DESIGN GUIDELINES FOR GREEN ROOF SYSTEMS FOR COMPOSITE CLIMATE IN INDIA

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF ARCHITECTURE

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this dissertation report entitled **"DESIGN GUIDELINES FOR GREEN ROOF SYSTEMS FOR COMPOSITE CLIMATE IN INDIA"** in partial fulfillment of the requirement of the award of Degree of Masters of Architecture submitted in the Department of Architecture and Planning, Indian Institute of Technology, Roorkee is an authentic record of my own work carried out during the period of June 2008 to June 2009 under the supervision of **Dr. Mahua Mukherjee** and **Prof. R. Shankar,** Department of Architecture and Planning, Indian Institute of Technology Roorkee, Roorkee.

The matter embodied in this Dissertation has not been submitted by me for the award of any other degree.

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ABSTRACT

The environmental, social and visual contributions that green roofs can make towards sustainable living in high-density cities are widely acknowledged worldwide. Green roof is one such sustainable approach, use of which helps us in *insulating* the buildings and, thereby contributing to better energy efficient performance of the building. Green roofs also provide habitat to different species, reduce the rainwater runoff and better manage the carbon-dioxide cycle. Despite these benefits, 'Green roofs' are not as common a feature in India as they are in other European and American cities. In this dissertation an effort has been made to sensitize about the advantages of this technology in India.

The dissertation has extensively dealt with literature survey in Chapter 2 on origin of green roof, its benefits and constraints for the community and private sectors. A description of the climatic conditions and other environmental factors affecting the application of green roof, latest international, regional concepts, and approaches, including policies on green roofs is discussed.

Chapter 3 critically reviews green roof types in different setting and with different purpose to assess the current context of the same in India. The objective of the Study in Chapter 4 is to conduct a quick review of the composite climate zone in India and its characteristics. In later part of this chapter, latest concepts on green roof, material specifications, maintenance consideration has been detailed out with an objective of analyzing cost factor for green roof in India.

Discussion about the potential location for green roofs in New Delhi as a case and prevalent roof type scenarios in Indian context has been elaborated in Chapter 5. In this chapter, potential areas for green roof opportunities are identified, drawn and elucidated with the help of illustrations. Through this, technical constraints, uncertainty and risks are identified for application potential of green roof for composite climate in India.

This dissertation is summarized by evaluating a wide spectrum of building typologies in terms of criteria like economic viability, sustainability, acceptability, durability, adaptability, suitability (climatic), maintenance, affordability, aesthetics etc., to arrive at an *'Appropriateness Matrix'* and Guidelines for the available green roof technologies and policies recommendation for select area in India.

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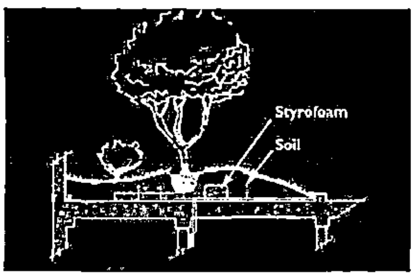
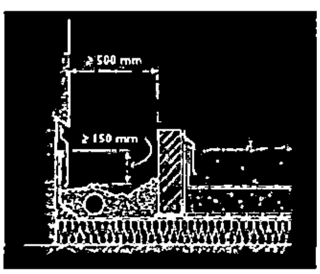
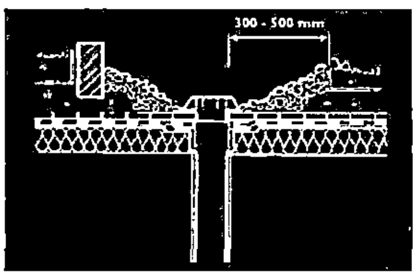






1.1 PREAMBLE

"A green roof is a roof of a building that is partially or completely covered with vegetation and soil, or a growing medium, planted over a waterproofing membrane"[1]

The origin of Green roof technology has been limited to indigenous architecture of European cultures particularly in a temperate climate zone. Reminiscence of this technology can still be traced in the Scandinavian settlements for its advantages. Vernacular variations of this technique have been adopted for varying purposes like insulation, fire proofing (which was extensively found in German villages in late 18 century). In India rudimentary green roofs can be found at different places of Himalayan states.

'*Green roofs*' are also referred as *Eco-roofs*; *vegetated roofs* and *living roofs*. Greening of our building rooftops helps us in *insulating* the buildings, provide *habitat to different species, reduce the rainwater runoff, and provide 'extra' usable space*. Green roofs have been classified into *three* types on the basis of their technical details; *Extensive Green Roof; Intensive Green Roof and Semi-intensive Green Roof.*

In this dissertation an effort is made to critically review technical details of the Green roof technology and applicability of the same in a composite zone. With the help of this analytical review, an *'Appropriateness Matrix'* would be formulated based on numerous permutations of building typology and technological variants. A select combination shall be undertaken to elaborate this exercise and suitable guidelines shall be eventually proposed for this identified set (typology, technique, climate, economy).

1.2 DEFINITIONS OF GREEN ROOF

Brownlie (1990) describes a roof garden as "*An area of usually ornamental planting with a substrate isolated from the natural ground by a man-made structure of at least one-storey*".

Grant et al. (2002) extends this to include "*Roofs that have been initially planted and/or so sown, as well as those that have been allowed to colonize and develop naturally*". Grant et al.'s extension of Brownlie's definition.

The term green roof is cited in this report is taken to mean a roof either purposely planted or where vegetation has been allowed to colonize naturally rather than a roof with environmentally friendly features like photovoltaic. Vegetated rooftops where the growing medium is isolated in specially raised containers such as plant pots and '*Earth-sheltered'* structures where vegetation forms a continuous layer between the roofs and the ground (as at the Eden Project in Cornwall, UK) are excluded.

Figure1.1. Earth Sheltered Building

Source: http://www.recklessgardener.co.uk/gardenvists/cornwall/eden_project.jpg

1.2.1 Extensive

Also known as eco-roofs, extensive roofs are low profile with thinner layers (drainage, media, and plants) than semi-extensive and intensive green roofs.

Low growing plants are established in eight inches to six inches of growing media.

These rooftops are usually less expensive and lower maintenance when compared to other types of green roofs [2].

1.2.2 Semi-extensive

These green roofs are designed to be low maintenance, but with deeper layers (drainage, media, and plants) than extensive but not as deep as intensive. Typical layers range four to eight inches. A larger variety of plants can grow on this roof when compared to an extensive roof [2].

1.2.3 Intensive

Intensive green roofs have the deepest layers (drainage, media, and plants) and a wider plant variety. The growth media is eight to twelve inches in depth.

Many intensive roofs are designed to be at least partially accessible.

1.2.4 Eco-roof

Synonym for "Green roof". Also used to distinguish vegetated roofs from roofs that have another ecological function, for example, a roof covered with photovoltaic cells[2].

1.2.5 Brown roof

A roof purposefully covered with substrate or a loose material such as urban development by-products like brick rubble, crushed concrete, and sub-soils. Vegetative colonization of the roof is possible but occurs without human intervention (Dunnett, 2004).

1.2.6 Vegetated roofs

The term *vegetated roofs* is a more precise but at the same time less restrictive description of the system, as it focuses on the fact that the system includes vegetation and that it is installed on buildings,"[3].

1.2.7 Plant-based Surface Systems

"An alternative scientific term, *plant-based surface systems* (PBSS), has been proposed by Tapia Silva *et al.* (2006)."

1.2.8 Rooftop Gardens

Rooftop gardens are accessible areas on the roof with containerized plants instead of layers of membranes and growth media that are installed directly on the roof deck [2]

1.3 NEED FOR STUDY

The phenomenon of rapid urbanization in India has resulted in urban sprawl and increased urban densities; this increase in urban density causes a reduction in urban open spaces, localized concentration of pollutants in the air and water, more and more energy consumption, more demand of recreational spaces, and increase in noise pollution due to vehicles. Urban sprawl also results in permanent loss of valuable agricultural land.

All the issues discussed above can be alleviated by incorporating Green roof in both new and existing structures. Greening of our buildings helps us in *insulating* the top of buildings and, thereby contributing to energy efficiency of the building. It also helps in replacing lost habitats in urban areas as well as provides other benefits associated with green space like removing particulates from the air and water, 'fixing carbon', lessening the 'urban heat island effect', reducing surface water run-off, controlling noise and thermal stress better and benefiting to human health. It can also provide new opportunities for 'urban agriculture'. In totality it will be helpful in long run for creating a '*liveable cities*'.

Green roof technologies are widely adopted to harness both the environmental benefits as well as a extra garden space within a manageable maintenance budget.The design and construction of green roofs aspires to compensate for the dying '*Habitats*' and '*Niche*' in urban areas.

Green roofs, selection of appropriate type depends upon the following factors viz. Location, climate, building typology, architecture design and user characteristics. Issues like economic viability, sustainability, acceptability, durability, adaptability, suitability (climatic), maintenance, and aesthetics are the key criteria for evaluating technological performance of the same.

Benefits of green roof are well acknowledged and established fact; most of the developed countries have initiated in establishing comprehensive experimental studies on green roof[4]. Comparatively similar efforts are limited (Kumar and Kaushik, 2005). The need for a comprehensive study on green roof in Indian context has been strongly felt.

1.4 AIM

To frame guidelines on green roof for composite climate of India

1.5 OBJECTIVES

With the aim to frame Guidelines for Green roof, in India, following objectives have been identified

1. To understand concept of green roof, its typologies and green roof technologies.
2. To critically evaluate the potential benefits, implementation barriers and applicability of Green roof technology.
3. To identify and compare literature and live case studies of various types of Green Roof.
4. To draw inferences on appropriateness of green roofs in Indian buildings.
5. To formulate the design guidelines for green roof in buildings for Indian climate.

1.6 METHODOLOGY

In order to achieve the above stated objectives; following methodology will be adopted

A. Identification of problem

B. Featuring Literature review to understand the following

1. Composite climate and their impact at planning level and building level.
2. State of art reviewing of Green roof technology, its benefits and application.
3. To understand the thermal benefits of rooftop gardens in composite climate.

C. Case studies to understand

1. Available construction technique
2. Available maintenance paraphernalia for growing medium, vegetation structure, and location of each type.
3. Suitability analysis for various types of green roof technology

D. Inferences in terms of

1. Potential assessment of green roof for composite climate.
2. Its applicability in Indian context.

E. Formulation of 'Appropriateness matrix'.

F. Formulation of Design Guidelines for composite climate based on Appropriateness matrix.

G. Recommendations and conclusions.

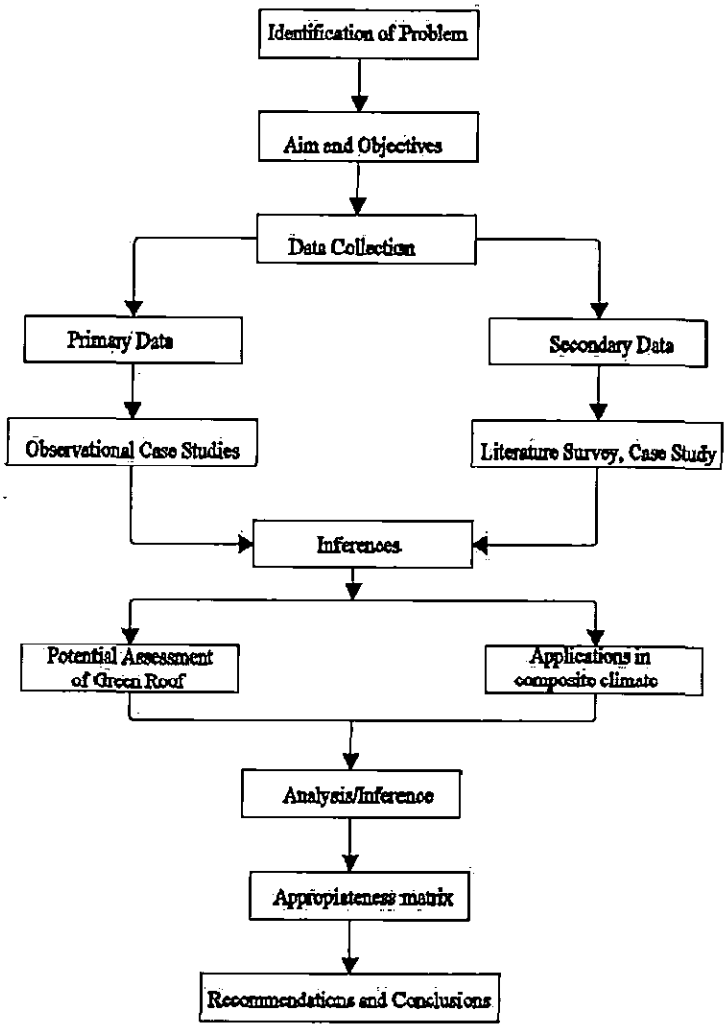


Figure 1.2 Image showing methodology graph

Source: Author

1.7 SCOPE AND LIMITATIONS

1.7.1 Scope

1. Scope of this study is to explore strengths and weakness of green roofs concepts, its technologies and details.
2. This study would also explore Green roof as an efficient tool to achieve energy efficiency.
3. Green roofs can also be productive in urban agriculture.

4. India has many climatic zones. The present study would concentrate primarily on composite climatic conditions.

1.7.2 Limitations

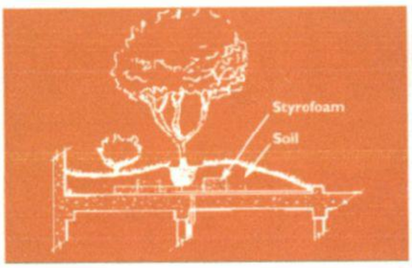
1. Work is limited to the study of only green roof; cool roof, roof pond etc., other viable alternatives would not be explored.
2. The extent of study is limited to the study of only composite climate of India.
3. The scope of study is limited to the low to mid-rise buildings.

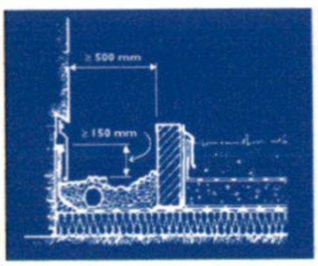
1.8 ORGANISATION OF THE DISSERTATION

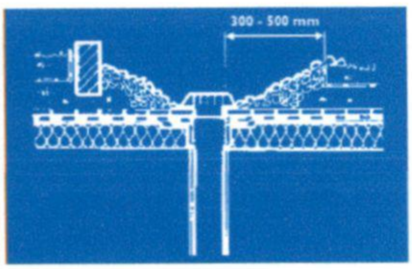
The dissertation topic has been introduced, in chapter1. In this chapter objectives set for the study, methodology adopted, scopes have been discussed. Chapter 2 critically reviews the literature on green roof such as evolution of green roof, its benefits to India various international approaches and its outcomes. Local and International examples of green roof are described and compared in Chapter 3. Chapter 4 describes green roof systems for composite climate of India, factors affecting design and construction details. It also discusses the basic components of green roof and there cost analysis in Indian context. Chapter 5 establishes the opportunities and constraints of green roof in India. Chapter 6 discusses the Design and technical guidelines for green roof in composite climate of India and derives proposal for Architecture and Planning Department IIT Roorkee. In the end conclusions and policy recommendations for green roof in India have been presented in Chapter 7.

CHAPTER 2

LITERATURE REVIEW







2.1 BACKGROUND

The environmental, social and visual contributions that green roofs can make towards creating sustainable living in high-density cities are accepted worldwide. The objective of the chapter is to create an understanding of origin of green roof its benefits and constraints for the community and private sectors. A description of the climatic conditions and other environmental factors affecting application of green roof, latest international, regional concepts, and approaches, including policies on green roofs is given for designing guidelines and policies for Indian context.

2.2 GREEN ROOF AND ITS EVOLUTION

Green roofs are not new; they have been considered standard construction practice in many countries for hundreds of years. This is mainly because of the excellent insulative qualities of the combined plant and soil layer (sod). In cold climates they help retain heat in the building, and in warm climates they help to keep the heat out. Green roofs can be traced back to the hanging gardens of Babylon and were known to exist in the Assyrian Empire.

As response to population pressures in urban areas since the Renaissance, it has been seen that steeply terraced gardens and these were common in the city of Genoa, Italy. In contemporary architecture, Le Corbusier and Frank Lloyd Wright made extensive use of green roofs. This renewed interest is due mainly to rising concerns regarding the degraded quality of the urban environment and the rapid decline of green space in intensely developed areas.

1. Le Corbusier envisioned urban areas with roads placed on roofs amid vegetation – '*his fifth point in A New Architecture was roof gardens*' He also included a green roof in the design of La Maison due Diable in 1913.
2. Wright has also implemented rooftop in his buildings for example; Midway gardens in Chicago, Cheney house [5].

A distant perspective allows viewing this technique as a potential green membrane over concrete in urban scenario. **Newton (1995)** has coined the term 'Building-Integrated Vegetation' and says "*Cities can be viewed from an entirely new perspective. Buildings* *offer surfaces parallel to natural landforms and these can be planted following clues form nature. The skin of the city can be transformed into a living landscape."* [3]

Grant et al. (2002) suggests that the term *"Building-integrated vegetation' should be used "wherever vegetation is deliberately planted, seeded or encouraged to establish itself on buildings either on the walls or the roof"*[6].

The timeline in other page is a general expression of green roof history. This timeline focuses on the progression of green roofs from ancient times, the Middle Ages and Renaissance, 1600-1875 AD, 1900 to WWII, and after WWII

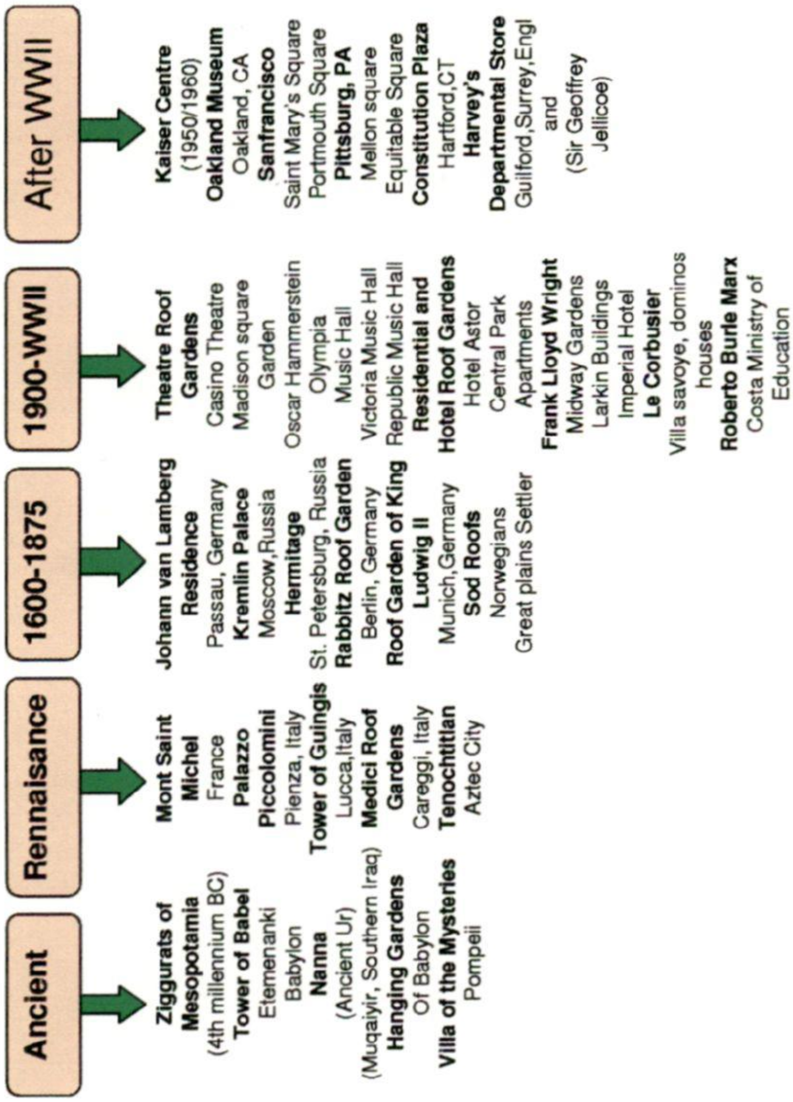


Figure2.1. Historic Green Roof Timeline
Source: Author

2.3 COMPONENTS OF GREEN ROOF

Green roof can be of different types depending on their construction technical details. In general this has been classified in three different types[7].

2.3.1. Extensive Green Roofs

Extensive green roofs are defined as usually being developed for aesthetic and ecological reasons. These usually have thin growing mediums (4- 8") and lightweight; low-maintenance plants are used for extensive green roofs. Access is normally for maintenance only. It can be more easily retrofitted onto existing roof structures than intensive roofs. Extensive green roofs are ideal for schools, industrial parks, large big-box stores and multi-family housing. Modular tray system is a kind of extensive green roof

2.3.1.1 Modular Tray System

Recent years have seen the introduction of tray systems into the extensive green roof market. These come in a variety of shapes and sizes and offer some advantages, particularly for maintenance. Figure 2.2 illustrates a typical large tray system (1.17m x 1.17m) needing equipment to install but being tightly connected to allow for additional soil to be installed above the bounds of the tray. Figure 2.3 illustrates a smaller and possibly more versatile system that can be installed manually. It appears to be completely self-contained and has drainage connected directly to roof outflow pipes rather than relying on the existing waterproofing. Although planting designs may be restricted by the rigidity of a grid system, well designed plant variety, as seen below in Figure 2.4, needs to be used to create a pleasant design.

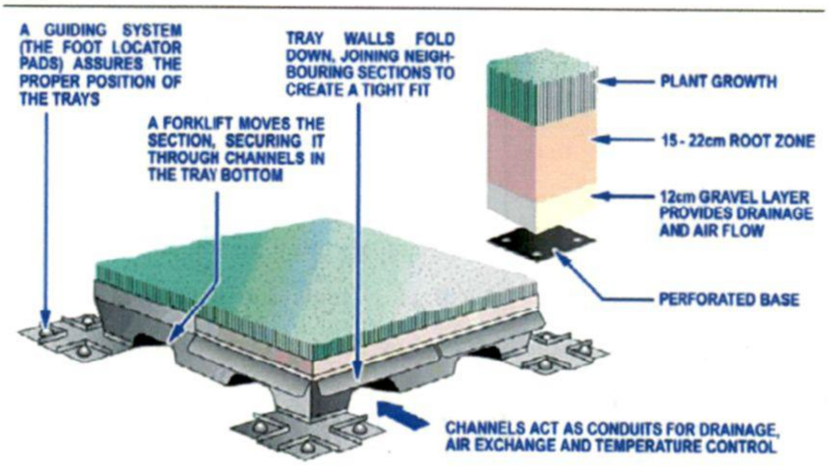


Figure2.2 Typical Extensive Green Roof Tray Systems

Source: GreenTech ITM™ Module by GreenTech, Inc.

Figure2.3Aesthetic Potential of Extensive Green Roof Tray Systems
Source: Weston Solutions, Inc

Figure2.4Typical Extensive Green Roof Tray System in India
Source: Weston Solutions, Inc

Tray Systems, like extensive green roofs in general, are suitable for retro-fitted green roofs. Despite the apparent ease of construction, tray systems have negative characteristics which must be also be considered. Advantages and disadvantages of this tray systems are discussed below in Table 2.1

Table 2.1Advantages and Disadvantages of Tray Systems

Advantages	Disadvantages
1. If the growing medium is completely contained, then the modules (only if small enough) can easily be removed and put back in place without disturbing the plants. 2. Plants are pre-planted and may be used for instant effect. Seasonal or festive effects may make use of this advantage though it would be a costly exercise. 3. Onsite installation is quicker. Downtime due to inclement weather is reduced. 4. Onsite installation can be done by less experienced labour as	1. In coming years older module designs may not be available in case of replacement. 2. Plastic trays will eventually deteriorate in the sun, even UV-resistant plastic. This compromises the aging benefits that green roofs offer over conventional roofs. 3. There is also the possibility that cheap copies using inferior short-aged plastics may flood the market. 4. Transportation and stacking difficulties and expenses may be higher, especially for larger tray systems. Larger cranes may be needed in many cases. (Only onsite installation may be quicker). 5. Being self-contained, trays may be slightly more prone to drying out, requiring more watering and care. (Tray systems must have

quality is maintained more at the plant propagation nursery rather than by the onsite contractors.	adequate soil depth and water reservoir layering to overcome this).
5. Alterations may be easier and installation in stages is easier.	6. Some tray systems have fixed soil depths which limits the overall design.
6. Concerns over various sub-contractors (if different) interfering with each other's layers, such as the waterproofing layer, are reduced.	7. Planting designs and maintenance pathways layout are largely dictated by the uniform squares of the trays. The exposed grids lines may also detract from the aesthetic qualities of a continuous landscape.
7. Tray systems may be well suited to sloped roofs.	8. As trays may be easier to dismantle they may invite developers to be only half-committed to green roofing.
8. Trays systems may be well suited to being specially mounted above some roof top utilities (e.g. pipe work).	9. If modules are rigidly connected or buried with soil above then the removal may be as cumbersome as normal extensive green roofs.
9. Designers may experiment or refine the planting design on site by mixing and matching the different pre-grown planting modules.	10. There is the possibility of roots growing through drainage holes in open module systems and compromising the roof slab below (particularly from undesirable self seeding weed trees).
	11. Uneven roof surfaces below the tray system may collect water. As this water may not evaporate away fast enough it may create breeding grounds for mosquitoes.

Major conditions for choosing a modular tray system might include the following:

1. If regular removal for inspection is foreseeable.
2. If the plastic used is guaranteed over the long term.
3. If long-term roofing cost benefits is not a concern.
4. If an instant effect is needed.
5. If liability issues between sub-contractors is a concern.

2.3.2. Intensive Green Roofs

Intensive green roofs are typically having thick growing medium (8-12 inches, or more) and typical garden varieties of plants are used. They are intensively managed and their purpose is usually to provide additional open space for people. As long as the correct conditions are created, virtually any kind of garden can be recreated on a roof.

Comparative discussion between extensive and intensive roofs is discussed in Figure 2.5 and Table 2.2.

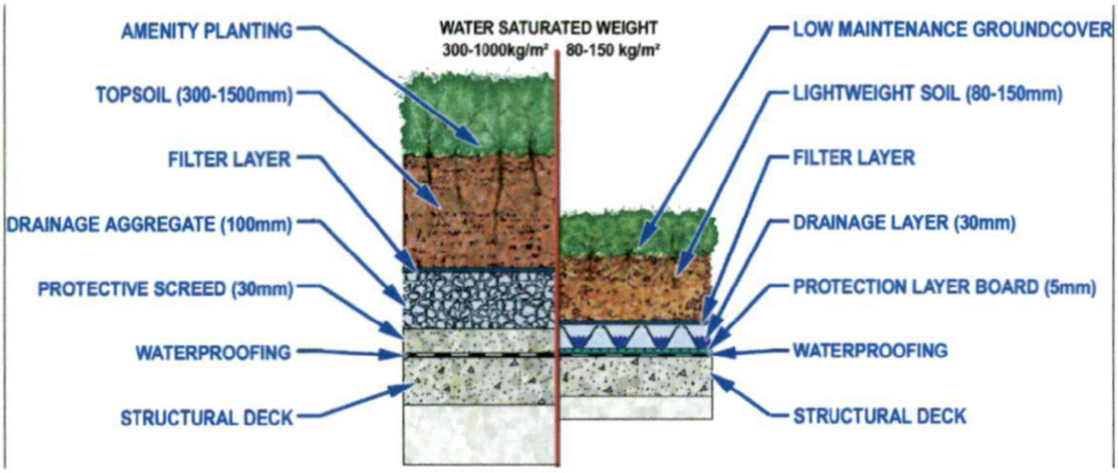


Figure2.5. Cross section of Intensive roofs and Extensive roofs
Source: Urbis Ltd., 2006

2.3.3. Semi-intensive Green Roofs

Semi-intensive roofs, combinations of both extensive and intensive green roofs, are typically adopted to harness both the environmental benefits of a green roof, as well as a diverse garden within a manageable maintenance budget. A comparative discussion on the extensive and intensive roof has been provided in Table 2.2.

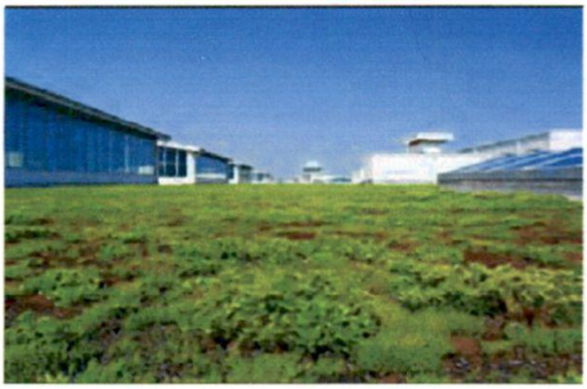


Figure 2.6 Extensive Green Roof
Source: http://www.greenroofs.org/.

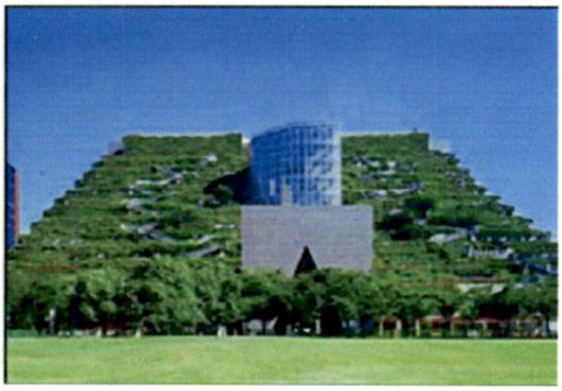


Figure 2.6 Intensive Green Roof
Source: http://www.greenroofs.org/.

Table2.2 Comparative discussion on the Extensive and Intensive roof

Characteristics	Extensive roof	Intensive roof
Purpose	Functional ; storm water management, thermal insulation, fireproofing	Functional and aesthetics; increased living space; environmental and economic benefits
Structural requirements	Typically within standards roof weight-bearing parameters; additional 70 to 170 kg per m^2	Planning required in design phase or structural improvements necessary; additional 290 to 270 kg per m^2
Substrate type	Lightweight; high porosity; low organic matter	Light weight to heavy; high porosity; low organic matter
Average substrate depth	2 to 20 cm	20-30or more cm
Plant communities	Low-growing communities of plants and mosses selected for stress-tolerance qualities. Native grass and ground covers variants.	No restrictions other than those imposed by substrate depth, climate, building height and exposure, and irrigation facilities. A variety of plants can be given.
Irrigation	Most require little or no irrigation	Often require irrigation
Maintenance	Little or no maintenance required; some weeding or mowing as necessary	Same maintenance requirements as similar to garden at ground level
Accessibility	Generally functional rather than accessible ;will need basic accessibility for maintenance	Typically accessible; bye law consideration

Source: http://www.archsd.gov.hk/english/knowledge_sharing/1353-Green-Roofs-ES-2007-02-16.pdf

2.4 BENEFITS OF GREEN ROOF

Green roof has found its applicability in the context of urban development challenges like urban sprawl. There are several reasons for green roofs to be acceptable in the urban setup. Following are some of the benefits out of green roof application.

2.4.1 Green Roofs are Energy Efficient

Green roofs reduce the heat flux through the roof, and less energy for cooling or heating can lead to significant cost savings. Shading the outer surface of the building envelope has been proven to be more effective than internal insulation.

1. In summer, the green roof protects the building from direct solar heat.
2. In winter, conserves heat gained from solar radiation which in turn gets re-radiated in the internal space at night after a time lag.
3. In winter, the green roof minimizes heat loss through added insulation on the roof.
4. Energy conservation translates into fewer greenhouse gas emissions.

Centre for the Advancement of Green Roof Technology has conducted a research on the efficiency of green roof from which they draw some tables showing the Median daily temperature fluctuation experienced by the roof membrane by different sections.

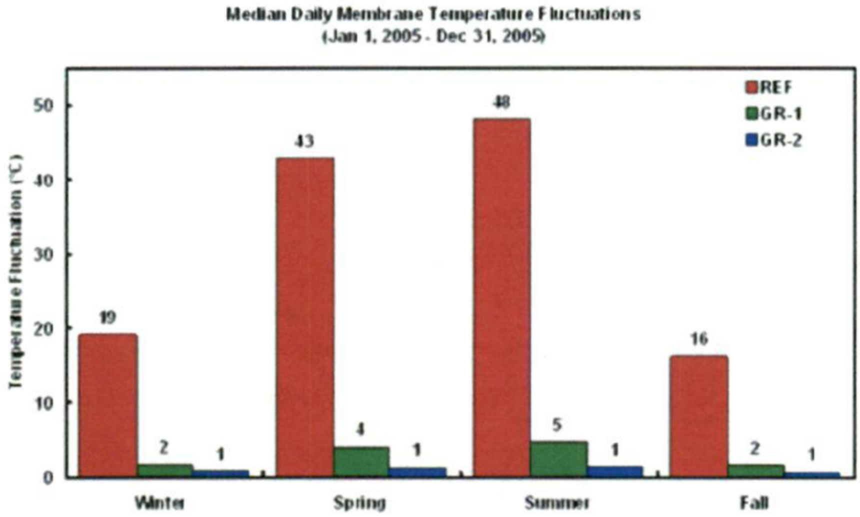


Figure2.8. Temperature fluctuation experienced by the roof membrane

Source: September 2006 CMHC Report

2.4.2 Green roofs reduce storm-water runoff

During heavy or continuous rain, runoff can overwhelm storm-water infrastructure and potentially damage waterways and fish habitat.

1. Green roof as a growing media retains rainwater, together with plants, return a portion of this water to the atmosphere through evaporation and transpiration (evapotranspiration).
2. Storm water that does leave the roof is delayed and reduced in volume.

3. Storm water that runs off a green roof is cleaner than runoff from a conventional roof.
4. Retention and delay of runoff eases stress on storm water infrastructure and sewers.
5. Cost savings from decentralized storm water mitigation reduces the need to expand or renovate related civic infrastructure.

Researchers of Centre for the Advancement of Green Roof Technology, of British Columbia Institute of Technology has conducted a research on the efficiency of green roof and with the help of statistics established the reduction in runoff in wet and dry season.

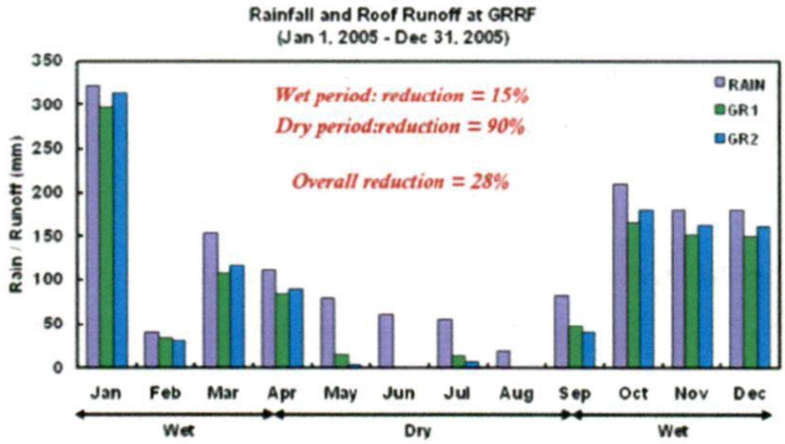


Figure2.9. Comparison of Rainfall and Runoff

Source: September 2006 CMHC Report.

2.4.3 Ecological Advantages

Plant leaf traps dust particles from the ambient air, and evapotranspiration cools ambient temperatures, so both ways the air quality improves towards comfortable one.

1. This results in less smog and less ground level ozone, thus leading to less heat trapping.
2. Temperatures in the urban core can be 3°-5° C warmer than rural and suburban areas this leads to Reduced Urban Heat Island profile.
3. In long term it can lead to less need for health care services resulting in collective cost savings.

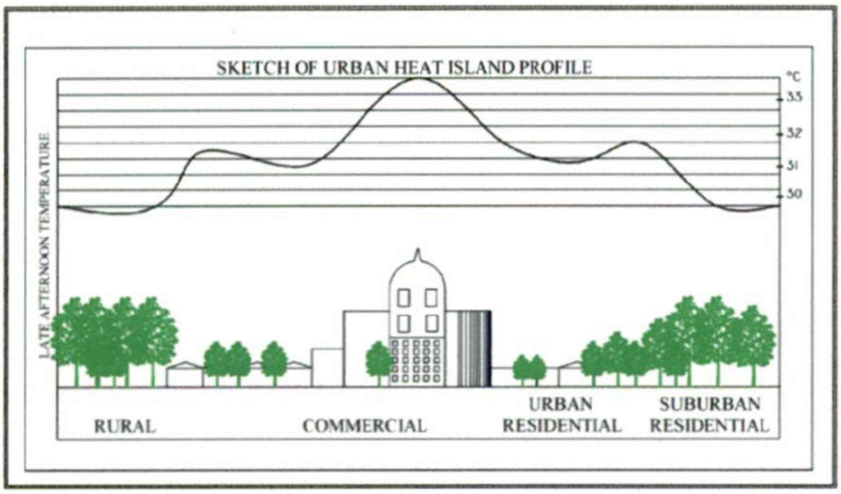


Figure2.10. Section of urban heat island profile
Source: Lawrence Berkeley National Laboratory

2.4.4 Alternate habitat

As undisturbed areas, rooftops can serve as refuge for creatures that struggle for survival especially in urban setup. Ground-nesting birds use green roofs for nesting and raising their young.

1. Vegetated rooftop habitats can serve as stepping stones, to create corridors connecting other patches across an urban sea to natural habitats beyond the city.
2. Natural habitats can serve as templates for green roofs designed for biodiversity.
3. Low maintenance green roofs can be designed to serve as refuge for species such as ground-nesting birds.

Figure2.11. Goose nest on a roof on Granville Island, Vancouver, Canada

Source: http://commons.bcit.ca/greenroof/faq.html.

2.4.5 Durability of Green roof

Green roofs cover the waterproofing membrane, protecting it from UV rays and extreme daily temperature fluctuations. This protection extends the lifespan of the waterproofing twice as long as conventional roofing, meaning that membranes under green roofs last twice as long as those on traditional roofs.

1. Reduced material waste from re-roofing.
2. Less frequent re-roofing, less costs over time.

2.4.6 Cost Benefits

The initial installation cost of a green roof is more than a traditional roof; however, the life cycle cost is competitive [8].

2.4.7 Provision of outdoors

Green roofs make the most of unused space within the increasing density of our cities. Rooftops can be developed into **social and interactive recreational** spaces and used for **urban agriculture. Advantages can be listed as follows:**

1. Amenity space for day care, meetings, and recreation.
2. Improved aesthetic views for neighbours in adjacent buildings.
3. Improved worker productivity and creativity.
4. Potential to enhance urban food security through rooftop gardening and food production.

The other benefits are as follows:

1. By improving energy efficiency and addressing the *"Urban Heat Island Effect"*, we can be a part in climate change.
2. Opportunities to recycle aggregate and compost is enhanced which helps in development of more sustainable urban environment.

2.5 GREEN ROOF BENEFITS IN INDIA

An analysis of the benefits that India might experience is presented in Table 2.3.

Table 2.3 Benefits Applicable to India

Green roof Benefits	Benefits to whom?	How Its Benefits	Significance Of Benefits
Amenity and Aesthetics Benefits Of Green Roof			
Leisure and Functional Open Space	Public / Building occupants / Property Owners	Additional passive recreational space is added to the city where the public or building occupants can escape from the busy streets below. Property Owners may benefit from increased property prices	High
Visual Aesthetic Value	Public / building occupants / government	The city is more appealing to look at. The government gains from a better image of the city	**High** – but only if a significant number of visible roofs are covered.
Health and Therapeutic Value	Public	Therapeutic benefits of calming the observer.	Moderate to High – but depends on location.
Food Production	Building Occupant/property owners	Food cost reductions	Low – not expected to run at any appreciable scale in the city centre.
Environmental Green Roofs			
Air Quality	Public	Healthier air to breathe. Scenic visibility might be improved with a reduction of city smog.	Moderate – but only if large areas are covered
Reduction in Urban Heat Island Effect	Public	Air-conditioning costs might be reduced (reduction in pollution associated energy production)	Moderate – but only if large areas are covered
Ecological and Wildlife	Wildlife	Habitat creation	Moderate to Low – depends on location and species used
Water Management	Government / Wildlife	Potential costs on storm-water infrastructure can be reduced. Contaminated storm-water entering the rivers is reduced.	Moderate to low
Sound Absorption	Building	Slightly quieter	Low – benefits

	Occupants	environment. (only 5dB)	are likely to be only on the top floors below the green roof and from noise from above.
Economic Benefits			
Building Insulation and Energy Efficiency	Building Occupants	Air-conditioning costs might be reduced by around 15%	High – though benefits are likely to be appreciated by upper floors only
Increased Roof Life	Property Owners/ Building Occupants	Property owners may derive roof cost savings but only if they intend to own and maintain the building in the long-term. This is not the case for most developers. Roof life costs are therefore a low incentive to developers.	Low – most developers in India build to sell and would therefore not see the benefits gained years later. Moderate –for Government owned buildings this issue becomes more relevant.

Source: Urbis Ltd., 2006

It is clear from the above that Green Roofs offer diverse benefits for India. Clear community benefits that would be enjoyed by the public include: increased public open space; increase visual amenity; improved air quality and a reduced urban heat island effect.

However, the direct financial benefit for developers and property owners is less easy to determine although overseas data suggests that green roofs provide tangible financial benefits for the private sector, there is no data from local research to substantiate this in the local Indian context.

2.6 LIMITATIONS OF GREEN ROOF

Any assessment is not complete without looking at the downside of the profile in terms of green roof technology it has some limitations in comparison to reflective roofs are

1. *Higher first costs because of the additional material needed.*
2. *Requires higher maintenance for plant care and upkeep until plants are fully established and the roof is fully covered.*
3. *Some ongoing maintenance is also required.*

4. *Highly vulnerable to high winds because they are not mechanically fastened to the roof.*
5. *Cannot work well on roofs with very steep slopes.*

Discussion with overall potential users reveals several implementation barriers which prevents these technologies to be used in mass scale. The barriers discussed in following section;

1. *Leak underneath a green roof* is one implementation barrier that seems to outweigh all its benefits
2. *Lack of adequate information and familiarity with green roof technology, design, and function*
3. *Little knowledge about maintenance requirements*
4. *Prevailing exclusion of green roof in building industry standards, design guidelines and specification*
5. *Non availability of qualified designers and contractors*
6. *Lack of institute incentives to make green roof applications.*

2.7 INTERNATIONAL APPROACH OF GREEN ROOF

Globally green roof policies are not prescribed at a national level. However, it is often the case that municipal regulations are borne from directives initiated at top level. This appears to be the case in Germany, Canada, the USA, and Japan. There are four general categories in municipal policies and incentives operations in Germany, many of which have been in place for over a decade:

A) Direct Financial Incentive

These financial incentives customarily take the form of subsidies available to property owners and developers who build green roofs. As an incentive, this approach can be tailor-made for any jurisdiction. It does not force property owners to create green roofs; they act voluntarily through clear economic gains and are still encouraged to retro green existing buildings. It is an incentive that operates on a clear per square meter basis and is proportional to the environmental benefits.

B) Indirect Financial Incentive

This approach uses *Split Wastewater Fees* and targets the storm water runoff problem created by impervious buildings. Sewers collect wastewater from both sanitary disposal and also storm-water disposal. This system provides monetary discounts to the storm-water part based on the storm-water infrastructure savings that green roofs contribute. It requires municipalities to split the municipal rates.

C) Ecological Compensation Measures

This is a policy that stems from the German "Intervention Rule" which is based on the Federal Building Code, the Federal Nature Conservation Act, and the Environmental Impacts Assessment Act. The Intervention rule is a decision-making process applied at the land-use and development level. In Germany green roofs may be used in the *Compensatory* option but are very specific to what the roof is compensating for and has proven difficult to monitor over the long term.

D) Integration into Development Regulations

Integrating development regulations is another tool available to increase the coverage of green roofs. Local authorities may include green roofs in their development regulations based either on *Ecological Compensation Measures* or based on the *German Federal Building Code*.

In some instances compulsory measures can be more effective than voluntary incentives. Its main benefit is that it requires no direct monetary input from government, though monitoring may still incur an expense. *'Density bonus regulations'* (green roofs as compensation for higher density) can also be integrated into development plans according to the '*Land-Use Regulation*'. From the German experience, introducing regulations into new development areas has proven especially effective while applying it to existing areas as retro-fit projects has been difficult.

Apart from regulations and incentives, there are numerous other tools available to municipal authorities to encourage green roofs. These include:

a) Competitions and Media Coverage

b) Leading by Example - Greening Public Buildings

c) Performance Rating Systems

Toronto has been pro-active in encouraging green roofs by installing green roofs on its municipal department buildings, helping the green roofs industry, and embarking on a free green roofs advice educational campaign.

2.7.1 City Policy Case Studies

Policy Case Study No. 1 - Portland, Oregon

Longitude 46°N **Latitude** 123°W

Average summer Temperature 20°C (68°F)

Average winter temperature4°C (39°F)

Average annual rainfall 900 mm (35 in.)

Average annual snowfall 50 mm (1.9 in.)

Snowfall in Portland contributes insignificantly to total precipitation

In Portland, the motivation for developing green roofs has been concern about water pollution from combined sewer overflow (CSO), particularly from major pollution of the Willamette River. Portland promotes green roof development through a number of policies. Portland has implemented the following strategies:

1. All new City-owned buildings are required to be built with a green roof that covers at least 70% of the roof. The remaining roof area must be covered with Energy Star rated roofing material. When practical, all roof replacements must include a green roof. The City has internal green building consultants to assist city buildings in order to meet green building policy objectives. Most public green roof projects have been financed by storm-water fees.
2. The City Zoning Code offers developers floor area bonuses when they implement stipulated options, like a green roof. The bigger the proportion of green roof coverage, the larger the bonus offered. The owner must sign an agreement ensuring proper roof maintenance (although proper long-term maintenance continues to be a concern).
3. Portland levies a storm-water management charge for commercial, industrial, and institutional rate-payers that is based on the amount of impervious area on site (Rs 322/ US$6.45 per 1000 square feet of hard surface per month). There is an initiative under consideration to reduce charges by 35% for owners who install

green roofs with coverage of at least 70%. Residences are charged for storm-water management at a flat rate.

4. In the Central City District, developments must comply with architectural design guidelines, and should undergo a design review process prior to approval. A green roof in a design is considered as an asset.
5. Portland provides education and outreach on green roof development, by providing technical assistance to building owners and guided tours of green roofs. It also monitors green roofs.
6. Portland has funded green roof demonstration exhibits and test sites.
7. In Portland Green roofs are formally recognized as a Best Management Practice in the City's storm-water manual.
8. A citizens' group called "Eco-roofs everywhere" promotes green roof development for lower income areas. It creates affordable demonstration projects, secures grants for small-scale developments, and negotiates lower prices with vendors.
9. These efforts have been effective in promoting green roofs - Portland is considered one of the North American leaders in green roofs. There were approximately 2 acres (0.81 ha) of green roofs in Portland in 2005, with about another 2 acres (0.81 ha) committed to be built. The City of Portland has promoted green roofs so effectively that the private sector and some private citizens are starting to build or install them on their own initiative. However, green roofs have not yet taken off in the industrial sector.

2.7.2 Policy Case Study No. 2 - Chicago, Illinois

Longitude 87°54' W **Latitude** 41° 59' N

Average summer temperature 27°C (80°F)

Average winter temperature 6°C (21°F)

Average annual rainfall 72 cm (28 in.)

Average annual snowfall 24 cm (9 in.)

In Chicago, the motivation for developing green roofs is concern about the urban heat island (UHI) effect, air quality and its effects on public health, and aesthetics. The Mayor has been a strong advocate of green roof development. Chicago has a variety of policies and programs that encourage green roof development, specifically:

1. The 2001 Regulation called the Energy Conservation Code requires that all new and retrofitted roofs should meet minimum standards for solar reflection (0.25reflectance). Chicago's Bureau of the Environment deemed that green roofs are an acceptable way to lower roof reflectivity, mitigate UHI and improve air quality.
2. A "Building Green/Green Roof" policy applies to construction projects that receive public assistance or certain projects that are subject to review by the Department of Planning and Development. Through this policy, the City of Chicago grants a density bonus option to developers whose buildings have a minimum vegetative coverage on the roof of 50% or 2000 sq. feet (whichever is greater), usually in the form of a green roof.
3. Chicago has various City-sponsored green roofs, including demonstration sites, test plots, and others. The City has partnered with green roof providers to build and compare test plots that use different kinds of plants and material. It has issued a report on some of its findings.
4. Chicago has engaged the Chicago Urban Land Institute which is a non-profit organization of real estate professionals, in seminars and surveys. This helped to determine which kinds of incentives would encourage green roof development.
5. Chicago offers a storm-water retention credit for green roofs, but does not levy a storm-water impact fee.
6. The City has a website that supports green roof installation, and provides information and technical assistance.
7. In 2005, Chicago offered a limited number of Rs 250000/US$5,000 grants for building small-scale residential or commercial green roofs.
8. There was no requirement in 2005 for green roofs in the private sector
9. As of June 2004, Chicago had more than 80 green roofs over municipal and private buildings in various stages of installation. The total area of these roofs is over 1 million square feet (9.3 ha).

2.7.3 **Policy Case Study No. 3 - Basle, Switzerland**

Longitude 47°33' N **Latitude** 7°35' E

Average summer temperature 24°C (75°F)

Average winter temperature 2°C (28°F)

Average annual rainfall 784 mm (31 in.)

In Basle, the motivation for developing green roofs is an interest in energy savings, and promoting protection of biodiversity. Basle has promoted green roof development through a number of policies, specifically:

1. In the mid-1990's, after a public poll found general support for an electricity tax to promote energy saving measures, and after consultation with stakeholders, Basle invested Rs 28.8 million (HK$6.4M) from electricity fees into a two-year incentive programme, providing a subsidy of Rs 576 (HK$128/m²) of green roof. Another programme like this is planned for 2005/06
2. Since 2002, building regulations stipulate that all new and renovated flat roofs must be greened to provide valuable habitat (primarily for invertebrates), using specified materials.
3. Basle provided a grant for research on the biodiversity protection benefits of green roofs. The results of this study shaped the design specifications for green roofs in Basle.
4. Basle promoted the programme by holding a contest for the best looking green roof.
5. In 1996 and 1997, there were 135 applicants for the green roof subsidy, and 85,000m² of roof-scapes were greened which resulted in 4 GW/year of energy savings. As a result of the regulations for new and renovated flat roofs, 15% of flat roofs in Basle have been greened. Basle is now exploring ways of enforcing proper green roof quality.
6. Basle's incentive programme concentrated efforts into a two year period, thereby raising the profile of green roofs in the City. The incentive programme was well received, media interest was high, and Basle received nationwide prominence as a result.
7. Basle's green roof regulations did not meet with any significant resistance, because all stakeholders were involved in the process from the beginning, and because of the success of the incentive programme.

2.7.4 Policy Case Study No. 4, Munster, Germany

Longitude 52°13 N' **Latitude** 7°70 E'

Average summer temperature 23°C (73°F)

Average winter temperature 0°C (32°F)

Average annual rainfall 756 mm (30 in.)

In Munster, the motivation for developing green roofs has primarily been concern about storm water management, and also interest in increasing green space. Munster has promoted green roof development through a couple of policies/programs:

1. Munster charges a storm-water fee, according to the amount of storm-water that runs off a property and into the sewer system (i.e. if there is no run-off, there is no fee). The fee is reduced by 80% or more when a green roof is installed. To implement this program, the Public Works department sends property owners a bill stating the amount of pervious and impervious surface area on the property, with the corresponding storm-water fee. The fees are used for maintenance of the sewer system.
2. Munster was evolved in incentive programme for a variety of environmental measures where green roof can be included. Subsidies were provided for green roof development, but this programme ended in 2002, due to financial constraints.
3. Munster's incentive programme was effective, resulting in a total of approximately 12,000m² of green roof coverage by the end of the programme.
4. The storm-water fee has also been very successful, and it has been accepted well by the community, however specific information about additional green roof development resulting from the fee is not yet available.

***2.7.5* Policy Case Study No. 5, Stuttgart, Germany**

Longitude 48°68′ N **Latitude** 9°21′ E

Average summer temperature 18°C (64°F)

Average winter temperature 1°C (30°F)

Average annual rainfall 731 mm (28.78 in.)

In Stuttgart, the motivation for developing green roofs has primarily been concern about air quality, since the city is situated in a basin-like valley where pollution tends to settle. Urban growth that has removed vegetation from surrounding slopes has exacerbated the problem. There is also interest in mitigating urban heat island effect. Stuttgart promotes green roof development in three ways:

1. Stuttgart is greening the roofs of its public buildings. It has an annual budget allocation for green roof development, and most green roofs are installed when the roof is due to be replaced.
2. Stuttgart has provided a financial incentive for green roofs since 1986. The programme has the equivalent of Rs 2551500/HK$567,000 available each year, and pays for 50% of costs, or a maximum of the equivalent of Rs 1882/HK$196/m² of roof. The City provides a free consultation and a comprehensive brochure to property owners explaining how to install green roofs.
3. Stuttgart has regulation requiring all flat and slightly sloped roofs (up to 12 degrees) of new development to be extensively greened to certain standards. Trade-offs or compromises with developers are common in the roof greening process.
4. All three approaches have been successful. 105,000m² of public roofs have been greened, and 55,000m² of roofs have been greened through the incentive programme. No data is available on the amount of roofs greened through regulation.

2.7.6 Policy Case Study No. 6, Toronto, Canada

Longitude 51°03'N, **Latitude** 114°05'W

Average summer temperature 15.2°C (60°F)

Average winter temperature 4.4°C (40°F)

Average annual rainfall 320.6 mm (12.6 inch)

Average snowfall 126.7mm (5 inch)

After numerous investigations of other cities around the world, Toronto has recently embarked on its own policies towards green roofs. These are generally motivated by all green roof benefits; the potential to mitigate impacts on storm-water quality and quantity, improves buildings energy efficiency, reduces the urban heat island effect, improves air quality, beautifies the city, provides natural green spaces in built-up areas, holds grounds for gardening, food production and horticultural therapy, and increases passive recreational space in densely-populated neighborhoods. Toronto supports green roofs through various initiatives [9, 10]:

1. Toronto has stipulated that green roofs (with coverage of 50% - 75% of the building footprint) be constructed on all new and existing city-owned buildings.

2. Toronto has begun adapting its zoning by-laws and regulations relating to site plan control applications to achieve green roofs.
3. Toronto has begun with direct financial incentives programmed for the retro-greening of existing buildings. Pilot incentive programs are started.
4. Toronto has set that a 'green roofs resource person is identified in each of the municipal divisions (Buildings, City Planning, Water, Facilities and Real Estate, Shelter, Support and Housing Administration, and Technical Services).
5. Toronto has actively embarked on a green roofs education and publicity campaign. These include technical booklets on construction and maintenance, holding workshops for developers and building owners, staff training, listing green roof suppliers and contractors, and establishing a green roof 'one stop shopping' page on the city's official website.
6. Toronto has also added an element of competition to its green roofs drive by adding Green Roofs as a Category for the Green Toronto Awards and has invited the Green Roofs for Healthy Cities to hold its 2008 international conference in Toronto to highlight its showcase examples.
7. Toronto's enthusiastic approach is very new. The effectiveness of its approach should be reviewed after it has been in place for some time.
8. The total available green roof area citywide was determined to be 5,000 hectares (50 million m²). The benefits were determined as initial cost savings related to capital costs, plus a level of annual cost savings.

2.7.7 Policy Case Study No. 7, Tokyo, Japan

Longitude 35°N **Latitude** 139°E

Average summer temperature 26°C (79°F)

Average winter temperature-4°C (39°F)

Average annual rainfall- 1,500 mm (59 in.)

After more than five decades of nearly unmitigated growth, only 14% of Tokyo's land area remains green. In fact, Tokyo has the lowest green-space-to-impermeable-surface ratio of any major metropolis. The resulting heat island effect has caused Tokyo's temperatures to increase at a rate five times faster than global warming. Tokyo was once a temperate seaport but has become ever more tropical with the number of hours above 30°C. Energy consumption for cooling has increased by 15% from 1990 to spring. Palm trees and wild parakeets have appeared and small outbursts of Dengue fever have also occurred.

1. In 2001 an Environment Ministry study found that the high ratio of impermeable heat absorbing surfaces directly contributed to the city's warming. In the face of intolerable temperatures, environmental and health concerns, and a land-use policy that was impossible to change at this stage, the city turned to green roofs as a solution. The urban heat island effect is therefore the city's prime reason for establishing green roofs.
2. Tokyo began with an informal incentive program that provided a free consulting service. This was followed by a subsidy program which resulted in 7000m² of rooftop greening.
3. Tokyo then accelerated the process by mandating that all new-construction buildings were to have green roofs. Private buildings larger than 1000m² and public buildings larger than 250m² must green 20% of the rooftop or pay an annual penalty of Rs 100000 / US$2000. In the first year (2000 to 2001) this law had a dramatic effect - it doubled the net area of green roofs in the city from 52,400m² to 104,400m². New reports30 indicate that green roof coverage is now 5 times what it was in 2000.
4. Tokyo has also set target goals, with the *Green Tokyo Plan* aiming at 1,200 ha (12,000,000m²) as its ultimate goal.
5. To promote the legislation, the city has constructed a green roof demonstration on the Tokyo Council Building and other facilities.
6. Although the laws are forceful towards new buildings, they have been widely accepted by industry, an aspect largely attributed to Japan's cultural sense of social and civic responsibility. Before the legislation, numerous surveyed companies were willing to convert to green roofs at their own expense. After the legislation, full compliance has been found with no penalties issued.
7. Encouraged by improvements, the Japanese government has followed Tokyo's lead. In 2003 the Ministry of Land, Infrastructure and Transport announced revisions to the national nature conservation regulations, mandating that all new constructions (multiple dwelling houses and offices buildings) green at least 20% of their rooftops. This law went into effect in 2005.

2.7.8 Overseas Green Roof Standards and Regulations

American Society for Testing Materials (ASTM) has developed numerous testing regulations few are suitable for green roofs. Some of the standards relevant to Green Roofs include:

1. WK575 Practice for Assessment of Green Roofs
2. WK4235 Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roofs
3. WK4236 Standard Practice for Determination of Dead Loads and Live Loads associated with Green Roof Systems
4. WK4237 Standard Test Method for Water Capture and Media Retention of Geo composite Drain Layers for Green Roofs
5. WK4238 Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roofs
6. WK4239 Standard Test Method for Saturated Water Permeability of Granular Drainage Media for Green Roofs
7. WK5566 Standard Guide for General Principles of Sustainability Relative to Buildings
8. WK7319 Standard Guide for Use of Expanded Shale, Clay or Slate (ESCS) as a Mineral Component in Growing Media for Green Roof Systems.

2.7.9 Guideline for the Planning, Execution and maintenance of Green Roof Sites, provided by the FLL (*Landscape Research, Development & Construction Society)* in Germany is a more established green roof standards publication. This guideline was initiated by the German *Ministry of Planning, Building Construction and Urban Areas* who gave the FLL the responsibility of researching cost effective methods for extensive and simple intensive green roofs. The guidelines were first published in 1990 and were revised in 1995 and 2002 to incorporate latest technologies. It is now widely accepted as a technical standard and is regularly referred to by the German DIN Standard. It covers the following topics:

1. Waterproofing
2. Structural Loading of green roofs
3. Protection against root penetration.
4. Protection against mechanical damage
5. Protection against corrosion

6. Joints and borders
7. Protection against emissions (such as on vent buildings)
8. Wind loads
9. Fire Protection
10. Protection against slipping and shearing
11. Trafficable paved surfaces
12. Landscape furniture (trellises, pergolas, lighting, ponds, etc)
13. Working layers: soil substrate, filter layer, drainage layer, protection layer, root barrier, separation layers, anti-bonding layers
14. Construction techniques
15. Water retention (maximum water capacity, water permeability, discharge co-efficient, etc)
16. Water storage and additional watering
17. Drainage Layer (materials and types, physical requirements, granule size, structural stability, behavior under compression, water permeability, pH, carbonate content, salt content and construction)
18. Filter Layer (materials and types, physical requirements, weight, cut-through strength, filtration effectiveness, susceptibility to root penetration, weathering, resistance to soil-borne solutions and micro-organisms, tensile strength, flexibility, frictional co-efficient, and construction)
19. Soil substrate (materials and types, physical requirements, granule size, organic content, structural stability, behavior under compression, water permeability, water storage capacity, air content, pH, carbonate content, salt content, nutrient content, weed content, foreign substances, and construction)
20. Application of Vegetation
21. Erosion Protection
22. Final care and readiness for handover
23. Subsequent upkeep and maintenance
24. Warranties and periods of limitation
25. Testing and monitoring methods
26. Reference Values for design loads.

In Table 2.4 International approaches are analyzed in terms of *'grounds'*, *'measures'* and *'outcome'*.

Table2.4. Comparative analysis of International Approaches of Green roof

City	Grounds	Measures	Outcome
	Reduced storm water runoff	Feasibility study	Green roof policy
Toronto	Reduced urban heat island effect and pollution	Demonstration projects	
	Replacement of green spaces	Cost benefit analysis	Pilot programs for financial incentives
Canada	Reduced urban heat island effect	Demonstration projects	Green roof policy
		Publicity	Density bonus for developers Energy conservation code
New York	Storm water management	Awareness building Workshops, resources for professionals and policy makers	Green roof policy
	Reduced storm water runoff	Publicity	No fees if there is no run off
		Demonstration of projects	
Germany			
	Replacement of Green Spaces	Green roof as a part of bye laws	Pilot programs for financial incentives
	Reduced Urban Heat Island Effect	Demonstration projects	Green roof policy
Japan	High Energy Consumption	Forceful law Awareness building	Free Consulting Policy

Source: Author

2.8 LOCAL ISSUES, CONCERNS, AND RESEARCH ON GREEN ROOF

It does not appear to be any detailed organized research done locally into green roofs neither into their construction technology, nor into attempting to quantify the benefits derived from them.

2.8.1 Research on green roof

Performance evaluation of green roof and shading for thermal protection of buildings

A small research project, initiated by Kumar and R. Kaushik, Researcher in IIT Delhi India.

The paper describes a mathematical model for evaluating cooling potential of green roof and solar thermal shading in buildings. A control volume approach based on finite difference methods is used to analyze the components of green roof, viz. green canopy, soil and support layer. Further, these individual decoupled models are integrated using Newton's iterative algorithm until the convergence for continuity of interface state variables is achieved. The green roof model is incorporated in the building simulation code using fast Fourier transform (FFT) techniques in MATLAB. The model is validated against the experimental data from a similar green roof-top garden in Yamuna Nagar (India), and is then used to predict variations in canopy air temperature, entering heat flux through roof and indoor air temperature. The model is found to be very accurate in predicting green canopy-air temperature and indoor-air temperature variations (error range +/- 3.3%, +/- 6.1%, respectively). These results are further used to study thermal performance of green roof combined with solar shading. Cooling potential of green roof is found adequate (3.02 kWh per day for LAI of 4.5) to maintain an average room air temperature of 25.7 degrees C. This model can be easily coupled to different greenhouse and building simulation codes.

2.8.2 News Media Topics

India is one of the fastest growing economies and populations in the world. However, India suffers from many of the same problems as the rest of the developing world, namely, air pollution, a shortage of regular power, as well as storm water management issues.

To help combat these problems and to provide a better life for all Indians, green roofs are one of the options. Green roofs will help reduce cooling costs for the new buildings by about 20%. Additionally, less strain will be put on the water system by the effective storm water runoff management that the green roofs supply.

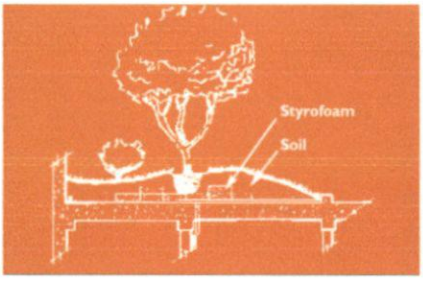
Green roofs are a cost effective solution to many of India's, and the developing world's problems. As the word spreads that green buildings produce great benefits, hopefully, more countries will have them(Hindu news paper, 11 April, 2008).

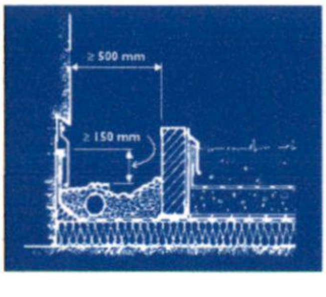
2.10 SUMMARY

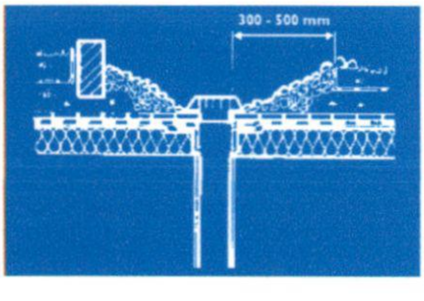
Above-mentioned standards, incentives and regulations for private and public application of green roofs vary greatly. They depend on a city's context, social values and individual case settings. The International policy approaches quoted above have arisen from their own background of social or environmental needs such as storm water management in Germany. Thus I can conclude that while designing the policies for India we should consider all social and environmental needs of the country.

CHAPTER 3

CASE STUDIES







3.1 BACKGROUND

This chapter Aimed to select a variety of green roofs type in different setting and with different purpose to assess the current context of green roofs in the India for designing the guidelines in composite climate

3.2 CHICAGO CITY HALL GREEN ROOF

3.2.1Context

The Chicago City Hall is located in downtown Chicago and surrounded by 33 taller buildings. City Hall was, developed as a study of heat reduction in urban environments and as an experimental demonstration of plants and their adaptability to Chicago rooftops[11].

The roof top is not accessible to the public or building occupants but is visible from the 33 surrounding buildings. The retrofitted 20,300 square foot green roof is located on the 11th story roof deck. The green roof acts as a demonstration to help bring green roof technology to the city. It was designed to deploy the widest range of materials and planting palette.

3.2.2Design Development

Two designs were developed. One was from existing loads without additional structural support and was mostly extensive with some semi-intensive and two intensive areas that were six feet in diameter over the structural columns of the building (shown in the following figure) [11].

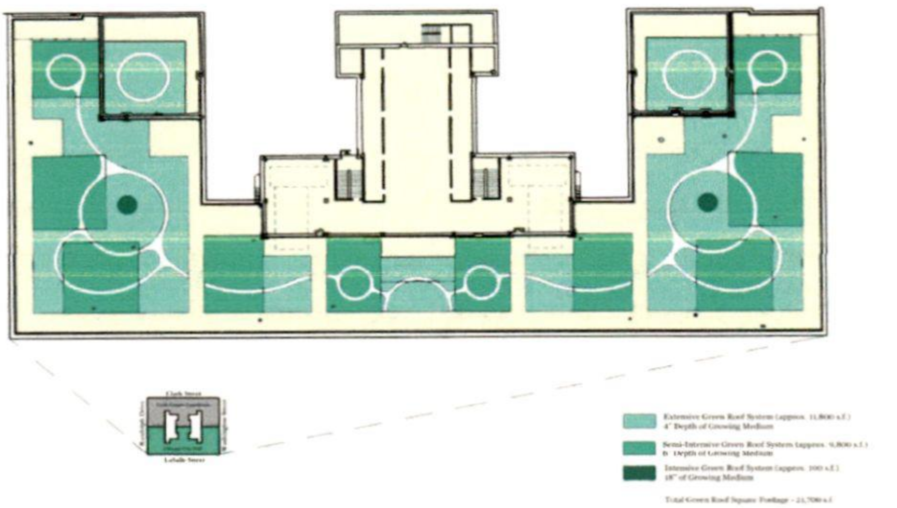


Figure3.1 Extensive, Semi-intensive and Intensive Areas in Chicago city hall

Source: Conservation Design Forum.

The second redesign consisted of structural reinforcement of the abandoned skylights for semi-intensive gardens. The increase in semi intensive area added to the diversity allowing for the 20,000 plants, including about 150 species[11, 12].

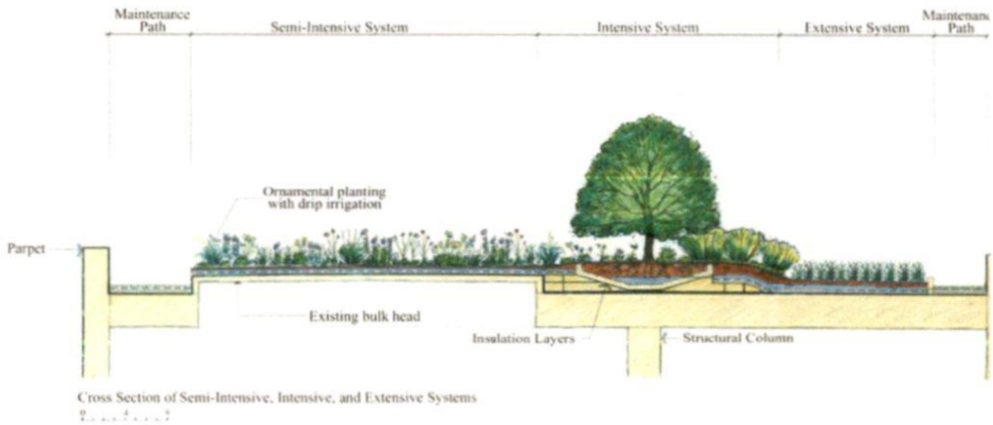


Figure3.2 Section Showing Green Roof System

Source: Conservation Design Forum.

The existing structural capacity was about 30 pounds per square foot. The two areas above the structural columns were able to support additional loads; therefore the hawthorn trees were placed above them. The old skylight areas were able to support loads for semi-intensive plantings. Retaining walls are used for the edges of the green roof and the existing drainage system for the building was kept in place for storm water in excess of what the green roof can handle. The rooftop was designed to store water in the drainage layer and growing medium up to what the structural loading of the roof structure is able to support. The system should be able to support a one inch rain [12].

A unique aspect of the Chicago green roof as opposed to many extensive green roofs is the Chicago design has verticality through the skylight areas that were built up.
The plants are placed in a sunburst pattern which allows for a colorful and attractive pattern and variant media depths and different species of plants, visible from surrounding buildings. The concrete decking of the city hall was sloped for strategic removal of excess storm water. Columns and skylight areas with extra structural support provided areas for semi-intensive and intensive green roof. Styrofoam was used to build up areas and bring them closer to visitors.

The Chicago green roof is irrigated through water collection on either side of the penthouse. The water is directed to tanks which, when needed, is integrated into the green roof layer. Initially drip irrigation was installed over the entire surface. This is only used in the summer when it is dry and there is threat of drought.

3.1.3Maintenance

Drip irrigation was installed on the green roof for initial establishment and for use during periods of drought. Water is collected from the penthouse roof into water tanks located near the downspouts of the penthouse which is used for drip irrigation. Overflow is released into the green roof media [12].

3.1.4 Inferences

The whole building does not benefit from energy savings. The upper floor benefits from a reduction in heat gain during the summer but the green roof only influences 1/12th of the building where a one story building is 100% influenced by a green roof. There are still economic and energy benefits. The air intakes for the cooling system are located on the roof therefore the benefits of the cooling properties of the green roof helped reduce the temperatures on the roof from which the HVAC must draw and cool the air. The air over the green roof was 90 to 100 degrees Fahrenheit instead of 170 degrees Fahrenheit on the control roof.

A weather station is temporarily set up on the roof as well as on the other half of City Hall that does not have a green roof. On the hottest days, the ambient air temperature was roughly 95 degrees Fahrenheit outdoors and 100 degrees Fahrenheit over the green roof. The non-green roof was 170 degrees Fahrenheit on a hot day.

According to the research carried out in Chicago city hall temperature measurement was taken on August 9, 2001 showing a 50°F difference between the green roof and the conventional black tar county roof on the other half of the building [12].

Paved City Hall Roof: 126 - 130°F

Planted City Hall Roof: 91 - 119°F

Black Tar County Roof: 169°F

The city calculated the projected energy savings due to the green roof:

Avoided energy cost: *$3600/yr.*

Total direct savings: 9272 KW hours per year (Chicago DOE, 2001).

The windy climate of the Chicago area in addition to the height of the building resulted in the need to use a bio-degradable netting to prevent wind erosion. Green roofs in similar windy situations should use some form of wind erosion control for the green roof media until the plants become established and can hold the soil.

The following two images are of the plan prepared by Conservation Design Forum and a photograph of the constructed design.

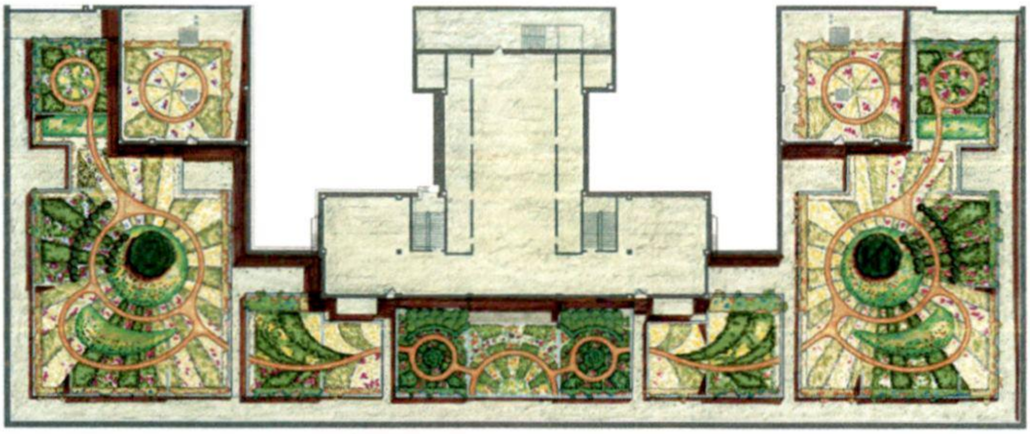


Figure3.3. Chicago City Hall Green Roof Plan
Source:http://www.asla.org/awards/2006/medals/images/da_01.jpg, 2008.

Figure3.4 Chicago City Hall Green Roof Aerial view

Source: http://www.asla.org/awards/2006/medals/images/da_03.jpg, 2008.

3.3FORD DEARBORN PLANT, MICHIGAN

3.3.1Context

The green roof is located on the Ford Dearborn Truck Assembly Plant in Dearborn, Michigan. The Dearborn Truck Factory is where the 10.4 acre vegetation covered roof is located[13].

3.3.2Design Development

As part of the revitalization of the Rouge Complex, the Ford Motor Company chose to implement a green roof on the new Dearborn Truck Factory. Michael McDonough, world renowned sustainable architect, worked with the company to design the 10.4 acre green roof and the building. Several influential factors of the green roof design were the size of the roof and 50 foot structural spans. Because the roof is so large, the installation method needed to be as simple as possible to allow for cranes and large staging areas. The 50 foot structural spans required a lightweight green roof.

Visitor education was an important factor to promote sustainable buildings. The arrangement of rooftop elements and the location of the green roof near the observation tower of the Ford Rouge Center were critical to allow visitors a view of the roof[14].

Figure3.5 Aerial view of Ford Dearborn plant

Source: http://www.greenroofs.org/img/grhc2004_ford2_medium.jpg

3.3.3 Maintenance

The one inch growing media requires that the entire 10.4 acres be irrigated by a sprinkler system which incurs its own maintenance schedule. The green roof was fertilized one time through the irrigation system during the first year with Rosa soil, a 100 percent organic product.

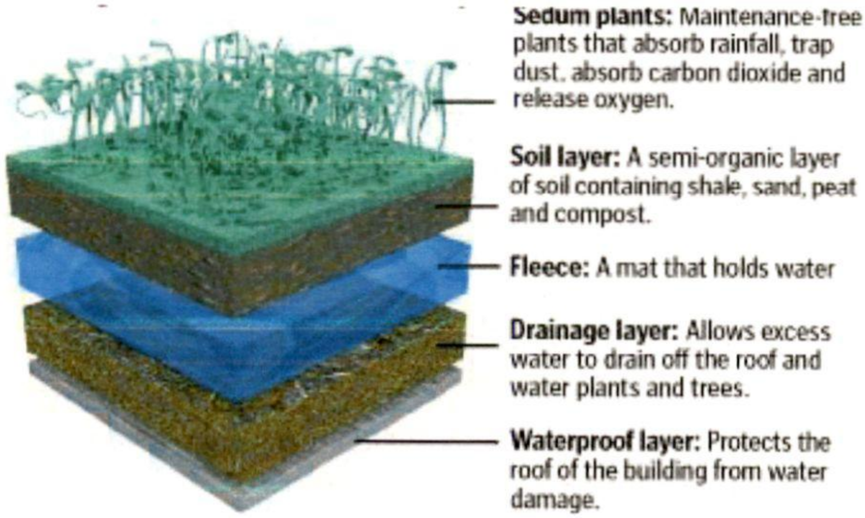


Figure3.6 Green Roof Layers in ford

Source:http://www.detnews.com/2004/project/0405/04/r04-140473.htm, 2008.

3.3.4 Benefits

The green roof adds a significant amount of open green space on an industrial site that for years has been without vegetation. The Green roof build-up and vegetation helps reduce ambient temperatures above the green roof, mitigates storm water runoff, reduces energy use and attracts wildlife. "Dr. H.J. Liesecke of the FLL in Germany concluded that the Ford roof would provide 25% of the productive habitat of an undisturbed green site; a 25% improvement over existing conditions." In addition to the habitat benefits, an improvement of 40% in air quality above the roof is expected in regards to dust absorption and hydrocarbon decomposition [14].

All 10.4 acres are irrigated due to a thin membrane, but the green roof is expected to retain about 50 percent of the rainfall over the green roof. The ability of the green roof to retain water resulted in not having to use a water treatment facility that would have cost in the tens of millions of dollars.

Michigan State University conducted research for the green roof and Ford Motor Company. "Researchers at Michigan State University tested a variety of plants under different soil depths. They investigated drought and freeze resistance, density of growth, weed control, fertilization, and irrigation requirements," Teaming universities with green roofs for research is an effective way to generate information about green roofs.

The size of the Ford Dearborn green roof raised two issues. One, coordinating the staging of the materials and two, the plants had to be grown in mats on the ground 12 weeks prior to installation. The green roof has an irrigation system intended for use only during the time needed for the vegetation to become established.

The ability of the architect and the client to turn a large industrial site into a demonstration for green roof technology and storm water benefits is a prime example of the potential for green roofs. The following figure shows part of the green roof on the Truck Assembly factory.

Figure3.7 Ford Green Roof
Source:http://images.businessweek.com

3.4 CII GODREZ, HYDERABAD

3.4.1 Context Building is located in Hyderabad. Building was, developed as a Platinum rated green building. The CII-Sohrabji Godrej Green Business Centre was inaugurated by the president of India in July, 2004. Seat of the Indian Green Building Council (IGBC), day lit office spaces of the complex, which also includes a large conference room and sheltered walkways. The roof top is not accessible to the public or building occupants. The green roof acts as a demonstration to help bring green roof technology to the city.

Figure 3.8 Aerial view of CII Godrez **Figure 3.9 view of Green roof**

Source: http://www.greenroofs.com/content/guest_features005.htm

3.4.2 Design Development

Of the 20,000 ft2 footprint, 55% of the CII-building is covered by extensive green roof. Measurements attest that the green roofs provide valuable insulation for the conference centre and offices, but this benefit is not likely perceptible under the concrete walkways. Given the minimal highlights or information about the green roofs at the CII building, it is clear that they are only part of a much greater package[15].

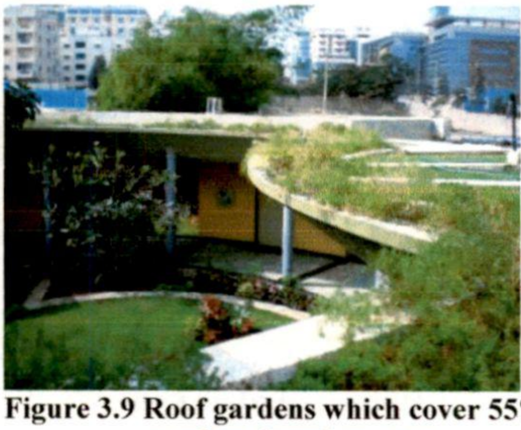


Figure3.8 Extensive green roofs **Figure 3.9 Roof gardens which cover 55% total roof surface area**

Source: http://www.greenroofs.com/content/guest_features005.htm

The green roofs on the curvy building are divided into parcels that are separated by parapets. On top of a concrete roof, the green roof system begins its build-up with three layers of waterproofing.

3.4.3 Maintenance

Automatic Sprinkler systems are installed for irrigation and grass cutting is done once a week which proves to be enough for the maintenance of green roof.

3.4.4 Benefits

The green roof system comprises 2" of sandy soil topped with the same pervious paver blocks used at grade, and overlain with a uniform grass sod. In their appearance and composition, the green roofs are identical to the grassy pedestrian and parking areas at grade. It reduces inside temperature by 2 °C and keeps the building cool and reduces the use of air-conditioning in daytime and water stored is used in other purpose like irrigation etc.

Figure3.10. This section of the CII green roof reveals a section of structural pavers where the sod is thinned, likely a seam.

Source: http://www.greenroofs.com/content/guest_features005.htm

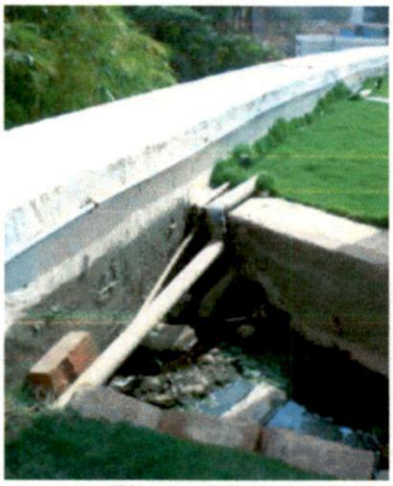



Figure 3.11 and 3.12 Shows drainage system of green roof in building
Source: http://www.greenroofs.com/content/guest_features005.htm

3.4 DILI HAAT PITAMPURA, NEW DELHI

3.5.1 Context The Dilli Haat is being constructed by the Delhi Tourism and Transport Development Corporation (DTTDC). It offers a kaleidoscopic view of the richness and diversity of Indian handicrafts and artifacts. Dilli Haat, which is an upgraded version of the traditional weekly market, tenders a delightful amalgam of craft, food and cultural activities[16]. A lot of effort has gone into making this project eco-friendly and visitor-friendly. The Pitampura Dilli Haat is being developed in an area of 7.2 acres.

The Haat has following facilities

1. A multi - purpose pavilion for crafts persons with a capacity of 100 display exhibit.
2. Food kiosks with capacity of 400 persons in the food court.
3. Restaurant with seating capacity of 60 persons at ground floor(Second Floor being added).
4. Double storeyed dormitory for craftsmen with capacity of 96 beds.
5. Amphitheatre with capacity of 450 persons.
6. Parking facilities of 232 cars and 210 two wheelers in basement.
7. Art gallery.
8. Spice market.
9. Sculpture court and large landscape greens.
10. Adequate internal and external lighting keeping the Haat illuminated.
11. A number of sculptures/art works to be displayed at strategic locations.
12. Conference room (second floor being added).

Figure 3.13 View of Dilli Haat Pitampura

Source: http://www.panoramio.com/photo/8114014

3.5.2 Design development

A unique feature which has been added for the first time in India is insulation of rooftops by growing natural green grass on it. Roof of all the craft shops, spice market, office and art gallery have gone green which would not only provide respite from the heat but would also add beauty to the structure. Vaulted roof is given with unique detail for the drainage of extra water and collection of water for further irrigation and reuse in toilets and other purpose.

3.5.3 Maintenance

Initial weeding was done until the sedums grew thick enough to keep most weeds at bay. Minimal spring and fall weeding are done.

3.5.4 Benefits

The steeply vaulted roof demonstrates how the designer and green roof engineer solved the unique design requirements to create an effective green roof technically and aesthetically. Drainage of the roof was solved technically and incorporated with aesthetic design to create a unique feature using gravity that adds to the holistic quality and concept of the Dilli haat. Though steeply vaulted, the green roof still slows the velocity and quantity of storm water runoff.

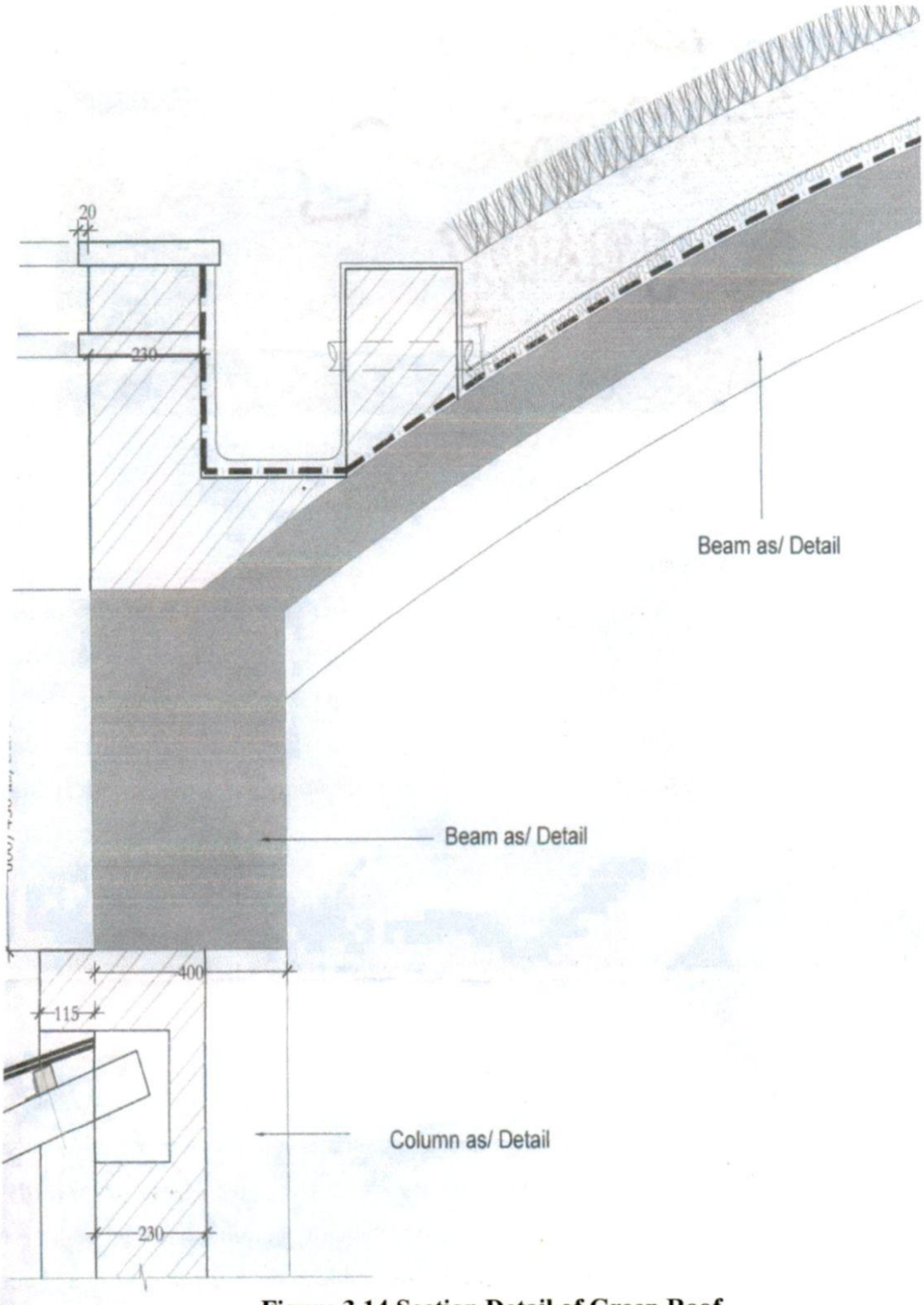


Figure 3.14 Section Detail of Green Roof
Source: Architect Pradeep Sachdeva Office

3.6 SUMMARY

This chapter presented precedent studies on green roofs. The precedent studies presented show a significant number of benefits, but in order to forward the green roof industry and improve sustainable GRIHA credits long term data should be collected. The following is a brief review of the precedent studies, highlighting important lessons.

Ford Dearborn

Shows how a green roof can reduce, or in the case of Ford, eliminate the need for a water treatment facility. There are predictions for a significant decrease in energy use. It also demonstrates a connection with university research (Michigan State University). The sheer size of the green roof was a feat in regards to structural issues but it also provides habitat for wildlife (birds) and insects.

Chicago City Hall

The publicity of this green roof promoted awareness of green roofs throughout the nation and internationally. While energy savings may be more limited because of the 12 storey building, the green roof was found to significantly cool the air above the roof.

CII Godrez Hyderabad

In this building inverted slab is taken as an advantage for a depth of green roof beams are used as a pedestrian for green roof. Sprinkler systems are attached for irrigation. Large amount of energy is saved through this approach.

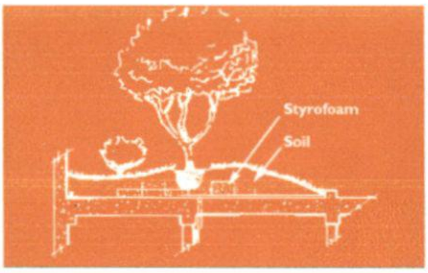
Dilli haat Pitampura, New Delhi

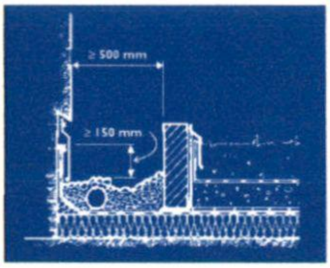
All kiosks are constructed with a vaulted green roof with self drainage system because of its shape and size these kiosks temperature is reduced by 2° C and it also enhances the ambience of the place.

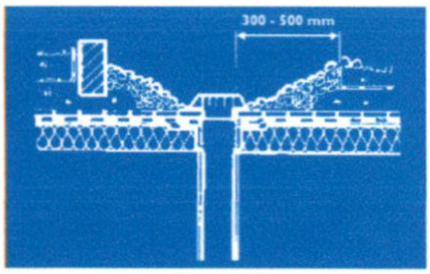
In Table 3.1 Comparisons between International and Local Case Studies is discussed in the next pages.

CHAPTER 4

GREEN ROOF SYSTEMS for COMPOSITE CLIMATE INDIA







4.1BACKGROUND

The environmental, social and visual contributions that green roofs can make towards creating sustainable living in high-density cities are accepted worldwide. The objective of the Study in this chapter is to conduct a quick review of the composite climate zone in India and its characteristics. In later part of chapter latest concepts on green roof, material specifications, maintenance consideration is detailed with a objective of analyzing cost factor for green roof in India with a aim of recommending guidelines adapted to suit local applications in India to promote public understanding and awareness.

4.2 COMPOSITE CLIMATE

Composite or monsoon climates are neither consistently hot and dry, nor warm and humid. Their characteristics change from season to season, alternating between long hot, dry periods to shorter periods of concentrated rainfall and high humidity.

There is a significant difference in air temperature, humidity, wind, and sky and ground conditions which can easily be appreciated by comparing the descriptions of warm-humid and hot-dry climates.

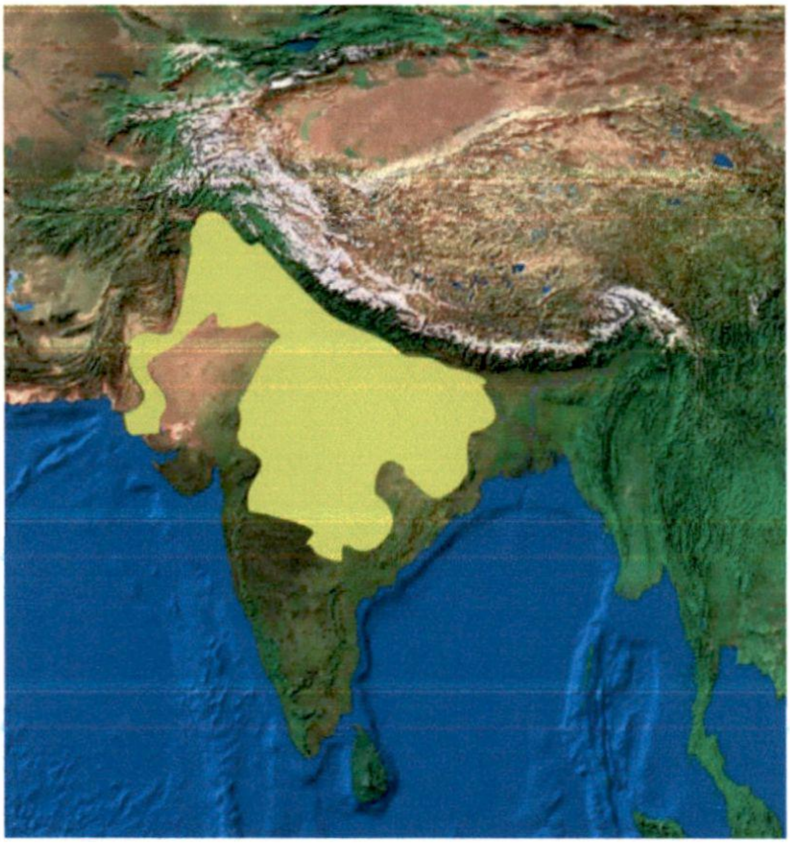


Figure 4.1 Yellow color showing region having composite climate
Source: www.learn.londonmet.ac.uk/.../india/images/0.jpg

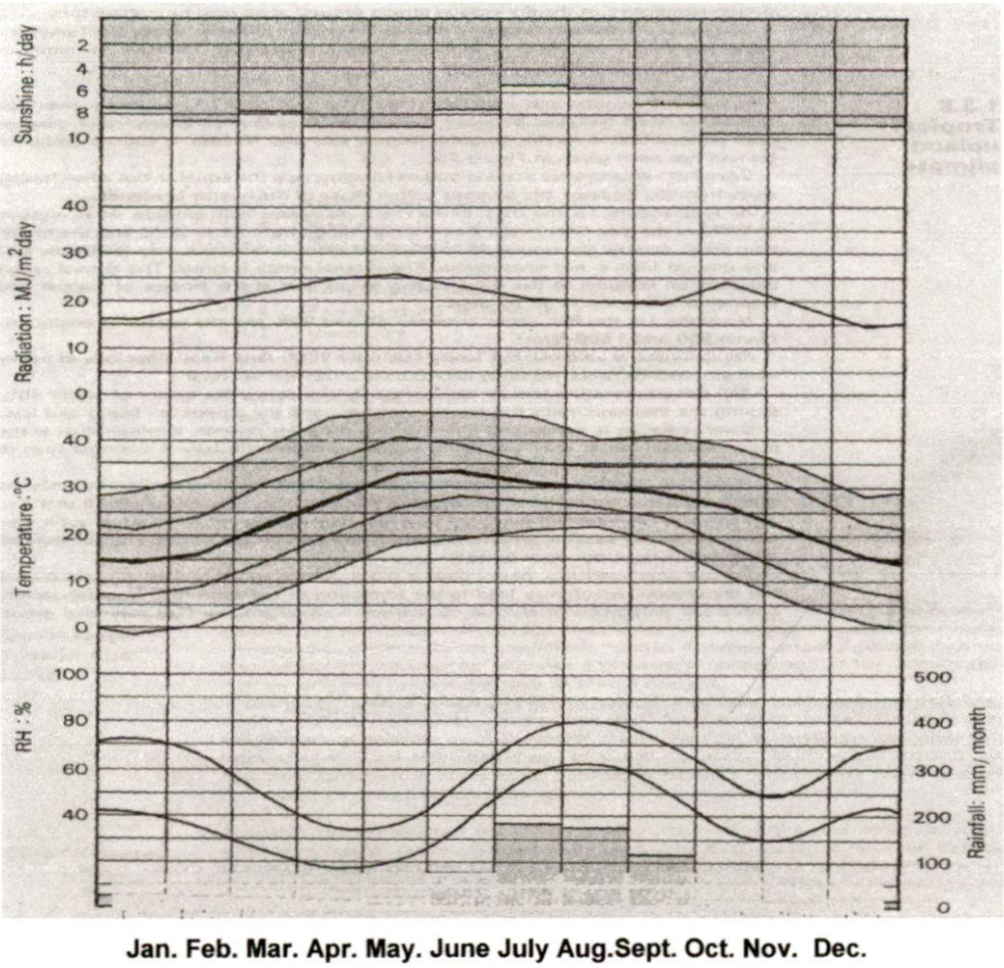


Figure 4.2 Showing temperature, relative humidity and radiation

Source: O.H Koenisberger, Manual of tropical housing and building, orient Longman, page 222

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Temperature	55	61	72	83	91	90	87	85	84	77	66	57
Avg. Max Temperature	68	74	85	97	103	100	94	92	93	90	82	72
Avg. Min Temperature	45	50	59	69	78	81	81	79	76	66	54	46
Avg. Rain Days	1	2	2	2	3	5	8	8	3	1	0	0
Avg. Snow Days	0	0	0	0	0	0	0	0	0	0	0	0

Figure.4.3 Climatic data of Delhi 28 58 N, 77 20 E, 708 feet above sea level

Source: http://www.climate-zone.com/climate/india/fahrenheit/delhi.htm

4.3ANALYSIS OF FACTORS INFLUENCING DESIGN & CONSTRUCTION IN COMPOSITE CLIMATE OF INDIA

The local climate and environment have an important role to play in the design of green roofs in composite climate of India considering example of Delhi.

4.3.1 Wind

Winds can cause serious damage to plants, particularly trees. Trees on green roofs need to be well secured, particularly during establishment, to ensure that they do not blow over and cause damage. Trees also cause additional wind loading on structures and green roof systems.

Trees will grow only as much as the soil volume allows, and consequently trees of the same species tend to grow to smaller sizes on green roofs, where normally smaller soil volumes are available than at grade. Nevertheless, tree pruning regimes need to be adopted for trees on green roofs to ensure that they do not grow as large as to pose a safety hazard during high winds.

4.3.2 Rainfall

Indian climate is characterized by high rainfall between *May and September* (wet season) and low rainfall between *October and March* (dry season). Consequently this means roof designs must be capable of shedding excess water in the wet season and retaining water in the dry season. Much of India natural hillside vegetation turns brown or yellow brown during the dry season, and ecological style planting on extensive green roofs in India might naturally do the same. Green roof systems must also be able to hold water without creating pools of stagnant standing water which would encourage mosquito breeding and create a health problem.

4.3.3 Temperature

It is important to realize that the Extensive Green roof techniques gaining popularity throughout the world, particularly in the cooler climates of Europe and North America, cannot be immediately transposed to the warmer climates of India without adjustment.

The reasons for this:

1. Extensive green roofs have been developed in Germany using low-maintenance alpine-meadow vegetation, mostly Sedums. These species are temperate climate

plants not well-suited to India sub-tropical conditions, particularly the higher temperatures.

2. India high rainfall and high temperatures during its summer months enables vegetation to develop prolific growth rates. This results in higher maintenance requirements when compared with cooler temperate climates.
3. The fast growth rate of local vegetation also means that it would generally out-compete Sedum like species, making invaders on extensive green roofs a particular problem.

4.3.4 Shade

Many existing or planned roof spaces in the urban area that offer potential for development as green roofs are shaded from the sun by surrounding tall buildings for much of the day. This influences plant selection in Green roof.

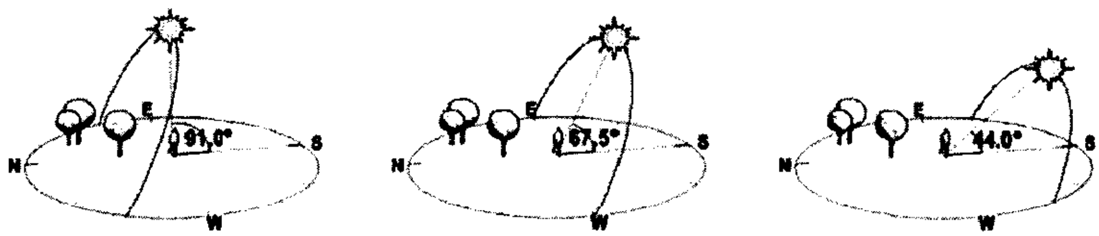


Figure 4.4 Illustrates sun paths as a means for predicting shaded areas.

Source: Urbis Ltd., 2006

4.3.5 Altitude and Exposure

Temperature drops and wind exposure increases with height above ground level, and green roofs built on upper floors of the types of high-rise developments common in India would be subject to more extreme weather conditions than those at lower levels, resulting in harsher growing conditions and less suitability for human use.

4.4 BASIC COMPONENTS OF GREEN ROOF

The basic components of green roof systems are basically the same for intensive and extensive green roofs. Numerous specialized layers may vary from the illustration below and may cater for unique conditions such as steep slope scenarios. The basic functions of these systems include[19, 20]:

1. Weatherproofing of roof
2. Protection of the roof surface from root penetration
3. Drainage
4. Support and growth of the vegetation layer

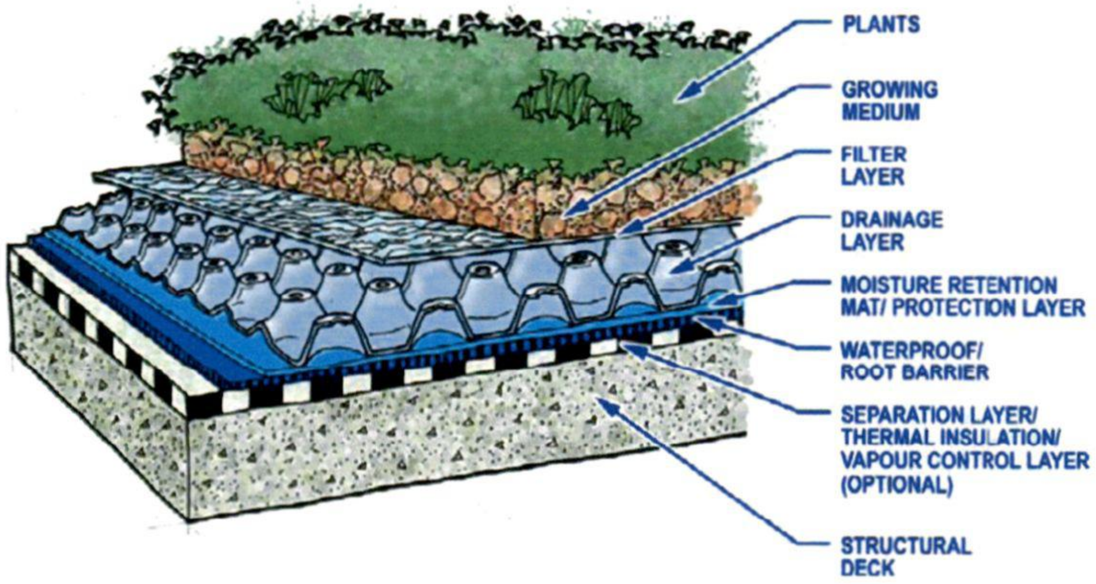


Figure 4.5 Basic Components of a Green Roof System (Intensive and Extensive)
Source: Urbis Ltd., 2006

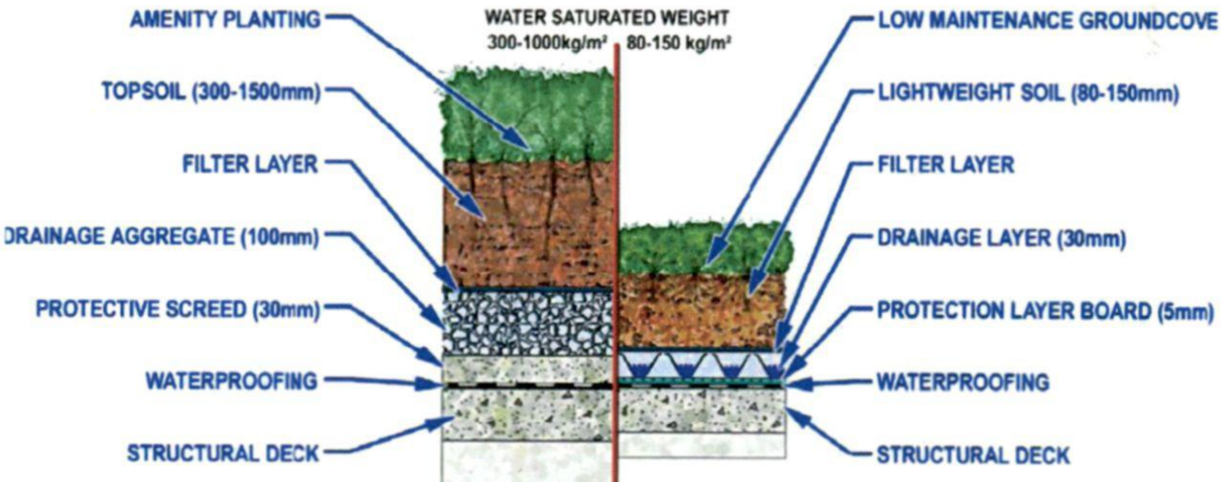


Figure 4.6 Conventional (Intensive) and Lightweight (Extensive) Green Roof Systems
Source: Urbis Ltd., 2006

Table 4.1 Basic components of a Green roof

Component	Function	Materials used
Waterproofing	Prevents water from entering the building and allows for storm water runoff during rainy periods	Modified bitumen reinforced with fibre glass or non-woven polyester
Root Repellent	Prevents plants from damaging the waterproof membrane in the long term	Copper linings
Drainage	Maintains proper drainage to the overlying growth media and ensures that plants do not drown from exposure to excess water and that water vapour can be released	Porous mats, granular media or polystyrene
Filter Cloth	Ensures that fine sediments from the substrate do not clog the drainage layer and helps prevent roots from reaching the repellent system	Non-woven, non-biodegradable Polyester or polypropylenepolyethylene mats
Growing medium	Used as fire resistance, insulation and waterproofing protection and as the growing media for vegetation	Mixtures of inorganics (vermiculite, clay, volcanic rock and coarse sands) and organics
Vegetation	Insulates the system, protects biodiversity, air particle filter, aids in storm water management, CO_2 sequester and O_2 producer and serves as a transpiration media	Perennial, biennials or annuals

Source: DeNardo *et al.*, 2003; Peck *et al.*, 1999.

4.4.1 Waterproofing

Waterproofing is arguably the most important pre-requisite of a green roofing system. For waterproofing to remain effective it must be root resistant over the long term and should fulfill the necessary standards.

Alternatively, if the waterproofing is not root resistant then the *green roof system* must include a separate root barrier. Numerous waterproofing systems exist. These include[22]:

A. **Bitumen/asphalt roofing felt or bituminized fabrics.** These materials generally have a limited life span of 15 to 20 years and degrade from temperature changes and ultraviolet radiation. A separate root protection barrier must be applied with such membranes.

B. **SBS modified bituminous membrane sheets set in SEBS polymer modified bitumen and coal tar pitch/polyester built-up systems.** These are a more robust system suitable for green roofs. However, they are only root resistant if a layer of copper is put inside membrane or if it is treated with chemicals. This kind of waterproofing is commonly used in Europe for Intensive green roof application.

C. **Fluid Applied Membranes.** These are available in hot or cold liquid form and are spray painted onto the surface. They do not suffer from jointing problems and are easier to apply vertically or to difficult shaped surfaces. Often a protection board (PVC sheet or expanded polystyrene) may be added above this layer. On flat roofs a layer of gravel, concrete slabs or sand may be added to protect the membrane from temperature fluctuations and UV radiation. (These gave rise to the observations of spontaneous plant colonization which sparked initial research on extensive roof greening in Germany).

D. **Single-ply roof membranes.** These membranes are rolled sheets (sometimes tiles) of inorganic plastic rubber material overlapped at the joints and sealed with heat, or with solvents if Ethylene Propylene diene monomer rubbers (EPDM) are used (requiring very clean and dry conditions). These membranes can be very effective if applied properly but are weakest at the seams between sheets and tiles. The PVC and butyl rubber are prone to UV degradation and should be covered at all locations. Thermoplastic polyolefin (TPOs) are also specified for green roof waterproofing and are often considered more environmentally acceptable. PVCs, EPDM's and TPO's are generally root-resistant. These kinds of membranes have a long proven track record in the green roof industry but rely on correct installation.

E. **Concrete admixture water-proofing. Concrete admixture waterproofing or Hydrophobic Pore blocking Ingredients (HPI)** is not well known in the green roof industry because they are applicable only to newly cast concrete roofs. From a construction and waterproofing viewpoint they perform better than PVC membranes and are generally cheaper too. With this system the concrete itself becomes permanently waterproofed in a more robust form which cannot be punctured, torn or damaged (a risk often associated with other waterproofing techniques when other sub-contractors are working on upper layers). Attachments to the roof slab (such as tree anchors) are also easy to install and do not form weak spots as they would through membrane waterproofing. However, when using HPIs it is important to find an admixture which is:

   a) Is effective at limiting water-absorption.
   b) Has a long and proven track record.
   c) Is guaranteed for a long time and is guaranteed despite workmanship which may occur above the slab.
   d) Chemically do not break down over time.

e) Does not leach out under pressure does not compromise the performance of the concrete. Another type of concrete admixture is crystal growth waterproofing which works by growing crystals within the pores of the concrete matrix. It is best used as a concrete admixture when the concrete is being cast but can also be effectively used as coating which penetrates into existing concrete. As a coated waterproofing its effectiveness may be dependant on the type and porosity of the concrete used.

On new roofs the ideal is to double-watcrproof the system using waterproofed concrete as well as a more flexible waterproofing layer above. Each waterproofing system has its own advantages and disadvantages but by combining the two systems far greater reliability is achieved. For example, although concrete admixtures are more robust and more repairable, the negative side of concrete waterproofing is that under certain conditions, where concrete expands and contracts, cracking is inevitable. These cracks would most likely be covered using a flexible system (PVC, etc). For existing roofs, where waterproofing the concrete system is impossible, it is still advisable that any leveling screed is also waterproofed.

On existing roofs it may be determined that the existing waterproofing is sufficient and that the green roof layers may be added without additional waterproofing. An assessment like this must be undertaken by a suitably qualified professional and/or the liability of failure removed from the green roof contractor's responsibility. When using liquid or sheet membranes, attention needs to be given to the following locations where water leakage is often present

a) Right angled bends such as corners or at the junction between a roof slab & a parapet wall

In these locations it is preferable to fix a triangular fillet prior to laying the membrane. This will form an obtuse angled junction, which is less likely to tear as a result of any subsequent movement that may take place, than a right angled one.

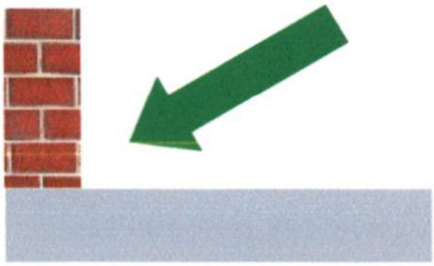


Figure 4.6 Junction of slab and parapet

Source: Author

b) For the prevention of rising damp

The membrane should be continued between 150mm & 300mm vertically up the side of a parapet wall at the perimeter of a roof, above the roof level & dressed into a horizontal groove & sealed. It should not just be stuck onto the side of the wall. The same principle applies to plinths & machine bases on the roof.

c) For pipe or service duct penetrations

Carry any liquid waterproofing material up the side 150- 300mm above the roof level. With sheet material, trim carefully around the base of the pipe & seal with a liquid applied sealant compatible with the membrane material.

d) Where the parapet is made of block or brickwork, rather than concrete

The waterproofing should be taken up the inner face of the parapet wall & beneath the coping on the top of the parapet. If this is not done, water will pass down through the brickwork & migrate behind the membrane at roof slab level.

e) Prevention of degradation

The surface of the membrane may need to be covered with tiles, lightweight mortar screeds, or reflecting paint in order to prevent UV degradation & radiant heat absorption into the roof slab.

f) Surface abrasion tears

Special care must be taken to ensure that waterproofing does not lie on a concrete/screed surface that is too rough. Expansion and contraction as well as the weight pushing the waterproofing onto this surface can cause punctures or abrasion holes. A separation layer is generally advisable.

4.4.2 Root Barrier

As mentioned above, a separate root protection barrier is needed if the waterproofing layer contains bitumen, asphalt, or any other organic material. It is important that this separation is continuous because any penetration of roots also provides access for micro-organisms which can actually attack these organic oil-based materials. Root Protection membranes are usually made of PVC rolls that are around 1mm thick. Intensive green roofs may need a far more robust root protection system capable of withstanding the penetration of tree roots. These are often thick hard plastic sheets or even metal sheets (usually copper) for exceptionally vigorous roots (such as from some Ficus trees or bamboos). For extensive green roofs with limited rooting, a single layer of 0.4mm thick HDPE membrane can also be installed without welding as long as the overlap is at least 1.5m. Figures illustrated below are showing variety of material used as a root barrier for green roof.

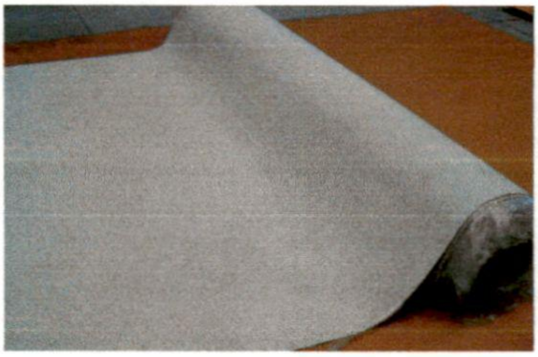


Figure 4.8 PVC roll

Source:http://www.hercules-online.com/ PVC.jpg

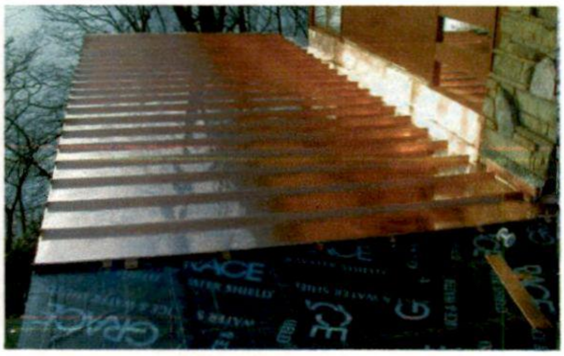


Figure 4.9 Metal sheet

Source:www.guttersupply.compublic/file/ha.

4.4.3 Protection Layer

Between the waterproofing and drainage layer a protection layer is often advised. This is usually a non woven geo-textile that protects the waterproofing from mechanical damage. Extensive green roofs usually use a 300gr/m² polypropylene layer. A stronger protection layer (ranging from 400-800 gr/m²) is advised for green roofs with higher strain or loadings. The application of protection layers is more critical if the drainage layer uses a more primitive granular mix.

4.4.4 Drainage Layer

The main purpose of the drainage layer is to drain *excess* water or underflow as rapidly as possible to prevent prolonged saturation. The operative word is excess, meaning that drainage is only necessary if the growing medium has reached saturation point. In fulfilling its main purpose, the drainage layer also protects the waterproof membrane. If drainage is inadequate then problems to the waterproof membrane may occur due to continuous contact with water or wet soil. It also helps to aerate the substrate, it helps in providing internal airflow, below and through the substrate it also helps to reduce the vacuum which occurs due to wind uplift along the edges of an extensive green roof. A permanently wet green roof is also likely to lose its thermal insulating properties.

The drainage layer may also double up, in some instances, as an irrigation mechanism, referred to as *irrigation by diffusion.* In such cases the troughs of the drainage layer, which are able to store water (away from the substrate), are actually able to provide water to the substrate through diffusion into the substrate which draws water up when dry.

Drainage layers are only applicable to flat or slightly angled surfaces (<5°). The addition of drainage layers on steeper slopes may in fact remove water too quickly and be disadvantageous to plant growth.

There are three main types of drainage materials

4.4.4.1 Granular Material.

These are usually coarse granules of gravel, stone chips, broken clay tiles, clinker, scoria (lava rock) and pumice. They contain large pockets of air or pore space between them when packed together in a layer or a space. It is this pore space that allows water to run freely through. This is the most low-tech drainage system but in some cases may be all that is necessary to lift the main substrate above the draining water. Often these layers may be lighter than the main growing substrate and can be used to lighten its overall load because they are still used as part of the root zone. Figure 4.9 is showing one of the options of drainage material for green roof this is easily available locally that is why it is highly preferred as a drainage material.

Figure 4.10 Brick ballast
Source: www.kingstonsupply.com/brick%20chips.jpg

4.4.4.2Porous mats

These mats operate in a similar way to horticultural capillary matting. They are made from numerous materials including recycled materials such as clothing and car seats and behave much like sponges, absorbing water into their structure. There is the danger that these materials may absorb too much moisture from the growing substrate or become too light when dry. Some materials (e.g. recycled foam) may decompose or shrink over time. Having no nutrient holding potential these materials may require continual fertilizing.

Figure 4.11Recycled Foam
Source: Earth Pledge, 2005

4.4.4.3 Lightweight plastic or polystyrene drainage modules

A great variety of proprietary products exist store water while others do not, and some can be filled with granular media. These interlocking modules are rigid enough to support the growing medium and vegetation which are kept away from the roof, and provide a permanent free-flowing lightweight drainage layer beneath. In some designs they store reserve water allowing plants to derive additional moisture. To prevent collapse during and after construction attention must be given to the strength that these drainage media offer. Thickened HDPE or High Impact Polystyrene (HIPS) may be considered in some circumstances.

Drainage outlets are an important consideration (existing roofs will already have their own drainage points installed). These need to be kept clear to fulfill their functions, especially from growing substrate. Drainage outlets should be connected by vertical piping to the surface of the growing medium so as to avoid and to clear blockages.

Drainage layers include a filter mat above, which prevents fine material being washed into the drainage which would negate its purpose and may also block the drainage outlets. Non-woven filter layers are ideal for most circumstances (having superior filtration) though woven versions may be considered for heavy duty applications. It is important that edges of the filter mat are taken up the edge of the planting medium.

If suitable soils are used, sloped green roofs (3°-10°) may drain naturally without the need for a drainage layer. For slopes above 10° it is advisable to include a drainage board that actually holds water in its specially designed pockets as the natural drainage may be too rapid.

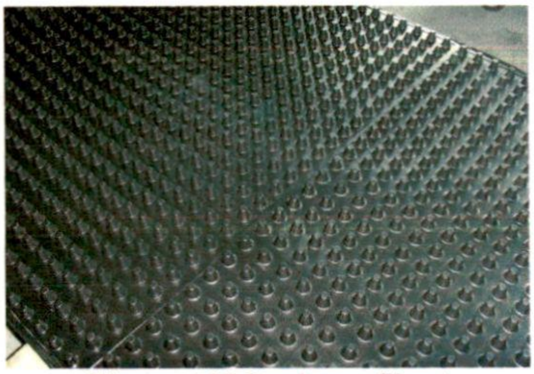


Figure 4.12 Drainage Sheet
Source: http://www.made-in-china.com

4.4.5 Growing Medium / Substrate / Soils

Finding the right soil mix for roof gardens is a critical aspect to its success. The general requirements of all growing media are the same:

1Efficient moisture retention

2Excess water is easily drained

3 Well aerated

4 Able to absorb and supply nutrients

5 Retains its volume over time

6 Provides adequate anchorage for plants.

Additional requirements that are important for green roof growing media include the following:

1 Light weight

2 Water retention capacities

3 Inert in a sub-tropical climate (i.e. artificial materials do not degrade); and

4 Fire resistant properties.

Light weight characteristics may be achieved using natural, artificial, or waste minerals. Lava (scoria) & pumice, perlite, vermiculite, light expanded clay aggregate (LECA), rockwool, diatomaceous earth (DE) 40 and numerous other materials are used. These may offer some other advantages, such as greater water absorption, but this light weight advantage usually comes at a cost, such as retaining soil volume or nutrient holding capabilities.

In extensive green roofs general garden soil or topsoil on its own is generally not suitable because it is too heavy and too fertile. However, thin layers of topsoil have been seen to be successful when used above lightweight, well-drained mediums below. Therefore, in the extensive green roofs developed in Europe, substrates are geared towards light-weight alpine-like meadow vegetation (i.e. *Sedum* species).

These prefer well-drained, low fertility soils where they have developed survival techniques to secure their niche. German research indicates that the ideal growing medium comprises 30%-40% substrate and 60%-70% percent pore space. Most commercial substrates are based on tailor-made non-organic mineral components. Clay and organic materials are sometimes added for their moisture and nutrient-holding capacities but noting the types of vegetation commonly used, and the negative aspects of these materials (potential clogging of the drainage systems and shrinkage of organic matter) these are usually applied sparingly. Fire resistant properties are important, particularly for extensive green roofs where the maintenance regime may involve minimal irrigation permitting the roof to remain dry for long periods in the dry season.

The depth of growing medium/substrate or soil for various vegetation types is critical to its success.

A list of the regular materials is presented in the Table4.2 showing the characteristics of each material.

Table 4.2 List of materials for growing medium

Materials	Comments
Natural minerals	
Sand	Fine texture can result in lack of pore space and problems of saturation of the substrate if drainage is poor. Conversely, coarse sands can be so free-draining as to require constant irrigation.
Lava (scoria) & pumice	Lightweight and valuable if locally available.
Gravel	Relatively heavy.
Perlite	Particles tend to collapse over time (Hitchmough 1994).
Vermiculite	Very lightweight, but has no water- or nutrient-holding capacity and may disintegrate over time (Hitchmough 1994).
Artificial minerals	
Light expanded clay aggregate (LECA) Expanded shale	Lightweight, produce large amounts of pore space because of their size, and absorb water because of their porous nature.
Rock wool	Very lightweight but energy-intensive production and no nutrient-holding capacity.
Crushed clay brick or tiles, brick rubble	Stable and uniform, some nutrient and moisture retention. Brick rubble may contain mortar and cement, which will raise the pH of the substrate.
Crushed concrete	Limited moisture retention and nutrient availability, alkaline. However, cheap and available in quantity as a demolition material.
Subsoil	Heavy, low fertility, readily available as by-product of construction.

Source: Dunnett & Kingsbury (2004), p73

Table4.3 Material Weights of Soils and Other Green Roof Components

Materials Weight (Saturated Weights Where Applicable) - x 100 for kg/m³			
Soil Substrate Material	**Weight of 1cm layer (kg/m²)**	**Other Materials**	**Weight of 1cm layer (kg/m²)**
Gravel	16-19	Stone	23-30
Pebbles	19	Granite	26.6
Pumice	6.5	Concrete (precast)	21
Sand	18-22	Concrete (reinforced)	24
Crushed Brick	10-13	Brick (solid with mortar)	18
Sand and gravel mix	18	Hardwood timber	7.3
Topsoil	17-20	Softwood timber	5.7
Topsoil (lightweight)	14	Cast iron	71
Water	10	Steel	78

Lava	8		Aluminum	27
Perlite (expanded)	5		Extruded Polystyrene fill	0.7

Source: Dunnett & Kingsbury (2004), p60, Also refer to http://www.simetric.co.uk/si_materials.htm and Chapter 13, 'Reference Values for Design Loads' of the FLL Design Guidelines

4.2.5.1 Image showing types of growing medium available in India

Figure 4.13Perlite[1]

Figure 4.14 Gravel[2]

Figure 4.15 River sand[3]

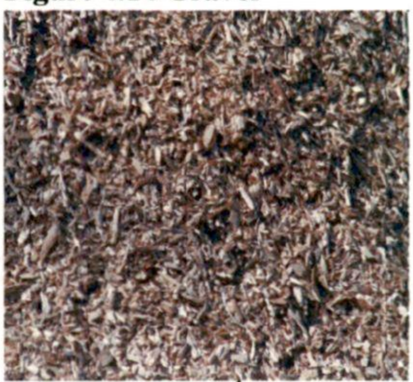


Figure 4.16 Mulch[4]

Figure 4.17 Vermiculite[5]

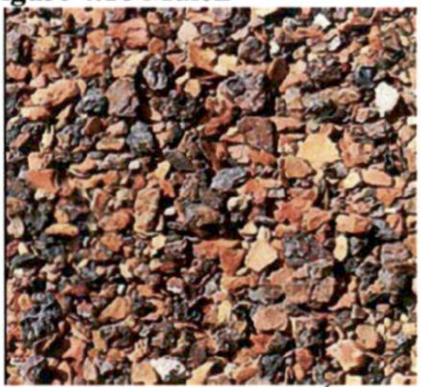


Figure 4.18 Brick ballast[6]

Image source

1. http://img.alibaba.com/img/buyoffer/12864863/Buy_Perlite_Sand_Size_1_18_1_70mm_10_14Mesh_.jpg
2. http://www.nylandsolutions.com/gallery/bluestone-gravel1.jpg
3. www.moremulch.comRiverSand.JPG
4. playnlearn.com/soft/images/redMulch.gif
5. www.1-hydroponics.co.uk/.../vermiculite.jpg
6. www.kingstonsupply.com/brick%20chips.jpg

4.4.6 Plant Selection of Green Roofs

4.4.6.1 The Importance of Trees

Any urban greening proposals, including green roofs, should consider the inclusion of trees. Compared to other types of greening, trees are generally the most effective in terms of:

1. The amount of greenery they provide versus the ground surface area they occupy (though roots may occupy substantial underground space)
2. Their provision of shade
3. Their rates of evapo-transpiration
4. Their total leaf surface area and ability to filter air-borne particulates and gaseous pollutants
5. Their life-expectancy
6. Their sensitivity to climatic and air quality fluctuations
7. Their visual mass
8. The ecological habitats they create
9. Their long term maintenance and water requirements
10. Their price

Trees greatly enhance the various benefits offered by green roofs. Trees define spaces and provide micro-climates conducive to the creation of amenity spaces on rooftops, which may ultimately enhance the value of the property. A plant selection matrix of trees, Annuals, Shrubs etc. applicable for intensive green roofs and extensive green roofs in India is presented in Annexure 1

4.4.6.2 Trees in Green roof

If trees are included in Green roof the following key aspects should be considered:

1. Provision of adequate soil volume for healthy growth and anchorage is critical. A simple rule of thumb is that 1.2m soil depth should be provided, although smaller trees may grow in shallower depths, provided that the lateral extent of soil is widened to compensate.
2. Soil depth may be locally deepened at tree locations (either by mounding the soil surface or locally deepening the planter). Trees may be located over structural columns to take advantage of loading efficiency.
3. Tree anchoring may be by staking or tying down of the root ball but in all cases must not interfere with the integrity of the waterproofing.
4. Species selection is critical. Trees need to be selected which have a strong branching system, are flexible in high winds and have leaves that do not appear battered when exposed to strong winds.

4.4.6.3 Calculating Plant Weights

Calculating plant weights at maturity (particularly for trees) is an important consideration during the initial design stages of a green roof. There is no industry standard for calculating tree weights.

Tree weight calculations consists of three components; stems, branches and roots. Weight calculations for roots can simply use the entire volume of the soil multiplied by an average soil density ($1750 kg/m^3$). The proportion of the roots (around 20%) can be ignored because the heavier density of soil builds in an adequate safety margin. The above-soil weight calculations are based on a tree being simplified into a consistent cylinder, where the volume is easy to calculate (¶.r^2 x H), multiplied by the density of hardwood ($650 kg/m^3$). The estimated radius at the branching height (usually ⅓ of the estimated total height) is considered a usable average for the volumetric calculations of the assumed cylinder.

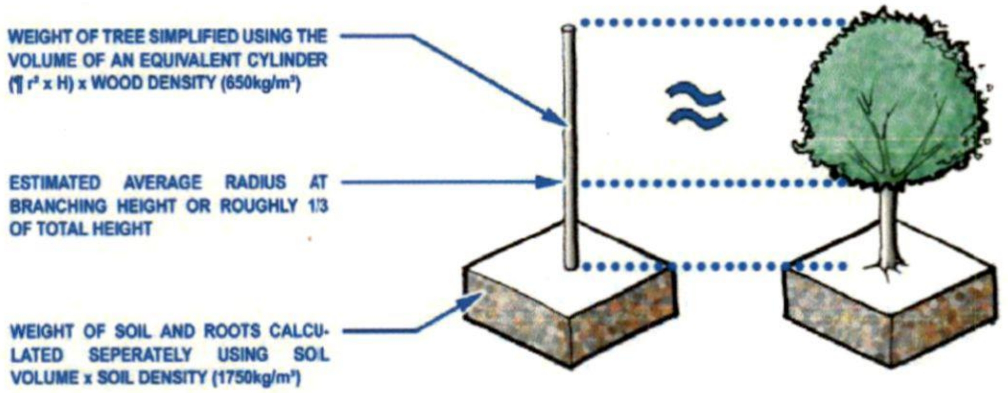


Figure 4.19 Calculating Plant Weights at Maturity

Source: Urbis ltd, 2006

Above calculations do not affect wind loading which needs to be added to the weight loading calculations. Additional wind loading results from the horizontal force of the wind being transferred to the roots of the tree, resulting in a downward pressure on one side and an upward pressure on the other side. This is best left for suitably qualified engineers and experts to determine. Also not included are tree supports and anchorage which may become exceedingly heavy with larger trees.

Determining plant weights during construction is also important. These weights need to be calculated to determine labour and transport costs and to ensure the balancing of cranes that may be used to lift heavy trees. Table 4.4 below presents a very general indication of typical weights for a variety of plant materials.

Table 4.4 Typical weights of Plants

Light Standard Tree	Stem dia. 35mm Total height 2.5m	Root ball dia. 350mm, depth 300mm 54 kg
Standard Tree	Stem dia. 60mm Total height 3.5m	Root ball dia. 350mm, depth 300mm 58 kg
Palms	Stem dia. 30mm Clear trunk height 300m	Root ball dia. 200mm, depth 250mm,14 kg
	Stem dia. 40mm Clear trunk height 700m	Root ball dia. 250mm, depth 250mm, 15 kg
	Stem dia. 80mm Clear trunk height 1500m	Root ball dia. 350mm, depth 300mm, 57 kg
	Stem dia. 100mm Clear trunk height 3000m	Root ball dia. 500mm, depth 450mm, 174 kg
	Stem dia. 120mm Clear trunk height 4500m	Root ball dia. 1000mm, depth 600mm, 881kg
	Stem dia. 150mm Clear trunk height 7500m	Root ball dia. 1300mm, depth 800mm, 1997 kg
	Stem dia. 170 mm Clear trunk height 9500m	Root ball dia. 1800mm, depth 1000mm, 4721 kg
Bamboo palms	Stem dia. 175 mm Clear trunk height 1500m	Root ball dia. 350mm, depth 300mm, 75 kg
	Stem dia. 210 mm Clear trunk height 2000m	Root ball dia. 350 mm, depth 300 mm, 97 kg
Bamboo	Stem dia. 50 mm Total height 600m	Container dia. 400 mm, depth 450 mm, 103 kg
Small Shrubs	Stem dia. 10 mm Total height 400 m	Container dia. 130 mm, depth 150 mm, 4 kg
Medium Shrubs	Stem dia. 15 mm Total height 600m	Container dia. 150 mm, depth 200mm, 6 kg
Small Ground covers	Average dia. 350 mm	Pot grown dia.125mm,depth150mm,3kg
Medium ground covers	Average dia. 500 mm	Pot grown dia.150mm,depth 200mm,6kg
Large ground covers	Average dia. 1200 mm	Pot grown dia.200mm,depth300mm,17kg

Source: Values provided by Asia Landscaping Ltd

1. **Extensive Green Roof Planting Approaches**

This section suggests planting options commonly associated with extensive green roofs. Extensive green roofs are designed for their low maintenance and/or ecological functioning and generally follow four basic approaches:

2. **Mono-culture planting**

This type of planting is simple and usually uses one plant species en masse. It is the easiest to prescribe and install. It is argued that mono-culture plantings are visually uninteresting but in some circumstances a uniform appearance may be appropriate. From an ecological viewpoint they may be susceptible to total die-back if drought or disease severely affects the species.

3. **Pattern Planting**

This type of planting is used primarily for its visual effect but uses more than one species. As an open canvas, a wide range of designs are possible. The usual design elements may be used for good effect: a play with materials and colors; a play with proportion and balance; a play with texture, pattern and line; and the use of rhythm and repetition. This approach may require higher maintenance levels than other planting approaches.

4. **Mixed Planting**

The approach uses a mix of species to create a random but colorful carpet. It is a relatively safe approach as the successful growth of various species will eventually find there own equilibrium. This approach does not necessarily use indigenous species and in most parts of the world uses a mix of sedums.

5. **Plant Communities Planting**

This approach is based on natural habitats. Plants are chosen and combined in proportions approximating nature and their occurrence in the wild. Community-based planting tends to be self-sustaining, requiring low maintenance inputs for their upkeep. By their nature, they would be informal with a naturalistic appearance.

This approach may often use wild grasses and may be considered untidy by some. Some examples from overseas have seen the careful and diverse selection of plants that flower almost year-round. This approach strives to use indigenous plants to fulfill a green roof's maximum ecological potential.

4.4.5 Extensive Green Roof Planting Approaches

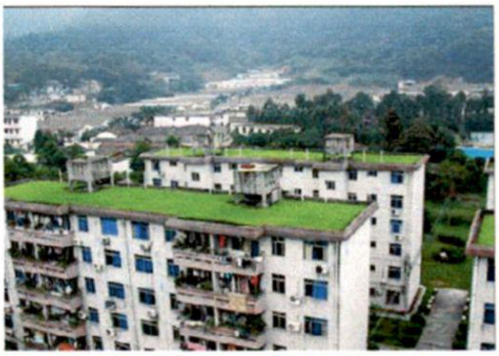


Figure4.20 Monoculture Planting
Source: Urbis Ltd.

Figure4.21 Pattern Planting
Source: Earth Pledge, 2005, photo Peter Philippi

Figure4.22 Mixed Planting
Source: Earth Pledge, 2005.

Figure4.23 Plant Communities Planting
Source: Dunnett & Kingsbury (2004), p 101

4.5 IRRIGATION SYSTEMS

Irrigations systems and plant water requirements are highly dependent on site location, water supply and pressure, maintenance access, size of planter, type of vegetation and the expected lifespan of plants and the irrigation system. There are three principal ways of irrigating green roofs:

1. Manual Hose Irrigation - a 20m hose pipe connected to water points located at 40 meter spacing.
2. Fully Automatic Irrigation Systems - a programmed system that irrigates at set times, running continuously with minimal supervision.
3. Semi-Automatic Irrigation Systems - a programmed system with various manual override options that are activated per day or as needs require.

Manual watering (with hose) is reliable, robust and tried-and-tested. Its main draw-back is its high labour costs. Automatic irrigation systems are systems that are controlled (usually electrically) to irrigate areas of planting without human intervention. They are able to deliver precise water quantities at very specific times.

Irrigation system has some advantages and disadvantages without knowing that we cannot decide the irrigation system. Maximum advantages and disadvantages are of manual and automatic irrigation system are discussed below in Table 4.5 and 4.6

Table 4.5 Manual Irrigation Systems

Advantages	Disadvantages
• Reliable and robust. • Tried-and-tested. • Low installation costs. • Labour does not need to be skilled.	• High labour costs. • Installation of water points may be needed. • Watering needs to occur during working hours when more evaporation occurs. • Water usage is not optimized and efficiency may be difficult to monitor. • Water dispersion may be unevenly distributed.

Source: Author

Table 4.6 Automatic Irrigation Systems

Advantages	Disadvantages
• Reasonably reliable. • Low recurrent costs. • Watering can occur at times best suited to minimize evaporation. • Water usage is optimized, is easier to control and to monitor.	• High installation costs. • Space required for pumps and other infrastructure such as electrical controllers. • Components are more delicate and planting of vegetation needs more care not to damage pipe-work. • Skilled operators are needed to understand programming of control systems.

Source: Author

4.6 Construction Detail

Drawings of typical evolved typical section of green roof and its details at all joints is shown through image 4.24 and 4.25.this section detail out the sequence of all layers of green roof and its thickness. Parapet section is explained in detail because this joint is the joint where probability of leakage is very high therefore waterproofing layer is to be installed very carefully.

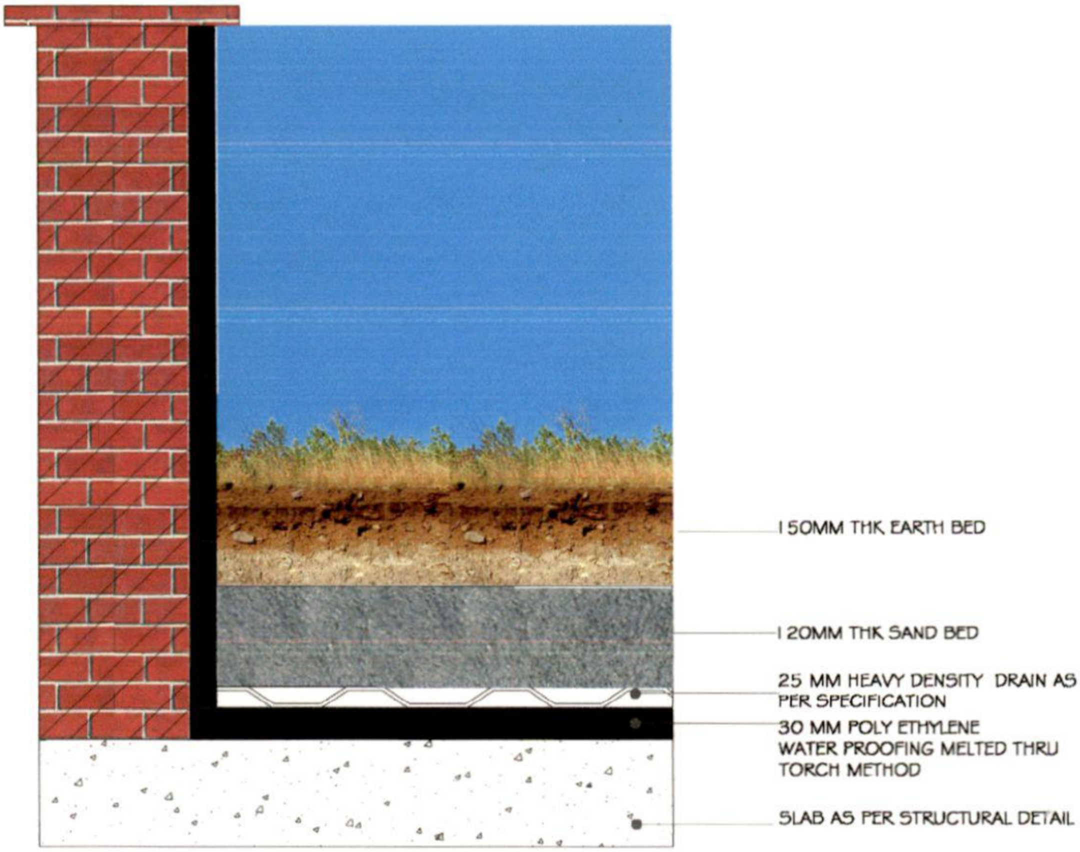


Figure4.24 Section at Parapet level

Source: Author

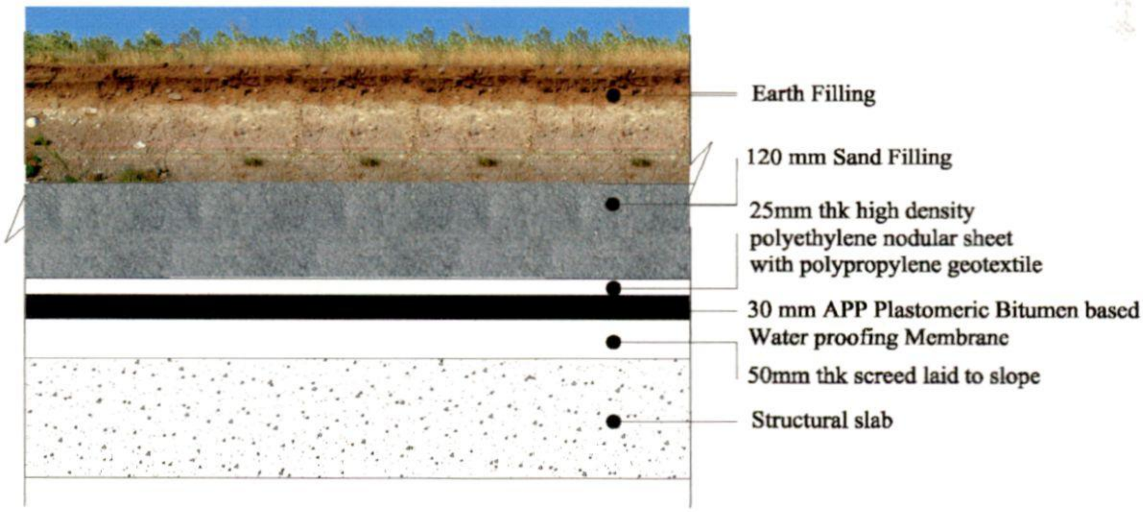


Figure 4.25 Typical roof Detail

Source: Author

4.7 MAINTENANCE CONSIDERATIONS

Maintenance requirements of green roofs are determined by many factors – height, micro-climate, soil types, soil depth, irrigation, species used and access. *Extensive green roofs* have been developed specifically to be low-maintenance. *Intensive green roofs,* on the other hand, are built for human usage and have maintenance considerations directly comparable to the maintenance of amenity planting at ground level locations.

Access is most often the most crucial factor influencing maintenance costs). Delhi's composite climate (high rainfall and humidity) necessitates higher maintenance requirements than in temperate climes. It remains to be determined whether the almost-zero maintenance achieved on some extensive green roofs in Europe can be achieved in India. Maintenance operations include:

a) Waterproof Inspections
b) Drainage Inspections
c) Removal of Litter
d) Electricity and Lighting
e) Plant Health Inspections
f) Replacement planting
g) Irrigation
h) Pruning
i) Mowing & Grass Cutting
j) Fertilizing
k) Disease & Pest Control
l) Weeding

Extensive green roofs have been developed specifically to be low-maintenance. *Intensive green roofs,* on the other hand, are built for human usage and have maintenance considerations directly comparable to the maintenance of amenity planting at ground level locations.

4.8 GREEN ROOF ESTIMATES FOR INDIA

Cost factors are the aspects of project which are often controlled by the design team and will determine the experience of a particular element. The prices ranges below are not recommendations but rather represent a survey of all materials throughout India.

4.8.1 Capital Costs

Capital Costs are largely dependent on labour, materials and access difficulties. However, compared with entire building costs in India, green roofs costs both intensive and retrofitted extensive are very small. A range of **Rs. 600/m² to 1500/m²** (average 1200/m²) is estimated for Local Extensive Green Roof in new construction. The costs for *retrofitting extensive green roofs* currently have no precedents in India. However, American research indicates that *new construction extensive green roofs* costs are around 60 to 70% more that of retro-fitted projects.

A typical breakdown of the costs involved is illustrated below in Figure 4.25 the specialized growing substrate is clearly the most expensive part.

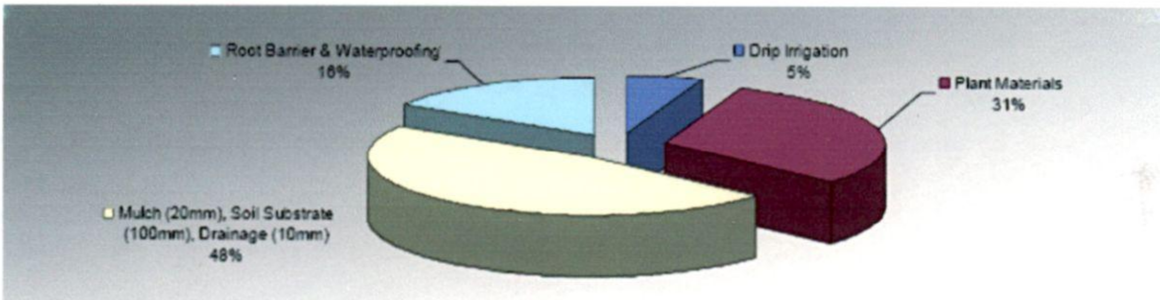


Figure 4.26 Typical Extensive Green Roof Capital Cost Breakdown

Source: Author

The costs of extensive green roofs are generally affected by the following:

a) Access constraints to the site during construction
b) Whether the project is a new construction or a retro-fit project
c) The slope of the roof
d) Status of the existing roof (if a retro-fit project)
e) The number and arrangement of rooftop utilities, affecting labour and wastage
f) The materials used, and the type of plant material used. This affects labour costs (plants may be individually planted, seeded, or have pre-grown sedum or turf mats applied)
g) Irrigation needs.
h) Growing medium depth
i) Access or safety components that need to be added

4.8.2 Intensive Green Roof Capital Costs

The costs of intensive green roofs are highly variable and therefore difficult to assess. They are estimated to be at least double the cost of an extensive green roof (if only soft-landscaping costs are considered).

*Lowest value for easily accessed intensive green roof is **Rs 1500/m²**. The general high-end range has been assessed at **Rs 2500/m²** and is based on a green roof having a highly thematic design, difficult access and where the landscaping contract and crane operations are brought in separately.*

The costs of intensive green roofs are generally affected by the following:

a) Access constraints to the site during construction
b) The ratio of hard- to soft-landscaping
c) The amount of specialized thematic designs and materials including water-features, canopies, etc. Whether the green roof is part of a larger building contract or not. This affects the availability of building equipment already on site. For example, costs can be drastically affected if cranes are brought in just for landscaping.
d) The size and maturity of the trees being installed and the type of vegetation being prescribed (Palms, bamboo, trees)
e) Depth of the topsoil
f) Irrigation needs.
g) Lighting.
h) Access or safety components that need to be added.

4.8.3 General Green Roof Capital Cost Breakdown

Below Table4.7 describes a typical breakdown of the costs involved for intensive and extensive green roofs. This table may provide a good indication for budgetary purposes, it should be noted that pricing of green roofing is normally by an Indian rate collected by a market survey till the month of May.

Table 4.7 Cost Breakdown of Green Roof

Basic Green Roof Components	Supply Costs	Install & Labour Costs	Additional Costs - due to height and Access constraints, etc.	Additional Notes & Descriptions
GROWING MEDIUM				
Mulch	20/m^2	Not included	Not included	
Topsoil	150/ m^3	Not included	Not included	
Sand	350/ m^3	Included	Included	
Lava (scoria) and Pumice	1800/ m^3	Not included	Not included	
Gravel	1100/ m^3	Included	Included	
Vermiculite	2800/ m^3	Not included	Not included	
Crushed clay Brick or tiles, Brick rubble	1000/ m^3	Included	Included	Price depends on availability of brick rubble in the area which is crushed on site.
PROTECTION & DRAINAGE LAYERS				
Filter Layer	20/ m^2	Not Included	Included	OPTIONAL- Separate root barrier is needed if waterproofing layer does not provide this function
Drainage Layer	1000/m^3 700 / m^2 850 / m^2	Included	Included	PVC layer. Costs include Moisture retention mat above and separation layer below
Separate Root Barrier / Root herbicide layer	220/ m^2	Included	Included	Robust and effective when used as an admixture to concrete (i.e. for new

				roofs). Needs a concrete layer of 150mm for effective guarantee.
Waterproof Layer (PVC membrane) and root layer.	180/ m^2 200/ m^2	Included	Included	OPTIONAL. May be needed if additional thermal insulation is desired.
Integrated Cement Waterproofing (Admixtures and Impregnations)	34 - 68/m^2 (150mm slab)	Included	Included	
Thermal Insulation Layer (Expanded Polystyrene)	180/m^2	Included	Included	
OTHER COMPONENTS				
Paved areas	300-500/ m^2	Included	Included	
Concrete roof slab	5000/m^3	Included	Included	
Concrete roof beams	7000/ m^3	Included	Included	
Railings added to parapet	1000/running meter	Included	Included	Free stand railing with concrete footings
Drip Irrigation System	240-400/ m^2	Included	Included	Price does not include additional tanks and pumping systems. It includes dispersal mechanism, controllers, timers and rain sensors.
Sprinkler Irrigation System	150-240/ m^2	Included	Included	

Source: Author

4.8.4 Recurring costs

Maintenance requirements for Intensive green roofs are directly comparable to the maintenance of grade parks, except for the difficulties associated with height access by maintenance staff. These proportions may vary considerably but are generally in the order of 30% which brings the local maintenance costs for intensive green roofs to between **Rs 900** per m² per year to **Rs 2100** per m² per year approx.

Estimated maintenance costs for extensive green roofs are based on industry experience in New Delhi and Lucknow. If installed as a proper Extensive Green Roof, maintenance should only require 1 minute per m² per year. This may increase but will very rarely exceed 3 minutes per m² per year. Translated into local labour costs this equates to between **Rs 500** per m² per year and **Rs 800** per m² per year approx. These values are typical for typical building rooftops. Very difficult access (such as on some highways structures) may have even higher maintenance values for extensive green roofs.

It is estimated that the maintenance of hybrid or semi-intensive green roofs, where more common amenity planting is used on thin lightweight substrates, will result in a maintenance cost range above true extensive green roofs but below the lowest range of Intensive green roofs, i.e. between **Rs 450** per m² per year to **Rs 1000** per m² per year approx.

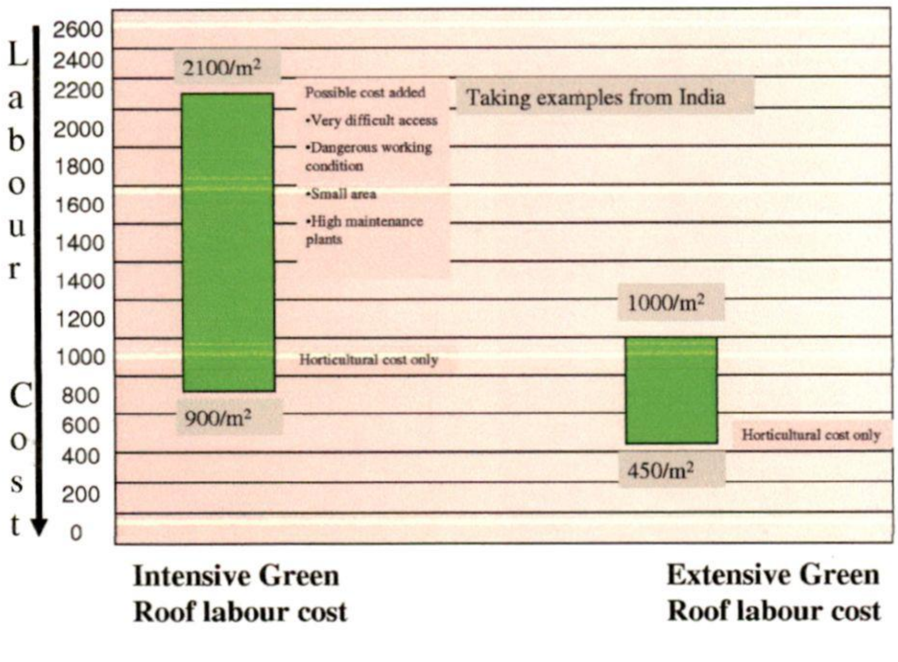


Figure4.27 Comparison of Intensive and Extensive Green Roof Maintenance Cost Ranges

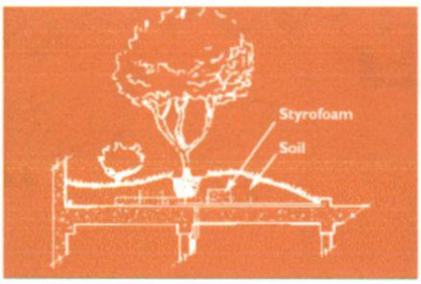
Source: Author

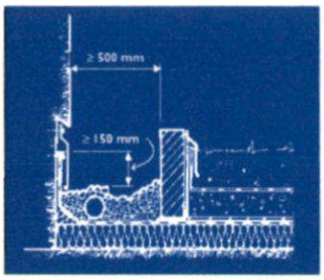
4.9 SUMMARY

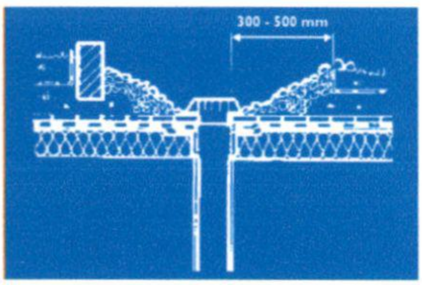
In this chapter all types of materials appropriate for green roof which is available in India with there specifications, market cost and evolved construction details from various case studies for composite climate is discussed which will further conclude in designing the guidelines for Indian composite climate. This way it will help in calculating life cycle cost of green roof for certain building typologies.

CHAPTER 5

OPPORTUNITIES AND CONSTRAINTS OF GREEN ROOF IN INDIA







5.1 BACKGROUND

This chapter discusses about the potential area for green roofs in New Delhi as a case and prevalent roof type scenarios in Indian context. From the above literature study potential areas for green roof opportunities are drawn and explained with the help of illustrations and few proposals are suggested showing the scope of green roof in Indian case, through this technical constraints and uncertainty risk is drawn for application potential of green roof for composite climate in India.

5.2 GREEN ROOF POTENTIALS IN INDIA: CASE-NEW DELHI

Green Roof Opportunities in the High Density area: Chandni chowk, Karolbagh

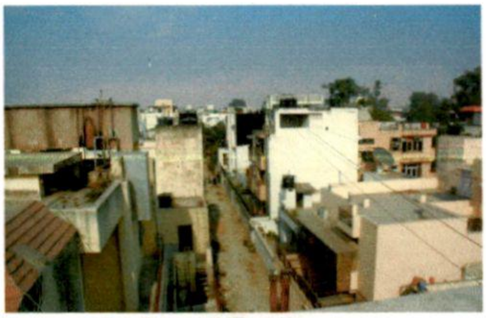


Figure 5.1 Karol Bagh

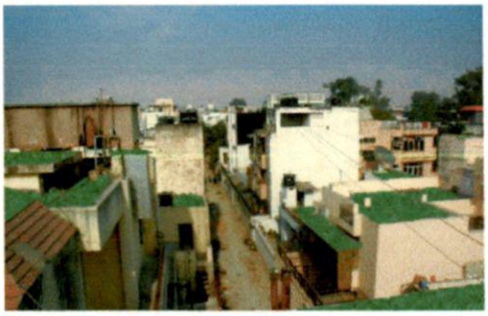


Figure 5.2 Proposed Green roof

Source: http://i.pbase.com/g3/88/589588/2/54450927.DSC_0079.jpg

Older areas in New Delhi have small street block have larger lot areas resulting in buildings with larger footprints with more space for green roofs.

Green Roof Opportunities in the City (Medium Density)

Figure 5.3 Galleria Market, Gurgaon

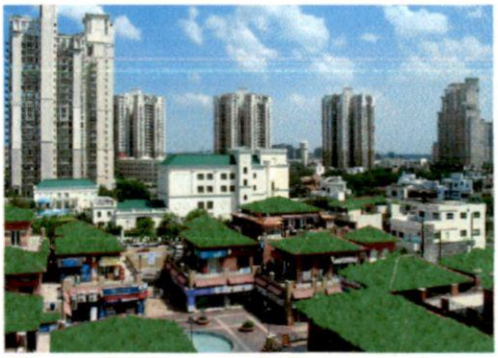


Figure 5.4 Proposed Green roof

Source:http://upload.wikimedia.org/wikipedia/ Skyscrapers_connaught_place_New _Delhi.

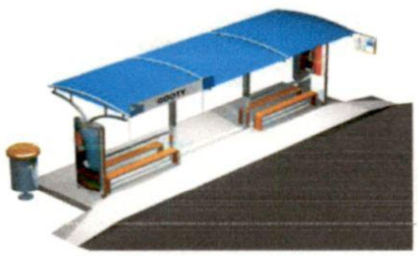
Newer areas in India have thin finger-like buildings with rooftop space cluttered with utilities. Retrofitted green roofs will be difficult to accomplish in these areas.

Green Roof Opportunities in Residential Areas

Figure 5.5 Residential area **Figure 5.6 Proposed Green Roof**
Source: http://www.qbtpl.net/images/Challng02.jpg

Large residential complexes offer space opportunities for green roofs. Regular heights allow for an environment without shadows which affects species choice.

Green Roof Opportunities on other Structures



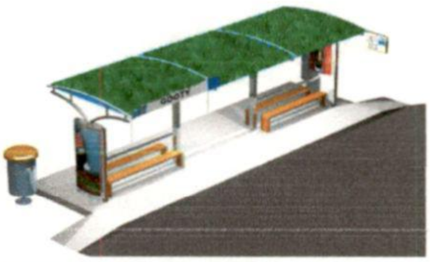


Figure 5.7 Bus Shelter **Figure 5.8 Proposed green roof**
Source:http://4.bp.blogspot.com/_CaUFHxmJoEk/RkdAUMdWnvI/AAAAAAAAADQ/OmfJ0Fx13pI/s400/concept1panel3-display.jpg

Noise enclosures offer good opportunities for green roofs, though sufficient sky lighting should be considered.

Other opportunities of Green roof in composite climate are *'Elevated footbridges'*, *'Noise barriers'*, *'Noise enclosures'*, *'Pumping stations'*, *'Electrical substations'*, *'Warehouses'*, *'Petrol stations'* and even *'Bus shelters'* are feasible locations for green roofs.

5.3 EXAMPLES OF GREEN ROOF FROM ABROAD

a) Before Retrofit **b)** After retrofitting

Figure 5.9 Photos of University of Hong Kong
Source: Cheung Shing Yuk Tong Co., Ltd., 2006

a) Before Retrofit **b)** After retrofitting

Figure 5.10 Photos of bus shelter green
Source: John YAU (Chun Wang), 2003)

Figure 5.11 Roof Greening of Noise Enclosures
Source: John YAU (Chun Wang), 2003

5.4 EXAMPLES OF GREEN ROOFS IN INDIA

Figure 5.12 Agriculture on roof in Mumbai [a]
(Semi intensive)

Figure 5.13 Farming on the roof in Mumbai [b]
(Intensive)

Figure 5.14 Terrace garden, Chennai.[c]
(Semi Intensive)

Figure 5.15 Commercial building, New Delhi [d]
(Semi Intensive)

Figure 5.16 Residence in New Delhi [e]
(Extensive)

Figure 5.17 Kitchen garden, Hyderabad [f]
(Extensive)

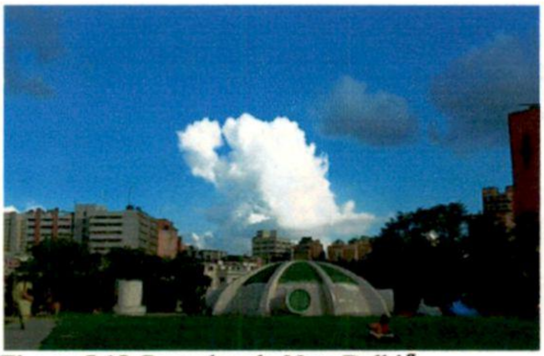


Figure 5.18 Central park, New Delhi [g]
(Extensive)

Figure 5.19 Garden in a restaurant, New Delhi [h]
(Extensive)

Image credits:

a) www.cityfarmer.info/.../2008/08/mumbai.jpg
b) www.cityfarmer.info/.../2009/04/fairmontroof.jpg
c) www.pcplandscapes.com/yahoo_site_admin/assets
d) Urbis Ltd., 2006
e) www.nrdc.org/water/pollution/lid/images/lid1.jpg
f) http://farm3.static.flickr.com/2383/1813200967_eec6214d2f.jpg
g) Author
h) http://media-cdn.tripadvisor.com/media/photo-s/01/1c/78/be/roof-garden.jpg

5.5 AVAILABLE ROOF TYPE SCENARIOS IN INDIA

In India we mainly trace three type of roof type

1. Flat roof
2. Pitched roof
3. Vaulted roof

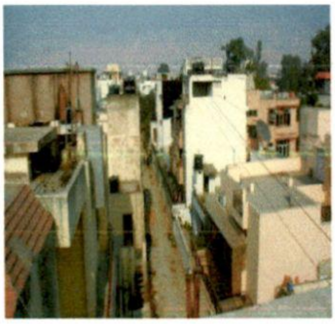


Figure5.20 High Density Area Karol Bagh Showing Flat Roof
Source: http://kolkataskyline. /untechcascades1sksky.JPG

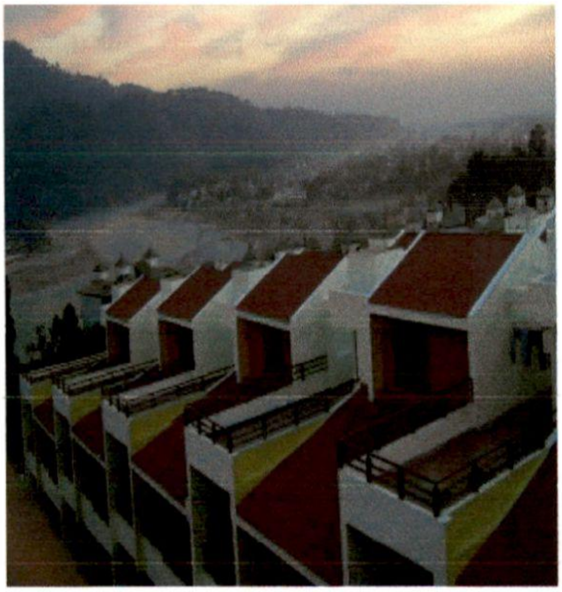


Figure5.21Pitched Roof in Apartments, Delhi
Source:http://data3.blog.de/media/896/2240896 _a62f3cfea8_m.jpg

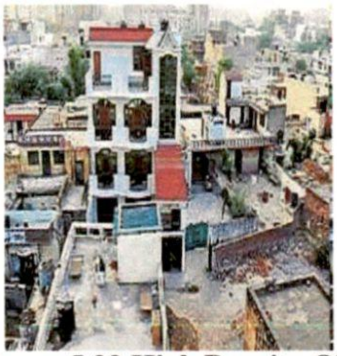


Figure 5.22 High Density Old Commercial space, Chandni Chowk
Source: http://www.qbtpl.net/ images/z11.jpg

Figure 5.23 Residential Colonies, Delhi
Source: http://images.google.co. inimgurl/TbkIC- /2008archive.html

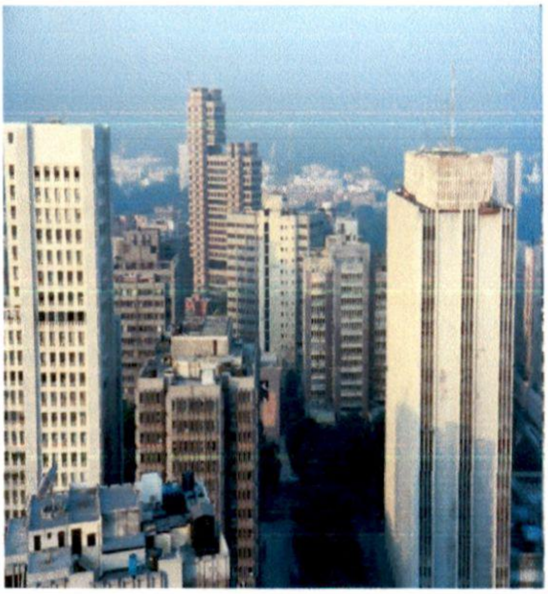


Figure 5.24 Nehru Place, Commercial Place, New Delhi
Source: http://wikipedia/commons/3/39/ Skyscrapers_New_Delhi.JPG

5.6 OPPORTUNITIES

India's urban form, context and climate are unique. In the CBD there are tall buildings providing minimal roof-greening opportunities. On the other hand other parts of the city have larger street blocks and buildings with more suitable roof greening opportunities. India also has numerous roof greening opportunities on infrastructure buildings, such as covered walkways, noise enclosures, railway station, bus shelters and pumping stations. Consequently, the potential opportunities for green roofs in India may be broadly categorized into three main Green roof scenarios –Sky gardens, New Buildings and Existing / Low Maintenance Buildings. Considerations for new and existing building in installation of green roof are explained through a Table 5.1 below.

Table 5.1 Considerations for New Buildings and Existing Buildings

New buildings	Existing Buildings
1. Costs can be saved in the design stage, as part of the existing contract. 2. Roof slabs can be designed to take heavier soil depth loads. 3. Irrigation and water supply can be built into the roof from the beginning 4. Waterproofing can be part of the concrete roof slab rather than using a membrane tanking system Utilities can be arranged to maximize the green roof area. 5. Favorable marketing opportunities may arise from the inclusion of green roofs. 6. Extended side walls to protect green roofs from excessive wind may be incorporated at the design stage 7. Barrier-free access (e.g. elevators) can be incorporated into the design if public access is considered.	1. Building requirements may limit growth medium depth. 2. The age and condition of the existing building and roof affects the feasibility of a green roof. 3. Installation of rooftop water points may be needed. 4. Installation of new drainage points may be needed. 5. Waterproofing needs to be considered as an additional layer. 6. Roof-top utilities placed in ad-hoc arrangements can limit the area of green roofs. 7. Access may be difficult and additional safety devices may need to be installed (Barrier-free access may be impossible to retro-fit).

Source: Author

5.6.1 Sky gardens

Sky Gardens are found on top of any high-rise buildings (usually 12 storey and above). Sky Gardens are usually designed as part of the building and may be **Intensive or Extensive Green roofs** depending on usage. Extreme growing conditions are often present. Wind is of particular importance and in some instances may rule out large trees. Conditions are also very exposed, enduring direct sunlight and temperature extremes. This may stunt the growth of some plants. Trees may be protected from high winds using wind screens. Structural anchorage as well as regular pruning of trees is important to avoid typhoon damage.

1. Safety is always a concern on high buildings. Railings for safe access are essential. The potential for lightning strikes also needs to be considered
2. Rooftop utilities are often located in positions that compete for space. It is essential to group rooftop utilities to maximize the space available for greenery. Refuge floor requirements are another building requirement that could potentially compete for space. Preserving panoramic views of the surrounding city is also an important factor affected by rooftop utilities.
3. Water pressure at roof top locations may also be a problem which may require complex tanks and/or pumps. Possible access by the public is another issue.
4. Hauling of materials and plants is a potential and expensive complication. Large trees are particularly difficult to move.
5. Waterproofing is critical on any roof and should be protected continuously from damage during construction, and after establishment. Special leak detection systems may be installed.
6. Critical plant selection is needed that includes non-invasive root systems and suits site-specific microclimates.

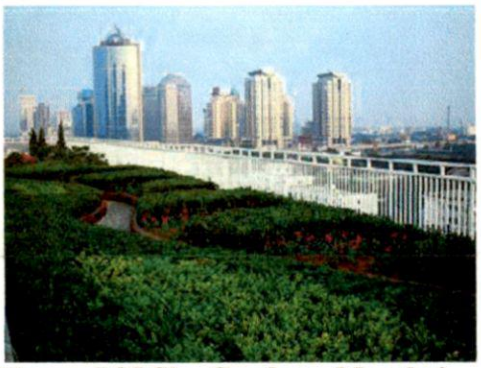


Figure 5.25 Sky Gardens, Mumbai
Source: ArchSD, 2005

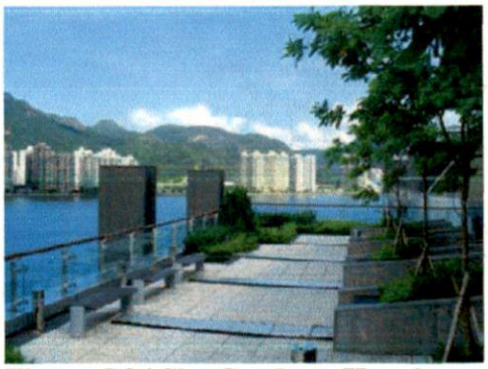


Figure 5.26 Sky Gardens, Hongkong
Source: ArchSD, 2005

5.6.2 Podium Gardens

Podium Gardens are usually 2 to 10 storeys up forming the base of a residential or office tower. These gardens are usually intended for full access by the building occupants or the public and are therefore always **Intensive Green roofs.**

Podium Gardens are usually 2 to 5 storeys high and are generally built for functional open space. As such numerous unique design issues need to be considered.

1. Safety is always a concern on roof gardens that are intended for high public usage buildings. Designs need to address the potential for creating mosquito problems. Playground equipment may be considered and needs to be designed with safety in mind. Structural anchorage as well as regular pruning of trees is important to avoid typhoon damage.
2. Podium floors are also often designed as refuge floors which may compete for space.
3. Waterproofing is critical on any roof and should be protected continuously from damage during construction, and after establishment. Special leak detection systems may be installed.
4. Critical plant selection is needed that includes non-invasive root systems and suits site-specific microclimates. Podia are often very shady or receive full sunlight for brief periods during the day.
5. Planting design needs to accommodate distant viewers who may look down onto the roof garden as well as the users of the garden. Variety, color and scale of the planting design are therefore an important consideration.

Figure 5.27 Podium Gardens, New Delhi
Source: Greenlink Küsters Ltd, 2006

Figure 5.28 Podium Gardens, Germany
Source: Urbis ltd, 2005

5.6.3 Existing and low-maintenance buildings

Existing and low-maintenance buildings include existing office and residential towers and other buildings such as public infrastructure buildings. Due to weight constraints and the need for low maintenance **Extensive Green roofs** would generally be prescribed. Existing and low-maintenance buildings are designed and retro-fitted primarily for environmental & building efficiency performance. Design issues usually revolve around loading, existing roof status, maintenance access and safety, soil depth, and successful low-maintenance species.

1. State of the existing roof is critical. The allowable weight and safety margins need to be critically assessed. The loading for extensive green roofs ranges from 80 to 150 kg/m² though loading may occasionally allow for Intensive Green Roof components at some locations. The state of the existing waterproofing is another major consideration.
2. Waterproofing is critical on any roof and should be protected continuously from damage during construction, and after establishment. Special leak detection systems may be installed.
3. Critical plant selection is needed that includes plants that 1) do well in lightweight and shallow soils, 2) are wind tolerant, 3) are drought tolerant, 4) are pollution tolerant and 5) have noninvasive root systems.
4. Growing media generally needs to be 1) super light-weight, 2) inert, 3) well-drained, 4) well aerated, 5) fire resistant, and 6) nutrient retentive. Despite being lightweight the growing media should provide adequate anchorage for all plants and also be resilient to wind erosion.

Figure 5.29 Low maintenance buildings, London.
Source: Green link Kusters ltd, 2006

Figure 5.29 Low Maintenance buildings, Portland
Source: Green link Kusters ltd, 2006

Utilities on New Buildings

Rooftop utilities can significantly influence the design, cost and eventual success of any green roof. Utilities on *extensive green roofs* can, if oddly placed, result in wastage of up to 30%. Rooftop utilities on *intensive green roofs* are even more important because they can significantly hinder the creation of user friendly roof-top spaces.

The arrangement of rooftop utilities on all new buildings is therefore an aspect that should receive significant consideration during the early design phase of a building. This is particularly important in the Indian context where tall finger-like buildings are largely cluttered with rooftop utilities.

The example in Figure 5.31 below shows how a variety of greening techniques (intensive and extensive), and a well thought-out use of level changes, can be adopted to achieve an uncluttered appearance. Users of the space are able to enjoy unobstructed panoramic views of the city – one of the few unique advantages that green roofs offer over at-grade greenery. Similar principles were followed in Roppongi Hills, Tokyo, as shown in Figure 5.32 to Figure 5.35.

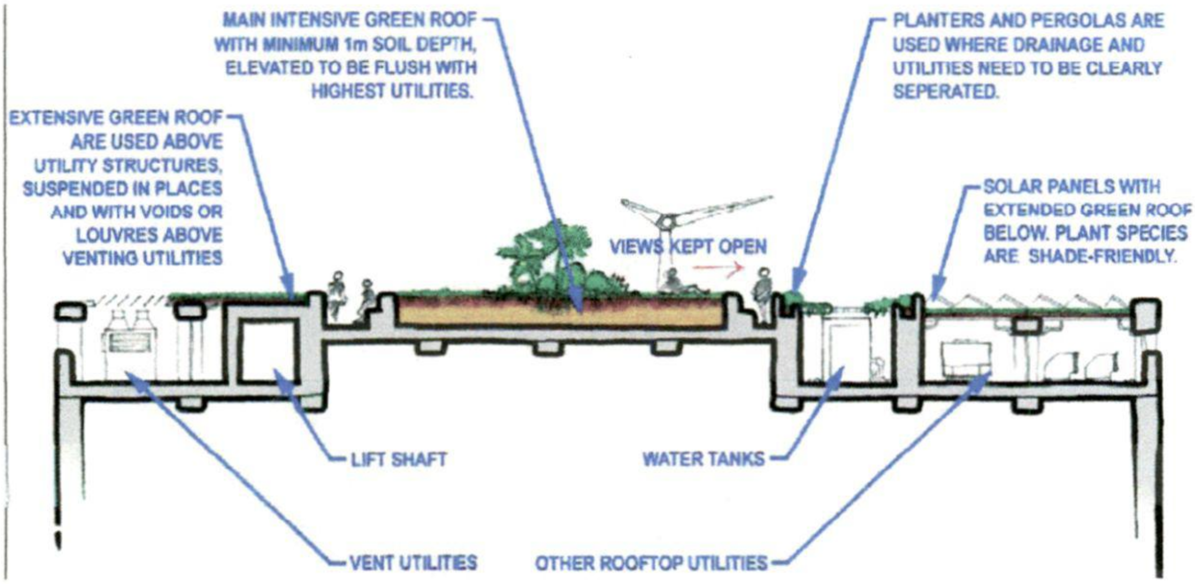


Figure5.31 Showing Utilities on New Building

Source: Urbis Ltd., 2006

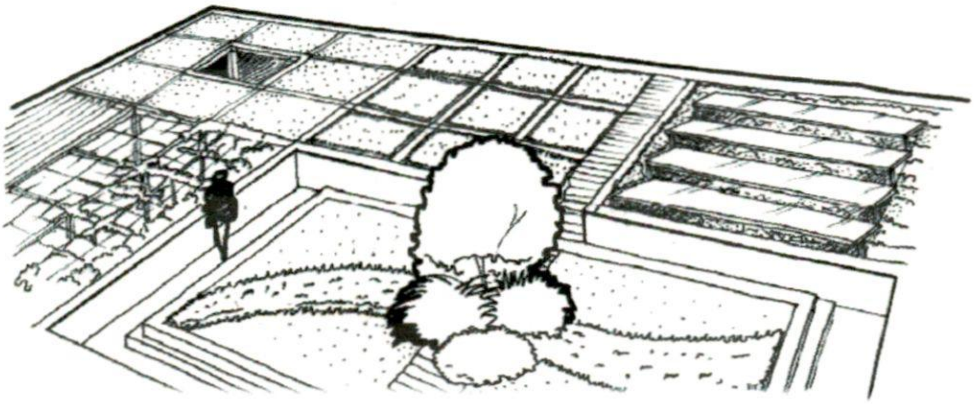


Figure 5.32 Isometric view
Source: Urbis Ltd., 2006

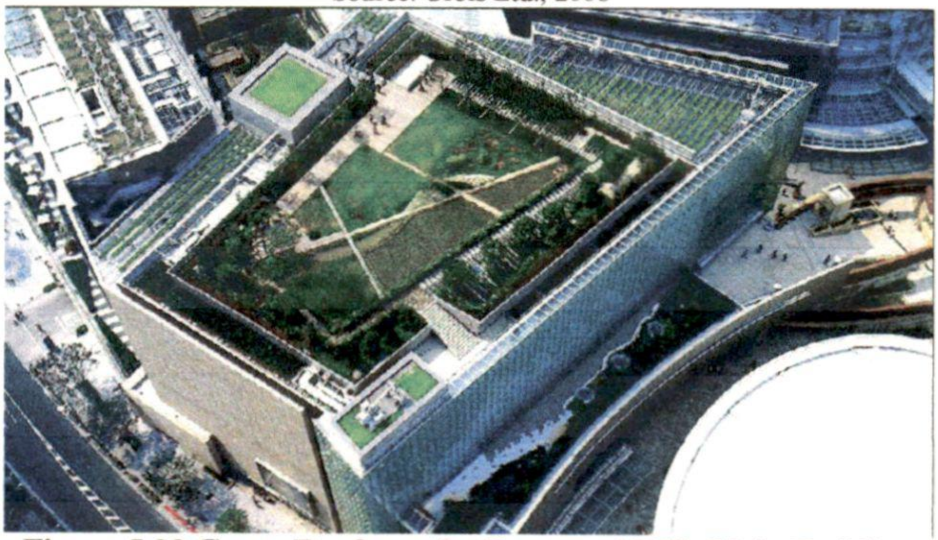


Figure 5.33 Green Roofs on the Roppongi Hills Main Building
Source: http://www.takenaka.co.jp/takenaka_e/news_e/pr0108/m0108_05.htm

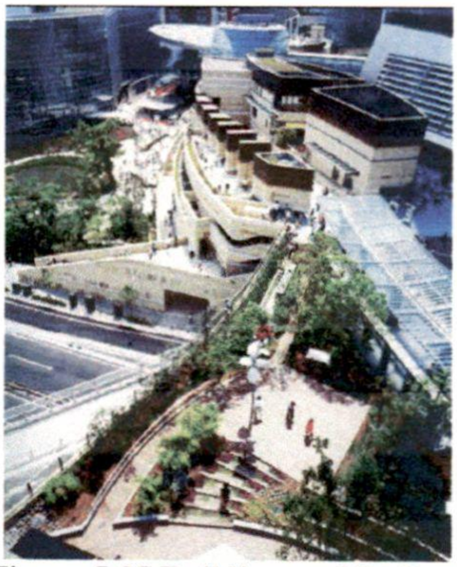


Figure 5.35 Building and Podium gardens are well connected
Source: http://www.takenaka.co.jp/takenaka_e/news_e/pr0108/m0108_05.htm

Figure 5.36 Green roofs includes traditional rice fields
Source: http://www.takenaka.co.jp/takenaka_e/news_e/pr0108/m0108_05.htm

5.7 CONSTRAINTS

The constraints or barriers against the development of green roofs (which apply in India to differing degrees for intensive and extensive green roofs), fall into four categories, namely:

5.8.1 Lack of knowledge and awareness

There is generally a lack of knowledge about extensive green roofs. Also, knowledge of the benefits of all green roofs has previously never been consolidated and used effectively in building design decision making. Greenery in the city is generally approached from an amenity and cosmetic point of view only.

5.8.2 Lack of incentive / statutory mandate

Many of the benefits would not accrue to property developers who build and sell immediately.

5.8.3 Economic constraints

There is a lack of understanding about direct tangible and long-term economic benefits of extensive green roofs. Green roof structural loading requirements require additional capital expenditure. Additional maintenance costs may be required.

5.8.4 Lack of available roof area

Many of India's buildings, especially the tall buildings in the CBD, are often so cluttered with roof-top utilities that green roofs may be impractical.

5.8.5 Technical issues and risks associated with uncertainty

This is particularly relevant for extensive green roofs (especially the retro-fitting of existing green roofs).

5.8 TECHNICAL CONSTRAINTS AND RISKS ASSOCIATED WITH UNCERTAINTY OF GREEN ROOF

5.8.1 Plan Area

From a technical standpoint, there is no minimum area for a green roof, the smaller the roof is, and the harder it would be to create effective greening alongside other elements that have to be located on the roof. This is a significant consideration in India where building footprints are frequently quite small.

Very small intensive green roofs may still provide useful benefits by virtue of their ability to create usable space for leisure and amenity, and also generate comparatively large volumes of greenery from trees growing out of a small floor plan.

On the other hand, the benefits of a small extensive green roof would be less than those of a small intensive green roof, since the former's *'two-dimensional'* nature has less visual greening impact than the latter's *'three-dimensional'* qualities; it cannot be used as leisure or amenity space; and the environmental benefits of extensive green roofs.

5.8.2 Altitude

There is no technical limit on the altitude of a green roof (since plant species may be chosen for any given situation), significant changes in environmental and microclimatic factors occur as the altitude increases, leading to significant constraints in design requirements and opportunities. Green roofs located at higher levels above ground require plants suited to cool, windy, exposed locations, and will present far more limited opportunities for human use.

5.8.3 Structural Loading

Although there is no technical reason why a sufficiently strong structure cannot be created for a green roof, there may be financial constraints on the provision of a suitably strong structure. This is more likely to be the case for intensive green roofs which require greater structural loading than extensive green roofs.

5.8.4 Water Leakage

From a technical standpoint, there is no reason why leaks should occur any more than in a normal roof system, (in fact they should be less likely to occur due to protection from weather, as noted in the section on benefits) but if leaks do occur, they are potentially more difficult to trace.

5.8.5 Maintenance

If roofing components need replacement, a more complicated process is likely, since plant material and growing medium would likely need to be removed and replaced. Accessible roofs need on-going care. The more complex the planting scheme, the more care is required, (e.g. pruning, etc.).

5.8.6 Safety

Accessible roofs must have full perimeter safety protection. Adequate safety protection must be provided for maintenance staff.

5.8.7 Plant Selection

Plant selection for use on intensive green roofs is well understood in the local landscape industry, and there is a huge variety of ground covers, shrubs and trees that are commonly used on podium landscape gardens in India.

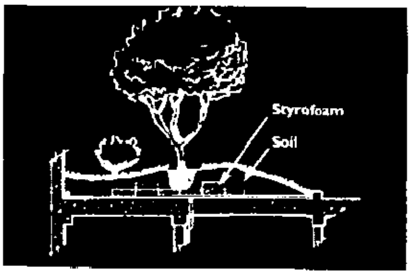
However, the limited experience of extensive green roofs in India means that there is uncertainty on the correct plant species for use on this type of green roof in the local context. The ornamental 'neat and tidy' approach to landscape that is prevalent in India suggests that the dry seasonal browning of ecological style planting on extensive green roofs may not be well received by certain sectors of the general public. A desire for 'neat and tidy' and 'always green' landscape implies higher levels of maintenance with associated costs. Although requiring less maintenance than intensive green roofs, extensive green roofs still need to be maintained to ensure that unwanted plant species (e.g. large shrubs or trees) do not invade the roof and cause damage.

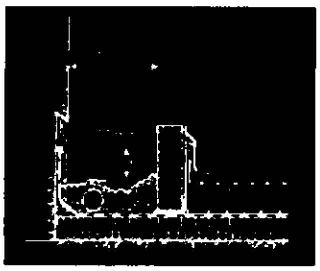
5.9 SUMMARY

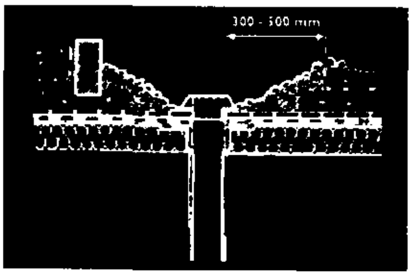
Identification of opportunities of green roof for different typologies of building is one of the important steps in process of designing guidelines. Benefits of green roof are identified according to the Indian climatic condition .But Assessment is not complete without looking at the downside of the profile in terms of green roof systems it has some constraints from which few of them are identified through which we can overcome from the flaws or defects in green roof and through which awareness towards this technology can be created.

CHAPTER 6

Design Guidelines for Green Roof for Composite Climate in India







6.1 BACKGROUND

Green roof infrastructure promises to become an increasingly important option for building owners and community planners. As we move into the 21st century, green roofs can address many of the challenges facing urban residents. Life cycle costing indicates that green roofs cost the same or less than conventional roofing and they are an investment which provides a significant number of social, environmental and economic benefits that are both public and private in nature. These benefits include increased energy efficiency (from cooling in the summer and added insulation in the winter), longer roof membrane life span, sound insulation, and the ability to turn wasted roof space into various types of amenity space for building occupants. Green roofs filter particulate matter from the air, retain and cleanse storm water and provide new opportunities for biodiversity preservation and habitat creation. They generate aesthetic benefits and help to reduce the '*Urban heat island effect*' - the overheating of cities in the summer which is a contribution of air pollution; materials used and increased energy consumption. This chapter describes how to implement a green roof in a retrofitting of a building.

6.2 DESIGN GUIDELINES FOR GREEN ROOF IN COMPOSITE CLIMATIC ZONE

The design and implementation of a green roof project is relatively straight forward, provided the following issues are considered and dealt with. It is to be noted that as every site; building; building owner; and end users are different, so each individual green roof project will vary from the previous. Checklist of questions which should be followed while designing the green roof and material selection has been incorporated in Annexure 2.

6.2.1 In the following section, Design guidelines for green roof in composite climate in India have been discussed in sequence:

a) The primary function a specific green roof is required to achieve because it has a profound effect on overall design. Therefore one should first identify the function of green roof and then proceed further in design of green roof. For example every building has its own requirement like hospital garden is suppose to be more aesthetically pleasant where as institutional garden serves different purpose there fore design will differ according to that. Refer Table 6.1 for selecting type of green roof in select typology of buildings.

Table6.1. Appropriateness Matrix

Building Type	Description	Need for Urban Greenery	Recommendations
City Centre	Multiple level high-rises (mostly offices) ranging from 5 to 15 storeys. Rooftops are often exposed and windy. Scenic views of city are common on some buildings. Rooftops are larger with less utilities and obstacles cluttering the area. Building owners can often afford green roofs or roof garden.	High	Intensive Green Roofs are needed and should be promoted for all new buildings. Extensive Green Roofs should be promoted for existing buildings.
New City Centre	Multiple level sky-rises (mostly offices) ranging from 10 to 30 storey. Sun and shade is unpredictable and often shady on lower rooftops. Rooftops are often exposed and windy. Scenic views of city are common on some buildings. Rooftops are often cluttered with utilities and obstacles. *Building owners can often afford green roofs or roof garden.*	High	Intensive Green Roofs are needed and should be promoted for all new buildings. Extensive Green Roofs should be promoted for existing buildings.
Residential towers	Older High-rise residential towers ranging from 5 to 15 storeys. Building owners can sometimes afford green roofs or roof gardens.	Medium	Intensive Green Roofs are needed and should be promoted for all new buildings. Extensive Green Roofs should be promoted for existing buildings.
Industrial buildings	Buildings ranging from 1 to 10 storeys. Building sizes are often wider than other buildings. Building owners can sometimes afford green roofs or roof Gardens.	Medium	Intensive Green Roofs and public accessibility should be promoted for all new buildings. Given the large areas available, Extensive Green Roofs should be actively promoted for existing buildings and for all non-accessible buildings.
Houses	Buildings range from 1 to 4 storey. Building owners can sometimes afford green roofs or roof gardens.	Medium low	Given the surrounding greenery, lower need for greenery and probable budgetary constraints, Extensive Green Roofs should be actively promoted.
Other Low-rise structures	Covered Pedestrian Walkways and Footbridges, Covered roads and noise enclosures, vent buildings, power substations, stadiums, service reservoirs and pump houses.	High	Lack of accessibility to rooftops as well as the large areas available, Extensive Green Roofs should be actively promoted.

Source: Author

b) Location of the green roof plays an important role in the design process. The height of the roof above ground, its exposure to wind, the roof's orientation to the sun and shading by surrounding buildings during parts of the day will have an impact. The general climate of the area and the specific microclimate on the roof should be considered for design of green roof. North facing gardens should be avoided.

c) If a green roof is part of the initial design of the building, the additional loading can be accommodated easily and for a relatively minor cost. Though green roof is installed on an existing building, the design will be limited to the carrying capacity of the existing roof and in such cases only '*Extensive type*' of roof should be proposed unless the owner is prepared to upgrade the structure, which is a significant investment.

d) Owners, tenants, and building managers should be made aware of the roof's loading restrictions, through a plan or as a part of a maintenance manual, to avoid future improper relocation or additional plantings in areas which cannot accommodate the weight.

e) If the green roof is accessible for more than routine maintenance - or if tenants or the public use the roof as an accessible outdoor green space - then the design should also comply with requirements for occupancy, exiting, lighting, guardrails, and barrier free access.

f) Building codes vary from place to place so one should check the specific requirements prior to proceeding with a project.

6.2.3 Construction and Installation

Construction of green roof is one of the very important factor in installing green roof .The installers should have experience with green roof systems.

a) There should be one company handling the whole project, from re-roofing to planting, this will avoid scheduling conflicts and damage claims between the various trades.

b) Methods for getting the materials up to the roof should be discussed before hand, to determine cost and potential equipment rentals.

c) Compartmentalization of the green roof into sections should be done with the purpose of allowing access to the membrane and the roof drains, for inspection and maintenance, without pulling up the whole installation.

6.2.4 Planning sequence for a roof garden

The Deem- Decide-Design (D-Three) model has been developed by the researcher to discuss planning sequence of a roof garden

1) Deem

• *Condition of the Roof*

• *Structural Capacity of the Roof*

• *Access to the Roof*

2) Decide

•*Weight of Garden*

• *Cost*

3) Design

• *Special Design of a Green Roof System*

• *Irrigation*

• *Drainage*

• *Selection of Plants and Growing Media*

• *Maintenance*

6.3 TECHNICAL GUIDELINES FOR DESIGNING NEW GREEN ROOF IN COMPOSITE CLIMATIC ZONE

Design

After choosing a general design type: Intensive, Extensive or Semi-intensive.

Intensive roofs are deeper, heavier, have larger plants, and require garden-type maintenance.

Extensive roofs have smaller plants with less diversity, a shallow substrate layer, are lighter, and require little maintenance.

Semi-intensive

Roofs fall between those two extremes.

In all three designs difference is a material thickness and additional layers. Material specification is same in all designs. Refer chapter 4 for material specification and there cost analysis

a) Water proofing is a most layer therefore care is to be taken while applying layer. (Refer Chapter 4 section 4.4.1)
b) In an old building where retrofitting should be conducted there should be continuous separation between the membrane and the plant layer, since the membrane will be susceptible to root penetration and micro-organic activity. Some of the new membranes developed specifically for green roof applications, although still bituminous, now contain a root-deterring chemical or metal foil between the membrane layers and at the joint/seam lines to prevent root damage (Refer Chapter 4 section 4.4.2)
c) If the drainage layer is too thin or if the routes to the roof drains become blocked, leakage of the membrane may occur, due to continuous contact with water or wet medium. There fore drainage layer is to made as per design of roof if its is intensive then drainage layer should not be less than 20 mm where as for intensive roof drainage layer should vary between 45 mm to 60 mm (Refer Chapter 4 section 4.4.4)
d) Green roof retains much of the rain that falls on it, maintaining proper drainage on the roof is still very important aspect. Parapets, edges, flashing, and roof penetrations made by skylights, mechanical systems, vents, and chimneys must be well protected with a gravel skirt.
e) On a roof slope greater than 20 degrees, the green roof installer needs to ensure that the sod or plant layer does not slip or slump through its own weight, especially when it becomes wet. This can be prevented through the use of horizontal strapping, wood, plastic, or metal, placed either under the membrane, or loose-laid on top. Support grid systems for green roofs have been designed by some green roof manufacturing companies specifically for this application such as Texas India Pvt. Ltd. And vendors in Delhi are providing assistance for installation.
f) For intensive green roof root penetration membrane is mandatory (Refer Chapter 4 section 4.4.2).

Plants

Location, wind, rainfall, air pollution, building height, shade, and soil depth are all factors in determining what plants can be grown and where.

a) The ability of plants to survive on a green roof is directly proportional to the amount of maintenance time and budget allocated to the project, particularly in the first two years when they are getting established.
b) Climatic conditions on a rooftop are often extreme. Unless one is willing to provide shading devices, irrigation, and fertilization, the choice of planting material should be limited to hardier or indigenous varieties of grasses and sedums.
c) Root size and depth should also be considered in determining whether the plant will stabilize in 10 cm (4") or in 60 cm (24") of growing medium.
d) It is very important to know where the plants were previously grown and if the growing conditions were comparable to the ones on the roof to ensure their ability to adapt and flourish (Refer Annexure 2).

Maintenance

Both plant maintenance and maintenance of the waterproofing membrane are required for the Green Roof.

a) Depending on whether the green roof is extensive or intensive, required plant maintenance will range from two to three yearly inspections to check for weeds or damage, to weekly visits for irrigation, pruning, and replanting.
b) To ensure continuity in the warranty and the upkeep, it is recommended that the fees for three to five years of this service be included in the original bid price, and that maintenance contracts be awarded to the company that installed the green roof, or to an affiliate.
c) Intensive systems typically require more maintenance than extensive systems due to the greater diversity of plants. Maintenance and visual inspections of the waterproofing membrane can be complicated by the fact that the green roof system completely covers the membrane.
d) Although the green roof protects the membrane from puncture damage and solar radiation, doubling its lifespan, leaks can still occur at joints and penetrations due more to sloppy installation than to material failure.
e) Regular maintenance inspections should be scheduled as for a standard roof installation, especially just before the warranty period expires.
f) Some companies are recommending the incorporation of an electronic leak detection system between or underneath the waterproofing membrane to pinpoint

the exact location of water leaks. Access strategies include keeping the sensitive areas free of plants and growing medium (gravel skirts, etc), and dividing the green roof into distinct compartments for ease of removal.

g) Eventually, after 30-50 years, the membrane will have to be replaced. Depending on the *roof size*, *building height*, *type of planting*, and *depth of growing medium*, the system will either be removed and reinstalled over the new membrane, or replaced entirely.

h) If the green roof can be removed and stored on the roof while the membrane is being replaced in sections, then the additional cost is "*labour*" only, and comparable to the original installation cost.

i) If the green roof has to be moved off the roof costs will increase accordingly.

j) Although a green roof extends the life of the underlying roof (typically X2), regular maintenance is required.

k) Intensive green roofs require the same level of maintenance as an ornamental garden.

l) Extensive green roofs only require two maintenance visits a year. During times of extreme drought, occasional watering will extend plant life.

6.3 PROPOSED GREEN ROOF DESIGN FOR ARCHITECTURE AND PLANNING DEPARTMENT IIT ROORKEE

Figure 6.1 Department of Architecture and Planning

Source: Author

6.3.1Green Roof Site Design

The site location is in IIT Roorkee, built in 1845. The roof top is to be greened which will help in saving the energy of a building and increasing the life of building roof.

6.3.2 Planning sequence

D- Three model is adopted as a planning sequence for proposing green roof for architecture and planning department building.

6.3.2.1 Design Intent/Goals

a) Manage storm water
b) Reduce heat island effects
c) Demonstration site/pilot project
d) Not accessible on foot by the public
e) Visible from indoors
f) Non-irrigated
g) Low maintenance
h) Public education

6.3.2.2 Site Details

a) Architecture department with surrounding plants.
b) Flat with a slight slope in towards center, drains more toward north and south ends of roof
c) Upper roof potentially drains slightly to site
d) Structural loading capacity unknown at this time
e) Concrete roof deck
f) Waterproof membrane new, re-roofed less than one year ago
g) Waterproof membrane: cold process asphalt sheets, torch applied, sheet is modified asphalt reinforced with polyester and fiberglass, two ply (two layers applied: bottom layer smooth, top layer is the gray gravelly surface visible)
h) **South** facing is exposed.
i) Total square footage (inside edge of the banister): **12094 $ft.^2$**

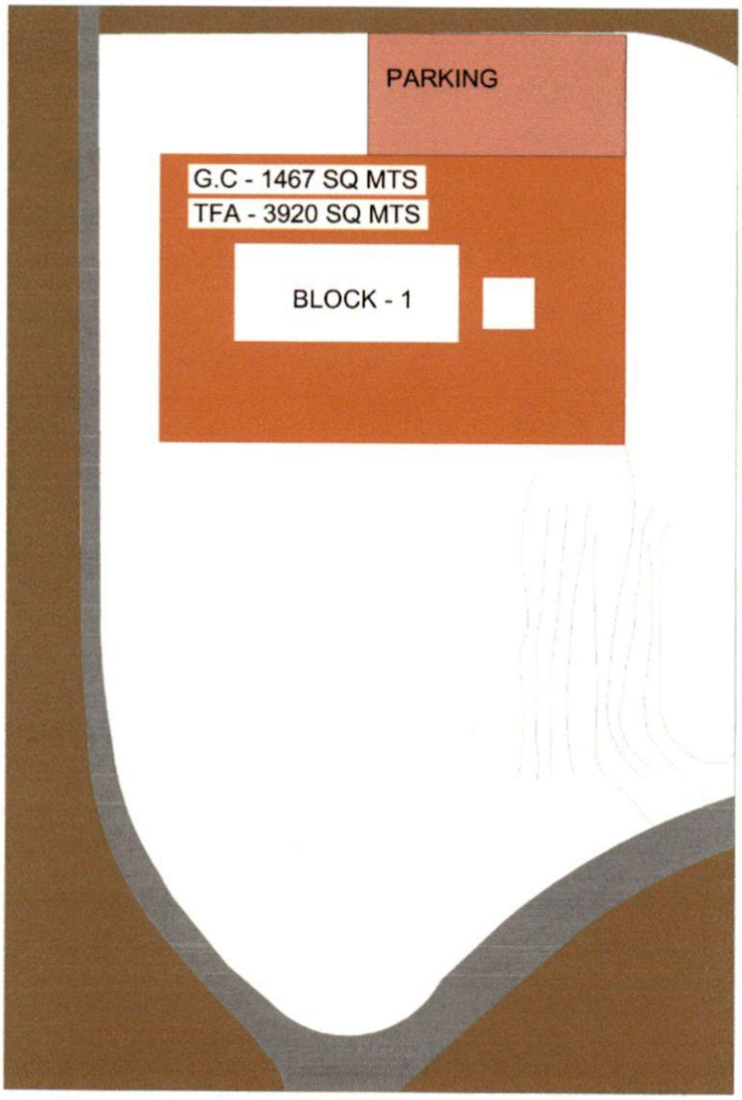


Figure 6.2 Site Plan of Architecture and Planning Department

Source: Author

An extensive green roof is the choice for this location based upon the site characteristics (Refer Table 6.1). The lightest weight for this green roof is necessary because this is an institutional building and structure more than 15 years old.

Structurally this roof was not expected by the designer to support a weight greater than 15 lbs./ft.², and this was a consideration when creating the design options. Extensive green roofs are typically designed for sites that have this type of weight restriction. A structural engineer is consulted prior to construction to verify the structural loading capacity of the roof.

The depth of the system has been designed to be no more than 6" in order to address the concern of the green roof altering the appearance of the façade of building. At this depth, and using plant materials that do not exceed 4" to 6" in ultimate growth height, the appearance of the building will be unaltered. This design will prevent visibility of the green roof from street level.

In both design options a minimum 1' border will be maintained inside of the banister for maintenance purposes. This border will also act as another layer of protection to prevent visibility from street level.

It should be noted that this is not a typical site for a green roof because it has no roof lip to contain storm water and prevent drainage over the side of the roof. While rainfall is absorbed by green roofs, at this site some rain will run off and drain to the sidewalk below because the entire roof will not be covered and there is no roof lip to prevent runoff. An edging material has been included to hold in the growing media and plants to prevent solids from washing over the roof edge.

6.3.2.3 A - Option 1: Loose Laid System

The first choice for this particular site is a loose laid system. A loose laid system allows for more design flexibility and opportunities. Pieced together with products supplied from multiple companies, a designer is better able to customize in order to meet the needs and goals of the green roof system. Loose laid systems typically have a lower cost than modular systems (see option budgets). Multiple professionals are typically involved in the design and installation process. This option allows for a total of 1000 ft^2 of green roof.

Materials require in construction of Green Roof

1. Colbond EnkaRetain & Drain 3111 filter fabric, drainage and retention assembly
2. Unique waterproofing bitumen sheets, designed for the green roof industry, very light weight Colbert, GA company
3. Wide variety of green roof plant material
4. Natural, growing media
5. Quality engineered green roof growing media
6. Polyethylene sheeting
7. Root barrier protection for waterproof membrane

Water Holding Capacity of Green Roof

The total weight of EnkaRetain & Drain saturated is 22.33 oz/ ft2 (1.39 lbs/ ft2).
For this 1000 ft2 system, that translates to 128.88 gallons of storm water retained and slowly absorbed by plant material and transpired to the atmosphere. This system could hold an estimated 2" of rainfall (where 1" of rain = 5 gallons) and prevent it from running off to the ground below.

Weight of Green Roof

Plant materials typically weigh no more than 1 lb/ft2, growing media is estimated at 22 – 26.6 1bs/ft2 (wet and drained) and the EnkaRetain & Drain system weighs 1.39 lbs/ft2 (saturated). The total weight of this loose-laid system is estimated to be no more than 29 lbs/ft2.

6.3.2.4 B- Option 2: Modular System

A modular system is quicker and easier to install and is essentially a "one-stop shopping" method of designing a green roof. Modular systems combine components of a green roof assembly into one product, usually contained in plastic trays, and laid directly on the waterproof membrane. This option allows for a total of 800 ft2 of green roof because of the manufactured size of the modules.

Materials require in construction of green roof

1. GreenGrid® modular green roof system
2. Complete system including drainage assembly, growing media and plants
3. 2'x4'x4' modules, 100 modules total are required
4. Designed for the green roof industry, very light weight
5. Increases aesthetics with a clean and attractive border, hiding the divisions between the trays
6. Polyethylene sheeting
7. Root barrier protection for waterproof membrane

Water Holding Capacity of green roof

The Green Grid® system can retain up to 99% of a 1-inch rainfall. Data is included in the appendix that shows storm water retention capability of the 4" modules specified for this project.

Weight of green roof

Per the product literature, the GreenGrid® system weighs between 15 – 18 lbs/ft2.

6.3.2.5 Budget

Table 6.1 A Option 1- Loose Laid System

Vendor	Product	Description	Amount/cost	Total price
Texsa India Pvt. ltd.	APP Plastomeric Membrane	Water proofing membrane	Rs 16/ ft2 Total required for 1000 ft2	Rs16000 +freight
Colbond Pvt. ltd	EnkaRetain & Drain 3111 filter fabric	Drainage sheet	Rs 77/ ft2 Total required for 1000 ft2	Rs77000
Landscape/Buil din g supply company - any	Polyethylene plastic, root barrier	0.8 mm min. thickness (FM Global standards)	1000 ft.[2]	Rs 900-1200
Locally available	Growing media	Extensive product	11.1yd[3]	Rs 5000-6000
Local nursery	Plant materials	Grass and small shrubs	Free of cost	Free of cost
			Total cost	Rs100200

Source: Author

Table 6.2 B Option 2 modular system

Vendor	Product	Description	Amount/cost	Total price
Green Grids, Weston Solutions	Green Grids modular green roof	2'x4'x4' modules	Rs 800/ft.[2] 100 modules	Rs 80000/-

Source: Author

6.3.2.6 Site Construction

Once a decision is made as to which option will be pursued, the following is suggested

1. Contact company representatives to order or reserve materials
2. File for permits: Certificate of Appropriateness from the Building Inspection Office

3. Contact professionals and volunteers
4. Install green roof system from root barrier up to growing media as soon as materials are received.
5. Install plants on the site in October for best chance of plant survival in our area. The team of professionals that will assist with the construction of this site would ideally be composed of the following: landscape architect, roofer, structural engineer, buildings manager, grounds maintenance and horticulturist. As the project progresses, more specialties may be required for consultation, which is normal for a green roof project.

6.3.2.7 Landscape Plan and Construction Details of Proposed Green Roof

Schematic landscape plan is detailed in Figure 6.5, typical section details are shown in Figure 6.4 and 6.6 for the building. Following sections and detail will define the sequence of all layers used in establishing the green roof on the roof of architecture and planning department IIT Roorkee. During the construction of roof following details should be followed in laying waterproofing layer which plays an important role in successful green roof.

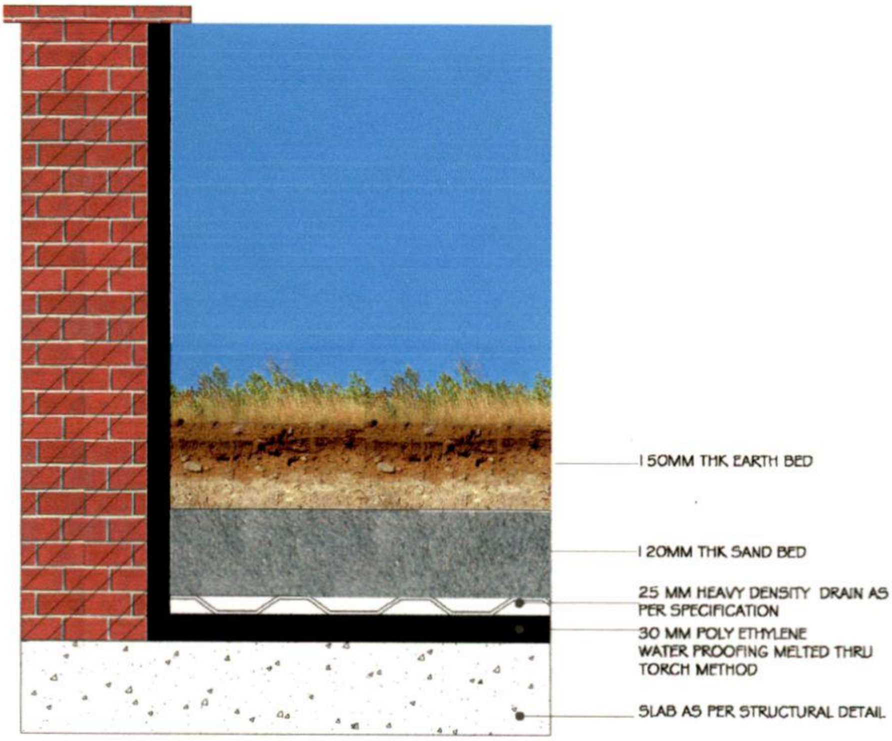


Figure 6.5 Parapet Detail for proposed roof

Source: Author

specific potential benefits, costs, and risks of green roofs and to provide a plan for a green roof on the Architecture and Planning Department Building.

The main purpose of the proposal is to show the implementation of features of green roof. Thus, by using various technological details in any building (old or new) green roof can be designed.

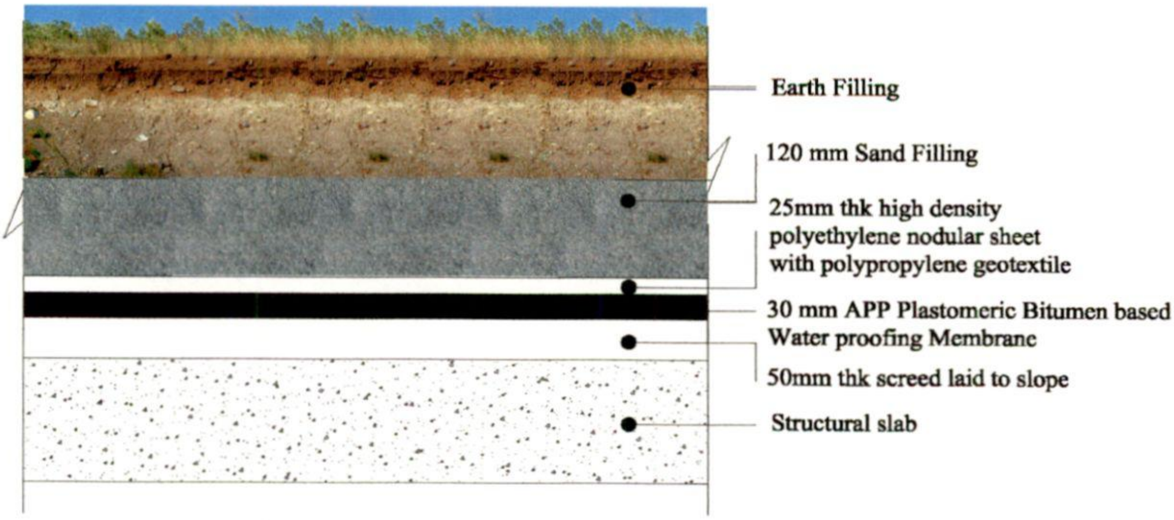


Figure 6.6 Typical sections for proposed roof

Source: Author

6.3.2.8 Site Maintenance

The maintenance for both options proposed is minimal. In the case of severe drought a periodic watering will help extend the life of the plants. Visual inspection of both the green roof system and the porch roof should be conducted at least twice a year. Minor horticultural maintenance, possibly monthly, may be necessary to prevent weed invasion before the plants reach their full growth size. Weeds should be removed by hand. No pruning, fertilizing, or application of herbicides or insecticides will be necessary. The type of plant materials used in this green roof (primarily sedums) do not benefit from additional nutrients beyond the organic matter provided in the growing medium. It is further recommended that no chemicals should ever be used on this green roof. Since this is not a typical site for a green roof because it has no roof lip preventing drainage over the edge of the building, rainfall amounts greater than the retention capacity of each system (see options 1 and 2) have the potential to drain to the sidewalk below and eventually to the storm water drains.

6.4 SUMMARY

Green roofs provide storm water reduction as well as numerous other benefits—ecological, economic, social, and educational—which make them logical additions to public buildings. As part of the IIT Roorkee, I have developed this proposal to outline

CHAPTER 7

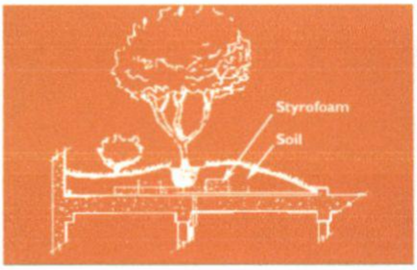
CONCLUSIONS AND RECOMMENDATIONS

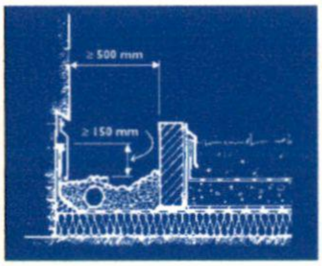
7.1 Conclusions

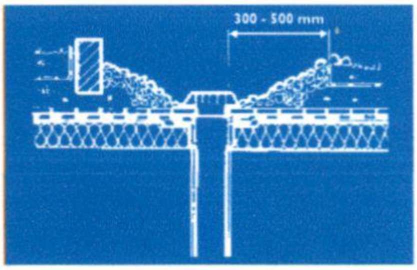
7.2 Policy Formulation

7.3 Recommendations

7.4 future research Scopes







7.1 CONCLUSIONS

This present study has comprehensively covered the costs and technical aspects of green roofs, showing that green roofs (extensive and intensive) are economically and practically feasible in the select climatic zone of India. However, the efficiency of certain benefits of green roofs is difficult to quantify; qualitatively its advantages cannot be overlooked.

The *social benefits* of green roofs are generally well understood, by the designer community (architects and planners) of India because of its commonly identified advantages to create for more hospitable and green environments in India. Some environmental benefits of green roofs, such as *improving air quality* and *reducing the Urban Heat Island effect*, are extremely complex issues to quantify. Economic benefits of green roofs, such as *building insulation and energy efficiencies*, also require more in-depth local knowledge before it is fully factored into any cost-benefit assessment. Of all the technologies available (solar panels, double skins, green roofs etc.), it is determined that green roof is the most cost-effective solution for India's context.

There are many green roof policies developed all around the world that may be considered and adapted for India's needs. These policies used in a foreign country should always be viewed in the context of each city's physical composition, social values and individual case settings. The approaches adopted elsewhere should not necessarily be copied directly in India. Policy formulation is explained in detail for developing policy for any type of climatic zone in India.

This research describes policy recommendations for developing green roof policies for select area in India. These recommendations are derived from literature references and gained through consultation with Indian green roof experts which will be helpful for the policy makers in future for deriving policies for Indian cities of different climatic zone Indian climate.

7.2 POLICY FORMULATION

This part of the discussion has been divided into three sections. The first one addresses the importance of policy objectives tailored to the needs of each jurisdiction, while the other two sections describe ways to develop and administer green roof policies[41, 42].

7.2.1 Overview

Green roofs are a proven technology that provides building owners with opportunities to utilize often wasted roof spaces for energy efficiency, storm water management, sound insulation, and aesthetic improvements. Accessible green roof systems can confer significant added value to a building's occupants or to the general public with benefits ranging from enhanced educational opportunities in schools, private "*roof parks*" for condominium owners, *public parkland, horticulture* and even *food production.* Each green roof system should be tailored to the specific needs of the client, with the variables determining costs. As more, governments should recognize the wide range of public benefits of green roofs and through this they can help in addressing many of the cities which are facing challenges, they should increasingly look for providing incentives for private building owners to undertake the additional capital costs associated with these systems and should frame some policies.

Defining Expected Benefits

By clearly defining the expected benefits, policy makers will be better positioned to set performance goals and resulting design and construction requirements [41]. The objectives are site specific and varied, which may lead to diverse policies across India. For example in New Delhi, the objective might be storm water retention and reducing the need for summer air conditioning. In Hyderabad, it might be microclimate improvement and so on.

Targeting Locations and Building Types

In addition to expected benefits, it is important to decide what locations and also what types of buildings are targeted. Property owners of different kinds of buildings and developments (e.g. new vs. retrofit, residential vs. commercial) are motivated by different types of incentives.

7.2.3 Developing and Writing Policy

Selecting Types of Policy

It is important to understand what motivates property owners to build green roofs. Accordingly it is better to say that green roofs are motivated by direct benefits to the project, costs and by the development approval process. An owner who is provided with good cost-benefit information may choose green roofs without extra incentives simple based on direct private benefits. Finally, there is the option of making green roofs mandatory by integrating them into development regulations.

Setting Minimum Design Requirements and Performance Goals

Policy should define how the green roof will differ from a conventional roof. There are two different approaches; one sets specific construction requirements (e.g. minimum growing medium thickness) and the other sets specific performance goals (e.g. maximum runoff coefficient). The advantages of the former are that it can address many goals at once, or goals that are difficult to quantify, and it is relatively easy to measure. This is an important consideration at the stage where the roof needs to be checked for compliance. The advantages of the latter are that it more accurately addresses the goals of the policy and it allows room for innovation. This aspect is important in India where there is still much experimenting left.

Financial Considerations

Green roofs cannot be valued accurately on financial aspects alone. Currently, some benefits can be quantified and translated into cost savings while others can be quantified but not easily assigned a monetary value and still others are very difficult to quantify. Storm water retention and energy savings are among the easier benefits to quantify.

Nature compensation can be quantified but not easily given a monetary value. Benefits such as the well-being of building occupants or the beauty of green roofs cannot be quantified. There is a danger that benefits whose monetary value is difficult or impossible to determine are considered valueless. Other ways of calculating benefits need to be considered to improve the accuracy of cost-benefit analyses.

Building Standards

Green roof policies go hand in hand to green roof building standards. Construction and maintenance standards are needed to ensure high quality products, establish warrantees, and ensure long-term function. Detailed standards and guidelines have yet to be produced in India. At the same time, there are areas where we will need to conduct local research, specifically as green roofs relate to different climates, different legislation, local materials and native plants.

7.2.4Policy Administration

Firm Support

Green roof policy should have the firm support of the political decision makers. Any exception to the rule is likely to set a bad example to others who will look for ways out. For example in Tokyo, green roofs are required only on flat roofs so owners can easily avoid installing them by having a gently sloped roof. Clearly the wording of the regulations should be clear and not allow for loopholes.

Ensuring Compliance with Performance Goals

Once a policy is in operation, there needs to be a strategy ensuring that the green roof is not only built to last over the long-term, but also that it is built to conform to the minimum design requirements and/or performance goals. One of the challenges is that green roofs are generally more difficult to access and view than conventional green spaces. Ways to ensure fulfillment should be considered when developing green roof policy.

7.3 RECOMMENDATIONS

Recommendations are proposed for New Delhi it lies in the composite zone of India as shown in Figure 4.1 in Chapter 4.similarly policies can be proposed for other climatic zones for India

7.3.1 Strategies for propagating Green roof in India proposed for New Delhi.

However, it is not advisable to delay the implementation and encouragement of green roofs simply because of lack of awareness. Of all the technologies that a city or building might employ to solve its problems it is seen that green roofs proves to be highly beneficial. The aesthetic and amenity benefits of green roofs are also a major aspect that other technologies are not likely to contribute to the city.

a) Early researches in context of pollution control and mitigation of the urban heat island effect has already started to prove that green roofs on a large scale can noticeably improve a city's environment. Where as Overseas research in this field is ongoing and is likely to deliver useful results in the near future.

b) Early research from a building-energy-saving's point of view shows that green roofs, as a living skin, are more cost-effective than the reflective surface. Green roofs also help to lower ambient temperatures, making solar panels more effective, which suggests that green roofs are likely to be an integral part of this technology. It should also be noted that green roofs reduce energy demands, which in the field of resource efficiencies, is considered more sound than simply adding additional components and maintenance to a building to cater for high energy demands.

Considering the above statements, it is apparently seen that green roofs offer clear benefits for India and could become an integral part of the city's solutions. The main benefits to aim for are considered to be:

a) To increase the *amenity of the city.*

b) To increase the *usable green space.*

c) To improve building *Energy savings.*

Therefore it is considered that *Intensive Green Roofs* should be promoted as the prime direction for the future of green roofs in India. *Extensive Green Roofs* could be considered for retro-fitting projects and situations where Intensive Green Roofs are not practical. The long term objective of green roofs is to achieve collective environmental benefits through city-wide application of green roofs. Various steps are needed to achieve this. They are presented below and are divided into Short, Medium and Long Term Goals.

7.3.2 Short term Recommendation

a) **Propagation of Information** through the media is recommended to actively promote green roofs and to encourage better understanding of their potential benefits.

b) **Trade Shows**_demonstrating green roof technologies are recommended for India.

c) **Engaging with stakeholders** (including real estate professionals, construction industry representatives, developers and suppliers) is recommended to encourage green roof development in composite climate of India.

d) **Government should lead by example**_by continuing to implement green roofs on all new buildings, and to review the retro-fitting of green roofs for existing roofs.

e) **Introducing rating systems and elements of competition**_should be maintained and strengthened by expanding the role of green roofs in LEED and GRIHA labeling systems.

f) **Pilot schemes and further research** is needed to fulfill the need for more local information on green roofs. Information is needed to more accurately determine:

1. Changes in ambient temperature, building surface and interior temperatures.
2. Changes in pollution and particulate levels.
3. Changes in water runoff.

Objective is to accurately determine building energy efficiencies applicable to India's composite climate and building forms. Further horticultural research is also needed to determine the viability of different species for extensive green roofs.

7.3.3 Medium and Long Term Recommendation

a) **Collecting Citywide Scientific data** on green roofs is recommended. This would involve doing cost-benefit analysis studies to establish the geographical extent to which green roofing could be achieved in India, and the resultant benefits would be enjoyed by the community. This could take the form of a G.I.S. study. Monitoring of green roofs on a regular basis is also recommended. This would provide knowledge of the progress over time and would assist the formulation of effective policies and incentives to promote green roofs.

b) **Developing reliable standards** is suggested to promote industry and to prevent low-quality products and construction from entering the market. Although podium gardens are well-established in India, there are still no standards ensuring quality in this field. The development of standards should cover extensive and intensive green roofs. For example *'Green roof bonus option'* is one initiative that should be recommended.

A Green roof bonus option

Green roofs is encouraged in the metropolitan cities because they reduce storm water run-off, counter the increased heat of urban areas, and provide habitat for birds [43,44,45].

B Eligibility and Standards

Buildings with green roofs are eligible for floor area bonuses, provided they meet the following minimum standards:

I. Documentation must be submitted demonstrating that the roof can support the additional load of plants, soil, and retained water, and that an adequate soil depth will be provided for plants to thrive.

II. The roof area should contain sufficient space for future installations (e.g., mechanical equipment) that will prevent adverse impacts (e.g., removal of or damage to plants or reduction in area) on the green roof.

III. Vegetation should be maintained for the life of the building.

IV. Private decks or terraces associated with individual *dwelling units* should not qualify for floor area bonuses.

C Bonus

1.Where the total area of green roof is at least *10 percent* but less than *30 percent* of the building's footprint, *each square foot* of green roof earns *one square foot* of additional floor area.

2.Where the total area of green roof is at least *30 percent* but less than *60 percent* of the building's footprint, *each square foot* of green roof earns *two square feet* of additional floor area.

3.Where the total area of green roof is at least *60 percent* of the building's footprint, *each square foot* of green roof earns *three square feet* of additional floor area.

4.Before an application for a land use review will be approved, the applicant must submit a letter from local authority certifying that authority approves the green roof. The letter must also specify the area of the green roof.

7.3.4 Reviewing Government policy

It is suggested maximizing the amount of greening possible in the city, after collective environmental/economic benefits have been proven and are supported by public consultations. There are numerous green roof policies around the world that may be considered and adapted for India's needs. These policies used abroad should always be viewed in the context of each city's physical composition, social values and individual case settings. The approaches adopted elsewhere should not necessarily be copied directly in India[46].

7.3.5 Many concepts are tried elsewhere that may be considered. These include:

1) *Direct Incentives to the Private Sector*, such as cash grants towards capital costs.

2) *Indirect Incentives to the Private Sector.*

3) The Introduction of the *Polluters Pay Concept,* based on the "*eco-tax/carbon tax*" concept against polluters, where the provision of a green roof might be used to reduce this tax because of its contribution towards energy efficiency.

7.4 FUTURE RESEARCH SCOPES

Further research should be conducted under the following topics

1. Research should be made in calculating the cost benefit analysis and in quantification of all benefits of green roof in monetary terms so that green roofs turn out to be one of the finest solution for all the problems discussed in chapter 1.
2. Further research should be done in urban farming concept on green roof for Indian climate.

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ANNEXES

ANNEXURE 1 PLANT MATRIX

Annuals

Scientific Name	Common Name	Flowering time	Maintenance	Wind tolerant	Pollution tolerant	GROWTH RATE
Bellis perennis	Common daisy	wint	**	*	*	**
Calendula officinalis	Pot marigold	wint	**	*	*	**
Callitephus chinesis	China Aster	wint	**	**	**	**
Dimorphotheca annua	Cape marigold/African daisy	sum	**	**	*	**
Gaillardia aristata	Blanket Flower	-	**	**	**	**
Helichyrsum baacteatum	Straw Flower/everlasting	-	**	**	**	**
Iberis amara	Candytuft	wint	**	*	*	***
Kochia sloparia	Summer Cypress	sum	**	*	**	***
Pisum sativum	Sweet pea	wint	**	**	**	***
Mesembryanthemum criniflorum	Ice Plant / Living Stone Daisy	wint	**	**	**	**
Nicotiana affinis	Flowering Tobacco plant	sum	*	**	***	**
Papaver Alpinum	Poppy	sum	*	**	***	**
Phlox Adsurgens	Phlox	-	**	**	**	**
Portulaca Grandi Flora	Sun Plant/Rose Moss	wint	**	**	**	*
		wint	**	**	*	**
Solidago Arendsii	Golden Rod	wint	**	**	*	**
Vioca Wittrockiana	Pansy	wint	**	**	*	***
Helianthus Annus	Sun Flower	-	**	**	*	**
Digitacis Grandiflora	Fox Glove	-	**	*	**	**
Dianthus Barbatus	Sweet William	wint	**	*	*	**
Dianthus Caryophullus	Carnation	-	**	**	*	**
Dianthus Caesius , D.chinensis	Pink	wint	**	*	*	**
Brachycome Iberidifolia	Swan River Daisy	sum	**	**	**	***
Centaurea Cyanus	Corn Flower	-	*	*	*	**
Schizanthus Pinnatus	Butterfly Flower	wint	**	*	*	**
Centaurea Moschata	Sweet sultan	-	**	*	*	**

Cineria Cruenta	Cineraria	-	**	**	**	**
Clarika Elegans	Clarika	-	**	*	**	**
Delphinium Consolida	Larkspur	wint	***	**	**	**
Chrisanthemum Uligindsum	Moon Daisy	wint	***	**	*	**
C.Maximum	Shasta daisy	wint	**	**	**	**
Linum Usitatissimum	Coman Flax	wint	**	**	**	**
L. Grandielorum	Scarlet Flax	wint	**	**	*	**
Antirrhinum Majus	Snap Dragon	-	*	**	*	**

Ground cover /Grass

Cynodon dactylon	Couch Grass (hariyali) Doob Grass	Sum	*	*	**	***
Poa Annua	Annual Winter Grass	Wint	*	*	*	**
Trifolium Repens (for temporary ground cover)	White Clover	Sum	***	*	**	**
Axonopus Affinis	Carpet Grass	Rainy	**	*	***	***
Axonopus Compressus	Broad leaved Carpet Grass	Sum	**	**	***	***
Dichondra Repens	Kidney weed	Sum	**	*	**	***
Lippia nodiflora	Lippia	sum	**	**	**	**

Trees

Plumeria rubra obtusa	Pagoda tree – White (farangipani)	-	**	**	**	**
Prunus cerasus	Flowering Cherry	-	**	**	**	**
Aruacaria Cookii	Christmas Tree	-	**	**	**	*

Shrubs

Allamanda Neriifolia	Allamanda (climber)	Wint	**	**	**	**
Barleria Cristata Candida And its varieties	December Flower	Wint	**	**	**	**
Bauhinia Acuminata	Orchid Tree	wint	**	**	*	***
Bauhinia Tomentosa	Small Kachnar	wint	*	**	**	**
Brunfelsia Americana And its Varieties	Yesterday today Tomorrow	-	**	**	**	**
Caesalpinia Pulcherimma (Syn. Poinchiana P)	Pride of Barbados Orange Flower	Sum	**	**	**	**
Cestrum Nocturnum	Queen of the Night	Sum	**	**	**	**
Coleus Blumei Variegata and other varieties	Coleus	-	**	**	**	**

Duranta Repens Variegata and other varieties	Duranta	Sum	**	**	**	**
Euphorbia Pulcherrima	Poinsettia	Sum	**	**	**	**
Carissa Carandas	Karonda	Sum	**	***	**	*
Codiaeum Variegatom	Croton	-	**	**	**	**
Gardenia Jasminoides Veitchii	Moonbeam (chandni)	-	**	**	**	**
Hibiscus Mutabilis	Changeable Rose	Wint	***	**	*	**
Hibiscus rosa-sinesis and many Varieties	Hibiscus (Gudel)	Alltime	*	**	**	**
Hydrangea Macrophylla and its varieties	Ixora	-	**	**	**	**
Ixora Chinensis and its varieties	Yellow Jasmine	-	*	**	**	**
Jasminum Humile	Crape Myrtle	sum	*	**	**	**
Laregestroemia Indica	Trailing Lantana	-	**	**	**	**
Lantana Camara depressa and varieties	Mussaenda	Sum	**	**	**	**
Mussaenda Erythrophylla (and its varieties)	Egyptian Star Cluster	Sum	**	**	**	**
Pentas lanceolata and its many varieties	(Kaner) Nerium	-	*	***	**	**
Nerium Oleander and its varieties	Curry Leaves	wint	*	***	**	**
Murraya Koenigii	Hennah Mehandi	wint	*	***	**	**
Lawsonia alba	Yellow Bell	sum	**	***	**	**
Tecoma Stans	(Harsingar) Queen of the night	sum	*	***		

Climber /Creeper

Allamanda Cathartica and its varieties		-	**	**	*	***
Antgonon Leptopus		-	**	**	**	**
Bougainvillea and its many varieties		Wint	**	**	**	**
Campsis Grandiflora (or techoma Grandiflora) and its varieties		wint	**	**	**	**

Clitoria Ternatea and its varieties	Mussel Shell Climber (Shanku)	wint	**	**	**	*
Clerodendron Splendens		-	**	**	**	**
Ficus Pumila	Creeping Fig	-	**	**	**	**
Campasis Radicans	Orange shower or Trumphet climber	Sum	**	**	**	**
Hedera Helix and other varieties of Hedera	Ivy	-	**	**	*	**
Ipoemea Palmata and other varieties	Railway creeper	Sum	**	**	*	**
Jasminum Officinale Grandiflorum and varieties	Jasmine	-	**	**	*	**
Monstera Deliciosa		-	**	**	**	**
Philodendron and its varieties		-	**	**	**	**
Passiflora Edults and other Varieties	Passion Fruit	Rainy	*	**	**	**
Quisqualis Indica	Rangoon creeper	wint	**	**	**	**
Petrea Volubills	Purple Wreath	wint	**	**	**	**
Rosa Setigera Tomentosa	Wild Climbing Rose/ Rankder Rose	wint	*	**	**	**
Thunbergia Alata and its varieties	Black Eyed Susan	-	*	**	**	**
Scindapsus anreus and its varieties	Pothos or Money plant	Sum	*	**	*	**
Bignonia Venusta or Pyrostegia Ignea	Golden Shower	wint	**	**	*	**
Ipomea purpurea	Morning Glory	-	**	**	*	**

House plants

Aspharagus Plumosus and its varieties	Aspharagus Fern	-	**	**	***	**
Begonia Semperflorens and its many varieties	Flowering Begonia	Wint	*	***	**	**
Begonia Rex and its varieties	Foliage Begonia	-	*	***	**	**
Ficus Benjamina and its varieties		Sum	**	**	***	*
Impatiens wallerina 'carpets' and other varieties	Balsam	-	**	***	**	**
		-	**	**	**	**

Ophiopogon Jaburan 'variegata'	White lily Turf					
Pelargonium Hortorum and its varieties	Zonal Gemium	-	**	**	**	*
Pepromea Scandens Variegata	Creeping Variety	-	**	**	*	**
Pilea Cadierei	Aluminim Plant	-	**	**	*	**
Syngonium Podophyllum and its varieties		wint	**	**	**	**
Tradescantia Albiflora 'Albovittata'	Wandering Jew	-	**	**	**	**
Zebrina Pendula And its varieties	Silvering Wandering Jew	-	**	**	**	*
Portulaca Grandiflora	Sun plant/ Rose Moss	wint	**	**	**	***
Tagetes Patula	Marigold (Genda)	Wint	**	**	**	***
Vinca Rosea	(Sada Suhagan)	wint	**	**	**	***
Canna Indica, C. Flaccida, C. Speciosa etc.	Canna	wint	**	**	**	***

LEGEND

1	**Wint.**	**Winter season**
2	**Wint.**	**Summer season**
3	**Rainy**	**Rainy season**
4	*	**Low/ slow**
5	**	**Moderate/ Medium**
6	***	**High/ Rapid**

ANNEXURE 2 GREEN ROOF DESIGN CHECKLIST SUITABLE FOR INDIA

Numerous decision-making steps need to occur before a green roof can be considered on any building. These ordered questions are presented below as a checklist for consideration:

CATEGORY	CHECKLIST QUESTIONS	NOTES,TIPS AND REFERNCES
a. General	What are the client's objectives for implementing a green roof?	
	What are the city's main objectives for implementing green roofs?	
	What kind of budget does the client have for both capital and recurrent costs?	
	Who will see or appreciate the green roof?	Green roofs not visible to the public may be designed less for visual appeal and more for ecological or building efficiency performance.
	Is a green roof justified in the local context?	In some cases (such as rural areas, where the benefits of green roofs may not be appreciated) a thorough investigation into the needs for a green roof need to be assessed. At-grade planting may prove more effective in terms of visual results, and low capital and recurrent costs.
	Will the green roof be applied to special structures with special maintenance requirements or special access?	The greening proposals for Highways structures should be assessed on a case-by case basis and should take into account local site conditions and also the guidelines provided in the Transport Planning and Design Manual.

Type of Roof	Is the roof new, existing, or in need of replacement or major repair? Can the existing waterproofing accommodate new layers and workmanship above without the need for new waterproofing? If so, who takes responsibility for the waterproofing?	A deteriorating roof may be the most opportune and most cost-effective time to replace the roof with a green roof.
Roof Space	Is there sufficient space on the roof to incorporate a significant area of plants, access pathways, rooftop utilities, safety railings or devices, and access via ladders or staircases, etc? On new buildings, have the rooftop utilities been arranged to optimize the functional open space and to maximize the amount of greening?	Due consideration should be given to space needed for refuge floor areas.
Roof Pitch	Is or will the roof be flat or sloped? Has slippage of the growing medium been considered? How is drainage affected by slope?	Drainage layers on some pitched roofs may not be necessary as the medium is able to drain very easily by itself. In some cases drainage through the medium may be too fast. The drainage requirements under these circumstances are best left to experienced specialists.
	Have the surface flows and water penetration rates been considered? Is the drainage layer below the growing substrate capable of removing excess water effectively?	Simple methods like timber battens and grids may be used to curb to problem up to pitches of 30 degrees. Steeper pitches may require special substrate mixes and devices.

Winds and Climate	Will severe winds be a problem? Have the wind limits of the site been determined?	Some wind problems occur as a result of vortexes at the edge of the roof created by updrafts from the face of the building. From the outset, the building may be designed to limit this problem using irregular or 'rougher' faces (plant covered balconies, for example). High wind uplift is most severe near the edges and corners.
	Are the green roof layers vulnerable to wind shear?	
	Does the waterproofing layer need to be bonded to the roof beneath?	
	Has the wind erosion of the soil mix been considered?	Wind vortex problems may also be mitigated by angling and extending the shape of the parapet coping. Erosion problems may necessitate the use of anti-erosion netting placed just below the soil surface. These are the same systems commonly used on slopes in India.
	Has the staking or weighting down of trees been considered? If so, how does this interface with the waterproof layer if it needs to connect directly to the structure? Are additional lightning conductors needed to avoid striking people or trees?	
Accessibility	Is or will the roof be accessible or inaccessible? How will the roof be accessed?	Accessibility and safety for maintenance also needs to be considered. Difficult or unsafe access during construction and

		maintenance may increase the labour insurance premiums.
	If the roof is to be accessible, does it have space and loading capacity for additional railings, lights, paving, etc.? If accessible by the public will it be secure and safe? Have durable lightweight materials been used for the walkways?	Special cases may require the erecting of temporary scaffolding for maintenance.
Structural Limits	What are the structural loading limits of the roof?	The typical loadings of extensive green roofs range from 80 to 150kg/m² while intensive green roofs range from 300 to 1000 kg/m².
	Have the loading calculations been done by a Registered Structural Engineer or suitably qualified person?	
	Has the dead load included all components (structure, paving, pipes, HVACs, etc)?	
	Have the live load estimates included all components (rain, wind, and people)?	
	Has the dead weight of the green roof materials and plants been included? Do the soil substrate weights include moisture content at saturation point?	
	Has plant weight at maturity been included, particularly for trees?	
	Have maximum loading capacities for the roof been separated into different	I.e. loading directly above support beams and walls may allow for significant

	areas? Are polystyrene or other lightweight materials being used to increased depth without adding significant weight? Has the green roof manufacturer provided detailed information and attested to the fully saturated weight?	increase in soil depth

Green Roof Design Checklist for India: PLANNING AND FEASIBILITY

	Will any roofing components be removed from the roof which allows for additional weight?	
General Design	Have structural joints been incorporated into the green roof design from the beginning? Have maintenance paths been incorporated as part of the design?	Structural movement joints need to be accessible for maintenance. Roof gardens on bridges may require large concrete slabs on either side of the joint which should be recognized early in the design stage. Maintenance paths are especially relevant for extensive green roofs because they often create a distinctly visible intersection within the green roof canvas.

Green Roof Design Checklist for India: COMPONENTS

Insulation and light weight fills	Is additional thermal Insulation necessary? Are lightweight fills needed or desired to create level differences? What kind of insulation or lightweight fill is required?	
Water proofing	What kind of waterproofing will be used?	

	Are leak detection tests planned prior to installation? Does the waterproofing have any guarantee? With different contractors building the green roof-scape layers above the waterproofing is this guarantee still valid? How is waterproofing quality control ensured? How will the various sub-contractors co-ordinate to ensure that the water-proofing layer is not compromised during their construction?	
Root barrier	Does the green roof system need an additional root barrier? Or does the waterproof membrane fulfill this purpose? Are the root barriers tied into flashings and roofing terminations? How effective is the root barrier?	If laid loose root barriers should overlap at least 1.5m to prevent lateral root growth.
Drainage layers and drainage	If the slope is more than 21° have mechanisms such been installed to prevent slippage of the layers? What will the drainage layer be made of? Has the drainage been designed for major storm events? Are there at least	Cheaper but heavier granular layers, lightweight plastic drainage mats made for water storage, or more robust plastic drainage grids engineered for rapid removal of excess water and for heavy loads.

	two roof outlets or overflow drains? In the event of a major storm event will the vegetation be drowned? If so, for how long? Does the drainage capacity increase closer to the drains? Has the drainage layer adequately catered for the average rainfall events? Has a drainage specialist investigated the impacts? If rain water is being retained within the substrate (Moisture reservoir layer) or drainage layer, how long will it last? Will it last till the next rainfall or will irrigation be needed in-between? If the drainage layer stores water, has its loading capacity been considered during the structural calculations?	
Filter layer	Is the filter layer lightweight, rot-proof, inexpensive, easy to- install and permanent? Is the filter layer effective? Non-woven is preferable. At the edges and seams, is the filter cloth appropriately overlapped? Is the filter layer designed to properly deal with the edges and curbs?	
Growth medium / substrate	Has the growing media been specified by an experienced professional? Has the medium been well-	

	established and tested? Does the growing medium have the characteristics specific to the green roof design? (weight, water absorption, stability, resistance, drainage and surface area) How is the growing media being transported to the roof?	