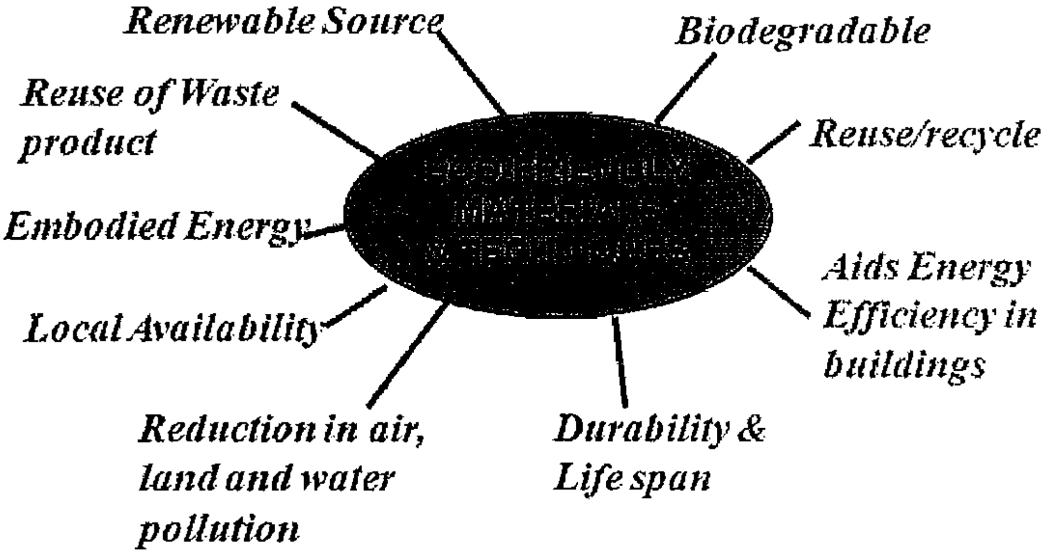
UNIT-2



BAMBOO:

Bamboo is a very fast growing, renewable and easy-to-grow resource. It is an extremely versatile material with countless uses including construction, clothes, food and fuel. There are over 1000 species of bamboo. This amazing plant grows in tropical and temperate environments and is very hardy, not needing pesticides or herbicides to grow well. It is a type of grass and grows from it's roots, when it is cut it quickly grows back with most species maturing in 3-5 years.

Some facts about the sustainability of bamboo are:

- It is grown without pesticides or chemical fertilizers
- It requires no irrigation
- It rarely needs replanting
- It grows rapidly and can be harvested in 3-5 years
- It produces 35% more oxygen that an equivalent stand of trees
- It sequesters carbon dioxide and is carbon neutral
- It is a critical element in the balance of oxygen and carbon dioxide in the atmosphere
- It is an excellent soil erosion inhibitor
- It grows in a wide range of environments
- It's production into fibres has lower environmental impact than other forms of fibre, especially synthetic ones.

USES OF BAMBOO:

Houses, schools and other buildings:
According to UNESCO, 70 hectares of bamboo produces enough material to build 1000 houses. If timber was used instead, it would require the felling of trees from an already diminishing forest. Today, over one billion people in the world live in bamboo houses.

Roads and bridges:
It is being used in road reinforcements in India and it is also used in bridges built in China, capable of supporting trucks that weigh as much as 16 tons.

Medicines:
In China, ingredients from the black bamboo shoot help treat kidney diseases. Roots and leaves have also been used to treat venereal diseases and cancer. According to reports in a small village in Indonesia, water from the culm (the side branches) is used to treat diseases of the bone effectively.

Clothes:
It's the new hemp, it can be made into a strong and durable fabric a bit like canvas and can be made into all sorts of clothes. Additionally, bamboo fabric is breathable, thermal regulating, wicks moisture better than polyester performance fabrics, will resist odour and is absorbent and fast drying keeping you dryer and more comfortable than any cotton or polyester fabrics. Beware though: it is also made into Rayon in a chemical process that is unsustainable.

Accessories:
It is also used to make necklaces, bracelets, earrings, and other types of jewellery.

Food:
Shoots are used mainly in Asian food preparations. In Japan, the antioxidant properties of the bamboo skin prevent bacterial growth, and are used as natural food preservatives.

Fuel:
Charcoal made from this amazing plant has been used for centuries as cooking fuel in China and Japan. The Bamboo vinegar or pyroligneous acid is extracted when making charcoal and is used for hundreds of treatments in almost all fields. This liquid contains 400 different chemical compounds and can be applied for many purposes including cosmetics, insecticides, deodorants, food processing, and agriculture.

Scaffolding:
It is often used for scaffolding because it proves to be an eco-friendly and cost-effective resource. In Hong Kong, bamboo scaffolding is preferred over metal scaffolding because its easily available and cheaper.

Furniture:
Beautiful and intricately crafted beds, chairs and tables are made from bamboo

Rugs and textiles:
Exotic woods like the mango are often used in Oriental rugs. Buying a bamboo rug will ensure that you save a tree.

Paper:
Pulps are mainly produced in China, Myanmar, Thailand and India, and are used in printing and writing papers.

Nappies:
According to Japanese scientists, bamboo cloth can retain its antibacterial quality even after 50 washings.

Utensils and tableware:
Cups and saucers, spoons and ladles can all be made from this incredibly versatile material.

- **Establishing bamboo plantations has a wide array of advantages, including:**

- Reducing cost per uses of bamboo
- Increasing jobs
- 35% higher oxygen emission into the atmosphere than trees
- 40% more CO_2 absorption than trees
- No fertilizer or pesticides required for growth
- Establishing an extensive root system into soils, which in turn draws in and stores double the amount of water into watersheds, thus preventing soil erosion.

Internal Uses for Bamboo:

- Flooring
- Support columns
- Electrical wire coverings
- Interior walls
- Eco-friendly products for kitchen and bath

External Uses of Bamboo:

- Structural frames
- Corner posts
- Girders
- Joists
- Studs
- Braces

- Tie beams
- King posts
- Purlins
- Ridgepoles
- Rafters
- Sheathing
- Roofing
- Exterior walls

Because of the nature of the plant, it is susceptible to deterioration agents such as insects, rot, fungi, and fire. It is important to treat the structure, inside and out. Untreated, sections of the bamboo would need to be replaced every 2 to 3 years. Some of the best preventative measures include:

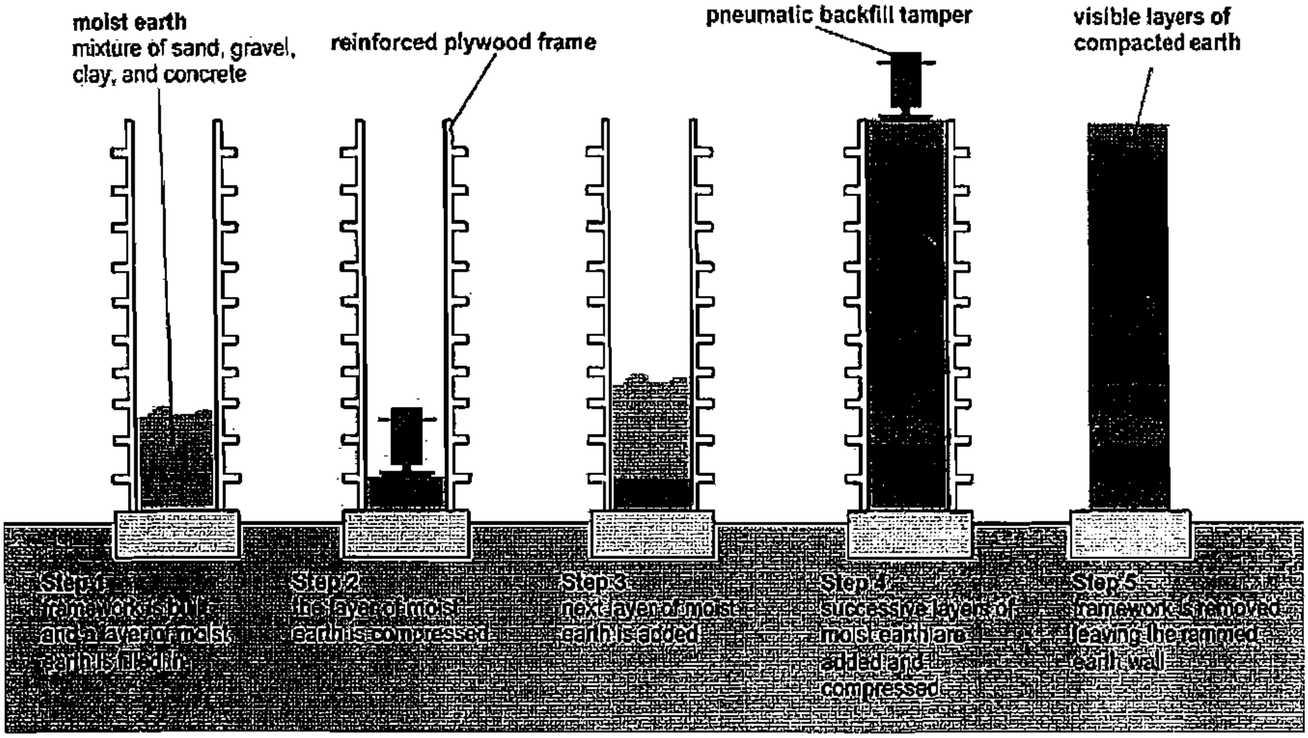
"Bamboo poles should be stored horizontally, laid above ground and supported to prevent sagging or bending. Bamboos should be stored in a dry, shaded and well cooled area, laid in shelving type system with the first layer not less than 50 centimeters above ground level for good air circulation. Smoking fires or heating bamboo in kilns can protect the canes from insect attack. Applying chemical coating such as are kerosene, diesel oil containing DDT and varnish can protect the canes from termites, beetles, wet rot and fungus attack."

Bamboo solutions are a highly sustainable, cost-effective and beautiful construction material for homes. It can be used throughout the entire structure (inside and out) and if preventative measures are utilized, can last for many years. It is no wonder that Asian and Central and South American cultures have grown to rely upon this hearty grass for so many facets of their lives. One can only wonder what other uses we will find for bamboo as North America adopts an increasing focus on sustainable building.

1. http://www.greenspec.co.uk/building-design/rammed-earth/

RAMMED EARTH

Rammed earth walls (aka pise) are constructed by the compacting (ramming) of moistened subsoil into place between temporary formwork panels. When dried, the result is a dense, hard monolithic wall.



• A vernacular green building material as well as in more recent 'Eco houses', rammed earth is an ancient form of construction, usually associated with arid areas. There remain plentiful examples of the form around the world – evidence that rammed earth is a successful and durable way of building. A few historical rammed earth buildings are to be found in the UK.

• In recent years, rammed earth has become popular amongst environmentally-conscious architects as well as those seeking an element of exoticism. Contemporary examples include:

• Though there is a growing number of buildings including rammed earth in the UK, its prospects of entering mainstream construction as a structural material are limited due to formwork and labour costs involved together with a climate that has relatively high humidity and moderate external temperatures.

- The likely future for the application of rammed earth is as:
  - Thermal mass.
  - Internal load-bearing unstabilised walls.
  - External load-bearing stabilised walls.

- Distinct appearance
- Natural and readily available
- Low embodied energy (a level similar to brick veneer construction)
- Unstablised earth is reuseable post-demolition
- High moisture mass, hygroscopic - helps regulate humidity
- Use of local soils supports sustainability practices
- High thermal mass (though work is still underway to quantify its extent)
- Airtight construction achievable
- Traditional form of construction
- Modern methods are widely tried and tested overseas eg Australia
- Concerns over durability – requires careful detailing
- Poor thermal resistance – external walls require additional insulation
- Not all soil types are appropriate
- High levels of construction quality control are required
- Longer than average construction period
- Few modern examples exist in the UK – relatively untested in UK climate
- High clay content can cause moisture movement. Structures may need to accommodate this.
- No UK codes of practice
- Adding cement stabilisation can compromise environmental credentials

Rammed Earth (RE) and Stabilised Rammed Earth (SRE)

Many of the shortcomings associated with the durability of rammed earth (primarily external surface protection, water resistance, shrinkage and strength) can be averted by the addition of a stabiliser. This has become general practice in Australia where it perceived to reduce uncertainty and risk. Though other forms have been used, the most common stabiliser is cement, which when added typically makes up between 6 or 7% (by volume) of the mix.

The addition of cement (high embodied energy), however, is seen by many to compromise the environmental credentials of rammed earth – though this might be balanced out when additional protection and maintenance of non-stabilised rammed earth is built into the equation.

Building Regulations

For walls constructed from **stabilised rammed earth** (SRE):
Part A – Structure

• Rammed earth has proved to be suitable for loadbearing and non-loadbearing construction.
• Compressive strength is a maximum of 1MPa for unstabilised rammed earth and approximately 10MPa for stabilised rammed earth.

Part B – Fire Safety

• Rammed earth can be classed as non-combustible material (Table A6).
• A 300mm wall is capable of providing fire resistance of at least 90 minutes.

Part C – Resistance of moisture

• Rising damp is prevented by DPCs.
• Penetrating moisture is limited through absorption and subsequent evaporation.
• Weather erosion is reduced / prevented through appropriate detailing eg extended eaves, raised plinths, rainscreens etc.

Part E – Resistance to the passage of sound

• Rammed earth walls provide effective acoustic separation
• Where floors are supported by separating (party) rammed earth walls, design detailing should follow the norm for other solid masonry walls, but with the additional requirement to accommodate moisture movement.

Part L – Conservation of fuel and power

• U-value of 300mm rammed earth wall "H 1.5 – 3 W/m^{2}K, therefore insulation needs adding in external wall applications.

Regulation 7 – Materials and Workmanship

• Fitness of rammed earth materials determined by sampling, lab testing of materials or precedence.

• Adequacy of quality is measured against provision of the specification, test panels and previous works.

Design Issues

1. Insulation:

• There are few examples of rammed earth walls combining insulation in the UK. Most contemporary walls remain **un-clad**. The following suggested solutions have yet to be thoroughly tested.

• Because of rammed earth's poor thermal performance, **extra insulation** will be required.

• Rammed earth is **hygroscopic**. Wherever walls are clad externally, cladding systems and finishes must be vapour-permeable to allow evaporation. This is important for unstabilised walls, but less-so for stabilised walls where the stabilising agent will impair breathing. Non-the-less, it might be wise to consider vapour permeable solutions for both instances to reduce the chance of condensation build-up on the inside face of insulation.

• Vapour permeability is less of a concern when specifying internally applied insulation - when moisture is encouraged to evaporate externally. Internally, insulation specification is a lot more flexible, though its application directly to the face of the wall should be avoided.

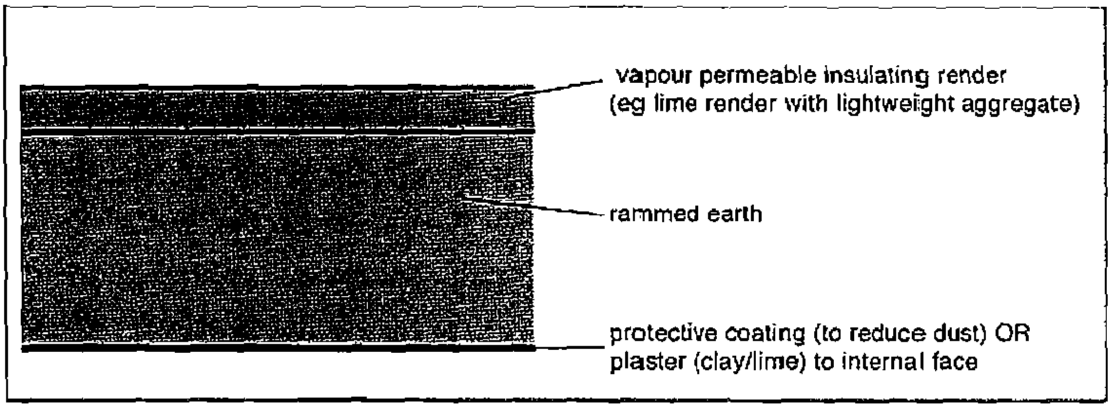
The strategic decision to be made is where to locate it - inside or outside - both have advantages and disadvantages:

External insulation

Wall is protected from weathering

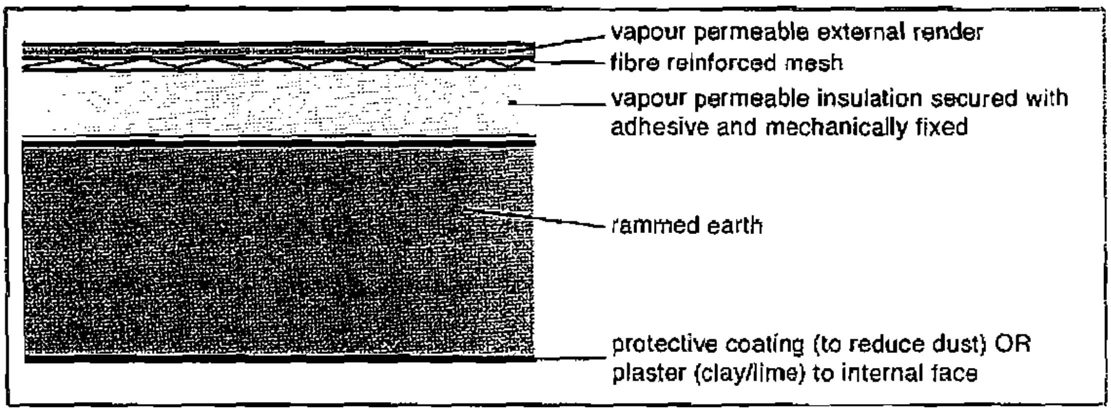
Exposed thermal mass internally

Loss of characteristic appearance externally



Materials: hemp Lime, proprietary renders, mineral-based renders and hygroscopic insulation (see also: • Insulation materials compared)

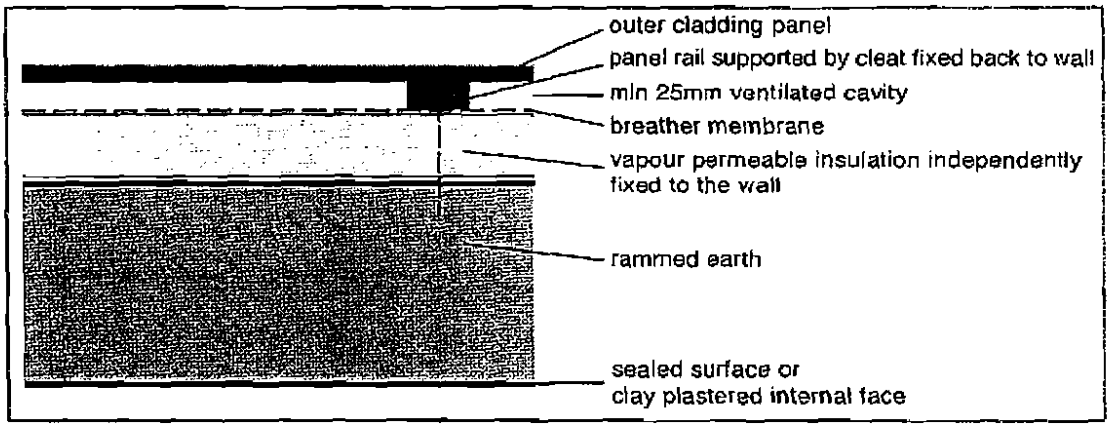
• Insulation board and render:



Insulation materials: breathing insulation: cellulose slab, composite wood wool board (not cement-based), wood fibre board, cork, hemp, hemp-lime . (see also: • Insulation products and • Insulation materials compared)

Render: limecrete, mineral render, glaster, proprietary permeable renders

• Rain screen cladding



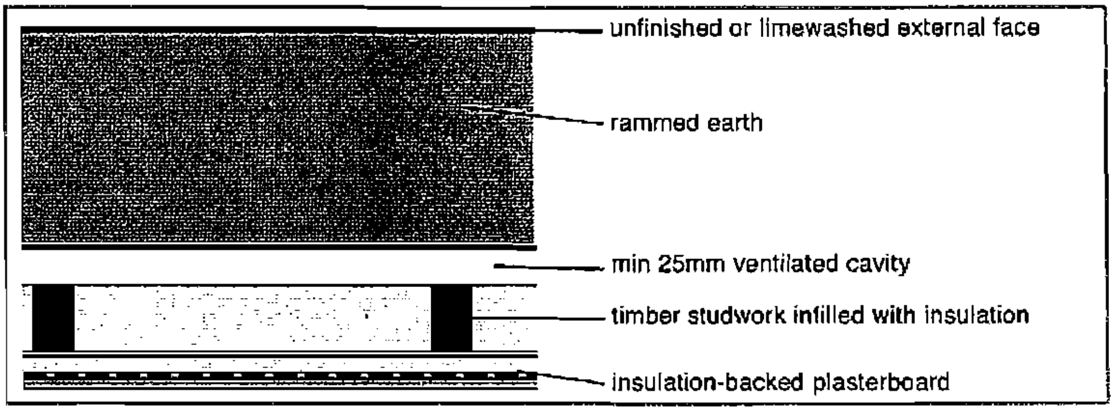
Insulation materials: breathing insulation: cellulose slab, composite wood wool board (not cement-based), wood fibre board, cork, sheep's wool, hemp, hemp-lime (see also: • Insulation products and • Insulation materials compared)
Cladding: wood, tiles, slate, board and polymer-based render, proprietary cladding systems

Internal insulation

External appearance maintained

Loss of available thermal mass

Free-standing studwork with infill insulation

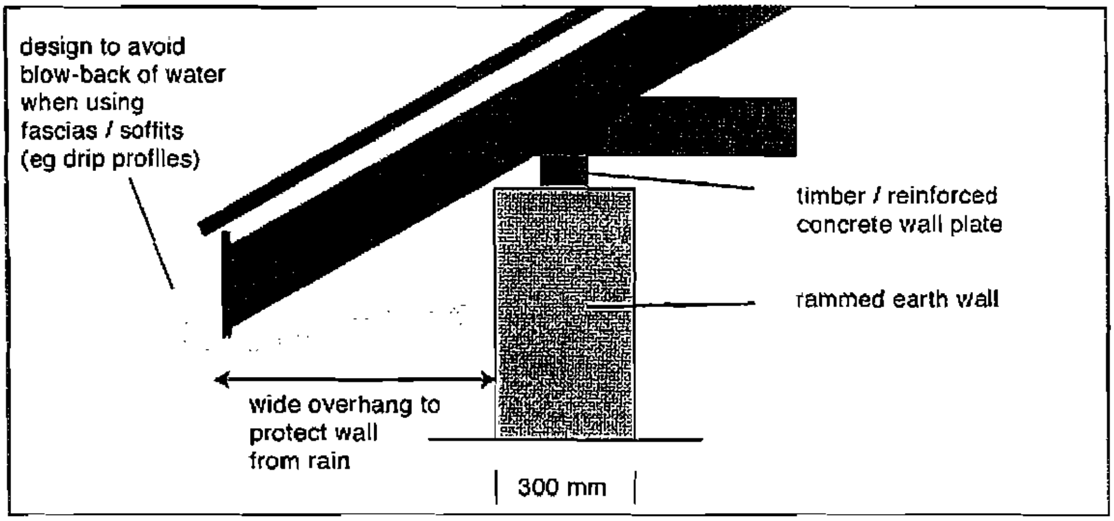


Insulation materials: Cellular glass, Mineral wool slab, Expanded polystyrene, Phenolic foarm, Polyisocyanurate (PIR), Polyurethane (PUR).

2. Weather protection:

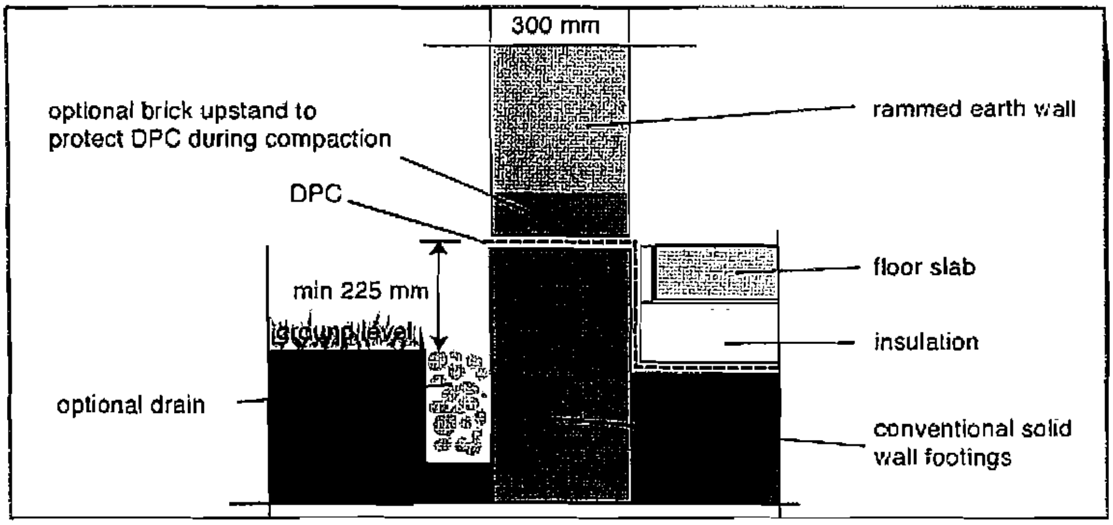
- All water should drained away from the walls
- Walls should be constructed upon raised footings
- Avoid sites that are liable to flood
- Protect the wall where possible from rain using adjoining elements such as projecting roofs
- Allow excess moisture means to evaporate from walls
- On exposed sites, consider rain screen cladding or render
- Water sealant protective coatings are not recommended

Protection given by the roof



• The eaves provide protection from rain. An emerging rule-of-thumb states that the overhang should be equivalent to a third of the overall wall height. (source: Peter Walker)

Footings and base



- The DPC should be finished flush with the wall suface to avoid splash.
- Blue engineering brick might be considered as an alteranative to the DPC membrane.
- A filter drain will also reduce the height of splash by means of radom splash effect.
- As with all solid walls, ensure careful detailing to avoid cold-bridging.

STABILIZED MUD BLOCK (SMB)

Stabilized Mud Block (SMB) Technology an alternative to bricks

1. Background:

i. With the rapid increase in population and industrial growth, the demand for natural raw materials and sources of energy is increasing day by day. Demand for new buildings as well as the cost of building construction is growing at a steady pace. Bricks, cement, steel, timber, plastics, glass etc represent some of the commonly used conventional materials for the construction of buildings and other structures. Generally these materials are transported over great distances spending fossil fuel energy. Manufacture of such conventional materials requires expenditure of energy in various forms and many of these manufacturing processes are detrimental to the environment.

ii. Conventional building technologies like burnt bricks, steel and cement are high in cost, utilize large amount of non-renewable natural resources like energy, minerals, top soil, forest cover etc. Cement, steel and bricks are conventional energy intensive building materials. Around 1.5 billion bricks are produced annually by small and medium size processing units consuming annually about 3 million cubic meters of top soil- most of it is fertile soil. The burning of bricks in the vicinity of fields damages plant life and digging of soil for brick making causes collection of water in pools creating unhygienic conditions and erosion of good agricultural soil. The thermal efficiency of kilns leads to environmental pollution.

iii. Steel and cement factories emit toxic gases leading to air pollution. Excessive quarrying of limestone for lime burning or cement manufacturing has disturbed the ecological balance.

iv. Cost effective, labor intensive and energy efficient traditional building materials and techniques like mud wall, thatch roofs etc are available but these require frequent repairs. Use of conventional materials to satisfy the demand for new buildings can drain the available energy resources and cause environmental degradation/ pollution. Also energy intensive building materials are expensive. Building materials amount for 70-75% of the total cost of construction. Due to large scale construction programs in the country the demand for conventional building

v. The cost of SMB depends on a number of factors such as

- Machine Depreciation Cost
- Cost of soil and sand
- Cost of cement
- Labor cost

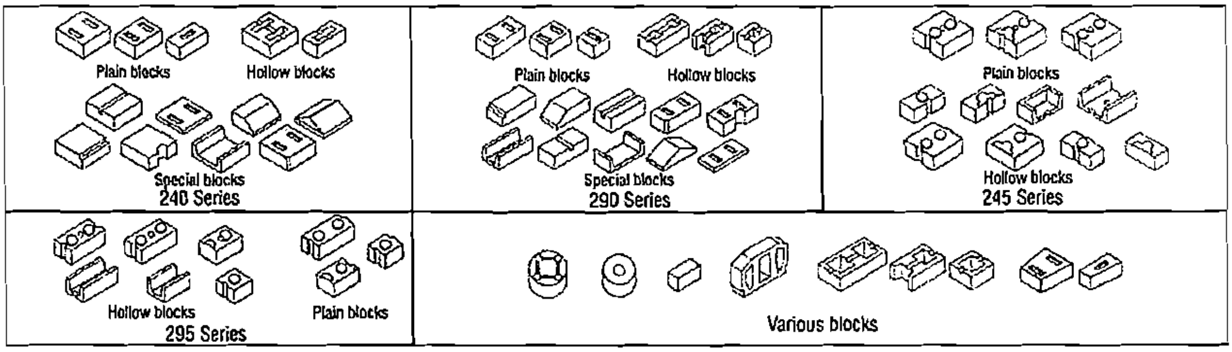
vi. 230 X 190 X 100 mm (2.5 to 2.8 times brick volume) will be in the range of Rs.3 to Rs.7 depending upon the above factors. Cost can be drastically reduced by the use of local materials and self help labor. Cost of the mud block is independent of the scale of production.

vii. Production activities can be carried out throughout the year. During rainy season the production activities can be carried out without any difficulties provided that the raw materials are protected from the rain and procured before the rainy season.

The soil, raw or stabilized, for a compressed earth block is slightly moistened, poured into a steel press (with or without stabiliser) and then compressed either with a manual or motorized press. CEB can be compressed in many different shapes and sizes. For example, the Auram press 3000 proposes 18 types of moulds for producing about 70 different blocks.

Compressed earth blocks can be stabilised or not. But most of the times, they are stabilised with cement or lime. Therefore, we prefer today to call them Compressed Stabilised Earth Blocks (CSEB).

The input of soil stabilization allowed people to build higher with thinner walls, which have a much better compressive strength and water resistance. With cement stabilization, the blocks must be cured for four weeks after manufacturing. After this, they can dry freely and be used like common bricks with a soil cement stabilized mortar.



Type of Soil

i. Soils containing predominantly non expansive clay minerals are suited for cement stabilized blocks. Most of the red loamy soils are suitable with minor modifications. Expansive soil such as black cotton soil requires addition of lime and the process of making SMB is cumbersome using black cotton soil. Highly silty soils also pose problems of green strength and compaction. Soil with 10 15% clay and > 65% sand is ideal for SMB production using cement as a stabilizer. If some soils contain more clay fraction, then it is advisable to bring down the clay fraction by addition of sand or inert materials like stone quarry dust.

ii. The Stabilized Mud Blocks production machines are available in mechanized as well as manually operated form. The machine weighs 170-200 kg depending upon the different moulds. Manually operated machines are ideal in rural areas for decentralized production. Mardini soil block press is one such manually operated machine. A team of 6-7 persons can produce 200- 500 numbers of blocks per day from a single machine depending upon their professional efficiency. For the production of 500 blocks 2 tons of soil and sand each along with 275 kg of cement is required.

iii. Two block sizes (305 X 143 X 100 mm and 230 X 190 X 100 mm) have been standardized. These two sizes can be used to construct walls of thickness 305 mm, 230 mm, 190 mm, 143 mm or 100 mm. These blocks are 2.5 to 2.8 times bigger in volume when compared with conventional bricks.

- Stacking and Curing of Blocks
- Block strength

iv. Compressive strength of the block greatly depends upon the soil composition, density of the block and percentage of stabilizer (cement/ lime). Sandy soils with 7% cement can yield blocks having wet compressive strength of 3-4MPa. This kind of strength will be sufficient to construct 2 storey load bearing buildings with spans in the range of 3-4 m.

materials like cement, steel, bricks and timber has outstripped their supply. The exponential population growth and the existing housing shortage being 41 million have made the situation even more alarming. It is thus quite evident that the present available stock of building materials in the country is not in a position to meet the overgrowing demand of housing. These materials are scarce but the rising demand is leading to depletion of the resources. This clearly indicates the need for energy efficient, environmental friendly, economical alternative building materials and technology.

2. Stabilized Mud Block Technology

i. Stabilized Mud Block Technology is a simple, cost effective, environmental friendly technology developed by Centre for Science and Technology, Indian Institute of Science, Bangalore. It utilizes local materials and reduced energy consumption and thus, reduces the cost.

Advantages:

- Energy efficient- 70% savings when compared to burnt bricks
- Economical (20-40% when compared to brick masonry). The net financial advantage in terms of labour per block is Rs.1.50 whereas in conventional methods is 30-40p
- Plastering of walls can be eliminated
- Highly decentralized production
- Better block finish
- Aesthetically pleasing
- Lower amount of mortar required for wall construction

2.2 Technology component of the Project

- The process of production involves,
- Sieving the soil
- Mixing the soil with sand and stabilizer such as cement and lime
- Mixing of optimum quantity of water
- Pressing the wet mixture into a dense solid block using a simple manually operated machine
- Curing the block for a period of 3-4 weeks by sprinkling moisture

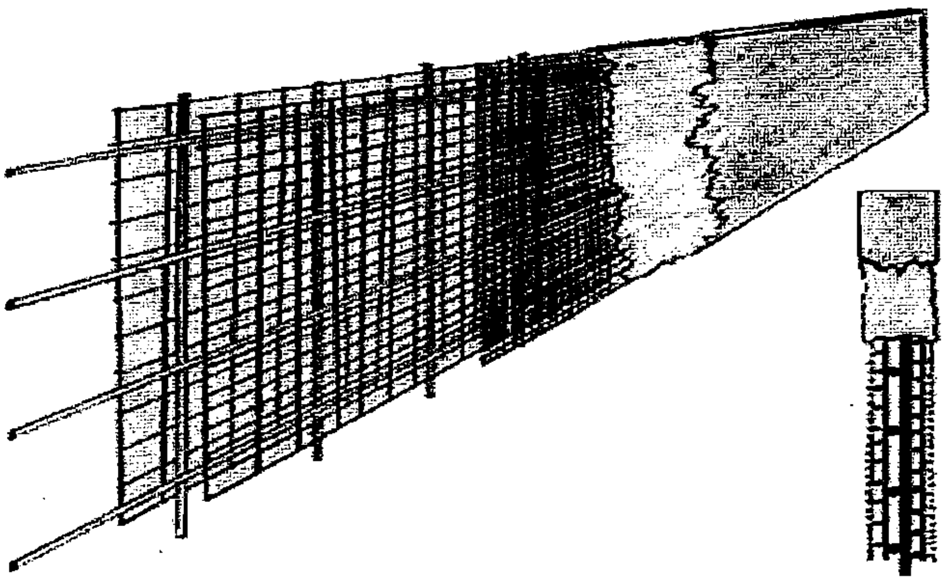


Fig: Typical cross section of ferrocement structure.

Constituent Materials for Ferrocement

1. Cement
2. Fine Aggregate
3. Water
4. Admixture
5. Mortar Mix
6. Reinforcing mesh
7. Skeletal Steel
8. Coating

Advantages and Disadvantages of Ferrocement

Advantages

- Basic raw materials are readily available in most countries.
- Fabricated into any desired shape.
- Low labour skill required.
- Ease of construction, low weight and long lifetime.
- Low construction material cost.
- Better resistance against earthquake.

Disadvantages

- Structures made of it can be punctured by collision with pointed objects.
- Corrosion of the reinforcing materials due to the incomplete coverage of metal by mortar.
- It is difficult to fasten to Ferrocement with bolts, screws, welding and nail etc.
- Large no of labors required.
- Cost of semi-skilled and unskilled labors is high.
- Tying rods and mesh together is especially tedious and time consuming.

Process of Ferrocement Construction

- Fabricating the skeletal framing system.
- Applying rods and meshes.
- Plastering.
- Curing

Applications of Ferrocements in Construction

- Housing
- Marine
- Agricultural
- Rural Energy
- Anticorrosive Membrane Treatment.
- Miscellaneous.

Cost Effectiveness of Ferro cement Structures

- The type of economic system.
- Type of applications.
- Relative cost of labor.
- Capital and local tradition of construction procedure.
- Doesn't need heavy plant or machinery.
- Low cost of construction materials.

Recent Applications:

- Residential and Public Buildings.
- Industrial Structures.
- Agricultural structures.

ENERGY EFFECTIVENESS

Initial embodied energy (MJ/m^3 of materials)	Carbon emission (Kg of CO_2 /m^3 of materials)
CSEB are consuming 11 times less energy than country fired bricks: CSEB produced on site with 5 % cement = 548.32 MJ/m^3 Country fired bricks = 6,122.54 MJ/m^3	**CSEB are polluting 13 times less than country fired bricks:** CSEB produced on site with 5 % cement = 49.37 Kg of CO_2 /m^3 Country fired bricks = 642.87 Kg of CO_2 /m^3

COST EFFECTIVENESS

CSEB are most the time cheaper than fired bricks and concrete blocks. In Auroville, a finished m^3 of CSEB masonry is always cheaper than fired bricks: between 15 to 20% less than country fired bricks (April 2009). See Comparison of building materials in Auroville. The cost breakup of a 5 % CSEB produced in Auroville with an AURAM press 3000 is as follow (July 2012):

Labour (soil sieving and block making): ~45 %	Raw materials (soil, sand, water): ~ 27 %	Cement: ~25 %	Equipment: ~3 %

Of course this breakup will vary a lot according to the local context, but in general the labour cost (which includes the soil digging, its preparation and the block making) and the cement cost are the highest. Therefore if the productivity decreases, the cost of the block will increase proportionally a lot. In general, to reduce the cost of the block one should optimise the productivity of workers and reduce the amount of cement if 5% cement is not required. Further, the cost of the equipment is not so high and therefore, one should not try to cut down the cost of the lock by buying cheap quality machines, which would not last long and would not give strong blocks.

SUSTAINABILITY AND ENVIRONMENTAL FRIENDLINESS OF CSEB

- Earth is a local material and the soil should preferably extracted from the site itself or not transported too far away
- Earth construction is a labour-intensive technology and it is an easily adaptable and transferable technology.
- It is a cost and energy effective material.
- It is much less energy consuming than country fired bricks (about 4 times less).
- It is much less polluting than country fired bricks (about 4 times less).

INITIAL EMBODIED ENERGY PER M^3 OF WALL	POLLUTION EMISSION (Kg of CO_2) PER M^3 OF WALL
CSEB wall = 631 MJ / m^3 Kiln Fired Brick (KFB) = 2,356 MJ / m^3 Country Fired Brick (CFB) = 6,358 MJ / m^3	CSEB wall = 56.79 Kg / m^3 Kiln Fired Brick (KFB) = 230.06 Kg / m^3 Country Fired Brick (CFB) = 547.30 Kg / m^3

SOIL SUITABILITY AND STABILIZATION FOR CSEB

Not every soil is suitable for earth construction and CSEB in particular. But with some knowledge and experience many soils can be used for producing CSEB. Topsoil and organic soils must not be used. Identifying the properties of a soil is essential to perform, at the end, good quality products. Some simple sensitive analysis can be performed after a short training. Cement stabilisation will be better for sandy soils. Lime stabilisation will be better suited for clayey soils.

GOOD SOIL FOR COMPRESSED STABILISED EARTH BLOCKS

The selection of a stabilizer will depend upon the soil quality and the project requirements. Cement will be preferable for sandy soils and to achieve quickly a higher strength. Lime will be rather used for very clayey soil, but will take a longer time to harden and to give strong blocks.

Soil for cement stabilisation: it is more sandy than clayey	Gravel = 15%	Sand = 50%	Silt = 15%	Clay = 20%
Soil for lime stabilisation: it is more clayey than sandy	Gravel = 15%	Sand = 30%	Silt = 20%	Clay = 35%

The average stabilizer proportion is rather low:

	Minimum	Average	Maximum
Cement stabilisation	3 %	5 %	No technical maximum
Lime stabilisation	2 %	6 %	10%

These low percentages are part of the cost effectiveness of CSEB.

LIME AND POZZULANA LIME

Lime is one of man's oldest and most vital chemicals. The ancient Romans used lime in building and road construction, uses which continue to the present day. From earliest times, lime has been made by heating limestone (calcium carbonate) to high temperatures. This process, known as calcining, results in quicklime, or calcium oxide.

Hydrated lime (calcium hydroxide) is produced by reacting quicklime with sufficient water to form a dry, white powder.

1. Lime Allows Buildings To Breathe

In the search by architects and conservators for building materials sympathetic to traditional construction, lime was found to be one of the most important. One of the reasons lime binders are promoted by the Society for the Protection of Ancient Buildings for repairs is because they are vapour permeable and allow buildings to breathe. This reduces the risk of trapped moisture and consequent damage to the building fabric

11. Self Healing

The nature of ground conditions and the elements are such that all buildings are subject to varying degrees of movement over time. When buildings made with lime are subject to small movements they are more likely to develop many fine cracks than the individual large cracks which occur in stiffer cement-bound buildings. Water penetration can dissolve the 'free' lime and transport it. As the water evaporates this lime is deposited and begins to heal the cracks. This process is called autogenous, or self healing.

ADVANTAGES OF CSEB

- **A local material**

Ideally, the production is made on the site itself or in the nearby area. Thus, it will save the transportation, fuel, time and money.

- **A bio-degradable material**

Well-designed CSEB houses can withstand, with a minimum of maintenance, heavy rains, snowfall or frost without being damaged. The strength and durability has been proven since half a century.

But let's imagine a building fallen down and that a jungle grows on it: the bio-chemicals contained in the humus of the topsoil will destroy the soil cement mix in 10 or 20 years… And CSEB will come back to our Mother Earth!

- **Limiting deforestation**

Firewood is not needed to produce CSEB. It will save the forests, which are being depleted quickly in the world, due to short view developments and the mismanagement of resources.

- **Management of resources**

Each quarry should be planned for various utilisations: water harvesting pond, wastewater treatment, reservoirs, landscaping, etc. It is crucial to be aware of this point: very profitable if well managed, but disastrous if unplanned!

- **Energy efficiency and eco friendliness**

Requiring only a little stabilizer the energy consumption in a m^3can be from 5 to 15 times less than a m^3 of fired bricks. The pollution emission will also be 2.4 to 7.8 times less than fired bricks.

- **Cost efficiency**

Produced locally, with a natural resource and semi skilled labour, almost without transport, it will be definitely cost effective! More or less according to each context and to ones knowledge!

- **An adapted material**

Being produced locally it is easily adapted to the various needs: technical, social, cultural habits.

- **A transferable technology**

It is a simple technology requiring semi skills, easy to get. Simple villagers will be able to learn how to do it in few weeks. Efficient training centre will transfer the technology in a week time.

- **A job creation opportunity**

CSEB allow unskilled and unemployed people to learn a skill, get a job and rise in the social values

- **Market opportunity**

According to the local context (materials, labour, equipment, etc.) the final price will vary, but in most of the cases it will be cheaper than fired bricks.

- **Reducing imports**

Produced locally by semi skilled people, no need import from far away expensive materials or transport over long distances heavy and costly building materials.

- **Flexible production scale**

Equipment for CSEB is available from manual to motorized tools ranging from village to semi industry scale. The selection of the equipment is crucial, but once done properly, it will be easy to use the most adapted equipment for each case.

- **Social acceptance**

Demonstrated, since long, CSEB can adapt itself to various needs: from poor income to well off people or governments. Its quality, regularity and style allow a wide range of final house products. To facilitate this acceptation, banish from your language "stabilized mud blocks", for speaking of CSEB as the latter reports R & D done for half a century when mud blocks referred, in the mind of most people, as poor building material

13. Local Limes Enhance Regional Identity And Diversity

The diversity of limestone types provides variety and local distinctiveness. Different limes will vary in colour, texture and setting properties. Local limes have a regional identity, they give a sense of place and provide a continuous link with the local aesthetic. Local colour is the obvious example in respect of limewashes.

3. The Use Of Lime Has Ecological Benefits

- **Lime has less embodied energy than cement.**
- **Free lime absorbs carbon dioxide in the setting process of carbonation.**
- **It is possible to produce lime on a small scale.**
- **The gentle binding properties of lime enable full re-use of other materials.**
- **A very low proportion of quicklime will stabilize clay soils.**
- **Small quantities of lime can protect otherwise vulnerable, very low energy materials such as earth construction and straw bales.**

FERRO CEMENT

What is Ferro cement?

Ferro cement is a construction material consisting of wire meshes and cement mortar. Applications of ferro cement in construction are vast due to the low self weight, lack of skilled workers, no need of framework etc.

It was developed by P.L.Nervi, an Italian architect in 1940. Quality of ferrocement works are assured because the components are manufactured on machinery set up and execution time at work site is less. Cost of maintenance is low. This material has come into widespread use only in construction in the last two decades.

Properties of Ferrocement:

- Highly versatile form of reinforced concrete.
- It's a type of thin reinforced concrete construction, in which large amount of small diameter wire meshes uniformly throughout the cross section.
- Mesh may be metal or suitable material.
- Instead of concrete Portland cement mortar is used.
- Strength depends on two factors quality of sand/cement mortar mix and quantity of reinforcing materials used.

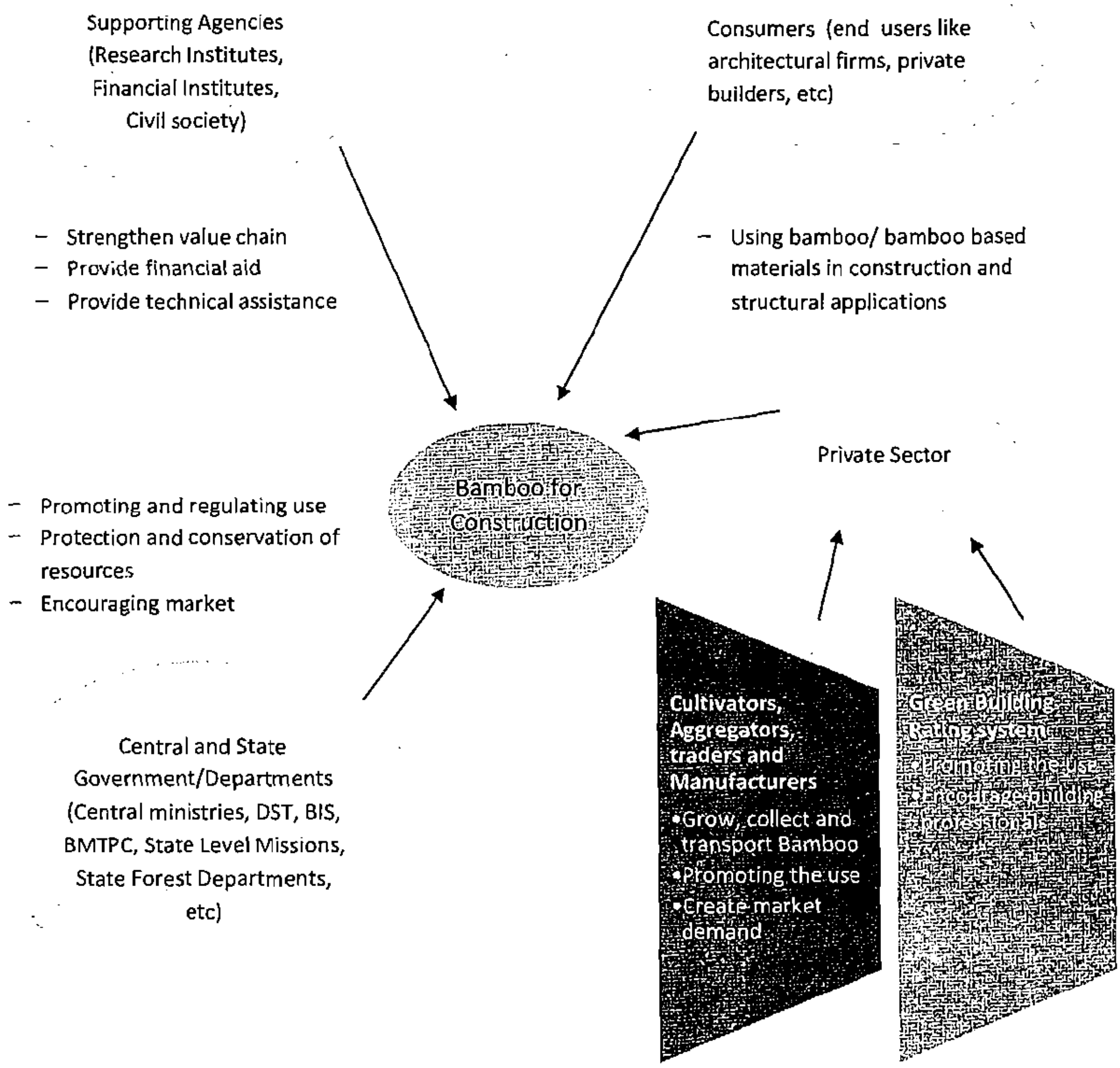


Figure 4: Key Stakeholders in Bamboo Sector

- Bureau of Indian Standards: It has come out with the standards relevant for utilization of bamboo and bamboo composite material in structural application like IS 13958: 1994 Specification for bamboo mat board for general purposes, IS 14588: 1999 Specification for bamboo mat veneer composites for general purposes, IS-15476: 2004 Bamboo mat corrugated sheets, IS 8242:1976 Methods of tests for split bamboos, IS 8295 (Part 1): 1976 Specification for bamboo chicks: Part 1 Fine, IS 8295 (Part 2): 1976 Specification for bamboo chicks: Part 2 Coarse, IS 6874:1973 Methods of

Course: III B.Tech II Semester (R13 Regulation)

Branch: Civil Engineering

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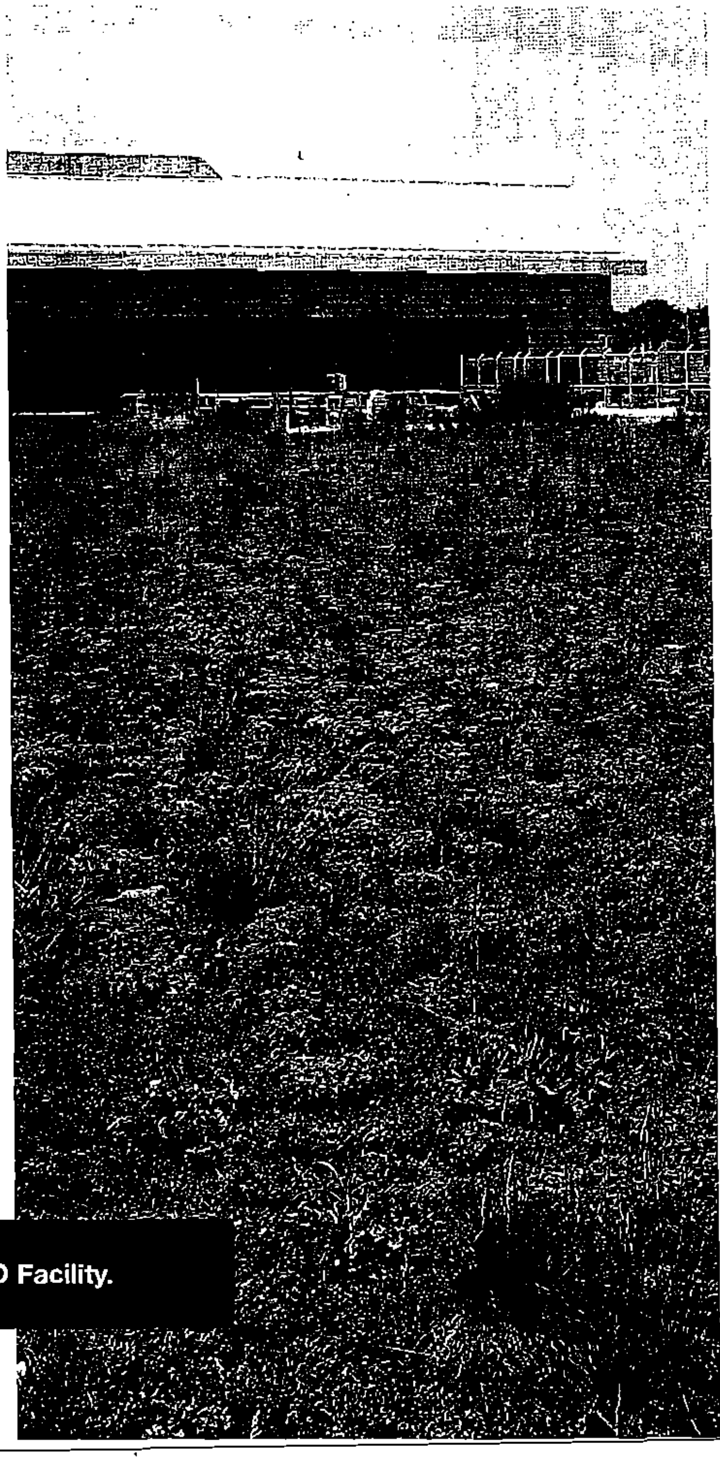
LAB SUBJECTS	

HOD

SECTION 4

ROOFTOP SYSTEMS

Rooftop systems provide temporary storage of stormwater runoff on roof surfaces, slow release to the sewer system and retention where evaporation or vegetative uptake is feasible. This section describes typical rooftop systems that comply with DEP's stormwater performance standard. Selection of the appropriate rooftop system will depend on a number of factors, including siting, design and construction considerations specific to each development. In addition to these considerations, general operations and maintenance recommendations are provided in this section.



A green roof at DEP's Paerdegat CSO Facility.

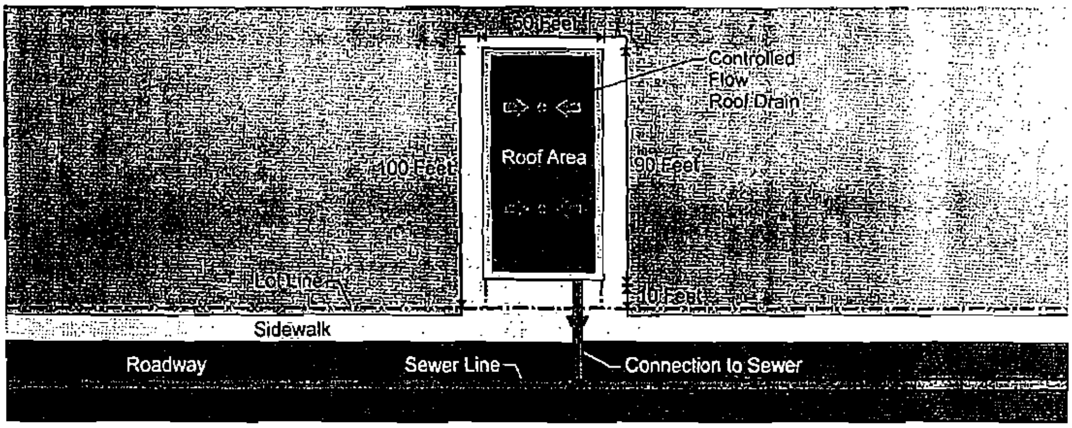


Figure 4-1: Example development lot where a blue roof may adequately control site runoff given a large building footprint.

4.1 Types of Rooftop Systems

Rooftop systems are an effective practice for controlling runoff on a wide variety of sites. Choosing and designing a rooftop system for a specific site requires a careful review of the building and site characteristics early during planning and design phases. Two types of rooftop systems — blue roofs and green roofs — are described below.

Typically, if rooftop systems are used as standalone practices or in a parallel configuration, they require a controlled flow roof drain to comply with DEP's stormwater performance standard.

For some sites, rooftop systems may be connected to subsurface systems to adequately manage total site runoff. Rooftop systems may also be incorporated into rainwater recycling systems, where flows routed from rooftop systems to cisterns or other harvesting features are captured and used for onsite purposes such as site irrigation, thus, permanently retaining the water. (See Section 5, Combination Systems, for further information.)

4.1.1 Blue Roofs

Blue roofs consist of controlled flow roof drains to regulate the rate of runoff from the roof. Weirs or orifices attached to the roof drains slow flow into the building's storm drains or roof leaders. Water will pond on the roof surface for a short period after a rain event as the runoff is slowly released through controlled flow roof drains.

Roof drains that integrate volumetric weirs within the drain assembly are commercially available. Alternatively, a manufacturer can customize an orifice size for a specific development. The number and sizing of weirs and orifices are based on a pre-determined relationship between the water depth approaching the drain and the flow rate entering the drain. A waterproofing membrane must be installed as part of the roofing system if the roof is designed to detain stormwater.

4.1.2 Green Roofs

Green roofs consist of layers of growing media and plants on top of the roofing system. Green roofs detain rooftop stormwater runoff and reduce the rate of runoff entering the city sewer system during rainfall events. Green roofs can also

Advantages and Limitations of Rooftop Systems

Advantages:

- Well suited for lotline-to-lotline buildings.
- Requires no additional land area.
- No excavation required.
- Easy to install.
- Extends the life of the roof by protecting roofing membranes from ultraviolet radiation.
- Commercially available products.
- Readily coupled with other storage techniques, such as subsurface storage or cisterns.
- Compatible with other rooftop uses.
- Green roofs add economic value to developments when used as passive recreational features or rooftop farms.
- Green roofs provide co-benefits, such as heat island reductions, energy conservation and climate change offsets, air quality improvements and increased wildlife habitat value.

Limitations:

- Roofs with steep slopes (greater than 2% slopes for blue roofs and greater than 5% for green roofs) will provide limited storage.
- Regular inspection and maintenance of roof surface and roof drains are required.
- Limited benefit on sites where roof area makes up only a small portion of the total impervious area.
- Additional loading on roof may add to the cost of the building structure.

retain stormwater and permanently remove runoff from the sewer system, as the growing media absorbs stormwater and the vegetation evapotranspires water into the atmosphere. Green roof systems in these guidelines are grouped into two categories: single-course and multi-course systems. The primary distinction between the two systems is that multi-course systems have a separate drainage layer, while single-course systems do not. The type of system that is selected may influence calculations of required storage volumes.

Single-course systems, as shown in **Figure 4-2**, rely on the growing media alone to provide sufficient drainage, without using a separate drainage layer. Accordingly, the media used is designed to have a higher porosity and permeability than that used in other assembly types. Typical single-course assemblies are a minimum of four inches thick and include a waterproofing membrane, root barrier, sheet drain, insulation, filter fabric, growing media and vegetation layers.

Multi-course systems incorporate a drainage or reservoir layer consisting of plastic or geocomposite sheets. The drainage layer captures water on top in troughs or cups and allows for flow to drain freely below the troughs **(Figure 4-3)**. Alternatively, a capillary layer can be composed of granular mineral media to minimize the shock to the root system of the vegetation under wet conditions **(Figure 4-4)**. Given the multiple layers, the total height of the system is typically greater than four inches. In addition to the components of the single-course system and the separate drainage layer, multi-course systems may also include a filter layer to trap soil and sediment.

4.2 Siting Considerations for Rooftop Systems

Rooftop systems are appropriate for different land uses in urban environments. Rooftop systems are particularly suitable for buildings with footprints that cover all or most of the lot and relatively flat roofs. This section outlines key siting considerations for selecting the appropriate rooftop system during site planning and building design.

4.2.1 Site and Building Characterization

The first step in designing an effective rooftop system is to understand how rooftop runoff contributes to the total developed flow from the site. If non-roof area is small (i.e., less than 10% of total site area), the site's total developed flow may be equivalent or nearly equivalent to the rooftop runoff, and rooftop systems would be a cost-effective option to consider. On certain sites, it may be possible to detain the entire required storage volume with a rooftop system. On sites where the non-roof area is significant, additional analysis of site conditions is required to determine whether a subsurface system or combination of rooftop and subsurface systems would be most effective. (See Section 5, Combination Systems.) Rooftop systems may be used to compensate for non-roof areas and reduce the size of a subsurface system. At sites that use combination systems, the total combined flow from rooftop and subsurface systems exiting the site should not exceed the required release rate for the total lot area per DEP's stormwater performance standard.

Blue roofs are considered a low cost detention option. Coupled with light colored roofing material, they can also help to minimize the urban heat island effect and provide rooftop cooling.

In addition to considering non-roof areas, the desired physical characteristics of the roof surface, including roof slope, roofing materials, and deflection/loading capacity must be considered when selecting a rooftop system. Slope should be a major consideration during building and rooftop design if a rooftop system is the selected method of detention. Large slopes may reduce stormwater storage capacity on roofs below required storage volumes and cause greater depths of ponding and loading at the drains.

Blue roofs utilizing controlled flow roof drains generally require flat or nearly flat roofs (e.g., less than 2% slope). Blue roofs with modifications approved by DOB and DEP that mitigate slope and more evenly distribute the ponded water may be considered for roofs with slopes greater than 2%. Green roofs being used as stormwater management systems are recommended only on roofs with relatively shallow slopes (e.g., less than 5% slope). See additional information about the impact of slopes on rooftop systems in Section 4.3.5, Roof Slope, Ponding Depth and Drainage Configurations, and Section 4.3.7, Loadings and Structural Capacity.

In addition, both green and blue roof drains should be located away from trees, if possible, to prevent leaf litter that would result in the clogging of the drains and additional ponding on the rooftop.

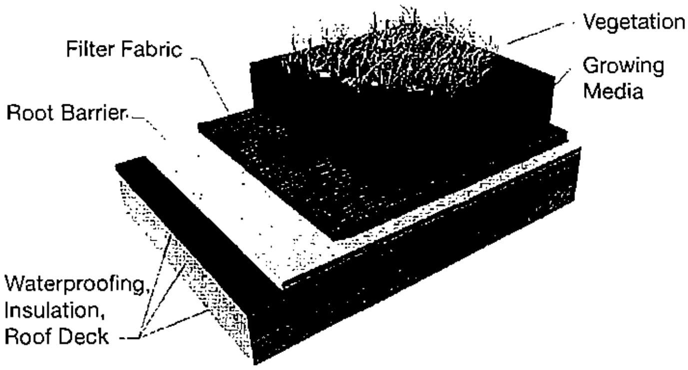


Figure 4-2:
Typical layers of a single-course roof system.

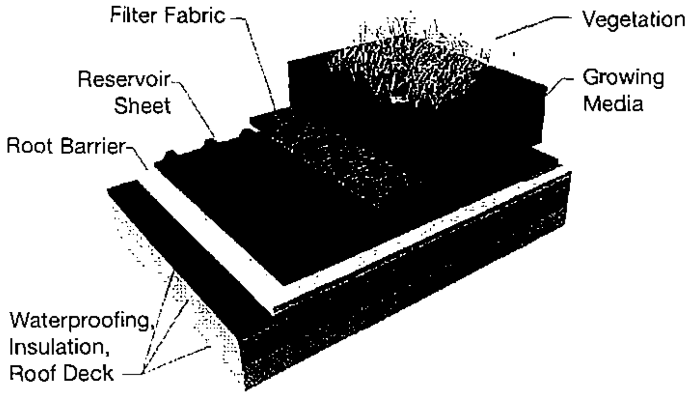


Figure 4-3:
Typical layers of a multi-course roof system with synthetic drainage layer.

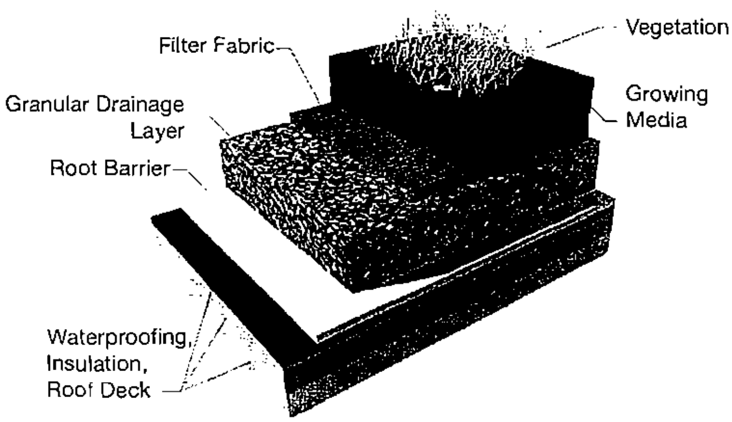


Figure 4-4:
Typical layers of a multi-course roof system with granular drainage layer.

Different Types of Green Roofs

The single-course and multi-course green roof assemblies discussed in the guidelines are both variations on extensive green roofs, the difference being that multi-course green roofs incorporate a drainage layer in their design.

Common extensive green roof features include:

- Four to five inches of growing media;
- Lightweight growing media designed for water retention;
- Shallow rooted, drought tolerant vegetation; and
- Typically irrigation free after the establishment period.

Common intensive green roof features include:

- Greater than five inches of growing media;
- Heavier, more nutrient laden growing media;
- Deeper rooted vegetation, often including trees or shrubs;
- Require irrigation past the first year; and
- Much heavier green roof assembly overall.

Intensive green roofs provide stormwater control equal to or greater than extensive green roofs do, but are not discussed specifically in these guidelines because designs are much less universal. Credit for intensive roofs beyond that provided for extensive green roofs may be discussed on a case-by-case basis with DEP for compliance with the stormwater performance standard.

4.2.2 Complementary Uses

Rooftop systems generally do not restrict the roof from being used for other functions or purposes such as siting mechanical equipment, providing passive recreation, or serving as a means of egress or a point of rescue for fire safety. Possible uses for the building's roof structure should be considered in the design of a rooftop system and can be designed to be compatible with uses proposed in the current development plan or in the future. Rooftop systems are designed to hold only a few inches of ponded water on the roof for short periods, ranging from a few minutes to a few hours after a rain event, at times when the rooftop is unlikely to be used by residents or visitors.

If such water ponding is determined to be incompatible with current or future uses, the rooftop system may be designed to occupy a portion of the roof area, leaving additional roof space available for the other uses. For passive recreational uses, decking over a blue roof could provide space above the ponded area. Passive recreational features such as picnic areas should be relegated to paved or decked areas, and not be placed on a green roof. Green roofs are not designed to have foot traffic which could cause damage to plants, soil compaction, and erosion. Walkways or pavers should be incorporated into the design of the green roof if needed for resident or visitor access to different parts of the roof. Americans with Disability Act (ADA) requirements for walkway pitches, railing heights, and threshold offsets should be observed for roofs intended for public access. In general, green roofs do not require pathways specifically for maintenance activities, as these activities usually involve a comprehensive sweep of the entire green roof surface to weed, fertilize, and infill bare spots.

The use of solar panels on top of green roofs can also be implemented, as long as the panels allow sunlight and stormwater to reach the green roof. Otherwise, solar panels should be installed on non-green portions of the roof. Photovoltaic panel stands that have been specifically designed to be ballasted by green roofs are now available from several manufacturers.

Mechanical equipment and other rooftop structures should be installed on raised pads above the roof deck. The pads should be appropriately flashed with waterproofing material. Locating equipment on raised pads will reduce the extent of roof penetrations and flashing required. If structures and equipment are mounted directly on the roof within the area intended for ponding water, it may be necessary to provide additional waterproofing around the structure or equipment or to elevate the equipment above the anticipated maximum water depth to prevent damage and provide access for maintenance.

It is recommended that pads also be constructed for potential structural or mechanical uses that may be constructed in the future. In addition, access should be provided for façade rigging equipment including the use of temporary equipment (beams and weights) that may be needed in the future. If appropriate staging areas for façade maintenance are not provided, damage to the rooftop system may result.

Sufficient structural loading analysis that considers cumulative loads where multiple uses are proposed and incorporated into the design should be conducted by licensed professionals, in accordance with the Construction Codes. Section 4.3.7 provides additional detail on loading considerations.

4.2.3 Considerations for Multiple Roof Levels

For buildings with multiple roof levels, rooftop systems can be applied on each level where drains control runoff. Alternatively, a roof at a higher elevation can drain directly onto a lower roof with a regulated discharge. In this case, the storage volume on the lower roof would be calculated based on the combined runoff from all contributing roof levels. This storage volume would then be used to determine the maximum water depth on the lower roof.

Other Benefits of Green Roofs

- Green roofs can help a project applying for Leadership in Energy and Environment Design (LEED) certification achieve a number of Sustainable Sites credits.
- Green roofs are eligible for a property tax abatement from New York City.
- When maintained appropriately, green roofs improve runoff water quality by filtering out particles, nutrients and heavy metals.
- Evapotranspiration from the roof helps to lower temperatures, helping to address the heat island effect that leads to higher temperatures in the City.
- Green roof vegetation improves air quality by intaking carbon dioxide (and other harmful volatiles) and producing oxygen through photosynthesis. Airborne particles and heavy metals are also trapped by the plants and growing media, reducing particulate loading in the air.
- Green roofs can provide a habitat for flora and fauna, enhancing biodiversity in the city.
- Green roofs used for agricultural production can contribute fresh food to communities and additional revenue for building owners.

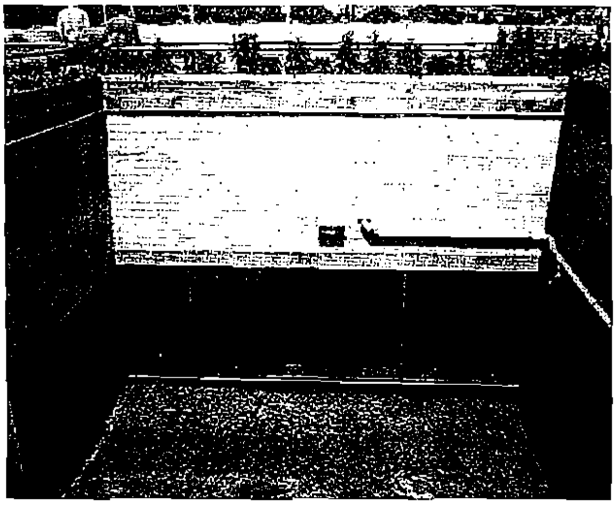


Figure 4-5:
Multiple level green roof on DPR's Five Borough Building on Randall's Island.

For green roofs, draining a roof at a higher elevation directly onto a lower roof is recommended only if the lower roof is designed with a multi-course green roof. Draining the upper roof can cause erosion on the lower roof if the lower roof is a single course system. With the multi-course system, the upper roof leader can discharge directly to the drainage layer, thereby avoiding damage to the growing media and vegetation.

4.3 Rooftop System Design

Proper design will help to ensure that the rooftop system is built to provide adequate storage, support the desired use on the roof, conform to existing rules and regulations, and allow for appropriate operation and maintenance over time, as needed. The following guidelines, along with manufacturer-provided specifications, will assist the licensed professional in designing rooftop systems to comply with DEP's stormwater performance standard.

4.3.1 Roof Assemblies and Materials

Durability of the roof assembly is important for maximizing the operating life of a rooftop system. Materials selected should have a long life expectancy and be accompanied by a manufacturer-provided quality control program. All roofing systems generally consist of roofing materials that provide insulation and waterproofing on top of the roof deck and structural support members. Therefore, while many types of insulation and waterproofing are available and can work as part of a rooftop system, the intended use of the roof for storage of water should be confirmed with the manufacturer to ensure the warranty covers such use.

New York City Fire Codes

Similar to conventional roofs, green and blue rooftop systems are subject to the New York City Fire Department's (FDNY) Fire Code (2008). The Fire Code should be consulted during the design and construction process for compliance with fire operations features, fire resistance rated construction, means of egress and other regulations. Additionally, rooftop systems must provide appropriate access and means of ventilation to FDNY for emergency conditions, and ensure structural loading consistent with the Construction Codes.

Unprotected Roof Assembly

Unprotected roof assemblies are roof systems where the insulation lies between the roof deck and the membrane, as shown in **Figure 4-6**. Unprotected roof assemblies may require ballast where the waterproofing membrane is loose-laid rather than adhered to the insulation and roof deck. Depending on the dry weight of the green roof, it may provide the ballast needed to weigh down the membrane, avoiding the need for another type of ballast or adhesive. Caution should be used with thinner green roofs, as their weight may not be substantial enough to be used as ballast, especially if erosion of soil media occurs.

Green roofs help protect the roof assembly from the elements, providing the benefits of a protected roof assembly and extending the roof life.

Although the insulation lies below the waterproof membrane in unprotected roof assemblies, it is still advisable to use water-resistant insulation materials to avoid harm to the insulation, which could lead to roof repair or complete replacement. Rooftop systems require insulation with a relatively high compressive strength to handle the additional weight. Therefore, it is essential that the designer calculates the total weight of the rooftop system so that the insulation can be strengthened accordingly.

Protected Roof Assembly

Also known as a protected membrane roof (PMR) assembly or an inverted roof membrane assembly (IRMA), a protected roof assembly consists of an insulation layer that covers the waterproofing membrane on top of the roof structure **(Figure 4-7)**. The insulation layer tends to have stronger compressive strength than the insulation layer in unprotected roof assemblies, and fewer modifications to standard roof design may be required for rooftop systems.

Protected roof assemblies often use ballast, rather than adhesives, to hold the insulation in place. When creating blue roofs on roofs with ballast, the depth and porosity of the ballast will be part of the design criteria and may require additional ponding depth or surface area to achieve the same storage volume. As with unprotected roof assemblies, the dry weight of the green roof may be able to provide the ballast needed to weigh down the insulation, avoiding the need for adhesives or another type of ballast. Caution should be used with thinner green roofs, as their weight may not be substantial enough to be used as ballast, especially if erosion of soil media occurs or large rainfall events result in flotation.

4.3.2 Waterproofing Membrane

Rooftop detention systems are considered wet systems and, thus, require waterproofing. In general, the waterproofing membrane should withstand the temporary ponding of water on a regular basis. Common waterproofing membrane systems include modified bitumen roofing (MBR), waterproof types of single-ply roofing, metal roof panels, spray polyurethane foam (SPF) roofing, and liquid-applied (including polyurethane-based and polymer-modified bituminous products) roofing. The first four are typically found in unprotected roof assemblies, though they can also be used for protected assemblies. SPF membranes are not classified as either a protected or unprotected roof assembly because they incorporate the insulation into the membrane. Liquid-applied membranes tend to be used in protected roof assemblies.

High quality MBR sheet roofing products are suitable for use with rooftop systems. These systems involve two or more layers of MBR sheets tiled to minimize seam vulnerability. These are generally not resistant to root attack and should

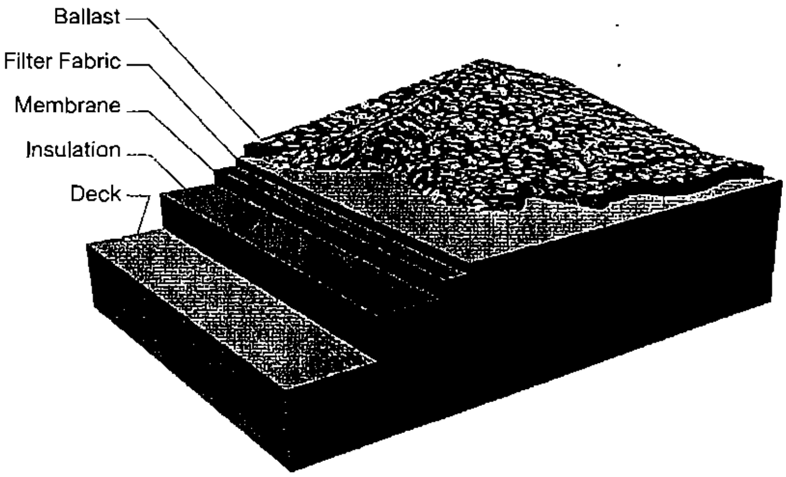


Figure 4-6:
Unprotected roof assembly (with geotextile and ballast if required by design).

be installed in conjunction with a supplemental root barrier layer.

Lower quality MBR roof systems are not recommended for use below rooftop systems because they contain many layers of asphaltic sheets with fiber reinforcement that can wick moisture and many seams where water can penetrate the system. These systems are also fairly thin and less durable than other types of roof assemblies, requiring regular maintenance and more frequent replacement. Metal roof panels are also not recommended for blue roofs due to their required 2% minimum slope, per the Construction Codes.

Many single-ply systems are designed specifically for green roof applications, and thus are capable of holding water during a storm. Single-ply membranes come in large sheets of thermoplastic, or thermoset (i.e., rubber), and therefore have fewer seams. The sheets come in variable thicknesses, and their thick, durable layers with few seams make these membranes particularly well-suited for rooftop detention systems. Thermoplastic membranes can be seamed using hot-air welding methods that can result in seams that are as strong and durable as the field membrane itself.

SPF membranes incorporate insulation into the membrane and do not need a stand-alone insulation layer. These roofing systems are considered to be more stable than others and, therefore, tend to be used in areas where hurricanes or high wind speeds are a concern and on roofs with atypical configurations. SPF roof systems are not common in the city because of high associated costs. However, because the system has no seams and is durable, this membrane is suitable for rooftop systems.

Fluid-applied membranes are similar to SPF systems in that they are applied onsite as a coating. However, fluid applied membranes require a separate insulation layer. The liquid is poured onto the roof and spread with a squeegee until the desired thickness is reached. The liquid-applied membrane is self-healing and very durable, making the use of these membranes a viable option for blue roofs. Liquid-applied membranes tend to last the longest of any roof system with little maintenance required, but the initial cost of these membranes tends to be more expensive

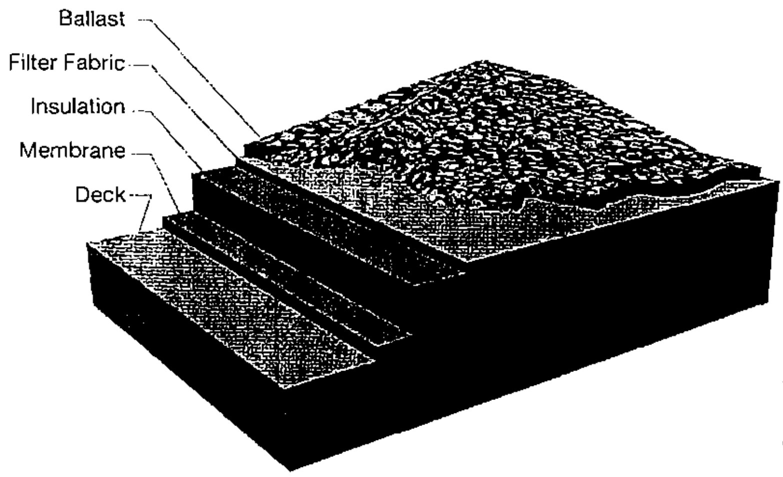


Figure 4-7:
Protected roof assembly (with geotextile and ballast if required by design).

than other membrane types. These membranes are available in both hot and cold fluid-applied versions.

The New York City School Construction Authority (2007) recommends use of a "hot fluid applied, rubberized asphalt, fabric reinforced roofing system in a protected membrane configuration" for new construction that includes blue and green roof systems. The durability and lack of seams makes this membrane suitable for use with rooftop systems. Cold liquid-applied systems are equally effective and may be comparable in cost due to strict regulations on the use of the propane-fired devices for hot fluid systems. For green roofs, polymer-modified bituminous products require a supplemental root barrier layer.

4.3.3 Leak Detection Systems

Leak detection is an important element in the design and construction of rooftop systems. Some systems involve installation of a network of sensors as part of the initial roof design, while other options include low and high voltage surveying. Leak detection should be conducted during construction (after the installation of the waterproofing membrane), and on a regular basis after installation of the rooftop system. Both passive and active electrical methods are available for locating leaks.

The most common passive technique is low-voltage leak surveying. This method does not require the permanent installation of any components, provided the waterproofing is installed over a cast-in-place structural concrete, steel, or composite steel-concrete deck. The survey should be conducted by a trained technician. High voltage methods, while effective for evaluating watertightness during the construction phase, are not useful after a blue or green roof is installed because the waterproofing must remain in a dry condition.

Active systems involve the installation of a network of electrical sensors beneath the waterproofing membrane. These systems can be designed to continually check for leaks and to set off an alarm when a leak is detected. Active systems are not compatible with liquid-applied and most other adhered waterproofing systems.

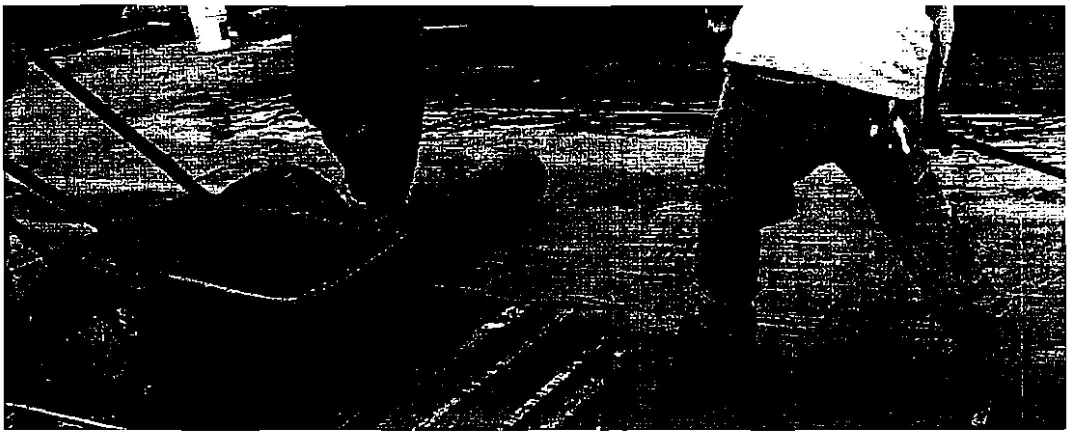


Figure 4-8: Installation of fiberboard and first ply of waterproofing membrane during construction of a blue roof at PS118 in Queens.

It is recommended that some type of long-term leak detection system is employed. It is up to the licensed professional and property owner to decide which system provides adequate protection, balancing the cost with the associated risk of leakage.

4.3.4 Roof Drains and Scuppers

Roof drains and leaders for blue and green roofs should be sized in the same manner as conventional roof drain systems and in accordance with the Construction Codes. If a site's stormwater runoff is to be controlled on the rooftop, controlled flow roof drains are required for blue roofs and green roofs to comply with DEP's stormwater performance standard. These drains are commercially available and typically incorporate volumetric weirs into the drain assembly to control the flow rate entering the drain.

Depending on the roof design and required release rate, off-the-shelf or custom drain designs may be used. Designers are advised to use the storage volume and release rate calculations in the DEP Criteria and Section 2 of these guidelines, rather than rely solely on manufacturer-provided sizing charts. Weir-style controlled flow roof drains must be tamper-proof to prevent unauthorized modifications, which could alter system performance.

As with conventional roof systems, blue and green roof installations should include secondary (emergency) scuppers or roof drains to comply with the Construction Codes. Secondary drains and scuppers should be located at the desired ponding depth of the blue roof. Green roof installations will almost always be four inches thick or greater, which will require setting the secondary drain higher than four inches over the low point of the roof and the scuppers higher than four inches from the surface of the roof assembly. If the green roof is designed to allow ponding on the surface of the green roof, the scuppers may need to be raised accordingly. The structural design of the building should account for the maximum ponding depths at the secondary drains and scuppers.

In addition to the secondary drains or scuppers, excess flows may enter the controlled flow roof drain at an uncontrolled rate by flowing over the top of the drain.

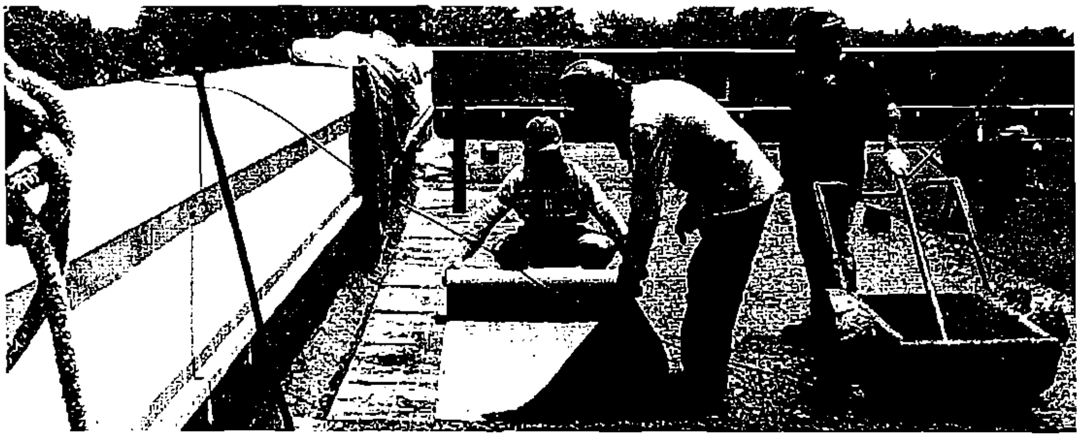


Figure 4-9: Installation of waterproofing membrane during construction of a green roof at PS118 in Queens.

Clogging of roof drains through accumulation of debris can significantly alter the relationship between water depth and flow rate, and diminish system performance. To ensure that the system performs as designed and to avoid overburdening maintenance personnel, strainers should be placed around the drain inlets to catch debris before it enters the drains. Such strainers, commonly found on standard roof drains, are commercially available in various diameters to fit common drain sizes.

4.3.5 Roof Slope, Ponding Depth, and Drainage Configurations

To function as an effective stormwater control, a blue roof should provide adequate storage volume to control release rates in accordance with DEP's stormwater performance standard. For this reason, application of blue roof systems is most effective on roofs with slopes of up to about one-quarter-inch per foot (or 2% slope).

The slope of a roof has a significant impact on the volume of water that can be detained on the roof while maintaining shallow ponding depths around the roof drains. For a given roof configuration, the available storage volume depends on a number of variables including roof size, drainage configuration, direction of slope and maximum allowable ponding depth.

For ponding depths greater than four inches, additional structural analyses are required according to the Construction Codes. Section 4.3.7 provides additional detail on loading considerations. For a given ponding depth, the drainage configuration should be designed to achieve the maximum possible storage volume. One way to increase the available storage volume on a sloped roof is to increase the number of drainage areas. The optimal number of drainage areas for a given roof size depends on the slope of the roof and the maximum ponding depth.

Regardless of how the roof area is divided into drainage areas, one potential problem with this approach is that as sloped roofs become larger, more drainage areas and drains are required to maximize the available storage volume. Given a fixed total roof area, as the number of drains increases, the required release rate per drain may become too small to achieve using commercially available controlled flow roof drains.

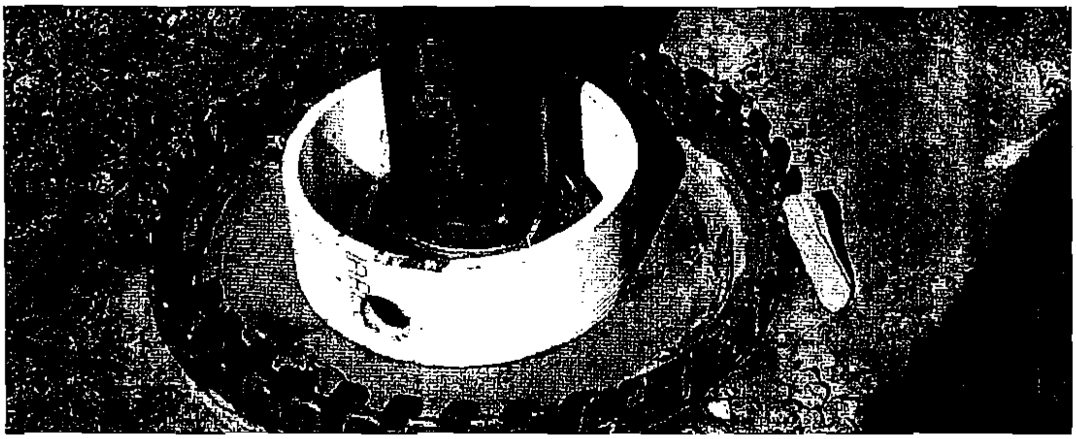


Figure 4-10:
The orifice in this controlled flow drain sets the ponding depth and controls the outflow from the roof on DEP's Storage Facility in Brooklyn.

For alterations to existing buildings, rooftop storage may be maximized by installing check dams or weirs at intermediate locations along the roof surface or ponding trays throughout the roof surface. Check dams or weirs may be constructed of any material that can temporarily detain water and withstand environmental conditions on rooftops. Appropriate materials include angle iron, fiberglass, roof tiles, and pavers with roof flashing. These modifications should be appropriately weather sealed and secured to the roof structure. Spacing of a series of check dams or weirs on sloped surfaces should ensure that one does not cause backwater against another at maximum water surface storage.

Table 4-1 is included for planning purposes only to show available storage volumes for a range of alternate roof drain configurations with a uni-directional slope of 0.5%. While the uni-directional slope configuration is not the most restrictive configuration, it is used to provide guidance for sloped roof applications.

Storage volumes are calculated assuming three inches of ponding depth with controlled flow roof drains rated at 9.1 gallons per minute per inch (0.02 cfs per inch). To determine the available storage volume on such a roof using this table, the total roof area and the length-to-width ratio of the individual drainage areas must be known. By selecting the roof area and length-to-width ratio from the appropriate row and column in the table, the available storage volume for the roof configurations illustrated in **Figures 4-11a**, **4-11b**, and **4-11c** can be estimated. Uni-directional roof slopes result in more storage volume than multi-directional sloped roofs, and most roofs have slopes steeper than 0.5%. Therefore, **Table 4-1** illustrates the high range of available storage. Design calculations for available storage volumes are needed for all roofs intended to be used as rooftop detention.

4.3.6 Growing Media and Vegetation

The engineered soil used in green roof construction is referred to as growing media. In order to satisfy a range of physical and horticultural requirements, media for green roofs is usually based on lightweight aggregates. These materials, lighter than most soil, have high surface area and porosity and moderate to high permeability.

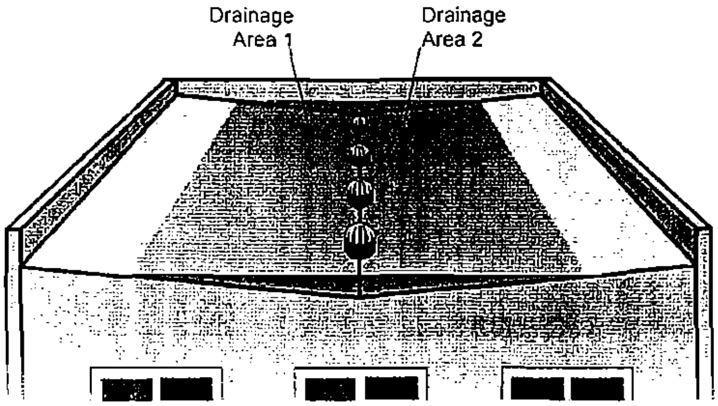


Figure 4-11a: Uni-directional sloped roof with four drains and two drainage areas.

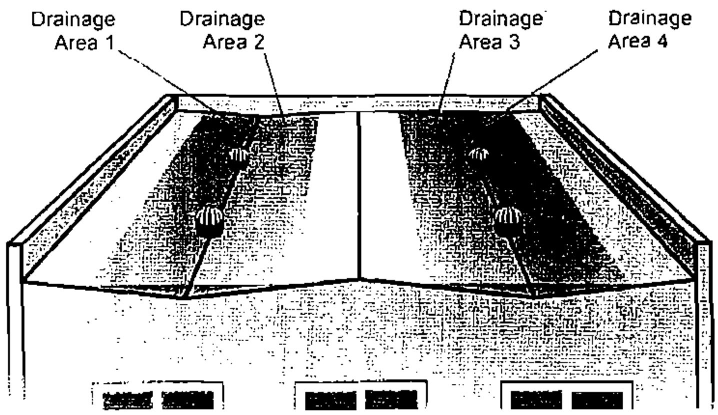


Figure 4-11b: Uni-directional sloped roof with four drains and four drainage areas.

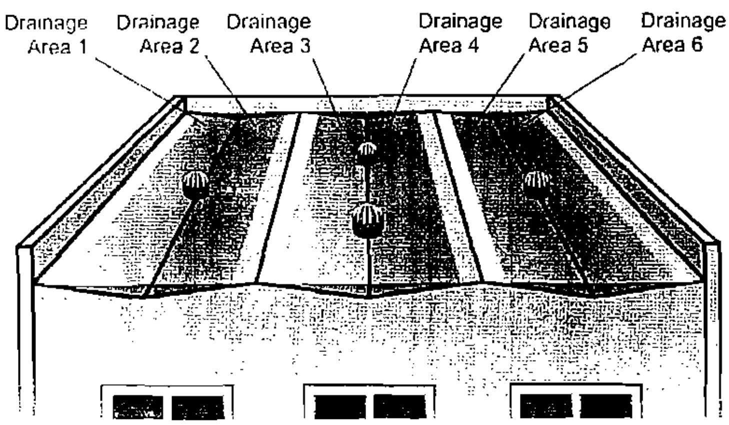


Figure 4-11c: Uni-directional sloped roof with four drains and six drainage areas.

Table 4-1: Available storage volume (cu ft) for uni-directional sloped roofs of different sizes and length-to-width (L/W) ratios (for planning purposes only)

Roof Area (sq ft)	2,000	4,000	6,000	8,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000
Number of Drainage Areas (N) = 2												
L/W = 1	388	684	919	1,106	1,250							
L/W = 2	342	553	678									
L/W = 3	306	452	494									
L/W = 4	276	368										
Number of Drainage Areas (N) = 4												
L/W = 1	444	842	1,210	1,553	1,875	2,602	3,232	3,779				
L/W = 2	421	776	1089	1,368	1,616	2,126						
L/W = 3	403	726	997	1,225	1,417							
L/W = 4	388	684	919	1,106	1,250							
Number of Drainage Areas (N) = 6												
L/W = 1	463	895	1,306	1,702	2,083	2,985	3,821	4,603	4,335	6,022	6,667	7,273
L/W = 2	447	851	1,226	1,578	1,911	2,667	3,333	3,921	4,438			
L/W = 3	435	817	1,165	1,484	1,778	2,424	2,959					
L/W = 4	425	789	1,113	1,404	1,667	2,219						

*Assumes ponding depth of three inches and slope of 0.5%

Plant species should be carefully selected to achieve a vigorous plant cover over the green roof. Despite the relatively shallow media depth of many green roofs, plants with long roots, such as Panicum and Andropogon grass, can adapt to the thin veneers of green roofs. Plants that do not have a documented record of success over a period of at least three years under similar conditions should be used sparingly and with caution. Plants that require irrigation past the establishment period should not be included in green roofs unless the roof is designed as a rooftop farm. Species having deep tap roots should be avoided. Several additional planting recommendations are summarized below:

- The selected plant community should be able to accommodate brief periodic saturated soil conditions;
- Plants with differing growing media requirements should not be mixed or located in the same area of a roof;
- Ground covering plants should always be included in the design. Measures that promote the rapid development of this groundcover should be introduced early during construction;
- Typically, evergreen perennials dominate in green roof design, as it is often desirable to maintain a continuous foliage ground cover for aesthetic purposes. For extensive green roofs with thin layers of media and without irrigation, consider also sowing annual or biennial plants in the fall. This can add color and interest and will also provide dense spring foliage to help in suppressing weeds.

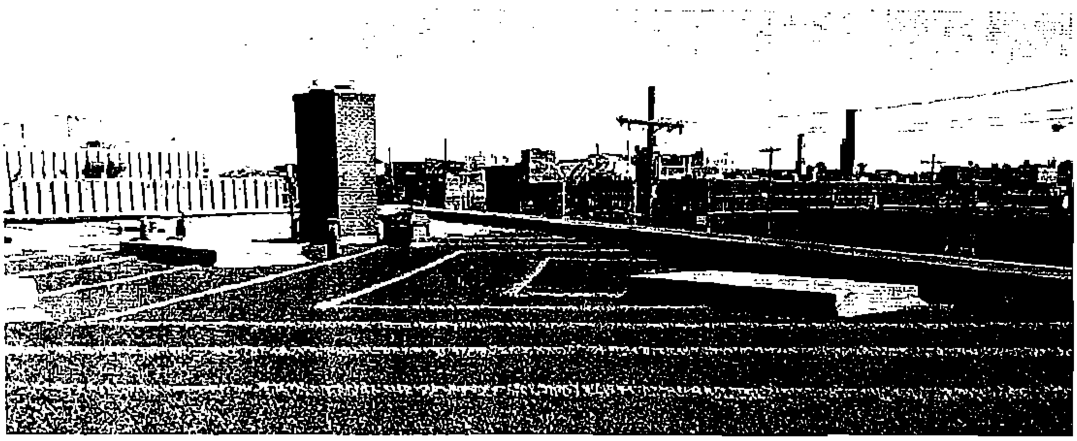


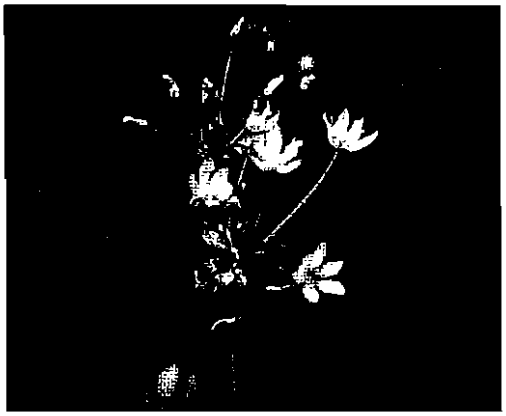
Figure 4-12: Intermediate check dams were installed on DEP's Storage Facility in Brooklyn to control flow on sloped portions of the roof.

Self-sowing annuals are another way to enhance the green roof. Regardless of the use of evergreen or other green roof appropriate species, establishment of a dense, perennial root mass is important for green roof function;

- Many Sedum varieties, the most common vegetation used on green roofs, are deciduous and distinctly seasonal. Sedums can survive in the windy and sun exposed conditions found on most green roofs, and are very good at establishing the necessary initial plant cover. Once the plant cover is established, other non-Sedum varieties can be established a few years into the life of the green roof; and
- Plants with particularly aggressive rhizome roots should be avoided. In particular, bamboo species and Miscanthus should not be used on extensive green roofs. Some native plants that are suitable for shallow soil (less than five inches) without irrigation are Allium and Rudbeckia.

All selected species should be appropriate for the specific green roof design, and a landscape or green roof specialist should be consulted. The project goals (ecological, horticultural, or other) will dictate the appropriate combination of native and non-native species. The Greenbelt Native Plant Center, a division of DPR, has compiled a list of native species appropriate for green roofs in the northeast. This information is provided in Appendix F of these guidelines. The species recommended by the Greenbelt Native Plant Center have not been fully tested to-date for viability on green roofs in the northeast; however, the species were carefully selected based on a number of criteria and will be updated as studies progress.

The number of drains and sizing of each drainage area on the rooftop can help mitigate slope impacts when designing a blue roof. For green roofs, quality and quantity benefits can be enhanced by maximizing the flow path length from roof high points to drains.



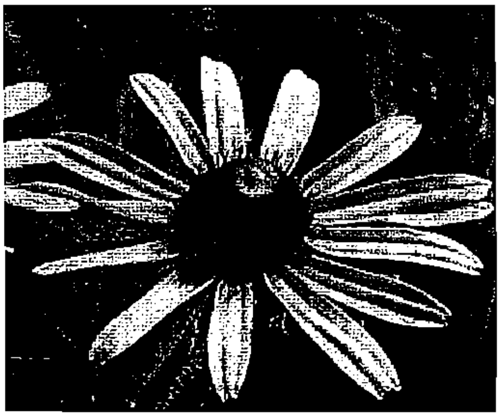


Figure 4-13:
Native plants such as Allium (left) and Rudbeckia (right) have shallow root systems suitable for green roofs. (Source: Harry Cliffe and Joseph Marcus, Lady Bird Johnson Wildflower Center).

4.3.7 Loadings and Structural Capacity

Where a blue or green roof is employed, the building needs to be designed and built to have adequate structural capacity to support the weight of the stormwater storage volume and rooftop system components. The roof and building structural systems should be designed by a licensed professional to comply with the Construction Codes and requirements for rain and snow loads, controlled drainage, and deflection due to ponding. At a minimum, rooftops in the city are designed for a live load of 30 pounds per square foot.

One inch of ponded stormwater on a rooftop adds approximately five pounds per square foot of loading. The weight associated with one inch of saturated green roof media is generally in the range of seven to eight pounds per square foot, but will vary widely based on the particular assembly. The maximum dead load associated with a green roof includes the weight of the waterproofing system and insulation, all media and synthetic materials in a wet condition, and mature plants. To demonstrate compliance with the allowable dead loads for a particular project, use the procedure outlined in ASTM Standard Procedure E2397, Determination of Dead Loads and Live Loads associated with Green Roof Systems.

During the construction process, a licensed professional should be retained by the owner to assume responsibility for special or progress inspections, as required by the Construction Codes.

Analysis for deflection, which describes the degree to which a structural element is displaced under a load, is particularly important for roofs where ponding instability may occur near the drain. Per the Construction Codes, roofs with a slope of less than 2% must be analyzed to ensure that the roof provides adequate stiffness to prevent progressive deflection as rain falls or snow melts on the roof surface. As slopes between one-half and 2% are optimal to maximize the storage volume available for blue roofs and many green roofs, these designs generally require a deflection analysis by a licensed professional to ensure compliance with this requirement.

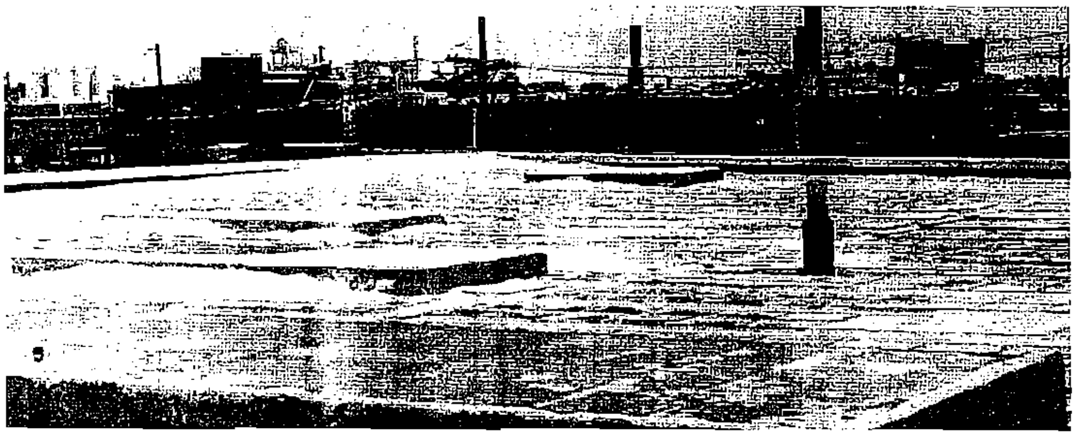


Figure 4-14: Blue roof system during winter installed at DEP's Storage Facility in Brooklyn. Prior to rain events, it may be necessary to clear ice and snow from around roof drains to allow for blue roofs to function properly during the winter.

4.3.8 Climate Considerations

Significant freezing of standing water from a rainfall event is unlikely because roofs with controlled flow roof drains have short drain times, ranging from a few minutes to a few hours, and the stormwater is constantly flowing toward and down the drain. Similarly, green roofs should be designed to have positive drainage, and storage of water within the drainage layer should not last for more than a few hours. Rooftop systems should be designed to drain down within 24 hours to ensure storage volume is available for subsequent rainfall events.

Clogging of drains by snow and ice accumulated on a roof prior to a rain event is a potential problem. As with conventional shallow sloped roofs, maintenance procedures for blue roof systems include the removal of accumulated snow prior to an anticipated rain event to prevent possible overloading and damage to the roof. Homeowners or building maintenance staff should remove snow from the blue roof using the same removal methods used for conventional roofs. Snow removal on green roofs (except around the roof drains) is not recommended as the snow acts as a protective layer for the vegetation. This extra load should be accounted for in the structural design.

Wind is also a concern for green roofs, as the wind can scour vegetation and growing media, damaging the system. The eroded soil can also impair stormwater flow off the roof by clogging the roof drains, which could lead to excessive ponding of water on the roof. Generally, wind-stabilized margins consisting of course stone or pavers should be considered at roof perimeters where the parapet height is less than three feet high, and on regions of the roof where the estimated design wind uplift will exceed 25 pounds per square foot.

The potential for disruption or damage by wind may vary with building height, building geometry, geographic location, and local topography. As a result, green roofs are best suited for low buildings, but can be installed on tall buildings or buildings with higher wind loads when designed properly. The probability of wind damage is greatest immediately after installation and diminishes as the green roof system matures. With many green roof systems, temporar-

Figure 4-15: Application of tar and waterproofing membrane during installation of a green roof at PS 118 in Queens.

ily protecting the media prior to establishment of a mature plant ground cover is advisable. This can be accomplished with wind scour erosion blankets fabricated from organic fibers, tackifying agents, or pre-grown modules and mats.

Due to the constant movement of water and short drain down time, mosquitoes are not a nuisance associated with rooftop systems, as mosquito larva need 72 hours of stagnant water to survive.

4.4 Rooftop System Construction

The following construction techniques are recommended to ensure proper installation of the system, protect the roof structure and equipment, allow access to the roof, and ensure the roof functions safely and effectively over time as a means of controlling site runoff. Other activities suggested or required by the roof membrane manufacturer or the green roof supplier should be followed in order to avoid nullifying respective warranties.

Urban Agriculture

Rooftop gardens and farms offer opportunities for local food productionand are an additional means of providing residents with additional access to healthy, affordable and local produce. Mayor Bloomberg's PlaNYC Update 2011 includes initiatives to facilitate agricultural projects throughout the city and through partnerships with public schools and high density residential complexes.

Before any construction for the rooftop system begins, construction of all major components of the building's structural system should be completed and a construction inspection by a licensed professional should be conducted to verify that the building, as constructed, has the capacity to support roof loads from the rooftop system. Specific construction sequence guidelines along with manufacturer-provided installation instructions will assist in constructing rooftop systems that comply with DEP's stormwater performance standard.

4.4.1 Pre-Construction Meeting

A pre-construction meeting should be conducted prior to the installation of any rooftop system. The recommended attendees include property owner, general contractor, subcontrac-

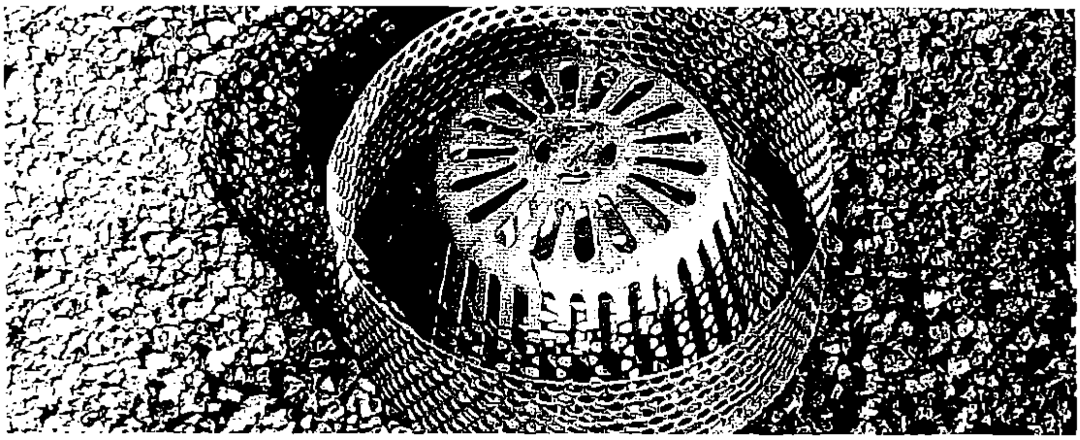


Figure 4-16: Roof drain screens and covers help prevent leaves and other debris from entering and clogging roof drains.

tors, licensed professional of record, and supplier of the system (if proprietary). At this meeting, design specifications for the roof assembly and rooftop system should be reviewed and any site-specific concerns should be discussed. No work should begin until all parties are in agreement that the materials and methods used will not compromise warranties for the installation.

4.4.2 Waterproofing System

Roof membranes should be installed in accordance with manufacturer specifications to provide proper waterproofing. The system should have a waterproof seal along all seams in the roof membrane and in areas where mechanical devices, equipment, or other structures are affixed to the roof surface. The waterproofing system should be attached to the roof surface using adhesives or other methods approved by the system manufacturer. Adhesives that may corrode or otherwise compromise the performance of the membrane or roof system should be avoided. If a green roof is to be used as ballast for the membrane, temporary ballast should be used until the green roof is installed.

Waterproofing and associated flashing should also be protected from damage due to abrasion, puncture, and ultraviolet light. Flashing should be designed with the same expectation for longevity as the field membrane that is protected by the green roof. In most cases, this involves installing protective counter-flashing or adhering a protective sacrificial membrane to the flashing. Geotextile can be used to protect the field membrane from punctures associated with normal use, including maintenance. Depending on the assembly type, a geocomposite drainage layer may serve this purpose.

4.4.3 Installation of Controlled Flow Drains

Controlled flow roof drains should be included in both blue and green roof designs to ensure compliance with DEP's stormwater performance standard. Specifications for the required water level and flow rate for a given roof should be determined by a licensed professional. This information is then supplied to the drain manufacturer as part of the design process, and the drain openings are sized to achieve these values. These specialized drains are then installed in place of conventional roof drains. The set-

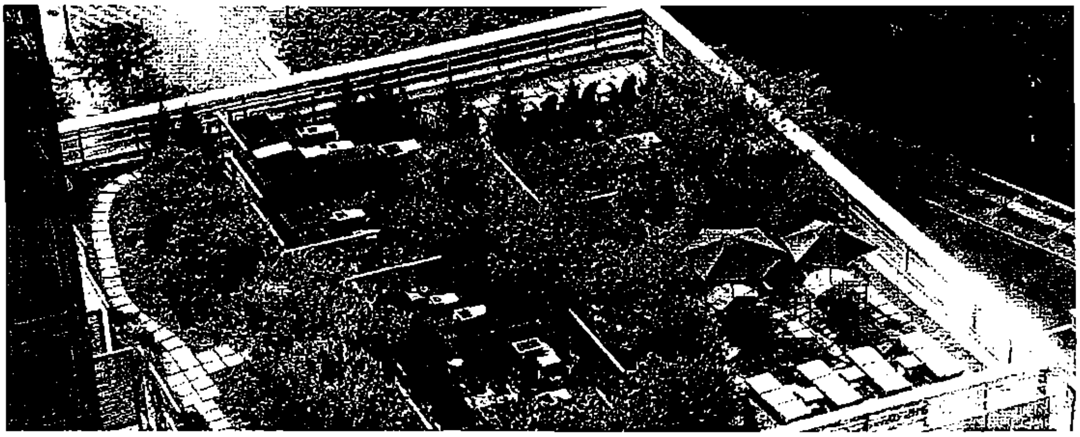


Figure 4-17: The green roof on The Verdesian, a residential building in lower Manhattan, provides dedicated space for access, passive recreation and the building's mechanical equipment.

tings on these drains are set prior to installation, and any adjustable components of the drainage assembly must be fixed to prevent future modification. Flood tests should be conducted after installation of the controlled flow drains.

To prevent leaves and other debris from entering the drain, each drainage inlet should be equipped with a screen or strainer that completely encloses the inlet. Such screens consist of a mesh surface with sufficient surface area to catch debris while allowing unrestricted passage of water to the drain. Screens should be attached securely to the roof with screws or bolts and must be tamperproof to prevent unauthorized modifications to the drain inlets.

4.4.4 Installation of Green Roof Systems

Outlined below are the different components of typical green roof systems. Depending on the building and roofing system specifications, different combinations of the below components may be used. At a minimum, green roofs should consist of vegetation, growing media, a protection course (fabric layer, insulation, and sheet drain) and a root barrier.

Membrane

Prior to installing the green roof system, the roof assembly should be carefully inspected and tested for watertightness using a method agreeable to all parties (i.e., flood testing or leak detection). Flood testing involves closing the roof drains off and filling the roof with water to determine if there are any leaks apparent during the membrane installation process. All leaks should be fixed before the green roof system is installed on top of the membrane which would make further leak detection and membrane repair more difficult.

Protection Courses and Root Barriers

All green roofs require the same level of protection against root penetration. Over an extended time period and without attentive maintenance, annual grass and perennials are likely to estab-

> As with conventional roof systems, the type of insulation selected needs to comply with thermal resistance (R-value) requirements based on the building type, per New York City Energy Conservation Code requirements.

Recommended Construction Sequencing

1. For new development projects, install rooftop systems toward the end of the construction process, if possible. The rooftop system should be installed only after the waterproofing system, all rooftop equipment, and architectural features (e.g., parapets, hatchways, thresholds, fixed lighting, and plumbing) have been completed.
2. Install leak detection systems (if applicable) after the rooftop structural capacity is approved by a licensed professional.
3. Construct and install all necessary downspouts, scuppers, and controlled flow roof drains in accordance with the manufacturers' standards and recommendations, if applicable.
4. After the installation of the controlled flow roof drains, a flow test should be conducted at the roof drains to ensure the proper conveyance of water off the roof and that each drain is flashed appropriately to prevent leaks.
5. For green roof systems, install all protective courses, root barriers (if required), and drainage layers according to the specifications of the licensed professional.
6. For green roof systems, install a filter layer followed by the growing media. The filter layer should be placed to prevent migration of the growing media into the drainage layers.
7. For green roof systems, plant or seed directly into the growing media at an appropriate season for plant establishment. Generally this is in the spring or fall.

lish in Sedum-based green roofs. The waterproofing system should be able to resist attack from the rhizomes of aggressive annual plants. Only plastic or rubber membranes are acceptable as root barriers. When waterproofing is used without a supplemental root barrier, the waterproofing materials should be tested for root resistance. Seams should provide the same level of root resistance as the root barrier membrane. Acceptable seaming methods are hot-air welding (thermoplastic membranes) or overlaps of at least five feet combined with an adhered seam. Sealing the root barrier seams also provides additional waterproofing for the system and, potentially, extends the life of the roof.

Drainage Layers

For multi-course systems, the functions of the drainage layer are to: (1) maintain the overlying growth media in a drained and aerated condition, (2) promote the flow of percolated water toward controlled flow roof drains, and (3) prevent surface flow. Important properties of drainage layers are thickness and in-plane flow capacity, also known as transmissivity. Transmissivity of the drainage layer and the location of drains on the roof have a direct influence on the time of concentration (the time it takes for a pulse of rainfall to reach the roof drains).

The controlled flow roof drains create backwater into the green roof assembly, so the green roof should be explicitly designed to be compatible with this condition. This may involve increasing the thickness of the drainage layer by adding granular drainage, introducing a thick geocomposite drainage component, or some combination of both.

In single-course roofs the protective layer may provide some water retention. However, those assemblies do not have an independent drain-

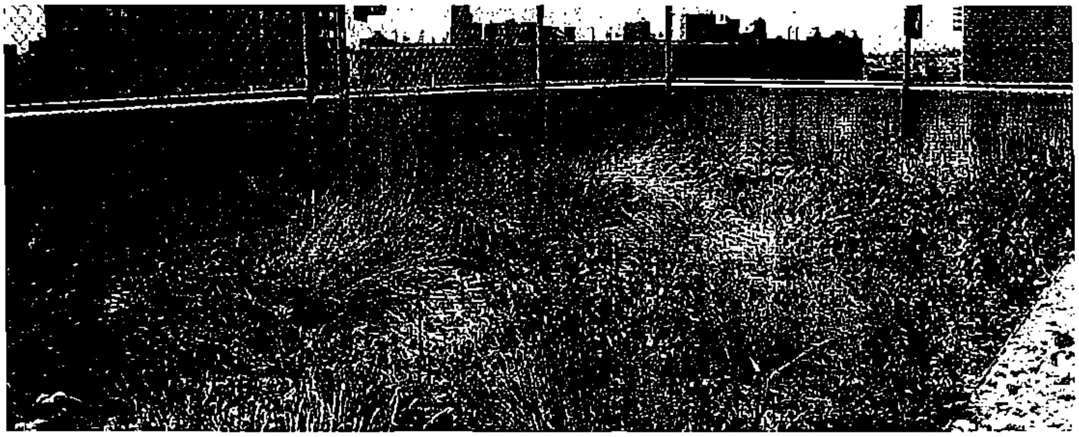


Figure 4-18: Fence installed on St. Simon Stock School in the Bronx to allow student access to the green roof.

age layer. Instead, they depend on the transmissivity of the growing media to drain and aerate the media.

Geocomposites

Care should be exercised to select a drainage product that is appropriate for the design conditions and does not compromise meeting DEP's stormwater performance standard. Geocomposite drainage layers may have moderate to high transmissivity (typically greater than 2.5 gal/min/ft where i=1, based on ASTM D4716). In addition to transmissivity, important properties of green roofs include compressive strength, resistance to biological activity, and permeability to vertical flow or percolation. Over-draining or under-draining a green roof can adversely affect the plant foliage. Geocomposite drainage layers should not be confused with protection layers (though they may be combined), which generally feature lower transmissivity.

Reservoir sheets are a special class of geocomposite drainage layers that have indentations on their upper surface to capture and retain water. There are two types: (1) sheets that are transmissive on both sides, and (2) sheets that are transmissive on the underside only. Granular mineral drainage media is frequently used in combination with reservoir sheets for sheet stabilization, reducing shock to plant roots and improving transmissivity.

Granular Drainage Layers

Granular mineral drainage media can be used to provide a drainage layer that moderates flow toward drains and increase the time of concentration. Granular drainage layers may be as thin as one inch, but are typically two to four inches in thickness. This type of drainage layer can be used to supplement assemblies that include reservoir sheets and fill in some void space to reduce shock to the root system. Layers that incorporate drainage media become part of the root zone of the plants and the materials should be chosen accordingly.

Granular drainage layers should contain as little silt and clay as possible, and should have high permeability and porosity. Green roof installers should consider the minimum granular drainage layer recommendations indicated in **Table 4-2**.

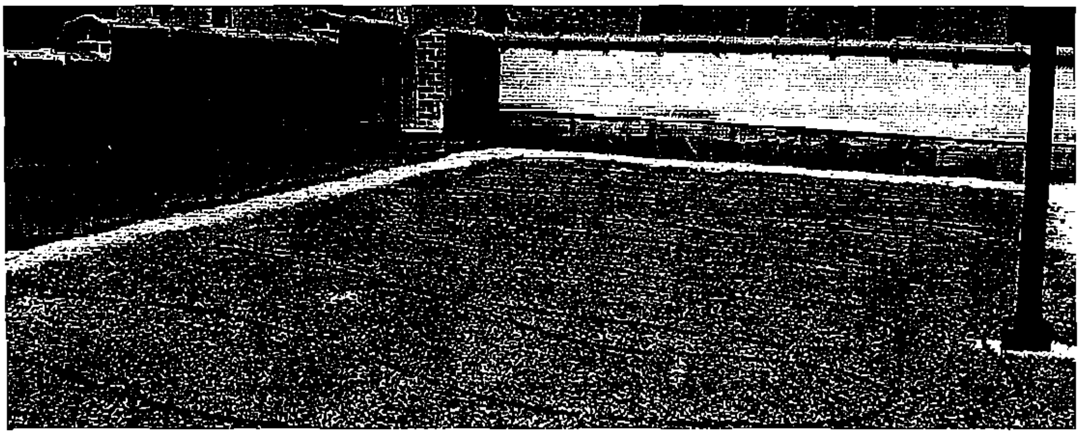


Figure 4-19: Drip irrigation on a constructed green roof at Fordham Bedford Housing in the Bronx.

Water Retention Mats

Water retention mats are not necessary for green roof assemblies, but are sometimes incorporated to store an additional amount of water and keep water distributed across the extent of the roof assembly. Storage ability of the mats (typically fleece or mineral wool) vary based on the thickness of the material. This functionality is sometimes integrated into the protection layer that lies on top of the root protection barrier. Water retained in the mats can be included in the volume of water detained on the roof.

Filter Layers

Filter layers are used to keep the growing media from migrating into the drainage layer and to keep the growing media in place. On green roofs, geotextiles are used for filtration, either in the form of fleece or woven fabric. The geotextile either lies between the drainage layer and the growing media, or is built into the drainage mat. The fabric should allow root penetration, be resistant to microbial attacks and chemicals, and need not be weather resistant. Green roof installers should consider the geotextile recommendations in **Table 4-3.**

Growing Media

The growing media should not be vulnerable to degradation caused by freeze-thaw cycles, perennially moist conditions, compression, or biodegradation. To prevent long-term hazard of fabric clogging or loss of permeability, media used in green roofs should not contain more than 15% particles in the silt-size fraction, nor should it contain more than 3% in the clay-size fraction.

For single-course green roofs where no efficient drainage layer is present, the combined clay and silt content should not exceed 10% by mass, and the total organic content should be less than 2.5 pounds per cubic foot of media based on the mass lost upon combustion. A maximum of 50% of the growing media should pass through the No. 10 sieve (2 mm).

For multi-course green roofs where an efficient drainage layer is present, the combined clay and silt content should not exceed 15% by mass, and the total organic content should be less than four pounds per cubic foot of media, based on the mass lost upon combustion. Between 30% and 80% of the growing media should pass through a No. 10 sieve (2 mm).

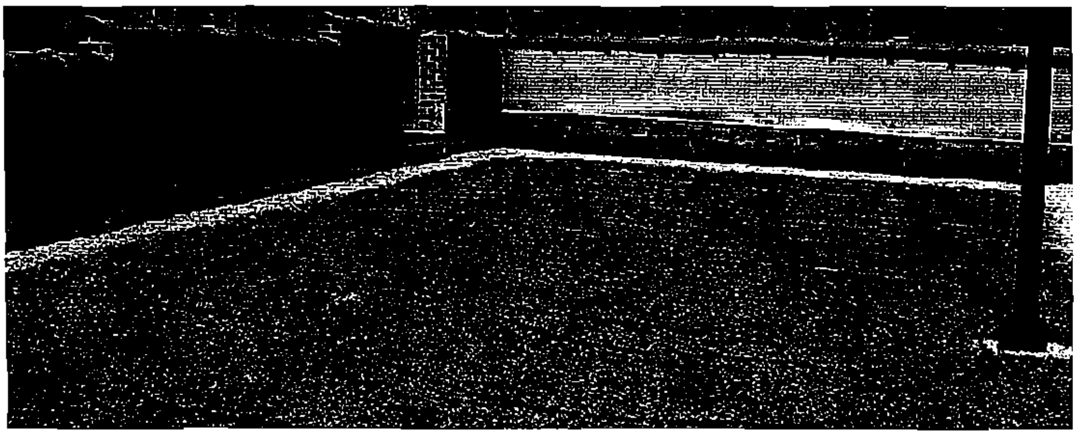


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Table 4-2: Granular drainage layer recommendations (Source: FLL)

Property	Reference Value	Unit
Proportion Silt[1] Proportion Clay[1]	≤ 10 ≤ 2	Percent by mass Percent by mass
Water Permeability[2]	≥ 15	in/min
Air-filled Permeability[3]	≥ 20	Percent by volume
pH Value[4]	6.0-8.5	N/A
Salt Content (water extract)[1]	≤ 0.22	lb/cu ft
Salt Content (gypsum extract)[1]	≤ 0.16	lb/cu ft

Notes:

1. The value should be as low as possible
2. Based on ASTM E2396 (Note: This exceeds FLL recommended minimum of seven inches per minute)
3. Based on ASTM E2399 (Applies where backwater or extended water storage in the drainage layer is anticipated)
4. Where needed

Table 4-3: Geotextile recommendations

Property	Reference Value	Unit	ASTM Test
Density	≥ 8	oz/sq yd	D3776
Apparent Opening Size	≥ 0.06 ≤ 0.2	mm	D4751
Permittivity	≥ 1.5	1/sec	D4491
Puncture Resistance	130	lbs	D4833
Mullen Burst Strength[1]	≥ 300	psi	D3726

Notes:

1. For filter fabrics covering dimpled sheets

Recommendations for optimal growing media choices for both single and multi-course green roofs are provided in **Table 4-4.**

Vegetation

Early fall is the preferred season to plant green roofs, so that plants can take advantage of the fall and spring growing seasons to develop a more substantial root structure prior to the first summer. This is true whether starting from seed or cuttings. Spring planting is also acceptable, though more irrigation may be required during the first summer. Factors that are essential to a healthy, comprehensive root cover include using the correct growing media with proper porosity and nutrient levels for the type of green roof system, and planning for irrigation needs if the roof is planted in the spring or summer.

A complication associated with green roofs is that weeds may start to take hold in the growing media, forcing out the desired vegetation. Strategies to minimize weed 'pressure' include:

- Introducing measures that promote the rapid development of groundcover in the first growing season;
- Not installing a thicker media layer than needed to support the plants;
- Not mixing plants with differing growing media requirements in the same area of a roof; and
- Planning for appropriate O&M in terms of irrigation and weeding.

Pre-grown mats or modules can be used to accelerate ground cover. When planted at the

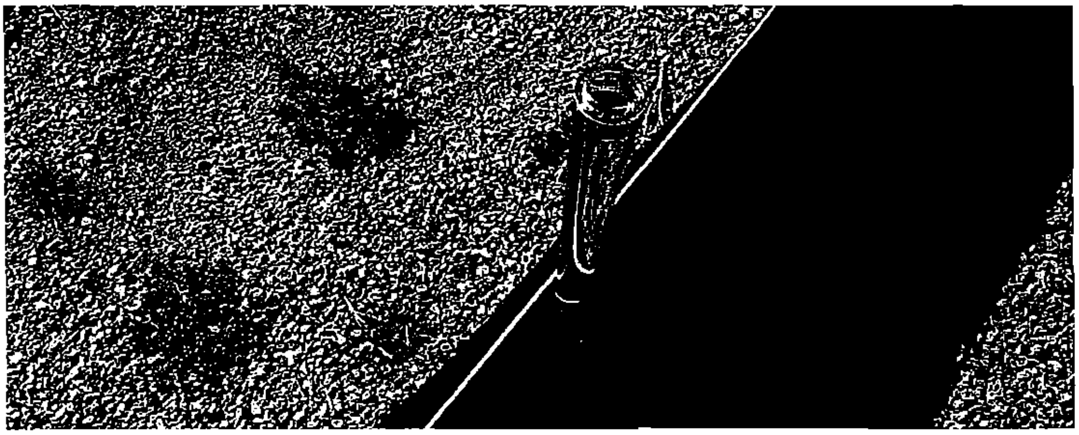

Figure 4-20: Rain gauge at PS118 in Queens.

proper time and using best practices, cuttings and seed can also be used to provide a rapid cover. Plugs should be installed at a minimum density of two plants per square foot. As noted above, temporary irrigation is advised throughout the first full growing season for all projects. At least 80% of the ground should be covered by vegetation by the end of the first full growing season.

Signage

After installing a rooftop system, signs should be posted on bulkhead doors that provide access to the roof and near drainage inlets to inform building owners, maintenance staff, and others that the roof is designed for storing stormwater. Signs should indicate that several inches of water may pond after storm events and that roof drains require specific maintenance procedures and should not be altered. This type of informational signage will help to increase awareness of the rooftop system and prevent future modifications, which may be incompatible with the roof design.

4.4.5 Construction Inspections and As-Built Certification

During the construction process, a certified licensed professional should be identified to assume responsibility for special or progress inspections, as required by the Construction Codes. In addition, it is recommended that the following inspections be performed for rooftop systems under the supervision of a licensed professional:

- Building structural system and roof deck;
- Leak/flood testing of the roof membrane system and drains after installation;
- Verification that the controlled flow roof drains and screens have been properly installed; and
- Testing of the roof drainage system's connection to the sewer.

Once construction is complete, the licensed professional should submit the Technical Report 1 (TR1) certification to DOB along with as-built drawings to ensure that the constructed rooftop system complies with the approved drawings. Departures from the permit documents should

Table 4-4: Growing media recommendations (Source: FLL)

Properties	Single-Course	Multi-Course	Unit
Granular Distribution			
Proportion Silt & Clay	≤ 10	≤ 15	Percent mass
Proportion Gravel	≥ 75	≤ 50	Percent mass
Water and air management			
Maximum Water Capacity	≥ 20 & ≤ 65	≥ 35 & ≤ 65	Percent volume
Air Content at Max. Water Capacity[1]	≥ 10	≥ 6	Percent volume
Air Content at pf 1.8	-	≥ 20	Percent volume
Water Permeability	2.5 - 15.5	0.02 - 2.8	in/min
pH value, salt content			
pH Value (in $CaCl_2$)	6.0-8.5	6.0-8.5	N/A
Salt Content (water extract)[2]	≤ 3.5	≤ 3.5	g/l
Salt Content (gypsum extract)[3]	≤ 2.5	≤ 2.5	g/l
Organic substances			
Organic Content (loss on ignition)	≤ 40	≤ 65	g/l
Nutrients			
Nutrients Available to Plants			
Nitrogen (N) (in $CaCl_2$)	≤ 80	≤ 80	mg/l
Phosphorus (P_2O_5) (in CAL)	≤ 200	≤ 200	mg/l
Potash (K_2O) (in CAL)	≥ 700	≥ 700	mg/l
Magnesium (Mg) (in $CaCl_2$)	≤ 200	≤ 200	mg/l
Nutrients Available to Plants (in CAT)			
Nitrogen (N)	≤ 80	≤ 80	mg/l
Phosphorus (P_2O_5)	≤ 50	≤ 50	mg/l
Potash (K_2O)	≤500	≤500	mg/l
Magnesium (Mg)	≤ 200	≤ 200	mg/l
Foreign Bodies			
Diameter > 6mm			
Tiles, Glass, Ceramics and Similar	≤ 0.3	≤ 0.3	Percent mass
Metal, Plastic	≤ 0.1	≤ 0.1	Percent mass
Total Area for Plastics	**≤ 0.3**	**≤ 0.3**	**sq.ft/cu.ft**

Notes:

1. Recommend using measured actual particle density as basis for computing porosity of lightweight aggregates
2. The value should be as low as possible
3. Where needed
4. Either in CAL(calcium acetate lactate)/calcium chloride or CAT(Calcium chloride Diethylene triamine pentaacetic acid)

Figure 4-21: Green roof drain inspection chamber on St. Simon Stock School in the Bronx.

be noted, along with shop drawings or notes that describe special conditions or supplemental features of the installation that are not part of the permit documents. It is the owner's responsibility to ensure that documented inspections are conducted during construction in accordance with the Construction Codes. In many cases, contractors will provide construction quality assurance services and furnish close-out documents to the owner at the point of substantial completion.

4.5 Operations and Maintenance for Rooftop Systems

Rooftop systems must be inspected and maintained in order to function as designed, ensure required release rates and storage volumes over time, and comply with *Chapter 31*. DEP and DOB are not responsible for any onsite or offsite injuries or damage to persons or property resulting from improper design, construction, operation, or maintenance.

4.5.1 Post-Construction Monitoring

Post-construction monitoring during the first year after installation is important for gauging the effectiveness of rooftop systems during operation and determining whether any system modifications are necessary to ensure systems function as intended. Monitoring debris at roof drains and ponding on the roof surface, along with weather conditions, can provide useful information about system performance during and after rain events. In addition, regular and frequent inspections during the first year would help to determine the appropriate activities and schedule for future maintenance.

4.5.2 Inspections

To ensure proper inspection and maintenance, it is important to inform maintenance staff and other potential users of the roof that a rooftop system has been installed. Posting signs on the roof, as discussed in Section 4.4.4, and clearly communicating expectations for maintenance, are critical to prevent damage and tampering, and to ensure that rooftop systems function properly over time.

Table 4-5: Recommended inspection activities for blue roofs & green roofs

Schedule	Activity
Blue Roofs	
Semi-annually under dry conditions	• Inspect roof drain inlets to ensure in good condition • Inspect drain inlet screens/strainers to ensure in good condition • Inspect roof membrane to check for signs of deterioration
Quarterly and after rain events	• Inspect roof to verify achievement of water depth and drain time requirements • Inspect secondary drainage inlets for blockage or debris
After snow/icing events	• Check roof drain inlets for blockage caused by buildup of snow or ice
Green Roofs	
Monthly during growing season, under dry conditions	• Inspect green roof to identify invasive species, weeds and bare spots • Inspect for signs of drought during extended dry periods
After rain event	• Inspect roof to verify achievement of water depth and drain time requirements • Inspect secondary drainage inlets for blockage or debris
Semi-annually under dry conditions	• Inspect roof drain inlets to ensure in good condition (during irrigation activities, over-watering can be identified by dry weather flow at the drains) • Inspect drain inlet screens/strainers to ensure in good condition • Inspect the condition of exposed waterproofing and flashing • Inspect temporary or permanent wind blankets
Annually under dry conditions	• Soil samples to determine nutritional requirements
After snow/icing events	• Check roof drain inlets for blockage caused by buildup of snow or ice

As with conventional roofs, routine post-construction inspections of green and blue roof systems are necessary to ensure continued performance. Inspections are particularly important within 24 hours of significant rain events to ensure the specified ponding depths and drain times are being achieved, standing water does not persist for more than 24 hours, and there are no leaks as a result of roof conditions. Water depths or drain times exceeding the design values for the system may be indicative of debris clogging the system or improper performance of outlet control structures. Any debris observed around the roof drains should be removed. Extensive ponding of water beyond the design level may be indicative of damage to the green roof, leading to media leakage and clogging of the drains.

Inspections of inlet screens, drainage inlets, and the roof membrane system are recommended every six months during dry weather to check for debris or signs of damage.

Table 4-5 outlines regular inspection activities and their frequency. This list can be modified after the first year of maintenance based on site specific conditions. The troubleshooting section below may be used to address issues found during inspections.

4.5.3 Maintenance

Chapter 31 requires property owners and their successors to file a deed restriction to ensure operation and maintenance of stormwater management systems throughout the life of the system or until replacement is approved by DEP. In

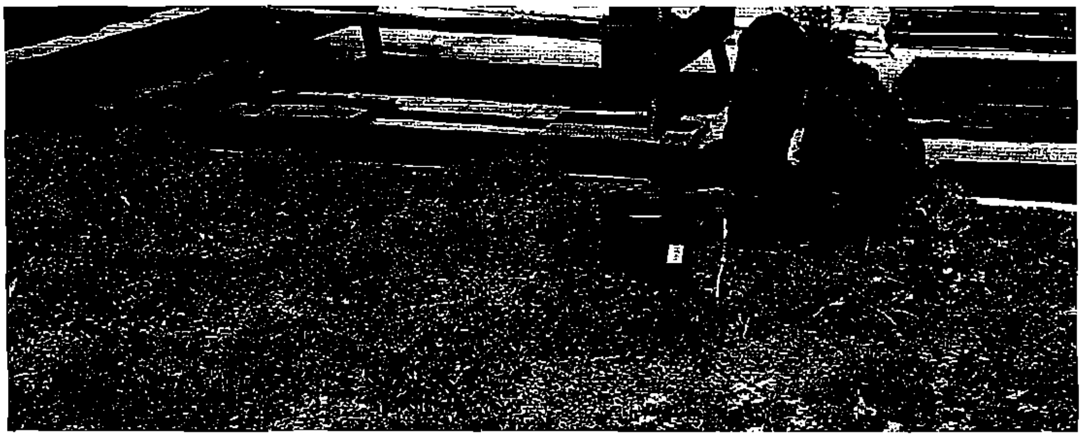

Figure 4-22: Staff performing maintenance on DPR's Five Borough Building green roof.

addition, the property owner must retain records and furnish proof of maintenance in the form of a certification by a licensed professional submitted to DEP every three years.

Property owners may enter into annual or bi-annual maintenance contracts with commercial vendors that are able to provide the range of maintenance activities described in these guidelines and manufacturer specifications. All maintenance activities should occur during dry weather unless an emergency situation necessitates maintenance or repairs during rain events.

Maintenance activities for blue roofs focus on preventing clogging of drainage inlets and preventing deterioration of the roof membrane. Maintenance activities for green roofs focus on ensuring healthy vegetation with minimal weeds or bare patches and preventing clogging of drainage inlets.

After the conclusion of the establishment period for vegetation on green roofs (usually two or three years), ongoing maintenance should be minimal. Nonetheless, without regular annual inspections and maintenance, green roofs may develop problems, including wind erosion, bare spots, infestations of annual weeds that can choke out beneficial cover plants, and nutrient deficiencies.

Factors that are essential to a healthy, comprehensive root cover include using the correct growing media with proper porosity and nutrient levels for the type of green roof system, irrigation if the roof is planted in the spring or summer, and attentive weeding until the desired groundcover is established. Plants should not be over fertilized. Irrigation should be limited to the first full growing season with focus on the establishment period, and then eliminated after plants are established except in times of extreme drought. Timely service visits should be made to catch weeds before they go to seed.

For blue roofs, maintenance activities can generally be performed by individual building owners or site maintenance staff as needed. Contact the contractor responsible for the installation of the rooftop system immediately if it is not performing as designed. For green roofs, building owners may enter into contractual arrange-

Figure 4-23: DCP's Parking lot requirements and impervious surface reductions may allow for smaller required storage volumes.

ments with the green roof designer or installer to perform maintenance activities. Onsite maintenance staff may, in certain instances, be trained to also perform this function.

For all rooftop systems, adequate maintenance of the secondary drainage system is essential to ensure its performance in the event of a failure of the roofing system. In addition, the rooftop system and membrane should be evaluated every 20 years to assess the need for replacement.

Table 4-6 includes recommended maintenance considerations for blue and green roofs.

4.5.4 Developing an Inspection and Maintenance Plan

Developing a site stormwater inspection and maintenance plan is crucial to the success of the rooftop system and should be updated based on the results of the first-year post-construction monitoring program. The maintenance plan should identify a maintenance manager who is responsible for operating and maintaining the rooftop system.

The plan should include a maintenance schedule developed for the life of the rooftop system. The schedule should outline the specific maintenance activities that are required to be completed, the frequency and timing, and the person or entity responsible for completing the activity. The property owner must keep all records of inspections and maintenance activities and regularly update the plan (i.e., every five years) based on actual system requirements, the results of maintenance activities, and compliance with DEP's stormwater performance standard.

4.5.5 Troubleshooting

If problems are identified during routine maintenance and inspection, the property owner should take time to troubleshoot the problem.

Problems with a blue roof system generally fall into two categories: (1) the system drains too slowly, resulting in buildup of excess water on the roof for extended periods of time, bypasses of the controlled flow roof drains, or overflow via secondary drains/scuppers during small rainfall events, or (2) the system drains too quickly, exceeding the design release rate. **Table 4-7** outlines these common problems and offers potential solutions. If problem persists, a licensed professional should be consulted.

Table 4-6: Recommended maintenance activities for blue roofs & green roofs

Schedule	Activity	Equipment
Blue Roofs		
During inspections or as needed to ensure performance	• Remove debris from drainage inlets and inlet screens to prevent clogging • Remove debris from secondary drainage inlets/scuppers	• Shovel
Winter considerations	• Break up ice formation around inlets	• Ice pick, or equivalent tool
Green Roofs		
During inspections or as needed to ensure performance	• Hand weeding • Chemical weed management (e.g., use of pre-emergent preparations to combat the germination of annual weeds) • In-fill planting in bare spots. In most cases this can be accomplished by separating healthy plants and using these cuttings to re-establish areas that have been the victim of weed infestation, wind erosion, etc. • Apply fertilizer, based on nutritional requirements test and roof manufacturer guidelines • Irrigate plants if extended dry period leads to excessive dryness in growing media • Remove debris from drainage inlets and inlet screens to prevent clogging • Remove debris from secondary drainage inlets/scuppers	• Gloves • Hand tools • Water supply and hose • Spray or spread applicators
Winter considerations	• Break up ice formation around inlets	• Ice pick, or equivalent tool

Problems with a green roof system generally fall into three categories: (1) the system drains too slowly, resulting in buildup of excess water in the growing media for extended periods of time, (2) the system drains too quickly, exceeding the design release rate, or (3) the vegetation does not take to the growing media. If the information in these guidelines does not solve these problems, contact a licensed professional or green roof designer for further assistance.

PRODUCTS FROM WASTES (AGRO BASED AND INDUSTRIAL WASTE)

- Activated carbon from coconut shell
- Bio fertilisers
- Carpet from cotton waste
- Cement from rice husk
- Coconut shell powder
- Crude oil bleaching for petroleum jelly
- Fatty acid from waste vegetables
- Fuel briquettes from agro waste
- Furfural from rice hull/husk
- Hard board from bagasse
- Hard board from rice husk
- Kraft paper from bagasse
- Kraft paper from waste carton boxes
- Kraft paper from waste paper (paper waste recycling unit)
- Ossein and gelatine
- Oxalic acid from rice husk
- Paper cones & tubes
- Paper from rice husk & wheat husk
- Paper waste recycling plant (paper mill)
- Paraffin wax from slack wax
- Particle board
- Pectin from mango peel
- Pectin from orange peels
- Plastic granule from waste
- Plastic granules or powder from plastic scrap
- Plastic waste recycling plant (rufia washing)
- Polyester yarn from waste
- Power plant (hydro based)
- Production of bio oil for power generation from coffee husk
- Re-refining of used engine oil
- Reclamation of nickel spent catalyst from vanaspati industry
- Reclamation of used bleaching earth
- Reconditioning of empty cement jute bags
- Reconditioning of fluoroscent tube
- Reconditioning of picture tube

- Recovery of gold from p.c.b & other electronic waste
- Recovery of lead from disposed lead acid battery
- Recovery of silver from waste
- Recovery of silver nitrate from photographic waste fixer
- Recycling of rubber from old tyres
- Recycling of waste cellulose acetate into cellulose acetate sheets
- Recycling of waste cellulose from baby diapers, pantyliners/ feminine napkins manufacturing
- Rubber goods from waste rubber
- Rubber reclaiming
- Rubber reclamation (reclaim rubber)
- Secondary lead extraction by scrap battery plates, pipes & sheet
- Silicon from rice husk
- Silk waste processing and spinning
- Silver extraction from waste hypo solution (x ray film and cinema film)
- Sodium silicate from rice husk
- Technology of products from wastes industrial, agriculture, medical, municipality, organic & biological (hand book)
- Toluene and sbp from crude naphtha
- Tread rubber
- Utilization of coconut husk in manufacturing of rope
- Vermi composting
- Zinc and copper sulphate from brass ash
- Zinc metal from zinc ash

SECTION TWELVE
ROOF SYSTEMS

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Building owners and designers have many deck, insulation, and roof covering materials to choose from for low-slope and steep-slope roof systems. The various systems available can fulfill a wide range of functions, such as energy conservation, acoustical and thermal insulation, and water, fire, and wind resistance. Their ability to do this over their expected service life depends on good design, quality materials, good application, and a commitment by building owners to maintenance.

This section is intended to give an overview of the following: materials for low-slope and steep-slope roofing (including deck, insulation and roof coverings), key design considerations, application, warranties, maintenance, and reroofing. At the end of this section, a list of trade associations (Art. 12.20) and a list of publications (Art. 12.21) is given for those readers interested in further specific information.

ROOF MATERIALS

A **roof system** is an assembly of interacting roof components designed to weatherproof and, normally, to insulate a building's top surface. The roof assembly includes the roof deck, vapor retarder and roof insulation (if they occur), and the roof covering.

12.1 ROOF DECKS

A good roof is dependent upon the structural integrity of the deck and compatibility of the deck with the roof covering and other materials attached to it. Following are descriptions of commonly used decks.

Cementitious wood-fiber panels are composed of treated wood fibers that are bonded together with portland cement or other binder and compressed or molded in flat panels. These panels provide some acoustical attenuation and some thermal resistance.

Lightweight insulating concrete roof decks and fills are produced on the job site by combining insulating aggregates, such as perlite or vermiculite, with portland cement and water. Another variation of this type of deck is referred to as "cellular," lightweight insulating concrete. Rather than using aggregate, cellular concrete is produced with a foaming agent that creates small air cells within the matrix. The compressive strength and thermal resistance of lightweight insulating concrete decks depend on the mix design and composition.

Lightweight insulating concrete may be cast over steel decks or bulb-tee and formboard systems. Some types may also be cast atop concrete decks. For enhanced thermal resistance, molded expanded polystyrene (EPS) boards may be incorporated into lightweight insulating concrete.

Venting of these deck types is an important consideration. Excess water, not consumed during the hydration process, can result in a deck system with a high moisture content. The fills which utilize insulating aggregates, such as perlite or vermiculite, typically have a high water-to-cement ratio. These fills generally require a form deck that allows downward drying. This can be accomplished through the use of perforated (slotted) steel decks, or by permeable formboard and bulb-tee deck systems. "Cellular" lightweight insulating concrete fills generally require less water in the mixing process and therefore have a lower moisture content. These fills may have the ability to be applied over non-vented substrates.

Poured gypsum concrete decks, although widely used in the past, are now seldom used, except in a few locations in the United States. This type of deck is produced on the job site by combining gypsum with wood fibers or mineral aggregates and water. The mixture is then cast on formboards.

Structural concrete decks can either be cast-in-place, post-tensioned, or precast (tees, double tees, channel slabs, flat slabs, or hollow-core slabs).

Steel decks are fabricated by roll-forming cold-rolled sheets. They are available in a variety of depths, 1½ in being most common. The panels are available in narrow-rib (Type A), intermediate-rib (Type F), or wide-rib (Type B), the wide-rib being most common. Common thicknesses are 22, 20, 18, and 16 ga. The panels are available in a paint (prime coat or prime and finish coat) or galvanized finish. (See also Arts. 8.22 to 8.24.)

Steel decks can be fabricated with slots to allow downward-drying. Slotted decks are often used with certain types of wet-fill toppings. Acoustical decks, which have numerous small perforations, are also available. Batt insulation is usually installed in the flutes on the top side of the acoustical deck.

Thermosetting insulating fill is produced on the job site by mixing perlite aggregate with a hot asphalt binder. The mix is then placed over a structural deck. This fill provides some insulation, and it can be utilized to provide slope for drainage. Although more common years ago, this type of system is still available.

Wood planks or panels can be composed of solid wood planks (usually tongue-and-groove) or sheathing panels. Sheathing was originally composed of all-veneer plywood, but now, oriented strand board (OSB) also is used. OSB is composed of compressed, strand-like particles arranged in layers oriented at right angles to one another. If sheathing is required for roof decking, sheathing intended for this purpose should be specified.

12.2 VAPOR RETARDERS

These comprise a wide range of materials used to control flow of water vapor from the building interior into wall or roof systems. Unless precautions are taken, water vapor in the interior of a building, especially if it has a high-moisture occupancy, may condense within the cold roof system, saturating the insulation and reducing its effectiveness, or will drip back into the building, staining the ceiling or wetting the floor.

A vapor retarder placed in an appropriate location, however, can control such condensation. For many years NRCA has maintained that vapor retarders should be considered when both of the following conditions occur: the outside average January temperature is below 40°F (4°C), and the expected indoor winter relative humidity is 45% or greater. However, these are very simple guidelines. Both the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) and the U.S. Army Corps of Engineers' Cold Regions Research and Engineering Laboratory (CRREL) have developed recognized practices for determining the need for a vapor retarder in a roof system. These methods differ, and designers should choose the methodology which they deem most applicable for a given project.

Situations more likely to require the inclusion of a vapor retarder are those where interior conditions of high humidity exist, such as in textile mills, laundries, canning factories, creameries, breweries, and indoor pools.

Perm Ratings. The effectiveness of a vapor retarder is measured by its perm rating, which is a measure of porosity of material to passage of water vapor. Perm ratings are established by ASTM procedures. To be classified as a vapor retarder, the material should have a perm rating between 0.00 and 0.50 perms.

A perm rating for a material is the number of grains of water vapor (7000 grains equal 1 lb) that will pass through 1 ft^2 of the material in 1 hr when the vapor-pressure differential between the two sides of the material equals 1 in of mercury (0.49 psi).

Retarder Materials. Following are descriptions of some frequently used vapor retarder materials:

Bituminuous vapor retarders are constructed on the job site. They are composed of alternating layers of hot-applied asphalt and asphalt roofing felts (Art. 12.4.1). Generally, two plies of felt and two or three moppings of asphalt are specified.

Kraft paper retarders are typically factory fabricated by adhering two layers of kraft paper together with asphaltic adhesive and glass-fiber reinforcement. At the job site, the rolls of kraft paper are adhered to the substrate and to one another with a cold-applied asphalt adhesive.

Polyethylene sheets (typically 4, 6, or 8 mils thick) are employed in some types of roof systems. In some cases, they are loose-laid, or they may be attached with mechanical fasteners. The laps can be sealed with tape or sealant. In the past, polyethylene or similar types of plastic film materials were adhered with a cold-applied asphaltic adhesive. However. because of difficulties in obtaining secure attachment, plastic-sheet vapor retarders are no longer typically attached in this manner.

Aluminum foil used as a vapor retarder is typically applied to the face of an insulation product in the factory. Aluminum foil is also used as a "reflective insulation system" or a "radiant barrier system" (Art. 12.3). Aluminum-foil facers on rigid insulation boards are usually not considered a vapor retarder, because of the discontinuity at board joints.

12.3 ROOF INSULATION

Many of the insulation products described in the following are available in tapered configurations.

Cellular glass is a rigid insulation composed of heat-fused closed glass cells.

Cellulosic fibers are generally used as loose-fill insulation. They are made of recycled paper.

Glass-fiber batts or blankets (the only difference being the length of the product) are composed of glass fibers and a binding agent. The batts may be finished on one side with a kraft paper or aluminum-foil facer, or they may be left unfaced.

Glass-fiber board is a rigid insulation composed of glass fibers and a binding agent and is faced on the top surface with kraft paper.

Mineral-wool batts are similar to glass-fiber batts, except that they are composed of mineral fibers (produced from molten rock). Mineral-wool batts have high resistance to heat. Typically, they are used for fire-safing; for example, curtain walls or sealing at fire wall or floor penetrations, or steel fireproofing. Mineral batts are typically not used for roofing, except for insulating seismic joints or expansion joints, where enhanced fire resistance is desired.

Mineral-wool board is a rigid insulation similar to glass fiber boards except that it is composed of mineral fibers (produced from molten rock). These boards are available faced or unfaced with aluminum foil.

Perlite rigid insulation is composed of expanded perlite, cellulose, and a binding agent.

Phenolic resin has been formed into a rigid, plastic-foam insulation. It is no longer produced in the United States. It should be noted that phenolic insulation has shown a high potential for causing steel deck corrosion, and in some instances, the structural integrity of the roof deck has been impaired. Deck repair or replacement should be anticipated where phenolic insulation over a steel deck exists.

Polyisocyanurate may be used as rigid, plastic-foam insulation. It resembles, and has essentially replaced, polyurethane board insulation because of better fire resistance. Polyisocyanurate boards have been produced with a variety of facers. Glass-fiber and organic/inorganic are now the most common. The boards are also available as composites, which are factory produced by foaming the insulation to perlite, wood sheathing, or other types of substrates. Currently, the foam is produced by an HCFC (hydrochlorofluorocarbon) blowing agent, which initially is the gas that fills the cells. Over considerable time, oxygen and nitrogen diffuse into the cells, and the HCFC diffuses out, thereby decreasing the thermal resistance. This phenomenon is known as **thermal aging** or **thermal drift.** Polyisocyanurate insulation has the highest *R*-value (thermal resistance) per inch thickness of any insulation currently produced in the United States.

Due to government regulations, the HCFC blowing agents currently used in the manufacture of polyisocyanurate foam insulation are scheduled to be phased-out by the end of 2002. It remains to be seen what type(s) of blowing agents will be used in the next generation of this type of insulation.

Polystyrene made into a rigid plastic foam has two distinctly different forms. Molded expanded polystyrene (EPS) has air-filled cells and hence is not subject to thermal aging. EPS is available with a variety of densities, and its *R*-value is a function of the density. Extruded polystyrene is blown with HCFC; thus it has a higher *R*-value than EPS. Extended polystyrene insulation is very resistant to water and water vapor and is available in very high compressive strengths. Accordingly, it is the only type of insulation recommended for use in protected membrane roofs (PMR) or plaza decks (Art. 12.15).

Radiant barrier system (RBS) utilizes aluminum foil product with a low-emittance (high-reflectance) surface. An RBS is intended to reduce radiant heat transfer between a hot roof deck and cooler floor below (or vice versa).

Reflective insulation system (RIS) employs double-sided aluminum foil product, which is used in combination with bulk insulation, or in lieu of bulk insulation. The system incorporates an enclosed air space that may contribute significantly to the thermal resistance.

Spray-applied polyurethane foam (SPF), in addition to providing thermal insulation, also functions as the roofing system (Art. 12.4.6).

Wood fiberboard is a rigid insulation manufactured from wood or cane fibers and binders.

12.4 LOW-SLOPE ROOF COVERINGS

Roof coverings may be classified into two main groups in accordance with the slope of the roof. Low-slope roof coverings generally utilize a weatherproofing membrane and are designed for slopes on which water proceeds slowly to drainage outlets. Steep-slope roof coverings are designed for roofs with swift drainage. Generally, they are considered "water shedding" and are comprised of many individual pieces or components installed in a shingle fashion to shed water from one course to the next.

12.4.1 Built-Up Roofs (BUR)

This is the traditional low-slope membrane roof covering. It is composed of bitumen (either asphalt or coal tar), usually applied hot, felts (either organic, glass-fiber, or polyester), and a surfacing, such as aggregate, coating, or cap sheet (Fig. 12.1). The membrane is composed of three to five plies of felt (as few as two plies are sometimes specified when polyester felt is used). The first ply is typically either set in a continuous layer of hot bitumen or is nailed to the deck. Subsequent layers of felt are set in a continuous layer of hot bitumen.

An alternative to a traditional BUR is the protected-membrane roofing system. It consists of several layers installed in a sequence different from the usual one in which insulation is placed below the roof deck. First, standard built-up roofing is applied directly to the deck. Then, rigid insulation that is impervious to moisture, such as extruded polystyrene foam, is bonded to the top of the built-up roofing with a mopping of steep asphalt (Fig. 12.2). A layer of ¾-in crushed stone (1000 lb/square) or paving blocks or structural concrete on top of the insulation completes the assembly. Gravel or slag should not be used, because the sharp edges would damage the bare insulation underneath.

The theory is that the insulation, set above the roofing, both insulates the building and protects the built-up roofing from the harmful effects of thermal cycling, ultraviolet degradation, weathering, and roof traffic. Most common defects caused by these elements, such as blistering, ridging, cracking, alligatoring, and wrinkling, are virtually eliminated.

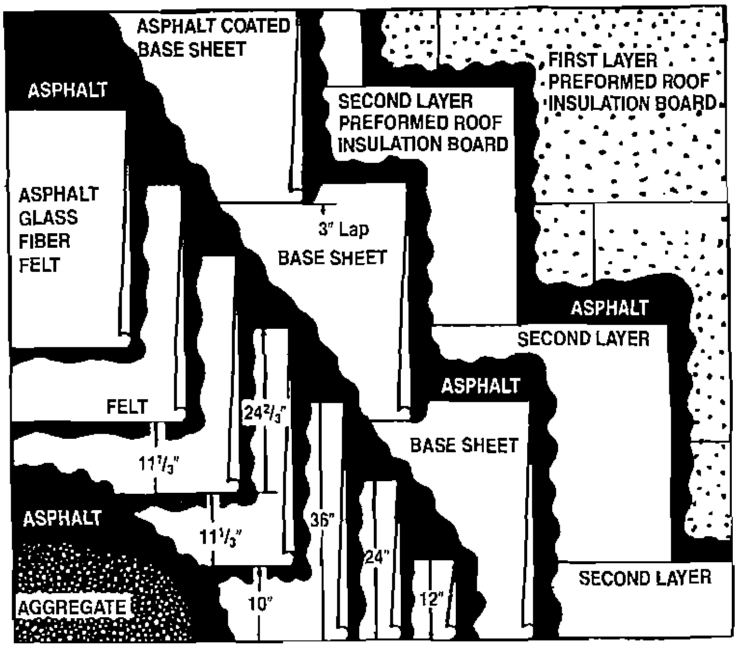


FIGURE 12.1 Built-up roofing over two layers of preformed insulation board. Three plies of asphalt-impregnated glass-fiber felt, embedded in a continuous application of hot asphalt, overlay a base sheet adhered with asphalt to the insulation. Aggregate surfacing, about ⅜ in in diameter, is spread in the top flood coat of asphalt. (*NRCA Roofing and Waterproofing Manual.*)

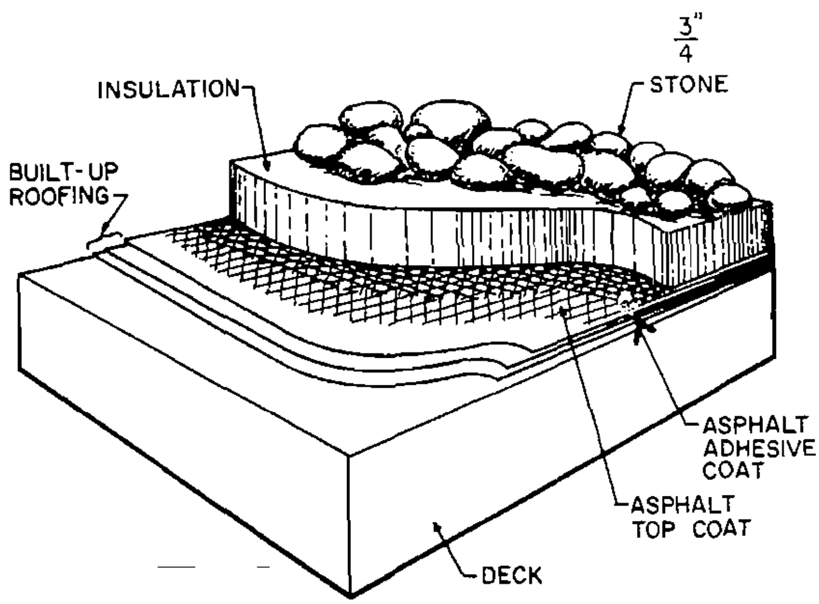


FIGURE 12.2 Protected-membrane roof with aggregate and insulation placed over, instead of under, the built-up membrane.

ROOF SYSTEMS

Bitumen may be asphalt or coal tar. Roofing asphalt is a derivative of petroleum. It is described in ASTM Standard D312, which includes specifications for Types I, II, III, and IV. Each type has a different softening-point range, which should be considered by the specifier when specifying the type of asphalt to be used. Coal tar, described in ASTM D450, is a derivative of the production of coke from coal. Type I is referred to as "old-style pitch." Type II is used for below-grade waterproofing. Type III, or coal-tar bitumen, was developed to be less of an irritant during application than Type I; however, Type III is no longer produced.

Felts are sheet materials used to reinforce waterproofing and roofing membranes. The predominant type of felt used is glass fiber although organic felts are still commonly used in the construction of coal-tar systems. Polyester is an alternative type of felt. Asbestos felts were used in the past but are no longer produced in the United States.

There are two primary categories of felt—base sheets and ply sheets. **Base sheets** are heavier felts that are often used for the first layer of felt to be installed. If the felt is to be nailed, a base sheet is recommended because of its greater strength. **Ventilating base sheets** are intended to allow for the venting of moisture-vapor pressure by lateral (horizontal) movement. However, if a ventilated base sheet is to be used, the designer should take into account the small driving force for horizontal moisture transport and the small amount of moisture that can be moved horizontally.

Surfacings as applied to built-up membranes, are typically small pieces of aggregate or slag, liquid-applied coatings, or a cap sheet. Common coatings include cutbacks and emulsions, which are both cold-applied. **Cutbacks** are composed of asphalt and solvent and often include an aluminum pigment for reflectivity. **Emulsions** consist of clay and asphalt particles dispersed in water. Some emulsions include aluminum pigment or titanium dioxide for reflectivity. The cutback and emulsion coatings are available in fibrated or nonfibrated grades. Latex (acrylic) coatings are also available, but for built-up roofs, these coatings are not used as often as the other types of coatings. **Cap sheets** are heavy coated felts that are factory surfaced with mineral granules.

Cold-process roof coverings (also known as cold-applied) are similar to hot-applied BUR, except that instead of hot bitumen, asphalt-based cutbacks or emulsions are typically used. They are applied by sprayer, brush, broom, or squeegee.

12.4.2 Liquid-Applied Roof Coverings

Liquid-applied systems are supplied as either single or two-component elastomeric materials. They are applied by sprayer, brush, roller, or squeegee. Typically these systems are applied directly over concrete or wood sheathing. Deck joints and cracks normally require special preparation. See also cold-process roof coverings (Art. 12.4.1) and coatings on polyurethane foam roofs (Art. 12.4.6).

12.4.3 Metal Roof Coverings

These are generally used for steep-slope roofs rather than for low-slope roofs. See Art. 12.5.3. However, some standing-seam structural panel systems can be used successfully in low-slope situations. These systems are considered "hydrostatic," that is, they have the ability to resist water intrusion under some pressure. These panel systems generally incorporate a sealant in the seam, or an anti-capillary hem to provide the necessary protection from moisture infiltration through the seams.

12.4.4 Modified Bitumen Membranes

These are typically composed of prefabricated sheets of polymer-modified asphalt with polyester or glass-fiber reinforcement or a combination of these. The polymers most used for asphalt modification are atactic polypropylene (APP) or styrene-butadiene-styrene (SBS). These prefabricated sheets are commonly installed over a base sheet (Art. 12.4.1), which may or may not also be composed of modified bitumen. Sometimes the assembly also includes a ply sheet (Art. 12.4.1).

In the past, modified bitumen membranes were occasionally applied in a single layer. However, two or more layers are now the predominant system (Fig. 12.3).

SBS sheets are generally set in a continuous layer of hot asphalt, but some sheets may be torch-applied or set in cold adhesive. Self-adhering styrene-ethylene-propylene-styrene (SEPS) sheets are also available. SBS and SEPS sheets need protection from ultraviolet light (UV). Protection is typically provided by factory-applied mineral granules. They may also be surfaced with coatings (Art. 12.4.1).

APP sheets are generally torch-applied (Fig. 12.4). When APP sheets were introduced in the United States in the late 1970s, they were generally used without surfacing, since UV protection was reportedly provided by the APP modifier. While some such APP membranes weathered very well, others did not. Hence, coatings (cutbacks, emulsions, or latex) or granules are now often used.

The ASTM material standards for polymer-modified bitumen sheet products are as follows:

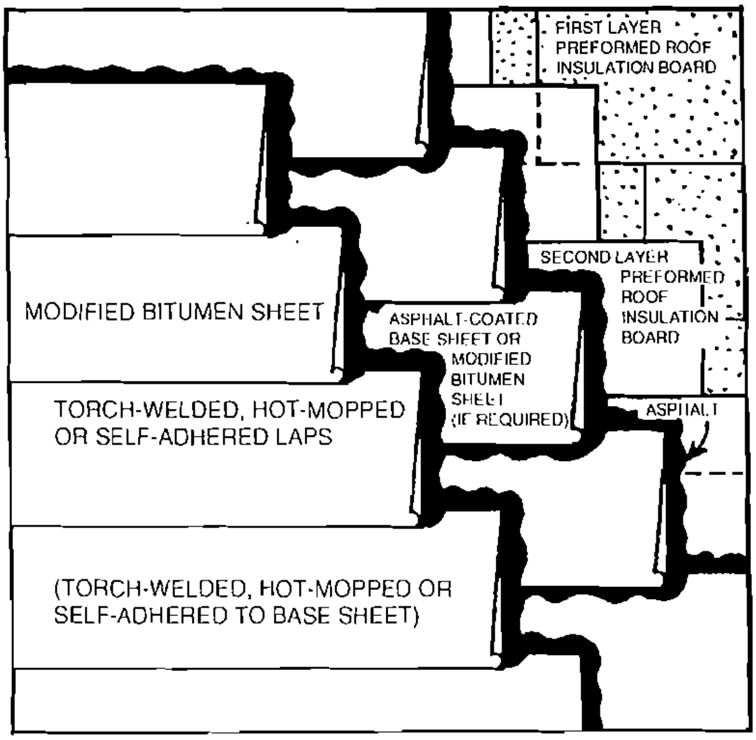


FIGURE 12.3 Modified bitumen roof with a base sheet overlaying two layers of preformed insulation board. (*NRCA Roofing and Waterproofing Manual.*)

ROOF SYSTEMS

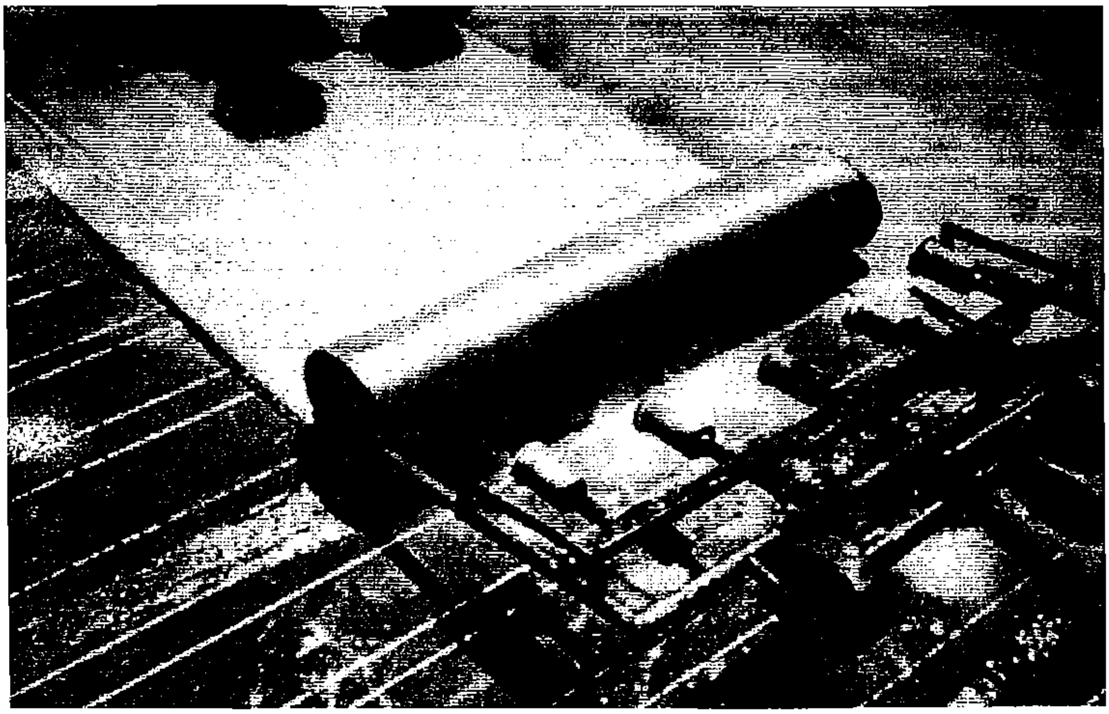


FIGURE 12.4 Torch application of atactic polypropylene (APP) modified bitumen membrane.

- ASTM D6162, "Standard Specification for Styrene Butadiene Styrene (SBS) Modified Bituminous Sheet Materials Using a Combination for Polyester and Glass Fiber Reinforcements"
- ASTM D6163, "Standard Specification for Styrene Butadiene Styrene (SBS) Modified Bituminous Sheet Materials Using a Glass Fiber Reinforcements"
- ASTM D6164, "Standard Specification for Styrene Butadiene Styrene (SBS) Modified Bituminous Sheet Materials Using Polyester Reinforcements"
- ASTM D6222, "Standard Specification for Atactic Polypropylene (APP) Modified Bituminous Sheet Materials Using Polyester Reinforcements"
- ASTM D6223, "Standard Specification for Atactic Polypropylene (APP) Modified Bituminous Sheet Materials Using a Combination of Polyester and Glass Fiber Reinforcements"
- ASTM D6298, "Standard Specification for Fiberglass Reinforced Styrene Butadiene Styrene (SBS) Modified Bituminous Sheets with a Factory Applied Metal Surface"

For each of these standards, except ASTM D 6298, type classifications (e.g., Type I, Type II) differentiate products (covered by the same standard) by the products' dimensions, masses and physical properties. In addition, grade classifications differentiate products by the products' surfacing type: Grade G designates granule surfacing and Grade S designates smooth surfacing.

Instead of incorporating prefabricated modified bitumen sheets, membranes can also be constructed with modified mopping asphalt and felts (of the type used for BUR construction). For modification of asphalt for application by mopping or by mechanical spreaders, styrene-ethylene-butylene-styrene (SEBS) polymers are utilized.

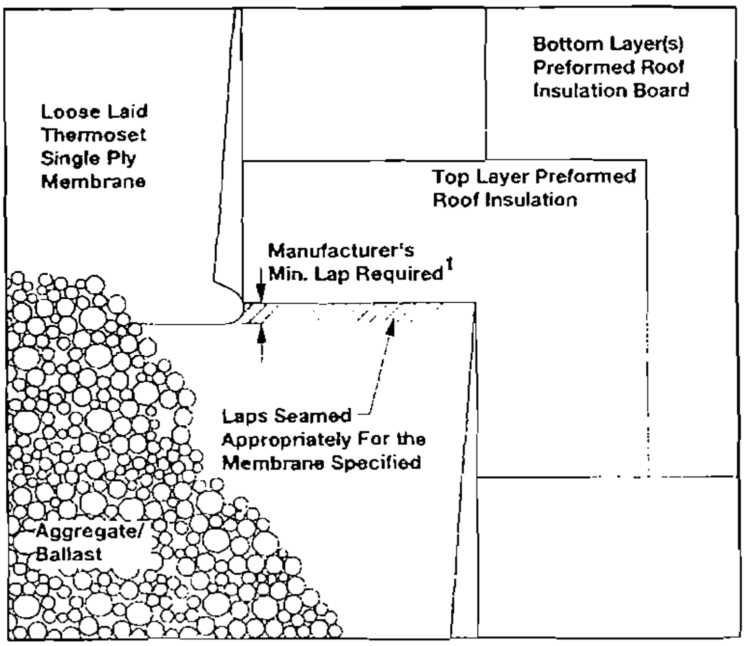
12.4.5 Single-Ply Roof Coverings

The single-ply family of roofing materials includes some distinctly different products. (Modified bitumen products [Art. 12.4.4] are sometimes included in the single-ply category.) The single-plies can be classified as either thermoset or thermoplastic materials. Thermoset materials normally cross-link (cure) during manufacturing. Once cured, these materials can only be bonded to themselves; for example, at a seam. Bonding is accomplished with an adhesive. Thermoplastic materials do not cross-link. Therefore, they should be capable of being welded together throughout their service life. Welding is usually accomplished with hot air.

There are three primary methods for attachment of single-ply membranes to a roof deck. In the ballasted system, the membrane is laid loose over the substrate and then covered with ballast to resist uplift from the wind (Fig. 12.5*a*). The ballast can either be large aggregate or concrete pavers. In the second method of attachment, the membrane is fully adhered in a continuous layer of adhesive (12.5*b*). In the third method, the membrane is mechanically attached to the deck (Fig. 12.5*c*).

The mechanically attached system generally utilizes screws with stress plates, or metal batten bars, located within the membrane lap (seam). Alternately, the battens may be placed on top of the membrane and covered with a stripping ply of the membrane material. There are other variations of the mechanically attached system, many of which are proprietary to a single membrane manufacturer.

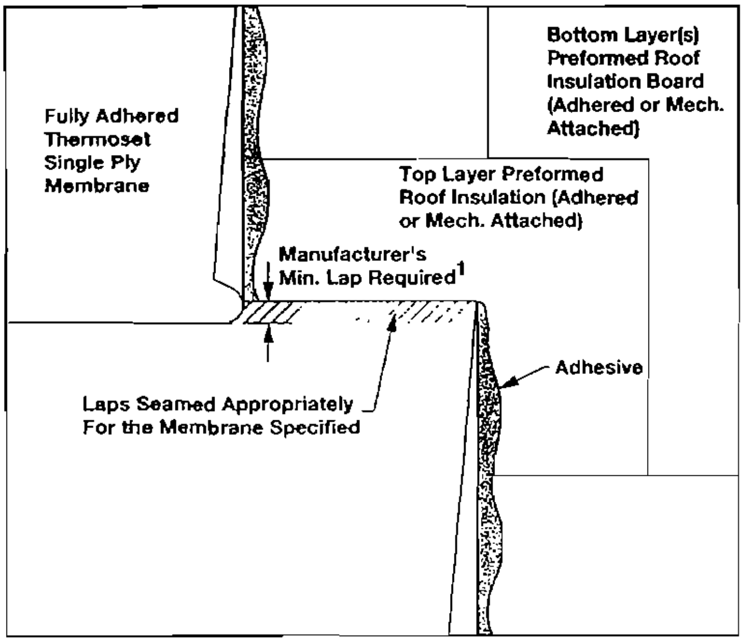
Following are descriptions of single-ply membrane materials.



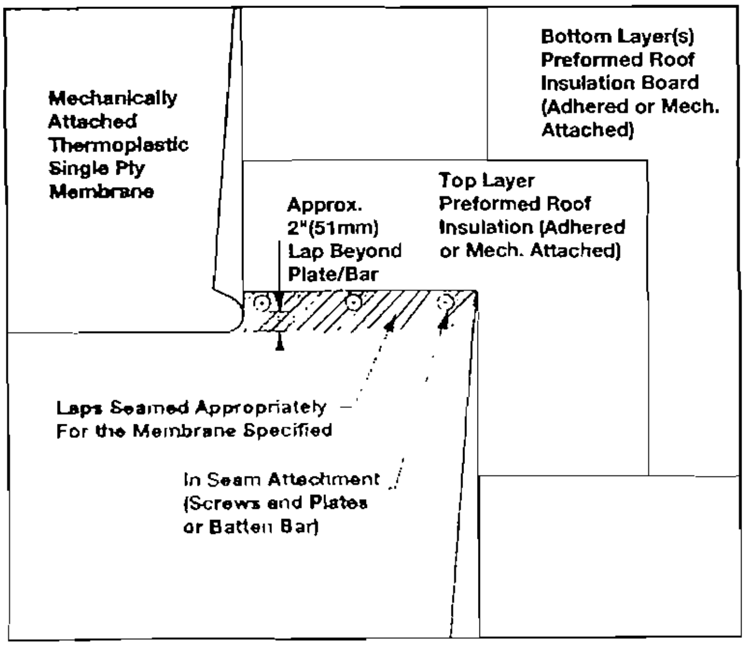
(a)

FIGURE 12.5 Methods of installing single-ply membrane over insulation board: (*a*) ballasted; (*b*) fully adhered; and (*c*) mechanically attached.

ROOF SYSTEMS



(b)



(c)

FIGURE 12.5 (*Continued*)

Chlorosulfonated polyethylene (CSPE) is commonly known by the trade name *Hypalon*. It is a thermoset product, but it cures after installation on a roof. This product is specified in ASTM D5019 (Type I). It is usually supplied in a white color.

Ethylene propylene diene terpolymer (EPDM) is a synthetic rubber membrane. It is a thermoset product specified in ASTM D4637. This standard includes specifications for Type I, non-reinforced; Type II, scrim (or fabric) internally reinforced, and Type III, fabric backed. It is available in a white color, but black is used most often.

Polyisobutylene (PIB) is a thermoplastic product, specified in ASTM standard D5019 (Type II). It is available in a black or white color.

Polyvinyl chloride (PVC) is a thermoplastic product, specified in ASTM D4434. Different types and grades are specified in ASTM D4434 and identify a membrane by the type and location of the reinforcement or fabric backing. It is available in a variety of colors.

PVC blends (also known as *copolymer alloys*) are based on PVC resin. They are similar to PVC membranes. The next revision of ASTM D4434 will probably also cover PVC blends.

Thermoplastic polyolefin (TPO), as the name denotes, is a thermoplastic product containing polyolefin polymers. TPOs are newer to the marketplace in the United States; however, variations of this membrane have been used in Europe for many years. Currently, an ASTM standard is being drafted for this single-ply membrane product.

12.4.6 Spray-Applied Polyurethane Foam (SPF) Roof Coverings

These consist of polyurethane foam insulation, which is spray-applied to the substrate, and topped with a surfacing (Fig. 12.6). Traditionally, the foam is surfaced with a coating of latex (acrylic), polyurethane, or silicone. Mineral granules are sometimes applied to the wet coating for additional abrasion and impact resistance (at traffic walkway areas or throughout the entire roof).

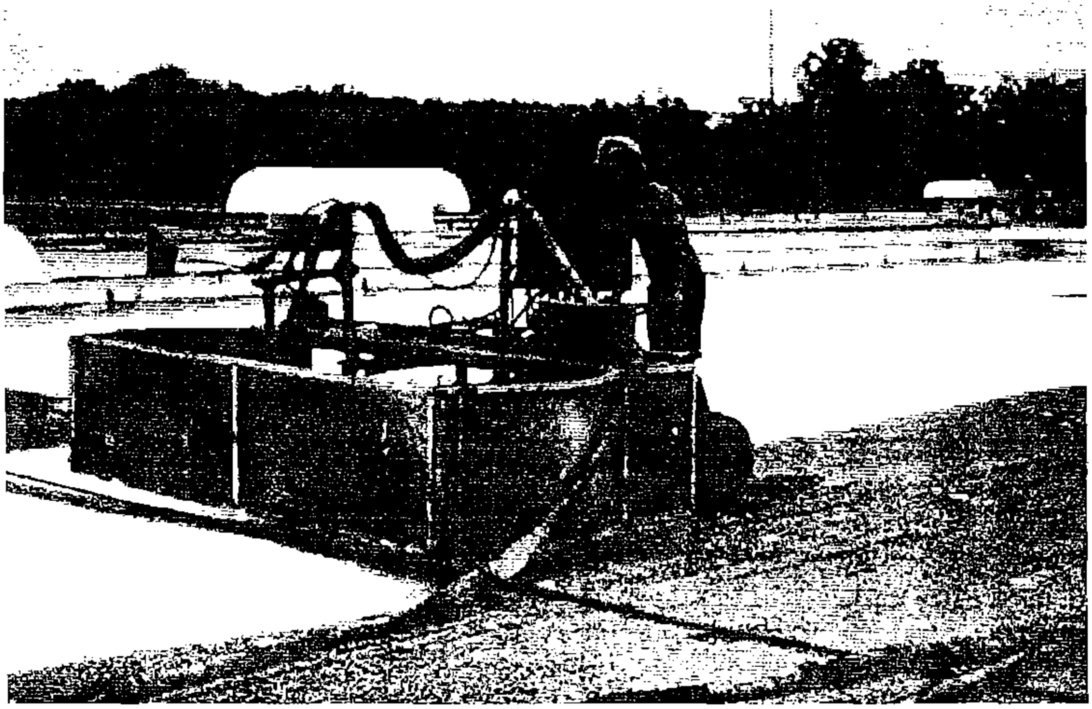


FIGURE 12.6 Robotic sprayer applying polyurethane foam.

An alternative surfacing is aggregate, similar to the type used for BUR placed directly over the foam. In this system, coatings are used only on vertical surfaces, such as parapets or equipment curbs.

See also Art. 12.21, "Roof Systems Bibliography."

12.5 STEEP-SLOPE ROOF COVERINGS

These differ from low-slope roof coverings in that on steep-slope roofs water flows rapidly over exposed units to eaves. Many of the low-slope roof coverings described in Art. 12.4 can be successfully used on steep slopes. Many of the low-slope materials, however, become slick when wet. This should be taken into account before they are specified for steep slopes.

12.5.1 Asphalt Shingles

These are composed of a reinforcing mat (organic or glass fiber), a specially formulated asphalt coating, and mineral granules. (Glass-fiber reinforced shingles are sometimes referred to as *fiberglass shingles.* Organic-reinforced shingles are sometimes referred to as *asphalt shingles,* which is confusing, for this term properly

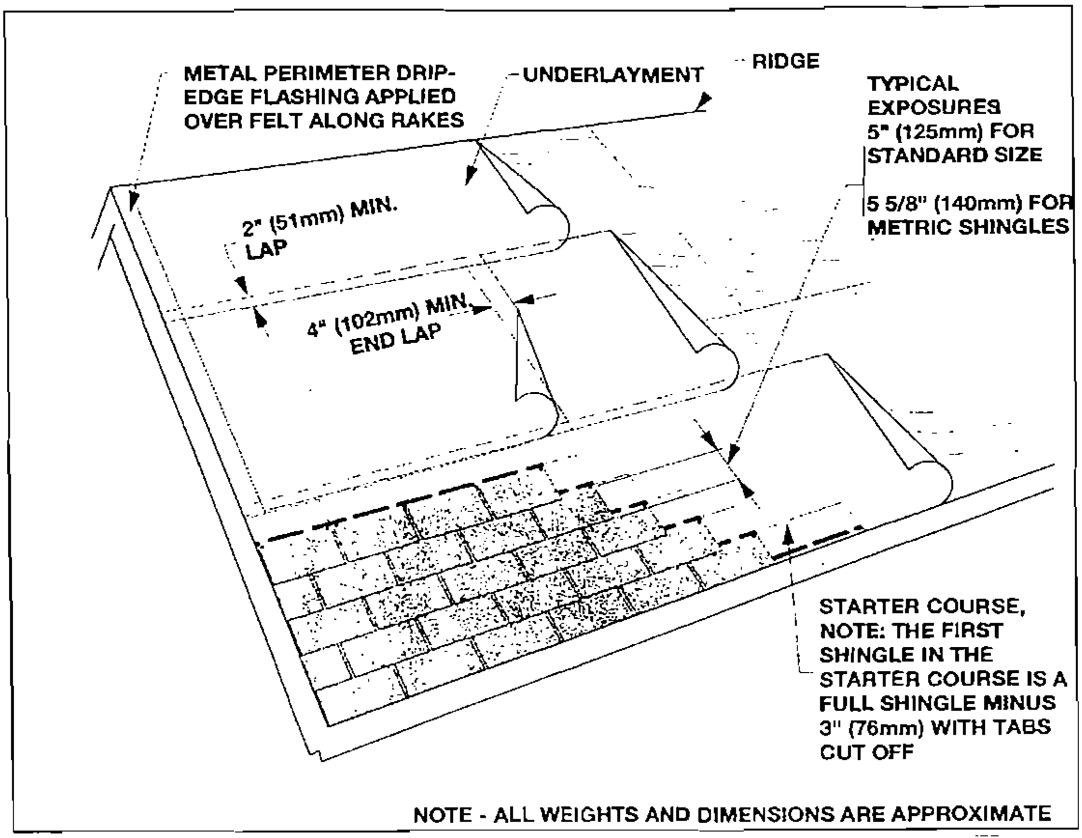


FIGURE 12.7 Three-tab asphalt-shingle roof.

applies to both the organic and glass-fiber reinforced products.) Most asphalt shingles are manufactured with a self-seal adhesive for wind resistance.

Asphalt shingles are available in a variety of weights. (Weight, however, is not necessarily an indicator of product performance.) Also, they are available in a variety of styles and colors, including three-tab strip shingles (Fig. 12.7), strip shingles, shingles without cutouts, and laminated (architectural) shingles. Laminated shingles have a heavy texture. Shingles that enhance the three-dimensional look by adding shadow lines or shading through use of colored granules are also available. Glass-fiber reinforced asphalt shingles are specified in ASTM D3462. Organic-reinforced asphalt shingles are specified in ASTM D225. Shingles are also available which utilize a polymer-modified bitumen in lieu of the more traditional coating-grade asphalt.

12.5.2 Cement-Fiber Shingles

Formerly reinforced with asbestos fibers and hence known as *cement-asbestos shingles,* cement-fiber shingles are now reinforced with fibers other than asbestos. Some of these products are intended to visually simulate other products, such as slate.

It is important to note that some of these products have restrictions in climatic locations where freeze/thaw cycling is experienced. Consult the product manufacturer for specific information regarding appropriate locations.

12.5.3 Metal Roof Coverings

The metal category includes a large variety of products, such as metal shingles and panels. Metals used to form the products include aluminum, copper, galvanized steel, and aluminum-zinc-alloy steel (*Galvalume*). Steel and aluminum panels are available with several different types of pain finishes and colors. Many of the products are formed in a factory, while others are formed on the job site by the roofing contractor.

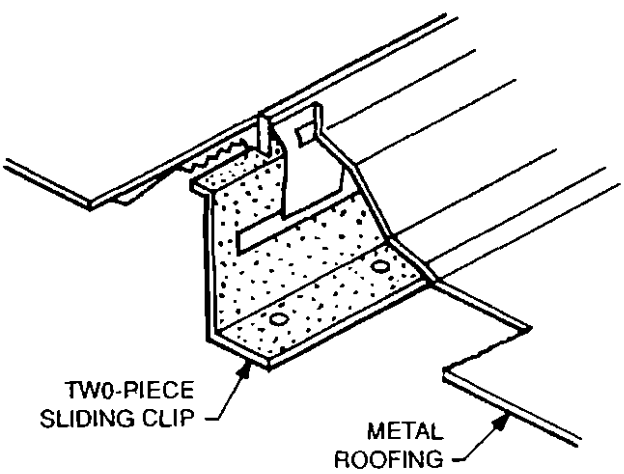


FIGURE 12.8 Trapezoidal-shaped structural metal-panel roofing system with concealed clips at seams.

Metal roof panels include four primary types: structural standing seam, architectural standing seam, exposed fastener, and traditional metal roofing. Standing-seam panels are available with or without battens. The standing-seam and exposed-fastener panels are roll-formed, while traditional panels are typically press-brake formed. The exposed-fastener panels have largely been replaced by standing-seam panels, except for very inexpensive construction.

Architectural and most traditional panels need to bear on a continuous structural substrate (deck) in order to carry live loads, such as snow. However, architectural panels should be designed to accommodate design wind loads.

Structural panels (Fig. 12.8) have the capability of spanning between supports. Accordingly, they can be placed over purlins (as is the case with preengineered metal buildings), as well as over continuous structural substrate. Some structural panels have the capability of being successfully used as low-slope coverings.

12.5.4 Roofing Slate

Slate is a dense durable rock that has a natural cleavage plane. The surface texture and color of slate after it is split depend on the characteristics of the rock from which it is quarried. Roofing slate is a long-lasting but very heavy material.

Slate roofs may be classified as standard slate, graduated slate, and textural slate. The latter is the older form, in which slates are delivered to the job in a variety of sizes and thicknesses, to be sorted by slaters. The longer and thicker slates are placed near the eaves, medium sized at the center, and the smallest at the ridge.

Standard slate roofs have one uniform width and length. The lengths are typically square and laid to a line. Textural slate roofs are composed of textural slate, which is usually rougher than standard slate, have uneven tails, and vary in size and thickness. Roofing slate is specified in ASTM C406 (Fig. 12.9).

Active roofing slate quarries in North America exist in New York, Pennsylvania, Vermont, and Virginia, as well as the Canadian provinces of Quebec and Newfoundland. Imported slate is available from Spain, Wales, China, Brazil, South Africa, and other countries. Information concerning the quality of slate produced domestically is more readily available than with most imported slate. It may be necessary to test slate, according to ASTM C406, if the quality of the slate's source location (bed or quarry) is unknown or inconsistent.

12.5.5 Synthetics

This class of materials includes a variety of products that are intended to simulate other materials. Typically, synthetics simulate wood shingles or shakes, tile, or slate. The imitation materials include cement-fiber and metal (Arts. 12.5.2 and 12.5.3), and polymer composites.

12.5.6 Roofing Tile

Produced from clay or concrete, tiles (Fig. 12.10) are available in a variety of shapes, colors, and textures. Clay tiles are specified in ASTM C1167. Quality tiles can have a long service life when properly designed and installed.

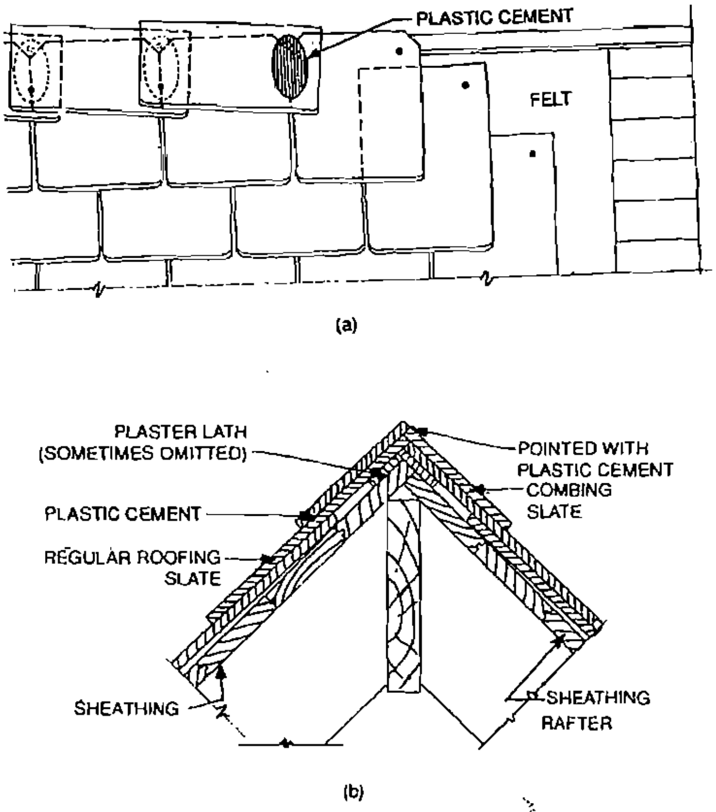


FIGURE 12.9 Slate roof, (*a*) Slates in each course cover joints in those below, have a headlap of 3 in over the lowest course below, and have an exposure (portion not covered by next course above) equal to $\frac{1}{2}(L - 3)$, where L is the slate length, in. (*b*) Section at roof ridge illustrates the saddle-ridge method, in which regular slates extend to the ridge so that slates on opposite sides of the ridge butt flush. Another course of slate, called combing slate, is set on top, butting flush at the ridge.

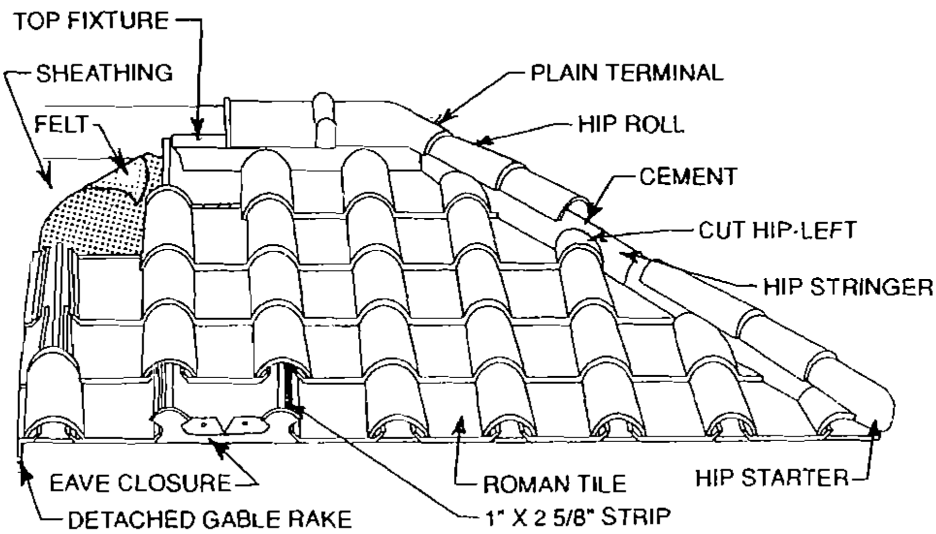


FIGURE 12.10 Roman tile application at hip and ridge of a roof.

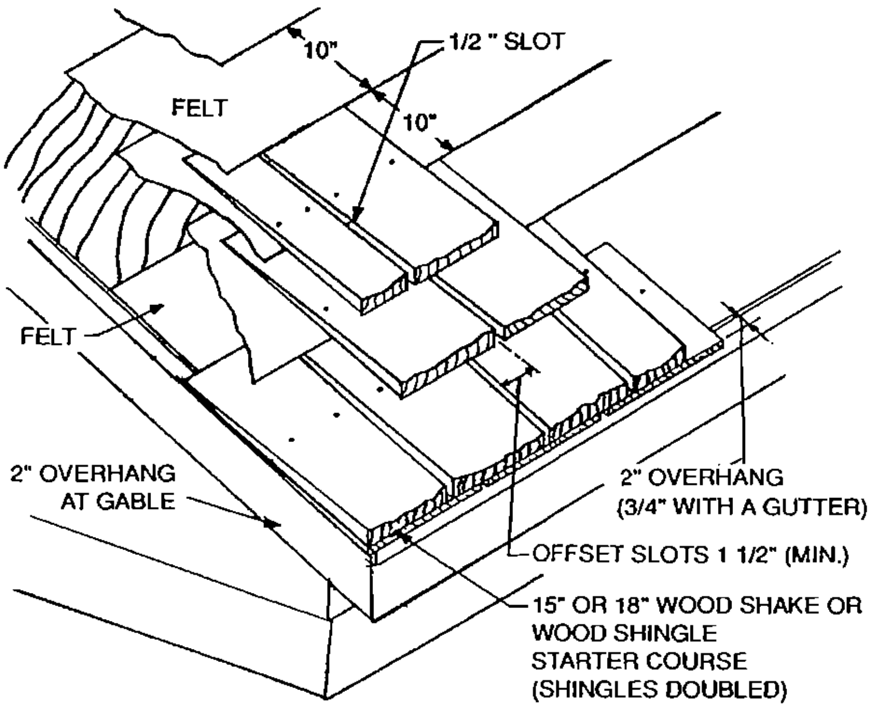


FIGURE 12.11 Wood shake application at the eaves of a roof.

12.5.7 Wood Shingles and Shakes

Shingles are sawn on both sides, while shakes are split on at least one surface. Cedar is typically used for wood roofs, but other species of wood are sometimes used. There are different grades of shingles and shakes, and they can be pressure-preservative treated or pressure treated for fire resistance. See also Art. 12.21, "Roof Systems Bibliography." Figure 12.11 shows a typical wood shake installation.

KEY DESIGN AND APPLICATION CONSIDERATIONS

A complete discussion of design considerations for the primary types of low-slope and steep-slope roofing systems is beyond the scope of this book. However, a few general key considerations are discussed in the following.

12.6 NEED FOR FAMILIARITY WITH ROOF DESIGN

A common pitfall for designers is lack of familiarity with the principles of roof design. This is manifested in selection of inappropriate materials or systems or inadequate details, or use of poorly prepared specifications. To assist designers, several periodicals and books are available (Art. 12.21) and seminars are offered by the Roofing Industry Educational Institute and the National Roofing Contractors Association (Art. 12.20).

In addition to these resources, designers would find it helpful to establish a working relationship with a professional roofing contractor. Many contractors are willing to spend some time with designers. This can be particularly helpful if the designer is working on a project that has some unusual aspect, or if a material or system is being contemplated with which the designer is not familiar. For more extensive input, utilization of a professional roofing consultant may be advantageous.

12.7 BUILDING OWNERS' REQUIREMENTS

It is important for roof designers to determine if the building owner has any specific requirements, such as type of materials; what the building owner's expectations are regarding the roof's longevity; and to what extent the owner is committed to maintenance. If the owner is unwilling to allocate adequate funds for maintenance, a conservative durable system should be selected.

Also, designers should determine how detrimental leakage or a roof flow-off would be. For most buildings, these events are unpleasant but generally manageable. But, if the roof is over very expensive electronic equipment, or a critical facility such as a hospital, a conservative roof design may well be appropriate. It is also desirable to determine if the owner's insurer has specific requirements for the roof system.

Contract documents should be carefully designed and administered. A good roof design should be complemented with comprehensive, unambiguous specifications and drawings, so that the design intent is clearly communicated to the contractor.

12.8 BUILDING-CODE PROVISIONS FOR ROOFS

Designers should be aware of building-code requirements affecting design of the roof. Model building codes and many state and local codes have provisions related to roof systems (for new construction, as well as reroofing).

Fire and wind resistance, material standards, storm water drainage, structural loading, and energy efficiency are some of the many objectives of building codes that are common to roof design. Many local jurisdictions have such requirements for residential and/or commercial construction.

12.9 EFFECTS OF CLIMATE

The climate in the region where the roof will be constructed often plays a key role in design of the roof system. Climate considerations should include the type of weather that will likely be encountered during application, as well as the climatic conditions that follow. For example, if the roof is to be constructed during cold weather or in a location that experiences frequent rains, selection of materials and a system that is more tolerant of these conditions can play a key role in obtaining a successful roof.

12.10 EFFECTS OF ROOF SIZE, SHAPE, AND SLOPE

Roof size and shape often dictate material and system selection. For example, if the roof is only 2 or 3 ft wide and several feet long, a system other than built-up roofing (BUR) would probably be easier to install than BUR.

Roof slope is a major factor in determining the rate of flow of rainwater over a roof to a drainage outlet, and good drainage is essential to good performance of a roof. Hence, regardless of the type of materials or system specified, adequate slope should be provided for drainage.

For low-slope roofs, NRCA recommends that the roof be designed and built to ensure **positive drainage.** NRCA defines positive drainage as "the drainage condition in which consideration has been made during design for all loading deflections of the deck, and additional roof slope has been provided to ensure drainage of the roof area within 48 hours of rainfall, during ambient drying conditions." Ponding water can be detrimental to roof systems and can result in:

- Deterioration of the roof surface and membrane
- Debris accumulation, vegetation, fungal growth, and resulting membrane damage
- Deck deflections (sometimes resulting in structural problems and other complications)
- Ice formation and resulting membrane degradation or damage
- Tensile splitting of water-weakened organic or asbestos felts
- Difficulties in repair, should leaks occur
- Water entry into the building if the roof membrane is punctured or fails in a ponding area
- Voiding of manufacturers' warranties

Every roof has its own specific set of drainage criteria. Simply specifying a standard ¼ in/ft (degrees) slope or ⅛ in/ft (degrees) slope will not ensure adequate drainage of the roof system. In order to achieve the necessary slope throughout the entire roof area, many things should be considered, including: the structural framing system, deck type and characteristics, deck deflections between spans, roof insulation, roof membrane type, rooftop penetrations (and additional support or blocking for the deck), and the building and roof layout.

Other items which can assist in positive drainage are: tapered insulation (crickets and saddles) at key points, such as between drain locations and at the up-slope side of penetrations; recessing primary drains and scuppers slightly below the roof membrane surface; and performing maintenance semiannually to help prevent clogged drains.

The use of secondary or overflow drainage devices (e.g., through-wall scuppers) is recommended and, in most cases, required by building codes.

For steep-slope roofs, the minimum recommended slope is a function of the type of roof-covering material used and the type of underlayment. The minimum recommended slope for most steep-slope roof coverings is 4:12 (degrees), unless special provisions are made. Depending on the material, some manufacturers and building codes allow lower slopes. Since most steep-slope materials are water-shedding, rather than waterproofing, a steeper slope typically decreases the likelihood of damaging or other undesirable conditions.

12.11 DECK SUITABILITY

In selection of a deck or the type of roof-covering material and system, it is important to develop a design that incorporates materials that are compatible. For example, if a mechanically attached single-ply membrane is desired, it would be appropriate to specify a deck that can readily accept the fasteners yet have sufficient capacity to hold the fasteners. In this case, a steel deck, wood plank, or thick plywood deck would normally be good options. But if the deck did not readily accept fasteners; for example, a concrete deck, or if the deck possessed minimal strength; for example, a lightweight, insulating-concrete fill, then a system other than a mechanically attached single-ply membrane should be selected.

12.12 EFFECTS OF ROOFTOP TRAFFIC

If there will be periodic traffic on a roof; for example, to maintain mechanical equipment, traffic walkway pads should be specified to protect the roof. Pads can also be beneficial around mechanical equipment, to protect against dropped tools. For aggregate-ballasted systems, use of concrete pavers for walkways can be helpful in protecting the roof and providing a comfortable surface on which to walk.

For heavier rooftop loading, greater protective measures; for example, installation of heavy concrete pavers may be needed. In some cases, window-washing equipment causes damage to roof coverings, because they do not have sufficient resistance to the high impact loads that can result as the equipment is moved around and dropped.

12.13 ESTHETIC CONSIDERATIONS

While esthetics typically is not of concern for low-slope roofs, it generally is with steep-slope roofs. For some low-slope roofs, an attractive roof is also desirable. Where esthetics is an issue, special effort is needed to achieve the desired goal.

For example, a clean white roof may look good for a year or two. But after it has deposits of wind-blown dirt, or from contaminants exhausted from mechanical equipment, or from sediment from ponded water, it may look less attractive. If a more uniform appearance is desired, an aggregate-surfaced built-up roofing or ballasted (with aggregate or pavers) single-ply membrane may be specified.

To be sure that a proposed design will produce the desired look, designers should visit an existing roof that has a similar roof covering to determine if expectations will likely be met.

12.14 EFFECTS OF WIND ON ROOFS

Particularly in those areas subjected to hurricanes or other high winds, provision for resistance to wind in design of roof systems is necessary for successful performance. Different roof systems are loaded differently, and they resist the loads in different ways. For example, loading and load resistance of asphalt shingles, a modified bitumen membrane, a ballasted single-ply membrane, and a mechanically attached single-ply membrane are all different.

An understanding of the loading and load response is needed to design wind-resistant roof coverings for use in high-wind environments. In particular, design of metal edge flashing (gravel stops) is a critical aspect for many types of roof systems. Further information regarding wind design is available from publications listed in Art. 12.21.

12.15 PROTECTED MEMBRANE ROOFS AND PLAZA DECKS

A special type of low-slope roof system is the protected membrane roof (PMR). In this system, extruded polystyrene insulation boards are placed above the membrane. The insulating boards are then covered with aggregate or concrete paver ballast. (If aggregate is used, a fabric mat is first placed over the insulation.) This construction protects the membrane from mechanical damage (dropped tools, wind-blown debris) and from direct exposure to the weather (UV, high and low temperatures). Figure 12.2 illustrates a PMR that incorporates a built-up membrane.

Plaza decks are similar to protected membrane roofs, except that they are designed for heavy traffic loads. Because of the difficulty in repairing these types of roof systems, they should be designed and constructed with care. If this is done, they can provide a long and successful service life.

Application of Roofing. If a roof has been adequately designed and quality materials have been specified and provided, the next step toward achieving a successful roof is to have it installed by a reputable roofing contractor. After a contractor has been retained to perform the work, the following items are of importance.

12.16 PREROOFING CONFERENCE

The project designer should specify a preroofing conference. This meeting is normally attended by the roofing contractor (including the job-site person who will be in charge of the work), the building owner's representatives (including the project designer), and the general contractor. An inspector familiar with the type of roofing being installed, if retained, should also attend. If the project has a lot of rooftop mechanical or electrical equipment, these subcontractors would also normally attend the meeting.

The purpose of the meeting is to review the salient features of the drawings and specifications, to ensure there is understanding by all parties. If there are problems with the design or other aspects of the project, the intent is to identify and resolve them prior to commencement of the field work. As part of this meeting, the roof deck should be reviewed to verify that it is ready for roofing. The need for avoiding damage to the work after its completion should also be discussed.

12.17 WARRANTIES

Long-term roofing warranties are quite common, but often their importance is overemphasized in selection of a roof. Many building owners and designers have focused on specifying warranties rather than on other aspects that are more likely to result in a successful roof. The "Consumer Advisory Bulletin on Roofing Warranties," 1992, National Roofing Contractors Association (NRCA), suggested the following:

> The length of a roofing warranty should not be the primary criterion in the selection of a roofing product or system because the warranty does not necessarily provide assurance of satisfactory roofing performance. The selection of a roofing system for a particular project application should be based upon the product's qualities and suitability for the prospective construction project. A long-term warranty may be of little value to a consumer if the roof does not perform satisfactorily and the owner is plagued by leaks. Conversely, if the roof system is well-designed, well-constructed and well-manufactured, the expense of purchasing a warranty may not be necessary.
>
> Manufacturers who use long-term warranties as a marketing tool have encountered a highly competitive roofing market and have found themselves compelled to meet or exceed warranties of competitive manufacturers. It is suspected that in some cases the length of the warranty was established without appropriate technical research or documentation of in-place field performance.
>
> NRCA believes that the roofing consumer, with the assistance of a roofing professional, should focus his purchase decision primarily on an objective and comparative analysis of proven roofing system options that best serve his specific roofing requirements and not on warranty time frames.
>
> NRCA further advises that the roofing consumer consult the membrane warranty section of the "Roofing Materials Guide" for a comparative analysis of the specific provisions, remedies, limitations, and exclusions of the warranties of those roofing systems under consideration. All questions should be addressed to the respective roofing manufacturers for specific written clarification.

12.18 ROOF MAINTENANCE

After a good roof has been delivered to the building owner, it is important for the owner to commit to a program of periodic roof inspections and to follow-up maintenance or repairs as needed. While some systems require less maintenance than others, no roof should be forgotten about after it is installed!

Semiannual inspections are recommended for all roofs. The purpose of these inspections is to determine if debris removal is needed; for example, cleaning of roof drains, and if the roof is showing signs of distress. In many instances, undesirable conditions can be minimized if they are detected and corrected early. Without inspections, a small problem, such as a puncture, can go unnoticed until a large area of the roof is wet and in need of replacement.

To assist in the care of the roof, many professional roofing contractors offer maintenance contracts to building owners. By making a commitment to periodic inspections and appropriate maintenance and repair, the building owner can optimize the roof's service life and maximize the roofing investment.

Maintenance guides specific to low-slope membrane types have been developed by NRCA (Art. 12.22). These guides provide useful information for establishing maintenance programs, emergency and permanent repair procedures, and historical data files; they include a general description of typical maintenance activities by roof system type, as well as inspection checklists.

12.19 REROOFING

Replacement of existing roofing or installation of a new roof covering over it is usually much more complicated than roofing a new building. Besides issues that are normally considered in design of a new roof, may additional issues arise when roof replacement is needed. For example, it is not uncommon to find existing undesirable building conditions including those that contributed to the demise of the existing roof. Unless these are adequately corrected in the new design (which may be difficult or expensive to do), they can also be expected to affect the new roof adversely.

Therefore, as part of the reroofing design process, it is important to determine the reason for the problems with the existing roof. Are they simply a consequence of old age, or are there fundamental conditions that could affect the new roof adversely; for example, migration of water from a curtain wall into the roof system? If there are inherent troubles, they need to be corrected as part of the reroofing work. Also, as part of the design process, the integrity of the roof deck should be assessed by an engineer, if deteriorated deck is suspected. And if the new roof system adds weight to the structure, the capacity of the structure should be evaluated by an engineer.

12.19.1 Reroofing Procedures

There are two primary approaches to reroofing: Either the existing system can be removed down to the deck, or it may remain in place and a new roof covering installed over it. The removal option is the most conservative approach, inasmuch as it allows a complete view of the top side of the deck. If there are deteriorated areas, they will be likely to be found. Also, this approach eliminates entrapment of water in the existing roof. However, this option is often more expensive, and it exposes the interior to water damage during the reroofing process.

The recover option has the advantage of retaining the thermal value of the existing insulation, and the existing roof provides protection against sudden rainfall during the application process. In some parts of the United States, this is not important, but in other areas, this advantage makes the recover option very desirable.

The number of existing roofs will in many instances eliminate the recover option. Generally, no more than two layers of roofing systems are recommended. Model building codes have specific requirements for reroofing, including the maximum number of roof layers allowable. In some instances, complete removal of all existing roof systems (in lieu of removal of the top roof layer only) is required by building codes before installing a new roof system.

Prior to recovering, it is important to determine if there are areas of wet insulation. If so, it is recommended that it be removed. The utilization of nondestructive evaluation (NDE) can be very helpful in identifying areas of wet insulation.

Unless the designer is very knowledgeable of techniques for assessing existing roof systems and of reroofing design, the designer would be well advised to work with a professional roofing contractor or other roofing professional.

12.19.2 Roof Moisture-Detection Surveys

Moisture within a roof membrane system tends to migrate from its point of entry. Thus, blisters, cracks, and splits caused by the moisture are often located at a distance from the source of a leak. Several methods are available for locating such sources. The equipment utilizes infrared photographic techniques, or nuclear or electronic devices, or variations of these systems. Each method has advantages and disadvantages but can be effective if properly used.

In the method employing an infrared roof scanner, an infrared reading is taken of the roof at night using a portable (hand-held) infrared camera. Another method of infrared thermography uses a helicopter to take a reading from a distance. The infrared camera identifies temperature differences (anomalies) across the surface of the roof; these anomalies may be the result of wet insulation.

The electronic and nuclear methods use differing means for locating roof moisture, but the procedures are similar. First, a drawing to scale of the roof is made, showing all projections, roof equipment, etc. A grid is marked on the drawing, then physically reproduced on the roof with ropes or paint. Trained operators take readings at every grid intersection and record the observation. At the same time, the roof is visually inspected and observations are carefully noted. The data collected then are evaluated by a specialist and adjusted for the effects of up to nine different factors, such as gravel depth, roof construction, etc. The information is entered on a final map of the roof, to provide a picture of water-damaged areas, under-membrane water-flow patterns, percentage of moisture in the roof, and locations of moisture. From this map, it is possible to determine where replacement is necessary, where repair will be sufficient, and what to budget for future work that may be needed to maintain the roof or whether to replace it section by section as required. Such moisture detection surveys are valuable tools for saving energy and for management planning.

It is important to note that none of these methods directly determine the presence of moisture in a roof assembly. Instead, they identify potential areas of moisture by assessing certain properties that may be caused by moisture trapped in the roof assembly. All three methods require core sampling (destructive testing) of the roof system to verify the presence of any trapped moisture.

12.20 *ROOFING INDUSTRY ASSOCIATIONS AND RELATED ORGANIZATIONS*

American Fiberboard Association (AFA)
1210 W. Northwest Highway
Palatine, IL 60067-3609
847-934-8394
FAX: 847-934-8803
E-mail: afa@fiberboard.org
http://www.fiberboard.org

American Iron and Steel Institute (AISI)
1101 17th St. Northwest Ste. 1300
Washington, DC 20036-4700
202-452-7100
FAX: 202-463-6573
E-mail: mjackson@steel.org
http://www.steel.org

American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)
1791 Tullie Circle Northeast
Atlanta, GA 30329
404-636-8400
FAX: 404-321-5478
E-mail: ashrae@ashrae.org
http://www.ashrae.org

American Society for Testing and Materials (ASTM)
100 Barr Harbor Drive
W. Conshohocken, PA 19428-2959
610-832-9500
FAX: 610-832-9555
E-mail: service@astm.org
http://www.astm.org

APA-The Engineered Wood Association
7011 S. 19th St.
P.O. Box 11700
Tacoma, WA 98411
253-565-6600
FAX: 253-565-7265
http://www.apawood.org

Asphalt Institute (AI)
2696 Research Park Drive
P.O. Box 14052
Lexington, KY 40512-4052
606-288-4960
FAX: 606-288-4999
E-mail: asphalti@asphaltinstitute.org
http://www.asphaltinstitute.org

Asphalt Roofing Manufacturers Association (ARMA)
Center Park
4041 Powder Mill Road Suite 404
Calverton, MD 20705
301-348-2002
FAX: 301-348-2020
http://www.asphaltroofing.org

Building Officials & Code Administrator International (BOCA)
4051 W. Flossmoor Road
Country Club Hills, IL 60478-5795
708-799-2300
FAX: 708-799-4981
http://www.bocai.org

The Cedar Guild
P.O. Box 249
Lyons, OR 97358
503-897-2541
800-270-2541
FAX: 503-897-2422
E-mail: cedarinfo@cedar.guild
http://www.cedar-guild.com

Cedar Shake & Shingle Bureau (CSSB)
P.O. Box 1178
Sumas, WA 98295-1178
604-462-8961
FAX: 604-462-9386
E-mail: info@cedarbureau.com
http://www.cedarbureau.org

The Construction Specifications Institute (CSI)
99 Canal Center Plaza, Suite 300
Alexandria, VA 22314-1588
703-684-0300
FAX: 703-684-0465
E-mail: csimail@csinet.org
http://www.csinet.org

Copper Development Association (CDA)
260 Madison Ave.
New York, NY 10016
215-251-7200
FAX: 212-251-7234
http://www.copper.org

EPS Molders Association
2128 Espey Court Suite 4
Crofton, MD 21114
410-451-8341
FAX: 410-451-8343
E-mail: bdecampo@aol.com
http://www.epsmolders.org

Factory Mutual Research (FM)
1151 Boston-Providence Turnpike
Norwood, MA 02062
781-762-4300
FAX: 781-762-9375

Forest Products Laboratory (FPL)
One Gifford Pinchot Drive
Madison, WI 53705-2398
608-231-9200
FAX: 608-231-9592
E-mail: mailroom/fpl@fs.fed.us
http://www.fpl.fs.fed.us/

Gypsum Association
810 First Street, NE #510
Washington, DC 20002
202-289-5440
FAX: 202-289-3707
http://www.gypsum.org

Infraspection Institute (II)
3240 Shelburne Road, Suite 3
Shelburne, VT 05482
802-985-2500
FAX: 802-985-2726
E-mail: support@infraspection.com
http://www.infraspection.com

International Conference of Building Officials (ICBO)
5360 Workman Mill Road
Whittier, CA 90601-2298
562-699-0541
FAX: 562-699-8031
http://www.icbo.org

International Staple, Nail and Tool Association (ISANTA)
512 W. Burlington Ave., Suite 203
La Grange, IL 60525
708-482-8138
FAX: 708-482-8186

Metal Building Manufacturers Association (MBMA)
1300 Sumner Ave.
Cleveland, OH 44115-2851
216-241-7333
FAX: 216-241-0105
E-mail: mbma@mbma.com
http://www.mbma.com

Metal Construction Association (MCA)
104 S. Michigan Suite 1500
Chicago, IL 60603
312-201-0193
FAX: 312-201-0214
jimstanley@metalconstruction.org
http://metalconstruction.org

National Insulation Association (NIA)
99 Canal Center Plaza Suite 222
Alexandria, VA 22314
703-683-6422
FAX: 703-549-4838
E-mail: niainfo@insulation.org
http://www.insulation.org

National Roof Deck Contractors Association (NRDCA)
P.O Box 1582
Westford, MA 01886-4996
800-217-7944
FAX: 978-250-9788
E-mail: nrdca@nrdca.org
http://nrdca.org

National Roofing Contractors Association (NRCA)
10255 W. Higgins Road Suite 600
Rosemont, IL 60018
847-299-9070
FAX: 847-299-1183
E-mail: nrca@nrca.net
http://www.nrca.net

National Tile Roofing Manufacturers Association (NTRMA)
P.O. Box 40337
Eugene, OR 97404-0049
541-689-0366
FAX: 541-689-5530
E-mail: info@ntrma.org
http://www.ntrma.org

North American Insulation Manufacturers Association (NAIMA)
44 Canal Center Plaza Suite 310
Alexandria, VA 22314
703-684-0084
FAX: 703-684-0427
http://www.naima.org

Polyisocyanurate Insulation Manufacturers Association
1331 F Street, NW, Suite 975
Washington, DC 20004
202-628-6558
FAX: 202-628-3856
E-mail: pima@pima.org
http://www.pima.org

Roof Coatings Manufacturers Association (RCMA)
4041 Powder Mill Road Suite 404
Calverton, MD 20705
301-348-2003
FAX: 301-348-2020
http://www.roofcoatings.org

Roof Consultants Institute (RCI)
7424 Chapel Hill Road
Raleigh, NC 27607-5041
919-859-0742
FAX: 919-859-1328
E-mail: rci@rci-online.org
http://www.rci-online.org

Roofing Industry Educational Institute (RIEI)
2305 East Arapahoe Road, Suite 135
Littleton, CO 80122
303-703-9870
FAX: 303-703-9712
E-mail: rieiroof@aol.com
http://www.riei.org

Rubber Manufacturers Association (RMA)
1400 K St. Northwest #900
Washington, DC 20005
202-682-4800
FAX: 202-682-4854
http://www.rma.org

Sealant Waterproofing & Restoration Institute
2841 Main
Kansas City, MO 64108
816-472-SWRI
FAX: 816-472-7765
E-mail: swrionline.org
http://swrionline.org

Sheet Metal and Air Conditioning Contractors' National Association (SMACNA)
4201 Lafayette Center Drive
Chantilly, VA 20151-1209
703-803-2980
FAX: 703-803-3732
E-mail: info@smacna.org
http://www.smacna.org

Southern Building Code Congress International (SBCCI)
900 Montclair Road
Birmingham, AL 35213
205-591-1853
FAX: 205-599-9893
E-mail: info@sbcci.org

Spray Polyurethane Foam Alliance (SPFA)
1300 Wilson Boulevard
Suite 800
Arlington, VA 22209
703-253-0659
800-523-6154
FAX: 703-253-0664
http://www.sprayfoam.org.

SPRI, Inc.
200 Reservoir St. Suite 309A
Needham, MA 02494
781-444-0242
FAX: 781-444-6111
E-mail: lkspri@aol.com
http://www.spri.org

Steel Deck Institute (SDI)
P.O. Box 25
Fox River Grove, IL 60021-0025
847-462-1930
FAX: 847-462-1940
E-mail: steve@sdi.org
http://www.sdi.org

Underwriters Laboratories Inc. (UL)
333 Pfingsten Road
Northbrook, IL 60062
847-272-8800
FAX: 847-272-8129
http://www.ul.com

Western Red Cedar Lumbar Association
555 Burrard St., Suite 1200
Vancouver, B.C. V7X 1S7
Canada
604-684-0266
FAX: 604-687-4930
E-mail: wrcla@wrcla.org
http://www.wrcla.org

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"SPRI/NRCA Manual of Roof Inspection, Maintenance, and Emergency Repair for Existing Single-Ply Roofing Systems," 1992, National Roofing Contractors Association, Rosemont, Ill., Single Ply Roofing Institute, Needham, Mass.

"Quality Control Guidelines for the Application of Sprayed Polyurethane Foam Roofing," 1997, National Roofing Contractors Association, Rosemont, Ill., Spray Polyurethane Foam Division, Washington, D.C.

"The Manual for Inspection and Maintenance of Spray Polyurethane Foam-Based Roof Systems: A Guide for Building Owners," 1998, National Roofing Contractors Association, Rosemont, Ill., Spray Polyurethane Foam Division, Washington, D.C.

"Repair Manual for Low-Slope Membrane Roof Systems," 1997, Asphalt Roofing Manufacturers Association, Calverton, Md., National Roofing Contractors Association, Rosemont, Ill., Single Ply Roofing Institute, Needham, Mass.

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