closed loop system', which re-circulates the same air, or a 'hybrid system' which combines both processes. The earth acts as a heat exchanger for air that passes through this tunnel.

EARTH AIR TUBES



References:
1. Passive Cooling for your North Carolina Home by North Carolina Solar Centre.
2. Energy Efficient Solar Homes/Buildings, Ministry of New and Renewable Energy, Govt. of India.
3. http://www.earthairtubes.com

PASSIVE VENTILATION



Wind tower is a traditional Persian architectural system to create natural ventilation in the buildings. The top part of wind tower is divided into several vertical air spaces ending in the openings in the sides of the tower. The function of this tower is to catch cool breeze that prevails at higher level above ground and to direct it into the interior of the buildings.

In summer, the hot ambient air enters the wind tower through the openings, gets cooled and this becomes heavier and sinks down. In the presence of wind, air is cooled more effectively and flows faster down the tower and into the living area. Inlets and outlets in room induce cool air movement. After a whole day of air exchanges, the tower becomes warm in the evenings.

References:

1. An overview of Passive Cooling Techniques in Buildings: Design Concepts and Architectural Interventions by Mohammad Arif Kamal, AMU, India, 2012.

2. http://rmnathan.hubpages.com/hub/ Wind Tower An Architectural Element of Local Identity in UAE.

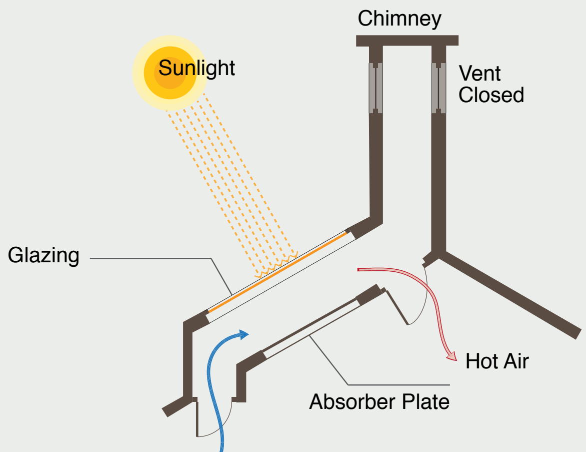
PASSIVE VENTILATION

Solar chimney operates on the principle of stack effect – if the warm air inside the building is allowed to escape from a vent at roof level, cooler air can be admitted through vents and windows at lowest levels to replace it. This movement is enabled by the solar chimney which is an exterior vertical duct open at the top and with vents connecting it to the building interior. To maximize the stack effect, the system makes use or a dark painted and partially glazed surface at the top of chimney or integrated into the roof, to heat outside air.

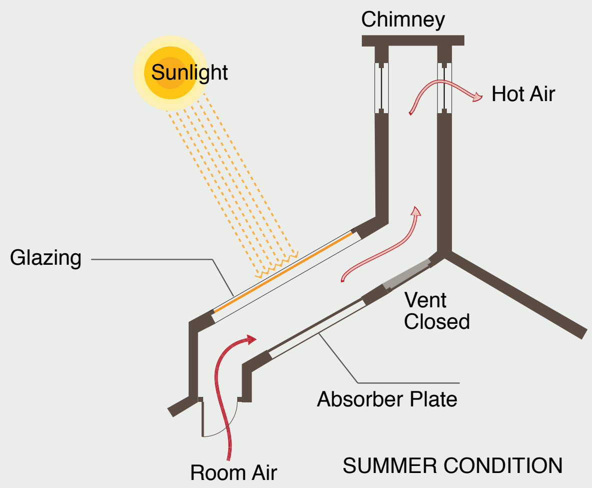
This system is better suited to low-rise buildings up to 4 stories, as there are practical limitations as to the size and geometry of the space that can be adequately ventilated by the stack effect or a solar chimney on its own. The system can work very well in combination with evaporative cooling hot and dry or Composite climate, wherein evaporative cooled air replaces the warm air which rises and escapes through the solar chimney.
If the ambient air is warmer than inside air, then continuous use of solar chimney will start heating the building inside. It can be designed for both summer and winter. External vents are closed during winter to circulate the warm air inside the building.

References:
1. An overview of Passive Cooling Techniques in Buildings: Design Concepts and Architectural Interventions by Mohammad Arif Kamal, AMU, India, 2012.
2. Passive Architectural Design Systems, Eco Housing Assessment Criteria - Version 2, August 2009.

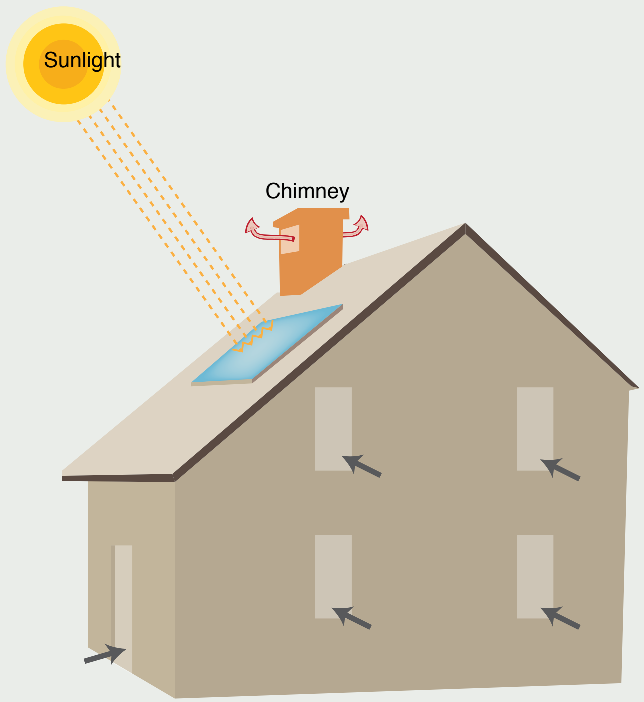
SOLAR CHIMNEY

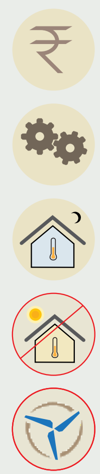


WINTER CONDITION



SUMMER CONDITION





Low cost solution.

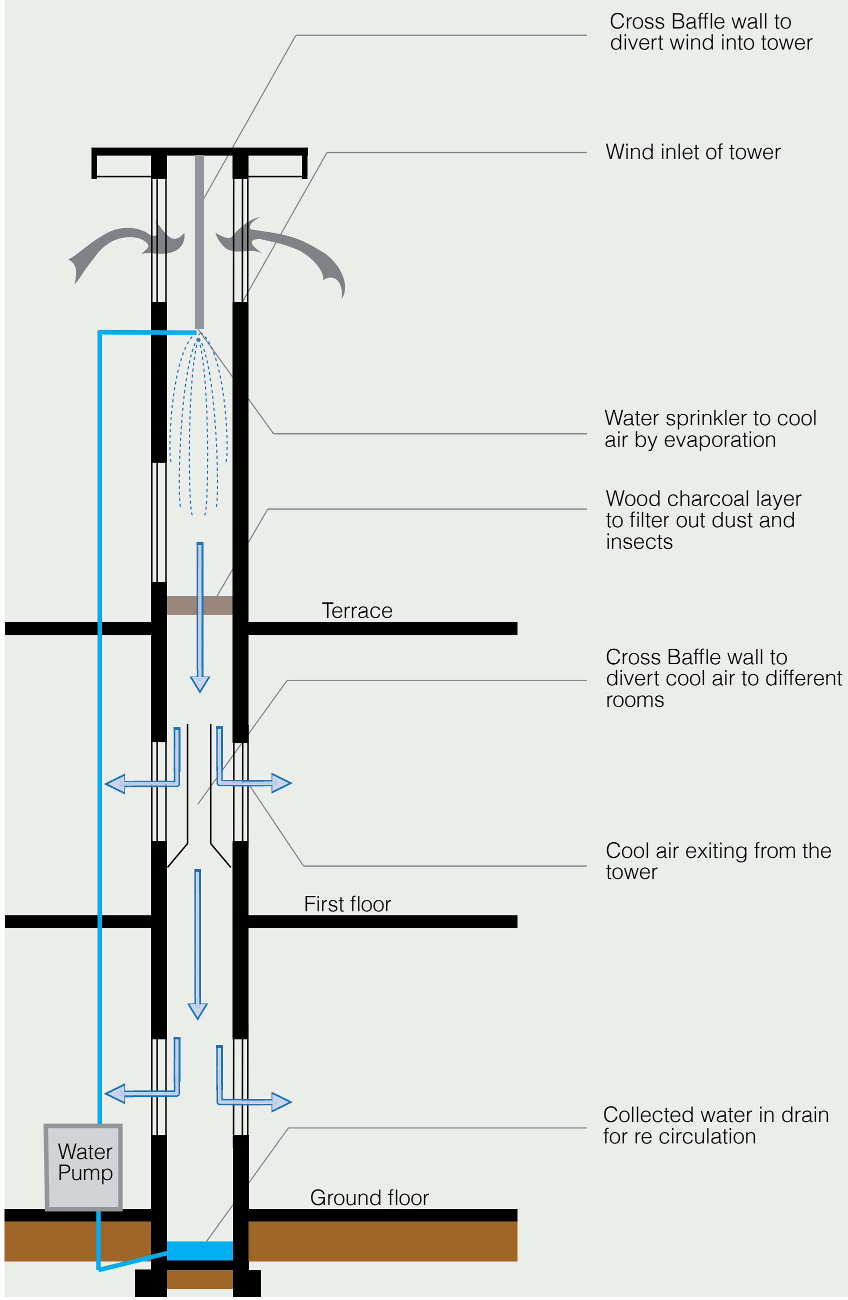
Doesn't need any mechanical equipment to draw air.

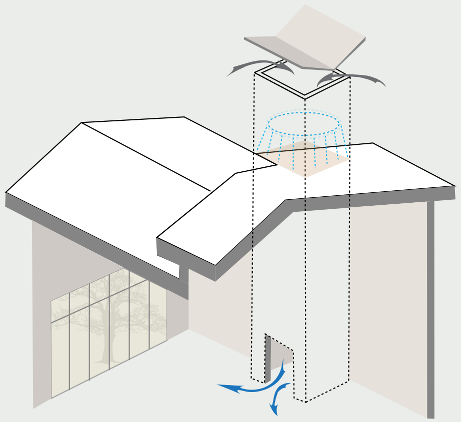
Helps in achieving comfort by cooling the building at night.

Not effective when outside temperature is warmer than inside.

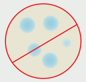
Advisable for low wind speed areas.

PASSIVE DOWNDRAFT EVAPORATIVE COOLING






Suitable in hot and dry weather


Doesn't provide comfort in a very humid region


Difficult to apply in arid zones due to water scarcity

PASSIVE VENTILATION

Passive downdraft evaporative cooling system consists of a downdraft tower with wetted cellulose pads at the top of the tower. Towers are equipped with evaporative cooling devices at the top to provide cool air by gravity flow. Water is distributed on the top of pads, collected at the bottom into the sump and re circulated by a pump. Certain designs exclude the recirculation pump and use the pressure in the supply water line to periodically surge water over the pads, eliminating the requirement for any electrical energy input.

These towers are often described as reverse chimneys. While the column of warm air rises in a chimney, in this case the column of cool air falls. The air flow rate depends on the efficiency of the evaporative cooling device, tower height and cross section, as well as the resistance to air flow in the cooling device, tower and structure (if any) into which it discharges.

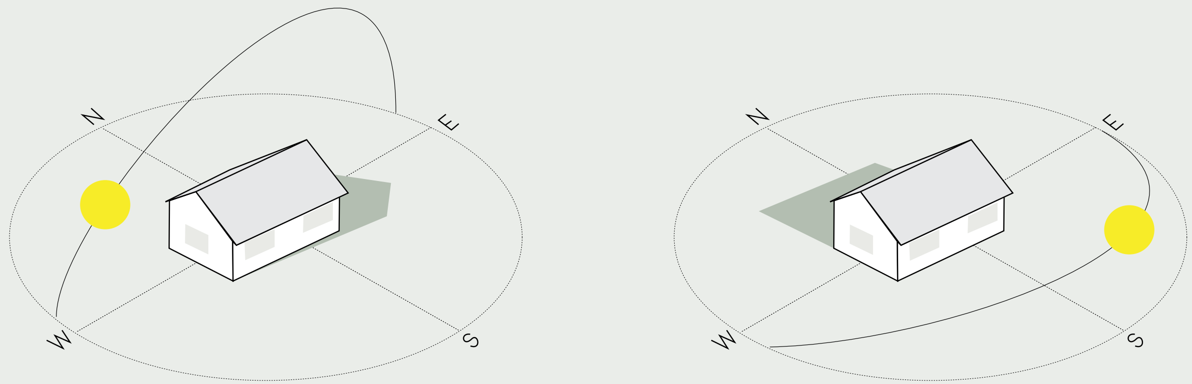
References:
1. An overview of Passive Cooling Techniques in Buildings: Design Concepts and Architectural Interventions by Mohammad Arif Kamal, AMU, India, 2012.
2. Passive Architectural Design Systems, Eco Housing Assessment Criteria - Version 2, August 2009.

PASSIVE VENTILATION

Orientation of the building plays a crucial role with respect to solar exposure and wind direction. Orientation affects the head gain through building envelope and thus the cooling demand of the building. Buildings should be oriented in such a way that they receive minimum solar radiation in summer and maximum in Winter. Non habitat rooms can be located on the outer surfaces to act as thermal barrier. Surrounding built form affects the daylight factor and air movement around the buildings.

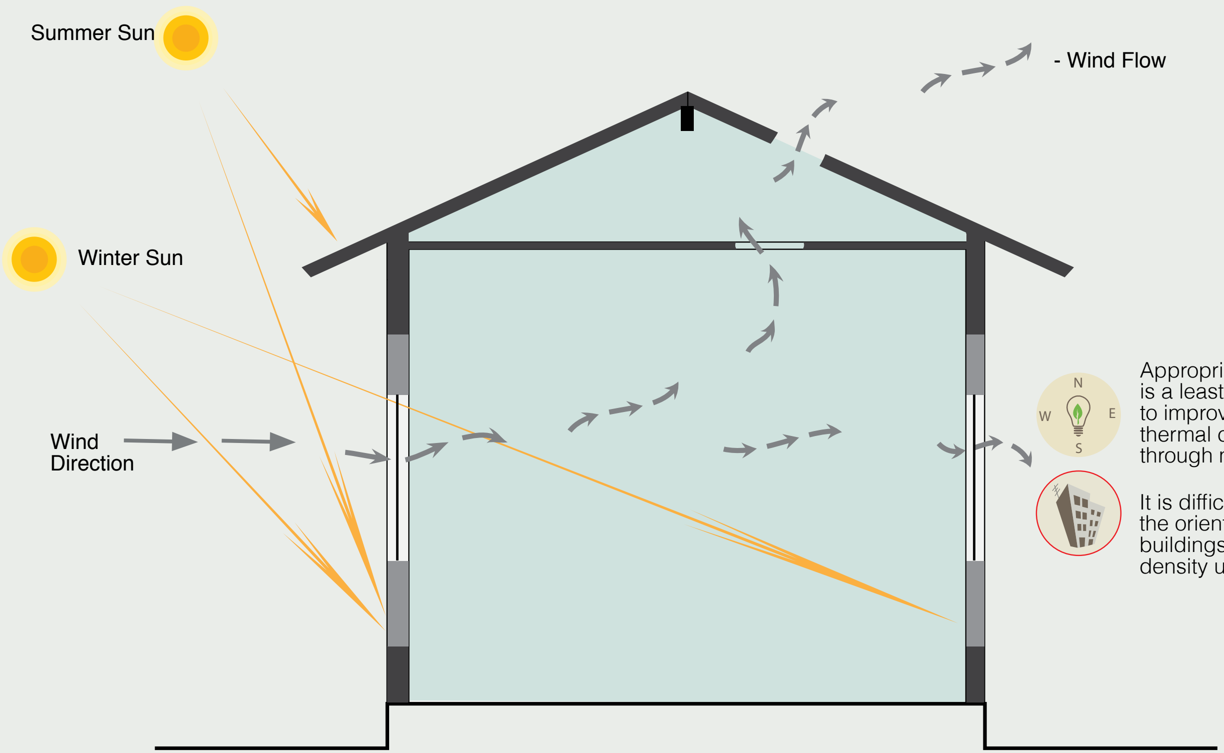
In a hot tropical climate like India, long facades on the buildings are preferred in the north south direction. Properly oriented doors and windows, while open provide the natural cross ventilation. More cooling can be obtained if air is forced to take the longer path between inlet and outlet. Smaller window opening for inlets and large openings for outlets increase the air speed and hence improve the cooling effects.

ORIENTATION OF THE BUILDING



Sun Path: Summer

Sun Path: Winter

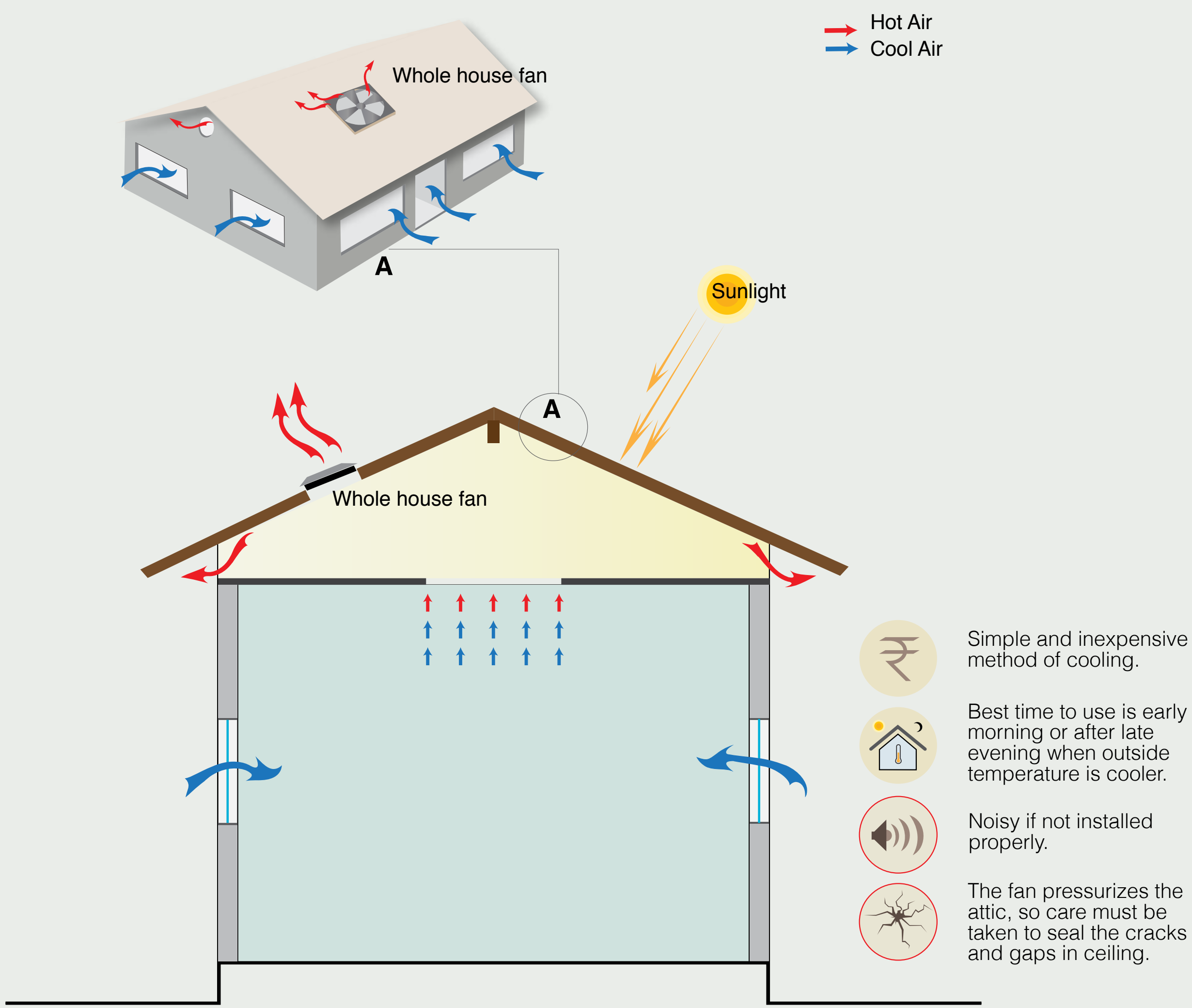


Appropriate orientation is a least cost measure to improve indoor thermal comfort through natural means

It is difficult to choose the orientation of buildings in high density urban areas.

References:
1.Passive Architecture Design Systems, Eco Housing Assessment Criteria - Version 2, August 2009.
2. An overview of Passive Cooling Techniques in Buildings: Design Concepts and Architectural Interventions by Mohammad Arif Kamal, AMU, India, 2012.
3. Alternate Home Cooling Methods by Platte River Power Authority, 2000.

ATTIC VENTILATION: WHOLE HOUSE FAN



ACTIVE VENTILATION

A whole house fan is a simple and inexpensive method of cooling a house for relatively dry climate where nights are cooler. It provides good attic ventilation in addition to the whole house ventilation. The fan draws cool outdoor air inside through open windows and exhausts hot indoor air through the attic to the outside.

In summer, the air inside a home is heated during the hot part of the day, while in morning, late evening and night, the outside air is often cooler and can be used to replace the inside air. Operating the whole house fan at these times will cool interior materials. A whole house fan can be used as the sole means of cooling or to reduce the need for air conditioning.

References:
1. http://www.pge.com/includes/docs/pdfs/shared/saveenergymoney/rebates/whftechsheetv5.pdf
2. http://www.builditsolar.com/Projects/Coling/eere%20Whole%20House%20Fan%20 26291.pdf
3. Alternate Home Cooling Methods by Platte River Power Authority, 2000.

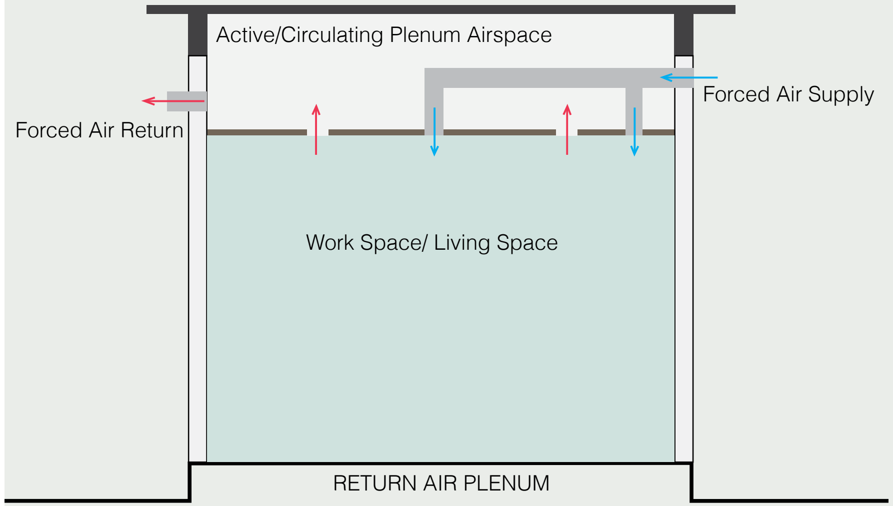
VENTILATION / INSULATION

False ceiling helps in both insulating and ventilating the space. Return Air Plenum method can be used to ventilate the space. The area between the roof and false ceiling acts as a buffer space. This space provides thermal insulation and also active plenum airspace. False ceiling lowers the heat load on HVAC cooling system and in turn reduces the energy costs.

Along with insulation and ventilation, false ceiling also increases the light reflectance in the space. At least 70% of the light is reflected from the suspended false ceiling. This helps to reduce the number of light fixtures in the space and hence brings down the lighting energy costs.

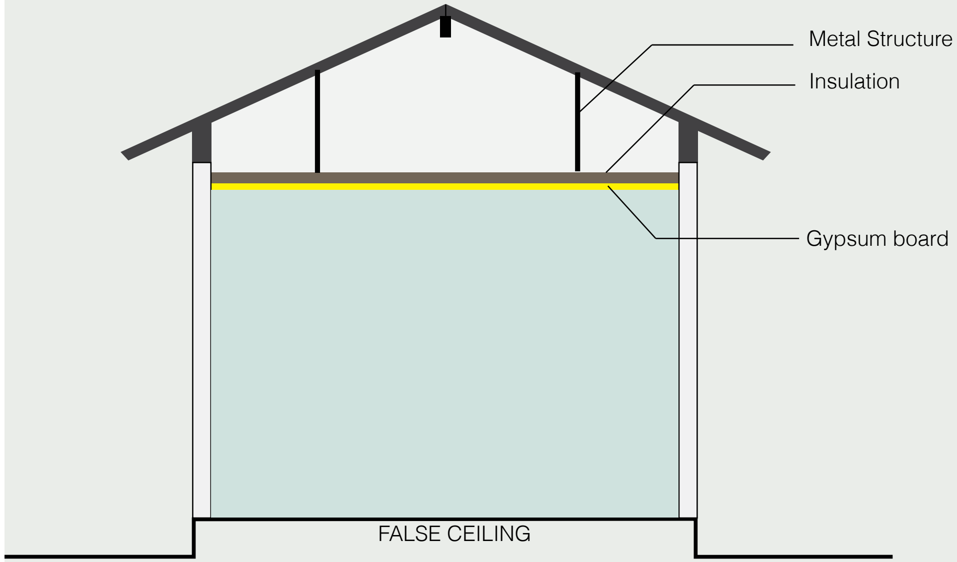
**HVAC: Heat Ventilation and Air Conditioning*

FALSE CEILING



RETURN AIR PLENUM

Reduces the heat load on HVAC system, thereby reduces the energy costs



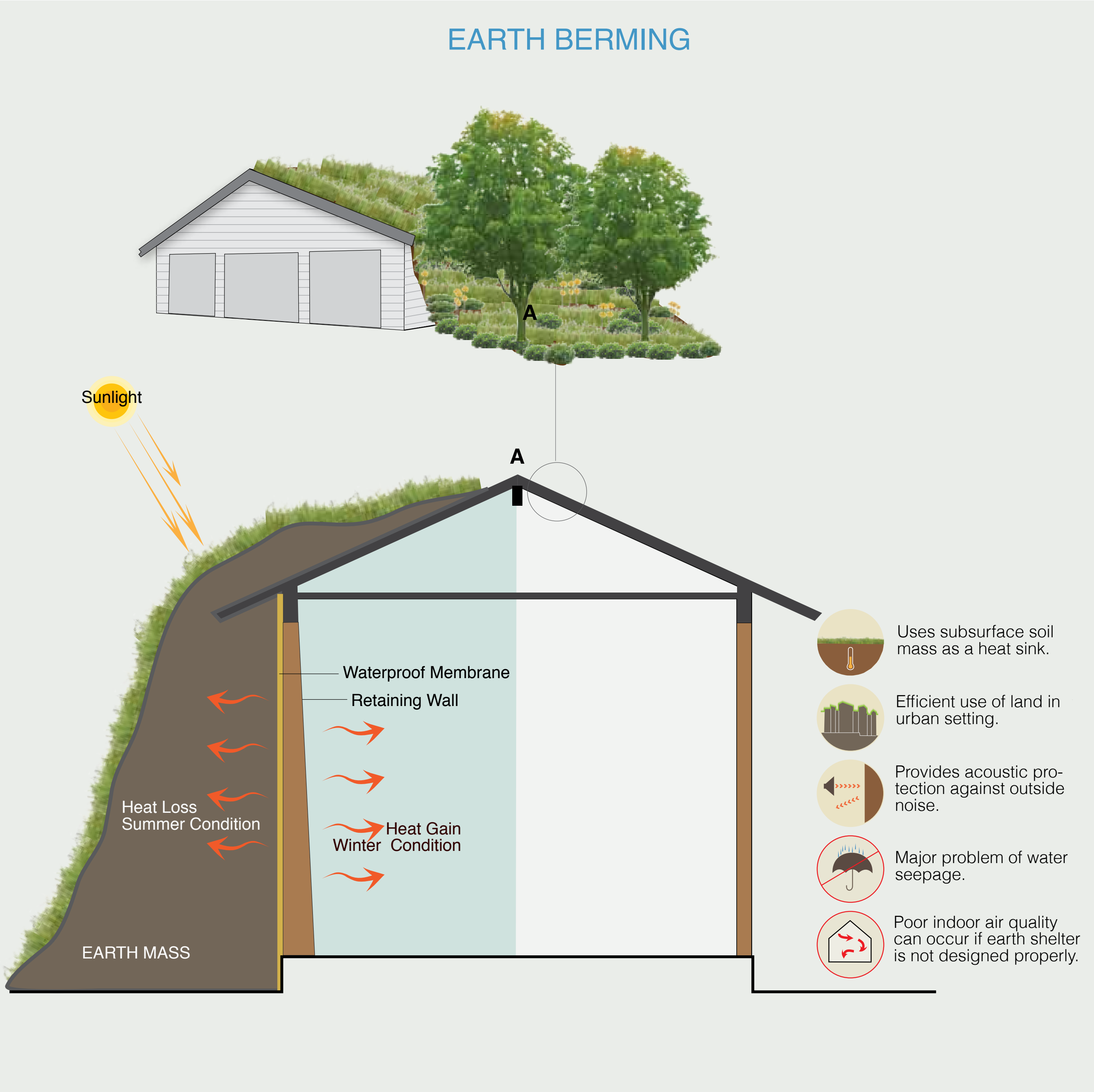
FALSE CEILING

Increased light reflectance in the space

Saves energy consumption for HVAC and lighting

Provides thermal comfort

References:
1. http://www.soundproofingcompany.com/soundproofing-solutions/soundproof-a-ceiling/



THERMAL INSULATION

This technique is used both for passive cooling as well as heating of buildings, a feature which is made possible by the earth acting as a massive heat sink. The earth sheltered structure has to be heavier and stronger to withstand the load of the earth and the vegetation above. Besides, it should be suitably waterproofed to avoid ground moisture and water seepage.

Summer as well as winter variations die out rapidly with increasing depth from the earth's surface. The temperature at the depth of few meters remains almost stable throughout the year. In an earth sheltered building or an earth bermed structure, the reduced infiltration of outside air and the additional thermal resistance of the surrounding earth considerably reduces the average thermal load. The cooler sub surface ground can by utilized as heat sink.

References:
1. http://www.newlearn.info/packages/clear/thermal/buildings/passive_system/earth_berming.html
2. An Overview of Passive Cooling Techniques in Buildings: Design Concepts and Architectural Interventions by Mohammad Arif Kamal, AMU, India, 2012.

THERMAL INSULATION

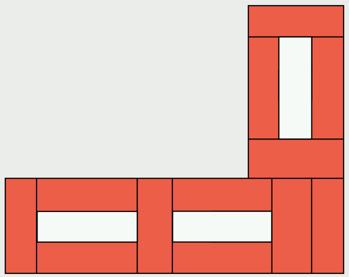
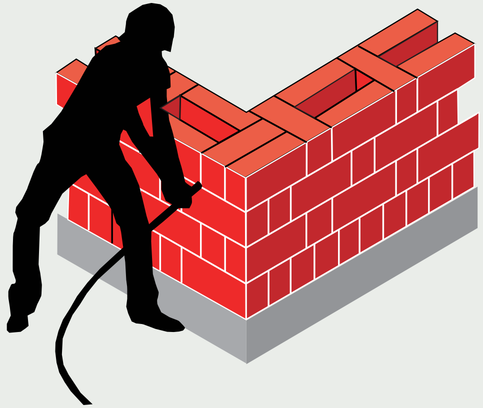
Rat-trap bond is a masonry technique in which the bricks are laid in such a manner that a cavity is formed between two faces of the wall. Typically, a 75mm cavity is formed in a 230mm thick wall. This technique offers advantages of both reducing the number of bricks by at least 20% and improving the insulating capacity of brick walls. Virgin materials such as bricks, cement and steel can be considerably saved upon by adopting this technology. It is possible to further increase the thermal performance of Rat-trap walls by insulating the cavity with foam insulation, thermocol, plastic waste, etc.

Rat-trap masonry should only be used where good quality bricks of minimum compressive strength 60 kg/cm2 and of neat edges are available. For the purpose of housing, this system can be used for as in-fill walls (in RCC frame) in multi-storied housing or as load bearing walls for simple double storeyed houses. Because of the cavity, chasing in masonry is not feasible, so, electrical and plumbing conduits should be planned in advance, prior to construction.

References:

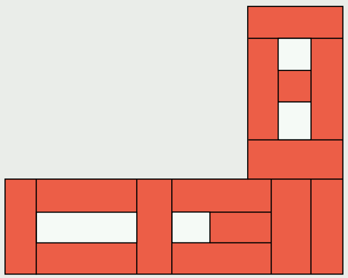
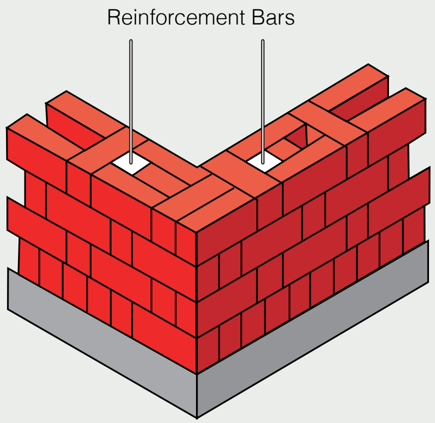
1. http://www.webstersinsulation.com/cavity.html
2. http://archnet.org/forum/view.jsp?message_id=162655
3. http://www.archidev.org/spip.php?article918)
4. http://sepindia.org/ihd-sep/ceeef-technologies/rat-trap-bond-a-masonry-technique

RAT TRAP BOND MASONRY

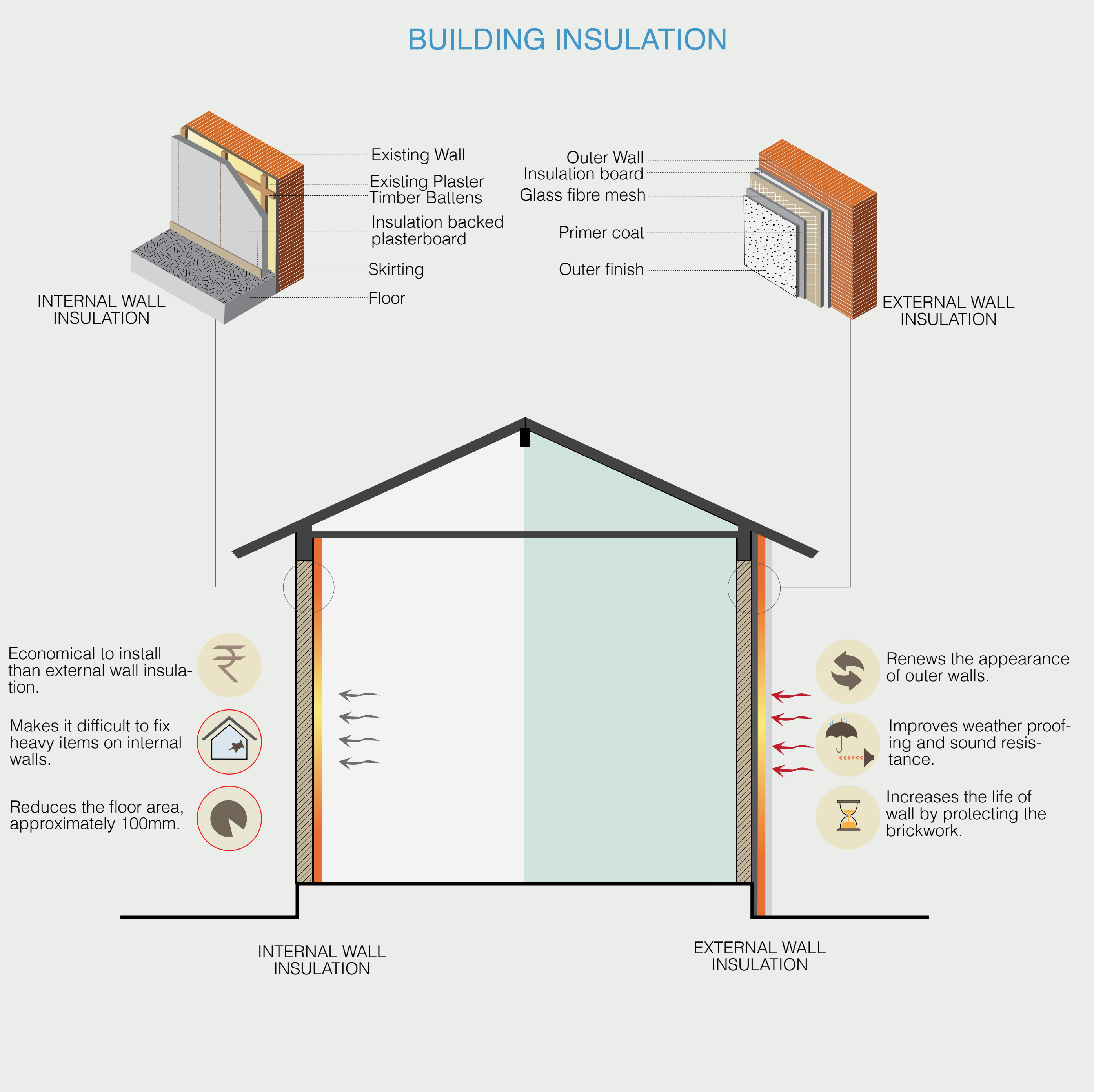
RAT TRAP BOND WITH FOAM INSULATION

- Less time consuming
- Water Resistant
- Maintains room temperature and Sound proof
- Reduces condensation
- Helps to stabilize two parting walls in a semi detached house
- Not suitable for multi-storyed/ load bearing structure
- Expensive

RAT TRAP BOND WITH CAVITY

- Reduces the cost of materials in construction
- Uses 475 bricks as compared to 550 per cum in conventional masonry
- Provides thermal comfort
- Can be used in multi-storeyed/ load bearing structure
- 20% less dead weight
- Building services like electrical, plumbing and drainage have to be planned in advance.



THERMAL INSULATION

Insulation is the most basic method of energy saving and increasing indoor environmental comfort and work on the principle of reducing heat gain and heat loss through the building envelope. Some commonly used insulation materials are mineral wool, extruded/expanded polystyrene, polyurethane foam and vermiculite, etc. R-values (or its inverse, U-value) are a measure of material's resistance to heat flow, and are used to quantify the insulating capacity of a material.

In hot climates, it is better to place insulation on the outer surface of the wall for a more effective de-coupling of ambient conditions with the building interior.

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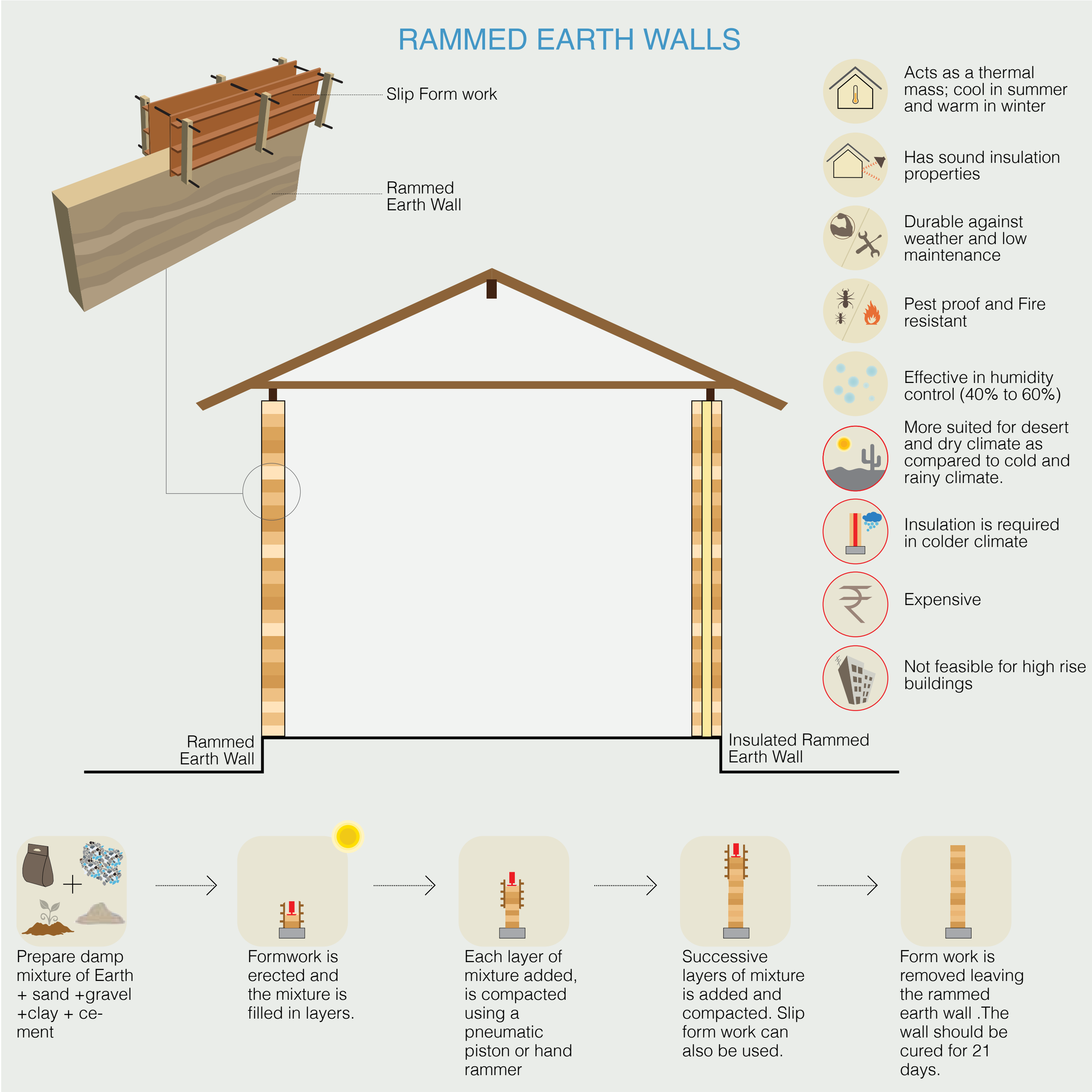
THERMAL INSULATION

Rammed Earth walls rely on their thermal mass to controlling extreme indoor environmental temperatures. They are more effective in extreme climates. Commonly, they are stabilized with cement for better resistance to water penetration and can also be coated with transparent silicon-based coatings for the same purpose. The thickness of these walls can be varied according to ambient conditions and space constraints. Rammed earth walls have excellent load bearing capacity and can obviate the need for framed construction. They are also one of the most environment friendly construction techniques.

For maximizing thermal performance, insulated rammed earth walls can be constructed. Rammed earth walls can easily have a life span of more than 20 years with the appropriate design considerations for water resistance in place. CSIRO tests showed that 250mm of rammed earth block wall achieved 4 hours fire resistance rating. It is difficult to construct the wall in rainy season.

**CSIRO: Commonwealth Scientific and Industrial Research Organization*



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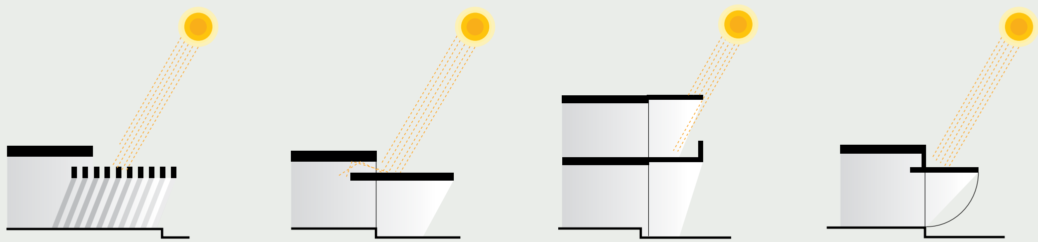
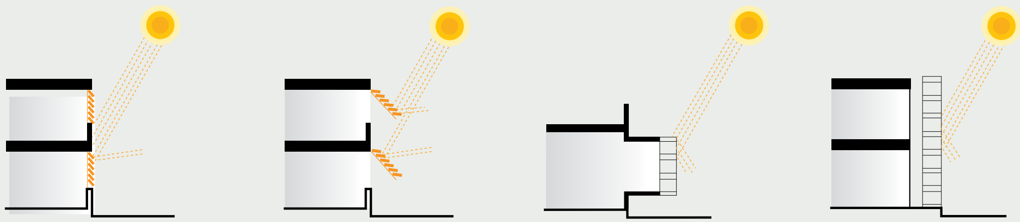
EXTERIOR SHADING DEVICES



Pergolas/Trellis | Reflected light | Balcony | Operable shutters

DIFFERENT TYPES OF OVER HANGINGS

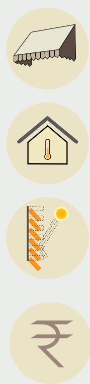


Louvers | Operable louvers | Window screen | Facade screen

DIFFERENT TYPES OF SCREENS

Awning | Venetian Awning | Rolling louvered shutter

DIFFERENT TYPES OF WINDOW SHADINGS



Awnings provide flexibility to span without need of extra support.

Properly installed awnings can reduce heat gain by 65% from south and 77% from east.

Adjustable louvers can control the sunlight entering into the building.

Least cost solution for cutting heat gain into the building

EXTERIOR SHADING DEVICES

Shading devices are an effective means of cutting down on solar heat gain into the building and thereby reducing the external surface temperatures of the envelope which can easily reach up to 10% higher than ambient temperatures in hot climates. Their effectiveness is maximized when placed externally, where they directly cut down on incident radiation striking the building envelope. They can be provided either by extension of the building shell or by utilizing the structural frame of the building to attach shading devices externally. The latter is a better approach because of the thermal break it provides, being detached from the building structure.

Exterior shading devices can be provided in a variety of materials and designs, including sunshades, awnings, louvres, bamboo screens, 'jaali', green cover through vines. These can be implemented with minimal cost implications and have the most favorable cost-benefit relation with respect to thermal comfort. This can further be improved if the devices are provided for western exposure, walls where it is difficult to block sun till late in the afternoon in summer season.

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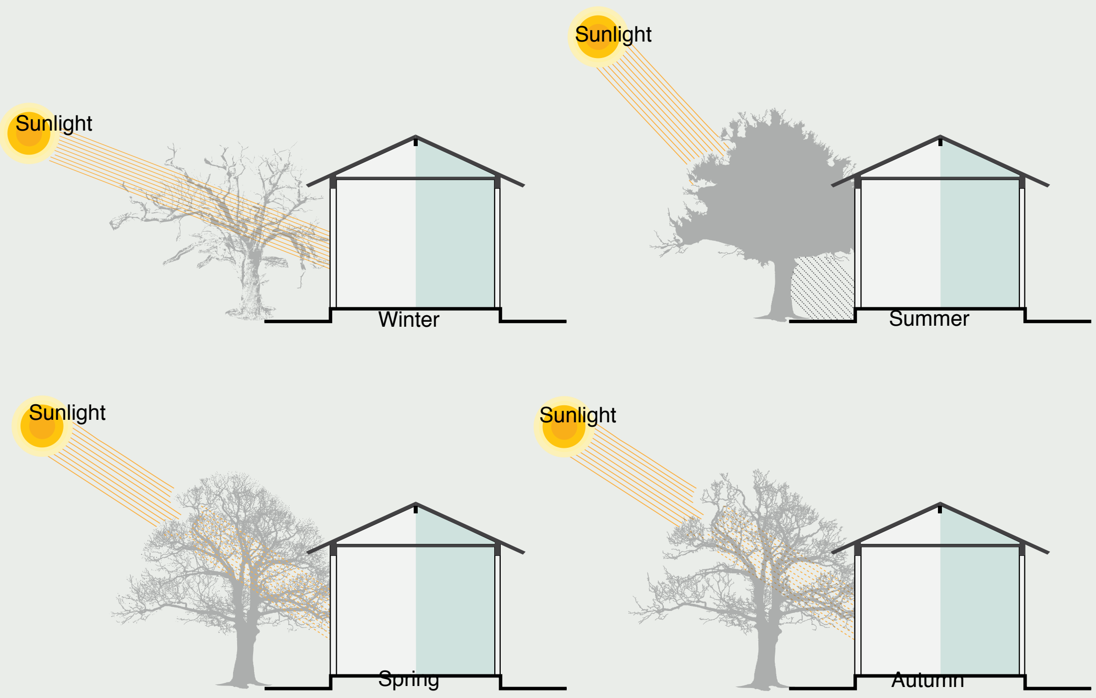
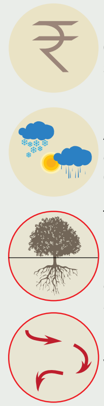
SHADING

Shading is one of the most simple and effective way to cool buildings by reducing the sun exposure to the building. Shading with trees (along with evapotranspiration) can reduce the ambient temperature near outer walls by 2^{o} C to 5^{o} C. Landscaping helps shade south, east or west facing windows from summer heat gain. It is better to avoid dense vegetation too close to a building as it can trap the air movement resulting in warmer ambient temperature near the building. Wall creepers, pergolas and trellis can also be used to shade windows and wall from the sun's heat.

It is appropriate option for thermal cooling of buildings in developing countries due to their cost effectiveness and easy implementation. Deciduous trees are the most beneficial in saving the energy cost as they block the heat in summers and allow heat to enter in the winter season as they start losing their leaves in autumn itself.

SHADING: LANDSCAPING





It is an economical solution.

Applicable for all weather conditions.

Trees with deep roots can damage building and associated structure.

Dense vegetation can make the air near the building warmer.

SHADING OPTIONS FOR WINDOWS AND WALLS

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