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HANDBOOK

ROOFING AND WATERPROOFING

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ABSTRACT

This military handbook covers many aspects of roof design and construction, beginning with the structural deck, choice of insulation, vapor control, many different systems of surfacing, an guidelines for plaza and below-grade waterproofing.

FOREWORD

This handbook has been developed from an evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command (NAVFACENGCOM), other Government agencies, and the private sector. This handbook uses, to the maximum extent feasible, national and institute standards in accordance with NAVFACENGCOM policy. Do not deviate from this handbook for NAVFACENGCOM criteria without prior approval of NAVFACENGCOM Criteria Office, Code 15C.

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MIL-HDBK-1001/2	Materials and Building Components	LANTDIV
DM-1.03	Architectural Acoustics	LANTDIV
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ROOFING AND WATERPROOFING

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Section 1: INTRODUCTION

1.1 Scope. This handbook sets forth guidelines for design of roofing, LAYOUT 1 and waterproofing systems for building construction. It covers design of new low-slope and steep roof systems, reroofing of existing buildings, and waterproofing, and dampproofing systems.

1.2 Roof Design Synthesis. Roof-system design requires a synthesis of the following factors:

a) Suitably firm and stable surface for roofing;

b) Slope for drainage;

c) Fire resistance (refer to MIL-HDBK-1008, Fire Protection for Facilities Engineering, Design, and Construction);

d) Wind-uplift resistance;

e) Thermal resistance;

f) Vapor control;

g) Life-cycle costing of available systems;

h) Ice dams and sliding snow;

i) Maintainability.

1.3 Roof-Mounted Equipment. Rooftop location of mechanical and electrical equipment should be avoided whenever practicable. Penthouses and covered ground level locations are preferred. Rooftop equipment creates many roofing problems:

a) Difficult flashing details;

b) Obstruction of drainage paths;

c) Increases hazardous rooftop traffic by repairment;

d) Makes roofing inspection, repair, and replacement more difficult.

1.4 Climatic Conditions. Varying climatic conditions have a big impact on roofing design. Vapor retarders are usually needed in cold climates and for buildings with high interior relative humidity. In warm, humid climates, e.g., Hawaii and Guam, however, vapor flows downward through the roof toward an air-conditioned interior. Placing a vapor retarder on the deck and below the insulation is harmful in a tropical climate. It prevents venting of water vapor to the interior, entrapping it in the roof sandwich where it may condense in the insulation (refer to Section 4).

This difference in predominant vapor-flow direction may influence the proper choice of roof system: conventional assembly with insulation sandwiched between the deck below and membrane above, or a protected membrane roof (PMR) assembly, with membrane and insulation positions reversed, i.e., with insulation above the membrane. In a cold climate where the predominant vapor-flow direction is upward from a heated interior, the membrane in a PMR doubles as a vapor retarder. This is an efficient arrangement. In a humid tropical climate, however, where the predominant vapor-flow direction is downward, the conventional roof assembly's position with the membrane above the insulation may be more efficient, with the membrane again functioning both as waterproofing and vapor retarder.

1.4.1 Solar Radiation. Solar radiation embrittles asphaltic materials and thermoplastic sheets. Plasticizers are lost through the combined effects of heat and sunlight. Shielding of the membrane and flashings is important. Aggregate, mineral granules, or heat-reflective coatings may be used as shields to increase the membrane's service life and cut cooling-energy costs.

1.4.2 Wind Velocity. Wind velocity has an impact on roof design apart from the obvious requirement of better anchorage (or heavier ballast) in high-wind areas. Loose aggregate ballast should not be used in high-wind areas. "Windstripping" of aggregate-surfaced built-up bituminous membranes has been noted in such diverse locations as Guam and Grand Forks, ND.

1.5 Roofing Material Selection. See Table 1 below for selection of low-slope membrane roofing. See Table 2, in Section 9, for selection of materials for steep roofing.

Table 1

Membrane Adaptability to Different Roof Systems				
MEMBRANE MATERIAL	LOOSE-LAID BALLASTED	ADHERED	ANCHORED MECHANICALLY FASTENED	
			BAR TYPE	INDIVIDUAL
Elastomeric, PVC, Uncured elastomeric sheets	Yes	Yes	Yes	Yes
Liquid-applied Coating	No	Yes	No	No
Modified-bitumen sheets	Yes[1]	yes	No[2]	Yes[2]
Conventional Built-up Roof	No	Yes	No	Yes[2,3]

[1]Limited to a few products, "No" for the majority.
[2]Underlayment sheet is mechanically fastened; membrane is adhered to underlayment sheet by means of torch or asphalt mopping.
[3]Base sheet only.

Note: Select membrane systems which are currently covered by COE and/or NAVFAC Guide Specifications.

Section 2: STRUCTURAL DECK

2.1 Functions. The structural deck serves two functions:

a) For structural resistance to gravity, wind and seismic forces;

b) As substrate for the roof system.

2.2 Design Factors. Structural decks must be designed with consideration of the following design factors:

a) Slope for drainage;

b) Dimensional stability;

c) Moisture absorption;

d) Anchorage (for wind-uplift resistance);

e) Deck surface and joints;

f) Expansion joints.

2.2.1 Drainage. In new construction, provide slope for drainage in the structural deck, when practicable, with minimum slope of 1/2 inch per foot (4 percent). For reroofing, provide a minimum slope for drainage of 1/4 inch per foot (2 percent). (Refer to Section 10.) Provide saddles or crickets in valleys and other locations requiring additional drainage-promoting techniques. Locate drains at low points, i.e., at center of simple spans and other locations of maximum vertical deflection.

Where provision of slope in the structural deck is impracticable specify tapered (sloped) insulation to provide slope. The choice between interior or exterior drains depends upon building size and configuration and local climate. Provide interior drains in cold climates where subfreezing temperatures may create drain-blocking ice in exterior drains.

Design the primary drainage system to accommodate the rainfalls listed in DM-3.01, Plumbing Systems. Where the roof is bounded with perimeter parapets, design a scupper system as secondary drainage, with bottom scupper elevations designed to limit ponding depth to a structurally safe depth in case the primary drains are clogged. Design perimeter scupper drains by the same criteria as the primary drain system, by the "contracted-weir" formula.

EQUATION: $Q\ (ft^3/min.) = 200(b - 0.2H)\ H^{1.5}$ (1)

where

b = scupper width (feet)
H = hydraulic head (feet), assumed 2-inch maximum depth

Have the total scupper cross-sectional area be a minimum of 3 times the cross-sectional area of the primary vertical drains, with minimum individual 3-inch scupper depth and minimum width/depth ratio of 2.5.

2.2.2 Deflections. Deflections maintained within normal limits (refer to par. 2.3.1) will have no practical effect on drainage on a roof surface with the minimum roof slope.

2.2.3 Expansion Joints. Roof expansion joints are recommended at the following locations:

a) Junctures between changes in deck material (e.g., from steel to concrete);

b) Junctures between changes in span direction of the same deck material;

c) Junctures between an existing building and later addition;

d) Deck intersections with nonbearing walls or wherever the deck can move relative to the abutting wall, curb or other building component;

e) Maximum spacings of 200 to 300 feet (61 to 91 meters);

f) Junctures in an H, L, E, U, or T-shaped building;

g) At building expansion joints.

Expansion joints should be located at high points, with drainage directed away from them. They should allow for relative movement in three directions, vertical, transverse, and longitudinal, detailed for minimum 8-inch (203-millimeter), maximum 12-inch (305-millimeter) curb height, with base and counterflashing.

2.2.4 Roof Assemblies. Design roof assemblies to satisfy established fire ratings, and Factory Mutual (FM) or Underwriters Laboratories, Inc., (UL) requirements. (Refer to Section 11.)

2.2.5 General Precautions

a) If the building is expected to have high interior moisture, refer to Section 4 and consult deck material manufacturer for information and recommendations;

b) Wood blocking around openings and drains must be installed before insulation and roofing is installed.

2.3 Precautions for Specific Roof Decks

2.3.1 Precast Concrete Panel Roof Decks

a) Camber differentials that exceed 1/8 inch (3 millimeters) must be corrected by using a Portland cement fill or grout, feathered to a maximum slope of 1/8 inch per foot (one percent);

b) To prevent bitumen drippage, joints should either be stripped in with felt or tape material recommended by roofing system manufacturer or grouted with cement fillings where openings occur.

2.3.2 Prestressed Precast Concrete Roof Decks. If rigid insulation is used, differentials in adjacent prestressed concrete units must be corrected by fill or grout, feathered to a maximum slope of 1/8 inch per foot (one percent).

2.3.3 Wood Board or Plywood Roof Decks. For all wood decks, a barrier of rosin sized sheathing paper or similar material should be placed between the roof membrane and the deck to allow relative movement.

2.3.4 Cement-Wood Fiber Panel Roof Decks

a) Resistance to wind uplift and lateral movement should be provided by one of the following anchorage techniques: (1) Clips, nails, or other devices anchoring the deck directly to the roof framing; or (2) Sub-purlins anchored to the roof framing system. Voids around tees should be grouted with material recommended by the deck manufacturer.

b) Because of the vulnerability to moisture, insects, and in some cases fire, these panels may be prohibited by some Military Construction Offices. Request specific permission to use before specifying.

c) Approved mechanical fasteners should be used for anchorage of the roof membrane to the deck. The anchorage recommendations of the manufacturer and insurance rating agencies should be followed. Above-deck insulation board should be solid-mopped to a mechanically anchored coated base sheet. Insulation may also be mechanically anchored if provided in two layers (e.g., bottom anchored, top set in hot bitumen).

2.3.5 Poured Gypsum Concrete Roof Decks

a) When insulation requirements and thicknesses permit, insulation is generally incorporated in the formboards. Because of the difficulties in applying a vapor retarder to this material, poured gypsum should be avoided where upward vapor flow is predominant. However, a vapor retarder should be considered when specifications require the installation of additional insulation on the top side of the deck.

b) The ceiling plenum should be adequately ventilated to the exterior or supplied with dehumidified air to prevent moisture buildup.

2.3.6 Lightweight Insulating Concrete Fills

a) To promote drying of the wet mix, lightweight insulating concrete should be limited to decks with underside venting: slotted, galvanized steel decks (minimum 1.5 percent open area) or permeable formboards (e.g., fiberglass).

b) Where high thermal resistance is required, additional, specially designed, closed cell insulation should be incorporated into the concrete. The practice of installing additional preformed insulation boards directly upon the deck is not recommended because it inhibits the drying of the concrete fill by solar radiation.

c) Fasten to the deck with approved fasteners a "venting" base sheet underlayment conforming to the American Society for Testing and Materials (ASTM) D 4897, Asphalt-Coated Glass-Fiber Venting Base Sheet Used in Roofing.

Section 3: THERMAL INSULATION

3.1 Purposes for Insulation. There are several purposes for using roof insulation as follows:

a) Reduce heating and cooling equipment capacity.

b) Reduce heating and cooling energy use.

c) Occupant comfort.

d) Condensation control.

e) Provide smooth substrate for roofing membrane.

f) Provide slope to flat roof decks.

3.2 Design Factors. A number of physical properties and application criteria must be considered in the design of each roof. Evaluation of these factors should consider the entire range of conditions that the roof assembly will be exposed to, including the extremes.

3.2.1 Compressive Strength. Consider the likely extent of roof traffic (including construction traffic) and insulation type and thickness.

3.2.2 Moisture Absorption. Where roof insulation is used in humidified buildings or in areas with large vapor pressure differentials, it is likely that moisture will accumulate in the insulation, even with the use of vapor retarders (refer to Section 4). Moisture absorption reduces the thermal resistance of insulation. When it is probable that moisture will accumulate in the insulation, the types of insulation material to be utilized should be those which are least likely to absorb moisture.

3.2.3 Dimensional Stability

3.2.3.1 Temperature. Provisions for expansion should be provided in order to accommodate changes in dimension due to temperature. The temperature range should consider the annual extremes. During colder weather, clear sky radiation can result in roof temperatures lower than design temperatures. During warmer weather, as a result of solar radiation, and depending upon roof color, roof temperatures in excess of 150 degrees

Fahrenheit (F) (66 degrees C) can be reached. Temperature ranges of more than 100 degrees F (38 degrees C) can be experienced in a single day.

3.2.3.2 Moisture. Provisions for expansion and contraction of roof insulation due to changes in moisture content should be made in the same manner as for temperature changes. Depending upon the type of insulation material utilized, the change in dimension due to moisture can exceed that due to temperature.

3.2.3.3 Dimensional Compatibility. Adequate provisions for changes in dimension should consider both the range of temperatures to be encountered and the likely range in moisture content. In addition, the dimensional stability of the insulation relative to the other materials in the roof assembly, such as the roof membrane and roof deck, should be considered. Where the change in dimension due to temperature varies considerably between the insulation and some other component of the roof assembly, provision should be made to accommodate this differential change in dimension.

3.2.4 Compatibility. It is important to establish the compatibility between the insulation and other components of the roof assembly. When using unfaced plastic foam insulation under built-up roofing, specify an additional top layer of wood fiber, fiber glass, or perlite insulation to guard against membrane blistering.

3.2.5 Thickness. With the high thermal resistance and low U-values commonly used for roof insulation, the thickness of insulation can be a substantial consideration in roof design. Drawing details should allow adequate space for the insulation's thickness.

3.2.5.1 Layering. When board type insulation is used, it is often necessary and preferred to have multiple layers. The insulation boards should be as large as can be practically handled and the joints should be staggered and offset between layers. Proper type and length fasteners should be used and consideration given to possible lateral movement of the roof insulation. Layering will reduce fastener heat transfer when the bottom layer is mechanically fastened.

3.2.6 Design Criteria. The energy evaluation of a building will determine the required thermal resistance or R-value for the roof by the application of design criteria and analysis of life cycle cost. Roof thermal resistance should meet or exceed agency criteria and requirements for Federal buildings.

3.2.6.1 Documents. The NRCA Energy Manual and the 1985 American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) 1985 Handbook - Fundamentals, Chapter 20, contain discussions on heat-flow calculations and economic insulation thickness for building envelopes.

3.2.6.2 Variations. High levels of thermal resistance are not always life cycle cost effective. Refer to the discussion on "Buildings With Dominant Internal Loads" in Chapter 20 Errata of the ASHRAE 1985 Handbook - Fundamentals.

3.2.7 Evaluation. An energy evaluation should be conducted for each building to determine if the roof insulation thermal resistance should be higher or lower than set forth above.

3.2.7.1 ASHRAE Methods. Chapter 28 of the ASHRAE 1985 Handbook - Fundamentals, provides a number of methods for estimating energy consumption associated with roof insulation. Hour by hour, detailed computer simulation methods are preferred. At least three levels of thermal resistance should be evaluated for the roof over each type of space in each building.

3.2.7.2 Life Cycle Cost. Economic evaluation of roof insulation should be carried out in accordance with NAVFAC P-442, Economic Analysis Handbook, or equivalent.

3.2.7.3 Important Considerations

a) Where some space heating is accomplished by means of heat recovery, or where some space cooling is accomplished by free cooling methods such as economy cycle, or cooling tower, or cooling resulting in lower purchased energy requirements, lower levels of thermal resistance can be justified on a life cycle cost basis. Where energy is expensive, higher levels can be justified.

b) Each area of a building may vary. The level of thermal resistance for each area of the building does not necessarily have to be the same throughout. Quite often, areas with long hours of operation and high internal heat gains will require less insulation than areas with little or no internal heat gain and/or short hours of operation. Compensate for reductions in R-value due to fasteners and structural members.

c) Roof surface color has an impact on energy consumption and membrane temperature and color should be considered in the evaluation of energy and life cycle cost, and when determining the suitability of the roof membrane.

3.2.8 Location. Roof insulation can be located either above or below the roof deck. In low slope roof buildings, above deck insulation is preferred.

3.3 Materials. A wide variety of insulation materials are available for use as roof insulation in buildings. Each material usually has a unique set of properties and compatibility with other roofing components which must be properly evaluated so that the roof will perform satisfactorily.

3.3.1 Board Insulation. This form may be either a single component material or a composite of two or more different materials.

a) Single Component Insulation

b) Composite Board Insulation. In order to provide compatibility with certain types of roofing materials and also to provide the desired fire rating, composite board insulation is available, consisting of two or more pre-assembled layers of differing insulation materials. Use of composite board insulation often allows application criteria and thermal resistance criteria to be met with minimum insulation thickness.

3.3.2 Insulating Concrete. Several types of lightweight insulating concrete are available for roof insulation purposes. They are typically installed over ventilated roof decks or formboard on low slope roofs, since it is possible to slope the concrete in order to provide roof drainage. The concrete must be able to exhaust original mixing water to the interior space. Also, refer to Section 2.

3.3.3 Sprayed Plastic Foam. Sprayed-in-place plastic polyurethane foam insulation is available for roof insulation. Refer to Section 7.

3.3.4 Properties. Physical property data are usually available from the insulation manufacturer and often consist of testing laboratory reports. Care should be taken that the data reported are appropriate for the conditions under which the roof will perform. Physical property data are also published in the

ASHRAE 1985 Handbook - Fundamentals, and the Manual of Built-up Roof Systems by Griffin. Where data reported by insulation manufacturers differs from that shown in handbooks, appropriate justification and explanation should be obtained. Where the thermal resistance declines with age, the aged values should be used.

3.4 Tapered Insulation. Where the roof deck is flat or level, one reasonable means available for providing adequate roof slope for drainage purposes is by using the insulation; tapered factory fabricated insulation may be used for this purpose. Manufacturers of several types of board insulation provide a variety of tapers. Where tapered insulation is to be used, careful detailing and dimensioning is necessary in order to ensure that the proper slope and positive drainage are achieved. The use of tapered insulation should be limited to reroofing of existing low slope roof buildings.

3.5 Application Criteria. It is extremely important that the type or types of insulation to be used are appropriate for the roof assembly. Refer to other sections in this handbook for specific criteria with each type of roof deck and/or roof membrane. Carefully read and evaluate the detailed application criteria and limitations on use for several major manufacturers of the type of insulation to be utilized or permitted along with other sections of this handbook, in order to eliminate any incompatibility.

Specific provisions should be set forth for the insulation manufacturer and contractor to meet to set up requirements regarding storage and installation of insulation. The insulation must be kept dry, both when stored on the job site and when installed on the roof. Waterproof covering over stored insulation is essential, as is elevating the insulation so that ground water cannot enter. Require that stored material be adequately secured from blowing away. Insulation must be covered at the completion of each day's work with completed roofing.

Means for securing the roof insulation to the roof deck to resist displacement, such as adhesives and/or corrosive resistant mechanical fasteners, which are compatible with the materials used, should be specified. Refer to Section 12.

Section 4: VAPOR CONTROL

4.1 Psychrometrics. The design of roofing must take into account the principles of moisture in air to prevent condensation of moisture in roof insulation and under roof surfaces. Psychrometrics deals with determination of the properties of moist air and utilization of these properties in analysis of conditions and processes involving moist air. A detailed discussion and tables of moist air properties are included in ASHRAE l993 Handbook - Fundamentals, Chapter 6.

4.1.1 Vapor Pressures and Flow. In order to determine the magnitude and direction of water vapor flow, examine the range of indoor and outdoor conditions that will exist over the course of a year. Moisture vapor flows from regions of higher vapor pressure to regions of lower vapor pressure.

4.1.1.1 Indoor. Indoor water vapor pressure is increased by the liberation of moisture from construction materials and building occupants, as well as moisture generated by plants, building processes and humidification. This tends to make the indoor vapor pressure higher than outdoor, causing the potential for flow of water vapor up through the roof in cold weather. When indoor space is air conditioned, including dehumidification, it is possible for the indoor vapor pressure to be lower than outdoors.

4.1.1.2 Outdoor. Outdoor vapor pressure is continuously varying throughout the year in any given location. When outdoor pressure is higher than indoor vapor pressure, there will be a tendency for vapor to flow outdoors to indoors through the roof.

4.1.1.3 Design Criteria. ASHRAE 1993 Handbook - Fundamentals shows outdoor design conditions for most locations throughout the world. Once indoor design conditions are established, the vapor pressure differential between indoor and outdoor can be readily determined. In order to establish the magnitude and direction of potential vapor flow under all conditions of operation, determine the variations in indoor and outdoor vapor pressures throughout a typical year of building operation.

4.1.2 Dewpoint. An analysis should be conducted to determine the potential for condensation to take place throughout all conditions of operation, both within the roof itself and on the surfaces of the roofing assembly. Such an analysis will determine the need to consider increasing the thermal resistance of insulation and/or incorporating specific methods for controlling vapor flow. Refer to ASHRAE 1993 Handbook - Fundamentals, Chapter 21.

4.1.3 Influence on Roof. Moisture condensation in the roof can result in reductions in insulation thermal resistance and dripping of condensed water from the underside of the roof. The dew point analysis should consider all potential condensation possibilities in order to provide proper control measures to preclude condensation. Generally, these control measures include insulation, ventilation, and vapor retarders. The analysis should consider not only design conditions of temperature and vapor pressure, but also daily and seasonal variations.

4.2 Vapor Control Methods. A variety of methods exist for controlling vapor in buildings and are generally set forth in ASHRAE 1993 Handbook - Fundamentals, Chapter 20.

4.2.1 Vapor Resistance. All building materials have some degree of resistance to vapor flow. A table of values for most building materials is included in ASHRAE 1993 Handbook - Fundamentals, Chapter 21, along with calculation methods to determine the magnitude of vapor flow and location of condensation planes.

4.2.1.1 Materials. Any material to be used as a vapor retarder should have a maximum rating of 0.5 perm (28.75 perm). Selection of the perm rating required for any given conditions should be based on the analyses described above. Water vapor retarders may be classified as rigid, flexible, or coating types of materials. Materials chosen should provide long term performance and be compatible with the other roofing materials. Frequently used vapor retarders are the flexible types, including plastic films and coated krafts and felts. These materials are available in a wide variety of perm ratings.

4.2.1.2 Calculations. Calculations for vapor flow should be made in accordance with ASHRAE 1993 Handbook - Fundamentals, Chapter 21.

4.2.1.3 Location. Where vapor flow is out of the building, locate vapor retarder as close as possible to the inside surface of the building envelope, usually on top of the roof deck. Where vapor flow is into the building, most often, the roofing membrane provides adequate vapor resistance to the vapor flow. Where vapor flow is both into and out of the building, the general preference for vapor retarder location is close to the indoor surface.

4.2.1.4 Application. Pay particular attention to the manner of installing and sealing the vapor retarder material. The design should also consider damage of the vapor retarder both during construction and operation of the building.

4.2.2 Ventilation. Since it is possible that some moisture will accumulate in the insulation, allow escape of the moisture by providing means for ventilation. In the case of wood frame residential type construction with attics, a variety of methods are commonly available to allow moisture which passes through the ceiling insulation to escape to the atmosphere. With low slope roof construction, other methods for ventilation are required. This approach can be called a self-drying system.

4.2.2.1 Below Insulation. Using boards or sheets with perforations or slots underneath low slope roof deck insulation will allow moisture to escape from the roofing system to the outdoors or indoors.

4.2.2.2 Above Insulation. Ventilation above the insulation in low slope roof decks can be accomplished either by using edge vents or top vents. Top vents penetrate the membrane and will increase the potential for leaks. Top vents, if used, should be spread uniformly throughout the roof area. Use caution when applying ventilation above or below insulation, because the same paths that allow moisture to escape will also allow moisture to enter if the vapor pressure differential is reversed. Top venting should not be used over insulation having limited moisture movement capability, such as plastic foams.

Section 5: BITUMINOUS BUILT-UP ROOF MEMBRANE

5.1 Material Description. As the weatherproofing component of a built-up roof system, the built-up bituminous membrane comprises three elements: bitumen, felts, and surfacing.

5.1.1 Bitumen. Bitumen resists water penetration in the interply adhesive films mopped between felt layers and the bituminous surface-coating or flood coat. The two types of bitumens are blown (i.e. oxidized) asphalts and coal tar pitch.

5.1.2 Felts. Felts stabilize and reinforce the membrane. Felts prevent excessive bitumen flow when the bitumen is warm and semi-fluid and distribute contractive tensile stress when the bitumen is cold and glasslike. Felt plies separate the interply bitumen moppings and provide the membrane's multiple lines of waterproofing defense.

5.1.3 Surfacing. Surfacing of built-up membranes comprises one of four basic types: aggregate, smooth, mineral surfacing, or protective/reflective coating.

5.1.4 Flashing. Flashings seal the joints where the membrane is interrupted or terminated. Base flashings, essentially a continuation of the membrane, form the edges of a watertight "tray." Counterflashings shield or seal the exposed joints and edges of base flashings.

5.1.4.1 Base Flashings. Recommended materials are the following:

a) One ply of granular surfaced modified bitumen sheet, over 2 plies of glass-fiber felt.

b) Three-ply glass-fiber felt (sometimes reinforced and granular surfaced).

c) Metal base flashings should be restricted insofar as practicable to vent-pipe seals, gravel-stop flanges, and drain flashings, where there are no practicable alternatives.

5.1.4.2 Counterflashings. Counterflashings (sometimes called "cap flashings") are usually made of metal: aluminum, galvanized steel, stainless steel, copper, or lead sheets designed to shield exposed base flashing joints and shed water from vertical or slanting surfaces onto the roof.

5.2 General Requirements

5.2.1 Felts. Organic felts are highly vulnerable to moisture-induced deterioration; use the more durable fiber glass felts. Organic felts can, however, be used in temporary membranes that are to be removed or in coal-tar pitch membranes.

5.2.2 Modified Bitumen Flashing. Single-ply modified bitumen sheets may be used for flashing material.

5.2.3 Compatibility. Check with the manufacturer of built-up roofing membrane and flashing materials to assure that proposed roof system and materials are compatible with roof deck, vapor retarder, insulation, and geographic location.

5.3 Membrane Design Recommendations

5.3.1 Bitumen Slope Limits

SLOPE (inches per foot (percent)	BITUMEN TYPE	SOFTENING POINT (degrees F (C))
1/2 (4) or less	Asphalt, ASTM D 312, Type I	135 - 151 (57 - 66)
1/2 to 1-1/2 (4 to 12)	Asphalt, ASTM D 312, Type II	158 - 176 (70 - 80)
1 to 3 (8 to 25)	Asphalt, ASTM D 312, Type III	185 - 205 (85 - 96)
Steep and flashings	Asphalt, ASTM D 312, Type IV	205 - 225 (96 - 107)
1/4 (4) or less	Coal Tar Pitch, ASTM D 450 Type I	126 - 140 (52 - 60)
1/2 (4) or less	Coal Tar Pitch, ASTM D 450 Type III	133 - 147 (56 - 64)

Require bitumen manufacturer to provide equiviscous temperature (EVT) stenciled on every bitumen container or tanker weight bill to facilitate application at proper viscosity.

5.3.2 Flashing Design Principles. Good flashing design requires the following:

a) Elimination of as many penetrations as practical;

b) Location of individual roof penetrations at least 18 inches (457 millimeters) apart;

c) Consolidation of as many openings as possible into a smaller number of larger openings;

d) Use bituminous base flashings, i.e., modified bitumens or glass fiber flashing felts, at parapets, walls, expansion joints, and curb framing access hatches, vents, or equipment openings.

e) Location of flashed joints above the highest water level on the roof, with drainage away from flashed joints;

f) Allowance for differential movement between base and counterflashing;

g) Firm connection of flashings to solid supports;

h) Contouring of bituminous base flashings with cants to avoid sharp bends;

i) Avoidance of surface-applied cap flashings.

j) Always avoid pitch pockets always in new construction and whenever possible in reroofing. When required, fill with a crowned pourable sealer.

5.3.2.1 Differential Movement. Flashing details must provide for differential movement among the different parts of the building. Where there is any possibility of differential movement between the roof deck and vertical elements, do not anchor base flashings to the intersecting vertical elements. Anchor the counterflashing to the wall, column, pipe or other flashed building component. Review detailing carefully.

5.3.2.2 Contour Flashings. With built-up flashing materials, use cants with 45 degree (100 percent) slope. Cants should also be used with modified bitumen flashings.

Wood cants (southern yellow pine, Douglas fir, or equivalent), pressure-treated with water-base preservatives may be preferable to fiberboard cants where they brace the right-angle joint between vertical and horizontal nailers at equipment or wall curbs. Avoid fiberboard cants for torch-applied modified-bitumen flashing.

5.3.3 Foot Traffic. Refer to par. 10.7.

5.3.4 Details. For details on flashings, anchorage, felt laps, requirements on felt requirements on felt backnailing, all metal work, and application of built-up membranes to various substrates, refer to the National Roofing Contractors' Association (NRCA) Roofing and Waterproofing Manual, and Sheet Metal and Air Conditioning Contractors National Association (SMACNA) Architectural Sheet Metal Manual.

Section 6: SINGLE-PLY ROOFING SYSTEMS

6.1 Single-Ply Roofing Description. A membrane, sheet or liquid-applied, with only a single layer of material designed to resist water penetration.

6.1.1 Single-Ply Sheet-Applied Materials. Sheet-applied membranes can be chemically classified in one of the following categories: elastomers (synthetic rubber), plasticized thermoplastic polymers, uncured elastomers, or modified bitumens. (Refer to Table 1 for membrane adaptability to different roof systems.)

6.1.1.1 Elastomeric Sheet. The most common elastomeric sheet is ethylene propylene diene monomer (EPDM).

Field lap seams are the most vulnerable component in elastomeric sheet systems. EPDM is a thermosetting polymer and requires use of contact adhesive and tape. Contact adhesive generally requires:

a) thorough cleaning of the material with solvent-soaked rags;

b) a waiting period for the contact adhesive to attain proper consistency;

c) thorough pressure-sealing of the lap; and

d) application of a side lap sealant for temporary protection while the contact adhesive cures.

Defective seams are vulnerable to rainwater ponding, especially frozen water. Prolonged water intrusion impairs the performance of neoprene-based contact adhesives. Non-neoprene-based adhesives are significantly less vulnerable to moisture intrusion.

6.1.1.2 Plasticized Thermoplastic Sheets. Plasticized thermoplastic sheets are represented by PVC membrane sheets, reinforced and unreinforced. Watertight field lap seams are formed in PVC sheet by comparatively easily installed solvent-welded or heat-welded lap seams. These seams are true fusions of base and jointing material.

A major liability of PVC sheet membranes is that they may, under certain exposures, become embrittled and shrink from loss of plasticizer. Unreinforced, they have an extremely high coefficient of thermal contraction-expansion. However, reinforcement (woven fiberglass mat or polyester reinforcement) can vastly improve dimensional stability.

6.1.1.3 Uncured Elastomers. Uncured elastomers are chemically intermediate between the thermosetting (i.e., elastomeric) and thermoplastic polymers. The single-ply membranes containing these intermediate polymers are CPE (chlorinated polyethylene), CSPE (chlorosulfonated polyethylene, known commercially as Hypalon), and PIB (polyisobutylene).

Relative to elastomeric and thermoplastic sheets, advantages are:

a) lap seams can be heat-or adhesive-bonded.

b) easier field-forming of reliable lap seams;

c) may cure or vulcanize over a period of time and become thermosets.

A major disadvantage is that they lack the abrasion resistance of vulcanized rubber. Another disadvantage of CSPE is that after it has cured, it is difficult to repair using heat-bonding methods.

6.1.1.4 Modified Bitumens. Modified bitumens are essentially rubberized asphalts. The addition of rubber to the asphalt imparts elastomeric properties to the asphalt and increases the membrane's breaking strain by a factor of 10 or more compared with a conventional built-up bituminous membrane's breaking strain. The polymers used to make these physical improvements in the modified-bitumen membranes include atactic polypropylene (APP), styrene-butadiene rubber (SBR), and styrene-butadiene-styrene block polymer (SBS). Reinforcement is generally polyester or glass fibers, sometimes in combination.

The Canadian General Standards Board (CGSB) divides modified bitumen membranes into three categories:

a) By exposure: Type 1, exposed (always anchored); Type 2, shielded (anchored or loose-laid);

b) By surfacing: Class A, granule-surfaced; Class B, metallic-surfaced; Class C, plain-surfaced;

c) Service conditions: Grade 1, standard; Grade 2, heavy-duty.

6.1.2 Liquid-Applied Coatings. Liquid-applied coatings are a special class of fully adhered membranes. Chemically, they are synthetic rubbers.

6.1.2.1 Uses. A major use of liquid-applied coatings is on a substrate of sprayed polyurethane foam (PUF) roofs, which require a waterproof coating. Liquid-applied coatings for sprayed PUF roofs include polyurethane, neoprene, hypalon, acrylic, and silicone. Other acceptable substrates for these coatings are bare concrete and plywood.

6.1.2.2 Advantages. Within their narrow range of applicability, fluid-applied membranes have these notable advantages:

a) conformance to irregular roof surfaces with good adhesion and little waste;

b) continuous, seamless waterproofing (including base flashing at penetrations and edges for some systems).

6.1.2.3 Disadvantages. They have:

a) Overwhelming dependence on high-quality field work. In a concrete deck, cracks must be located, marked, and either sealed or taped. Cracks and seams greater than 1/64 inch (0.4 millimeters) must be sealed. A viscous mastic and seams greater than 1/64 inch (0.4 millimeters) must be sealed. A viscous mastic material seals cracks between 1/64 and 3/8 inches wide (0.4 and 9.5 millimeters), and because of mastic shrinkage, satisfactory joint filling may require two mastic applications. Cracks or joints over 3/8 inches (9.5 millimeters) require taping.

b) Cast-in-place concrete decks must be steel-troweled and then cured for at least four weeks to reduce repairs of post-application shrinkage cracks.

c) To prevent moisture entrapment in the liquid-applied membrane, at least two days must be allowed between the latest rainfall on the substrate and membrane application.

6.2 Perimeter Anchorage. With the possible exception of liquid-applied systems, single-ply systems are anchored at their perimeters and at openings. Such anchorage serves several purposes:

a) To prevent stress concentration at flashings, which could either split or pull loose from their backings and become vulnerable to puncture. (Loose-laid systems receive maximum membrane tensile forces at perimeters and other terminations, according to field strain tests);

b) To restrain contraction in materials subject to long-term shrinkage;

c) To reduce membrane wrinkling which can obstruct drainage.

6.3 Design Requirements/Considerations

6.3.1 Single-Ply Roofs. For roofs on new facilities (Refer to Section 10 for reroofing):

a) Require minimum 1/2 inch per foot (4 percent) slope, 2 inch per foot (17 percent) maximum slope for loose-laid, ballasted systems.

b) Review material properties, limitations, advantages and disadvantages, and past performance of all systems under consideration (check 10-year performance in your geographical location);

c) Determine wind and fire resistance during this preliminary survey. Consult Single Ply Roofing Institute (SPRI) Wind Design Guide for Ballasted Single-Ply Roof Systems Single-Ply Roofing. Ballasted systems should not be specified in coastal areas;

d) Check substrate for suitability: for sheet membranes, suitable substrates are structural concrete (cast-in-place and precast), lightweight insulating concrete with low moisture content, plywood, and rigid insulation board; for fluid-applied membranes, suitable substrates are structural concrete (cast-in-place and precast) and sprayed-in-place polyurethane foam;

e) For cast-in-place concrete decks, check concrete curing agents to ensure compatibility with synthetic membranes. Some curing agents can cause poor adhesion or even premature deterioration of the membrane;

f) Limit plywood to 5/8 inch (16 millimeters) minimum thickness, smooth-surfaced exterior grade, with edge support limiting differential deflection of adjacent panels to 1/8 inch (3 millimeters) at panel edges and 1/16 inch (2 millimeters) at ends;

g) Do not specify fluid-applied synthetic membranes when substrate joint movement is anticipated;

h) Consider repairability in case of future damage.

i) Roof deck structural capacity: For loose-laid, ballasted systems, design for additional 10 to 25 psf (0.0005 to 0.0012 Pascal) dead-load capacity for ballast and/or concrete pavers;

j) If there is waste spillage or exhaust onto roof surface, determine the nature of waste material. Periodic roof wash-down may be required; or other special membrane maintenance;

k) Check compatibility of adhesives, films and insulations.

l) Do not permit "torching" of modified bitumen sheets on buildings with combustible substrate components.

6.4 Applicable Details. Refer to SMACNA Architectural Sheet Metal Manual or manufacturers' information.

6.5 Single-Ply Membrane Standards. Where applicable, standards to be used for single-ply membrane materials are promulgated by the Rubber Manufacturers Association (RMA), American Society of Testing and Materials (ASTM), and the Canadian General Standards Board (CGSB).

Section 7: SPRAYED POLYURETHANE FOAM

7.1 Material Description. Sprayed polyurethane foam (PUF) is a field-produced, monolithic plastic foam roof insulation, produced in the field by nozzle-mixing of two separate liquid streams, an A (isocyanate) component and a B (hydroxyl or polyol) component. In addition to these basic chemical ingredients, the sprayed field mix also requires:

a) a blowing agent (fluorocarbon gas) to form foamed cells that expand the polyurethane foam resin's volume;

b) a surfactant to control cell size and cell-wall rigidity;

c) catalysts to control the reaction rate between the two chemical components);

d) fire retardants.

7.2 Uses. Although sprayed polyurethane foam can be used for new roofs, its major use is in reroofing.

7.2.1 Advantages. Compared with conventional built-up roof systems, PUF offers the following advantages:

a) High thermal resistance per unit thickness;

b) Lightweight (roughly 1 psf (5 kilograms per square meter) for 3-inch (76-millimeter) thick foamed insulation plus membrane coating);

c) Fast construction (generally two to three times the rate of conventional bituminous systems);

d) Adaptability to steeply sloped, curved, and other irregular roof surfaces;

e) Excellent adhesion, capable of producing 3,000 psf (0.14 Pascal) uplift resistance when placed on a clean, dry, properly prepared substrate;

f) Simple flashing details;

g) System is seamless;

h) Exterior damage is localized by its closed cell structure;

i) Recoating will "renew" the system; some coatings are guaranteed for 10 years.

7.2.2 Disadvantages. Compared with conventional built-up roof systems, sprayed polyurethane foam has some offsetting disadvantages:

a) Added cost of recoating the fluid-applied membrane periodically;

b) Greater difficulty in obtaining a level surface and uniform insulation thickness;

c) Extremely high dependence on applicator's skill;

d) High dependence on good substrate preparation;

e) Reduced traffic and impact resistance;

f) High vulnerability to degradation in hot, humid climates;

g) Vulnerability to bird-pecking. Birds will peck through the outer covering, dig out the foam, and sometimes build nests in the cavity.

7.3 Design Recommendations. Consider both design and field-application requirements. First, consider the following design items:

a) Slope of substrate. Do not rely on applicator varying foam thickness to provide slope-to-drain (minimum 1/2 inch per foot (4 percent) for new construction and 1/4 inch per foot (2 percent) for reroofing);

b) Wind uplift resistance conforming to FM requirements;

c) Substrate requirements. Most systems prohibit foam application directly to a conventional ribbed steel deck. They require a minimum 3/8 inch (10 millimeters) thick exterior-grade plywood (untreated) fastened to the deck. Fastenings should conform with FM requirements for anchoring insulation boards

d) Vapor retarder (if required);

e) Membrane coating (refer to par. 7.3.3);

f) Fire resistance ratings. Class A when tested by UL 790, Tests for Fire Resistance of Roof Covering Materials and FM Class 1 for most applications;

g) Flashing details.

7.3.1 Foam Thickness and Slope. Whenever possible, slope the deck rather than varying foam thickness to provide surface slope. Slope may also be provided by installation of compatible, tapered roof insulation as a substrate before spray application of uniformly thick foam. Uniform thickness is more apt to produce uniform quality because varying thickness requires varying spray rate to maintain uniform chemical reaction rate. If slope is provided by foam, use tapered boards to indicate proper surface contours of foam.

7.3.2 Control Joints. Provide control joints at all re-entry corners, with roof divided into sections of 10,000 square feet (929 square meters) or less.

7.3.3 Membrane Coatings. Polyurethane foam requires a protective membrane covering. A good membrane coating must have these properties:

a) Good adhesion;

b) Temperature stability (i.e., viscous at high temperature, but not brittle at low temperature);

c) Abrasion resistance;

d) Weather resistance (to solar radiation, rain);

e) Maintainability (ease of repair when damaged, integration of repaired section with original material);

f) Durability;

g) Strength and elasticity;

h) Low permeability in humid climates.

7.4 Application Considerations. Consider the following application items:

a) Polyurethane foam resins field-sprayed to uniform thickness (1 inch (25 millimeters) minimum thickness, 2-1/4 inches (57 millimeters) maximum thickness) (two to three inches (51 to 76 millimeters) in semi-tropical environments) for best control of foam cell size, density, and overall uniform foam quality.

b) Membrane coatings applied to sprayed polyurethane foam substrates should always be fluid-applied. Fluid application works best with sprayed polyurethane foam because it fills the irregular substrate and adapts better to the slightly irregular surface of sprayed foam, to the "day's-work" termination details, and to the flashing of sprayed foam substrate. Foam applied today must be coated today. Coating should be applied in two or more coats with total minimum thickness as follows: 30 mils (0.76 millimeter) for silicone, 40 mils (one millimeter) for urethane or acrylic. In hot climates increase urethane to 45 mils (1.1 millimeter) and do not use acrylics.

7.5 Flashings. Fluid-applied flashings are generally self-sealing extensions of the membrane coating, applied simultaneously. Always specify cants.

7.6 Applicable Details. Polyurethane Foam Contractors' Division of the Society of Plastics Industry and Manufacturers' publications.

Section 8: PROTECTED MEMBRANE ROOF SYSTEM

8.1 Description. The protected membrane roof system (PMR), also known as the "IRMA" roof, or inverted roof membrane assembly, reverses the positions of membrane and insulation in the conventional built-up membrane roofing system. Instead of its conventional exposed position atop the insulation, a PMR membrane is sandwiched between the insulation above and the deck below. A PMR, from bottom up, may include the following components:

a) Deck;

b) Suitable underlayment leveling board (steel decks only);

c) Additional layer of insulation (optional; for energy savings; may be tapered to improve slope to drain);

d) Membrane;

e) Percolation course (optional);

f) Insulation;

g) Filter fabric;

h) Ballast (aggregate or pavers).

8.2 General Design Recommendations

8.2.1 Structural Capacity. First consider the structure's load-carrying capacity. There must be structural capacity to carry the additional ballast or paver dead load required by this system.

8.2.2 Slope. Slope deck and membrane a minimum 1/2 inch per foot (4 percent) for new construction.

8.2.3 Water-Test. When practical, require that roofer water-test completed membrane before installing insulation and surfacing with special attention to expansion joints and flashings. Leaks generally occur under expansion joints, flashings, and at embedded edge metal.

8.2.4 Climate. PMR's are well-suited to cold climates, as the membrane doubles as a vapor retarder. The best location for a PMR membrane in a perpetually cold climate is obviously below the major insulation. (An optional thin layer of minor insulation can level the membrane substrate and reduce heat/energy losses from convective and evaporative cooling following a rain. For additional energy savings, a layer of expanded polystyrene or other type of insulation under the membrane may be more cost effective than excessive extruded polystyrene above the membrane.) In perpetually humid tropical climates, the best location for the membrane is above the major insulation, such as for a conventional system, where the membrane serves as both roof and vapor retarder. PMR is excellent for areas with high ultraviolet exposure.

8.3 Specific Design Recommendations. PMR system design requires attention to the following aspects:

a) Drainage: slope to drains minimum 1/2 inch per foot (4 percent) for new construction and 1/4 inch per foot (2 percent) for reroofing projects;

b) Deck: Refer to par. 8.2.2; design to support ballast and live loads;

c) Membrane: built-up bituminous membrane; modified bitumen; single-ply sheets; liquid applied;

d) Percolation course: Optional, 1-1/2- to 2-inch (38- to 51-millimeter) minimum washed rock;

e) Insulation: use only extruded polystyrene conforming to ASTM C 578 Rigid, Cellular Polystyrene Thermal Insulation, Type IV, above the membrane;

f) Filter fabric: non-rotting material (i.e. porous mat of polyester, polypropylene, polyethlene, etc.);

g) Ballast: 3/4- to 2-1/2-inch (19- to 64-millimeter) washed rock, spread at a 10 to 20 psf (49 to 98 kilograms per square meter) density; concrete pavers, concrete wearing surface, or composites of polystyrene and latex mortar. Large arrays of flat bottom pavers should be elevated on pedestals to allow for drainage.

8.3.1 Drainage

a) To properly function, a PMR must have fast rainwater runoff. Assure this by requiring a sloped membrane, percolation course, well-drained insulation, and smooth-finished surface.

b) Locate roof drains where they will not freeze. The first few feet of pipe from drains must be thermally protected in cold regions. Provide weep holes in drain at each sub-assembly level.

c) Consider using elevated scuppers in case drains become blocked.

d) In geographical areas subject to intense rainfall, overflow drains should be considered. Overflow drains are smaller in diameter than regular drains. They are placed upstream 10 to 15 feet (3048 to 6096 millimeters) and terminate at the top of the insulation, or percolation course, if included, with weep holes at the membrane level. The drain cage must be fine enough to prevent infiltration by percolation materials.

8.3.2 Percolation Course. The optional percolation course is designed to allow easy and free access of water to the drains and the insulation above to dry. This rock course should be graded 1-1/2- to 2-inch (38- to 51-millimeter) maximum size. It must be rescreened before sending to the roof as fines develop in transit.

8.3.3 Flashings. Flashings for a PMR are essentially the same as for conventional roofs. They are, however, more vulnerable to damage, especially at cants adjacent to pavers. They should be carried a minimum of 8 inches (203 millimeters) above the roof's surface.

8.4 Variations. The insulation may be placed directly on the membrane, and the percolation course can be placed directly on the insulation with its filter fabric. The percolation course then serves as a ballasted finish.

8.5 Other Considerations

8.5.1 Single-ply or Liquid Membrane. A four-ply fiberglass built-up system set in hot bitumen or a modified bitumen system are the most common membranes used in a PMR. However, a single-ply or liquid membrane may also be used.

8.5.2 Expansion Joint. In flush joints, never drape membrane materials in or over an expansion joint. Use preformed joint formers.

8.6 Applicable Details. NRCA Roofing and Waterproofing Manual, SMACNA Sheet Metal Manual, SPRI and design information and specifications of extruded polystyrene insulation manufacturers.

Section 9: STEEP ROOFING

9.1 Steep Roofing Description. Steep roofing comprises a wide variety of roofing materials used on slopes exceeding 1-1/2 inches per foot (14 percent). Shingles, shakes, and tiles depend on the gravitational-force component provided by slope to assure positive water-shedding. The gravitational water shedding force must exceed all the opposing forces (kinetic, capillary, and atmospheric suction) tending to draw water up the slope between overlapping roof units. A slope of 4 inches per foot (33 percent) is adequate for most steep roofing systems to assure dependable water-shedding. When used on lower slopes (less than 1-1/2 inches per foot (14 percent)), steep roofing requires additional measures to assure good performance.

9.2 Materials. Steep roofing materials including the following: asphalt shingles, asphalt roll roofing, wood shingles and shakes, clay and concrete tiles, metal, and slate. Consult the NRCA Steep Roofing Manual, the SMACNA Architectural Sheet Metal Manual, and the Asphalt Roofing Manufacturers Association (ARMA) Residential Asphalt Roofing Manual for steep roofing details.

9.3 General Design Requirements

9.3.1 Slopes. Minimum slopes for various steep roofing materials are shown in Table 2. In snow country, designers should consider hazards of sliding and drifting snow.

9.3.2 Decks. Structural plywood decks facilitate the most convenient, economical, and dependable fastening techniques. Other deck materials, such as concrete, require installation of nailing strips, laths, horizontal battens, etc. These are described in the NRCA Steep Roofing Manual.

9.4 Underlayments. Several purposes are served by underlayments:

a) To keep the deck dry until shingles or tiles are installed;

b) To provide secondary water resistance protection if shingles or tiles are damaged, wind-lifted, or if wind-driven rain or water behind ice dams at cold eaves ever penetrate beyond the overlapped shingle;

c) Form a cushion for slates;

d) Minimize possible chemical reactions between resins in wood decks and asphalts in asphalt shingles or roll roofing.

9.4.1 Underlayments for Steep Roofing. Underlayments generally consist of one layer, non-perforated asphalt saturated felt for slopes of four inches per foot and higher. For lesser slopes, two layers of the same felt may be required and should be applied with a 19-inch (483-millimeter) overlap. Modified bituminous membranes are used at cold eaves in cold regions.

9.4.2 Underlayment for Wood Shake, Clay Tile, and Concrete Tile Roofs. Underlayment is required only in the following areas:

a) In valleys or eaves where ice dams may form;

b) Where blowing dust or sand occurs regularly;

c) In hurricane zones.

Regardless of the type of underlayment required, or the slope of the roof, in locations where the January mean temperature is 30 degrees F (-1 degree C) or less, two plies of No. 15 felt, set in hot asphalt or mastic, or an adhered bitumen membrane should be applied as the underlayment starting from the eaves to a point 24 inches (610 millimeters) inside the inside wall line of the building to serve as an ice shield.

Wood shake roofs of less than 4 inches (33 percent) slope require other measures; i.e., one layer asphalt saturated felt underlayment nailed to wood decks followed by one layer of the same type of felt applied with hot moppings of asphalt, plus construction of a vented lattice work of boards above the structural deck. For other measures designed to improve water-resistance and overall roof system performance, refer to the NRCA Steep Roofing Manual.

Table 2

Minimum Slopes for Steep Roofing

MATERIAL	MIN. SLOPE (in./ft. (percent))	NOTES
Flat Shingle Tile (clay or concrete)	5 (42)	
One-piece Barrel Tile (clay or concrete)	4 (33)	Double-layer felt underlayment required 4-in./ft. (33 percent) slope, single layer for slope greater than 4 in./ft. (33 percent)
Two-piece Shingle Tile (clay)	4 (33)	
Interlocking Flat-ribbed Tile (clay or concrete)	4 (33)	
Asphalt Shingles	4 (33)	1 layer, non-perforated saturated felt underlayment for 2-1/2-in./ft. (21 percent) slope may be used if special precautions, described in the NRCA Steep Roofing Manual and ARMA Residential Asphalt Roofing Manual are taken.
Wood Shakes and Shingles	4 (33)	
Metal (Corrugated Stl., Alum.)	3 (25)	Refer to SMACNA Manual.
Asphalt Shingles	2-1/2 (21)	Requires nonperforated, (square-tab strip) saturated felt underlayment, double layered with 19-in. (483-mm) overlap and set in roofing cement.
Asphalt Roll Roofing	2 (17)	Requires double-coverage (exposed nails) roll, 3-in. (76-mm) top lap.
Asphalt Roll Roofing	1 (8)	6-in. (152-mm) end lap, (Concealed nails) 19-in. (483-mm) selvage.
Copper, Tern	1/2 (4)	With double locked soldered seams.
Standing Seam, Metal	1/2 (4)	Requires floating-clip design.

9.5 Ventilation. Ventilation is required in attic spaces between the steep-roofing framing and the ceiling to prevent condensation from forming on cold surfaces when warm, humid air flows upward from heated interiors or, in warm climates where it is simply entrapped in these attic spaces. Air movement prevents or alleviates condensation on under-surfaces of shingles, tiles, or roof decks and, therefore, prevents fungus rot of wood in the attic. Provide screened vents at eaves and gable ends to remove humid air. Ventilation also reduces roof temperatures, therefore prolonging membrane service life and, in cold climates, preventing ice dam formations and snow slides. For cold region designs, consult U. S. Army, Cold Regions Research and Engineering Laboratory (CRREL), 72 Lyme Road, Hanover, NH 03755-1290, to ensure good performance.

9.5.1 Vents. A minimum net free ventilation area of one square foot for every 300 square feet (28 square meters) of attic area is required. Ridge vents should be used whenever practicable, in conjunction with eave soffit vents. Ridge vents induce air-pressure differentials and accelerate air movement through the attic. In small gabled roofs without ridge vents, when the ceiling is applied to the bottom of the rafters, l-inch (25-millimeter) diameter holes should be drilled through the ridge beam in every joist space to provide unobstructed transverse air flow to outside area.

9.6 Anchorage Techniques

9.6.1 Fasteners. Nailing types and sizes for different steep roofing materials are shown in Table 3. Fasteners should be corrosion resistant. For asphalt shingle fasteners, consult the ARMA Residential Asphalt Roofing Manual, or ARMA Asphalt Roofing With Staples Manual. Fastener requirements for clay and concrete tile vary with slope and wind design conditions. Wiring may also be required for anchoring of clay and concrete ridge tiles.

9.6.2 Special Anchorage. In addition to fasteners, anchorage of various steep roofing material requires other techniques. Lap cement is used at seams in asphalt roll roofing (side, end, ridge and hip strips). Asphalt shingles have self-sealing strips. Clay and concrete tiles may require embedment in plastic cement. Plastic cement is often used to secure slate units at ridges and hips.

9.6.3 Anchorage in Hurricane or High-wind Zones. These require additional anchorage precautions. Clay and concrete tiles should be secured with special hurricane clips, additional fastening, and additional headlap (3 inches (76 millimeters) additional in 70 to 100 miles per hour (113 to 161 kilometers per hour) wind zones, 4 inches (102 millimeters) additional in hurricane zones of 100 plus miles per hour (161 kilometers per hour) winds.)

9.7 Flashings. Flashings are required on steep roofs as well as low slope roofs to seal the joints at roof terminations and intersections - e.g., where roof planes intersect to form valleys, where dormers, chimneys, skylights, and other components pierce the roof, and at roof perimeters. For general guidance to the materials and techniques in flashing steep roofs refer to Table 4.

9.8 Applicable Details. NRCA Steep Roofing Manual, SMACNA Architectural Sheet Metal Manual, and ARMA manuals (latest issues).

Table 3

Fasteners for Steep Roofing

ROOF MATERIAL	FASTENER REQUIREMENTS
Asphalt Roll Roofing	No. 11 or 12 gauge hot dipped galvanized 3/8-inch (10-millimeters) minimum heads, shank length long enough to penetrate through the roofing and deck or at least 3/4 inch (19 millimeters) into a plywood or lumber deck.
Clay or Concrete Tile	No. 11; galvanized, yellow metal or stainless steel, shanks to penetrate minimum 3/4 inch (19 millimeters) into sheathing or through it.
Asphalt Shingles	No. 11 or 12 gauge, hot-dipped galvanized, 3/8-inch (10-millimeter) minimum heads, with shank length long enough to penetrate through the roofing and through a wood panel deck or at least 3/4 inch (19 millimeters) into a lumber deck.
Wood Shakes, Shingles	Rust-resistant, galvanized or aluminum nails, l4 gauge, 3d x 1-1/4 inch (32 millimeters) long for 16-inch (406-millimeters) and 18-inch (457-millimeter) shingles or shakes; 14 gauge, 4d x 1-1/2 inch (38 millimeter) long for 24-inch (610-millimeter) shingles or shakes.
Slate	Copper slating nails only. 3d up to 18-inch (457-millimeter) long slates, 4d for 18-inche (457 millimeters) and longer slates, 6d nails at hips and ridges. Minimum length = 2 x slate thickness + 1 (e.g., 1-1/2 inch (38 millimeter) minimum length for 1/4-inch (6-millimeter) slate).

NOTE: "Hot" roofs in cold regions should slope 4 inches per foot (33 percent) or more (with backnailing) and have eave overhangs of less than 12 inches (305 millimeters) to minimize ice dam problems.

Table 4

Steep Roofing Flashing Guide[4]

ROOF MATL FLASHING CONDITION	TILES (Clay, Concrete)	ASPHALT SHINGLES	WOOD (Shakes, Shingles)	SLATE	ASPHALT ROLL ROOFING
CHIMNEY CRICKET	NO	YES[1]	YES[1]	YES[2]	YES
STEEP FLASHINGS	YES	YES	YES	YES	NO
VALLEY FLASHINGS		METAL SURFACED ROLL ROOFING	MINERAL	METAL[3]	METAL CONSULT ARMA RESIDENTIAL ROOFING MANUAL
PERIMETER	METAL	METAL	METAL	METAL	MEMBRANE TERMINATION

[1]DECK CRICKET
[2]METAL CRICKET
[3]OR “ROUND-VALLEY” CONSTRUCTION
[4]Consult the NRCA Steep Roofing Manual and SMACNA Architectural Sheet Metal Manual for details

Section 10: REROOFING

10.1 Introduction. Reroofing is necessary when it is no longer economically viable to maintain the existing roof. Reroofing options are recovering or replacement. However, the recover option is usually not the best option. Before deciding on either option, determine why the existing roof failed.

10.2 Reroofing. Reroofing of steep roofing usually requires removal of old materials - either total or individual removal of cupped, wrinkled, or other damaged units - in tile and slate roofs. For these materials, reroofing is governed by the same criteria as new construction.

For asphalt and wood shingles and shakes, however, recover roofing is an option. Asphalt shingles can be applied over old asphalt shingles or old wood shakes or shingles and, conversely, wood shakes and shingles can be applied over old asphalt shingles. Roll roofing can sometimes be safely recovered with asphalt shingles, but it is generally prudent to remove old roll roofing before asphalt shingle replacement. For guidelines on repairs, substrate examination, and preparation required before recovering old steep roofing, consult the NRCA Steep Roofing Manual and the ARMA Residential Asphalt Roofing Manual.

10.3 Premature Failure Preliminary Investigation. Analyze the roof with the following in mind:

a) Structural conditions contributing to the roofing problem;

b) Interior space psychrometrics contributing to the roofing problem;

c) Topside deficiencies contributing to the roofing problem.

10.3.1 Structural Influence. The existing roof deck, supporting structure, and, in many cases, wall sections projecting above the roof elevation have a direct bearing on the longevity of the roofing composite. Structural influences to be considered include the following:

a) Type of roof deck material;

b) Deterioration of roof deck and/or structure;

c) Deflection of roof deck and/or structure;

d) Expansion joints and/or control joints;

e) Structural adequacy or load-bearing capacity in conformance to current design criteria;

f) Deterioration of parapet walls and/or adjacent step-up walls.

10.3.2 Interior Space Conditions. Psychrometric factors to be considered include the following:

a) Building occupancy (current and proposed);

b) Existing building heating, ventilating, air conditioning, and humidification systems;

c) Maximum hour location of dew point within the roof composite;

d) Vapor retarder requirements. Be aware of vapor pressure direction in humid climates which is usually downward.

10.3.3 Topside Deficiencies

a) Design;

b) Materials;

c) Workmanship.

10.4 Design Considerations. The most basic design decision in reroofing is to either recover or replace. Always use nondestructive testing before designing. A leaking roof which is classified as a premature failure must be evaluated for potential contributions to the failure (refer to par. 10.3). Never recover even a partially water-saturated insulation-membrane system. If the roof has been recovered once, a second recovering is not allowed. Design options are either recovery or replacement. Consider all options for best choice.

10.4.1 Drainage. Adding slope will eliminate the major cause of premature roofing failure. However, on some existing low slope decks it is costly or impractical to create a 1/2-inch per foot (4 percent) slope with tapered insulation. Where existing low slope or near level roofs have failed due to old age and not water ponding, consider replacement in kind. Otherwise where adding slope is impractical, replace the membrane with a minimum of four plies in coal-tar pitch and aggregate surfacing. Also, consider providing additional drains where necessary. Asphalt, single-ply, or foam systems are not permitted on any roofs which will pond.

Where practical, a new roof design should incorporate positive slope that will eliminate all standing water conditions within a 24 hour period after rain. Review the number, type, sizing and location of drains, use of scuppers for overflow, and use of crickets for slope to prevent ponding between the drains. Never use wet fills to achieve slope.

10.4.2 The Insulation System. Consider the following:

a) Required R-value of the system;

b) Formation of roof slope including preformed tapered insulation;

c) Method of attachment to the substrate and new components to existing components and ability of existing construction to accept new attachments;

d) Compatibility with adjacent roof composite materials;

e) Fire and wind requirements;

f) Load carrying ability of the structure;

g) Dimensional stability relative to temperature change and exposure to moisture;

h) Product availability and maintainability;

i) Costs, life cycle economics, etc.

10.4.2.1 Tapered Insulation. Tapered insulation has the following disadvantages:

a) Difficult design coordination for flashing heights and other roof details affected by varying insulation thickness;

b) Require fairly complex field operations for some materials involving special drawings and coded insulation pieces;

c) Hazards of excess insulation thickness.

10.4.3 Membrane System. (Refer to par. 10.2 for reroofing steep roofing) In making a selection of membrane system, consider the following:

a) Ponding water conditions, slow draining roofs, and potential formation of ice;

b) Minimum slope restrictions. Standard is 1/4 inch per foot (2 percent) for reroofing;

c) Special construction logistics;

d) Weight limitation dictated by existing deck;

e) Expansion and/or control joint requirements;

f) Flashing requirements;

g) Fire and wind requirements;

h) Roof traffic requirements;

i) Maintenance requirement;

j) Susceptibility to vandalism;

k) Materials past performance record;

1) Product availability of all components from one manufacturer;

m) Product compatibility with adjacent roofing products and materials within the new roof composite;

n) Method of attachment;

o) Tensile or "T" peel strength requirements, especially lap seams of single-ply systems;

p) Cost.

10.4.4 Surfacing

10.4.4.1 Smooth-Surfaced Roofs. Smooth-surfaced roofs are relatively easy to inspect visually and repair but they require periodic recoating with cutbacks or emulsions. Smooth-surfaced roofs are not as durable as aggregate-surfaced roofs and should be considered only where aggregate-surfaced roofs have some disadvantages (e.g., at airports, structural considerations, etc.). Coatings can be a cost-effective way of extending the useful life of a bituminous built-up membrane. However, do not recoat if: (a) membrane is dry, brittle or delaminated; (b) system contains wet insulation or other subsurface problems; and (c) roof ponds water. Coatings should be fibrated. Aluminized coatings can significantly lower the temperature of the membrane, prolonging its useful life. However, the extra benefits of "penetrating coatings" (sometimes called resaturants) are disputed. Their extra cost is seldom justified.

Surfacing with cap sheets or sprayed granules eliminates the need for periodic recoating but does not provide as durable a surfacing as aggregate. Cap sheets are prone to blistering, especially when they are installed in cold weather.

10.4.4.2 Aggregate-Surfaced Roofs. Aggregate surfacing is a very effective way of armoring a bituminous built-up membrane against the weather, roof traffic, and other external abuse. However, when an aggregate-surfaced roof has deteriorated, it is very difficult to extend its useful life. In very limited cases it is possible to remove all loose aggregate and dirt, repair all flashing and membrane defects, then spray a coating of cutback asphalt or pitch as required onto the existing system and surface it with new gravel.

10.4.5 Coatings

10.4.5.1 Emulsions. Emulsion coatings are dispersions of asphalt or coal-tar in water with an emulsifier agent such as clay of approximately 50 percent solids. The material should have a consistency of mayonnaise at the time of application. It may be brushed or sprayed. Emulsions must be protected from freezing until all water has evaporated.

10.4.5.2 Cutbacks. Cutbacks have approximately 50 percent solids suspended in a solvent base vehicle.

10.4.6 Ponding. (Refer to par. 10.4.1)

10.4.7 Foot Traffic. Require walkway pads to accommodate periodic traffic over the roofing surface. Since the walkway pad will shrink while losing water and the shrinkage strain could be transmitted to the roof membrane, do not fully adhere thick pads directly to the roof surface. Adhered modified bitumen sheets or precut pavers placed on filter fabric may also be used.

10.4.8 Cold-Process Roofing. Cold-process systems are life extension and maintenance procedures on smooth roofs. There are coating and overlay types in asphalt or coal tar base with or without reinforcement. They must be placed on clean, dry surfaces with no entrapped wet insulation below.

Section 11: FIRE RESISTANCE

11.1 General. Fire hazards to roof systems are broadly classified as follows:

a) External, above-deck fire exposure from flying brands or burning debris blown over from neighboring buildings on fire;

b) Internal, below-deck fire exposure from interior inventory or equipment fires;

c) Time-temperature or fire resistance classifications.

11.2 External Fire Resistance

11.2.1 Membranes. Roofing membranes are tested and rated for their resistance to external fire. They should not spread flame rapidly, produce flying brands endangering adjacent buildings, or permit ignition of supporting roof decks.

11.2.2 Tests and Ratings. According to the industry standard for rating roof coverings, ASTM E 108, Fire Tests of Roof Coverings, classified roof coverings "are not readily flammable, do not slip from position, and possess no flying brand hazard." Their performance is rated as Class A, B, or C, depending on their resistance to external fires of varying intensity. Class A coverings provide the greatest resistance, Class C the least.

11.3 Internal Fire Hazards

11.3.1 Background Research. Research on acceptable fire spread from internal (i.e., below-deck) fires has focused chiefly on steel-deck roof assemblies. Because of its extremely high thermal conductivity, steel deck immediately transmits the heat energy of an interior fire to the above-deck roof components.

11.3.2 Safeguard. The chief safeguard required against internal fire is limitation of flame spread along the underside of the roof assembly.

11.3.3 Steel Deck. A steel deck roof assembly with 1-inch (25-millimeter), mechanically anchored, plain vegetable fiberboard insulation and a four-ply, aggregate-surfaced built-up membrane has become the standard roof construction for both UL and FM; the criteria for evaluating other roof-deck assemblies.

To qualify for UL listing as "acceptable," a roof deck assembly when subjected to a UL 1256, Fire Test of Roof Deck Constructions, flamespread test must not spread the flame farther than this standard steel-deck assembly.

11.4 Time-Temperature Ratings

11.4.1 Temperature. A roof assembly's time-temperature rating (given in time units of hours and fractions of hours) is established by its performance when subjected to the furnace test as specified in ASTM E 119, Fire Tests of Building Construction and Materials. The test subjects the tested assembly to a constantly rising temperature.

11.4.2 Fire-endurance Test. This test measures roof assembly performance when simultaneously carrying loads and confining fire. To qualify for a given fire rating, the tested assembly must: sustain the applied design load, permit no passage of flame or gases hot enough to ignite cotton waste on the unexposed surface, and limit the average temperature rise of the unexposed surface to a maximum 250 degrees F (121 degrees C) above its initial temperature or a 325 degrees F rise at any point.

11.4.3 Other Tests. For steel assemblies with structural steel, prestressed, or reinforced concrete beams spaced more than 4 feet (1219 millimeters) on centers, there are several other complex requirements specified in UL 263, Fire Tests of Building Construction and Materials.

11.5 Design Requirements. Follow MIL-HDBK-1008 Section entitled "Roof Coverings and Roof Deck Assemblies."

Section 12: WIND-UPLIFT RESISTANCE

12.1 Wind-Uplift Hazards. Wind-uplift hazards to roof systems depend on the phenomenon known as the Bernoulli principle: increased air velocity reduces the pressure exerted perpendicular to the direction of air flow. As a consequence, low slope roofs, in particular, experience maximum wind-uplift pressures.

12.1.2 Resistance. Wind-uplift resistance on low slope roofs is based on two radically different principles:

a) Resistance from fasteners and/or adhesives anchoring the various roof system components to the supporting structural deck;

b) Ballast, in the form of loose gravel or concrete pavers, designed to overcome wind-uplift pressure through gravitational counter pressures.

12.2 Failure. Failure modes for the two different anchorage techniques are radically different also. Anchored roof systems usually fail by blowoffs of membrane and insulation boards, which are rolled back from roof edges, exposing the deck. Ballasted systems have a more complex failure mode. Failure starts with wind scour, which exposes the loose-laid membrane in areas subject to highest wind-uplift pressures (generally at building corners.) Scouring may be followed by membrane ballooning, with possible membrane tearing, and is sometimes accompanied by insulation displacement into sub-membrane "hills" on the roof deck.

Although the 10 to 25 psf (49 to 122 kilograms per square meter) ballast weight may be only a minor fraction of the wind-uplift forces, ballasted systems seldom allow exposure of the huge deck areas that are sometimes exposed in failed anchored systems. An adhered system usually experiences a blow off from local failure, like the tensile failure of the weakest link in a chain. In contrast, in a ballasted system, any wind-lifted or ballooned area normally shifts its ballast to an adjacent area, where the uplift resistance is consequently increased.

12.3 Ballasted Systems. Ballasted systems are limited to single-ply membranes, usually elastomeric or plastic sheets, some modified bituminous membranes, and protected membrane roofs.

12.4 Dead Load. The additional dead load of 10 to 25 psf for gravel ballast or pavers is readily accommodated in new construction. But reroofing of existing buildings obviously requires a check of the original structural design to determine if the structural framing has excess capacity over its original design load. Inspection of the roof's structural components to assure its sound condition is also recommended. Additional ballast load required at the roof perimeter may sometimes be averted by a combination anchored/ballasted system, described in Factory Mutual Data Sheet 1-29 Technical Advisory Bulletin, Loose-laid Ballasted Roof Coverings.

12.5 Mechanical Fasteners. For manufacturers' approved mechanical fasteners and fastener patterns, refer to the latest edition of the Factory Mutual Approval Guide.

12.6 Design Data. For design guidance on wind-uplift pressures for various U.S. locations, wind-design procedures, and other details, consult Factory Mutual Publications. For design guidance for locations outside the U.S., refer to MIL-HDBK-1002/2, Structural Engineering - Loads.

Section 13: BELOW-GRADE WATERPROOFING

13.1 System Description. Basic considerations for below-grade waterproofing are the same as for plaza waterproofing (refer to Section 14). The below-grade location adds the extra requirement to handle probable static ground water pressure. Therefore, the primary objective is to drain away the water and prevent the build-up of hydrostatic pressure at the surface of the waterproofing.

For both horizontal and vertical surfaces, multiple-layer systems are superior. These systems may be applied hot or cold. Fluid-applied and single-ply sheet applications can be considered if conditions will not be severe and if access to the system in case of failure is relatively easy. Bentonite clay panels are sometimes used for waterproofing, especially below slabs and on vertical walls.

13.2 Uses. Below grade waterproofing may be required for basement slabs, foundation walls, planters, mud slabs, tunnels, sidewalk vaults, above-grade walls at earth berms, etc.

13.3 Precautions

13.3.1 Substrates. Substrates must be free of laitance, sharp projections, facial imperfections, curing compounds, oil, grease, and moisture in any form. In all cases, masonry requires priming with a material compatible with the selected membrane system.

13.3.2 Membrane. Membrane reinforcing must be provided at all joints, reinforced, non-reinforced, or expansion joints. (Refer to ASTM C 981, Guide for Design of Built-Up Bituminous Membrane Waterproofing Systems for Building Decks.) Reinforcing must also occur at all sharp turns, flashing terminations, penetrations, pedestals, drains, etc.

13.3.3 Membrane Protection. Membranes must be protected with protection board of sufficient thickness to withstand anticipated abuse. Boards conforming to ASTM C 208, Cellulosic Fiber Insulating Board, ASTM C 726, Mineral Fiber Roof Insulation Board, or ASTM C 578, Type II Grade 2, are acceptable.

Single-ply sheet waterproofing requires immediate ultraviolet protection and/or backfilling to prevent blistering. In direct, hot sunlight, blistering can occur in 20 minutes or less on some materials.

13.3.4 Drain Tile. Waterproofed walls should be blanketed with coarse rock, underlain at foundation level with perforated drain tile connected to adequate sumps or existing storm water systems. Drain tile must be sloped to outlets. The top of the drain tile should not be higher than 2 inches (51 millimeters) below the bottom of the interior floor slab.

13.4 Design Requirements

13.4.1 Slope of Concrete Slabs. All horizontal surfaces should have slope of 1/4 to 1/2 inch per foot (2 to 4 percent) in the monolithic pour if possible. Dead level slabs are often unavoidable, however.

13.4.2 Walls. Walls may require nailers to secure the top of the membrane 6 to 8 inches (152 to 203 millimeters) above grade. Horizontal nailers should be provided at 6-foot (1829-millimeter) elevation intervals, set in a bed of bituminous material and waterproofed with additional layers of fabric and bituminous cement. Plies of felt or fabric should run vertically.

13.4.3 Expansion Joints. These joints must receive preformed neoprene rubber gaskets, properly flashed.

13.4.4 Membrane Selection. The membrane may include use of felts, fabric and/or proprietary-coated fabric set in hot or cold bituminous material or proprietary adhesive. System should be multiplied, with sufficient plies to withstand the anticipated hydrostatic pressure. The following table offers guidelines for determining the number of felt and/or fabric plies and moppings needed to resist different hydrostatic pressures:

HEAD OF WATER(in Ft.(kPa))	PILES OF FELT AND/OR FABRIC	BITUMEN MOPPINGS	APPROX. TOTAL LBS. OF PITCH/100 ft^2 ($9m^2$)	APPROX. TOTAL LBS. OF ASPHALT/ 100 ft^2 ($9m^2$)
1-3 (3-9)	2	3	75-98 (34-44)	60-75 (27-34)
4-10 (12-30)	3	4	100-120 (45-54)	80-100 (36-45)
11-25 (33-75)	4	5	125-150 (57-68)	100-125 (45-57)
26-50 (78-149)	5	6	150-180 (68-82)	120-150 (54-68)

If single-ply sheet-applied membranes, such as PVC, neoprene, butyl, EDPM, Hypalon, etc., are elected, great care must be taken in the provision and testing of the lap seams before covering or back filling. All systems must be protected with insulation board. Extruded polystyrene is excellent for this purpose.

Preformed membranes: This class is factory-produced, consisting of a film of paper, polyethylene, polyvinyl chloride, etc., and coated on both sides with rubberized asphalt or coal tar pitch. Specify membrane manufacturer's recommended primer and adhesives.

13.5 Dampproofing. Many installations do not require an absolute waterproofed surface but only retarding of moisture penetration. This retardation can be accomplished with brushable or trowelable bituminous or synthetic materials hot- or cold-applied. All such materials require the appropriate primer when applied over masonry. At least two coats of dampproofing material are usually required.

13.6 Applicable Details. Refer to NRCA Roofing and Waterproofing Manual.

Section 14: PLAZA WATERPROOFING

14.1 System Description. Since it is impossible to keep all the water out all the time, the basic plaza waterproofing system must be designed to excrete water that does get in, without damage to the interior spaces below.

14.1.1 Options. Plaza waterproofing basic membrane options include hot-applied built-up roof membrane, elastomeric sheet, and liquid-applied waterproofing.

14.1.2 Materials. Of the three basic membrane types, the hot applied built-up bituminous offers the most advantages:

a) Multiple lines of waterproofing defense (via alternating layers of felt and bitumen);

b) Adaptability to hot-applied protection boards;

c) Excellent adhesion to concrete substrates;

d) Familiarity to waterproofing mechanics;

e) Known performance criteria.

14.2 Planters. Planters are notorious for leakage. Whether precast or poured-in-place, they should not interrupt the main deck waterproofing. If poured-in-place planters are selected, they must be handled as a perimeter flashing. Precast planters are recommended. Never locate a planter across an expansion joint.

14.3 General Requirements

14.3.1 Minimum Slope. Provide minimum 1/4 inch per foot (2 percent) slope, built into base slab (1/2 inch per foot (4 percent) is preferred). Do not rely on additional fills to provide slope. Provide crickets between drains at perimeter walls.

14.3.2 Joint Construction. Specify all joint construction with "watershed" concept in base slab (refer to ASTM C 981). These raised sections keep water freely drained from these very critical areas. All perimeter construction and expansion joints should be provided with appropriately shaped preformed joint formers flashed into adjoining membrane.

14.3.3 Vapor Retarder. Calculate the vapor pressure and flow direction and use vapor retarder where required. (Refer to Section 4).

14.3.4 Insulation. Insulation must have low water absorption and be of sufficient thickness to maintain membrane temperature above dew point.

14.3.5 Waterproofing Termination. Terminate waterproofing at 8 inches (203 millimeters) above the finish wearing surface of deck at all walls and other projections.

14.3.6 Flashings. All flashings must project onto horizontal membrane a minimum 4 inches (102 millimeters) with two additional plies of stripping and terminate a minimum of 8 inches (203 millimeters) above finished grade of the plaza deck. Require compatible elastomeric material to provide for movement.

14.3.7 Percolation Course. Specify a percolation course 2 inches (51 millimeters) thick, below insulation. Use washed smooth round river rock to drain water from insulation and to promote free flow to drains. Insulation board with preformed drainage channels is also acceptable.

14.3.8 Filter Fabric. Specify filter fabric over the percolation or insulation course to prevent clogging from dirt or other debris.

14.3.9 Pavers. Specify poured-in-place concrete slab wearing surface, pavers on mortar bed or pavers on pedestals. Pavers on pedestals are recommended for easy access in case of leaks. Do not specify bituminous wearing courses that require rolling for compaction. Pavers must be set and elevated to allow sufficient opening between joints and substrate to filter ponded water to percolation course and into drains. Pavers should bear firmly on all four corners.

14.3.10 Drains. Drains must have weep holes at every sub-assembly level and flashed into waterproofing membrane. (Consult drain manufacturers for special assemblies.)

14.3.11 Protection Boards. Require protection boards for membrane and insulation, or both, depending on location of these components.

14.3.12 Testing. Test waterproofing completely, specifically at flashings, expansion joints, and drains where most leaks occur, before additional components are added.

14.3.13 Overflow Drains. Refer to Section 8, par. 8.3.1.

14.3.14 Interior Gutters. Require interior metal gutters under expansion joints or skylight perimeters. Connect these gutters to the building's interior drainage system.

14.4 Applicable Details. Refer to ASTM C 898, Guide for Use of High Solids Content, Cold Liquid-Applied Elastomeric Waterproofing Membrane With Separate Wearing Course, ASTM C 981, and the NRCA Roofing and Waterproofing Manual.

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CEGS-07530	Elastomeric Roofing (EPDM)
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0750	Building Insulation

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L-P-375 (3)	Plastic Film, Flexible, Vinyl Chloride
O-F-506C	Flux, Soldering; Paste and Liquid.
FF-S-107C(2)	Screws, Tapping and Drive.
HH-I-1030B	Insulation, Thermal (Mineral Fiber, for Pneumatic or Poured Application).
HH-I-1972/GEN	Insulation Board, Thermal, Faced, Polyurethane or Polyisocyanurate (applies equally to Phenolic rigid boards)
QQ-A-250F/GEN	Aluminum and Aluminum Alloy, Plate and Sheet; General Specification for.
QQ-C-450A INT AMD 1	Copper-Aluminum Alloy (Aluminum Bronze) Plate, Sheet, Strip, and Bar(Copper Alloy Numbers 606, 610, 613, 614 and 630)
QQ-C-576B(1)	Copper Flat Products with Slit, Slit and Edge Rolled, Sheared, Sawed, or Machine Edges, (Plate, Bar, Sheet, and Strip).
QQ-C-585B	Copper-Nickel-Zinc Alloy, Plate, Sheet, Strip, and Bar (Copper Alloy Numbers 735, 745, 752, 762, 766 and 770).
QQ-N-281D INT AMD 1	Nickel-Copper Alloy, Bar, Rod, Plate, Sheet, Strip, Wire, Forgings, and Structural and Special Shaped Sections.
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Other Government Agencies and commercial organizations may procure Design Manuals and P-Publications from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402.

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MIL-HDBK-1006/1	Policy and Procedures for Project Drawing and Specification Preparation
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FACTORY MUTUAL SYSTEM (FM)

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(Unless otherwise indicated, copies are available from Factory Mutual System, 1151 Boston-Providence Turnpike, Norwood, MA 02062.)

NATIONAL ROOFING CONTRACTORS' ASSOCIATION (NRCA)

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(Unless otherwise indicated, copies are available from Sheet Metal and Air Conditioning Contractors' National Association, Inc., P.O. Box 221230, Chantilly, VA 22022-1230.)

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UL 790	Tests for Fire Resistance of Roof Covering Materials
UL 1256	Fire Test of Roof Deck Constructions

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GLOSSARY

Aggregate. Gravel, crushed stone, washed round river gravel slag or mineral granules either (a) embedded in a conventional built-up membrane's bituminous flood coat, or (b) laid on a membrane as a protective ballast. Crushed stone should be avoided if possible.

Alligatoring. Deep shrinkage cracks, progressing down from the surface, in smooth-surfaced membrane coatings and sometimes in bare spots of aggregate-surfaced membranes, a consequence of photo-oxidative hardening, shrinkage due to loss of aromatics.

Asphalt. A dark brown to black, highly viscous, hydrocarbon produced from the residuum left after the distillation of petroleum, used as the waterproofing agent of built-up roofs and other building components.

Atactic polypropylene. High molecular-weight, thermoplastic, amorphous polymers used as a chemical ingredient to improve flexibility, elasticity, and ductility of bitumen, used in some single-ply modified bitumen membranes for torching applications.

Backnailing. Slippage-preventing technique of "blind" (i.e., concealed) nailing in addition to hot-mopping.

Ballast. Aggregate, concrete pavers, or other material designed to prevent wind uplift or flotation of a loose-laid roof or insulation system. Aggregate should be smooth, round, without flat faces and sharp edges.

Base Flashing. See Flashing.

Base ply. A felt or mat, usually coated, placed as the first non-shingled ply in a multi-ply built-up roof membrane.

Batten. Narrow metal or wood band used to anchor a membrane against wind uplift.

Bitumen. Generic term for an amorphous, semisolid mixture of complex hydrocarbons derived from petroleum or coal. In the roofing industry there are two basic bitumens: asphalt and coal-tar pitch. Before application, they are either (l) heated to a liquid state, (2) dissolved in a solvent, or (3) emulsified.

Blindnailing. Nailing of felts with nail heads covered by overlapping top felts.

Blister. A spongy, humped portion of a roof membrane, formed by entrapped air/vapor mixture under pressure, with the blister chamber located either between felt plies (i.e., interply) or at the membrane-substrate interface (interfacial).

Blocking. Continuous wood components anchored to the deck at roof perimeters and openings and doubling as cross-sectional fillers and anchorage bases, used in conjunction with nailers.

Brooming. The field procedure of pressing felts into a layer of fluid, hot bitumen to obtain continuous adhesion - i.e., elimination of blister originating voids - of the bitumen film.

Btu (British thermal unit). Heat energy required to raise the temperature of 1 pound of water 1F.

Built-up roof membrane. A continuous, semiflexible roof covering of laminations or plies of saturated or coated felts or mats alternated with layers of bitumen, usually surfaced with mineral aggregate or asphaltic materials.

"Bull". Roofer's term for plastic cement.

BUR. Abbreviation for built-up roof.

Camber. Upward deflection built into a structural member subjected to flexural stresses to counteract the downward deflection from gravity loads.

Cant strip. Strip of wood, wood-fiber, or perlite board, triangular or trapezoidal in cross section, serving as transitional plane between horizontal and vertical surfaces. The cant provides backing for the stiff flashing felts of built-up roof construction, reducing the risk of cracking by halving the bend angle from 90 to 45 degrees.

Cap flashing. See Flashing.

Cap sheet. A mineral-surfaced, coated felt or mat used as the top ply of a built-up roof membrane.

Centistoke (cs). Unit of viscosity (antonym of fluidity). Water has a viscosity of roughly 1 cs; light cooking oil, l00 cs.

Channel mopping. See Strip mopping, under Mopping.

Chlorinated polyethylene. Synthetic rubber, used for single-ply membranes, composed of high-molecular-weight polyethylene, chlorinated to impart elasticity.

Chlorosulfonated polyethylene. Synthetic rubber based on high molecular-weight polyethylene with pendant sulphonyl chloride.

Coal-tar pitch. Dark brown to black solid hydrocarbon obtained from the residuum of distilled coke-oven tar, used as waterproofing agent of dead level or low-slope built-up roofs.

Cold-process roofing. A bituminous membrane comprising layers of saturated felts bonded with cold-applied asphalt roof cement and surfaced with a cutback or emulsified asphalt roof coating.

Counterflashing. See Flashing.

Crack. A membrane fracture produced by bending, often at a ridge (see Ridging).

Creep. (l) Permanent elongation or shrinkage of the membrane resulting from thermal or moisture changes. (2) Permanent deflection of structural framing or structural deck resulting from plastic flow under continued stress or dimensional changes accompanying changing moisture content or temperature.

Cricket. Ridge, triangular in cross section, built-up in flat valley or perimeter to direct rainwater to a drain.

Crosslinking. Chemical bond formed between long-chain molecules in cured polymers.

Curing. The final step in the irreversible polymerization of a thermosetting plastic, requiring a combination of heat, radiation, and pressure.

Cutback. Solvent-thinned bitumen used in cold-process roofing adhesives, flashing cements, and roof coatings.

Cutoff. A detail designed to prevent lateral water movement into the insulation where the membrane terminates at the end of a day's work or at an isolated roof section, usually removed before work continues.

Dead level. Absolutely horizontal, or zero slope (See Slope).

Deck. Structural supporting surface of a roof system.

Delamination. Separation of felt plies in a built-up membrane or separation of previously factory-laminated insulation boards.

Dew Point. Temperature at which condensation of water vapor in a space begins for a given state of humidity and pressure as the vapor temperature is reduced; the temperature corresponding to saturation (100% relative humidity) for a given absolute humidity at constant pressure.

DFT. Dry film thickness, used as a measure of liquid-applied coatings.

Double pour. A doubling of the flood-coat, graveling-in operation, to provide additional waterproofing integrity to the membrane (done once, loose aggregate removed and done again).

Edge stripping. Application of narrow felt strips to cover a joint between flashing and built-up membrane.

Elastomer. A macromolecular material that rapidly regains its original shape after release of a light deforming stress.

Elastomeric. Having elastic properties, capable of expanding or contracting with the surfaces to which the material is applied without rupturing.

Emulsion. An intimate mixture of bitumen and water, with uniform dispersion of the bitumen globules achieved through a chemical or clay emulsifying agent.

Envelope. The continuous edge formed by folding an edge base felt over the plies above, securing it to the top felt. The envelope thus prevents bitumen seepage through the exposed edge joints of the laminated, built-up roofing membrane.

Equilibrium moisture content. The moisture content of a material at a given temperature and relative humidity, expressed as percent moisture by weight.

Equiviscous temperature (EVT). The temperature at which bitumen has the viscosity of 125 centistokes for hot mopping.

Ethylene propylene diene monomer (EPDM). A thermosetting, synthetic rubber used in single-ply elastomeric sheet roof membranes.

Expansion joint. A flashed, structural separation between two building segments, designed to permit free movement without damage to the roof system.

Exposure. Transverse dimension of a felt not overlapped by an adjacent felt in a built-up roof membrane. Correct felt exposure in a shingled, built-up membrane is computed by dividing the felt width minus 2 in. by the number of plies - e.g., for four plies of 36-inch-wide felt, exposure = 36-2/4 = 8 1/2 inches.

Fabric. Woven cloth of organic or inorganic filaments, threads, or yarns.

Fallback. Reduction in bitumen softening point, sometimes caused by refluxing or overheating in a closed container.

Felt. Flexible sheet manufactured by interlocking of fibers with a binder or through a combination of mechanical work, moisture, and heat.

Felt layer. Spreader-type, wheel-mounted equipment for laying felt and simultaneously dispensing hot bitumen.

Finger wrinkling. Wrinkling of exposed felts in small, finger-sized ridges parallel to the longitudinal direction of the felt roll, caused by transverse moisture expansion of the felt.

Fishmouth. Membrane defect consisting of an opening in a membrane felt edge lap.

Flashing. Connecting devices that seal membrane joints at walls, expansion joints, drains, gravel stops, and other places where the membrane is interrupted. Base flashing forms the upturned edges of the watertight membrane. Cap or counterflashing shields the exposed edges and joints of base flashing.

Flashing cement. A trowelable, plastic mixture of bitumen and asbestos (or other inorganic) reinforcing fibers, and a solvent (a stiffer, more sag-resistant material than plastic cement).

Flash point. Temperature of combustible material, as oil, at which there is sufficient vaporization to support combustion of the vapor.

Flux. Bituminous material used as a feed stock for further processing and as a material to soften other bituminous materials.

Glaze coat. A thin, protective coating of bitumen applied to the lower surface or to the top ply of a built-up roof when application of flood coat and aggregate is delayed. It sometimes refers to an asphalt coating on a smooth-surfaced, built-up membrane.

Grain. Weight unit equal to 1/7,000 lb, used in measuring atmospheric moisture content.

Granule. See Mineral Granules.

Gravel. Coarse, granular aggregate resulting from natural erosion or crushing of rock, used as protective surfacing or ballast on roof systems.

Gravel stop. Flanged device, usually metallic, with vertical projection above the roof level and fascia, designed to prevent loose aggregate from rolling or washing off the roof and to provide a finished edge detail for the roof.

Gravelling in. Process of embedding aggregate surfacing into a bituminous membrane flood coat.

Grout. A fluid mixture of cement and water, or a mixture of cement, sand and water.

Head lap. Minimum distance, measured perpendicular to eave along the face of a felt or shingle from its upper edge to the nearest exposed surface.

Holiday. Area where interply bitumen mopping or other fluid-applied coating is discontinuous.

Hood. Sheet-metal cover over piping or other rooftop equipment.

"Hot stuff" or "hot". Roofer's term for hot bitumen.

Hygroscopic. Absorptive of moisture; readily absorbs and retains moisture.

Ice dam. Drainage-obstructive ice formation at eave of snow-covered sloped roof, caused by refreezing of water melted by escape of interior heat.

Inorganic. Comprising matter not of plant or animal origin.

Insulation. See Thermal Insulation.

Laitance. Weak material, consisting principally of lime, that is formed on the surface of concrete, especially when excess water is mixed with the cement.

Loose-laid roof system. Design concept in which insulation boards and/or membrane are not anchored to the deck but ballasted by loose aggregate or concrete pavers.

Lap. The dimension that a felt covers an underlying felt or sheet in a multiple built-up bituminous membrane or single-ply membrane. Edge lap indicates the transverse cover; end lap indicates the cover at the end of the roll.

Mat. Flexible, heat-cured sheet made of inorganic fibers and a resinous binder.

Membrane. A flexible or semi-flexible roof covering, the waterproofing component of the roof system.

Mineral granules. Natural or synthetic aggregate particles, ranging in size from 500 microns (1 micron = 10-6 meter) to 1/4-inch diameter, used to surface cap sheets, asphalt shingles, and some cold-process membranes and modified bitumens.

Mineral-surfaced sheet. Asphalt-saturated felt, coated on one or both sides and surfaced with mineral granules.

Monomer. Class of molecules with molecular weight ranging roughly between 30 and 250, capable of combining into huge, polymeric macromolecules, l00 to l0,000 times as large as the basic monomeric molecules, through chainlike repetition of the basic monomeric chemical structure.

Mop-and-flop. A technique which roof system components (insulation boards, felt plies, cap sheets, etc.) are first placed upside down adjacent to their final locations, coated with adhesive, and turned over and adhered to the substrate (a generally bad practice).

Mopping. Application of hot, fluid bitumen to substrate or to plies of built-up membrane with a manually wielded mop or a mechanical applicator.

Solid mopping	A continuous coating.

Spot mopping	A pattern of hot bitumen application in roughly circular areas, generally about 18-inch diameter, on a grid of unmopped, perpendicular bands.
Strip mopping	A mopping pattern featuring parallel mopped bands.
Sprinkle mopping	A random pattern of bitumen beads hurled onto the substrate from a broom, mop, or machine.

Nailer. A wood member bolted or otherwise anchored to a deck or wall to provide nailing anchorage of membrane roof felts or flashings.

Neoprene. A synthetic rubber (chemically polychloroprene) used in fluid or sheet-applied elastomeric single-ply roof membranes or flashing.

One-on-one. Non-shingled application pattern of a single ply of felt followed by application of a second ply (see Phased application).

Organic. Carbon and hydrogen atom matter of plant or animal origin.

Parting Agent. Powdered mineral (talc, mica, etc.) placed on coated felts to prevent adhesion of concentric felt layers in the roll (sometimes called a releasing agent or anti-stick compound).

Perlite. An aggregate used in lightweight insulating concrete and in preformed insulating board, formed by heating and expanding siliceous volcanic glass.

Perm. A unit of water-vapor transmission, defined as 1 grain of water vapor per square foot per hour per inch of mercury pressure difference. (1 in. Hg = 0.491 psi.)

Permeance. An index of a material's resistance to water-vapor transmission. (See Perm)

Phased application. The practice of applying the felt plies of a roofing or waterproofing membrane in two or more operations.

Picture framing. Rectangular membrane ridging forming over insulation board joints, found predominantly in smooth-surfaced membranes.

Pitch pocket. Flanged, open-bottomed metal container placed around a column or other roof-penetrating element and filled with bitumen or plastic cement to seal the opening.

Plastic cement. Trowelable, plastic mixture of bitumen and asbestos (or other inorganic) stabilizing fibers and a solvent, used mainly for horizontal surfaces as opposed to Flashing cement, which is designed for vertical surfaces requiring sag-resistance.

Plasticizer. High-boiling-point solvent or softening agent added to a polymer to facilitate processing or to increase flexibility or toughness in the manufactured material.

Ply. A layer of felt in a roof membrane; a four-ply membrane has at least four plies of felt at any vertical cross section cut through the membrane.

Polymer. Long-chain macromolecules produced from monomers, for the purpose of increasing tensile strength of sheets used as membranes or flashing.

Polyvinyl chloride (PVC). A thermoplastic polymer, formulated with a plasticizer, used as a single-ply sheet membrane material.

Power-trowel. Term applied to finish of a structural concrete deck slab's surface by a power-driven steel-troweling machine.

Primer. Thin liquid applied to seal a surface, to absorb dust, and to promote adhesion of subsequently applied material.

Protected membrane roof (PMR). A roof assembly with insulation atop the membrane instead of vice versa, as in the conventional roof assembly. (Also known as an inverted or upside-down roof assembly).

Psychrometric chart. A graphical representation of the properties of moist air, usually including wet and dry bulb temperatures, specific and relative humidities, enthalpy, and density.

Psychrometry. The branch of physics concerned with the measurement or determination of atmospheric conditions, particularly the moisture in air.

R-Value. In thermal insulation, the thermal resistance of insulation materials or constructions. See thermal resistance.

Re-covering. Covering an existing roof assembly with a new membrane instead of removing the existing roof system before installing the new membrane.

Rake. Edge of a roof at a gable.

Reglet. A horizontal groove in a wall or other vertical surface for anchoring flashing.

Relative humidity. Ratio (expressed as percentage) of the mass per unit volume (or partial pressure) or water vapor in an air-vapor mixture to the saturated mass per unit volume (or partial pressure) of the water vapor at the same temperature.

Rep. Unit of vapor-permeance resistance, reciprocal of perm.

Replacement. Process of removing and replacing an existing roof system (as opposed to mere re-covering, see above), also called tearoff-replacement.

Reroofing. The re-covering or replacement of an existing roof.

Resin. Basic raw material for manufacturing polymers, a synthetic polymer containing no deliberately added ingredients.

Ridging. Membrane defect characterized by upward displacement of the membrane, usually over insulation board joints (see Picture Framing).

Roll roofing. Coated felts, sometimes mineral-surfaced, supplied in rolls and designed for use without field-applied surfacing.

Roofer. Roofing contractor or subcontractor.

Roofing system. An assembly of interacting components designed to weatherproof, and normally to insulate, a building's top surface.

R-Factor. See Thermal Resistance.

Saddle. See Cricket.

Saturated felt. Felt that has been immersed in hot saturant bitumen.

Scupper. Channel through parapet designed for peripheral drainage of the roof, usually as safety overflow to limit accumulation of ponded rainwater caused by clogged drains.

Scuttle. Curbed opening, with hinged or loose cover, providing access to roof (synonymous with hatch).

Self-healing. Property of the least viscous roofing bitumens, notably coal-tar pitch, that enables them to seal cracks formed at lower temperatures.

Selvage joint. Lapped joint detail for two-ply, shingled roll-roofing membrane, with mineral surfacing omitted over a transverse dimension of the cap sheets to improve mopping adhesion. For a 36-inch-wide sheet, the selvage (unsurfaced) width is 19 inches.

Shakes. A wood roofing product that is split from a log and shaped by the manufacturer for commercial use. The three basic types of wood shakes are:

- handsplit and resawn shakes
- taper split shakes
- straight split shakes

Shark fin. Curled felt projecting up through the aggregate surfacing of a built-up membrane.

Shingles. Asphalt saturated roofing felt coated on both sides with asphalt, alone or stabilized with a finely powdered mineral material, the top coating usually being significantly thicker than the back coating and covered with roofing granules impressed in its surface. Most commonly used 12 inch x 36 inch, 3 tab self-sealing strip shingle.

Shingling. The pattern formed by laying parallel felt rolls with lapped joints so that one longitudinal edge overlaps the longitudinal edge of one adjacent felt, whereas the other longitudinal underlaps the other adjacent felt. (See Ply.) Shingling is the normal method of applying felts in a built-up roofing membrane.

Single-ply membrane. A membrane, either sheet or fluid-applied, with only a single layer of material designed to prevent water intrusion into the building.

Skater's cracks. Curved cracks observed in smooth-surfaced built-up membranes

Slag. Porous aggregate used as built-up bituminous membrane surfacing, comprising silicates and alumino-silicates of calcium and other bases, developed with iron with a blast furnace.

Slippage. Relative lateral movement of adjacent felt plies in a membrane. It occurs mainly in sloped roofing membranes, exposing the lower plies, or even the base ply, to the weather.

Slope. The tangent of the angle between the roof surface and the horizontal, in inches per foot. The Asphalt Roofing Manufacturers' Association ranks slopes as follows:

Level: 1/2-inch maximum
Low slope: over 1/2 inch up to 1-1/2 inches
Steep slope: over 1-1/2 inches

Smooth-surfaced roof. A roofing membrane surfaced with a layer of hot-mopped asphalt or cold-applied asphalt-clay emulsion or asphalt cutback, or sometimes with an unmopped, inorganic felt.

Softening point. Temperature at which bitumen becomes soft enough to flow, as measured by standard laboratory test in which a steel ball falls a measured distance through a disk made of the tested bitumen.

Softening point drift. Change in softening point from temperature change during storage or application (see also Fallback).

Solid mopping. See Mopping.

Split. Membrane tear resulting from tensile stress.

Spot mopping. See Mopping.

Sprinkle mopping. See Mopping.

Spudder. Heavy steel implement with a dull, bevel-edged blade designed to remove embedded aggregate from a membrane surface (also called a Scraper).

Strawberry. Small bubble in flood coat of gravel-surfaced membrane.

Stripping. (1) The technique of sealing the joint between base flashing and membrane plies or between metal and roofing membrane with one or two plies of felt or fabric and hot- or cold-applied bitumen. (2) The technique of taping joints between insulation boards or deck units.

Styrene-butadiene rubber. High molecular weight emulsion polymers, cross-linked to maximize elasticity via copolymerization of styrene butadiene monomers, used as the modifying compound in some modified bitumen roofing membranes.

Styrene-butadiene-styrene copolymer (SBS). High molecular weight emulsion polymers, with both elastomeric and thermoplastic properties, formed by the block copolymerization of styrene and butadiene monomers. The tri-block copolymer formed has a mid-block of butadiene with end blocks of styrene in some modified bitumen single-ply membranes.

Tearoff. Process of removing an existing roof system down to the structural deck.

Terne. Terne metal, prime copper-bearing steel, coated both sides with terne alloy, 20% tin, 80% lead. Terne metal is manufactured in a form of rolls in various widths and can be formed for standing seam roofs, batten seam roofs, and many types of flashing.

Thermal conductance (C-factor). The time rate of heat flow through unit area of a body induced by a unit temperature difference between the body surfaces. See thermal resistance.

Thermal conductivity (k-factor). The time rate of heat flow through unit thickness of a flat slab of a homogeneous material in the perpendicular direction to the slab surfaces induced by unit temperature gradient.

Thermal insulation. Material used on walls, ceilings, roofs and floors to retard the passage of heat.

Thermal resistance. Under steady conditions, the mean temperature difference between two defined surfaces of material or construction that induces unit heat flow through unit area. Note: Thermal resistance and thermal conductance are reciprocals. Thermal resistances are R-values; to obtain the U-factor, overall thermal transmittance, the R-value for either materials or constructions must first be evaluated because, by definition, the evaluated because, by definition, the U-factor is the reciprocal of the R-value.

Thermal shock. Stress-producing phenomenon resulting from sudden temperature drop in a roof membrane when, for example, a rain shower follows brilliant sunshine.

Thermal shock factor (TSF). Mathematical expression for calculating the theoretical temperature drop required to split a rigidly held membrane sample under tensile constructive stress. (TSF = tensile strength at 0 divided by load strain modules at 0F times coefficient of expansion in temperature range of 0 to 30 degrees F.)

Thermal transmittance (U-factor). The time rate of heat flow per unit area under steady conditions from the fluid on the warm side of a barrier to the fluid on the cold side, per unit temperature difference between the two fluids. It is evaluated by first evaluating the R-value and then computing its reciprocal.

Thermoplastic. Changing viscosity under thermal cycling (fluid when heated, solid when cooled).

Thermosetting. Hardening permanently when heated, owing to cross-linking of polymeric resins into a rigid matrix.

Through-wall flashing. Water-resistant membrane or material assembly extending through a wall's horizontal cross section, and designed to direct flow through the wall toward the exterior.

Tiles. Roofing tiles are produced by baking plates of molded clay into tile, with density determined by the length of time heated and by heating temperatures. Clay tile offers a wide range of design possibilities for residential roofs due to the variety of tiles available, i.e. roll tile and flat tile.

U-factor. See Thermal transmittance.

Vapor barrier. See Vapor Retarder.

Vapor migration. Flow of water vapor from a region of high vapor pressure to a region of lower vapor pressure.

Vapor retarder. A vapor-resistant layer of material applied to a surface to prevent vapor flow to a point where it may condense due to lower temperature.

Vent. Opening designed to convey water vapor, or other gas, from inside a building or building component to the atmosphere.

Vermiculite. Aggregate used in lightweight insulating concrete, formed by heating and consequent expansion of mica rock.

Viscoelastic. Characterized by changing mechanical behavior, from nearly elastic at low temperature to plastic, like a viscous fluid, at high temperature.

Viscosity. That property of semifluids, fluids, and gases by which they resist an instantaneous change of shape or arrangement of parts, the cause of fluid friction whenever adjacent layers of fluid move with relation to each other.

Walking in. Technique of manually forcing insulation boards against previously installed boards to tighten the joints and to embed board into a hot-applied adhesive.

Wood trowel. Term applied to the finish of a structural concrete deck slab's surface by a manually operated wood float.

Wrinkling. See Ridging.

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PROJECT NO.
FACR-1171

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