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UNIFIED FACILITIES CRITERIA (UFC)

COMMENTARY ON ROOFING SYSTEMS

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UNIFIED FACILITIES CRITERIA (UFC)

COMMENTARY ON ROOFING SYSTEMS

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes TI 809-53, dated 1 May 1999. The format of this UFC does not conform to UFC 1-300-01; however, the format will be adjusted to conform at the next revision. The body of this UFC is the previous TI 809-53, dated 1 May 1999.

FOREWORD

\1\
The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

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AUTHORIZED BY:

DONALD L. BASHAM, P.E.
Chief, Engineering and Construction
U.S. Army Corps of Engineers

DR. JAMES W WRIGHT, P.E.
Chief Engineer
Naval Facilities Engineering Command

KATHLEEN I. FERGUSON, P.E.
The Deputy Civil Engineer
DCS/Installations & Logistics
Department of the Air Force

Dr. GET W. MOY, P.E.
Director, Installations Requirements and Management
Office of the Deputy Under Secretary of Defense (Installations and Environment)

US Army Corps
of Engineers

TI 809-53
01 May 1999

Technical Instructions

Commentary on Roofing Systems

Headquarters
U.S. Army Corps of Engineers
Engineering Division
Directorate of Military Programs
Washington, DC 20314-1000

TECHNICAL INSTRUCTIONS

COMMENTARY ON ROOFING SYSTEMS

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FOREWORD

These technical instructions (TI) provide design and construction criteria and apply to all U.S. Army Corps of Engineers (USACE) commands having military construction responsibilities. TI will be used for all Army projects and for projects executed for other military services or work for other customers where appropriate.

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FOR THE COMMANDER:

DWIGHT A. BERANEK, PE
Chief, Engineering and Construction Division
Directorate of Military Programs

COMMENTARY ON ROOFING SYSTEMS

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CHAPTER 1

GENERAL

1-1. PURPOSE AND SCOPE. This document provides guidance for the selection of appropriate roofing systems for a specific structure under consideration.

1-2. APPLICABILITY. These instructions are applicable to all USACE elements and their contractors responsible for roofing system design, installation, and maintenance.

1-3. REFERENCES. Appendix A contains a list of references used in these instructions.

1-4. CONTENTS. Because at no time in the history of roofing has such a wide choice of materials and roofing system options been available, the objective of these instructions is to provide a road map for the selection of appropriate roofing systems. To utilize a road map, the user must know the point of origin and the destination. In the case of roofing, there are two distinctively different starting points: 1) In new design, the roof system selection can be part of the building design. For example, the building can be strengthened to support a heavy roof system, or the slope increased to accommodate the minimum required for the desired roof system. When dealing with an existing structure, weight, existing slope, and compatibility with existing materials all become constraints. 2) With an occupied building, construction noises, fumes, fire hazards, and building access during re-roofing all take on increased importance. Arrival at the destination (e.g., a satisfactory roof system) can take more than one route. Each path has considerations unique to that particular roof system. The principal variables involved are discussed in this document and supplemental resources are provided. Satisfactory roofing performance comes from the careful selection, specification, installation, and maintenance of roofing systems. Design alerts are provided in each chapter where special attention may be needed. Chapter 2 gives a general guide to selecting a path while Chapters 3 through 10 provide more detail on that particular route.

a. Problems. Roofing systems are exposed to the full brunt of the weather and can leak or fail prematurely if not properly designed, installed, or maintained. Leakage can adversely affect the function and mission of the building the roof is designed to protect. Since modern roofing systems contain considerable thermal insulation, moisture intrusion lowers thermal efficiency and hinders energy conservation efforts. Wet materials can support fungus or mildew and emit odors leading to sick buildings. At the end of the roofs' life, these construction materials are bulky and are a burden to landfills. Efforts should be pursued to use recyclable materials.

b. Design Considerations. The main design considerations of both water-shedding and low-slope roofing systems are discussed. Water-shedding (steep) roofing systems include shingles and shakes derived from asphalt or wood, metal, slate, tile, and architectural metal panels. Low-slope roofing systems include bituminous built-up (BUR) and modified bituminous (MB) roofing, single-ply (i.e., PVC, EPDM), sprayed-in-place polyurethane foam (SPF), and structural standing seam metal roofing systems (SSSMR). General guidelines for selection and design considerations of roofing are found in Chapter 2. Once a tentative roof selection is made, the user is referred to more detailed information in Chapters 3 through 10. For those existing, occupied buildings, refer to re-roofing and re-covering in Chapter 11. Chapter 12 covers roof maintenance as a design factor.

c. Appendices. Appendix B (Bibliography) includes subjects for further study and useful WEB sites. Appendix C contains acronyms used in these instructions. A Glossary of roofing terms is contained in appendix D. SI/I-P conversion factors for metrication are included in Appendix E.

CHAPTER 2

GENERAL SELECTION CONSIDERATIONS

2-1. STARTING POINTS FOR ROOF SYSTEM SELECTION. This Chapter is intended to introduce the major considerations in selecting a roofing system. Figure 2-1 depicts the various alternative roofing systems and how they relate. When commencing the selection process there are two different starting points.

a. New vs. Reroofing. The roof may be part of a new building design; or, it may involve the reroofing of an existing structure (replacement or re-cover). Today, approximately 75% of roofing activity is reroofing.

b. Steep-Slope vs. Low-Slope. In new construction the designer is very likely to have a preconceived notion as to whether a highly visible *sloped-roof* is wanted, or whether a less visible *low-slope* roof design is acceptable. Appendix 2-1, extracted from the *Decision Guide for Roof Slope Selection*, indicates the standard practice for use of today's common roofing systems, touching on slope and fire requirements. Positive drainage is a very important design criterion. In general, all *low-slope* roof systems should have a minimum of 2% (1/4 in. ft.) slope. When reroofing, it may be feasible to improve drainage by using tapered insulation or sloped deck fills.

2-2. SELECTION CONSIDERATIONS FOR STEEP ROOFING SYSTEMS. Table 2-1 evaluates common steep roofing systems based upon some use criteria.

a. Aesthetics. Steep roof systems make a strong visible statement about a building. The texture, shadow-line, and color are major factors in selection.

b. Minimum Slope Requirements. Steep roofs function by shedding water rather than by being waterproof (figure 2-2). Minimum slopes as shown in Table 2-13, are required in order to insure proper drainage.

c. Categories of Steep Roofing. Major categories of steep roofing include asphalt shingles, wood shingles and shakes, tile, slate, architectural metal, asphalt roll roofing, and fabricated units of metal or plastic intended to look like the others. Only asphalt roll roofing and asphalt or wood shingles may be re-covered.

d. Snowshedding and Ventilation. Sloped roofs are effective snowshedders. In addition, the attic space that accompanies steep roofing makes it easy to ventilate the roofing system.

e. Maintenance Requirements. Sloped roofs in general, require less maintenance than flat roofing systems.

f. Steep Roof Conversions. When considering reroofing a flat roof, it may be possible to convert the low-slope roofing system to a steeply sloped roof. This may improve the appearance of the building while resolving drainage problems as well. Steep roof conversions are a viable option for relatively narrow buildings. Refer to Chapter 11 and CERL Technical Report M-85/05 for more information on steep roof conversions.

Table 2-1. Steep Slope Selection Based Upon Use Criteria

	Asphalt Shingles			Asphalt Roll Roofing	Clay Tile	Concrete Tile
	Strip/Seal Down Interlocking	Laminated				
Severe Cold	Fair	Fair	Good	Fair	Poor	Poor
High Temp & Humidity	(e)	(e)	(e)	Fair	Fair/Good	Fair/Good
Severe Hail	Fair	Fair	Fair	Fair	Poor	Fair
Severe Wind	Fair	Fair	Good	Fair	(a)	(a)
Can Be Re-covered	Good	No	Good	Good	No	No
Appearance	Fair	Good	Fair	Fair	Good	Good

	Slate	Arch. Metal	Crafted Metal	Wood Shakes	Wood Shingles	Metal Look-Alike
Severe Cold	Fair	(c)	(d)	Poor	Poor	(c)
High Temp & Humidity	Fair/Good	Fair/Good	Fair/Good	(f)	(f)	Fair/Good
Severe Hail	Fair	Fair	(g)	Thickness	Poor	(g)
Severe Wind	Good	(b)	(b)	Thickness	Fair	(g)
Can Be Re-covered	No	No	No	No	Maybe	No
Appearance	Good	Good	Good	Good	Fair	Good

(a) Requires nose clips, extra fastening
(b) Depends upon gauge, clips design, closures
(c) Requires sealed underlayments
(d) Requires soldered joints, special detailing
(e) Algae resistance is available
(f) Treated wood needed
(g) Heavier gauge better

2-3. SELECTION CONSIDERATIONS FOR LOW-SLOPE (MEMBRANE) ROOFING. Membrane roofing is typically used on commercial buildings where the minimum slopes required by steep roofing render them impractical for larger buildings. Low-slope membrane systems are completely sealed at laps and flashings (figure 2-3) and can temporarily resist standing water conditions. Choices for membrane roofing include multi-ply bituminous built-up (BUR), polymer-modified bituminous (MB), elastomeric single-ply systems (e.g., EPDM), thermoplastic single-ply systems (e.g., PVC or TPO), sprayed-in-place polyurethane foam (SPF), and some metal (hydrostatic/low-slope/SSSMR) systems. Designers frequently select low-slope roofs when the roof is expected to accommodate rooftop equipment. With the exception of foam and metal, all low-slope systems can be incorporated into Protected Membrane Roof (PMR) designs.

2-4. REROOFING AND RE-COVERING.

a. Reroofing. The term *replacement* is used when the existing roofing system is to be either partially or totally removed and a new system installed. The designer should consider any existing problems and whether drainage and thermal performance needs to be improved. Existing surfaces such as walls and curbs may be contaminated with bitumen, which might affect compatibility with some reroofing options. Additional concerns (as compared to new roofing) include whether the existing structure can handle a significantly heavier roof system and whether construction activities of the reroof system will affect the occupants of the building (i.e., fumes, falling debris, and noise).

b. Re-cover. The term *re-cover* is used when a new roofing system is to be superimposed directly over an existing system. In this case, underlying conditions are obscured making assessment of their condition more difficult. Additional concerns include how the re-cover system will be attached to the existing membrane or roof deck, and compatibility with the substrate. The potential for trapped water between the old and new membrane may suggest the use of venting base sheets and/or roof vents.

2-5. ENVIRONMENTAL ISSUES. A relatively new design criterion is whether the roof system under consideration meets *green* criteria, such as whether the system incorporates post-consumer waste or is itself recyclable at the end of its useful life. Roof system waste is bulky and puts a great strain on waste disposal sites. Energy efficiency is also important in terms of raw materials acquired, production of finished goods, and application of the roof system. Thermal performance in service and retention of thermal value with age are equally important. A *sustainable* or *robust* roof is highly desirable as extension of the life of the roof contributes to overall conservation. High albedo (reflective) roofs may improve localized climate conditions. The felt used in asphalt organic shingles consists primarily of recycled wastepaper, wood chips, and sawdust. Asphalt itself is a by-product of petroleum refining. Wood fiber and perlite roof insulation contain waste paper. Glass fiber and asphalt organic shingles have been recycled into asphalt curbing and the like. Wood shingles and shakes can be recycled into garden mulch. Steel and aluminum contain recycled scrap and at the end of their life, metal panels can be recycled back into scrap. Tables 2-2 and 2-3 compare environmental considerations for steep and low-slope roofing systems.

Table 2-2. Preserving the Environment—Steep Roofing

	Used Recycled Material	**Minimize Health Risk**	**Maint/ Repair (e)**	**Recyclable Reusable**	**Typical Durability**	**Re-cover w/o Removal**
Asphalt Shingles						
Strip/Seal-Down	Yes	Yes	Easy	No (b)	15	Yes
Laminated	Yes	Yes	Moderate	No (b)	20	No
Interlocking	Yes	Yes	Easy	No (b)	15	Yes
Asphalt Roll Rfg	Yes	Yes	Easy	No (b)	10	Yes
Clay Tile	No	Yes	Moderate	Reusable	50	No
Concrete Tile	No	Yes	Moderate	Reusable	50	No
Slate	No	Yes	Moderate	Reusable	50	No
Architectural Metal	Yes	Yes	Moderate	Yes	(d)	No
Crafted Metal (Soldered)	Yes	Yes (a)	Moderate	Yes	25	No
Wood Shakes	Renewable	Yes	Easy	(c)	15	No
Wood Shingles	Renewable	Yes	Easy	(c)	15	Yes
Metal Look-Alikes	Yes	Yes	Moderate	Yes	(d)	No

(a) Lead-free solder.
(b) Economics not favorable at this time.
(c) Shred into mulch or incinerate.
(d) Finish may be warranted for 20 yrs.
(e) Ease of replacing damaged units.

Table 2-3. Preserving the Environment—Low-Slope Roofing

	Use RecycledMaterial	Reuse Production Scrap	Minimize Health Risk	MaintainableSustainable	Recyclable at End of Life
Built-Up Roofing		Dry Felt			
Smooth	Yes		Good	Easy	No (d)
Capsheet	Yes		Good	Fair	No (d)
Aggregate	Yes		Except Tar	Difficult	No (d)
Modified Bitumens					
Unsurfaced	No		Good	Easy	No (d)
Capsheet	No		Good	Fair	No (d)
EPDM		Non-vulcanized			
Adhered	No		Good	Easy	No (e)
Mechanically Fastened	No		Good	Easy	No (c) (e)
Ballast	No		Good	Fair	No (c) (e)
PVC Plasticized		Recycle Trim			
Mechanically Fastened	Maybe		Good	Easy	Maybe
Fully Adhered	Maybe		Good	Easy	Maybe
Weldable Unplasticized		Unreinforced			
Mechanically Fastened	No		Good	Easy	Maybe (c) (e)
Fully Adhered	No		Good	Easy	Maybe
Ballasted	No		Good	Fair	Maybe (c) (f)
SPF	No	No	Once set	Easy	No
Hydrostatic Metal	Yes	Yes	Yes	Fair	Yes

(a) Ballast could be reusable if cleaned and screened. Currently not done.
(b) Polystyrene insulation in unadhered applications could be cleaned and reused.
(c) Lightgard® pavers could be reused.
(d) BUR scrap, asphalt, felt and aggregate could be recycled into curbs or into low grade paving if economics were more favorable.
(e) EPDM could be reprocessed to extract oil, carbon, if economics were more favorable.
(f) Aggregate could be washed and screened to remove fines.

2-6. DETAILED INFORMATION. Once a tentative roofing system selection has been made using information provided by this chapter, refer to Chapters 3 through 10 for supplemental information and Design Alerts.

2-7. USING PRINCIPAL DESIGN CONSIDERATIONS TO REDUCE THE NUMBER OF POSSIBLE ROOF SYSTEMS.

a. Principal Design Considerations. Tables 2-4 and 2-5 list some of the principal design considerations in roof system selection. An explanation of the headings follow the tables. These tables are not all-inclusive but contains many criteria that the designer can consider to reduce the myriad of choices. Systems that fail to meet the principal project design criteria can be quickly disqualified from further consideration. For example, if an existing structure has reached its design load limit, then heavier roofs (such as ballasted single-ply roofs or concrete tiles) would have to be disqualified (or the structure would have to be strengthened at significant cost).

Table 2-4. Principal Design Considerations—Steep Roofing

Steep Sloped Roofing Systems	Initial Cost	LCC Cost	Construction Difficulty	Inspec. & Repair Difficulty	Life Years
Asphalt Shingles	L	L	L	L	15+
Wood Shingles	M	M	L	M	15
Wood Shakes	M	M	L	M	15
Slate	H	M	M	M	50
Concrete Tile	H	M	M	M	50
Clay Tile	H	L	L	M	50
Architectural Metal	H	L	L	M	20
Crafted Metal (Soldered)	H	M	H	M	50

Steep Sloped Roofing Systems	Suitable For Cold	Suitable For Hot	Wind Hail	Traffic Resist.	Resist Chem.
Asphalt Shingles	M	M (d)	M (c)	M	L
Wood Shingles	L	M (e)	L	L	L
Wood Shakes	L	M (e)	M	L	L
Slate	M	H	M	L	H
Concrete Tile	L	H (b)	M	L	M
Clay Tile	M	M (b)	H	L	M
Architectural Metal	M	H (a)	H	M	L
Crafted Metal (Soldered)	M	H	M	M	H (f)

L = Low, M = Medium, H = High
(a) Use heat-resistant underlayments.
(b) Requires nose clips and ties for high winds.
(c) Use extra nails and may require field application of tab cement or use of interlocking shingles.
(d) Use fungus resistant granules.
(e) Use rot-resistant (treated).
(f) Depends upon metal selected.

Table 2-5.
Principal Design Considerations—Low-Slope Roofing

Low-Slope Roofing Systems	Initial Cost	LCC Cost	Constuc-tion Difficulty	Insp. & Repair Difficulty	Life Years
BUR					
Smooth	L	M	L	L	15
Cap Sheet	L	M	L	L	15
Aggregate	M	L	L	M	20
MB	L	M	L	M	15
Single-Ply					
Mechanically	M	M	M	L	15
Adhered	M	M	M	L	15
Ballasted	L	L	L	M	15
PMR/Ballast	H	L	L	H	20+
SSSMR	H	M	M	M	20
SPF	L	M	L	L	20 (a)

Low-Slope Roofing Systems	Suitable For Cold	SuitableF or Hot	Wind Hail	Ponding	Traffic Resist	Resist Chem.
BUR						
Smooth	M	L	L	L	L	L
Capsheet	L	H	L	L	L	L
Aggregate	H	H	H	H	M	L (b)
MB	M	M	M	M	M	L
Single-Ply						
Mechanically	M	H	M	M	L	M
Adhered	M	H	M	M	L	M
Ballasted	M	M	H	M	L	M
PMR/Ballast	H	H	H	L	H	L
SSSMR	M	H	M	L	L	(c)
SPF	M	H	M	M	L	(d)

L = Low, M = Medium, H = High
(a) Requires periodic recoating.
(b) Coal Tar resists petrochemicals.
(c) Zinc/aluminum vulnerable to acids, alkali, salts.
Sealants vulnerable to solvents, oils.
(d) Depends upon coating selected.

b. Discussion of Headers in Tables 2-4 and 2-5.

(1) Initial Cost. This may include materials, labor, and special set-up for construction. Initial cost may determine if the roof, as designed, is affordable. Perhaps a somewhat less expensive system should be considered if it does not incur significantly increased maintenance costs or have a shortened life.

(2) Life Cycle Cost. LCC considers durability but also presumes that routine maintenance will be performed to achieve the projected life. Consider whether the building is temporary or permanent. It would be hard to justify an expensive copper or slate roof on a building scheduled for demolition in the near future. Also consider the mission of the building. There are levels of quality in many systems. For example, while 1.1 mm (45 mil) EPDM is the standard, for little extra cost 2.3 mm (90 mil) material with greater puncture resistance, or conversion to a PMR system, could be specified for a building with a critical mission.

(3) Construction Difficulty. Some systems require more clearance to accommodate application methods and equipment. Large prefabricated roof sheets (i.e., 15 m (50 ft.) by 60 m (200 ft.) may be fine on a large roof with few penetrations, but are impractical on a roof area that is broken up by many curbs and equipment supports. On multiple penetration surfaces, relatively narrow sheets (e.g., BUR, MB, thermoplastic single-ply) or sprayed-in-place polyurethane foam should be considered. Penetrations through standing seam metal roofing need to accommodate the expected thermal movement of the metal panels. Thermal movement is cumulative, increasing with distance from the point where the panels are restrained (typically the eaves). Penetrations in SSSMR panels must pass through the flat portion of the panel, not through the standing seam. Penetrations wider than a single panel require a diverter to carry water around the obstruction. Water must flow parallel to the raised seams, never over them.

(4) Periodic Maintenance—(The need for periodic maintenance and difficulty of inspection or maintenance.) Some roof systems require periodic recoating for weather protection. Aggregate surfaced roofs are more difficult to inspect and patch than smooth surfaced roofs.

(5) Life Expectancy. A mean life is listed but the actual life is affected by drainage, maintenance, and extreme use or abuse.

(6) Suitability in Severe Cold. Effects of freeze-thaw, hail, ice scrubbing, and traffic while cold (i.e., snow removal) is considered. Some materials embrittle dramatically at low temperatures (i.e., have a relatively high glass transition temperature); others may embrittle as they weather and lose plasticizer or are degraded by UV or thermal load. **H** indicates highly suitable; **L** indicates less suitable.

(7) Suitability in Extremely Hot or Humid Conditions. Effects of thermal expansion and algae growth are considered. **H** indicates more suitable, **L** indicates less suitable.

(8) Wind Resistance. Roofs are vulnerable to wind scour and blow-off. While arbitrary ratings are provided here, the resistance is affected by building height, terrain, parapet height and measures taken to upgrade perimeter and corner attachment. **H** indicates highly wind resistant (when properly designed). For membrane roofing, impermeable roof decks such as cast-in-place concrete are best. Air retarders are needed with loose laid and mechanically fastened single-ply systems as they may otherwise balloon from interior air leakage. Perimeter wood blocking must be well anchored to prevent peeling of the membrane or loss of fascia metal. Avoid the use of small aggregate (e.g., pea gravel) near tarmacs and on skyscrapers due to the damage it can cause if blown off the roof by high wind. Asphalt shingles may require manual application of tab adhesive. Interlocking asphalt shingles provide excellent wind resistance. Metal panel systems are wind resistant only when all components including clips, fasteners, and secondary structural members are installed as wind-tested. SPF has outstanding resistance to wind and to wind-blown

missiles. SPF roofs performed well in hurricane Andrew, especially when they were spray-applied directly to concrete roof decks.

(9) Resistance to Ponding Water. Membrane roof systems rely upon sealed seams to resist hydrostatic pressure. Water absorption may result in root or algae growth or cause rot. **H** infers highly resistant to these conditions.

(10) Traffic Wear Resistance. Roofs that have a lot of rooftop equipment will have foot traffic that can cause punctures or abrasion. Most roof systems are available with traffic protective overlayers, such as walkways. **H** indicates highly resistant to abuse assuming protective courses have been used.

(11) Resistance to Chemicals (resistance to oils, fats, grease, metal ions). Some roof surfaces are vulnerable to exhausted fumes or liquids. Thermoplastic polyolefins (TPO's) and Hypalon® (CSPE) may be better than bituminous materials in resistance to oils, greases, and solvents. Copper-containing runoff water from condensate coils or flashings will corrode zinc and zinc-aluminum SSSMR roofing. **H** indicates better than average resistance to attack.

c. Weight Factor. Consider the total number of roofs already installed, the weight of the proposed roof system possible, and construction loads. The unit weight of membrane systems vary dramatically, ranging from less than 2.4 kg/sq. m (0.5 psf) for a 50 mm (2 in.) thickness of SPF, to more than 100 kg/sq. m (20 psf) for ballasted single-ply systems. Typical roof system weights and construction loads are shown in Table 2-6.

d. Compliance with Fire & Wind Requirements. Roofing systems are rated as entire systems, including the roof deck, method of attachment to the deck (e.g., fasteners, hot bitumen, cold adhesives), vapor retarder (if used), thermal insulation, roof membrane, and surfacing. Typical External Fire Ratings (ASTM E-108, Class A, B or C) are shown in Tables 2-7 and 2-8. Combustible decks (wood/plywood/OSB) require selected combinations of underlayments, insulation, roofing, and surfacing to resist burning brands and intermittent flame as described in ASTM E108. (See Additional discussion in 10.h. Fire Considerations.) Also refer to MIL HDBK1008C.

e. Roof Decking. Principle roof decks for membrane roofing include steel, cast-in-place concrete, precast concrete, wood, plywood, OSB, and structural wood fiber. Variations of cast-in-place concrete include lightweight structural concrete (typically 1680 kg/m^3)(105 psf) and lightweight insulating concrete(480 kg/m^3)(30 psf). In new design, the roof deck is generally selected based upon construction considerations and materials. Steel is by far the most popular, followed by concrete and plywood/OSB. Table 2-9 lists some criteria for deck selection for new construction. Table 2-9 lists methods of attachment to the roof deck. Attachment options include full adhesion, mechanical fastening, and loose-laid/ballasted roofing. Steel decking requires a bridging course typically mechanically fastened roof insulation. For steep roofing, plywood and OSB roof decks are most common. They generally utilize flexible batts as underdeck roof insulation although architectural metal and cathedral ceiling constructions may use rigid insulation above the deck.

f. Suitability of the Membrane for the Substrate. Table 2-10 lists some possible combinations.

Table 2-6. Typical Weights of Material and Equipment

	Wt kg/m^2	**Wt lb./sq.ft**
Steep Roofing		
Asphalt Shingles	10 to 20	2 to 4
Wood Shingles	15 to 20	3 to 4
Wood Shakes	15 to 20	3 to 4
Concrete Tile	38	9
Clay Tile	38	9
Slate	38	9
Architectural Metal	2 to 13	0.5 to 3
Built-Up Roofing		
Smooth	10	2
Aggregate	24 to 34	5 to 7
BUR with Capsheet	7 to 10	1.5 to 2
Modified Bitumens		
Smooth or Capsheet	7 to 10	1.5 to 2
Single-Ply		
Mechanically fastened (or fully adhered)	5	1
Ballasted	50 to 100	10 to 20
PMR (including ballast)	24 to 100	5 to 20
Standing Seam Metal	5 to 10	1 to 2
Sprayed in Place Polyurethane Foam	2 to 5	0.5 to 1
Weights of Typical Roofing Equipment	**Wt/kg**	**Wt/lb.**
Ballast buggy with hopper extension	725	1600
Pallet of modified bitumen (16 rolls)	660	1450
Tear-off machine	180	400
Deballasting machine	385	850
Ballast hopper—loaded	1630	3600

Table 2-7. Fire Ratings and Required Underlayments for Steep-Sloped Roof Systems

	ASTM E108 Class A, B, or C	**Underlayments**
Asphalt Shingles		
Asphalt-Organic	C	No. 15/30 Felt
Asphalt-Glass	A	No. 15/30 Felt
Asphalt Roll Roofing	B/C	Base Sheet
Clay Tile	A	No. 30
Concrete Tile	A	No. 30
Slate	A	No. 30
Architectural Metal	Underlayment-?	(a)
Crafted Metal	Underlayment-?	(a)
Wood Shakes	C	(a)
Wood Shingles	C	(a)
Metal Look-Alikes	Underlayment-?	(a)

(a) May require gypsum board or special fire resistant underlayments for combustible decks.

Table 2-8. Fire Ratings and Required Underlayments for Low-Slope Roof Systems

	ASTM E108 Class A, B, C Combustible Decks (c)	ASTM E108 Class A, B, C Noncombustible (e)	Metal Deck Construction
Built-Up Roofing			
Smooth	B	A	Isoboard/Perlite/Glass Fiber
Capsheet	B	A	Isoboard/Perlite/Glass Fiber
Aggregate	A	A	Isoboard/Perlite/Glass Fiber
Modified Bitumens			
Unsurfaced	B-FR. (d)	A-FR.	Isoboard/Perlite/Glass Fiber
Capsheet	B-FR.	A-FR.	Isoboard/Perlite/Glass Fiber
EPDM			
Adhered	C-FR.	A-FR.	Isoboard (b)
Mechanically Fastened	C-FR.	A-FR.	Isoboard/Perlite/Glass Fiber
Ballast	A	A	Isoboard/Perlite/Glass Fiber
PVC Plasticized			
Mechanically Fastened	B	A	Isoboard/Perlite/Glass Fiber
Fully Adhered	B	A	Isoboard (b)
Weldable Unplasticized			
Mechanically Fastened	C-FR.	A-FR.	Isoboard (b)
Fully Adhered	C-FR.	A-FR.	Isoboard (b)
Ballast	A	A	Isoboard (b)
SPF	A	A	Some Listed Systems
Hydrostatic Metal	(a)	A	Not Required

(a) Depends on underlayment/(gypsum board?)
(b) Perlite/glass fiber may not be acceptable to single-ply systems because of asphalt content or dusty/solvent-degradable surface.
(c) On combustible decks, mass of surfacing or underlayment is important to prevent ignition of the deck.
(d) FR. means Fire Retarded Sheet required.
(e) Non-Combustible decks include steel, concrete and gypsum.

Table 2-9. Suitability of the Roof Deck for Various Conditions

Deck Type	Economy	Long Spans Available	Resist. Heavy Roof Traffic	Seismic Resist.	Internal Fire Resist.	ExternalFire Resist.	Wind Resist.
Insulated Steel	E	No	F	E	F	E	G
Cast-In-Place Concrete	P	No	E	F	E	E	E
Precast Concrete	P	Yes	E	G	E	E	G
Plywood or OSB	G	No	P	E	P	P	F
Structural Wood Fiber	P	No	P	F	P	F	P
Lightweight Insulating Concrete	F	No	G	P	G	E	G

E= Excellent, G = Good, F = Fair, P = Poor

Table 2-10. Membrane/Substrate Compatibility/Attachment Methods

	Deck Type					
Membrane:	InsulatedSteel/ Other	UninsulatedConcrete	UninsulatedWood/OSB	Existing BituminousSystem	Cemen-titious Wood Fiber	Lightwt. Insulating Concrete
Fully Adhered						
Built-Up Roofing	Hot Asphalt	Prime/Hot	Nail Base	Re-cover Board	Nail Base	Nail Vent Base
Modified Bituminous	Hot Asphalt	Prime/Hot	Nail Base	Re-cover Board	Nail Base	Nail Vent Base
Single-Ply	Adhesive	Fleece-back/Hot	Tape Joints	Re-cover Board	N/A	(a)
SPF	N/A	Yes	Seal Joints	Yes	N/A	N/A
Mechanically Attached						
Built-Up Roofing	Mop to Insulation	N/A	N/A	Re-cover Board	Nail Base	Nail Vent Base
Modified Bituminous	Mop to Insulation	N/A	N/A	Re-cover Board	Nail Base	Nail Vent Base
Single-Ply	Special Fasteners	Predrill Deck	Special Fasteners	Separator Needed	Special Fasteners	Special Fasteners
Loose-Laid & Ballasted						
Single-Ply	Ballast	Cushion	Check Structure	Separator	Check Structure	N/A

(a) Lightweight structural concrete 1680 kg/m^3 (105 pcf) may be acceptable.

g. Thermal Insulation. Rigid thermal insulations used under membrane roofing include wood fiber, perlite fiber, glass fiber, foamed glass, polystyrene (extruded or expanded), and polyisocyanurate (isoboards). Non-structural thermal insulations include glass fiber and mineral wool batts, blown loose insulations such as cellulose fiber, glass fiber, mineral fiber, and expanded vermiculite. Table 2-11 indicates suitability of rigid roof insulations for membrane roofing based upon intended method of use.

Table 2-11. Suitability of Roof Insulation for Method of Use

	Direct Attach-ment to Steel Decks	**Mechanical Attachment**	**Solvent Adhesive**	**High Thermal Value/Unit Thickness**	**Fire Resistant**	**Asphalt Compat-ible**	**Use in PMR**
Wood Fiber	(a)	Yes	Yes	No	No	Yes	No
Perlite Fiber	Yes	Yes	(b)	No	Yes	Yes	No
Glass Fiber	Yes	(f)	Yes	No	Yes	Yes	No
Polystyrene MEPS	(c)	(d)	No	Yes	No	No	No
Polystyrene XEPS	(c)	(d)	No	Yes	No	No	Yes
Polyisocyanurate	Yes	Yes	Yes	Yes	Yes	(e)	No
Foam Glass Board	Yes	Yes	Yes	No	Yes	Yes	No
Mineral Wool Fiber	Yes	(f)	No	No	Yes	Yes	No

(a) Wood fiber is available with <4% asphalt to meet under-deck fire requirements for steel decks.
(b) Asphaltic adhesives are permitted to attach membranes to perlite boards, but not single-ply adhesives.
(c) Some polystyrene applications have passed fire testing when used in conjunction with single-ply systems only. It is not universally agreed that this is an acceptable application.
(d) Mechanical fasteners compress polystyrene insulation, resulting in loss of restraining force. Overlay with rigid board such as perlite.
(e) Overlay with non-foam layer for hot BUR or MB application.
(f) Special stress plates needed to recess heads of screws.

(1) Thickness of Insulation. If thick layers of insulation are needed to meet a high therm resistance, thicker wood nailers and deeper fascia metal will be required. Foam plastics such as polyisocyanurate and polystyrene have the highest R values per unit thickness.

(2) Clearance of Metal Panels. In standing seam metal roof systems, the permissible thickness of blanket insulation may be limited by the clearance provided by the supporting clip design.

(3) Insulated Attic. Blanket insulation used in steep roofing systems is frequently placed on the floor of the attic where R-values of 30 (RSI = 5.4) or more may be possible (figure 2-13).

(4) Ceiling Insulation. Dropped ceilings are sometimes insulated by placing batts directly above the ceiling panels. This practice is not recommended as subsequent access to underdeck equipment or phone wires is blocked. When the insulation is displaced to gain access it is rarely put back in place correctly, if at all.

h. Suitability for Extreme Climates. Protected membrane systems (PMRs) are very well suited to extremely cold climates and have been successfully used in all climates. For extreme conditions of snow and ice, a cold (ventilated) roof should be considered. For most steep roofing this is achieved by allowing a flow of outdoor air between the insulation and the roofing system. This air cools the roof in summer, dries out any moisture that condenses in the roof, and greatly reduces the formation of icicles and ice dams along eaves. For regions prone to severe hail, ballasted EPDM roofs are very good and PMRs are excellent. Tiles, shingles, bare BUR, and metal systems are easily damaged by hail. In regions of semitropical climate (high temperatures and humidity), asphalt shingles should be treated to be fungus resistant and wood shakes/shingles should be pressure treated for rot resistance.

i. Installation in Cold or Wet Weather. Most membrane systems are difficult to install in subfreezing weather. If frequent precipitation during construction is a problem, factory fabricated single-ply systems with field welded seams may have advantages over systems where field application of adhesives or hot bitumen is needed. Torch applied modified bitumens are one of the few systems that can be applied, albeit slowly, in wet windy conditions.

j. Warranties. The NRCA *Commercial Low-Slope Roofing Materials Guide* contains a comprehensive side-by-side comparison of commercial roof warranties. The roofing industry offers two general types of warranties: Materials Only and Materials & Workmanship. Carefully read exclusions and limits. Note: The longest warranties are not necessarily the best, nor does the length of the warranty directly relate to roof durability. In many cases, manufacturers may restrict their warranties.

k. Maintenance Considerations. Sloped roofs require less routine maintenance and may be preferred when the facilities management is incapable of providing routine inspections and minor repairs. Modified bituminous and BUR systems may be superior in abuse resistance to thin single-ply systems. Various protection boards/walkways can be used around equipment where traffic is anticipated. Protected membrane roof systems (PMR's) are abuse resistant but more difficult to inspect and repair.

l. Roof Access, Fumes and Property Protection When Reroofing.

(1) Fumes. In reroofing situations fumes from kettles and solvents may be objectionable. Hot coal tar pitch is especially objectionable; hot asphalt is also noticeable but less noxious. Cold applied systems with taped or welded seams and metal roof systems generate few odors. It may be necessary to coordinate air-conditioning shutdown to avoid taking fumes into the occupied building.

(2) Ease of Construction Access. If the area around the construction site is congested it may make heating and hoisting of roofing materials difficult.

(3) Specifying Construction Procedures. Site access, material storage area, layout area, building and landscape protection should be identified on drawings.

(4) Safety and Disturbance to Occupants. The presence of occupants, vehicles, and pedestrians may be of concern. Reroofing is noisy. Dust and overspray may affect those nearby.

m. Installation. Roofing requires skilled installers. Qualified contractors and inspectors are more likely to be available if the system is customarily used in the region. It should be determined whether there are several manufacturer-approved installers capable of bidding the work.

n. Owner Preferences. Verify that the contemplated system is acceptable to the owner, occupants, and maintenance personnel.

2-8. CONSIDERATIONS WHEN SPECIFYING LOW-SLOPE (HYDROSTATIC) MEMBRANE ROOFING. With the exception of SSSMR, membrane roofing requires a suitable roof deck. Most constructions will also use thermal insulation. Vapor retarders are sometimes required to protect the roofing system from attack by interior moisture.

a. Built-up Roofing (BUR). BUR Consists of multiple reinforcements such as asphalt treated glass or organic felt laminated together with hot-applied bitumen (asphalt or coal tar pitch) or cold adhesives (figure 2-4). Surfacings include aggregate, coatings, capsheets, and sprayed roofing granules. A typical system includes thermal insulation and may include a vapor retarder.

b. Polymer Modified Bitumen. MB consists of reinforcing sheets factory-coated with polymer modified bitumen. They may be laminated in the field using hot bitumen, heat fusion, or by cold adhesives (figure 2-5). Surfacings include capsheets with mineral granules, metal foil, and field applied coatings.

c. Elastomeric (Single-Ply) Membranes. Elastomeric membranes consist of a factory-produced sheet generally of EPDM rubber with seams field-sealed with adhesive or tape (figure 2-6). Sheets are unsurfaced unless ballast is used. Elastomers are vulcanized (thermoset), and usually non-reinforced except when used in mechanically fastened systems. A fleece-backed sheet is also available for fully adhered systems when it is desired to use hot bitumen as an adhesive (e.g., for re-covering an asphalt-contaminated deck or old BUR).

d. Weldable Thermoplastic Membranes. These membranes consist of a sheet of reinforced thermoplastic material such as PVC or TPO. Sheets are unsurfaced or ballasted. Seams are generally heat fused although solvent welding and adhesive bonding are also possible (figure 2-7).

e. Structural Standing Seam Metal Roofing. SSSMR consists of metal panels with raised seams more than 37 mm (1-1/2 in.) high (figure 2-8). Sealants are utilized at side seams and endlaps to provide waterproofing. Most are considered hydrostatic, resisting standing snow and occasional ponding. Caution: ridges and valleys of a SSSMR may not be as watertight as the seams.

f. Sprayed-in-Place Polyurethane Foam. SPF is a thermoset rigid foam, field-formed by the reaction of liquid components (in the presence of a foaming agent) sprayed onto the substrate. SPF is protected by liquid-applied elastomeric coatings or an application of loose gravel (on slopes $< 4\%$).

g. Components of Membrane Roofing Systems (figure 2-9).

(1) The deck supports roofing loads and is selected to conform to fire resistant design classifications. Not all systems require a deck (e.g., structural standing seam metal roofing).

(2) A vapor retarder protects the insulation against moisture vapor attack from the warm, high vapor pressure side of the roof assembly. Not all buildings require a vapor retarder (*See General Considerations for Roofs*, CRREL Misc. Paper 3443 and CEGS 07220).

(3) An air barrier prevents air movement (infiltration or exfiltration) through the roofing system.

(4) Thermal insulation provides thermal resistance and prevents condensation on components beneath the insulation. It also furnishes support and a smooth, continuous substrate for the membrane.

(5) The membrane is intended to keep water out of the components below (as well as out of the building). The membrane system affects fire resistance.

(6) Individual roofing components may be held in place by adhesives, fasteners, ballast, or a combination of these methods.

(7) Perimeter flashings are waterproof vertical terminations of the membrane (perimeter flashing) (figure 2-10).

(8) Roof edging and fascia are usually low profile roof edge terminations and side trim.

(9) Roof penetrations include drains, vents, curbs, equipment supports, and the like.

(10) Surfacing materials screen UV light, improve fire ratings, and may improve water and/or hail resistance.

h. Attachment for Low-Slope Roof Systems.

(1) Full Anchorage**.** For relatively inelastic roof membranes such as BUR and MB, solid adhesion helps restrain the roof membrane and uniformly distribute thermal stresses. When insulation is used, it is fastened or adhered to the deck. The membrane is fully adhered to the thermal insulation using hot asphalt or cold adhesive. Polyurethane foam is sprayed directly to the substrate, especially in re-cover of existing BUR thereby being fully adhered as well.

(2) Partial Attachment. In partially attached systems the membrane is mechanically anchored through the insulation into the deck, or in a few cases, partially adhered with strips or spots of adhesive. This is common with flexible single-ply roof membranes. Fasteners are typically placed in the seams area where by can be covered by the overlapping sheet.

(3) Loose-Laid Attachment. For loose-laid systems the membrane is unattached to the substrate and is held in place by ballast. Restraint is required only at perimeters and curbs. Loose-laid roofs are used with elastomeric (EPDM) and some thermoplastic (e.g., TPO) systems. These are very inexpensive roof systems *if* the structure can handle the ballast weight. *Caution: In positive pressure buildings air barriers should be used with loose laid and partially attached membranes to avoid billowing and peeling.*

i. Labor.

(1) Highly Intensive: BUR, MB

(2) Moderately Intensive: SSSMR—The system is very unforgiving of installation defects.

(3) Medium Intensity: Fully adhered and mechanically fastened single-ply.

(4) Low Intensity: Spray Foam requires the smallest crew (but is the most machine intensive and weather sensitive).

j. Slope.

Table 2-12. Some Typical Slope Limitations for Low-Slope Roof Systems

	% Min.	In./ft. Min.	% Max.	In./ft. Max.
Ballasted Membranes	2	1/4	16.7	2
Gravel Surfaced BUR	1	1/8	25	3
Cap Sheets, Narrow Lap Widths	2	1/4	50	6
MB smooth or Cap Sheet	2	1/4	50	6

2-9. PRINCIPAL CONSIDERATIONS WHEN SPECIFYING STEEP-SLOPE (WATERSHEDDING) ROOFING. This category covers systems that range from asphalt shingles, wood shingles and shakes, clay and concrete tile, slate, and metal look-a-likes. Also included are architectural metal panels with a variety of seams (figure 2-11). Slopes are generally 25% (3:12) or greater. Most must be continuously supported on a solid deck (e.g., plywood or oriented strand board [OSB]). However, some varieties (e.g., clay and concrete tiles) may be supported on spaced horizontal batten boards. Underlayments such as roofing felt, self-adhering MB or plastic film are usually required over the entire roof to provide a secondary line of defense against driving rain and blowing snow. In cold regions, a completely sealed MB underlayment is needed along eaves, in valleys, and at dormers, skylights, chimneys and such to resist leaks from water ponded behind ice dams.

a. Aesthetics. By their very nature steep roofing is highly visible. Appearance may be of primary concern to the designer. Regional preferences exist. For example, red tile roofing is very common and highly desirable in the Southwest, while light gray concrete tile is preferred in Florida. Wood shakes give a textured natural look preferred in the Pacific Northwest.

b. Labor Intensity and Labor Skill.

(1) High Intensity. Heavy brittle units of clay, tile or slate.

(2) Medium Intensity. Architectural metal, wood shakes.

(3) Low Intensity. Shingles.

c. Watershedding. Steep roofs rely on gravity to cause water to flow away from headlaps. Recommended minimum slopes are shown in Table 2-13. Lower slopes are sometimes permissible by increasing overlap or enhancing the waterproofness of the underlayment.

Table 2-13. Minimum Slopes for Typical Steep Roofing Systems

	In./ft.	**%**
Asphalt Shingles	4	33
Wood Shakes	4	33
Slate	4	33
Tile	4	33
Wood Shingles	3	25
Asphalt Shingles with Sealed Underlayment	2	17
Roll Roofing	1	8
Architectural Metal	4	33
Some Architectural Metal with Sealed Underlayment	3	25
Structural Metal without Waterproof Joints	3	25
High Seams and Underlayments	2	17
Structural Metal with Waterproof Joints in Some Climates	1/2	4

(2) Valleys and Eaves. Valleys must be well constructed. The slope of a valley will be less than that of the intersecting planes that form it. Exterior drainage over the roof edge or to a gutter is typical but may be troublesome in cold regions since ice dams may form there.

(3) Underlayments. Sealed underlayments of self-adhering modified bitumen are typically used along the eaves to at least 610 mm (24”) beyond the interior wall line (figure 2-12a) and as valley lining. Occasionally the entire roof deck is covered with such a membrane. Note that this can lead to problems if indoor moisture is not isolated from the roof by well made vapor and air barriers. Underlayments are used in steep roofing as a secondary defense against water penetration (figure 2-12b). These include No. 15 felt, No. 30 felt, and self-adhering MB sheets. For hydrokinetic and crafted metal, self-adhering MB sheets are essential as a secondary water barrier.

d. Energy Efficiency. Steep roofs generally cover an attic space (figure 2-13) (with the exception of cathedral ceilings). The floor of an attic can be inexpensively insulated with nonstructural insulations such as fiberglass batts, mineral wool, expanded vermiculite, or treated cellulose. Where the thickness of the insulation is not limited by clearance problems, very high thermal resistances (e.g., $R_{si} > 5.56$, $R > 30$) can be achieved. If a vapor retarder is required for a cold arctic climate the retarder needs to be placed on the interior (warm side) of the insulation. The attic space above this insulation should be ventilated to remove moisture and to keep the attic relatively cold; this minimizes ice damming at eaves.

e. Durability. Mean durability of common steep roofing has been estimated in one survey as:

Table 2-14. Mean Durability of Common Steep Roofing

	Years
Natural Slate	60
Clay Tile	47
Asbestos Cement Shingles	31
Metal Panels	28
Organic Fiber/Cement Shingles	26
Better Quality Asphalt Organic Shingles	18
Better Quality Asphalt Glass Fiber Shingles	18
Cheap Asphalt Shingles (don't use)	Perhaps only 10

2-10. ADDITIONAL CRITERIA AND DISCUSSION.

a. Wind. Maximum wind speeds associated with locality and storm type determine needed resistance. ANSI/ASCE 7-95 and EI01S010 provide design information.

(1) Adhered Systems. Air impermeable roof decks such as poured concrete, with adhered or mechanically fastened insulation and fully adhered membranes, are highly wind resistant. Tests conducted by the Factory Mutual System have determined that BUR systems installed this way have resisted 8.6 kilopascals (180 psf).

(2) Metal Panel Systems. Metal panels are generally rated by the Underwriters 580 procedure, with UL 90 ratings considered excellent. However, because some SSSMR panel systems with UL 90 ratings have failed in service, structural standing seam metal roof systems must pass the ASTM E1592 test method (formerly known as the Corps of Engineers air-bag test).

(3) Ballasted Systems. Ballasted single-ply systems rely on heavier and larger ballast in more wind prone exposures. SPRI has developed wind guidelines in their ANSI-SPRI RP-4 document based upon ANSI/ASCE 7-95 guidelines. Higher parapets have a beneficial effect on ballasted systems. Above certain building heights, SPRI recommends against the use of ballast.

(4) Mechanically Fastened Systems. Mechanically fastened single-ply systems use narrower starter sheets and increased fastener density in high wind areas. Examples of layout can be found in Factory Mutual Loss Prevention Data Sheet 1-29.

(5) Foam Systems. Sprayed-in-Place Polyurethane Foam (SPF) systems have proven very wind resistant and are effective in protecting the structure against wind hurled missiles.

(6) Problems with Small Roof Aggregate. Roofs adjacent to airport tarmac activities should avoid aggregate surfacings as loose aggregate may be blown off the roof and sucked into engines. Loose stone ballast which is much larger, is used successfully at many airports.

(7) Wind Rated Roofs. Underwriters Laboratories lists wind rated systems in their Roofing Materials and Systems Directory as Class 30, 60 or 90. Factory Mutual Research Corporation lists wind rated systems in their *Approval Guide* with ratings ranging from 60 to 210 psf.

(8) Steep Roofing. For most steep roofing systems, additional fastening is required for high wind areas (e.g., six fasteners per asphalt shingle instead of four, addition of nose clips for tiles, etc.).

b. Ice and Hail. The formation of ice can cause the roof membrane to split. Ice can also affect roofing performance by scrubbing the membrane and eroding the surface. This can be especially detrimental to materials with a relatively high glass transition temperature (Tg). Bituminous materials have a Tg of approximately 0°C (32°F). Modified bituminous materials with an SBS modifier can have a Tg as low as minus 34°C (-30°F). EPDM membranes report a Tg less than -40°C (-40°F). The Tg of thermoplastics may increase with age (i.e., loss of plasticizer in PVC). Ponding promotes ice damage; drainage avoids it.

(1) Impact Damage. Falling ice, such as from overhead towers, causes impact damage. Ballasted EPDM provides some protection. Protected membrane roofs in which both polystyrene insulation and ballast are placed over the finished roof membrane provide excellent impact resistance.

(2) Perimeter Icing. Ice formation at eaves, scuppers, and gutters is a major design concern. For low-slope roofing selection of internal drainage where building heat keeps the drain lines unfrozen is recommended.

(3) Minimizing Icing Problems. For metal and steep roofing heating cables are sometimes necessary but not especially reliable. In cold regions use of a cold roof in which the roof is ventilated to prevent formation of icicles and ice dams is preferred. Self-adhering waterproof membranes are needed to avoid leaks from ice damming (figure 2-10).

(4) Hail Damage. Weather maps are available that generally divide the U.S. into regions that require resistance to severe hail (50 mm [2 in. dia.]), moderate hail (38 mm [1-1/2 in. dia.]), and areas of low hail probability. Hail resistance is affected by the compressive strength of the substrate, thickness of the membrane, tensile strength, and age/brittleness of the material.

c. Snow. Snow removal operations in which shovels or snow blowers are used can cause severe damage especially to cold, brittle membranes. Smooth single-ply membranes and metal roofing are extremely slippery when wet or when a thin ice film covers melt water. Roof walkways consisting of compatible materials are essential when it is necessary to walk on wet or frozen roofs.

(1) Metal Roofs. TI 809-52 recommends that SSSMRs should have a minimum slope of 8.3% in cold regions.

(2) Snow Loads. Snow load information is available in ANSI/ASCE 7-95, TI 809-01, and TI 809-52.

d. Slope. Drainage is essential on all roofing systems. (See ORNL-6520 *Decision Guide for Roof Slope Selection*.) For hydrokinetic roofing the drainage must be positive and rapid. Shingles, tiles, and the like, generally have industry minimum recommended slopes of 33% to 42%. Sometimes a lower slope option is available if waterproof underlayments are used.

(1) Metal Roofs. Minimum slopes for metal roofs vary from 4% to 33%, depending upon roof type as indicated in Table 9-1.

(2) Membrane Slope. Low-slope membranes should also comply with a minimum slope of 2% (1/4 in./ft.). Where ponding is unavoidable such as in spray ponds, a BUR with double poured aggregate and bitumen is sometimes used. Coal tar pitch membranes are used at slopes as low as dead level and to a maximum slope of 2% (1/4 in/ft.).

(3) Foam Slope. For Sprayed-in-Place Polyurethane Foam (SPF) systems positive drainage is also needed. However, small puddles are inevitable as SPF is never completely smooth. Small puddles should dry out within 24-48 hours after inclement weather. Additional elastomeric coating is recommended where ponding is anticipated.

(4) Reroofing. In reroofing and re-covering applications, correcting the slope to 2% (1/4 in./ft.) is sometimes unfeasible because of low windows, flashings, etc. In these cases, tapered insulation at 1.5% (3/16 in./ft.) slope may be an acceptable compromise.

(5) Steep Roof Conversion. Conversion of a poorly draining roof to a steep roofing system may be accomplished on a relatively narrow roof system building by installing new sloped joists.

e. Vapor, Humidity, Moisture and Condensation. Moisture can be carried through materials by diffusion or by the movement of air. Air barriers are needed to reduce air movement. They can be located anywhere within the building envelope. Vapor retarders, when needed, must be placed within the warm portion of the thermal insulation.

(1) Self-Drying Systems. In cold weather, warm moist indoor air driven from within the building towards the colder exterior may accumulate during the winter then dry back out again during the summer months. Guidelines for the use of vapor retarders in roofs are presented in CRREL Misc. Paper 2489, *Vapor Retarders for Membrane Roofing Systems*. Figure 2-14a indicates suggested maximum allowable relative humidities where summer dry-out should be adequate. Figure 2-14b is used to adjust figure 2-14a for temperatures other than 15.5°C (60°F).

(2) Reverse Vapor Drive. For hot humid climates a reverse vapor drive may occur especially in cooler and freezer buildings. In this case the membrane and wall retarder must be sealed and continuous. Roof vents and breathing edge details must be avoided. For freezer buildings, consider separating the roof system from the freezer.

(3) High Humidity Occupancies. For buildings with high interior relative humidity including bakeries, laundries, pools, kitchens, dining halls with serving lines and the like, vapor retarders are considered essential.

Table 2-15. Typical Indoor Relative Humidity in Winter.

Offices	30-50%
Hospitals	30-55%
Computer Rooms	40-50%
Department Stores	40-50%
Swimming Pools	50-60%
Textile Mills	50-85%

(4) Bituminous Vapor Retarders. Bituminous retarders are installed over solid fire barrier substrates such as concrete, gypsum board, or a fire resistant insulation. Bituminous retarders have near zero perm ratings. For most membrane roofing systems vapor retarder permeance should be below 0.5 perms (28.6 ng/s•sq m•Pa). Perm ratings for various vapor retarder materials can be found in the ASHRAE *Handbook of Fundamentals* as well as in industry literature.

(5) Non-bituminous Vapor Retarders. Non-bituminous single-ply systems may use plastic films as vapor retarders. These can be successful if the seams and penetrations are

carefully sealed with tape. Puncturing the retarder, either accidentally or by installing mechanical fasteners lessens its resistance to moisture.

(6) PMRs. Protected Membrane Roofing systems (PMR's) are very effective against vapor drive from within the building. The roof membrane itself serves as the vapor retarder as most, if not all, of the thermal insulation is located above it. Self-drying of the insulation (extruded polystyrene) to the atmosphere maintains the thermal resistance.

(7) SPF Systems. SPF systems are commonly installed on re-cover installations where the old bituminous membrane can be sealed to form a retarder. Dew point calculations are necessary to insure the dew point is within the upper SPF layer.

(8) Steep Roofing. In steep roofing systems the retarder is usually a plastic film (poly), treated kraft paper or foil facing on batt insulation installed with the retarder facing the interior. When an attic or cathedral ceiling is present, ventilation of the space above the insulation is essential since retarders are rarely completely sealed and some moisture accumulation would otherwise occur. Most codes recommend at least 1:150 net free ventilation area (total at eave and ridge) when a retarder is not installed to 1:300 when a retarder is in place. In cathedral ceiling construction larger net free areas are needed since friction losses in the narrow airway reduce ventilation.

(9) Metal Systems. In structural metal systems where draped batt insulation is used, it is difficult to completely seal the retarder facer even if tape is used. When high interior vapor conditions exist the use of a subdeck to support a retarder film may be necessary. Other roofing systems should also be considered as such systems are not good at resisting high internal relative humidities.

f. Considerations When Using Thermal Insulation. Thermal insulation is important in modern buildings both for energy conservation and human comfort and may impact roof membrane performance.

(1) Thermal Resistance. Resistance to heat flow through the entire roof structure (characterized by the R factor) should be as high as is both practicable and cost effective. In general the Corps of Engineers recommends an R factor of > 20 (R_{si} > 3.57). Note: U = 1/R therefore, the U factor should be < 0.05 Btu/hr•ft^2 ^{o}F (0.284 w/m^2 ^{o}K).

Table 2-16. Unit Resistances (i.e., Resistivity) of Common Roof Insulations

	Density (pcf)	**R/Inch (Hr•^{o}F/btu)**	**W•^{o}C/m^2**
Rigid Boards			
Rigid Polyisocyanurate Foam	2.0	6.2	1.1
Extruded Polystyrene Foam (XEPS)	2.2	5.0	0.88
Glass Fiber Boards	14	4.0	0.73
Expanded Polystyrene Foam (MEPS)	1	3.8	0.67
Foamed Glass	9	2.9	0.50
Expanded Perlite	10	2.8	0.49
Wood Fiber	18	2.8	0.49

SPF	2.7	6.2	1.1
Batts and Blankets			
Rock/Slag/Glass	1.5	3.5	0.53
R value varies with in-place density			
Loose Fill Insulations			
Cellulose (milled paper)	2.8	2.3	0.40
Expanded Perlite	5.6	4.1	0.72
Rock/Slag/Glass Fibers	1.5	0.6	0.10
Vermiculite, Exfoliated	7.6	7.0	1.23

Note: Thermal resistance (R=1/C where C = k/thickness). The higher the thermal resistance, the more efficient the insulation. Resistance may decline with age due to diffusion of air into foam cells (aging of foam). Absorption of water can reduce the insulating ability of most insulations to a small fraction of their dry value.

(2) Installation Locations. Thermal insulation may be installed in four locations.

(a) Underdeck insulation (figure 2-15).

1/ Wood frame structures with steep roofing often utilize batt insulation placed between the rafters. Vapor retarders of foil, kraft, or plastic film are located on the inside face of the insulation. With structural standing seam metal systems, batts are draped over the purlins. In attics, the insulation is usually positioned between ceiling joists.

2/ An advantage of underdeck insulation is that inexpensive nonstructural insulations such as batts may be used.

3/ A disadvantage is that the roof deck suffers greater thermal stress than when it is overlaid with insulation. Another disadvantage is that it is difficult to vapor seal such construction and make it resist air exfiltration and as a result moisture problems are prone to occur. Ventilation is usually required but ventilating low-slope framed roofs lacking tight air barriers is apt to increase moisture problems, not eliminate them.

4/ Common underdeck materials include compressible batts of glass fiber and mineral wool. Thermal spacers of rigid plastic foam are placed over the purlins of SSSMR systems to maintain the thermal resistance where the batts are compressed.

(b) Self-insulating roof deck (figure 2-16):

1/ Insulating decks such as structural wood fiber are less popular today because it is difficult to achieve high R values within the deck itself. In reroofing situations supplemental insulation would often be added on top of such a deck. In some new assemblies a composite of structural wood fiber topped with plastic foam is used. The underside of these self-insulating decks can be exposed to the interior and serves as an attractive acoustical ceiling.

(c) Thermal insulation within the roofing sandwich (figure 2-9).

1/ Insulation on top of the roof deck is the most common configuration for membrane roofing. For adhered membrane systems the thermal insulation restrains the membrane against wind loss or shrinkage and must have adequate structural strength. For mechanically anchored and ballasted systems compressive strength and stability are important. If hot asphalt or solvents are used in construction of the membrane, the insulation must resist degradation by these agents.

2/ Common materials for adhered systems include faced polyisocyanurate foam (ASTM C1289), perlite (ASTM C728), rigid glass fiber boards (ASTM C726), wood fiber (ASTM C208), and cellular glass (ASTM C552). Verify that the combination of membrane and roof insulation/facer are Fire and Wind Rated.

3/ For mechanically fastened and ballasted systems expanded and extruded polystyrene (ASTM C578) are added to the above list. (They could melt or dissolve if placed in contact with hot bitumen or solvent-based adhesives).

4/ Some decay of R value is observed with HCFC blown foams (urethanes and isoboards) due to diffusion of air and moisture into the cells of the foam. Manufacturers publish aged R values to reflect this decay. Always used aged R-values for these materials. Since diffusion starts at the surface of the foam, thicker foams are more thermally stable.

5/ Wood fiber boards should be manufactured to use as roof insulation (meeting ASTM C208), not sheathing boards, and should be limited to 1220 mm (4 ft.) in length and width.

6/ When mechanical fasteners are used to secure thermal insulation, it is recommended that the nail-one, mop-one technique be used. This minimizes a thermal bridging and avoids nail-popping of the membrane. When multiple layers of insulation are used, vertical joints should be offset to reduce heat losses. Straight-through joints can take away 10% of a roof's insulating ability.

(d) Protected membrane systems (figure 2-17).

1/ In PMR systems only extruded polystyrene is suitable in the sometimes wet environment above the completed roof membrane. This insulation protects the membrane from thermal stress and abuse.

2/ Ballast and filter fabric is needed to hold the loose-laid insulation in place.

g. Energy and Solar Radiation. The ratio of roof area on a low-rise commercial building is high relative to wall area. Such roofs can provide a great opportunity for energy conservation. This can be accomplished by using well insulated, high thermal mass structures to reduce summer cooling loads, garden roofs, or high albedo roof coatings.

(1) Heat Gain. For roofs in hot or temperate climates, light colored roof surfaces reduce heat gain. For membrane roof systems, light colored aggregate (gravel surfaced roofs) or mineral granules (capsheets [ASTM D249, D371, D3909] and MB capsheets [ASTM D6162, D6163, D6164, D6222, D6223]) will reduce heat maximum surface temperatures by up to 20°C (35°F) over black membranes. Aluminum coatings (ASTM D2824) are approximately the same, while white coatings (ASTM D6083) have been observed to reduce temperatures by more than 23°C (45°F) (provided that the roof stays clean). The use of pavers and heavy ballast reduce heat gain through thermal lag; that is, the high heat capacity stores some of the gained heat delaying the startup of the building's air conditioning system. The ASHRAE *Handbook of Fundamentals* uses the term Equivalent Temperature Difference (ETD) in energy calculations. The smaller the ETD, the better the system is at reducing peak solar loads.

Table 2-17. Equivalent Temperature Difference

Construction	**ETD (°C)**	**(°F)**
Light (wood, metal deck)	33	60
Medium (gypsum, lightweight concrete, 100 mm (4 in.) concrete slab	29	52
Heavy (150 mm [6 in.] + concrete slab)	25	45

(2) In residential construction, attic ventilation helps to reduce heat load as does the use of reflective roof surfacing materials (e.g., white granules on shingles). Radiant barriers (reflective foils) placed in attics are also effective.

h. Fire Considerations. (Also refer to MIL HDBK 1008C for roofing and insulation fire resistance requirements).

(1) Topside Fire Ratings. Because of its large surface area, roofing plays an important role in fire protection. Fire hazards can be defined as:

(a) External, where the source is outside the building such as from wind blown flaming debris. Tests for external fire resistance are referred to in building codes as Class A, B and C.

1/ An external fire rating is established by constructing and testing roofing assemblies by methods described in ASTM procedure E108 (also known as UL790). In this method relative degrees of fire resistance are established.

a/ Class A roof coverings are effective against severe fire exposures. Under such exposures roof coverings of this class are not readily flammable and do not carry or communicate fire; afford a fairly high degree of fire protection to the roof deck; do not slip from position; possess no flying brand hazard; and, do not require frequent repairs in order to maintain their fire-resistant properties.

b/ Class B roof coverings are effective against moderate fire exposures. Under such exposures roof coverings of this class are not readily flammable and do not readily carry or communicate fire; afford a moderate degree of fire protection to the roof deck; do not slip from position; possess no flying brand hazard; but, may require infrequent repairs in order to maintain their fire-resistant properties.

c/ Class C roof coverings are effective against light fire exposures. Under such exposures roof coverings of this class are not readily flammable and do not readily carry or communicate fire; afford some degree of fire protection to the roof deck; do not slip from position; possess no flying brand hazard; and, may require occasional repairs or renewals in order to maintain their fire-resistant properties.

2/ <u>Class A does not mean Grade A!</u> Note: In this classification only fire performance is considered. A specifier should select the degree of fire resistance required but recognize that selecting a higher rating does not assure better waterproofing nor longer life. In fact, some compromise in durability may have been made to meet the higher fire rating.

3/ ASTM E108 fire tests may be conducted on steep roofing, membrane roofing, SPF, and metal panels. Listings of systems that meet these requirements are found in the Underwriters Laboratories *Roofing Materials and Systems Directory*, the Factory Mutual *Approval Guide*, and reports/directories published by several other qualified testing agencies.

4/ Qualified listings:

a/ If a roofing assembly fails to meet burn-through requirements of ASTM E108 it may still be listed for use with non-combustible decks such as steel, concrete, and gypsum.

b/ Roofing assemblies are listed at the maximum incline to which the rating applies. As long as the structure under consideration is at a lower or equal incline to that listed it complies with the fire rating.

c/ If a listing is intended for use as a roof superimposed over an existing roof, it should be listed in the UL *Roofing Materials and Systems Directory* under the category *Maintenance and Repair Systems*. In the FM *Approval Guide* it will be listed as a *Re-cover*.

d/ In general, only the materials listed qualify and only when used in the manner described in the directories. Additional insulation, for example, might worsen the flame spread.

(b) An internal (underdeck) fire is when the flame spread is underneath the roof deck. Listings are referred to by the Approval Rating, usually *Factory Mutual Class 1* or *Underwriters Laboratories Insulated Metal Deck or Non-metallic Decks Constructions*.

1/ Background—In 1953, a large insulated steel roof deck building suffered an unexpected, catastrophic fire loss due to an underdeck fire exposure. The roofing components above the deck contributed fuel to spread the fire. Tests conducted on full scale test buildings confirmed the hazard. In the late 1950's, laboratory tests were established and correlated to the full scale data. Factory Mutual uses a calorimeter to establish fire performance while Underwriters Laboratories uses a modified Steiner Tunnel test. Successful systems are listed by FM as Class 1 while Underwriters lists them as either Rated Metal Deck or Rated Non-Metallic Assemblies.

2/ The underdeck ratings do not assure zero risk. The ratings assume an acceptable risk assuming normal fire detection and fire control procedures are available. If an insulated steel deck system fails to comply with the requirements of FM Class 1, it is designated Class 2. Class 2 constructions may be converted to Class 1 by the addition of underdeck fireproofing. Class 2 constructions may also be acceptable if an approved sprinkler system is used.

(c) Fire endurance tests. These are time-temperature tests (ASTM E119) in which the roof-ceiling assembly is subjected to a rising heat load until either the interior structural elements yield, or the temperature on the exterior roof system reaches 139^{o}C (250^{o}F) above the ambient.

1/ The minimum elapsed time required before the end point is reached is usually established by building code or occupancy (e.g., 1-hour, 1-1/2 hour, etc.).

2/ Rated assemblies are listed by UL in their *Fire Resistance Directory* and by FM in their *Approval Guide*. Other testing agencies list rated assemblies in their directories as well.

(d) Assure that fire compliance (ratings) pertain to the entire assembly. Each component of the system must be listed in the above directories. Materials delivered to the job site should bear labels indicating compliance with the construction intended. The label also provides third party assurance that the products delivered to the construction site are essentially unchanged from those tested and listed.

I. Seismic Requirements. While membrane roofing materials in general do not affect seismic stability of a structure, components of the roof system may be important. Roof decks, for example, usually serve as a diaphragm increasing lateral stability.

(1) Bracing for SSSMRs. Structural metal systems with floating clips require bracing since the structural standing seam metal panels do not provide diaphragm action. An alternative to bracing is to use a steel subdeck to serve as the shear diaphragm.

(2) Inertia Effect. Heavy roofing materials such as ballast or pavers may result in an inertia effect that should be included in the design. This may be beneficial or detrimental.

(3) Lateral Motion of Tiles. In steep roofing, seismic motion may shatter materials such as cement and clay tile. Correct use of mechanical anchors may prevent damage. Twisted wire systems are recommended for earthquake zones. The National Tile Roofing Manufacturers Association requires two nails or a nail and a clip on every tile to resist seismic damage.

(4) Restraining Roof Tiles. IR-32-1 (9/89), a Title 24 California code addresses the attachment of tile, and allows the combination of wire tie and nose clips (wind locks or tile locks). Nails or wire ties are to be copper, brass, or stainless steel 11 ga. minimum with two per tile. Nails are to penetrate roof sheathing, battens, or support members 19 mm (3/4 in.) min. Ring shanked nails may be used when sheathing thickness is less than 19 mm (3/4 in.).

(5) Parapet Walls. Parapet walls must be used with care. Through-wall flashings or cut reglets must be avoided as they reduce the wall's resistance to lateral forces.

(6) Roofing Over Seismic Straps. Seismic straps (heavy metal plates) are sometimes installed over plywood roof decks and between decks and walls. Where roof insulation is not used (i.e., west coast capsheet construction), use construction details provided by the Western States Roofing Contractors Association on how to roof over the straps (figure 2-18).

j. Adequate Design Details. Complete sectional views of every location where the roof changes plane or there is a roof penetration or attachment should be provided on contract drawings. Sections and design details should be drawn to a legible scale with each element of the roofing system identified.

Appendix 2-1. Roof Slopes and Fire Ratings for Various Materials

Low Slope (Hydrostatic) Membrane Roofing	Slope (Inches/Foot): 1/4, 1, 2, 3, 4, 5, 6, 7, 8, 9 — Slope %: 2, 8, 17, 25, 33, 50	Comments	Ratings
Built-Up			
Asphalt - 4 ply/gravel		Minimum slope on new roofs is 2% (1/4 in./ft). Aggregate surfacing is not suitable for slopes over 25% (3 in./ft). The maximum slope for ASTM D312 Type I asphalt is 2% (1/4 in./ft), for Type II—8.3% (1:12), for Type III—25% (3:12) limits except in very hot climate where Type IV is needed.	Class A on both combustible and non-combus decks.
Asphalt - 4 ply/cap sheet		Minimum slope on new roofs is 4% (1/2 in./ft). Slippage limits slope to 3 in./ft. Capsheet can be used for vertical flashing with adequate top nailing.	Class A or B rating can be achieved on slopes of 3 in./ft, or less for noncombustible deck construction. Class A or B rating can be achieved on slopes of 1 in./ft, for combustible deck construction.
Coal tar pitch - 4 ply/gravel		Current Air Force criteria limit the use coal tar to roofs with slopes of 1/8 in./f or less. Cold flow and slippage limit s to 1/4 in./ft, with fiberglass reinforcement and 1/2 in./ft, with organic felt reinforce-ment in most climes. Slopes over 1/4 in./ft are not recommended.	Aggregate surfacing permits Class A rating on both combustible and non-combustible decks.
Modified Bitumen			
Modified bitumen - smooth coated		Minimum slope on new roofs is 2% (1/4 in./ft). Torched and adhesively bonded systems required at slopes ab 8.3% (1:12).	With field applied fire resistant coatings, Class A or B rating can be achieved for use over noncombustible decks generally up to 8.3 (1 in./ft) maximum slope. Class A or B rating can be achieved for use over combustible decks with additional ply sheets and/or insulations generally up to 4% (1/2 in./ft).

Appendix 2-1. Roof Slopes and Fire Ratings for Various Materials

Low Slope (Hydrostatic) Membrane Roofing (cont'd)	Slope (Inches/Foot): 1/4, 1, 2, 3, 4, 5, 6, 7, 8, 9 Slope %: 2, 8, 17, 25, 33, 50	Comments	Ratings
Modified Bitumen (cont'd)			
Modified bitumen - granular		Minimum slope on new roofs is 4% (1/4 in./ft). Torched or adhesively bonded systems required at slopes above 8.3% (1:12).	Class A or B rating can be achieved for use ov noncombustible decks generally up to 8.3% (1:12). Class A or B rating can be achieved fc use over combustible decks with additional ply sheets and/or insulation generally up to 4% (1/2 in./ft) slope.
Single Ply			
EPDM - smooth surfaced/ mechanically attached or fully adhered		Minimum slope on new roofs is 2% 1/4" in 12).	Class A or B rating can be achieved over non-combustible decks with fire retardant formulated grades generally to a slope of 8.3% (1:12). Class A or B rating can be achieved fc use over combustible decks with ply sheets ar or insulations generally up to 4% (1/2 in./ft).
EPDM—ballasted		Minimum slope onnew roofs is 2% (1/4 in./ft). Ballast movement limits slope to 17% (2:12).	Ballast provides Class A rating for non-combustible and combustible decks when use in excess of 39 Kg/m^2 (8 lbs/ft^2).
Reinf. PVC, Hypalon®, Thermoplastic Polyolefin (TPO) smooth surfaced/ mechanically attached or fully adhered		Minimum slope on new roofs is 2% (1 ft). Hypalon® products with water abs tion > 3% require minimum slope of 4 (1/2 in./ft).	Class A or B rating can be achieved for PVC a fire retarded TPO for use over non-combustib decks generally up to 1 in./ft. Class A or B rat can be achieved over combustible decks with special underlayments and/or insulations generally up to 8.3% (1:12). Class A or B ratii can be achieved for Hypalon for use over non-combustible decks generally up to 2 in./ft max slope. Class A or B rating can be achieved ov combustible decks with special underlayment and/or insulations generally up to 17% (2 in./f maximum slope.

Appendix 2-1. Roof Slopes and Fire Ratings for Various Materials

Low Slope (Hydrostatic) Membrane Roofing (cont'd)	**Slope (Inches/Foot)** 1/4 1 2 3 4 5 6 7 8 9 **Slope %** 2 8 17 25 33 50	**Comments**	**Ratings**
TPO - ballasted		Minimum slope on new roofs is 2% (1/4 in./ft). Ballast movement limits slope to 17% (2:12).	Ballast provides Class A rating on non-combustible and combustible decks when use in excess of 39 Kg/m^2 (8 lb/ft^2).
Metal Roofing Including Structural Standing Seam Metal, Architectural Standing Seam, and Lap Seam Metal Roofing		Standing seams with factory applied s ant have greatly reduced the seam lea experienced by older lap seam metal roofing. A minimum slope of 4% (1/2 is required to provide positive drainage, reduce leak potential, and to prevent surface corrosion.	Acceptance is primarily based upon uplift considerations. Architectural metal roofing ov a combustible deck requires an approved underlayment.
Steep (Hydrokinetic) Roofing Shingles Asphalt - Fiberglass		Shingles require minimum 33% (4 in./ slope to prevent leakage unless an under-layment is used. No upper limit on slope except that field applied tab seal wind protection must be provided on slopes over 175% (21 in./ft).	Class A rating on all slopes above 17% (2:12)
Asphalt - Organic		Same as Asphalt—Fiberglass above	Class C rating on all slopes above 17% (2:12) suitable for watershed protection.
Shakes - Wood		Materials require minimum 4 in./ft slop prevent leakage.	None have Class A. Several manufacturers h Class B using special fire resistant treatments for the wood in conjunction with a special underlayment.

Steep (Hydrokinetic) Roofing (cont'd)	Slope (Inches/Foot) 1/4 1 2 3 4 5 6 7 8 9 Slope % 2 8 17 25 33 50	Comments	Ratings
Tiles - Cementitious, Clay and Metal		Materials require minimum 4 in./ft slop prevent leakage.	Some concrete and metal tiles cannot pass C A or B fire tests over combustible decks. Veri listings in the UL, FM or other testing agency's directory. Clay is considered non-combustible Some aluminum and steel tile products have (A ratings when used in conjunction with under layment or gypsum board.
EPDM = ethylene-propylene-diene terpolymer Hypalon® = chlorosulfonated polyethylene PVC = polyvinylchloride TPO = thermoplastic polyolefin UL = Underwriters Laboratories, Inc. FM = Factory Mutual Source of Code Restrictions: ASTM E-108	Key Standard Practice Also Applicable		
Updated for this EI 1998 Originally published as Decision Guide for Roof Slope Selection, 10/88, the Air Force Engineering and Services Center, ORNL-6520.			

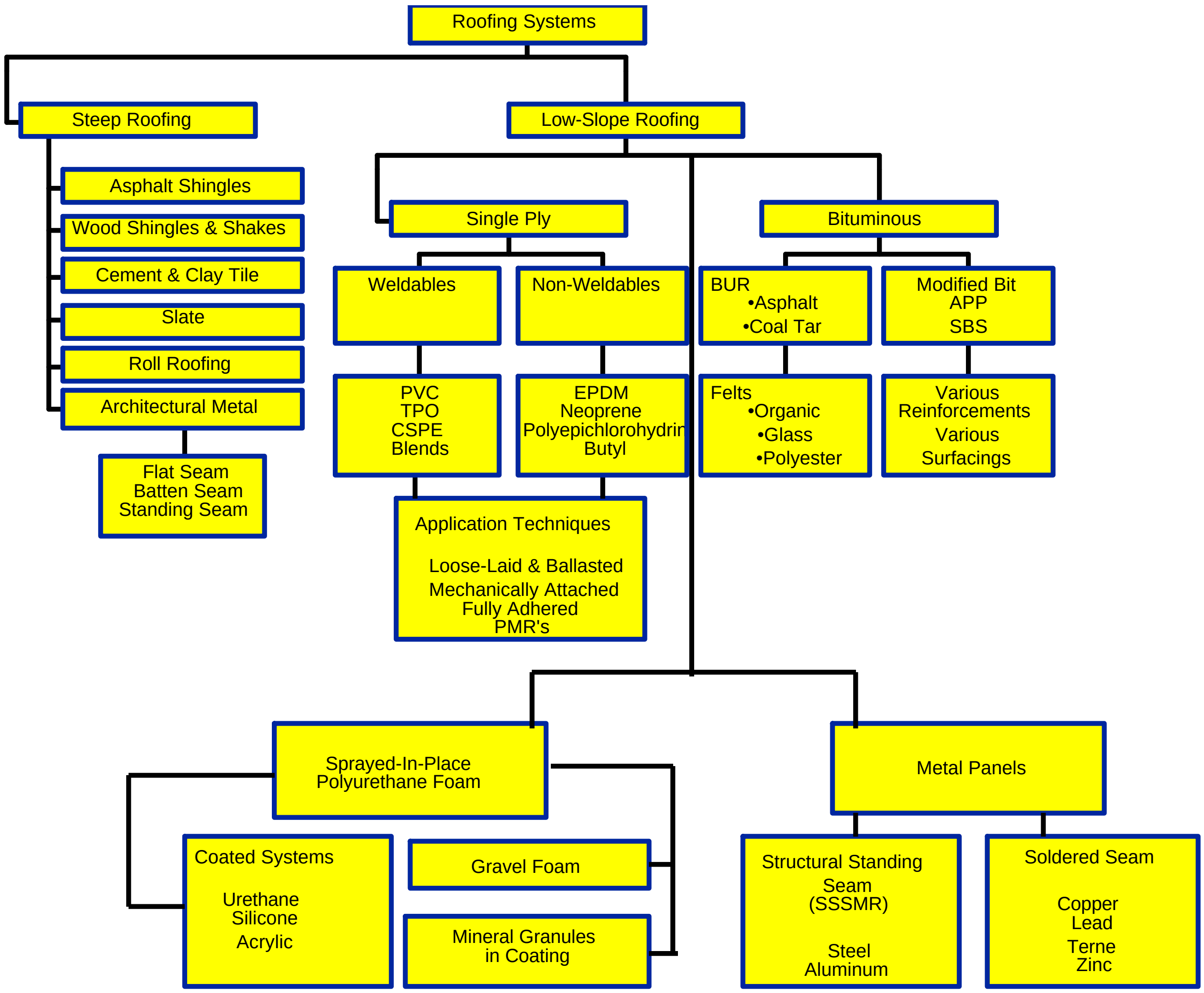


Figure 2-1. Material and Roofing System Options

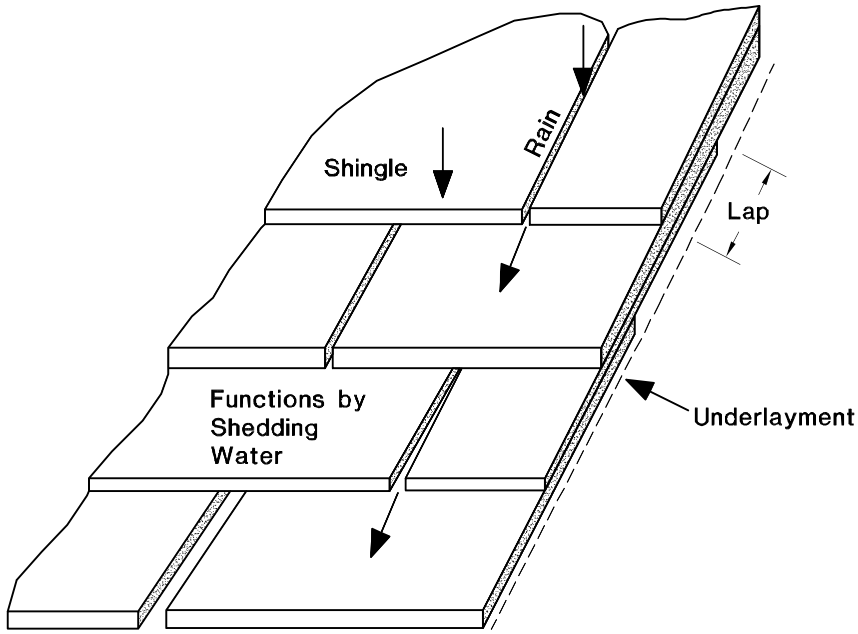


Figure 2-2. Steep Roofing (Hydrokinetic)

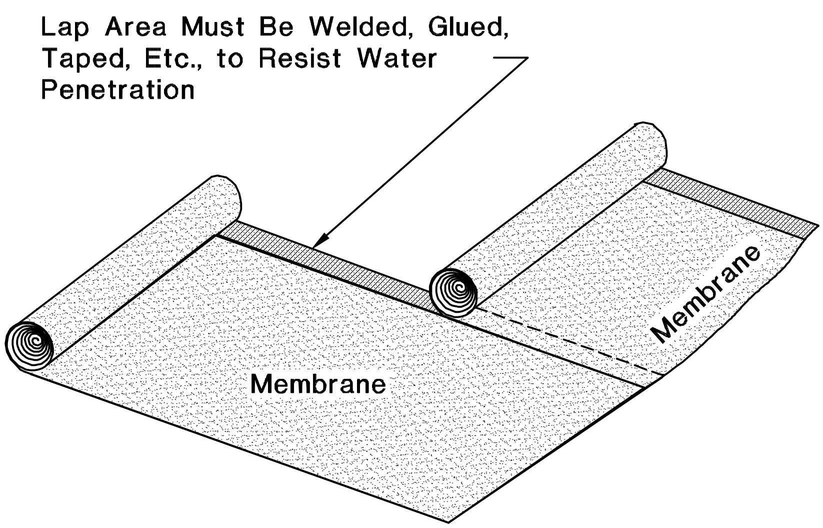


Figure 2-3. Low-Slope (Hydrostatic)

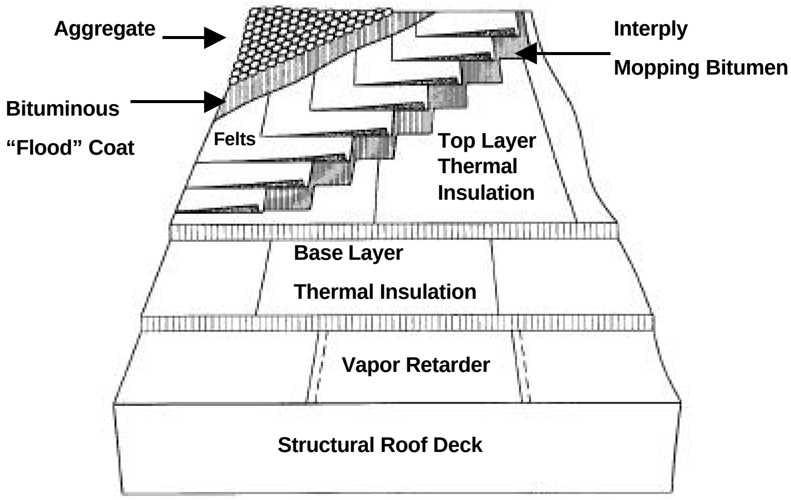


Figure 2-4. Typical BUR System

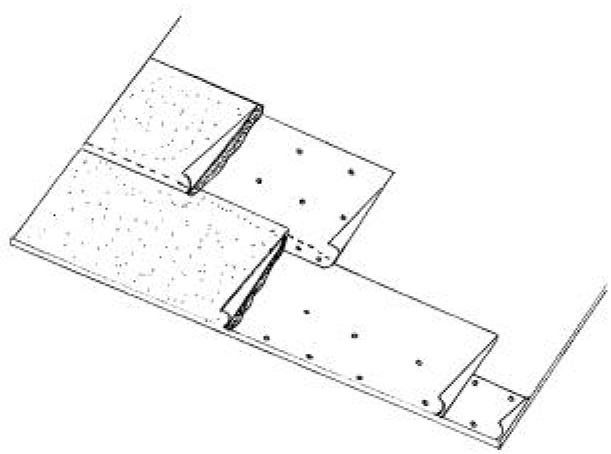


Figure 2-5. Polymer-Modified Cap Sheet Adhered to Mechanically Fastened Base Sheet

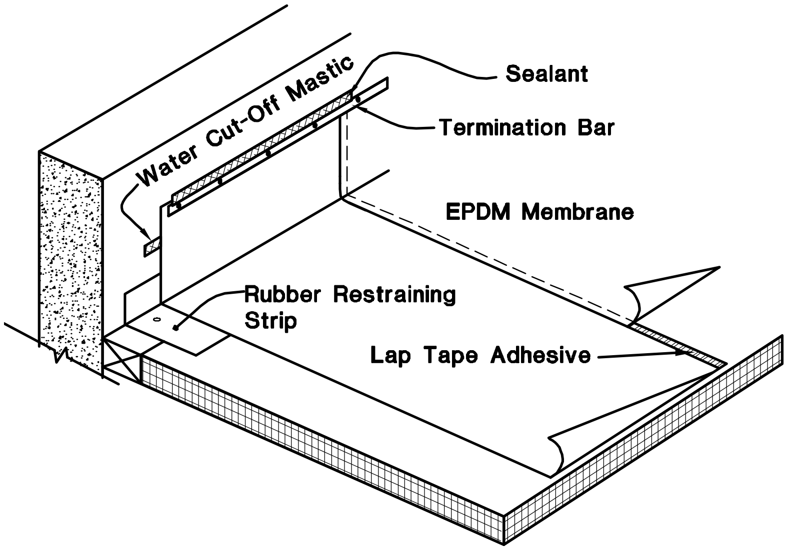


Figure 2-6. EPDM Roof System

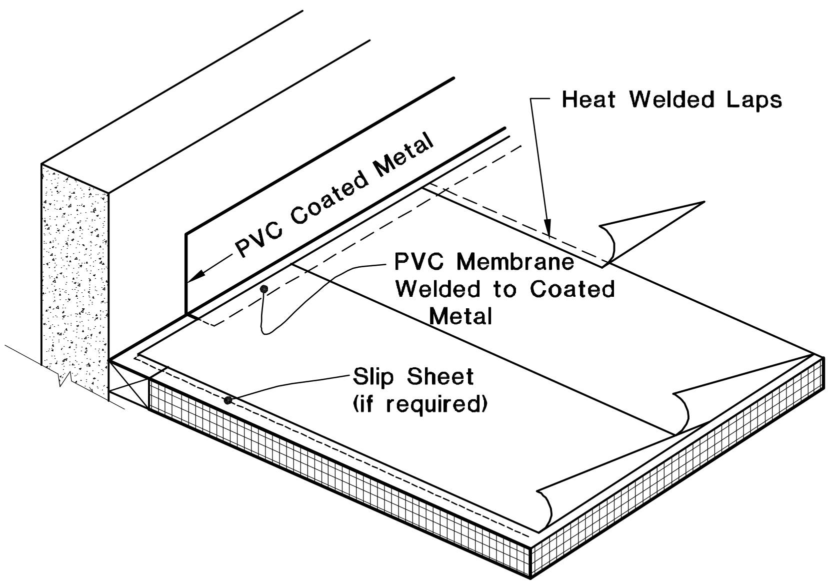


Figure 2-7. PVC Roof System

Notes:

1. SSSMR System with roofing panels greater than 300 mm (12 in.) should have standing seams rolled during installation.

2. Non-structural, non-hydrostatic standing seam metal roof systems may look similar.

Figure 2-8. Structural Standing Seam Metal Roofing

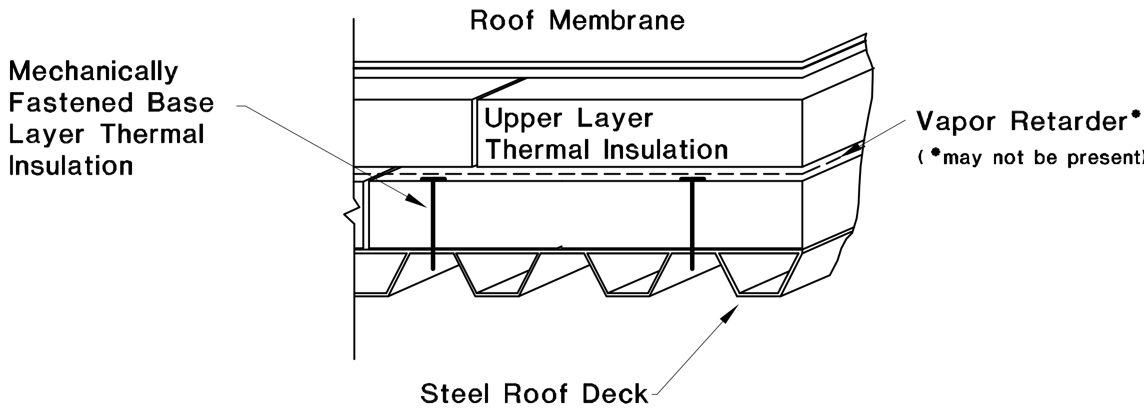


Figure 2-9. Components of Membrane Roofing System

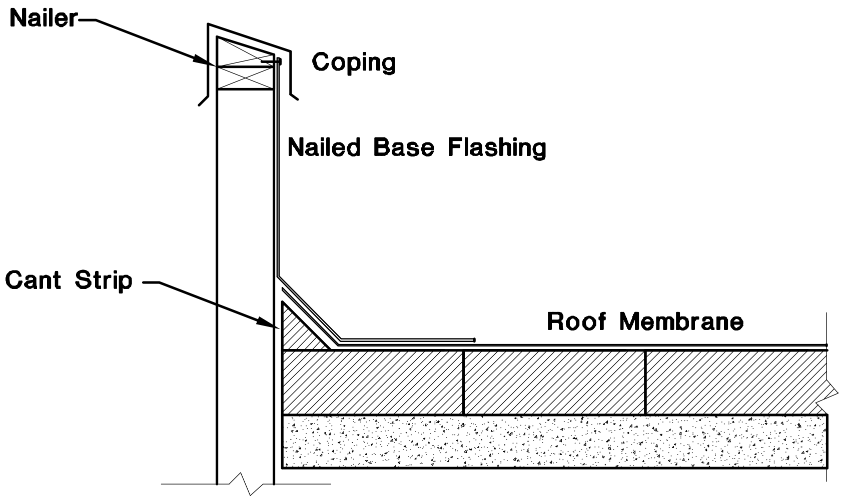


Figure 2-10. Wall Base and Cap Flashing

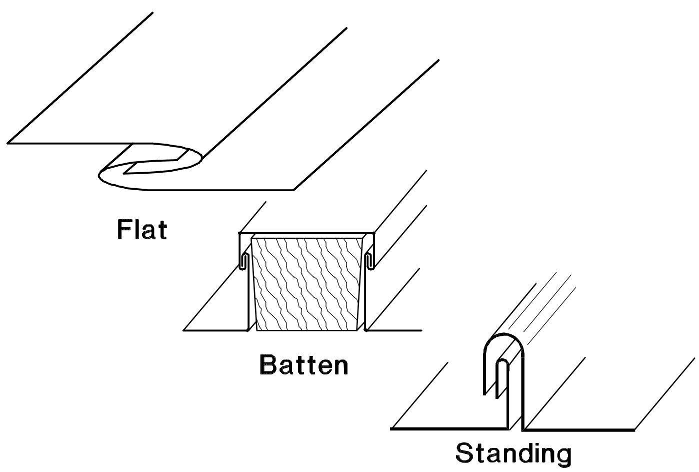


Figure 2-11. Architectural Metal Seams

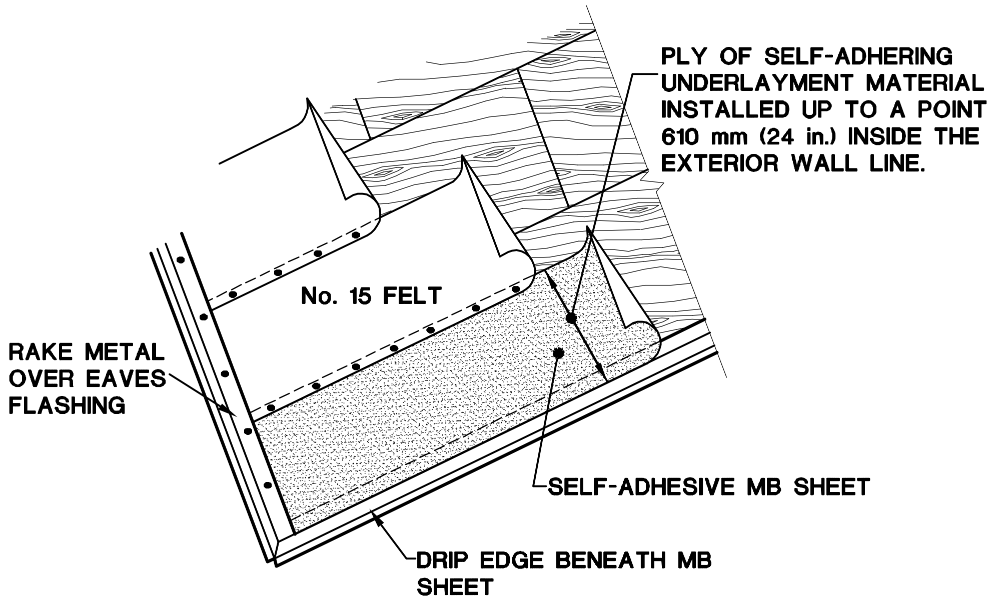


Figure 2-12a. Self-Adhesive Eaves Flashing

(Underlayment is sealed from eave to at least 610 mm (24 in.) within wall line)

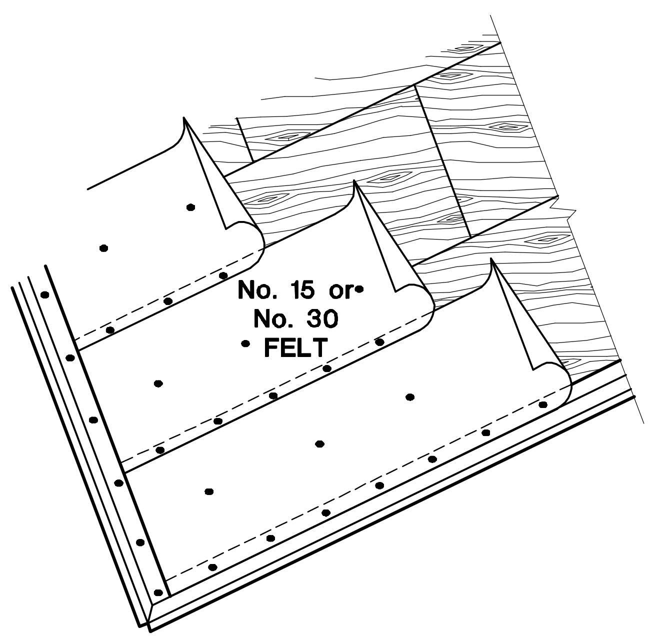


Figure 2-12b. Underlayment for Steep Roofing

(Underlay felt is unsealed)

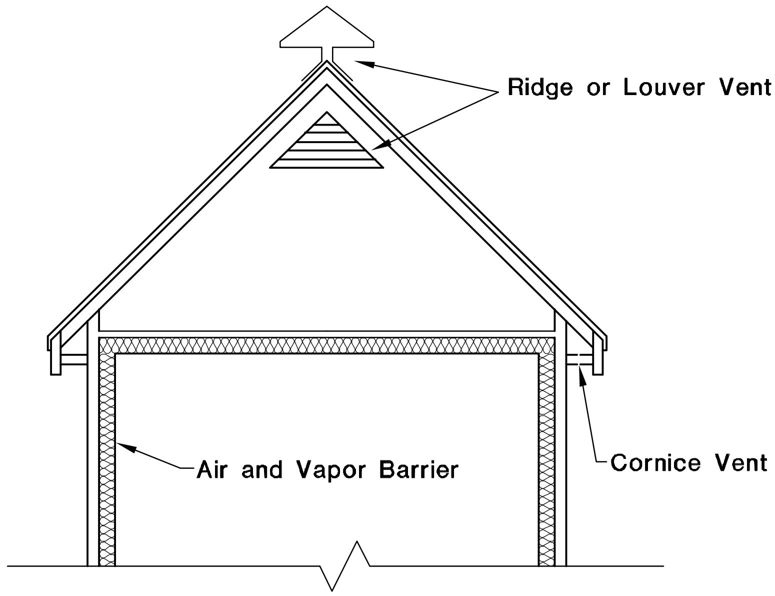


Figure 2-13. Vented Attic Space

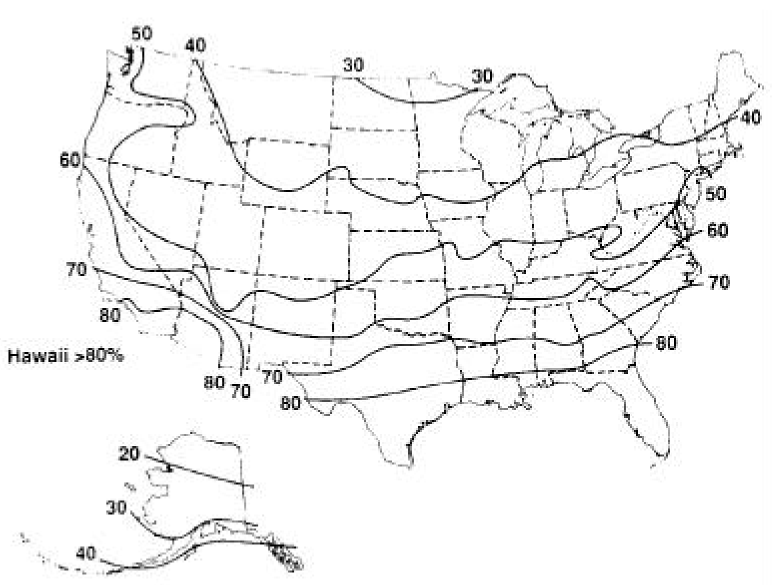
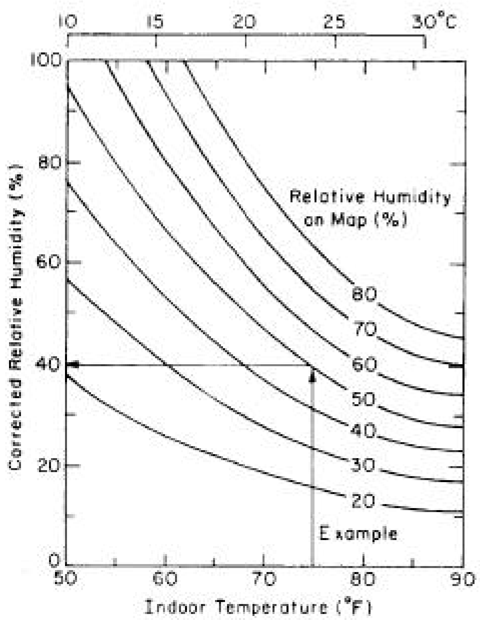


Figure 2-14a. Interior Relative Humidities (%) with Interior Temperature of 20°C (68°F)



Notes:

1. If designed interior RH is expected to exceed the percentages shown in 2-14a, summer self-drying will be inadequate and vapor retarders should be used.

2. Use 2-14b to *correct* maximum RH for interior temperatures that differ from 60°F.

Figure 2-14b. Temperature Conversion When Temperatures Differ From 20°C (68°F)

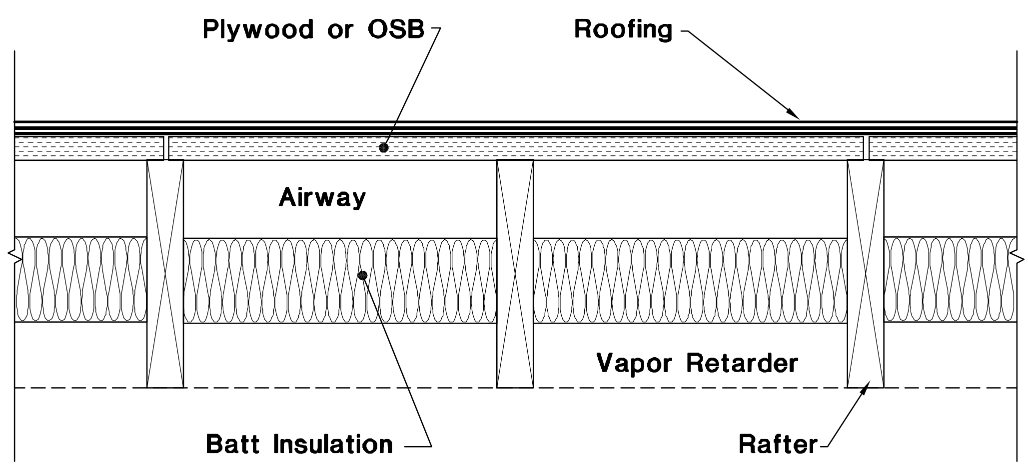


Figure 2-15. Under Deck Insulation

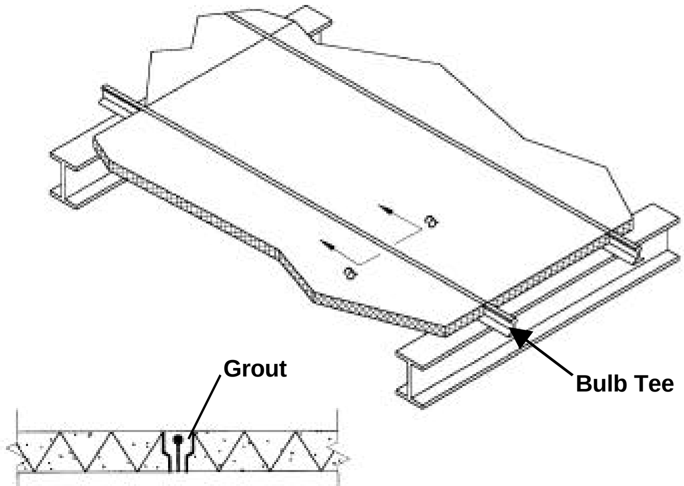


Figure 2-16. Self-Insulating Roof Deck

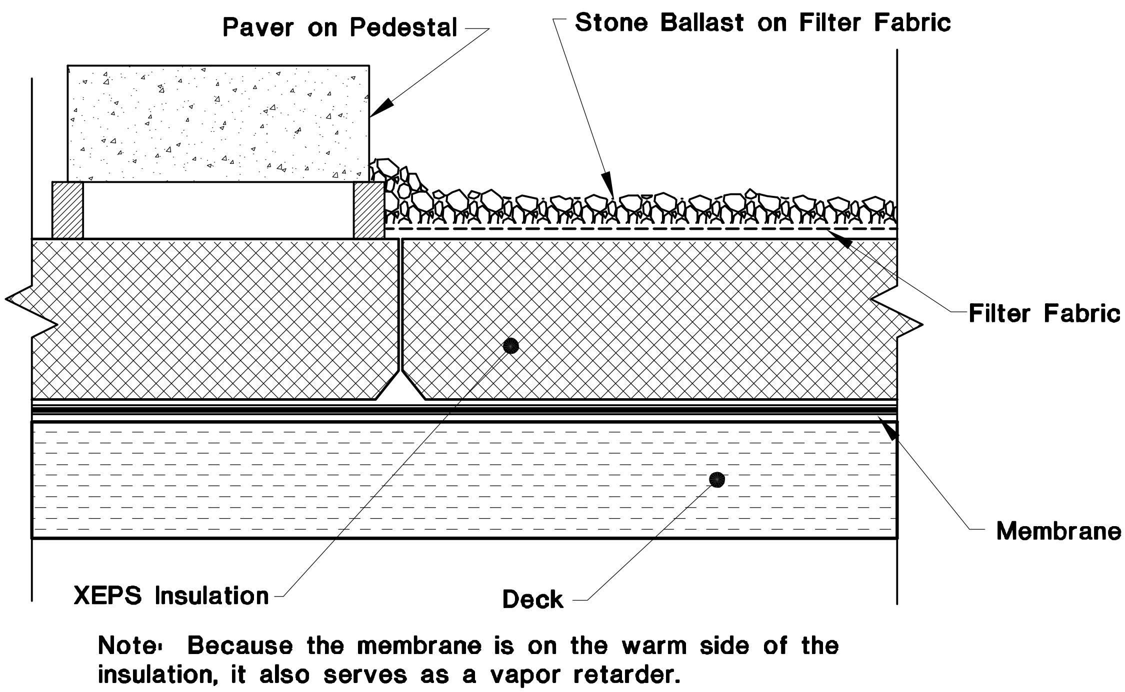


Figure 2-17. Protected Roof Membrane System (PMR)

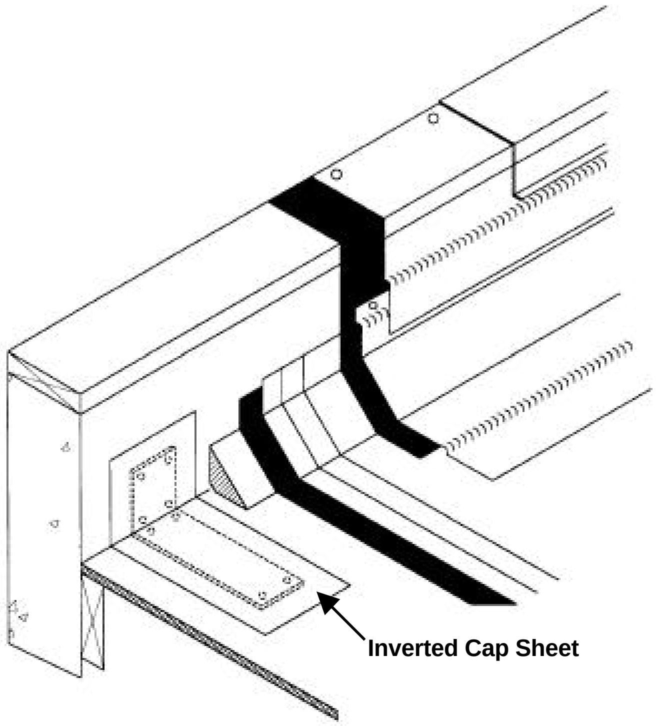


Figure 2-18. Roofing Over Thick Seismic Strap

CHAPTER 3

PROTECTED MEMBRANE ROOFING
REFERENCE CEGS 07550

3-1. OVERVIEW.

a. Concept of PMR System. In a protected membrane roofing system (PMR) the membrane is protected by an overlay of extruded polystyrene insulation, a filter fabric, and ballast (figure 3-1). Protection of the membrane is provided against accelerated oxidation and evaporation of volatile oils, ultraviolet degradation of organic materials, thermal movement (expansion and contraction), roof traffic, hail or other impact damages, cracking, warping or delaminating from ice contraction, blistering and ridging, and stress concentrations over insulation joints. Virtually all roof membrane systems may be used in a protected configuration. The slight cost increase (5 to 15%) is mitigated by much greater durability than with exposed membrane applications.

b. General Information. PMR systems place loose boards of extruded polystyrene foam insulation over the roof membrane (and flashings). Most rainwater flows to the drains along the surface of the membrane. Drainage channels (kerfs) approximately 13 mm (1/2 in. x 1/2 in.) on the bottom side of the insulation boards facilitate water flow. Porous fabric (filter-fabric or stone-mat) above the insulation boards keeps silt and fine stones from getting between the boards. The fabric and overlying ballast (stones or pavers) serve to *raft* the buoyant boards together during heavy rains so that they will not be displaced. The pavers should be placed on pedestals or be ribbed on the bottom surface to facilitate drying.

(1) Climate/Weather. PMRs are especially effective in extremely cold climates for the following reasons:

(a) Once the membrane and flashings are installed the rest of the installation (insulation, filter fabric, and ballast) can be done in cold or wet weather.

(b) The position of the insulation on top of the membrane shifts the dew point from below the membrane to above. The membrane now serves as the vapor retarder for the system eliminating the need for a separate vapor retarder, which can create a potential vapor trap.

(c) The insulation keeps the membrane warm in cold weather. It stays well above freezing eliminating ice damage. Any melt water that reaches the membrane remains as a liquid enroute to the drains. Snow that accumulates on the surface adds to the insulation value of the assembly. (Note: This advantage is diminished in cold, wet [maritime] climates where cold melt water flows across the warm membrane for extended periods of time.)

(2) Logistics. Substituting cement-faced composite panels for stone ballast allows installation even when quarries are frozen and ballast stone is unavailable. Interlocking pavers weighing only 22 kg/m^2 (4.5 psf) are available.

(3) Familiarity with the System and Site. Materials are identical to any other membrane roof system.

(4) Life Expectancy. PMR configurations will add years to membrane systems by protecting against abuse and weather degradation.

(5) Costs. PMR systems are slightly higher due to the relatively high cost of extruded polystyrene (XEPS) insulation, which is the only suitable insulation, and the use of filter fabric. On a life cycle basis PMR systems are often less expensive.

(6) Occupancy Considerations. The PMR is suitable for all occupancies. They are particularly well suited where interior relative humidity is high (> 50%). Special *paper-mill* designs may be needed when the RH is > 80%.

(7) Low-Sloped vs. Steep Roofs. PMR's are used on low-slope membrane systems at slopes up to 16.7% (2:12), but is best to limit the slope of any ballasted roof to 8.3% (1:13).

(8) Leaks. PMR systems are very durable; when properly built they require little maintenance. However, if they contain built-in deficiencies that cause leaks the flows are difficult to locate and repairs are complicated because everything above the membrane must be removed to get at it. Leaks are much easier to isolate if the membrane is fully adhered. Flood testing a protected membrane roof for 24 hours prior to adding insulation, etc., is worthwhile.

3-2. BUILDING ELEMENTS

a. Slope. Minimum slope of 2% (1/4 in./ft.) is required to insure positive drainage and to minimize flotation potential. Maximum slope is 16.7% (2:12) due to a tendency for slippage or sliding of surfacing ballast.

b. Low-Sloped Roofs. Protected membranes will be wet for long periods of time. Organic roofing felts and other moisture sensitive materials should be avoided. Consideration should be given to flood testing small sections of the roof before insulation and ballast are installed as it is difficult to detect flaws once the system is completed.

c. Structural Considerations. Protected membranes require continuous support. On discontinuous substrates a bridging layer of insulation or gypsum board may be needed. The membrane is applied to this substrate. Ballasted systems may add weight as follows: lightweight interlocking insulated pavers—22 kg/m^2 (4.5 psf); stone ballast—49 to 98 kg/m^2 (10-20 psf); and, concrete pavers—42 to 107 kg/m^2 (8.5-22 psf).

d. Expansion and Seismic Joints. No special requirements.

e. Re-entrant Corners. No special requirements.

f. Roof Access. Mortar surfaced insulation is only a suitable surface for light roof traffic. Some pavers cab support heavy loads. When stone ballast is used paver walkways are recommended.

g. Roof Venting. Since the thermal insulation is above the membrane venting is not applicable. Elevating pavers slightly above the insulation promotes self-drying, reducing the risk of freeze-thaw degradation of the pavers and insulation.

h. Roof Decks. Noncombustible decks should be smooth and free of abrasive debris. Steel decks require a fire rated bridging layer of roof insulation or gypsum board to support the roof membrane.

i. Vapor Retarders. Under most conditions the PMR system serves as its own vapor retarder.

(1) Special Condition for Condensation. For extremely high internal vapor pressures (c9mbination of high temperature and high humidity), it is possible for the roof deck to be temporarily chilled below the dew point. Condensation may result in drippage onto equipment or processes blow. This condition can be reached during a cold rain when the rainwater by passes the thermal insulation on the way to the drains. In this case a separate vapor retarder is installed

on the warm side of the assembly (e.g., on the deck followed by sufficient insulation to keep the vapor retarder temperature above the dew point [paper mill design]).

(2) Thermal Insulation and Heat Flow. PMRs are slightly less efficient than conventional roof systems because melt water can bypass the insulation. It may be appropriate to increase the R-value by 5 to 10% to compensate for this. When feasible use two (or more) layers of extruded polystyrene foam (XEPS) with joints offset in both directions. This is more thermally efficient as it reduces thermal bridges through insulation gaps and causes more water to flow at the surface rather than percolating down to the membrane level.

j. Membranes, Filter Fabric and Surfacings. BUR, MB, Single-Ply, and liquid waterproofing systems have all proven to be acceptable substrates for PMR systems. It is desirable that the foam not adhere to the membrane. Therefore, when insulating over sticky materials (e.g., some liquid systems or coal tar pitch) a divorcing sheet of plastic film or non-woven fabric should be first placed on the membrane.

(1) Filter Fabric. The filter fabric should be either a woven or non-woven pervious sheet stabilized against UV degradation.

(2) Interlocking Pavers. Pavers should consist of freeze-thaw resistive concrete or latex-modified, mortar faced, extruded polystyrene foam insulation. Some interlocking pavers can be lighter than conventional pavers and provide comparable wind resistance.

(3) Ballast. Stone ballast should comply with ASTM D448, Size 4, 3, or 2, following ANSI/SPRI RP-4, *Wind Design Guide for Ballasted Single-Ply Roofing Systems*. Crushed rock is permissible. Expensive rounded river stone is not required.

k. Penetrations. Flashings and details are similar to those of conventional membrane systems. Drains are treated differently to allow drainage not only at the membrane level but at the surface as well. Such drains retain heat and are seldom blocked by ice. Whenever possible, drains should *daylight* to the surface (figure 3-2). However, if pedestrian traffic or vandalism concerns necessitate hidden drains the pavers should be marked so that the drains can be inspected periodically. Wall and curb flashings can also be protected by placing extruded polystyrene (XEPS) foam insulation over them and using metal counterflashing to hold the foam board in place (figure 3-3).

l. Historical Roof Restoration. PMRs are used on low-slope buildings where appearance is not critical, where a plaza deck is desired, or where important functions below warrant an improved roofing system.

m. Aesthetics. Ballast and pavers are appealing in pattern and texture. Interlocking pavers are generally off-white. Heavy pavers give a plaza deck appearance. PMRs are used in urban landscaping. If vegetation or trees are desired, these must be installed in specially drained and flashed planters. Their weight suggests that they be placed directly over structural supports. If exposed metal strapping is used, use non-rusting strapping and fasteners.

n. Gaps, Flashings, Joints, and Sealants. Flashing details are determined by the membrane system selected. Caution must be taken to leave a gap between horizontal pavers and vertical flashings to avoid puncture while placing the paver. Cants are prone to such damage. Since organic solvents in sealants attack polystyrene foam, mastics and caulks should be allowed to cure before they contact the foam.

o. Drainage, Valley and Intersection Details. Kerfs and drainage channels should run parallel to the drainage paths. In valleys and roof edges truncated interlocking pavers do not interlock. They should be overlaid with additional high-density pavers (approximately 98 kg/m2 [20 psf]) or strapped to avoid wind problems.

3-3. DESIGN CONSIDERATIONS.

a. Guide Details. Guide details for PMR systems are provided in the *Low-slope Membrane Roofing Construction Details* provided by the NRCA (©1996):

BUR-P-8	TP-P-7
BUR-P-16	TP-P-15
BUR-P-21	TP-P-20C
BUR-P-23A	TP-P-22
MB-P-8	TS-P-7
MB-P-16	TS-P-15
MB-P-21	TS-P-20B
MB-P-23A	TS-P-22

b. Required Details. Additional details that may be required in design drawings include pavers used in valleys, at edges, and where truncated; protected wall flashings; and, where mortar-surfaced insulation needs metal strapping for high wind resistance.

3-4. CONSTRUCTION CONSIDERATIONS AND DESIGN ALERTS.

a. General. For loose-laid membrane systems (which are not recommended with PMR systems), temporary ballast may be needed until the insulation and final ballasting are installed. Loose-laid membranes require an airtight deck. Air barriers may satisfy this requirement.

(1) Overloading the Structure. Piles of ballast should not be accumulated on the roof. Verify structural load capacity and distribute weight uniformly.

(2) UV Degradation. Protect insulation from extended exposure to sunlight.

(3) Drain Freeze-Up. Place drains within heated portions of a building and cover with insulation to avoid freeze-up.

(4) Ponding. Slope must be adequate, 2% (1/4 in./ft.) minimum.

(5) Leak Detection. Consider flood testing prior to application of insulation and ballast.

(6) Heat Loss. Increase design R to allow for water-cooling in high rainfall areas. Use two layers of insulation with joints offset.

(7) Extreme Vapor Drive. Use *paper-mill* design for high (> 85%) interior humidities. (Paper-mill design requires sufficient thermal insulation beneath the membrane to keep the deck warmer than the interior dew point temperature. This will require a deck-top vapor retarder and rigid board insulation prior to installation of the PMR system.)

(8) Self-Drying. Provide for airflow between top of XEPS and pavers.

(9) Protective Fabric. Use specified filter fabrics.

(10) Protected Flashings. Consider protected flashing designs.

(11) Paver Displacement. Use strapping or overlayed, heavy pavers where interlock of lightweight pavers is ineffective such as at valleys, perimeters, and penetrations.

b. Pre-roofing Conference. Agenda items for the pre-roofing conference should correlate to the Chapter that covers the specific roof membrane being used. Flood testing procedures must be discussed (if called for). The membrane and flashing must be completed in decent weather. Installation of insulation, filter fabric, and ballast may be done in inclement weather.

c. Shop Drawing Submittals. Drawings for the membrane and flashing system should be provided with special attention to base-of-walls and curbs. If interlocking pavers are used, show details of strapping/ballasting where interlock is missing. Filter fabric should cover insulation and be turned up the raised curb at least 25 mm (1-in.). A certification should be furnished indicating the supplied insulation, filter fabric, and membrane meet the supplier's specifications for a warranted PMR system.

d. Field Review and Observation.

(1) Insulation Storage. Verify the insulation is protected against sunlight and open flames.

(2) Insulation Installation. Insure the installed insulation remains unadhered. Use slipsheets if the substrate is tacky or contains coal tar pitch. Drainage channels shall run parallel to slope.

e. Design Submittal Requirements and Checklist. The PMR system should be provided by the contractor as a complete system. The same manufacturer should supply the membrane and flashings.

3-5. MAINTENANCE CONSIDERATIONS.

a. General. Unprotected flashings are as vulnerable to damage as any other system. Wind scour or membrane lifting can cause displacement of ballast. Heavier ballast may be needed at the perimeter and corners (ANSI/SPRI RP-4).

b. Repair or Replace. Since insulation, filter fabric, and ballast are not adhered, they are reusable. To lift interlocking lightweight pavers it may be necessary to use a saw to cut off the tongue of a few pavers. Upon replacement such pavers can be strapped together with non-rusting sheet metal and fasteners or held in place with an overlying layer of heavy pavers.

c. Repairs: Emergency, Temporary, and Permanent.

(1) *Emergency repairs* would involve removing ballast, effecting repairs and replacing the system. Do not reinstall XEPS over fresh solvent-containing mastic until all solvent has evaporated.

(2) *Temporary repairs* might involve sandbags or dunnage to keep a wind disturbed roof in place until permanent repairs can be made.

(3) *Permanent repairs*—See ANSI/SPRI RP-4 for ballasting guidelines.

d. Repair Work by User. Repairs to the membrane and flashing would follow what is appropriate for that particular membrane system. Broken corners of interlocking cement-topped insulation can be repaired by filling in with latex-modified cement or by coating exposed XEPS with latex paint to retard UV degradation. Replacing damaged units may be better.

e. Maintenance Checklists.

(1) Visual Observation. Inspect the roof surface after precipitation to verify that the roof is draining.

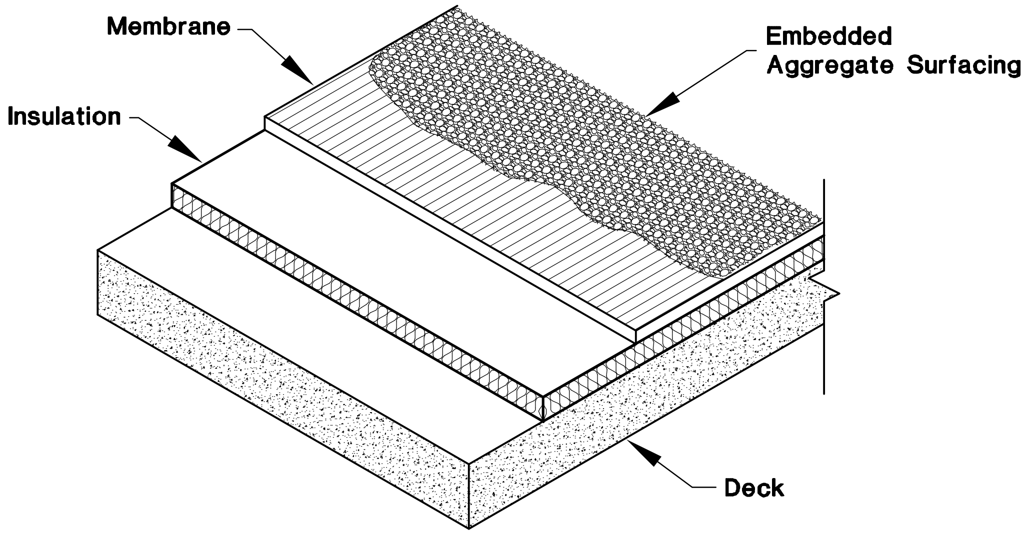
(2) Sediment Build-Up. Lift pavers and insulation and examine for silt build-up. If a filter fabric was not used in the original installation lift the insulation, remove silt and roots, and reinstall using filter fabric over the cleaned insulation.

(3) Examine flashings for damage. Repair and cover with metal counterflashing or convert to a protected flashing design.

(4) Displaced Insulation. Reinstall displaced insulation boards, install the filter fabric and replace the ballast.

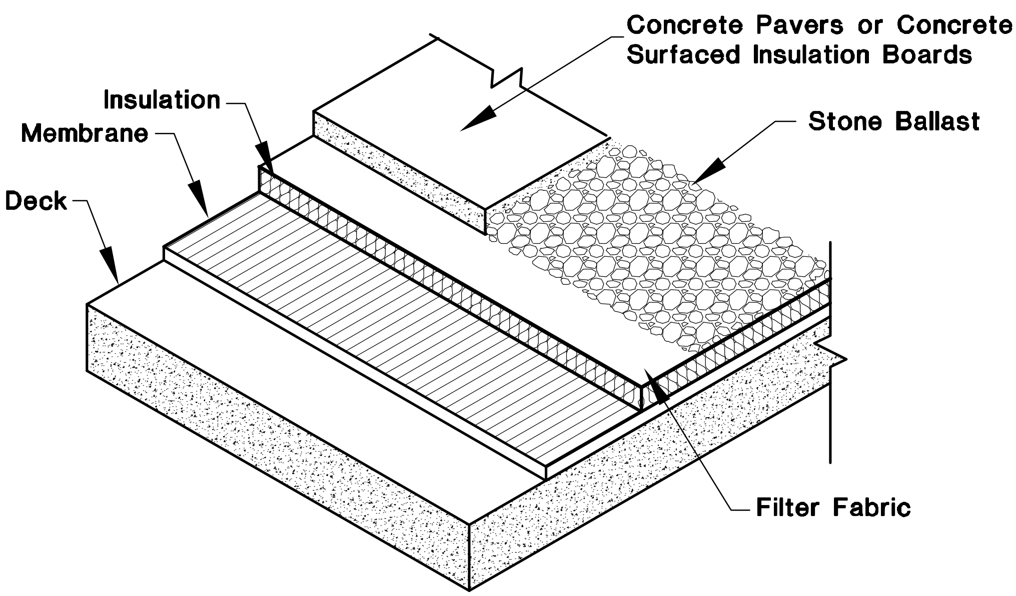
(5) Paver Integrity. Examine pavers for freeze-thaw damage. Replace damaged ones with freeze-thaw resistant pavers.

(6) Vented Pavers. If non-vented pavers are lifted to gain access to the components below, consider elevating them on shims or pedestals when they are replaced to improve drying of the system.



a) Conventional roofing system

All components *glued* together using hot asphalt.



b) Protected membrane roofing system

All components loose-laid except membrane which should be fully adhered to the deck.

Figure 3-1. Conventional vs Protected Membrane Roofs

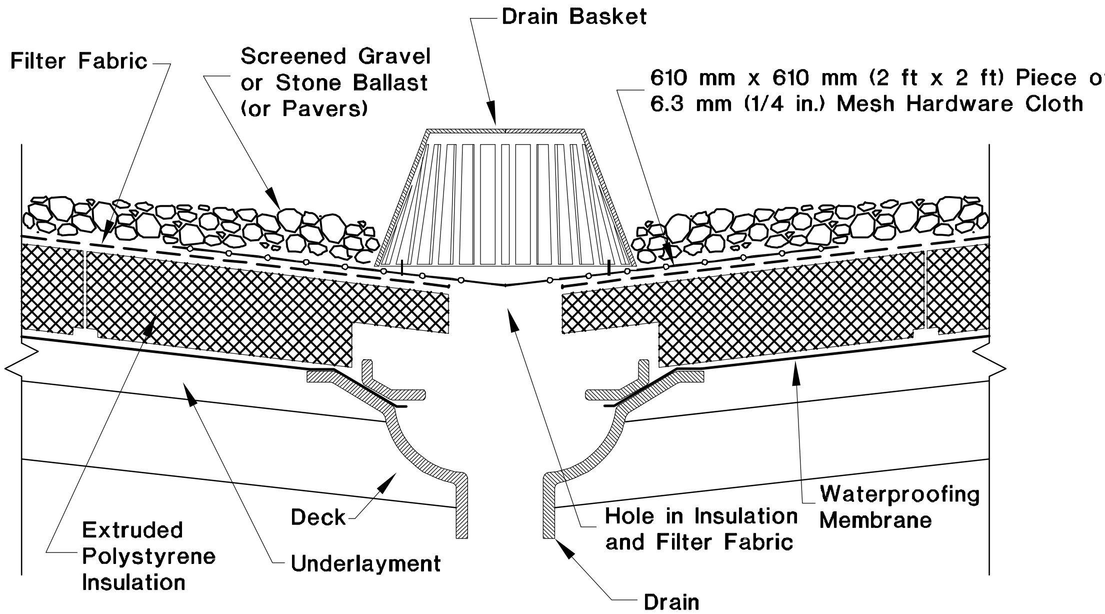


Figure 3-2. Roof Drain for PMR System

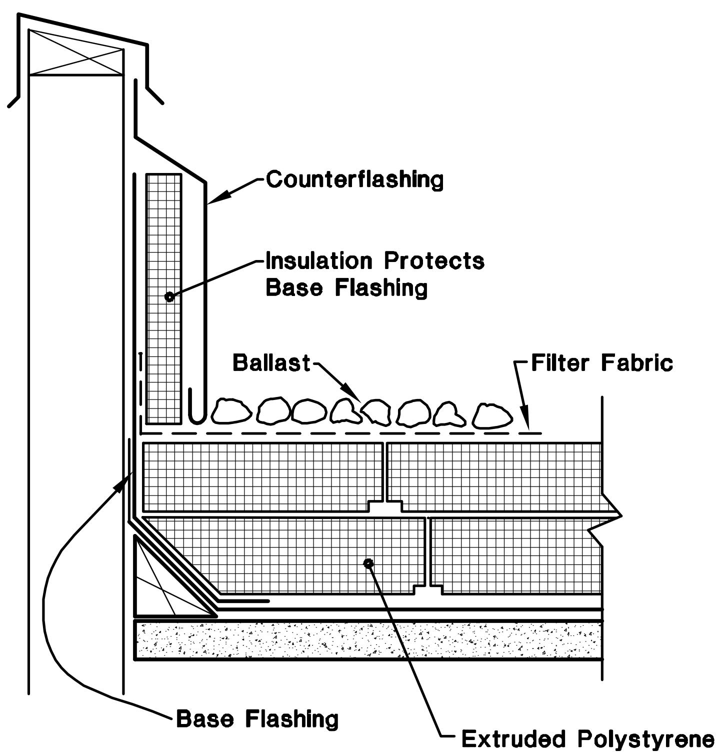


Figure 3-3. Protected Base Flashing

CHAPTER 4

BUILT-UP ROOFING SYSTEMS
REFERENCE CEGS 07510

4-1. OVERVIEW OF BUILT-UP ROOFING SYSTEMS.

a. Components. Two basic components, felts and bitumen, are laminated in the field (built-up) into a waterproofing membrane. The bitumen can be either asphalt (ASTM D312) or coal tar pitch (ASTM D450), which serves both as the system adhesive and as the waterproofing agent. Reinforcing felts of glass fiber (ASTM D2178), organic (ASTM D226), or non-woven (ASTM D5726) synthetic fiber mats provide strength and stability to the membrane. Surfacing (ASTM D1227, D1863, D2823, D2824, D4479, D6083) provides UV resistance and fire protection. Because the built-up roof membrane is field assembled, field quality control is very important to its success.

b. General Concept. A bituminous built-up membrane is more brittle than elastic when cold. It relies on firm anchorage to distribute stress uniformly across its surface. Suitable substrates for BUR include well anchored, heat resistant thermal insulation boards and stable, nailable and non-nailable decks. On nailable decks such as wood, OSB, plywood and nailable planks a base ply is mechanically fastened to allow for seasonal changes in deck dimensions. Remaining layers are adhered with hot bitumen. Over thermal insulation and non-nailable decks the base ply is adhered with hot bitumen. Key steps in installation include heating the bitumen to adequate fluidity, spreading the hot bitumen uniformly, and embedding the reinforcing felts while the bitumen is still hot. Application instructions are provided in industry literature and should be verified by field quality assurance.

(1) Climate/Weather.

(a) Cold and wet weather are serious detriments to the installation of hot built-up roofing. Entrapped moisture within the layers of a BUR can result in blistering. Roofing materials need to be kept dry before, during, and after delivery to the site. The substrate must be unfrozen, dry and warm. A conductive cold substrate can cool the bitumen enough to prevent proper attachment.

(b) Rolls of felt may have to be placed in heated storage prior to use. Hot bitumen gels within minutes so once the membrane is installed it is immediately weather resistant. Membrane tensile strength should exceed 35 kN/m (200 lbf/in.) at –18^{o}C (0^{o}F) for colder climates. Elongation should exceed 0.7%.

(c) In hot climates higher melt point bitumens, backnailing, and reflective surfacings may be needed to prevent slippage. Higher melt point asphalts should be used (Type III or IV/ASTM D312). Light colored membranes reduce heat load and slippage potential.

(d) Membrane strength of 26 kN/m (150 lbf/in.) at –18^{o}C (0^{o}F) is considered adequate for moderate climates. In colder, northern climates a minimum strength of 35 kN/m (200 lbf/in.) is recommended.

(e) Too thick an application of bitumen can result in slippage and too cool can result in delamination.

(f) Finished built-up membranes surfaced with aggregate when placed over incompressible solid substrates are relatively resistant to hail and ice.

(g) Nightly tie-offs need to be installed so that moisture does not get under finished work.

(2) Logistics. BUR systems are material intensive. Bitumen and felts are hoisted to the roof and placed where needed. Bitumen may be delivered to the job site in heated tankers, or heated in

kettles. Occasionally a kettle may be placed on the roof because of extreme height or transportation difficulty. Melted bitumen is transferred to luggers and applied using mops or bitumen spreaders. In cold weather, luggers, pump lines, and mop carts may be insulated to reduce heat loss.

(3) Familiarity with the System and Site. Built-up roofing is well known by most commercial roofing contractors. Since fumes are generated while handling the bitumen, the kettle should be placed where the fumes will be least objectionable. Burns from the hot bitumen are of concern. Workers should wear non-synthetic fiber work clothes with long sleeves, gloves, and work boots. Protective pedestrian fencing may be needed since the kettles remain hot for many hours after use and both the hot bitumen and heating fuel are dangerous.

(4) Life Expectancy. Well built BUR systems typically last 15 years or more provided periodic inspection and maintenance is performed. Poorly built, unmaintained systems usually are problematic within a few years. Penetrations and flashings are especially vulnerable. BUR systems are cost effective on both an initial and life cycle basis.

4-2. BUILDING ELEMENTS.

a. Slope. A minimum design slope of 2% (1/4 in./ft) is required. Aggregate surfaced BUR systems using either coal tar pitch or Type I asphalt have been used in ponded situations, but that is very risky.

(1) Low-Sloped Built-Up Roofs. Coal tar pitch should not be used on roofs with slopes greater than 2% (1/4 in./ft). Aggregate imbedded in a flood coat of bitumen is considered more water resistant than capsheets or bare, lightly coated surfaces.

(2) Steep Built-Up Roofs. At slopes above 4% (1/2 in./ft) wood nailers are needed to prevent slippage. The felts are backnailed to prevent slippage. Aggregate surfaced roofs are limited to a slope of 25% (3:12) while smooth surfaced membranes (properly backnailed) have been used at steeper slopes. Working with hot bitumen at slopes above 8% (1:12) is dangerous and torch-applied modified bitumens or cold applied membranes are preferred.

b. Structural Considerations.

(1) Roof Loads. BUR systems are not especially heavy—smooth surfaced roofs weigh approximately 5-10 kg/m^2 (1-2 psf); aggregate roofs weigh 29-34 kg/m^2 (6-7 psf). Roofing equipment may be very heavy and loads must be distributed by appropriate means (i.e., installing plywood walkways) to avoid deck damage.

(2) Drippage. Non-nailable plank decks may require grout or tape to prevent bitumen drippage into the interior.

(3) Deck Venting. Moisture bearing lightweight insulating fills require provisions for venting to the building's interior as well as for a nailed moisture resistant base sheet. Special fasteners are required for those low-density fills.

c. Expansion Joints, Seismic Joints, and Area Dividers (figures 4-1 and 4-2).

(1) Raised Joints. Joints should be located at high points where practicable and placed on curbs above the water line. This requires coordination of slope layout and drainage plans.

(2) Expansion Joint Locations. Expansion joints should be provided only at each expansion joint in the structure. Structures need expansion joints at intervals not over 60 m (200 ft) in length or width. Joints should also be used at changes in deck direction or membrane materials. If a structure does not contain enough expansion joints it is inappropriate to solve the problem by just adding expansion joints to the roofing system.

(3) Area Dividers. Area dividers do not provide for movement but are useful in subdividing big areas into isolated, smaller areas, each of which can be roofed (and maintained) separately.

d. Re-entrant Corners. Expansion joints or area dividers should be used at most re-entrant corners where stress concentrations are likely.

e. Roof Access. Roof access is essential to maintenance and inspection functions. Access should be controlled to block unauthorized entry (provided that it does not interfere with means of egress in an emergency).

f. Roof Venting.

(1) Roof Vents. On BUR membrane roof systems, roof vents have been proven to be of no value in drying wet materials and their efficacy for pressure relief is questionable. Roof vents may be required by the manufacturer's specification for some proprietary wet fill deck materials to augment venting base sheets. It is best to avoid using wet decks.

(2) Edge Venting. When a BUR is installed in a re-cover two membranes will be present. Edge venting may prevent pressurization of that space.

g. Roof Decks.

(1) Uninsulated Decks.

(a) Non-combustible/non-nailable decks such as poured and precast concrete should be cured and dry (28 day dry). Test for dryness by pouring some hot bitumen on the deck. If it can be peeled off, the deck is too wet. If moisture collects on the underside of a piece of glass placed on the deck, the deck is too wet. Asphalt primer (ASTM D41) is used to promote adhesion and to penetrate dirt and dust.

(b) Non-combustible/nailable decks such as precast lightweight planks and poured gypsum require base sheets (ASTM D2626, D4897) secured with proprietary fasteners designed for that deck type.

(c) Combustible/nailable decks such as wood, plywood, and OSB are dimensionally unstable in the presence of seasonal moisture changes. They require mechanically attached (not adhered) base sheets to avoid stress concentrations and splits at panel joints.

(2) Insulated Decks. Insulation may be anchored to the deck with bitumen or mechanical fasteners. Insulation should be divorced from moisture bearing wet fill decks by the use of a nailed asphalt coated base sheet.

h. Vapor Retarders.

(1) Vapor Retarder Location. On non-combustible decks two plies of bituminous felt mopped to the substrate and to each other provide an excellent vapor retarder. For nailable substrates a coated base sheet nailed, followed by a mopped felt is adequate. On steel roof decks mechanically fastened insulation or a fire rated underlayment is required to support the retarder. Thermal insulation is then mopped directly to the retarder. Refer to figure 2-14 to determine the need for a vapor retarder.

(2) Special Conditions for Freezers and Coolers. When a roofing system is used as the cover of a freezer or cooler building a severe reverse vapor drive occurs. Vapor pressure is higher outside the building and the primary vapor drive is towards the cold interior. The BUR membrane is itself the vapor retarder. Roof vents and vented roof edges must be avoided. In addition, the membrane must form a vapor seal with the wall retarder or ice damage will occur at this critical intersection. It may be

better to separate the cooler or freezer from the roof system by at least a 600 mm (2 ft) air space. The vapor retarder for the cooler or freezer is then positioned on the exterior of the freezer box facing the air space.

i. Thermal Insulation and Heat Flow.

(1) Polyisocyanurate Insulation. Isoboards are heat resistant. However, bituminous membranes should not be mopped directly to them. A layer of non-foam insulation should overlay the isoboard foam. Typically wood fiber or perlite board is mopped to the isoboard and the BUR is mopped to that.

(2) Re-cover Boards. Perlite, glass fiber, and wood fiber are used in re-cover situations where increasing thermal insulation is not a primary objective.

(3) Thermoplastic Foams. Polystyrene foam is damaged by hot asphalt. Some attempts have been made to adhere EPS with hot bitumen by allowing some cooling prior to embedment of the polystyrene. This technique is very vulnerable to workmanship error: too cool—no adhesion; too hot—insulation damage. The aliphatic and aromatic solvents used in cold process BUR adhesives also damage polystyrene.

j. Membranes and Surfacings.

(1) Reinforcements. Base sheets, ply felts, and mineral surfaced capsheets are used. Glass fiber mats dominate the market with small percentages of organic and synthetic fiber materials used. (Asbestos felts were used in the recent past.)

(a) Base sheets are used in nailable specifications. They generally have heavier asphalt coating for water and puncture resistance. Special base sheets have granules and channels on the bottom side to allow lateral movement of vapor.

(b) Ply sheets are thin, porous, conformable materials designed to lie securely into mopping bitumen. Asphalt treated felts are used with asphalt while tar treated materials are used with coal tar pitch moppings.

(c) Heavier coated ply sheets are generally used with cold applied bituminous adhesives. The heavier coating reduces demand for waterproofing bitumen from the adhesive and also permits light foot traffic during application without excessive bleed through. They may not be as heavy as base sheets.

(d) Mineral surfaced capsheets provide a lightweight reflective surfacing. They are especially popular in Arizona, California and Hawaii where aggregate surfaced roofs are less desirable.

(2) Bitumen. Asphalt is available in four mopping grades as described in ASTM D312. Type III is generally selected with glass fiber membranes, with Type IV used in the hot desert. Type I is sometimes used as a flood coat on roofs with a slope to 2% (1/4 in./ft.) because of superior water resistance. Coat tar pitch is available in two roofing grades as described in ASTM D450. Type I is called old style pitch and Type III is called low fuming. Both grades are suitable for slopes below 2% only. Suppliers are currently recommending Type I pitch only.

(3) Surfacing.

(a) A flood coat of bitumen is poured on the roof surface at a rate of approximately 2.9 kg/m^2 (0.60 psf), followed by aggregate meeting ASTM D1863 at a rate of 19-24 kg/m^2 (4-5 psf).

(b) For a glaze coat the bitumen is mopped or squeegeed at a rate of 1 kg/m^2 (0.2 psf) or less. This is far less durable than a flood coat and aggregate.

(c) A cutback coating is a solvent-based roof coating available with or without reinforcing fiber, similar to a glaze coat.

(d) An emulsion coating is an asphalt dispersion in water using a clay stabilizer. It is available with or without reinforcing fibers. Emulsions are more durable (sun and water-resistant) than glazings and cutbacks and provide better flame spread ratings. They cannot be stored or applied in freezing weather.

(e) Aluminized coatings (either fibrated or non-fibrated asphalt aluminum coatings) are popular on sloped surfaces but dull quickly on roofs that pond water. Reduction in solar loading and increased UV protection can be expected; recoating at 5-7 years is needed to restore protective qualities.

(f) Water-based asphalt-aluminum coatings are relatively new. Water mixed with fine aluminum flakes may result in hydrogen gas buildup. Storage is limited to about 6-months.

(g) Reflective latex-based coatings using acrylic elastomers are also available. As with emulsion coatings, they should be stored and applied under warm conditions only. They also require positive drainage for best performance.

(h) Some cold process systems spray an asphalt cutback onto the roof surface followed by blown roofing granules. Approximately 2 kg/m^2 (0.4 psf) of granules is applied.

k. Penetrations and Flashings. Flashing and detailing of BUR systems is critical. Construction Detail plates are available from the NRCA, SMACNA, and individual manufacturers. Pitch pockets and embedded metal gravel stops are especially troublesome and should be avoided by using raised curbs and edges whenever possible. Polymer modified bituminous materials are frequently used as flashings for BUR systems as they are tough, flexible and durable. However, they require careful workmanship as well. The MB and BUR materials should be from a single manufacturer.

l. Historical Roof Restoration. BURs are suitable for historical renovation.

m. Aesthetics. In typical low-slope applications aesthetics is rarely of concern. Aggregate is relatively attractive with some color choices available. Mineral capsheets and sprayed granule roofing provide some light reflectance and when carefully installed, can look good. Reflective coatings are pleasing while fresh but can become quickly objectionable if they flake off, dull unevenly, or craze due to substrate movement. BURs can also be converted into PMR plaza decks (when combined with extruded polystyrene insulation, filter fabric, and paver-ballast) for an attractive appearance.

n. Gaps, Flashings and Sealants.

(1) Gaps. Gaps in insulation in excess of 6 mm (1/4 in.) should be filled in by inserting pieces of thermal insulation or by replacing broken boards. Gaps in nailable decks are bridged with sheets of galvanized steel.

(2) Flashings.

(a) Vertical flashings on BUR systems require cant strips to reduce the angle at the base of the wall or curb. NRCA details, on occasion modified to specific job conditions, should be followed.

(b) Base flashings should extend not less than 200 mm (8 in.) above the membrane.

(c) Metals should not be used as base flashing, but are suitable counterflashing materials.

(d) Metal gravel stops embedded in the roof membrane should be avoided, as they require frequent maintenance. When used they must be attached securely. Use raised edges when possible (figures 12-7a and 12-7b).

(3) Sealants. Sealants are used primarily for metal work. Asphalt mastics are used on bituminous flashing details.

o. Drainage, Valley and Intersection Details.

(1) Drainage. Roof drains should be sized to meet or exceed the appropriate plumbing code. Secondary (overflow) drains or scuppers should be designed in accordance with ANSI/ASCE-7-95. Over-the-eaves drainage is acceptable in areas where ice dams are not expected. Interior drains are best in order to avoid drain and leader freeze-up. Primary roof drains should be recessed below the roof drainage line by using deck sumps (uninsulated decks) or by creating a sump out of roof insulation in order to properly collect water.

(2) Valley and Intersection Details. Valleys and intersections are fabricated out of membrane materials. Crickets and saddles help divert water to the drains. Refer to NRCA details for their design.

4-3. DESIGN CONSIDERATIONS AND ALERTS.

a. Attachment. Bituminous membranes require strong and uniform attachment to their substrate. The use of the nail-one, mop-one technique to install thermal insulation is a good way to achieve that.

b. Phased Construction. All components from the top of the roof deck through the completed membrane (excluding surfacing) should be completed in a single day. Just installing a base sheet to protect the substrate then returning later to install the rest of the plies, is called phasing and is to be avoided. Dirt and debris that collects on the base sheet creates a plane of weakness in the membrane.

c. Bitumen Compatibility. Use bitumen compatible with the reinforcements and appropriate for the climate and slope.

d. Walkways. Protective walkways are needed if more than occasional roof traffic is expected.

e. The Equiviscous Temperature Concept. EVT controls application temperatures. Follow NRCA procedures (See entire text of NRCA Bulletin in Appendix 4-1) for EVT use.

f. Coal Tar Pitch Slope. Do not use coat tar pitch specifications above 2% (1/4 in./ft.) slope.

g. Flood Coat. For the flood coat at least, use asphalt with the lowest practicable softening point suited to slope and climate as follows:

Table 4-1. Maximum Slope Recommended in ASTM D312

Maximum Slope (in./ft)*	ASTM Designation	Softening Point, °F
1/4	D-312, Type I	135 — 151
1-1/2	D312, Type II	158 — 176
3	D312, Type III	185 — 205
6	D312, Type IV	205 — 225

*Warm climates may limit the slope of asphalts to less than the maximums specified above.

When hot mopped bitumen is used to bond a base sheet to insulation specify Type III (or in some instances Type IV) asphalt.

4-4. CONSTRUCTION CONSIDERATIONS AND FIELD ALERTS.

a. General.

(1) Materials.

(a) Materials, including accessories, must be delivered to the job site and be ready to install when work begins. Built-up roofing is a continuous process and everything from vapor retarder through roof membrane must be installed in a single day.

(b) Materials must be stored off the ground and protected from weather and condensation.

(c) Edge nailers, roof drains, curbs, and penetrations should be in place prior to roofing.

(2) Vapor Retarders. Vapor retarders, when used, must be protected with insulation promptly to avoid construction damage.

(3) Insulation.

(a) Insulation boards should be butted together with joints staggered and offset if more than one layer is being used.

(b) Insulation should be firmly attached with specified type, length, and number of fasteners or embedded in bitumen/adhesive to substrate or underlying insulation as specified.

(c) Tops of adjacent insulation boards should not be vertically offset more than 6.35 mm (1/4 in.).

(4) Bitumen.

(a) Bitumen must be heated and transported so that it is within its EVT range + 14°C (25°F) at the point of application (Appendix 4-1). (Verify that thermometers are visible and working properly.)

1/ Asphalt. The mechanical spreader application temperature should be such that a viscosity of 0.075 Pa•s @ (75 centipoise) can be achieved. Viscosity for hand mopping should be 0.125 Pa•s (125 centipoise).

2/ Coal Tar Pitch. The mop and mechanical spreader application viscosity should be 0.025 Pa•s (25 centipoise).

(b) Interply bitumen is applied in a continuous thin film.

(c) Check for uniform interply hot moppings so that nowhere does felt touch felt. Average interply mopping weight must be within specifications ([49-98 Kg/m^2 (15-30 lbs/sq)].

(d) In cold weather require double (circulating) or insulated asphalt delivery lines as well as insulated asphalt carriers and mop buckets. (Also store felts in a warm enclosure.)

(e) Do not specify coal tar pitch on roofs with slope exceeding 2% (1/4 in.).

(f) Specify asphalt suited to the slope. Type I is preferred on roofs that occasionally pond water, at least for the flood coat on aggregate surfaced roofs. Type IV may be preferred for hot climates such as the desert southwest.

(5) Reinforcements. When hot mopped bitumen is used to bond a base sheet to insulation specify Type III (or in some instances Type IV) asphalt.

(a) Felts are installed with correct headlap, endlap, sidelap and exposure (figure 4-3).

(b) Roofing plies are installed so sidelaps and endlaps do not oppose (buck) water flow.

(c) Require immediate repair of felt laying defects such as fishmouths, blisters, ridges, splits, or misalignment.

(d) Use a nailed, asphalt coated base sheet for the first ply of built-up roofing membranes over wet decks (e.g., poured gypsum, lightweight insulating concrete).

(e) Felts are being broomed or squeegeed into the hot bitumen so that a continuous film of bitumen exists between reinforcing plies. Felts laps must be firmly embedded.

(6) Aggregate Application.

(a) Aggregate application should usually be delayed until an entire roof area is complete so that the aggregate does not contaminate work in progress. Unadhered aggregate should be removed from roofs near aircraft tarmacs to avoid wind caused damage.

(b) Provide trafficways or an entire traffic surfacing for roofs subjected to more than occasional foot traffic.

(7) Nightly Seals. Roof edges and end of day work must be sealed off to protect against water penetration.

b. Pre-Roofing Conferences. A pre-roofing conference should be held prior to construction. Representatives of the designer, user, roofing contractor, general contractor, materials manufacturer, field inspectors and other related subcontractors should be present. See Appendix 4-2 for suggested formats for pre-bid, preliminary, pre-application, and final inspection. Quality assurance measures should be discussed including field inspection, roof test cuts, and rejection procedures.

c. Shop Drawing Submittals. Drawings of intersections of expansion joints, curbs, edging, flashings and copings should be required. These should be detail specific and dimensioned, not manufacturer's standard detail plates.

d. Design Submittal Requirements.

(1) Manufacturer Assurance. Require the manufacturer to verify in writing that the proposed system is compatible with the roof deck, vapor retarder, and insulation and is appropriate for this application.

(2) Code Compliance. Require evidence of compliance of the complete roof system with fire, wind, or other specified code requirements.

e. Field Review and Observation. Full time visual inspection by qualified inspectors is recommended. On major roofing projects, require periodic inspection by the manufacturer.

4-5. MAINTENANCE CONSIDERATIONS.

a. General. Built-up roofing, especially at flashing and penetrations, is heavily dependent upon inspection and maintenance. Procedures listed in the joint NRCA/ARMA/SPRI and RIEI maintenance manuals should be followed.

b. Repair or Replace. Bituminous repairs are relatively uncomplicated, and may be accomplished using solvent based mastics with appropriate reinforcement, or by the use of hot, torched or cold applied modified bitumens. Large repairs can be more effectively achieved with hot bitumen. When areas are damaged and the insulation underneath is wet, the affected areas can be removed, replaced with intact materials, and tied back into the existing roof system.

c. Repairs: Emergency, Temporary, and Permanent.

(1) Emergency Repairs. Repairs may be made using asphalt mastic, peel and stick MB sheets, duct tape, or application of bentonite clay or portland cement to limit moisture intrusion. As soon as weather permits temporary or permanent repairs must be made.

(2) Temporary Repairs. Patches generally consist of reinforcing fabric embedded in cold mastics or torch-applied modified bituminous material. In either case cleaning and priming of the tie-in area is essential. Asphalt primer is generally used. (There is a tar primer for coal tar pitch membranes.) Asphaltic materials should be used on asphalt BUR and tar materials on coal tar membranes.

(3) Permanent Repairs. These repairs are similar to temporary but the restored area should at least equal the number of reinforcing plies in the rest of the membrane.

d. Repair Work by User. The occupants should keep compatible mastic, trowels, and reinforcing available for emergency repairs and patching. Torching of modified bituminous material requires fuel, appropriate tools and materials, fire extinguishers, and trained technicians but is quick and very effective when done properly.

e. Checklists. Use RIEI or ROOFER checklists for visual inspections. Perimeters and flashings are high priority items as are roof drains.

APPENDIX 4-1.

EQUIVISCOUS TEMPERATURE (EVT)
NRCA Bulletin 2-91 (December 1991)
Supersedes Bulletin #2 dated September 1988

The National Roofing Contractors Association (NRCA) makes the following recommendations regarding bitumen application temperatures for built-up roof systems.

Equiviscous Temperature (EVT): The temperature at which a bitumen attains the proper viscosity for built-up membrane application.

EVT Range: The recommended bitumen application temperature range. The range is approximately 14°C (25°F) above or below the EVT, thus giving a range of approximately 28°C (50°F). The EVT range temperature is measured in the mop cart or mechanical spreader just prior to the application of bitumen to the substrate.

EVT for Asphalt: The recommended EVT for roofing asphalt (ASTM D312, Type I, II, III, or IV) is as follows:

a. Mop Application: The temperature at which the asphalt's apparent viscosity[1] is 0.125 Pa•s (125 centipoise).

Note: If there are simultaneous mop and mechanical spreader applications, in order to avoid the use of two kettles, the EVT for mechanical spreader application may be used for both application techniques.

b. Mechanical Spreader Application: The temperature at which the asphalt's apparent viscosity[*] is 0.075 Pa•s (75 centipoise).

EVT for Coal Tar: The recommended EVT for roofing coal tar (ASTM D450l,Type I or III) is the temperature at which the coal tar's apparent viscosity[1] is 0.025 Pa•s (25 centipoise).

Product Labeling: NRCA recommends the following information be marked on each bitumen carton label or, for bulk material, provided on the bill of lading:

a. Product Type: Bitumen type and ASTM designation (e.g., Asphalt—ASTM D312, Type III; or Coal Tar—ASTM D450, Type III).

b. EVT: For asphalt, the EVT for both mop application and mechanical spreader application should be given.

c. Flash Point (as determined by ASTM D92).

[*]Apparent viscosity is measured by ASTM D4402. Viscosity is a measure of the resistance to flow of a liquid. Pascal Second and Centipoise are units of a liquid's apparent viscosity.

Bitumen Application Temperature Range for Surfacing: The optimum bitumen application temperature range for surfacing is dependent upon the type and method of surfacing. For glaze coating, wherein a relatively thin coating is desired, bitumen application temperature in the EVT range is generally recommended. For aggregate surfacing, a lower bitumen application temperature is generally recommended for the pour coat.

Bitumen Application Temperature Range for Adhering Insulation: The optimum bitumen application temperature range for adhering insulation boards is dependent upon the type of insulation, type of substrate, ambient temperature and wind conditions. Bitumen application temperature within or lower than the EVT range is generally recommended.

Supplementary Recommendations Regarding Bitumen Heating: Excessive or prolonged bitumen heating may have a deleterious effect on the physical properties of the product. Accordingly, the following is recommended.

a. Bitumen in kettles or tankers should be kept approximately 14°C (25°F) or lower, below the bitumen's flash point.

b. Bitumen should not be maintained above 260°C (500°F) for more than four hours unless bitumen is being added and drawn off periodically.

c. If bitumen is held in a tanker or in storage for more than 48 hours, it should be kept approximately 163°C (325°F) or lower.

Commentary on Bulletin 2-91 Revisions.

The major revision to this edition of the bulletin was the incorporation of separate EVTs for asphalt mop application and mechanical spreader application. Bitumen application temperature range information has also been added for surfacing and adhering insulation boards. Editorial changes have also been made.

Although the bulletin is intended for built-up membrane systems, portions of it are also applicable to certain aspects of hot-applied polymer-modified bitumen roof systems. Bitumen used to adhere base and ply sheets, and bitumen used to adhere roof insulation, is generally recommended to be applied at the temperature range recommended in this bulletin. However, the appropriate bitumen temperature application range for adhering modified bitumen capsheets may be hotter than the ranged recommended in this bulletin. For the recommended range when adhering modified bitumen capsheets, consult the sheet manufacturer.

References.

1. Cullen, W.C., "Equiviscous Temperature Concept Revisited", International Journal of Roofing Technology, 1990, p. 46.
2. NRCA and Trumbull Research Report, "Temperature and Viscosity Effects on the Application of Asphalt during the Construction of Built-Up Roofing Systems", September, 1988.
3. NRCA and Koppers Research Report, "Temperature and Viscosity Effects on the Application of Coal Tar Products during the Construction of Built-Up Roofing Systems", December 1986.

Appendix 4-2.

RECOMMENDED AGENDA FOR PRE-ROOFING CONFERENCES
PERTAINING TO MEMBRANE ROOFING SYSTEMS

Project Name: ____________________

Project Location: ____________________

Conference Date: ____________________

Conference Location: ____________________

Type of Conference:
- Prebid (to walk-over project for specification clarity)
- Preliminary (to open lines of communication)
- Pre-Application (to verify readiness and scheduling)
- Final

Project Parties:

User/Agency: ____________________

Architect: ____________________

General Contractor: ____________________

Roofing Contractor: ____________________

	Firm	Attendee	Title	Phone
User/Agency				
Architect				
General Contractor				
Roofing Contractor				
Deck Contractor				
Material Manufacturer (if roof warranty is req'd)				
Roofing Consultant/Testing Lab				
Others (i.e. sheet metal, HVAC, etc.)				

Agenda for Preliminary Conference

Purpose: Establish a direct line of communication, iron out initial questions regarding the project and to review project submittal requirements.

Timing: Meeting should be held shortly after award of roofing contract and at least six weeks prior to the anticipated start of roofing.

1. A complete set of construction documents (plans and specifications) to be available for review.
2. All meeting minutes to be furnished to all parties. Establish project recordkeeping procedures.
3. Review tentative progress schedule for roofing. Set approximate date.
4. Review roofing system and insulation requirements.
5. Weather considerations as they may apply to the project roofing installation.
6. Temporary roofing guidelines for the project. By whom and under what conditions will decisions be made on temporary roofing.
7. Inspection and Testing Requirements:

   Name of Inspection Firm: ______________________

   Name of Inspector: ______________________

   Phone: ______________________

   a. On-Site Inspection
   b. Laboratory Testing

   > discuss project requirements
8. Roof Deck:

   •Type and Thickness

   •Slope

   •Location and Type of Drains

   •Tentative Schedule for Erection

   •Nailers, curbs and sheetmetal must be completed prior to roofing application

   •FM or UL requirements

   •Responsibility (not roofers)
9. Anticipated material storage areas & equipment setup locations touched upon. Review requirements.
10. Specific submittals from the roofing contractor:
    a. Material approval list
    b. Shop drawings (if any)
    c. Product material samples
11. Detailed discussion of a specific project (include perimeter wall construction and rooftop mechanical equipment details).
12. Other: ______________________
13. Review above items briefly and establish tentative date for Pre-Application Conference.

Agenda for Pre-Application Conference

Purpose: To verify readiness for roofing
To review assignments of preliminary conference
Scan last minute details, changes or corrections
To review anticipated schedule of progress

Timing: Within one week of roofing application

(The roofing job superintendent or foreman should attend this meeting, as should the project roofing inspector.)

1. Copies of approved submittals should be available for review. Are any material changes required due to availability problems or other? Reminder that formal approvals still required.
2. Review minutes of preliminary conference.
3. Discuss revised roofing application schedule.
4. Equipment setup and on-site material storage.
5. Deck Readiness:
   a. Any required roof deck certifications must be in order
   b. Roof top inspection by those in attendance
   c. Drain hookups complete
   d. Curbs, nailers, roof deck penetrations, perimeter edges and mechanical equipment—should all be set and complete
6. Review roof system including insulation above deck. Discuss the required application of each component.
   a. Deck acceptance
   b. Bitumens—use of EVT
   c. Brooming of felts
   d. Use of torches on modified bitumen flashings
   e. Handling solvent-containing mastics and coatings
   f. Mechanical attachment
   g. Vapor retarders
   h. Flashings
   i. Surfacings
   j. Saddles or crickets
   k. Venting
   l. Sheetmetal application
   m. Walkways
7. Avoidance of phased construction require tie-offs at day's end.
8. Temporary roofing decisions.
9. Housekeeping, material handling, and protection of finished work.
10. Inspection and testing requirements—who, frequency, type, method of testing, reporting, rejection criteria and remedy.
11. Project changes in plans, specs or procedures to be followed—discuss and establish who can approve and how documented.
12. Warranties, guarantees, manufacturer bonds or maintenance agreements (terms, types, who issues, when). Requirements for written certifications.

Agenda for Final Inspection and Project Wrap-Up

Purpose: To assure 100% completion of project requirements

Timing: Just before the roofing contractor concludes work at the site

1. Attendance should include those in attendance at the Pre-Application Conference.
2. Complete rooftop walkover and review:
   a. Perimeter edges
   b. Walls
   c. Curbs and other equipment
   d. Drains
   e. Rooftop penetrations
   f. Site clean up
   g. Sheetmetal
3. Check list of items yet to be completed.
4. Summary of project records. Organize for final file. Wrap up any loose ends. Checklist for final documents should include:
   a. Warranties, guarantees, manufacturer bonds, or maintenance agreements
   b. Inspection forms, reports, certificate of final completion
   c. Laboratory final reports (if any required)
5. Recommendations for routine maintenance program to owner.
6. Discuss responsibility for roof system protection until project completed. Responsibility for coordination usually rests with General Contractor. Repair of damage and any additional roofing work to be completed by the original roofing contractor in order to keep the original guarantee valid.
7. Final acceptance by the owner/developer.

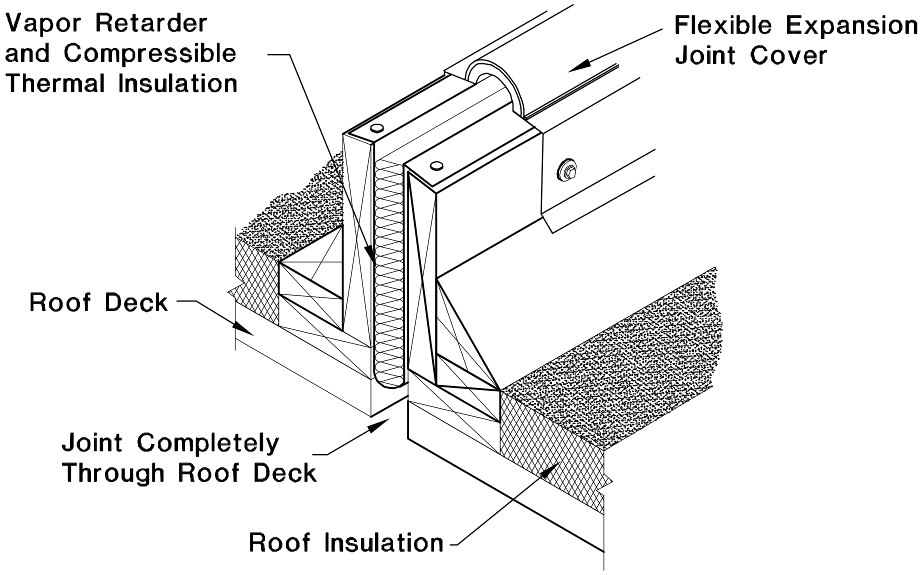


Figure 4-1. Raised Curb Expansion Joint

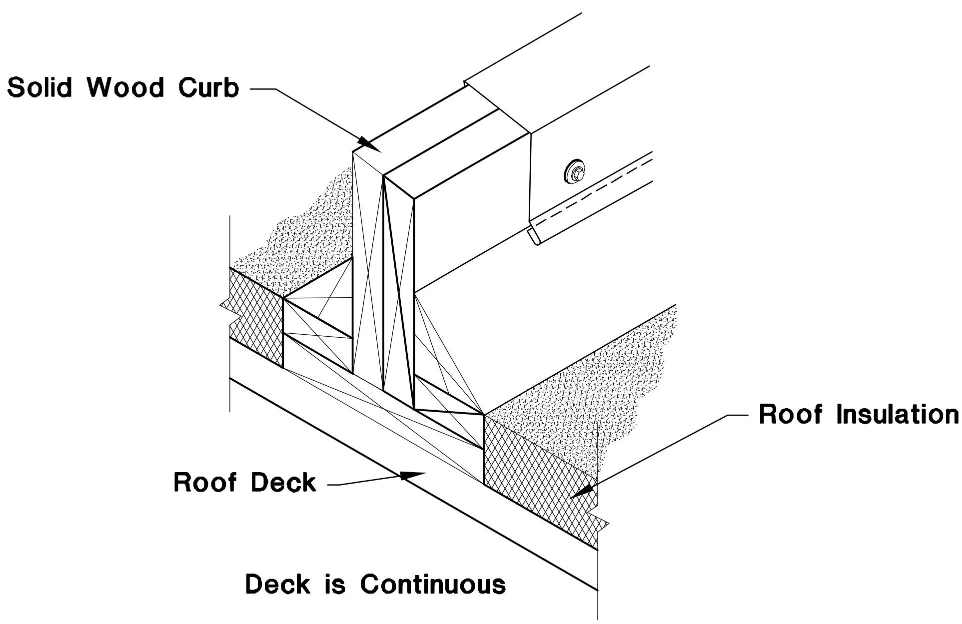


Figure 4-2. Raised Curb Area Divider

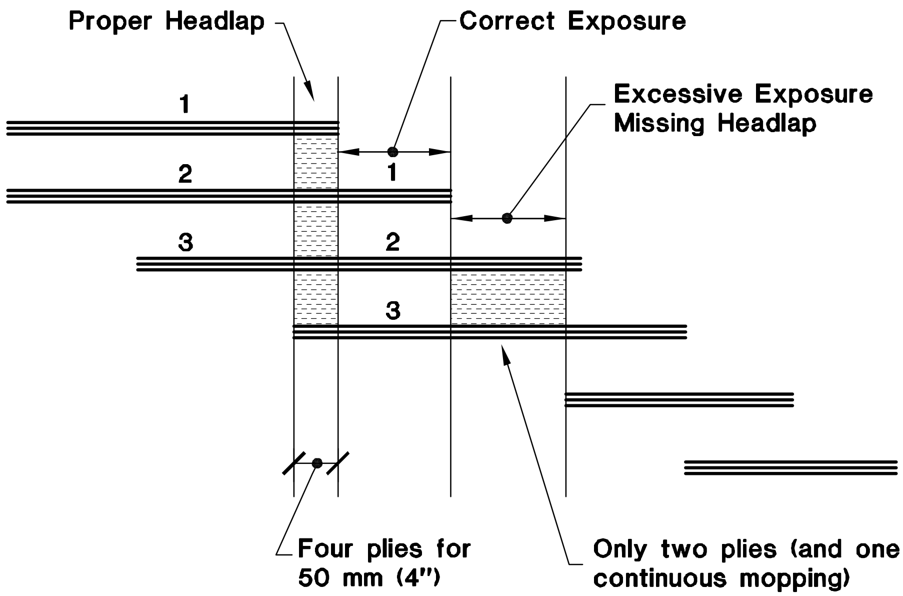


Figure 4-3. Headlap and Exposure in a 3-Ply BUR System

CHAPTER 5

MODIFIED BITUMEN ROOFING SYSTEMS
REFERENCE CEGS 07551

5-1. MB ROOFING SYSTEMS.

a. Overview. As contrasted to BURs which rely on field application of bitumen to make them waterproof, polymer modified bituminous systems (MB) use reinforcing sheets that have been factory-coated with rubberized bitumen. The sheets themselves are inherently waterproof. The use of polymers mixed with the coating bitumen improves flexibility, toughness and low temperature properties. A major advantage of MB systems over BUR is that they generally use fewer layers and are therefore less labor and material intensive. Two categories of MB roofing are SBS (ASTM D6162, D6163, D6164), and APP (ASTM D6222 and D6223).

b. General

(1) Three basic types of MB Systems.

(a) Heat fused systems use a torch or hot air to remelt the factory applied bitumen for use as the adhesive.

(b) Mopped-in-place systems which, like BUR systems, still rely on field-applied hot bitumen as the adhesive.

(c) In a few instances a solvent-based *cold adhesive* is used to adhere and seal the sheets (sometimes only the field of the sheet is adhesively bonded while side and end laps are heat fused).

(2) Polymer Modifiers. Generally either thermoplastic (Atactic Polypropylene/APP) or elastomeric (Styrene-Butadiene-Styrene/SBS) modifiers are used. Included in the thermoplastic modifier group are APP, APO (Alpha-Polyolefin) and Isotactic Polypropylene (IPP). APP systems usually are torch fused while SBS systems may be mop or torch applied. Both are occasionally installed using cold adhesive.

(3) Reinforcements. Reinforcements of glass fiber, polyester or combinations may be either woven (scrim) or non-woven. The reinforcement carries the sheet during manufacture and provides tensile strength and stability to the finished membrane.

(4) MB Systems. The completed membrane is frequently only two layers, compared to three or more in BUR. The top layer is surfaced with mineral granules, metal foil, or occasionally it is smooth surfaced. The base layer may be polymer modified or a conventional, less expensive coated BUR base sheet. Multiple plies of BUR ply felts are sometimes used below. When BUR components are used with MB capsheets the roofing is referred to as a *hybrid* system.

(5) Climate/Weather. Coated sheets, even with polymer modification, are stiff in cold weather. Rolls should be stored at temperatures above freezing for 24 hours before unrolling. SBS sheets are more flexible in the cold than APP sheets and thus are preferred in cold regions. MB sheets will blister if not fully adhered due to cold, wet or frozen substrates. In hot climates SBS sheets are prone to slippage. Backnailing and careful use of approved mopping bitumen (special Type IV asphalt) is necessary.

(6) Logistics. While material efficient as compared to BUR, MB systems require relatively heavy rolls. Torch application uses propane which necessitates safe handling and storage. A fire watch is needed each day for a period of time after the last torch is extinguished. Careless torching of

MB sheets has caused several very costly fires. Mop application avoids torch application by using hot bitumen as the adhesive, similar to BUR applications. MB systems require somewhat hotter asphalt (260°C/500°F+) at the point of application than most BURs do.

(7) Familiarity with the System and Site. Modified bitumens are well known to the commercial roofing trade. Only Certified Torch Applicators should be permitted to use torches. The certification (CERTA) consists of completing a minimum one-day safety-training course developed by the Midwest Roofing Contractors Association.

(8) Life Expectancy. MB systems are estimated to have a useful life of 15 years or more. Uncoated systems (where granules or foil have been omitted) require recoating at 5-8 year intervals.

(9) Costs. MB systems are competitive with BUR systems.

(10) Structural Considerations. As with BUR, most MB membranes are placed on thermal insulation. Nailed or mopped base sheets are needed. Torching directly to thermal insulation is not acceptable.

5-2. BUILDING ELEMENTS.

a. Slope. The minimum slope of 2% (1/4 in./ft) applies to MB systems. Maximum slope depends upon technique of application and backnailing. MB is used as vertical flashings when adequately top nailed.

b. Low-Sloped Roofs. Place sheets so that head and sidelaps do not buck water flow. Since thick sidelaps and tee joints are vulnerable to water penetration, minimize these features in valleys.

c. Steep Sloped Roofs. MB systems are suitable for folded plate and barrel roofs. Torched and cold adhesive specifications may allow slopes to 50% (6:12) with backnailing.

d. Structural Considerations. Pallets of MB rolls are heavy and weight should be distributed on the roof deck to avoid damage. In general, MB systems do not use ballast or aggregate and are therefore lightweight systems.

e. Expansion Joints, Seismic Joints and Area Dividers.

(1) Expansion Joint Locations. Joints should be located at high points where practicable and placed on curbs above the water line. Membrane expansion joints should be provided only at each expansion joint in the structure. Structures typically need expansion joints at intervals not over 60 m (200 ft) in length or width. Joints should also be used at changes in deck direction or membrane material.

(2) Area Dividers. Area dividers do not provide for movement but are useful in subdividing large areas into isolated smaller areas, each of which can be roofed (and maintained) separately.

f. Re-entrant Corners. Expansion joints or area dividers should be used at most re-entrant corners where stress concentrations are likely.

g. Roof Venting. Roof vents have been proven to be of no value in drying wet materials and their efficacy for pressure relief is questionable. Roof vents may be required in some proprietary wet-fill deck materials in conjunction with venting base sheets. When insulation and a MB membrane are installed over an existing bituminous membrane roof edges should not be sealed. This will prevent pressurization of the space between the two membranes.

h. Roof Decks.

(1) Uninsulated Decks.

(a) Non-combustible/non-nailable decks such as poured and precast concrete should be cured and dry (28-day dry). Asphalt primer (ASTM D41) should be used to promote adhesion and to penetrate dirt and dust. Test for dryness by pouring some hot bitumen on the deck. If it can be peeled off, the deck is too wet. If moisture collects on the underside of a piece of glass placed on the deck, the deck is too wet.

(b) Noncombustible/nailable decks such as precast lightweight planks, insulating lightweight concrete, and poured gypsum require base sheets secured with proprietary fasteners designed for that deck type.

(c) Combustible/nailable decks such as wood, plywood, and OSB are dimensionally unstable in the presence of seasonal moisture changes. They require mechanically attached (not adhered) base sheets to avoid stress concentrations and splits at joints.

(2) Insulated Decks. Insulation may be attached with bitumen or mechanical fasteners. Insulation should be divorced from moisture bearing wet fill decks by the use of a nailed base sheet.

i. Vapor Retarders.

(1) Vapor Retarder Location. One ply of MB felt, or two plies of saturated roofing felt mopped to the deck and each other provide an excellent vapor retarder for non-combustible decks. On nailable decks a coated base sheet, either modified or not, followed by one more ply of felt mopped to the base sheet is adequate for nailable substrates. On steel roof decks, mechanically fastened insulation or a fire rated underlayment is required to support the retarder. Thermal insulation is then mopped directly to the retarder.

(2) Special Condition of Freezers and Coolers. When a roof system is used as the cover of a freezer or cooler building a severe reverse vapor drive occurs. Vapor pressure is higher outside the building and the vapor drive will be towards the colder interior. While a MB membrane itself is an excellent vapor retarder roof vents and venting roof edges must be avoided. In addition, the membrane must form a vapor seal with the wall retarder or ice damage can occur at this structurally critical intersection. It may be better to separate the cooler or freezer from the roof system by at least a 600 mm (2 ft.) air space. The vapor retarder for the cooler or freezer is then installed on the exterior of the freezer box facing the air space.

j. Thermal Insulation and Heat Flow. Torching should not be permitted directly to any thermal insulation.

(1) Polyisocyanurate Insulation. Mopping MB membranes directly to isoboards is not recommended. A layer of non-foam insulation should overlay the isoboard. Typically, wood fiber or perlite board is mopped to the iso layer and the MB system is mopped to that.

(2) Aged R-factor. Some decay of R value is observed with HCFC blown foams (urethanes and isoboards) due to diffusion of air and moisture into the cells of the foam. Manufacturers publish aged R values to reflect this decay. Thicker foams are more thermally stable.

(3) Recover Boards and Cant Strips. Perlite, glass fiber, and wood fiber are used in re-cover situations where upgraded thermal resistance is not essential. Non-combustible cant strips should be used when torched flashings are used.

(4) Thermoplastic Foams. Polystyrene foam is damaged by hot asphalt or torch application. Some attempts have been made to adhere EPS with hot bitumen by allowing some cooling prior to

embedment of the polystyrene. This technique is very vulnerable to workmanship error, too cool—no adhesion; too hot—insulation damage. Solvents used in cold process systems also damage polystyrene.

(5) Thermal Bridging and Nail Popping. When mechanical fasteners are used to secure thermal insulation, it is recommended that the nail-one, mop-one technique be used. This minimizes thermal bridging and avoids nail popping of the membrane. When multiple layers of insulation are used, joints should be offset to reduce heat losses. Straight-through joints can take away 10% of a roof's insulating ability.

k. Membranes and Surfacings.

(1) Reinforcements. Reinforcements are internal to the MB sheets. They consist of woven and non-woven glass fiber or synthetic fibers. The MB family of products includes:

(a) Conventional and polymer-modified base sheets.

(b) Polymer-modified capsheets with mineral surfacing or metal foil.

(c) Unsurfaced MB sheets which must be field coated for heat reflection and UV protection.

(d) Glass ply felts (used in hybrid systems and as fire protective underlayments).

(2) Base Sheets. Base sheets form the bottom ply in many MB specifications. The base sheet can be nailed to nailable substrates, or mopped in place on others. Both unmodified coated base sheets and polymer-modified base sheets are used. In addition to bridging the substrate, the base sheet may serve as a fire barrier when installing torched-on MB systems. Conventional BUR base sheets should meet ASTM D4601 (glass fiber base sheet), D2626 (coated organic base sheet), or D4897 (glass fiber venting base sheet).

(3) Ply Sheets. Ply sheets, if used, should meet ASTM D2178 Type IV or VI (glass fiber ply sheets).

(4) MB Capsheets. Capsheets are the heart of most MB systems. They contain polymer-modified bitumen and may be unsurfaced or surfaced with mineral granules or metal foil. Torching grade materials have a thicker bottom side coating to serve as hot melt adhesive. Current ASTM standards include the following with additional standards under development:

D6162	SBS sheets with combination of polyester and glass fiber reinforcements
D6163	SBS sheets with glass fiber reinforcement
D6164	SBS sheets with polyester reinforcement
D6222	APP sheets with polyester reinforcement
D6223	APP sheets with glass fiber reinforcement

(5) Mopping Asphalt. Asphalt meeting ASTM D312 Type IV (or occasionally Type III) is used.

(6) Cold Adhesives. Solvent-based adhesives are also used to install MB systems. They may be ordinary cold process bituminous adhesives or polymer-modified bituminous adhesives depending upon the MB system used. Adhesive and MB sheets should be from a single manufacturer.

(7) Surfacing Options.

(a) Surfacing is part of the capsheet such as in mineral granule and metal foil systems.

(b) Flood coat and gravel. Quantities, materials, and techniques are identical to BUR. Flood coats and gravel are usually used only in ponded water situations or where a more robust surface is needed for hail protection.

(c) Field applied color coatings. Asphalt aluminum coatings (ASTM D2824) and white latex coatings (ASTM D6083) are used for heat reduction and UV protection. These will require periodic recoating.

l. Penetrations and Flashings. MB systems are well suited as flashings. They are compatible with and used on both BUR and MB roof systems.

m. Historical Roof Restoration. The many surfacing options of MB allow the finished appearance to match the designer's choice. Copper foil surfacing gives an appearance of copper roofing and has been used in domed structures as a low cost simulation of sheet copper.

n. Aesthetics. Mineral surfaced sheets, when installed neatly, can have a reasonably pleasing appearance. Loose granules may be sprinkled into exposed bitumen at end and sidelaps to improve aesthetics. The exposed bitumen on foil surfaced sheets may be touched-up with special paint provided by the MB sheet producer. Gravel surfaced roofs appear identical to BUR. Coated systems will be pleasing for a while, but recoating will be needed to maintain the appearance.

o. Gaps, Flashings, Joints, and Sealants.

(1) Gaps. Gaps in insulation in excess of 6 mm (1/4 in.) should be filled with thermal insulation by inserting pieces of insulation or replacing broken boards. Gaps in nailable decks are bridged with sheets of galvanized steel.

(2) Flashings.

(a) Vertical flashings for most MB systems require cant strips to reduce the angle at the base of the wall or curb. NRCA details, on occasion modified to specific job conditions, should be followed.

(b) Base flashings should extend not less than 200 mm (8 in.) above the membrane.

(c) Metals should not be used as base flashing but are suitable as counterflashing materials.

(d) Metal gravel stops embedded in the roof membrane should be avoided wherever possible, as they require frequent maintenance. When used they must be attached securely

(3) Sealants. Sealants are used primarily for metal work. Asphalt mastics (ASTM D2822 or D4479) are used on bituminous flashing details. Occasionally melted MB coating is scraped from the back side of scrap MB sheeting and used as a hot melt sealant.

p. Drainage, Valley and Intersection Details.

(1) Drainage. Roof drains should be sized to meet national plumbing codes. Secondary (overflow) drains or scuppers should be designed in accordance with ANSI/ASCE 7-95. Over-the-eaves drainage is acceptable in areas where ice dams are not expected. Interior drains avoid drain and leader freeze-up. Primary roof drains should be recessed below the roof line by using deck sumps (uninsulated decks) or by creating a sump out of roof insulation in order to properly collect water.

(2) Valley and Intersection Details. Valleys and intersections are fabricated out of membrane materials. Crickets and saddles help divert water to the drains. Refer to NRCA details for their design.

5-3. DESIGN CONSIDERATIONS AND ALERTS.

a. Attachment. Modified bituminous membranes require strong and uniform attachment to the substrate. The use of the nail-one, mop-one technique to install thermal insulation is a good way to achieve that.

b. Phased Construction. All components from the top of the roof deck through the completed membrane (excluding surfacing) should be completed in a single day. Just installing a base sheet to protect the substrate then returning later to install the MB capsheet is called phasing and is to be avoided.

c. Adhesion Type. Use torch, mop, or cold mastic techniques as required by system choice.

d. Walkways. Protective walkways are needed if more than occasional roof traffic is expected. Polyester reinforced SBS modified cap sheets may be used as a walkway. This layer is in addition to the membrane specified.

e. Equiviscous Temperature. The EVT concept may be inappropriate for MB application. Follow the minimum bitumen temperatures specified by the proprietary specification, typically 230°C (450°F) or higher.

f. Flashings. Specify two-ply, not single-ply base flashings.

g. Overlay Boards. Require protective cover boards with taped joints to be installed over EPS insulation to prevent melting of the EPS.

5-4. CONSTRUCTION CONSIDERATIONS AND FIELD ALERTS.

a. General. Materials must be delivered to the job site and ready to install when work begins. MB roofing is a continuous process and everything from vapor retarder through roof membrane must be installed in a single day. While it is tempting to delay the capsheet until an entire roof area is completed, this can result in delamination and blistering.

(1) Storage. Materials must be stored off the ground and protected from weather and condensation.

(2) Bitumen Temperatures. Bitumen for hot-adhered systems must be heated and transported to meet the temperatures required at the point of application. Generally temperatures to apply MB products will be higher than EVT.

(3) Vapor Retarders. Vapor retarders (when used) must be protected with insulation as soon as installed to avoid construction damage.

(4) Edge Seals. Roof edges and end of day work must be sealed off to protect against water penetration.

(5) Surfacings. If field applied surfacings are used, they should not be installed until the entire roof area is completed. Manufacturers may recommend long delays for some coatings to allow the MB to stabilize.

(6) Material Compliance. Read labels on roll goods and verify compliance with specifications and UL and FM requirements.

b. Pre-Roofing Conference. A pre-roofing conference should be held prior to construction. Representatives of the designer, user, roofing contractor, general contractor, materials manufacturer, field inspector, and other related subcontractors should be present. Fire safety should be an agenda item.

c. Shop Drawing Submittals. Drawings of intersections of expansion joints, curbs, edging, flashings and coping should be required. These should be detail specific and dimensioned, not manufacturer's standard detail plates.

d. Design Submittal Requirements and Checklist.

(1) Manufacturer Assurance. Require the manufacturer to verify in writing that the proposed system is compatible with the roof deck, vapor retarder, and insulation and is appropriate for this specific application.

(2) Application Manual. Require submittal of foreman's application manual. Discuss any planned deviations.

(3) Start-Up. On major roofing projects require startup assistance and periodic inspection by the manufacturer.

(4) Base Sheets. Use nailed, asphalt coated or modified base sheet for the first ply in MB roofing membranes installed over wet decks (e.g., poured gypsum, and lightweight insulating concrete fill).

(5) Bitumen. Mopping bitumen should be as specified. Generally this will require ASTM D312 Type III or Type IV asphalt.

e. Field Review and Observation.

(1) Inspection. Full time visual inspection by qualified inspectors is recommended. Is the installation following the manufacturer's application instructions? (Usually available in the foreman's pocket manual.)

(2) Torching. If torching is being performed, are safety requirements being followed? Are the individuals using torches safety certified? Do propane tanks have pressure regulators? Are tanks shut off at the cylinder and in-line gas burned off during the lunch break; overnight? Is a fire watch in place? Are fire extinguishers present?

5-5. MAINTENANCE CONSIDERATIONS.

a. General. MB roofing is heavily dependent upon inspection and maintenance especially at seams, flashing, and penetrations. Procedures listed in the joint NRCA/ARMA/SPRI and RIEI maintenance manuals should be followed.

b. Repair or Replace. MB repairs are relatively uncomplicated, and may be effected by solvent based mastics with MB membrane, or by applying torched in place repairs. Surface preparation and priming are needed.

c. Repairs: Emergency, Temporary, and Permanent.

(1) Emergency repairs. Expedient repairs may be made using asphalt mastic, peel and stick MB sheets, duct tape, or application of bentonite clay or portland cement powder to limit moisture intrusion. As soon as weather permits temporary or permanent repairs must be made.

(2) Temporary repairs. Patching generally consists of embedding reinforcing fabric into a cold applied asphalt mastic (ASTM D4586). Cleaning and priming of the tie-in area is needed.

(3) Permanent repairs. A durable repair will use the same MB material as in the original membrane torched, mopped, or adhered as appropriate for that material to a properly prepared substrate.

d. Repair Work by User. The occupants should keep compatible mastic, trowels and reinforcing on site for emergency repairs and patching. Torching of MB requires storage of propane fuel (which is a fire hazard), appropriate tools, membrane material, fire extinguishers, and trained technicians. Torching is quick and very effective when done properly. Training may be provided by MRCA certified trainers.

e. Checklists. Use RIEI or other industry checklists to aid in conducting visual inspections. Perimeters, seams, tee-joints and flashings are high priority items, as are roof drains.

CHAPTER 6

ELASTOMERIC (EPDM) ROOFING SYSTEMS
REFERENCE CEGS 07530

6-1. ELASTOMERIC SYSTEMS.

a. Overview. By definition an elastomer is a material that can be stretched to at least twice its original length and when the deforming force is removed, will return to approximately its original dimensions. These materials are sometimes referred to as *rubber* or *vulcanized thermosets*. Of the elastomers used in membrane roofing, EPDM (originally ethylene propylene-diene *monomer*, now *terpolymer*) (ASTM D4637) rubber is by far the most popular today. Others that have occasional use include neoprene (chloroprene), butyl (IIR) and polyepichlorohydrin (ECO). These elastomeric membranes are true single-ply systems. The polymer is factory compounded with carbon black, other fillers, oils, processing aids, fire retardants, and curatives and formed into sheets. Commonly, roll widths are further processed into large tarpaulins and then vulcanized. EPDM is neither remeltable nor recyclable. In the field the giant rolls are unrolled over a suitable substrate, seamed to adjacent sheets, and flashed. Because of high elasticity, EPDM roofing can be applied as a loose-laid or partially- attached system in addition to being fully adhered. The carbon black provides reinforcement for the polymer as well as UV protection. EPDM membranes may be unreinforced or have internal scrim reinforcement. (Scrim reinforcement is used in mechanically fastened systems.) Typical product thicknesses are 1.1 mm (0.045 in.), 1.5 mm (0.060 in.), and 2.2 mm (0.090 in.). Black is the most durable color but white is available for special purposes. Fire retarded sheets are also available.

b. General. While EPDM sheets are waterproof, seams may be moisture sensitive. The roof must have positive drainage; seams should not buck water.

(1) Installation. Key steps in installation include hoisting the heavy rolls to the roof, unrolling, allowing the membrane to *relax* (to relieve winding stresses), and then:

(a) Attaching it to the substrate with *adhesive* followed by seaming sheets together and flashing the system, or . . .

(b) *Mechanically attaching* the membrane to the substrate followed by seaming and flashing, or . . .

(c) Seaming the loose sheets together securing them at the perimeter and at penetrations, flashing the system, and then *ballasting* the loose-laid membrane to resist wind forces.

(d) Application. Application instructions are provided in industry literature. Field quality assurance should verify that they are followed.

(2) Substrates. Suitable substrates for adhered systems include solvent resistant thermal insulation boards (i.e., not polystyrenes) and most flat decks. Polystyrene insulation is used for loose-laid systems.

(3) Climate/Weather. During installation, rubber sheets require clean, dry substrates and above freezing temperatures. Excessive wind will make application difficult. Loose-laid membranes require temporary ballast to prevent blow-off until all ballast is placed. Ballasting may be done in inclement weather. Black EPDM is very hot to work on under the summer's sun.

(4) Logistics. EPDM rolls tend to be wide and heavy; in some cases they weigh a ton or more. Proper hoisting equipment is essential, and once hoisted the rolls should be supported so as to avoid localized overloading of the deck. Adhesives may be flammable and the quantity stored on the roof should be limited to the day's needs.

(5) Familiarity with the System and Site. EPDM is well known by many commercial roofing contractors. Only *manufacturer-approved* contractors should install these systems. All membrane components should be from a single source. Since primers and adhesives use toxic, flammable solvents, avoid fume intake into the building's air handling system.

(6) Life Expectancy. EPDM systems typically last 15 or more years although some have had seam and flashing problems much sooner. Wind erosion of ballast and shrinkage problems occur on occasion.

(7) Costs. EPDM systems are very cost effective on both initial and life cycle bases. Ballasted systems using MEPS (molded, expanded polystyrene) insulation are one of the most cost-effective membrane roof systems, especially on roofs where there are few penetrations. Fire retarded (FR) EPDM is more expensive and is used in unballasted systems only. (The rock ballast protects the non-FR EPDM membrane against external fire exposure.)

6-2. BUILDING ELEMENTS.

a. Slope. A minimum slope of 2% (1/4 in./ft.) is required.

b. Low-Sloped Roofs. Moisture and vegetation attack can occur where water ponds and root growth occurs. Laps joined together with self-adhesive tape are more resistant to moisture than seams made with liquid neoprene or butyl adhesives.

c. Steep Roofs. At slopes above 16.7% (2 in./ft.), ballasting is no longer feasible. Mechanically attached and fully adhered systems have been used on barrel vault and folded plate roofs. Mechanically attached systems should not be used on steep roofs in windy areas.

d. Structural Considerations. Ballasted EPDM systems are heavy with ballast at 49-108 kg/m^2 (10-22 psf) depending upon expected wind force. Mechanically fastened membranes weigh approximately 5-10 kg/m^2 (1-2 psf). They are subject to wind flutter and increased fastener density is required at corners and perimeters. The heavy EPDM rolls require appropriate hoisting equipment. Dunnage should be used to distribute the weight so that the structure is not overloaded.

e. Expansion Joints, Seismic Joints and Area Dividers. Joints should be located at high points where practicable, and placed on curbs above the water line. Expansion joints should be provided only at each expansion joint in the structure. Structures need expansion joints at intervals not over 60 m (200 ft.) in length or width. If a structure does not contain enough expansion joints, it is inappropriate to solve that problem by just adding expansion joints to the roof system. Joints should also be used at changes in deck direction or material. Because of the flexibility of EPDM, the membrane material (supported by flexible foam) is sometimes run directly over the curbs of the joint without a change of material. Raised joints should be used rather than flush joints at water level.

f. Re-entrant Corners. EPDM systems require no special treatment.

g. Roof Access. Roof access is essential to maintenance and inspection functions; however, unauthorized access should be controlled (provided that it does not interfere with means of egress in an emergency). Heavily trafficked areas should use either pavers installed over protective matting or rubber walkways.

h. Roof Venting. Roof vents have been proven to be of no value in drying wet materials and their efficacy for pressure relief is questionable. However, pressure-reducing vents have been used in single- ply systems to reduce under-membrane uplift pressure.

i. Roof Decks.

(1) Uninsulated Decks.

(a) For adhered membrane systems, non-combustible/non-nailable decks such as poured and precast concrete must be cured and dry. If moisture collects on the underside of a piece of glass or loose membrane placed on the deck, the deck is too wet. The deck must be free of grit or sharp edges, which could cut the membrane. The adhesive may require a special primer.

(b) If insulation is not used, non-combustible/nailable decks such as precast lightweight planks and poured gypsum require a slip-sheet and a mechanically fastened system using fasteners designed for that deck type.

(c) Combustible/nailable decks such as wood, plywood, and OSB require adhered or mechanically fastened systems as the decks are unlikely to support the weight of ballast.

(2) Insulated Roofing Systems.

(a) For adhered membrane systems insulation may be attached to the deck with bitumen, special adhesives, or more typically with mechanical fasteners.

(b) For mechanically attached systems each insulation board should receive a minimum of two *preliminary* fasteners in addition to those used to secure the membrane.

j. Vapor Retarders. Two plies of bituminous felt mopped to the substrate and each other provide an excellent vapor retarder for non-combustible decks. Where bitumen is to be avoided, metal foil, kraft paper laminates, or plastic films (i.e., polyethylene sheeting meeting ASTM D4397) with taped laps may be suitable following the recommendations of the manufacturer. When a roof system is used as the cover of a freezer or cooler building a severe reverse vapor drive occurs. Vapor pressure is higher outside the building and the primary vapor drive is towards the colder interior. EPDM is only a fair vapor retarder. A foil layer with taped seams placed directly beneath the EPDM sheet reduces permeance. Vented edges and roof vents should be avoided. The EPDM membrane or underlying foil film needs to be completely sealed to the wall vapor retarder system. It may be better to separate the cooler or freezer from the roof system by at least a 600 mm (2 ft.) air space. The vapor retarder for the cooler or freezer is then placed on the exterior of the freezer box facing the air space. Bare, black EPDM (or any other bare membrane) should not be used in coolers or freezers due to the high solar load.

k. Thermal Insulation and Heat Flow.

(1) Polyisocyanurate Insulation. For adhered systems the facers must be well adhered to the isoboard and compatible with the bonding adhesive used. The EPDM membrane manufacturer should specifically approve the faced insulation.

(2) Wood Fiber and Perlite Board. For adhered membranes wood fiber may be an acceptable substrate. Perlite board is generally unacceptable due to its lower peel strength.

(3) Thermoplastic Foams. For ballasted membrane systems polystyrene foam (MEPS or XEPS) with a minimum density of 16 kg/m^2 (1 pcf) should be used.

(4) Thermal Bridging. When mechanical fasteners are used to secure the membrane there is some conductive heat flow through the fasteners. This is obvious on a roof with frost or light snow, and in a colder climate can lead to condensation, corrosion, or wind blow-off problems. Such systems should not be used for high humidity buildings in cold regions.

l. Membranes and Surfacings.

(1) EPDM Membrane. The most common membrane used in ballasted systems is 1.1 mm (0.045 in.) black, unreinforced EPDM. Reinforced EPDM with a minimum of 0.38 mm (0.015 in.) of polymer coating over the scrim is required for all mechanically fastened systems. Thicker membranes are more durable and less likely to wrinkle when installed in fully adhered systems. ASTM D4637 covers EPDM sheeting material and ASTM D4811, nonvulcanized rubber used in some flashing applications.

(2) Surfacing. EPDM membranes have excellent weather resistance and need no surfacing. While white EPDM may be available the durability is considered inferior to that of black. It is more cost effective to add additional thermal insulation to a black membrane system to conserve energy than to rely on white rubber to reduce solar loads or to attempt to apply reflective coatings to black rubber. When ballasted, EPDM rubber needs no fire retardant. Expensive fire retarded (FR) EPDM is necessary to meet most fire requirements for unballasted applications.

m. Penetrations and Flashings. Flashing, perimeter securement, and detailing of EPDM systems is critical. Construction detail plates are available from the NRCA, SMACNA, and individual manufacturers. Pipe flashings are handled by using molded boots that are clamped to the penetration and bonded to the membrane. Pitch pockets are filled with a compatible, curing pourable sealer (non-bituminous).

n. Historical Roof Restoration. EPDM membranes may be very useful in historical renovation. Adhered and mechanically fastened systems are light in weight and very versatile.

o. Aesthetics. In typical low-slope applications aesthetics is rarely of concern. Ballast and pavers are relatively attractive with some color choices available. Black membranes are acceptable but not overly pleasing. EPDM membranes can be converted into PMR's, or plaza decks, when combined with extruded polystyrene, filter fabric, and ballast.

p. Gaps, Flashings, Joints, and Sealants

(1) Gaps. Spaces in the substrate wider than 6 mm (1/4 in.) should be filled in with thermal insulation by inserting pieces of insulation or replacing broken boards. Gaps in uninsulated nailable decks are bridged with sheets of galvanized steel.

(2) Flashings and Termination Bars. Flashings for EPDM systems do not require cant strips to reduce the angle at the base of the wall or curb. Termination bars are required to secure the flashing membrane at the top of the wall or curb. Manufacturer details, modified to specific job conditions, should be followed. Perimeter restraint is necessary to minimize the potential for shrinkage.

(3) Sealants. Sealants are used primarily within seams and at exposed lap edges in adhesive systems, and to seal the interface between termination bars and vertical walls.

q. Drainage, Valley and Intersection Details.

(1) Drains. Roof drains should be sized to meet the National Plumbing Code. Secondary (overflow) drains or scuppers should be designed in accordance with ANSI/ASCE 7-95. Over-the-eaves drainage is acceptable in areas where ice dams are not expected. Interior drains avoid drain and leader freeze-up. Primary roof drains should be recessed below the roof line by using deck sumps (uninsulated decks) or by creating a sump out of roof insulation in order to properly collect water.

(2) Drain Clamps. The roof membrane is bonded to the drain bowl using *water cut-off mastic* where the clamping ring compresses the membrane.

(3) Ballast Retention. Ballast retainers may be installed around drains. Special perforated metal ballast retainers are used to retain ballast at eaves and scuppers.

(4) Valleys, Crickets, Saddles. Valleys are fabricated out of membrane material. Keep membrane seams out of the low point of the valley. Crickets and saddles help divert water to the drains. Refer to NRCA details for their design.

6-3. DESIGN CONSIDERATIONS AND ALERTS.

a. Attachment. Adhered systems are practical for sloped roofs where ballast is impractical or where ballast weight is unacceptable. Mechanically fastened systems are usually intermediate in price and labor intensity between fully adhered and ballasted systems. Each insulation board on a mechanically fastened system should have a minimum of two fasteners installed (called preliminary fastening) before the membrane is fastened. This keeps the boards from shifting. Anchorage at roof edges is critical to resist membrane shrinkage as well as wind flutter. Nailers and nailer installation should be anchored to meet the wind uplift requirements of Factory Mutual (FM) Class 1-60, 1-90 or higher, and ANSI/SPRI RP-4 recommendations (Appendix 6-1). The perimeter nailer installation must be in accordance with Factory Mutual (FM) Loss Prevention Data Sheet 1-49 entitled, *Perimeter Flashing*.

b. Phased Construction. Since this is a single-ply system, membrane phasing is not possible. However, edges of completed work need to be sealed at night to prevent water entry. Temporary ballast needs to be replaced with properly distributed final ballast as expeditiously as possible.

c. Protective Walkways. Walkways are needed if more than occasional roof traffic is expected. These may be rubber pads partially bonded to the membrane, wood duck boards on wood sleepers, or concrete pavers. Boards, sleepers, and pavers must be installed over protective fabric, shims, or extra membrane for puncture protection. Thicker membranes provide added puncture resistance. Pavers should be a minimum of 38 mm (1-1/2 in.) thick and 21 MPa (3000 psi) minimum compressive strength, air entrained freeze-thaw resistant concrete.

d. Contamination. EPDM should not be used in areas exposed to asphalt, coal tar, grease, oil, solvents, vegetable or mineral oil, animal fat, or steam venting. An oil resistant coating may be used where the roofing will be exposed to petroleum, grease, oil, or solvents. Some manufacturers recommend the use of neoprene or epichlohydrin membranes for difficult areas. Fleece-backed sheeting is used to separate EPDM from underlying bitumen.

e. Wind Design. Follow ANSI/SPRI-4 for ballast guidelines. Stone or paver ballast may be used in the vicinity of aircraft operations as it is much bigger than the pea size stone ballast allowed in BUR surfacing and thus much more resistant to winds. For mechanically fastened systems, reinforced EPDM is required. Increased fastener density is required in corners and perimeters. Follow SPRI *Wind Design Guide for Edge Systems Used With Low-Slope Roof Systems*.

6-4. CONSTRUCTION CONSIDERATIONS.

a. General. Materials, including accessories, must be delivered to the job site in the manufacturer's original unopened packages clearly marked with the manufacturer's name, brand name, and description of contents.

(1) Temporary Ballast. For loose-laid systems temporary ballast may be needed to protect work until final ballast can be installed.

(2) Protection. Avoid traffic over the recently completed membrane. Use a protective mat over the membrane if crushed rock is used in lieu of rounded river gravel as ballast.

b. Pre-roofing Conference. A conference should be held prior to construction. Fire safety with combustible adhesives and fume control should be discussed. Discuss construction of water cutoffs to be used at membrane terminations at the end of a day's work to seal the roofing system from water intrusion.

c. Shop Drawing Submittals. Drawings of flashings, edge restraints, and other critical items should be provided. These should be detail specific and dimensioned not the manufacturer's standard detail plates. Spacing of fasteners for termination bars and types of fasteners appropriate for the substrate being anchored to should be shown. For mechanically fastened systems, layout of fastening to comply with required wind resistance should be provided. Require Material Safety Data Sheets (MSDS) for adhesives and primers.

d. Design Submittal Requirements and Checklist.

(1) Manufacturer Assurance. Require manufacturers to verify in writing that the proposed system is compatible with the roof deck, vapor retarder, fasteners, and insulation and is appropriate for this specific application.

(2) Application Manual. Require submittal of foreman's application manual. Discuss any planned deviations.

e. Field Review and Observation.

(1) Inspection. Full time visual inspection by qualified field inspectors is recommended. On large projects require that the manufacturer's technical service representative be present at startup to train inspectors and installers. A copy of the foreman's handbook should be provided to the field inspector.

(2) Layout Placement of each membrane panel should be recorded on a roof plan for future reference. Verify that each panel is identified as fire rated (FR) if such a rating is called for. Note whether additional fastening or ballasting is being done in corners and perimeters.

(3) Protection. It is easy to puncture an elastomeric membrane during ballasting if heavy buggies run over pieces of stone.

(4) Ballasting. Measure ballast load as ballasting proceeds. Adjust the ballast to stay within 10% ± of the required load.

6-5. MAINTENANCE CONSIDERATIONS.

a. General. EPDM is very weather resistant but is attacked by solvents, greases, oils, and fats. Mechanical equipment that exhausts such material must be modified to collect the contaminants. If this is impossible, replace the degraded EPDM in these areas with a manufacturer recommended chemically resistant system such as polyepichlorohydrin or neoprene. Avoid bituminous repair materials. Follow the procedures in the joint NRCA/ARMA/SPRI and RIEI maintenance manuals.

b. Repair or Replace. To endure, EPDM repairs must be carefully done. Surface oxidation and dirt must be abrasively removed and the area washed and primed. New membrane material is installed in adhesive or tape**.** Shrinkage problems are handled following NRCA/MRCA recommendations: *Repair Methods for Re-Attaching EPDM Membrane and Flashing Experiencing Shrinkage*. This provides for cutting the membrane loose where bridging or wrinkling has occurred, reattaching the membrane, splicing-in extra membrane material, and resealing the system.

c. Repairs: Emergency, Temporary, and Permanent. (Refer to NRCA/ARMA/SPRI Manual)

(1) Emergency repairs. Repairs can be made using peel and stick elastomeric materials, duct tape, or even asphalt mastic. If asphalt mastic is used the contaminated area will have to be replaced when making a permanent repair.

(2) Temporary Repairs. If appropriate manufacturer approved EPDM materials are used and surfaces are properly prepared, temporary repairs will be permanent. If termination bars are pulled away from the wall or if sealant has failed, re-anchor the bar and apply sealant. Manufacturer supplied sealant is not required since the bar is in contact with the wall, not the EPDM membrane.

(3) Permanent Repairs. Open seams, punctures, and defective *tee-joints* can be covered with a new membrane material using manufacturer supplied primer, adhesive (or tape), and membrane.

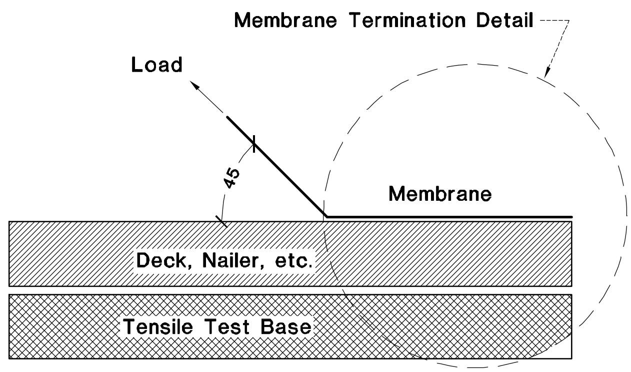
d. Repair Work by User. Use compatible materials; avoid bituminous materials. Authorized contractors should make leak repairs while the roof is under warranty. Since some repair materials (adhesives, uncured flashing) have limited shelf life, it may be better to establish a source of fresh material than to store materials on site.

e. Checklists. Use RIEI or ROOFER checklists for visual inspections. Perimeters, seams and flashings are high priority items as are roof drains.

Appendix 6-1. SPRI Test Method RE-1

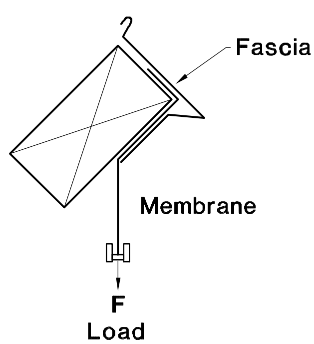
Test for Roof Edge Termination of Single-Ply
and Modified Bitumen Roofing Materials.

The method with which the edge of the roof membrane is terminated (gravel stop, nailer, or other) is the last anchor point to hold the membrane in place should the membrane happen to separate from the roof deck during a high wind. When this happens, the roof system will put a load on the termination. For this reason, the termination must withstand a minimum force of 1.46 kN/m (100 lbs/ft.) when testing using the following method.



A 305 mm (12 in.) wide mock-up of the termination system should be constructed and mounted on the base of a tensile testing device so the membrane is pulled at a 45 degree angle to the roof deck to simulate a billowing membrane.

Fascia Membrane Termination
Test Set Schematic
(Force = F = 445 N or 100 lbf)



The jaws of the tensile tester are connected to two bars which clamp the membrane securely between them so that the load is distributed uniformly along the width of the membrane. The tensile tester is loaded until failure occurs. Failure is defined as any event which allows the membrane to come free of the edge termination or the termination to come free of its mount.

The roof edge termination strength is satisfactory if the test force at failure on a 305 mm (12 in.) wide sample exceeds 445N (100 lbf).

CHAPTER 7

WELDABLE (THERMOPLASTIC) ROOFING SYSTEMS
(including PVC, CSPE, TPO)
REFERENCE
07548 (Polyvinyl Chloride [PVC] Roofing Only)

7-1. OVERVIEW OF WELDABLE SINGLE-PLY SYSTEMS. Thermoplastics are materials that soften when heated and regain their physical properties upon cooling. They are appealing in a roofing system because once the seams are properly welded they are waterproof and permanent. Among the earliest thermoplastic polymers used in membrane roofing were Poly(vinyl)chloride (PVC), Chlorinated Polyethylene (CPE), and Chlorosulfonated Polyethylene (CSPE or Hypalon®). More recently the weldables have been expanded to include thermoplastic polyolefins (TPO's), ketone ethylene esters (KEE) and various polymer blends. To date, ASTM has published two thermoplastic single ply material specifications: D 4434 for PVC material and D5019 for Hypalon® CSPE and Polyisobutylene ((PIB). Two recommended practices, D5036 *(Application of Fully Adhered Single-Ply PolyvinylChloride Roof Sheeting),* and D-5082*, (Application of Intermittently Attached Single-Ply Poly(vinylchloride Sheet Roofing*) are also available. Other material standards and recommended practices for thermoplastic roofing are in preparation. During the manufacture of weldable single-ply membranes thermoplastic polymers are blended with pigments, stabilizing agents, plasticizers, and processing aids, laminated with reinforcements and formed into machine-width sheets. They are then rolled up as relatively narrow rolls, or in a few instances, factory joined into large tarpaulins and shipped to the roofing site ready to be installed. In the field they are unrolled over a suitable substrate, allowed to relax to eliminate winding stresses, seamed by heat fusion, flashed, and are immediately ready for the weather. Because of their flexibility they can be mechanically attached or fully adhered. Loose laid systems, while once quite popular (using unreinforced sheets), are rarely used today. Most of the weldable thermoplastic roofing systems are compounded to white or other light colors to reduce solar heat gains. Pigments may be combinations of *chalking* materials, which gradually wash off to help maintain reflectance and nonchalking pigments for greater durability. Thermoplastics may be recyclable. Current thermoplastic systems have internal scrim reinforcement. Typical thickness of the membrane sheet is 1.14 mm (0.045 in. [i.e., 45 mil] although, products range from 0.91 mm (0.036 in.) to 2.4 mm (0.095 in.). The minimum coating or laminate thickness above the cross points of fabric should be 0.40 mm (0.016 in.).

a. General. While prefabricated single-ply membranes are waterproof when manufactured they should be sloped to drain. Water flow should be away from field seams.

(1) Installation. Key steps in installation include hoisting the rolls to the roof, unrolling, allowing the membrane to *relax*, and then:

(a) Attaching to the substrate with adhesive, seaming sheets together and flashing, or

(b) Mechanically attaching the membrane to the substrate, seaming and flashing.

(c) Application instructions are provided in industry literature (ASTM D5036, D5082) and should be verified by field quality assurance.

(d) Seam welds are accomplished with hand or machine hot air welding. Solvent welding that was popular in the past is no longer common. Welds should be tested periodically during installation to verify that they are adequate.

(2) Substrates. Suitable substrates for adhered systems include solvent resistant thermal insulation boards (i.e., not polystyrenes) and most flat decks (plywood, OSB, structural concrete).

(a) For mechanically anchored systems both expanded and extruded polystyrene foam insulation may be used. However, an overlay of rigid fiberboard is recommended to avoid relaxation of the foam with the loss of screw compression.

(b) Plasticized PVC should not be used in direct physical contact with EPS insulation, asphalt, coal tar pitches, petroleum products, or where coal tar fumes are present. Approved separator/slip sheets are recommended.

b. Climate/Weather. Thermoplastic sheets require clean, dry substrates during application. Excessive wind can make application of the light, flexible sheets difficult. Hot air welding may compensate for damp or cool membrane conditions. Automatic seam welders that monitor the temperature of the weld help insure proper welds.

c. Logistics. Weldable thermoplastic rolls are usually not shipped in rolls wider than 2 m (80 in.), although a few products are custom fabricated into large roof panels. Rolls or panels should be protected from distortion by following the manufacturer's recommended storage and hoisting procedures. Welding machines require adequate and consistent voltage. Generators provided by the contractor may be required rather than using building power.

d. Familiarity with the System and Site. Weldable thermoplastic membranes are understood by most commercial roofing contractors. Only *manufacturer-approved* contractors should install these systems, and all components should be from a single source. Since deck primers and adhesives may use toxic or flammable solvents, avoid fume intake into the building's air handling system. Heat welding can also create noxious odors.

e. Life Expectancy. Well constructed weldable thermoplastic systems typically last 15 years or more. Some flashing maintenance and repairs are to be expected during this period. Past problems with membrane shrinkage and embrittlement are no longer of great concern.

f. Costs. Weldable systems are cost effective on both initial and life cycle bases. While materials are more expensive than asphaltic roofing, labor is generally less.

7-2. BUILDING ELEMENTS.

a. Slope. A minimum slope of 2% (1/4 in./ft.) is required.

b. Low-Sloped Roofs. Moisture and vegetation attack can occur where water ponds and roots grow. Properly welded seams are resistant to moisture attack.

c. Steep Roofs. Mechanically attached and fully adhered systems have been used at all slopes. Mechanically attached systems should not be used on steep roofs in windy areas.

d. Structural Considerations. Mechanically fastened membranes are subject to wind flutter and increased fastener density is required at corners and perimeters. The deck must be suitable to receive fasteners. Anchorage of nailers must meet FM 1-49 (Perimeter Flashing) recommendations.

e. Expansion Joints, Seismic Joints, and Area Dividers. Joints should be located at high points where practicable and placed on curbs above the water line. Expansion joints should be provided only at each expansion joint in the structure. Structures need expansion joints at intervals not over 60 m (200 ft) in length or width. Joints should also be used at changes in deck direction or membrane materials. If a structure does not contain enough expansion joints it is inappropriate to solve the problem by just adding expansion joints to the roofing system. Area dividers do not provide for movement but are useful in subdividing big areas into isolated, smaller areas, each of which can be roofed (and maintained) separately.

f. Re-entrant Corners. Expansion joints should be used strictly as the structure demands. Single ply systems have adequate elongation and flexibility to withstand typical stress concentrations found at re-entrant corners. Area dividers may be preferred to serve as permanent physical separators between this particular membrane and other membrane materials such as BUR, SPF, MB or EPDM.

g. Roof Access. Roof access is essential to maintenance and inspection functions; however, unauthorized access should be controlled. Heavily trafficked areas should have walkways or pavers installed over protective matting.

h. Roof Venting. Roof vents have been proven to be of no value in drying wet materials and their efficacy for pressure relief is questionable. However, pressure-reducing vents have been used in single-ply systems vents to reduce under-membrane uplift pressure. They are only effective if the substrate is airtight.

i. Roof Decks.

(1) Uninsulated Decks.

(a) Non-combustible/non-nailable decks such as poured and precast concrete should be cured and dry (28 day dry). Test for dryness by placing a piece of glass or membrane material on the deck. If moisture collects on the underside, the deck is too wet. Primer is used to promote adhesion and to penetrate dirt and dust. A fleece backed membrane is more suitable over rough substrates. Some specifications allow hot asphalt in lieu of solvent adhesives.

(b) Non-combustible/nailable decks such as precast lightweight planks and poured gypsum require fasteners designed for that deck type.

(c) It may be necessary to tape or grout deck joints to provide a smooth substrate.

(d) Combustible/nailable decks such as wood, plywood and OSB accommodate either adhered or mechanically fastened systems.

(2) Insulated Roofing Systems.

(a) Insulation may be attached to the substrate with bitumen, special adhesives, or mechanical fasteners. Care must be taken not to spill asphalt on the single-ply membrane, nor to traffic on it with work boots or equipment.

(b) Insulation should be divorced from moisture bearing wet fill decks by the use of a nailed base sheet. Some plasticized thermoplastic membranes require a divorcing *slipsheet* between the top surface of the insulation and the membrane (if that surface contains asphalt or if the insulation is unfaced polystyrene).

j. Vapor Retarders.

(1) Installation. Two plies of bituminous felt mopped to the substrate and to each other provide an excellent vapor retarder for non-combustible decks. Where bitumen is to be avoided, metal foil, kraft paper or plastic films (i.e., 4 mil polyethylene) with taped laps may be suitable following the recommendations of the manufacturer.

(2) Coolers and Freezers. When a roof system is used as the cover of a freezer or cooler building a severe reverse vapor drive occurs. Vapor pressure is higher outside the building and the primary vapor drive will be towards the colder interior. Most thermoplastic membranes are only poor vapor retarders, especially if mechanically attached where moist air can migrate laterally. Thicker membranes would have lower permeance, or it may be feasible to install a foil layer with taped seams

beneath the single-ply membrane. Vented edges and roof vents should not be used. The single-ply membrane or foil underlayment needs to be hermetically sealed to the wall vapor retarder system to be effective. It may be better to separate the cooler or freezer from the roof system by at least a 600 mm (2 ft.) air space. The vapor retarder for the cooler or freezer is then positioned on the exterior of the freezer box facing the air space.

k. Thermal Insulation and Heat Flow.

(1) Polyisocyanurate (ASTM C1289) Insulation. For adhered systems the facers must be well adhered to the isoboard and compatible with the bonding adhesive used.

(2) Wood Fiber and Perlite. For adhered membranes wood fiber (ASTM C208) may be an acceptable substrate. Perlite board is generally unacceptable when solvent-based adhesives are used, due to its lower peel strength.

(3) Thermoplastic Foams. Polystyrene foam (MEPS) (ASTM C578) with a minimum density of 16 kg/m^3 (1 pcf) or XEPS should be used. Plasticized PVC membranes require a separator layer.

(4) Thermal Bridging. When mechanical fasteners are used to secure the membrane there is some conductive heat flow through the fasteners. This is obvious on a roof with frost or light snow and, in a colder climate, might lead to condensation or corrosion problems.

l. Membranes and Surfacings. Thermoplastic membranes are compounded for weather resistance. Most thermoplastics should not require coating during their lifetime. However, some Hypalon® sheets have been observed to chalk and craze excessively. Special surface preparation and the use of primers and coatings may extend their life and reflectivity.

m. Penetrations and Flashings. Flashing, perimeter securement, and detailing of thermoplastic systems is critical. Construction detail plates are available from the NRCA, SMACNA, and individual manufacturers. Pitch pockets and pipe flashings are handled by using molded boots that are clamped to the penetration and welded to the membrane or by field fabrication. Since contact with bitumen must be avoided, pourable sealers should be non-asphaltic. Polymer-coated galvanized steel is used as flashing in some systems. The field membrane sheet is heat welded directly to the coated flashing metal.

n. Historical Roof Restoration. Single-ply membranes may be used in historical renovations. The very light weight of single-ply adhered and fastened systems may be useful in reroofing historically significant buildings that have only marginal load capacity. Pavers installed on pedestals or fleece pads provide an attractive appearance for pedestrian ways.

o. Aesthetics. In typical low-slope applications aesthetics is rarely of concern. Exposed light colored membranes are reflective but because they are so thin and flexible they telegraph irregularities in the substrate. On highly visible applications special attention must be given to smoothing of the substrate. Thermoplastic membranes in various colors have been used to give domed stadiums very distinctive roofs.

p. Gaps, Flashings, Joints, and Sealants.

(1) Gaps. Gaps in insulation in excess of 6 mm (1/4 in.) should be filled in with thermal insulation by inserting pieces of insulation replacing broken boards or taping joints. Gaps in nailable decks are bridged with sheets of galvanized steel.

(2) Flashings. Flashings for single-ply systems do not require cant strips to reduce the angle at the base of the wall or curb. NRCA details, modified to specific job conditions, should be followed. Base flashings should extend not less than 200 mm (8 in.) above the roofline. Special polymer coated metals may be used as base flashing and roof edging. Anchorage must be adequate to resist wind

loading and shrinkage forces. Refer to *membrane termination* requirements provided by ANSI/SPRI RP4. Proprietary metal gravel stops should be used. Follow industry details.

(3) Expansion Joints. Because of the flexibility of thermoplastic membranes, the membrane material (supported by flexible foam) is sometimes run directly over the curbs of the joint without a change of material. Raised joints should be used rather than flush joints at water level.

(4) Sealants. Sealants are used primarily at seam edges and to seal the interface of termination bars and vertical walls. Only compatible materials should come in contact with the membrane.

q. Drainage, Valley and Intersection Details.

(1) Drains. Roof drains should be sized in accordance with plumbing codes. Secondary (overflow) drains or scuppers should be designed in accordance with ANSI/ASCE 7-95. Peripheral drainage is acceptable in areas where heavy ice buildup is not expected. Interior drains avoid drain and leader freeze-up. Primary roof drains should be recessed below the roof line by using deck sumps (uninsulated decks) or by creating a sump out of roof insulation in order to properly collect water. The roof membrane may be bonded to the drain bowl using specified adhesives or welded to a special polymer coated metal drain flange.

(2) Valleys and Crickets. Valleys and intersections are fabricated out of membrane materials. Crickets and saddles help divert water to the drains. Refer to NRCA details for saddle design.

(3) Intersections. Building intersections benefit by the use of expansion joints or area dividers.

7-3. DESIGN CONSIDERATIONS AND ALERTS.

a. Attachment. Single-ply membranes do not require attachment to the substrate; however, adhered systems are convenient for steeply sloped roofs. Mechanically fastened systems are generally less labor and material intensive than fully adhered systems. Anchorage at roof edges is critical to resist membrane shrinkage as well as wind flutter. Nailers and nailer installation should be anchored to resist the wind uplift of Factory Mutual (FM) 1-60 or 1-90 (or higher). The perimeter nailer installation must be in accordance with Factory Mutual Loss Prevention Data Sheet 1-49 entitled, *Perimeter Flashing* and ANSI/SPRI RP-4 recommendations (Appendix 6-1).

b. Phased Construction. All components, from the thermal insulation through completed membrane, should be completed in a single day. Edges should be sealed at the end of a day's work to preclude moisture penetration.

c. Protective Walkways. Walkways are needed if more than occasional roof traffic is expected. These may be proprietary plastic pads partially bonded to the membrane, or wood duck boards/concrete pavers installed over protective fabric, shims, or extra membrane.

d. Compatibility. Thermoplastic sheets containing plasticizer need a separator layer when installed over polystyrene insulation or insulations containing bitumen. In re-cover or reroofing separation from bitumen-contaminated walls and penetrations may require refacing the contaminated surface with plywood, using fleece backed sheets, polymer-clad metal base flashings, or using bitumen-resistant sheets where needed i.e., at drain flashings.

7-4. CONSTRUCTION CONSIDERATIONS.

a. General. Thermoplastic membranes require special heat welding equipment. Contractors may need to use portable generators to obtain adequate electrical power.

(1) Vapors and Fumes. Solvent-based adhesives (for fully adhered systems) are flammable and their odor may be objectionable to occupants. Shut off air intakes or take other preventative measures to avoid fumes entering occupied spaces.

(2) Contamination. Avoid contamination of work in progress and finished work by wind blown particulates, especially from aggregate removal on adjacent areas.

b. Pre-roofing Conference. A conference should be held prior to construction. Representatives of the designer, user, roofing contractor, general contractor, materials manufacturer, field inspector and other related subcontractors should be present. Discussions should include protection of the thin membrane after installation and how nightly water cutoffs will be.

c. Shop Drawing Submittals

(1) Drawings. Drawings of intersections of expansion joints, curbs, edging, flashing, and coping should be required especially when polymer clad metal is used. Details should be detail specific and dimensioned not the manufacturer's standard detail plates.

(2) Layout Diagram. Since some of these products are available in fire rated (FR) and non-fire rated sheeting, determine which is needed for each roof area and include layout on shop drawing. (Generally FR will be required on steeper slopes.)

(3) Nailers. Nailers must be anchored to resist 270 N/m (200 lb/ft.) for adhered thermoplastic systems and 300 N/m (300 lb/ft) for mechanically anchored systems. Submit details of how this will be achieved (dimensions of nailers, frequency and size of fasteners). Anchorage should meet the greater of the above requirements and FM 1-49 (Perimeter Flashings) recommendations.

d. Design Submittal Requirements and Checklist. Require the manufacturer to verify in writing that the proposed system is compatible with the roof deck, vapor retarder, insulation, and is appropriate for this specific application. On major roofing projects require quality assurance inspection. Require evidence of compliance with fire ratings, wind loads, or other specified code requirements.

e. Field Review and Observation.

(1) Inspection. Each of the various thermoplastic systems has special application techniques. On large projects, representatives of the manufacturer should be present to verify application techniques and to train the inspector. The manufacturer foreman's manual should be provided to the field inspector.

(2) Welds. Daily field tests of welded seams are recommended.

(3) Nailers. Nailers must be installed as specified.

(4) Stress Relaxation. Before it is attached, the membrane must be unrolled and allowed to relax for at least 1/2 hour when the ambient temperature is above 15°C (60°F) and up to 2 hours at lower temperatures.

(5) Finished Work Protection. Prevent tracking of bitumen onto new membrane from wheeled roof equipment or roofer's boots.

7-5. MAINTENANCE CONSIDERATIONS.

a. General. Thermoplastic single-ply membranes are designed for weather resistance and do not require coating during their life. (Some CSPE sheets have suffered algae attack and may show crazing under field exposure. Primers and coatings may help.) Exhausted solvents, oils, particulates, hot air, or steam will damage most thermoplastic membranes.

b. Repair or Replace. Most thermoplastic membranes are reweldable throughout their life. (However, CSPE cures and is more difficult to patch.) Repairs require compatible material preferably from the same manufacturer as well as suitable heat welding equipment.

c. Repairs. The joint NRCA/ARMA/SPRI and RIEI maintenance manuals provide repair guidelines, as does the literature of individual manufacturers.

(1) Emergency repairs. Use of a peel and stick elastomeric material or duct tape is recommended. Asphalt mastic will serve in an emergency but the contaminated areas will have to be removed to effect permanent repairs.

(2) Temporary repairs. Use of self-adhering butyl tape and other EPDM materials will provide a temporary patch (even though the membrane is thermoplastic and the patch will eventually disbond).

(3) Permanent repairs. Permanent repairs consist of properly welded membrane. If the roof is under warranty an authorized contractor must do the repair work.

d. Repair Work by User. In some cases, membrane manufacturers have trained building maintenance personnel in proper repairs, provided tools and materials, and authorized them to serve as approved contractors. This training program is especially useful at remote sites.

e. Maintenance Checklists. Use RIEI or ROOFER checklists for visual inspections. Perimeter anchorage, flashings, penetrations, and roof drains are high priority items to check since most problems originate there. Pulling of flashings, elevated membrane, and sheet distortion at penetrations may indicate shrinkage. Embrittlement of some plasticized sheets has led to shattering. Refer to the NRCA/SPRI Bulletin (Appendix 7-1) on this subject.

APPENDIX 7-1

SHATTERING OF AGED UNREINFORCED PVC ROOF MEMBRANES
(A Joint Document from the NRCA and SPRI)

This document is based upon information developed through a survey conducted by the National Roofing Contractors Association (NRCA) in an attempt to clarify the incidence of shattering of unreinforced polyvinyl chloride (PVC) roof membranes. In an effort to educate professional roofing contractors, building owners, architects, engineers, roof consultants, sales representatives, material distributors and suppliers, and others with the latest available information on the subject, NRCA and the Single Ply Roofing Institute (SPRI) have developed this joint document, which includes the following sections:

1. Description of the Shattering Phenomenon
2. Membrane Identification
3. Early Warning Signs
4. Cold Weather Precautions

Building owners with an unreinforced PVC membrane roof should determine the manufacturer of the membrane. The manufacturer should then be consulted for specific information regarding maintenance and modifications. If the manufacturer is no longer in business, a professional roofing contractor or qualified individual knowledgeable about the installation and maintenance of PVC roof membranes should be contacted.

> Note: There is no evidence that shattering occurs in reinforced or fiber supported PVC membranes (see definition in Section 2). Reinforced or fiber supported membranes are the type of PVC membranes that are now commonly installed.

If the roof membrane is under a manufacturer's warranty, the building owner should consult the manufacturer for specific information.

> Note: The building owner should be aware of warranty terms and conditions in order to prevent voiding the warranty inadvertently. For example, a warranty may indicate that repairs, alterations, or additions performed without prior approval of the manufacturer will cause the warranty to become null and void.

The following information reflects current knowledge as of September, 1990.

1. Description of the shattering phenomenon

"Shattering" is characterized by a generalized nonlinear fragmentation of the membrane. Each fragment may be a few square feet or a few hundred square feet in total area. Typically, when a shatter occurs, it extends throughout the entire roof area, from one edge or perimeter to the other, and is judged to be nonrepairable. This condition is contrasted with cracking and splitting, which are defined as:

- Cracking: Localized, nonlinear repairable separation of the membrane, with branches.

- Splitting: A single, linear, repairable separation of the membrane.

Cracking and splitting are not addressed in this document.

Shattering may occur suddenly and prior to the onset of noticeable preconditions that warn of the potential for shattering.

Based on the data obtained through the survey, shattering appears to:

- Be related to aged unreinforced membranes, the majority of which were ballasted (see Section 2).
- Occur most frequently in cold weather.
- Be unrelated to membrane thickness.
- Have a median roof age of 8-1/2 years, with a range of 4 to 13 years.

Information gathered to date indicates that only a relatively small number of unreinforced PVC roofs have experienced shattering.

2. Membrane identification

It is important for the building owner to know whether an unreinforced PVC membrane is on the roof, so that proper precautions and maintenance procedures may be followed.

> Note: Unreinforced PVC roof membranes are defined as those containing no internal fabrics or supporting fibers.

If the owner does not have historical records that identify the type of membrane, a professional roofing contractor or qualified individual knowledgeable about the installation and maintenance of PVC roof membranes should be contacted to identify the membrane.

> Note: Professional roofing contractors and qualified individuals should consult with the manufacturer of the membrane for specific recommendations and guidance regarding membrane identification, maintenance, repair, new penetrations, or reroofing. If the manufacturer is no longer available, the contractor should consult with another PVC manufacturer.

Investigations should not be performed in cold weather (see section 4).

3. Early warning signs

Shattering may occur without warning. However, early warning signs may sometimes be present.

> Note: The early warning signs discussed below do not necessarily indicate the roof will shatter. It is also important to note that at this time, no reliable method exists to predict whether any one given roof may or may not shatter.
>
> •Embrittlement: “Embrittlement” describes a condition wherein the membrane has lost flexibility.
>
> •Displaced Wood Nailers, Base Flashings or Metal Flashings: Wood nailers, base flashings or metal flashings that have pulled away from their initial position may be indicative of high membrane stress or building movement. A membrane under high stress may appear to be visibly taut.

PVC roofs, like all roof systems, should be inspected twice a year. At the time of these normal inspections, the presence of the warning signs noted above should be determined. Inspections should occur in the spring and fall, when the ambient temperature falls within the guidelines listed in Section 4.

Inspections should be performed by the membrane manufacturer, a professional roofing contractor or by a qualified individual knowledgeable about the installation and maintenance of PVC roof membranes. As a result of the inspection, small splits (if found) should be repaired and precautions taken where items are identified which could puncture or fall onto the roof (e.g., tree limbs), since these items could initiate shattering.

4. Maintenance and cold weather precautions

According to the survey data, shattering occurs most frequently in cold weather. When the roof membrane is identified as an unreinforced PVC, rooftop traffic should be avoided when the ambient temperature is below approximately 10°C (+50 degrees F).*

If any roof traffic is required (e.g., for membrane investigation or inspection, or service of HVAC or other equipment) at temperatures lower than noted above, on unreinforced PVC membranes, there is a risk of initiating shattering.

If the building owner elects to have any roofing work (reroofing, repair, maintenance) or any other type of work done at temperatures lower than noted above, the building owner is assuming some risk that this activity may initiate shattering.

> Note: Because there is no evidence that reinforced or fiber supported PVC membranes are subject to shattering, cold weather restrictions on rooftop traffic are similar to other membrane systems.

For recommendations regarding reroofing, maintenance, repair, new penetrations or modifications, contact the manufacturer, a professional roofing contractor or a qualified individual knowledgeable about the installation and maintenance of PVC roof membranes.

References:
1. Survey Results, Shattering of unreinforced PVC, July 26, 1990, NRCA.
Note: The survey data have not been verified by third party visual inspection.

Disclaimer: SPRI disclaims any responsibility on behalf of itself, its members, and its agents for any damage to roofing as a result of inspections or for any other cause. SPRI does not make any recommendations on the usage of industry members' products.

*SPRI recommends that the individual manufacturer of the product be consulted for a specific recommendation regarding minimum temperature.

CHAPTER 8

CONSIDERATIONS FOR STEEP ROOFING SYSTEMS
(Shingles, Shakes, Tile and Slate)
REFERENCES
07310 (Slate Roofing)
07311 (Roofing, Strip Shingles)
07320 (Clay Tile Roofing)

8-1. STEEPLY SLOPED ROOFING SYSTEMS.

a. Overview. Watershedding roofing incorporating indigenous materials precedes recorded history. Shedding of water is essential to waterproofness. Slate (ASTM C406) and other stone materials with flat cleavage planes were used as early as the 8th century for roofing. Locally available materials and the use of primitive felling and splitting tools led to the introduction of wood based roofing products. Cedar provides durable shakes and shingles. Where clay is available (figure 8-1), durable clay tile (ASTM C1167) roofing is used. Concrete and fiber reinforced concrete tiles (figure 8-2) serve a similar purpose. Asphalt shingles and roll goods came into wide use when asphalt became readily available as a by-product of petroleum processing. Organic shingles (ASTM D225) are a simple, durable, inexpensive option for steep roofing. Shingles made with glass fiber reinforcing (ASTM D3462) provide better fire ratings and require less bitumen than organic shingles. Asphalt shingles are available in a range of qualities. It is never appropriate or cost effective to purchase low quality shingles. Figures 8-3 and 8-4 list asphaltic roofing products used in steep roofing. Look-alike products that use formed steel, aluminum, and plastic are other steep roof options as are architectural metal panels. Other options for sheds where appearance is not critical include corrugated metal, roll roofing, and the like (ASTM D224, D249 and D371).

b. General. Steep roofing systems require a roof deck (usually solid but occasionally of spaced sheathing). Water-resistant underlayment closes in the building during construction and provides a second line of defense against exterior moisture (e.g., driving rain and blowing snow). Asphalt saturated roofing felt (i.e., ASTM D226 No. 15 felt) is commonly used as underlayment but pervious plastic films and impervious peel-and-stick modified bituminous (MB) sheets (ASTM D1970) are also installed. No. 30 asphalt saturated roofing felt is considered more durable than No. 15 and is recommended for roofing systems with design life in excess of 20 years.

(1) Climate/Weather.

(a) The selection of steep roof systems for each climate category follows hundreds of years of experience. Factors such as hail, intensity of rainfall, heat load, snow, and wind are important. In addition, eave and flashing details vary to accommodate different climate demands. For example, some old shingle roofs in the northeast U.S. use exposed metal sheets at the eaves to reduce the risk of leaks caused by ice dams. More recently such metal has been discontinued in favor of impervious MB sheets placed below the shingles.

(b) Where icings at eaves are of major concern, cold ventilated roofing is recommended. The Council of Forest Industries of British Columbia recommends:

1/ Chimneys should be located at the ridge or gable ends away from possible snow pressure on the slopes.

2/ The steeper the roof the better the performance.

3/ Plumbing pipes should be located on inside walls and should be extended between the rafters and vented at the ridge.

4/ Wide overhangs at the eaves should be avoided as they provide large cold areas for snow and ice buildup.

5/ A strip of metal along the eaves helps shed ice.

6/ Sliding ice and snow are constant hazards and should be given primary consideration in the total building design. Outside doors should not be located at the bottom of a roof slope. Entrances and all pedestrian traffic areas are better situated beneath the gable ends of the roof.

7/ In regions of heavy snowfall, wood shingles and shakes should be installed as a three-layer roof. For shake roofs, two layers of shingles and one of shakes are recommended at the eaves.

8/ Sidelap of wood shingles should be increased to 51 mm (2 in.) instead of 38 mm (1-1/2 in.).

9/ A typical cold roof detail is shown in Figure 8-5.

(2) Logistics. Long ago steep roofs used only local materials. This has changed with the introduction of lighter materials and greater transportation efficiency. However, freight can be a major cost factor with heavier and bulkier products. Loading of a roof and scaffolding for extreme slopes is a design consideration.

(3) Familiarity with the System and Site. Some steep roofing materials (e.g., shingles) are common and well known. Installers need to be experienced in their installation. Valleys, penetrations, and flashings require the most skill. Information on steep roofing systems is readily available from manufacturers and trade associations; especially useful is the *Steep Roofing Manual* from the NRCA.

(4) Product Comparisons. Figure 8-6 compares costs, longevity, and pros and cons of common watershedding roofing systems. Scaffolding for complex and extreme slopes will greatly affect costs.

8-2. BUILDING ELEMENTS.

a. Slope. In wet, cold, or windy climates minimum slopes should be increased.

b. Low-Sloped Roofs. In some cases, lower slopes are permissible when waterproof underlayments are used. These may be self-adhering modified bituminous sheets or overlapping of a field sealed bituminous sheet. Bituminous built-up membranes with mineral surfaced cap sheets are used as underlayment for mortar-set tile roofs.

c. Steep Roofs. At extreme slopes (> 21:12) (e.g., mansard constructions) manual tabbing of asphalt shingles is needed.

d. Structural Considerations. Tile and slate systems are heavy. Lightweight tile systems may be suitable in regions of infrequent freeze-thaw cycling.

(1) Weight of Common Slate and Tile Roofings.

Table 8-1. Weight of Common Slate and Tile Roofings

Material	Thickness Inches	mm	Kg/m^2	lbs/sq ft
Slate	3/16 to1/4	4 to 6	34 to 49	7 to 10
Slate	3/8 to 1/2	9 to 13	73 to 100	15 to 20
Slate	3/4 to 1	19 to 25	145 to 200	30 to 40
Tile/Plain	1/4 to 3/4	6 to 19	60 to 90	12 to 18
Tile/Barrel			50 to 55	10 to 11
Tile/Interlock	1/2 to 2	13 to 51	40 to 44	8 to 9
S-Tile	1/2	13	44 to 54	9 to 11

(2) Re-covering. Adding a second or third shingle roof also adds significant weight.

e. Expansion and Seismic Joints. Lighter systems have no special requirements. Heavier products, because of inertia, require seismic joints and better fastening such as through the use of wire ties or dual fasteners. Expansion joints in the building should continue through the roofing system as well.

f. Re-entrant Corners. No special requirements are needed, as most steep roofing products are relatively small and can accommodate small movements.

g. Roof Access. Mechanical equipment that requires servicing is rarely placed on a steep roof. To handle rooftop equipment the designer may cluster mechanical equipment on a flat roof hidden from view by mansard roofs. This flat roof area needs access preferably by an internal roof hatch.

(1) Permanent Ladders. Sometimes permanent ladders are installed on steep roofs to facilitate access.

(2) Foot Traffic. Treading on the unsupported cantilevered ends of most steep roofing materials (slate, tile, shakes) may result in breakage.

h. Roof Venting. Attic ventilation is often necessary to control building moisture. Inadequate ventilation may cause moisture sensitive roof decking to expand, buckle or degrade. Half of the required net free ventilating area should be placed at the eaves through means of soffit vents, and half at the ridge through ridge or gable vents to take advantage of the *chimney* draft.

i. Roof Decks. Plywood and OSB (oriented strand board) are commonly used. Spaced sheathing and tongue and groove (T&G) wood boards are less common. There have been recent problems with fire retarded plywood. Degradation due to accumulated heat and moisture has occurred. When fire retarded plywood is necessary the APA recommends AWPA C27 low hygroscopic Interior Type A fire retardant be used.

j. Underlayment.

(1) Protection. The underlayment's first function is to keep the deck dry until the roofing system is installed. It also provides secondary water resistance when driving rain or blowing snow by-passes the shingles or tiles or they are damaged or wind lifted. Sealed underlayments can reduce leaks from wind driven water or water ponded behind ice dams. The underlayment also forms a cushion for slates and prevents chemical reactions between resin in wood nailers or cants and the asphalt in shingles or roll roofing. Typically No. 15 asphalt saturated roofing felt is used as an underlayment for shorter life materials such as asphalt shingles, while one or more layers of No. 30 felt or self adhering modified bituminous underlayment might be used with more durable slate, tile, copper, or heavyweight shake roofs.

(2) Mortar Set Roofing. For tiles laid in mortar on lower slopes a nailed base sheet and mopped mineral surfaced capsheet may serve as the underlayment. The roofing granules provide a preferred surface texture to bond to the mortar/adhesive.

(3) Eave Protection. In the past, at eaves and other locations where ice dams could cause temporary water backup, asphalt-saturated roofing felts were sealed together with asphalt mastic. Today, self-adhering modified bituminous sheets (ASTM D1970) are often used. Self-adhesive rubberized sheets have the added advantage of forming watertight seals where roofing nails penetrate them.

k. Vapor Retarders. Under most conditions with steep roof system designs the vapor retarder (when present) will be on the attic floor slowing (but not completely stopping) moisture penetration into the insulation. Unfortunately, most vapor retarders are not very effective at stopping air exfiltration as little attempt is made to seal them at edges and penetrations such as light fixtures and vent pipes. Much more attention to control air exfiltration can be justified considering the many problems caused by moisture. Roof ventilation can remove some moisture with the result that a few defects are generally not fatal. However, in more severe cases or for high humidity buildings, it is essential to severely limit air exfiltration. This may necessitate installation of a separate air barrier. In order not to create cold-side vapor traps, cold-side air barriers should have *high* vapor permeability.

l. Penetrations. Round pipe penetrations through steep roofing are handled with molded boots which slide over the pipe providing a snug fit. The base of the boot is installed shingle fashion covering the units of lower courses and with the up-slope end covered by later installed courses (figure 8-7).

m. Historical Roof Restoration. Since steep roofing is usually very visible efforts should be made to retain historical accuracy. Where materials are no longer available, or no longer comply with fire or other code requirements, refer to CEGS 02226 (Removal and Salvage of Historic Building Materials). Look-alikes of metal or plastic may provide lightweight replicas of heavier, more combustible materials.

n. Aesthetics. Increased depth and shadow improves appearance. Some asphalt shingles incorporate color blending of granules for enhanced appeal. Laminated asphalt shingles and thicker wood shakes increase visual appeal as well as durability.

o. Flashings, Counterflashings and Closures. Flashings generally use a formed metal base and step flashing. Each system has specific details for hip and ridge closures. See references or manufacturer details.

p. Drainage, Valley and Intersection Details. Roof drainage systems are discussed in detail in Chapter 1 of the SMACNA Sheet Metal Manual. Snow guards are necessary on most slate roofs in sections of the country where snow and ice accumulate.

(1) Gutters. Roof gutters should be designed so that the front edge of the gutter is lower than the back and so that any overflow will spill over the front of the gutter. The elevation difference should be 1/12 of the gutter width, but not less then 25 mm (1 inch).

(2) Roof Slope. Minimum Slope should be 33% (4 in./ft.) for tile, slate, or shingles. Some specifications permit lower slopes. In these situations more stringent underlayment (and/or interlayment) specifications, reduced exposures, and careful consideration of roof layout, valley details, and climatic conditions are necessary.

(3) Valley Details. Valley details may consist of formed metal combined with an underlayment. Open, Woven, and Closed Valleys may be selected. Open valleys are recommended where falling leaves and debris can accumulate on the roof.

8-3. DESIGN CONSIDERATIONS.

a. NRCA Details. Typical details for all steep roofing types are provided in NRCA *Steep Roofing* Manual (Volume 2, the NRCA *Roofing and Waterproofing* Manual-fourth edition).

b. Decking. The APA *Design/Construction Guide* explains veneer grades, exposure durability, recommended spans, diaphragm information, as well as fire and wind resistant construction for plywood and non-veneer decks.

c. Asphalt Products. The *Residential Asphalt Roofing Manual* by ARMA provides excellent design information for asphalt shingles and roll roofing.

d. Tile. The National Tile Roofing Manufacturers Association also has a manual that is helpful when designing with tile. Also useful and current are the *Concrete and Clay Roof Tile Installation Manual*; FRSA/NTRMA Minimum Standards; the *Clay Roof Tile Manual* from the Western States Roofing Contractors Association (WSRCA); and the National Tile Roofing Manufacturers Association (NTRMA) *Concrete and Clay Tile Roof Design Criteria Manual for Snow and Ice Regions*.

e. Slate. *Slate Roofs*, by Vermont Structural Slate Co., Inc., provides details and design information on slate. (The National Slate Association no longer exists.) Note that only copper, stainless steel, and brass fasteners are recommended, never iron or galvanized.

f. Metals. The *Architectural Sheet Metal Manual* from SMACNA contains many details for flashings, valley treatments and drainage.

g. Wood Shingles and Shakes. The Cedar Shingle and Shake *Design and Application Manual* provides excellent information on wood shingles and shakes.

h. Military References/Guide Specifications. Refer to:

- •TM 5-805-14 Roofing and Waterproofing 5/93
- •CEGS 07310 Slate
- •CEGS 07311 Strip Shingles
- •CEGS 07320 Clay Tile Roofing
- •CEGS 07412 Nonstructural Metal Roofing

i. ASTM Specifications

- •C408 Roofing slate
- •C1167 Clay roof tile
- •D225 Asphalt shingles (organic felt)
- •D226 Asphalt-saturated (organic felt) used in roofing and waterproofing
- •D249 Asphalt roll roofing (organic felt) surfaced with mineral granules
- •D371 Asphalt roll roofing (organic felt) surfaced with mineral granules; wide selvage
- •D1970 Self-adhering polymer modified bituminous sheet materials used as steep roofing underlayment for ice dam protection
- •D3018 Class A asphalt shingles surfaced with mineral granules
- •D3909 Asphalt roll roofing (glass felt)
- •D3462 Asphalt shingles (glass felt)
- •D4869 Asphalt-saturated (organic felt) shingle underlayment
- •D6162 SBS sheets with combination polyester/glass reinforcements
- •D6163 SBS sheets with glass reinforcements
- •D6164 SBS sheets with polyester reinforcements

8-4. CONSTRUCTION CONSIDERATIONS.

a. General. Wood roof deck products change in dimension with changing moisture content. Spacing and nailing guidelines for plywood and OSB must be followed in order to avoid buckling. In general, 3 mm (1/8 in.) spacing is necessary both at panel ends and edges. H-clips may be needed to achieve this.

b. Pre-roofing Conference. While generic categories exist for asphalt shingles, each type of tile and proprietary metal shingle will have closures and accessories unique to that type. Mockups may improve the likelihood that final appearance will be as intended.

c. Shop Drawing Submittals. Submittals have extra significance for historical restoration where matching the original material is very important. For example, new slate being incorporated into an existing slate roof should be from the same quarry or manufacturer, if possible (CEGS 07310). Drawings of transitions between steep roofing and other systems (e.g., membrane roofing) are necessary.

d. Design Submittal Requirements and Checklist. The steep system should be provided and warranted by the contractor as a complete system, including valley details, crickets, underlayments, penetrations, and flashings. The following checklist numbers in parenthesis refer to the CSI Masterformat number system.

(1) Decking. Install meeting APA recommended spacing (minimum 3 mm [1/8 in.]) at ends and sides of panels. Fasten at least every 150 mm (6 in.) o.c. at supports and 305 mm (12 in.) at intermediate supports. Place nails nominally 9.5 mm (3/8 in.) from ends and edges of boards. Verify that sheathing is spaced and sized properly. When spaced sheathing is used, the deck may be composed of 25 mm x 100 mm (1 x 4's) for the attachment of wood shingles and 25 mm x 150 mm (1 x 6's) for the attachment of wood shakes. The boards should be spaced on centers equal to the weather exposure at which the shingles or shakes are specified to be laid. Use solid sheathing for first 900 mm (36 in.).

(2) Underlayment (Sheathing 06113). Minimum of one layer of No. 15 (ASTM D226) asphalt saturated felt, layered horizontally to the roof slope, minimum headlap 50 mm (2 in.), sidelap minimum 100 mm (4 in.) nailed or stapled sufficiently to hold in place. Use self-adhesive MB or adhesively laminated underlay at valleys and eaves. For mortar and adhesive-set tile applications, a #30 or #43 organic base sheet (nailed) and mineral surfaced capsheet (mopped) may be used (see *Concrete and Clay Roof Tile Installation* Manual, FRSA/NTRMA).

(3) Eave Protection. Use a minimum of one ply No. 30, or two plies of No. 15 felt meeting ASTM D226, cemented together with lap cement (ASTM D4586 or D2822) or one continuous width of self-adhesive rubberized asphalt sheet meeting ASTM D1970.

(4) Eave Starter. Verify thickness or number of layers as specified.

(5) Ridge Cover. Confirm if fasteners are long enough to penetrate the deck or if the adhesive used is applied as specified.

(6) Flashings. Use a minimum dimension of 100 mm (4 in.) up vertical surfaces and 100 mm (4 in.) out onto the roof deck. Use step-flashing over the end of each course of shingles at all vertical intersections.

(7) Valleys. Use a minimum of one layer of corrosion resistant sheet metal 600 mm (24 in.) wide or two layers of roll roofing.

(8) Penetrations. Position penetrations near ridge in snow country.

(9) Snow Guards (07635). Specify if needed.

(10) Gutters (07631) and Downspouts. Expansion joints for gutters, slopes, materials and details: Gutters should be sloped towards leaders. For lengths over 10.7 m (35 ft) use two downspouts. The outer face of the gutter should be lower than the roof face so that the overflow is away from structure.

(11) Downspouts and Rain Water Leaders (07632). Strainers are recommended for leaders. They should be firmly anchored to the structure. Use splash blocks as needed.

(12) Specifications. Verify materials are in compliance.

(13) Plumbing Stacks (15405). Where snow is likely to slide, stacks should be located close to the ridge or protected by snow splitters or snow guards.

(14) Air Handling Vents (15800). Ventilate according to requirements.

(15) Roof Mounted HVAC (15650/15800). Check against project specifications.

(16) Chimneys

Masonry	(CEGS 0400)
Prefab	(10300)
Flashing	(CEGS 07625)

Install saddles and crickets to divert water flow round projections.

(17) Solar Heat Panels	(13980)
Solar Water Heaters	(13980/15431)

(18) Prefabricated Roof Specialties

Steeples	(10341)
Spires	(10342)
Cupolas	(10343)

(19) Anchorage. Verify fasteners, ties are as specified. Verify fasteners long enough for specified penetration. (Minimum 12 mm (1/2 in.) into, or all the way through decking.) Verify gauge of fasteners or wire meets specification. Verify high wind or seismic details are applicable.

(20) Offset. Verify following rows of material are adequately offset so those joints are not aligned. (Minimum offset 38 mm (1-1/2 in.) for shakes, shingles, and slates. (Tile may be designed to align.)

e. Field Review and Observation.

(1) Inspection.

(a) Verify deck spacing, fastening and smoothness is as specified.

(b) Verify the underlayment is as specified. (Especially along eaves and in valleys.)

(c) Fastening.

1/ Fasteners should be properly driven (figures 8-a and 8-b).

2/ Verify the fastener is of the correct type, size (length) and grade. (Asphalt shingles must be nailed, not stapled.)

3/ Verify there is sufficient fastening, especially for windy regions.

4/ Verify the alignment is proper at the start of the job.

5/ Verify the tab adhesive is used for cold weather application of asphalt shingles.

(2) Field Storage.

(a) Bundles of asphalt shingles should never be stacked over 1.2 m (4 ft.) high.

(b) Do not store materials directly on the ground or exposed to the weather.

(3) Packaging and Labeling.

(a) Examine all packaging and labeling for evidence of UL or code compliance

(b) Examine all lot or batch numbers (date code). Use the same lot for the entire face of the roof to avoid manufacturing variations in appearance.

(c) Steep *prepared* roofings are usually furnished with application instructions on the wrappers. Compare to published specifications.

(4) Eave Flashing (Drip Edge).

(a) Verify the eave flashing is installed per specifications.

(b) Verify the gauge and finish is per specification. (NRCA recommends 24 gauge or heavier, prepainted galvanized steel, or equivalent coated aluminum, copper, or stainless steel material be specified along perimeter roof edges.)

8-5. MAINTENANCE CONSIDERATIONS.

a. General.

(1) Asphalt Shingles. Some loss of roofing granules is normal with time. A pattern that follows the installation pattern (e.g., installed shingles from one bundle look better than the shingles adjacent from the next bundle) is probably a manufacturing problem. This effect can be minimized during installation by requiring that all shingles on a given area are from the same lot of material.

(2) Algae. Algae will cause darkening of the surface of shingles. Rinsing with a mixture of detergent, bleach, and water may help, or in warm humid regions where algae is a problem specify asphalt shingles with specially treated granules. Nailing zinc or copper strips at the eave is also effective.

(3) Slate. Durability is a function of hardness of the slate. Traffic on slate roofs can lead to breakage. Use copper, brass or stainless steel fasteners with all repairs.

(4) Traffic and Impact. Tile roofs are durable but vulnerable to roof traffic

(5) Debris. Hosing or brooming the spaces between wood shakes can be beneficial. Buildup of leaves, pine needles, and the like inhibits drainage and accelerates rot. Cleaning gutters every spring and autumn is beneficial to all sloped roofing systems.

b. Repair or Replace. All materials wear out. Asphalt shingle replacement is neither overly expensive nor complex. Coatings have not been effective as treatments for asphalt shingles and may actually accelerate failure by causing curling. Chemical treatments for wood shingles and shakes may be effective. With long-lived materials such as tile and slate, repair to flashings and penetrations make a great deal of sense if the primary roofing is relatively intact. Broken units take skill to replace.

c. Repairs: Emergency, Temporary, and Permanent

(1) Emergency repairs. Emergency repairs imply leaks are caused by a loss of roofing and underlayment. An emergency patch could consist of a nailed tarpaulin, roofing felt with mastic, plastic film, or a nailed sheet of galvanized metal.

(2) Temporary Repair. A temporary repair would be to reinstall underlayment and to cover with locally available material even if the appearance does not match the rest of the roof.

(3) A Permanent repairs. A permanent repair would be to install similar looking material making certain that new material extends well under remaining material so that water cascades away from laps. This permanent repair should last as long as the rest of the roof.

d. Repair Work by User. A common repair would be to replace a broken or missing roofing unit. Each type requires specific skill. In general, the broken unit would be removed by gently prying up the fasteners (if used) up-slope of the unit; a new unit would be inserted and fastened; the upstream fasteners would then be carefully redriven. Adhered units would be replaced and set in a fresh bed of mortar, asphalt mastic, or foam adhesive as appropriate. The steeper the roof, the more safety becomes of concern. Fall protection such as toeboards and body harnesses are essential. Traffic on old slates, tiles, shingles, and shakes can do considerable damage.

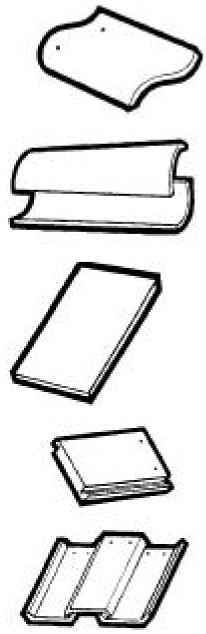


Figure 8-1. Types of Clay Tile

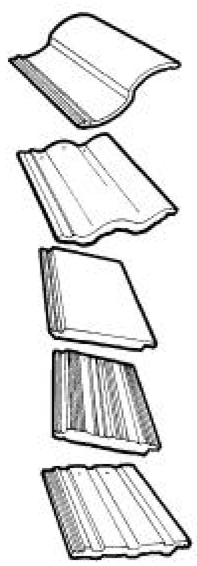


Figure 8-2. Types of Concrete Tile

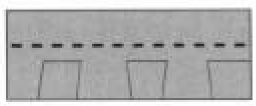
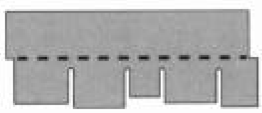
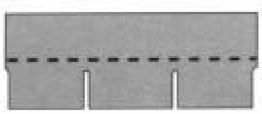
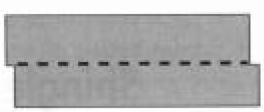
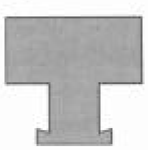
Table I: Typical asphalt shingles								
Product	Configuration	Appx. shipping weight per square (lbs.)	Shingles per square	Bundles per square	Width (in.)	Length (in.)	Exposure (in.)	ASTM fire and wind ratings
Laminated self-sealing random tab shingle 	Various edge, surface texture and application treatments	240-360	64-90	3-5	$11\frac{1}{2}$ - $14\frac{1}{4}$	36-40	4-$6\frac{1}{8}$	Class A or C fire rating. Many wind resistant.
Multi-tab self-sealing square tab strip shingle 	Various edge, surface texture and application treatments	240-300	65-80	3-4	12-17	36-40	4-8	Class A or C fire rating. Many wind resistant.
Multi-tab self-sealing square tab strip shingle 	Three-tab or four-tab	200-300	48-80	3-4	12-$13\frac{1}{4}$	36-40	5-$5\frac{5}{8}$	Class A or C fire rating. All wind resistant.
No-cutout self-sealing square tab strip shingle 	Various edge and surface texture treatments	200-300	65-81	3-4	12-$13\frac{1}{4}$	36-40	5-$5\frac{5}{8}$	Class A or C fire rating. All wind resistant.
Individual interlocking shingle (basic design) 	Several design variations	180-250	72-120	3-4	18-$22\frac{1}{4}$	20-$22\frac{1}{2}$	n/a	Class A or C fire rating. Many wind resistant.

Figure 8-3. Typical Asphalt Shingles

Table 2: Typical asphalt rolls

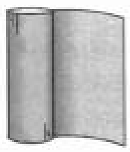
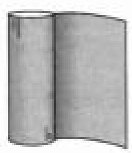
Product	Appx. shipping weight per roll (lbs.)	Appx. shipping weight per square (lbs.)	Squares per pkg.	Width (in.)	Length (ft.)	Selvage (in.)	Exposure (in.)	ASTM fire and wind ratings
Mineral surface roll 	75-90	75-90	1	36-39¾	32.7-38	2-4	32-34	Some Class C
Mineral surface roll (double coverage) 	55-70	110-140	½	36-39¾	32.7-36	19	17	Some Class C
Smooth surface roll 	50-86	40-65	1-2	36-39¾	32.7-72	2-4	34-37¾	None
Non-perforated felt underlayment 	24-60	6-30	2-8	36	72-288	2-19	17-34	May be a component in a comlete fire-rated system. Check with manufacturer for details.
Self-adhered eave and flashing membrane 	35-82	33-40	1-2¼	36	36-75	2-6	34	May be a component in a comlete fire-rated system. Check with manufacturer for details.

Figure 8-4. Typical Asphalt Rolls

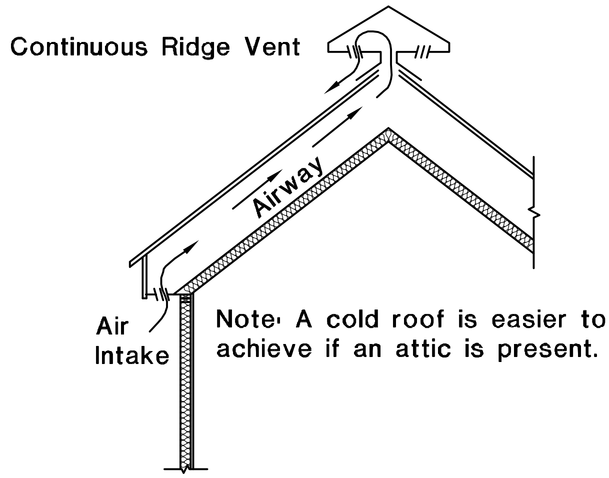
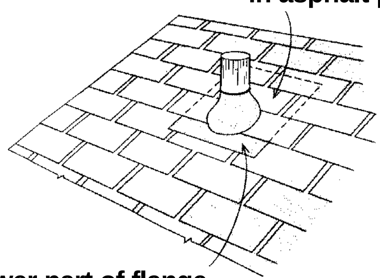


Figure 8-5. A Cold, Ventilated Roof Above a Cathedral Ceiling

	Cost 1=Low 5=High	Longevity	Min. Slope %	In./ft.	Advantages	Disadvantages
Asphalt Shingles *improve underlayment	2-3	10-25	33 17*	4 2	Easy installation Available in a variety of weights, colors, or shadow lines Requires little maintenance	Organic shingles—Class C Glass fiber shingles—Class A
Asphalt Roll Roofing	1-2	5-15	8	1	Easy installation and repair	Poor fire resistance for some types; drab appearance.
Wood Shingles	3-4	10-20	25	3	Attractive rustic appearance; natural insulator	Flammable unless specially treated. Should be laid over open planks or spaced battens so they can dry.
Wood Shakes	3-5	10-25	33	4	Attractive rustic appearance; natural insulator	Flammable unless specially treated.
Slate	5	50-100	33	4	Attractive traditional appearance; fire resistant	Heavy; brittle; requires sturdy roof support. Tricky installation that requires special tools and skills; difficult to repair.
Tile Concrete	4-5	30-100	33	4	Attractive traditional appearance; fire resistant	Heavy; brittle; requires sturdy support; time consuming installation that requires special skills; availability of replacement pieces unreliable; difficult to repair.
Tile Clay	5	30-100	33	4	Attractive traditional appearance; fire resistant	Heavy; brittle; requires sturdy support; time consuming installation that requires special skills; availability of replacement pieces unreliable; difficult to repair.

Figure 8-6. Comparison of Steep Roofing Systems



Notes:

1. Lower shingle cut to fit over pipe and set in asphalt plastic cement
2. Preformed pipe flange placed over pipe and set in roof cement
3. Bead of roof cement or caulk used between pipe and collar of pipe flange.

Figure 8-7. Pipe Penetration

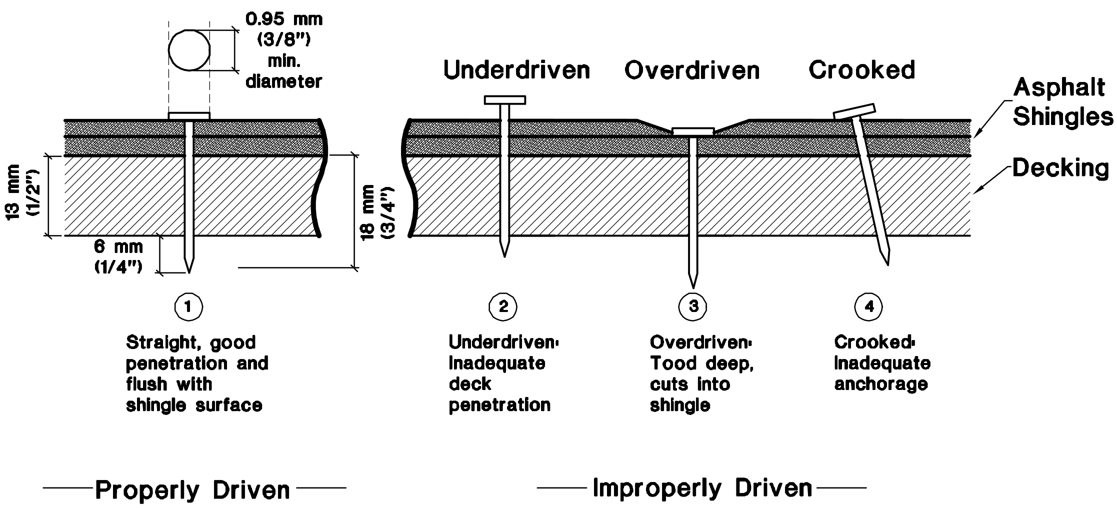


Figure 8-8a. Application of Roofing Nails

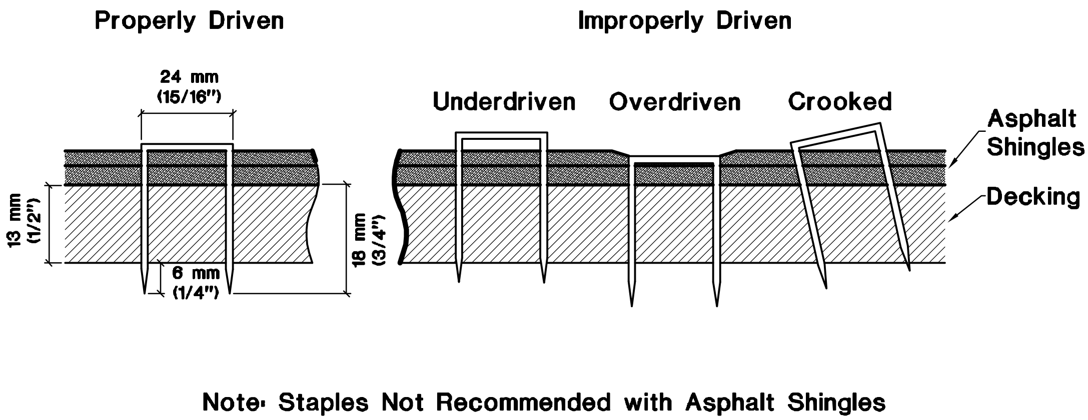


Figure 8-8b. Application of Roofing Staples

CHAPTER 9

METAL ROOFING
REFERENCES
CEGS 07412 Nonstructural Metal Roofing
CEGS 07416 Structural Standing Seam Metal Roof (SSSMR) System
ASTM E1514 Structural Standing Seam Steel Roof Panel Systems

9-1. OVERVIEW OF METAL ROOFING. Included in this section are factory-formed metal panels which may be used in low-slope roof applications (hydrostatic), and factory or field-formed panels and other shapes that are used in steep roofs (hydrokinetic) (figure 9-1). Either type will have varying structural characteristics (e.g., ability to resist applied loads between supports or anchorages).

a. Terminology.

(1) Low-Slope. Only factory-formed panels should be used for low-slope roofs. They require standing seams elevated more than 37 mm (1-1/2 in.) above the flat of the panel. Factory-applied sealants (figure 9-2) at sidelaps, and field-applied sealants at endlaps are required to enhance waterproofness. Seams must be squeezed tight with a mechanical device once the system is assembled. Minimum slope is 4% (1/2 in/ft.).

(2) Structural Panels. *Structural Panels* are long metal panels with sufficient beam strength to carry design loads while spanning between clips supported by framing members often spanning about 1.5 m (5 ft.). Large thermal movements accumulate in long metal panels. Two-part sliding clips are needed to allow such panels to *float* (i.e., to expand and contract freely as their temperature changes). If such panels are firmly attached to the frame of the structure at more than one place along their length, this freedom is lost. Waterproofing low-slope metal panels at their free ends, in valleys and at penetrations is not easy. Thermal movement in the cross-slope direction is accommodated within each seam and does not accumulate from panel to panel.

(a) Structural panels are commonly used within the pre-engineered metal building industry where they are supported by cold-formed purlins or bar joists. They are also used widely in mansard and equipment screen type applications, which are constructed with open framing members. They are used extensively in reroofing applications to avoid having to add a continuous deck needed by nonstructural panels. When they are used over structural decks their structural characteristics may not be fully utilized. Not all structural panels are suitable for low-slope (4% [1/2 in./ft.]) applications but most low-slope panels *are* structural panels. [A typical design load may be 1.44 kPa (30 psf) positive or negative while spanning not less than 914 mm (3 ft) in a continuous (3 or more) span condition. Maximum span length for corners, edges and edge zones is 750 mm (30 inches).]

(b) Clips for structural panels must be screwed or bolted into structural framing. Attachment of structural panel clips to metal decks, or other decks with questionable pull-out capacity, should not be permitted.

(3) Nonstructural Panels. Nonstructural panels are always supported on an underlying substrate. Batt insulation does not provide such support. Nonstructural panels are installed over wood or metal decks or over noncompressible insulation boards. The clips that attach them are typically screwed or nailed into a nailable deck and screwed into a non-nailable deck. Clip spacing is commonly 300 mm (12 in.) to 500 mm (20 in.) for standing and batten seam profiles. Very few nonstructural panels are suited for use on low-slope roofs. Most are for steep-sloped *architectural* applications with watershedding underlayment. Nonstructural panels may use standing, batten, or flat seams. The shadow line provided by vertical ribs (or battens) and the availability of durable, factory painted panels in many colors make

metal roofs aesthetically pleasing. The silvery metallic color of aluminum and zinc-aluminum alloys may suffice for industrial roofs.

(4) Waterproof (Hydrostatic) Joints. Hydrostatic joints, which can tolerate brief periods of submersion, (i.e., hydrostatic pressure) without leaking. The first waterproof (not just watershedding) joints in metal roofing were soldered flat seams. Thermal movement of the metal works to defeat such in-plane seams. In the 1960's, the preengineered metal building industry began to use sealants in structural standing seam panels. Sealant may be factory injected into the female joint component, or field applied. To be considered for low-slope applications by the Corps of Engineers sealant must be factory injected. *Caution: there are no ASTM tests to verify the performance of waterproof joints in metal roofing. Even if seams and endlaps are waterproof, the entire system may not be since there are many other termination and penetration points to consider.*

(5) Watershedding (Hydrokinetic) Joints. A hydrokinetic joint relies on slope and gravity, not a hydrostatic seal, for weather tightness. A watershedding joint would leak if submerged even briefly. To simulate wind driven rain ASTM E331 tests watershedding joints. The procedure directs a spray at the joint with reduced air pressure below the assembly. Air pressure is reduced until leaks occur. Some systems resist leakage much better than others do. Vacuum pressure is not specified by the ASTM test method. Leakage at 120 Pa (2.5 pounds) differential pressure would be unacceptable while 840 Pa (17.5 pounds) differential pressure would be considered excellent. At this time there is no agreed upon minimum pressure differential. This test is typically done for the roof panel seams only, not for the other joints, valleys, eaves, penetrations and ridges present on a metal roof. ASTM E331 also does not evaluate the effects of slope and underlayment on system performance.

(6) Other Metal Systems. There are metal products produced to look like tile or shingles. They usually hook together in some fashion and are installed over felts and nailable deck material or furring. Since they are for steep roofs only, they are discussed in Chapter 8 (Steep Roofing).

(7) Corrugated Metal Roofing. Corrugated metal roofing consists of corrugated structural panels with exposed fasteners and nested side and end seams. These are structural systems used as water shedding roofs only. When corrugations are deeper than 25 m (1 in.) spans can exceed 1.5 m (5 ft.).

(8) Copper, Lead-Coated Copper, Terne, Terne-Coated Stainless Steel, and Zinc Metal. These metals are termed *crafted metals* and are discussed in Chapter 10. They are also roll formed into hydrokinetic panels.

(9) Composite Interlocking Sandwich Panels. Composite interlocking sandwich panels are also used in the private sector for roofing. The core is usually rigid foam insulation and both skins may be metal. They are structural systems and often have hydrostatic joints, which allow them to be used on low-slopes. For Corps of Engineer projects, these panels will only be used on structures that require portability.

b. Climate/Weather. Metal panels must be clean and dry during installation. In pre-engineered systems, wind can make installation of batt insulation difficult. Metal panel systems have been used in all climates from tropical to arctic. Climate, slope, roof geometry, construction details, infiltration characteristics, and underlayment diligence affect roof performance. Metal panels can be shop fabricated simplifying application in wet or cold weather. Snow will slide easily off of smooth unobstructed metal surfaces. It may be necessary to install snow guards to eliminate hazards. Roof ventilation is often needed to prevent ice dams and leaks. Refer to EI01S011 and ANSI/ASCE 7-95 for information on snow loads.

c. Logistics. The length of factory formed panels may be governed by the width of the roof area or transportation requirements i.e., 12.8 m (42 ft.) for most tractor-trailer beds. Nested panels in bundles may be hoisted to the roof framing, provided the bundles are placed directly over the structural members and the weight is distributed to avoid overload.

d. Familiarity with the System and Site. Metal panel roofing systems are proprietary and should be installed by a manufacturer-approved, experienced installer.

e. Life Expectancy and Cost. Hot dip coatings of aluminum or zinc-aluminum can give 20 years of service in all but the most corrosive atmospheres. Colored coatings of poly-vinylidene difluoride (Hylar 5000® and Kynar 500®) and all-aluminum panels are also very durable. Metal roof systems generally have a much higher first cost than other roofing types discussed in this EI; but on a life cycle basis this may be justified because of greater durability and lower maintenance costs. Zinc-coated steel (galvanized) is less expensive but far less durable for unpainted (bare) applications**.** As a corrosion resistant base for color coatings, galvanized steel is still widely used in prepainted applications. Structural and nonstructural metal roof systems may have approximately the same installed cost. Steel and aluminum roof systems are recyclable. Glass fiber batts and plastic foam may be reusable or recyclable since the material is essentially uncontaminated by bitumen or other foreign material. Composite panels are difficult to recycle.

f. Occupancy Considerations. For high humidity occupancy in temperate or cold climates, conventional structural panel systems with faced batt insulation will not be adequate as it is difficult to seal the vapor retarder so it resists air exfiltration. A preferred metal roofing system would include a vapor retarder and rigid board insulation above the structural deck followed by a ventilated airway and the roof panel. An alternative would be to use an interlocking insulated panel system. In hot, humid climates condensation has been observed on the backside of metal panel systems when rain cools the panel quickly. Installation of a sealed plastic sheet (e.g., 4 mil polyethylene) directly underneath the metal panel will protect the back of the panel against condensation-caused corrosion.

9-2. BUILDING ELEMENTS.

a. Slope. Minimum slope varies with the type of panel (architectural or structural), the type of joint (watershedding or waterproof), and the amount of rain or snow expected at the site. Table 9-1 presents design requirements.

Table 9-1. Minimum Slope for Metal Roofing

	%	in./ft.
Metal panel roofing with watershedding (not waterproof joints)		
Architectural (nonstructural) panels	33	4
Structural panels wider than 305 mm (12 in.)	33	4
Architectural panels with seams at least 38 mm (1-1/2 in.), but less than 51 mm (2-in.) high, with underlayment	25	3
Structural panels no wider than 305 mm (12 in.), with seams at least 38 mm (1-1/2 in.), but less than 51 mm (2 in) high, with underlayment	25	3
Architectural panels with seams at least 51 mm (2 in.) high, with underlayment and structural panels no wider than 305 mm (12 in.,) with seams at least 51 mm (2 in.) high.		
Where the ground snow load is more than 98 kg/m^2 (20 psf)	25	3
Where the ground snow load is 98 kg/m^2 (20 psf) or less	17	2
Metal panel roofing with factory installed seam sealant designed and tested to be waterproof (i.e., to withstand hydrostatic pressure) and with field joints designed and sealed to the same high level of watertightness		
Where the ground snow load is more than 98 kg/m^2 (20 psf)	8	1
Where the ground snow load is 98 kg/m^2 (20 psf) or less	4	1/2

b. Low-Sloped versus Steep Roofs. As slopes increase greater down-slope loads are placed on supporting clips. They must be designed to handle such loads. Sliding clips will depend upon method of restraint as gravity force can cause slippage. Architectural panels are common on systems all the way to vertical; curved panels are also available.

c. Low-Sloped Roofs. Some structural hydrostatic panels have been used at slopes as low as 4% (1/2 in./ft.).

d. Steep Roofs. Usually colored panels are used since steep roofs are highly visible. Sliding snow can be a big problem. For simple shed, gable and hip roofs without penetrations or obstructions, it may be possible to let the snow slide to the ground. However, sliding snow can peel apart seams in valleys, tear off vent pipes, damage other roof features and create hazards. Snow guards distributed over the surface of the roof must be quite strong to hold back snow. Guidelines are presented in EI 01S011, *Commentary on Snow Loads*.

e. Structural Considerations. With nonstructural metal panels the deck below provides the diaphragm needed to resist lateral loads. Structural panels supported on clips do not resist lateral loads. Either cross bracing or a supplemental deck is needed.

f. Expansion Joints and Seismic Joints.

(1) Joint Location. When the longitudinal dimension of the roof exceeds 30 to 40 m (100 to 135 ft.) step expansion joints are used (figure 9-3). The maximum allowed run will depend upon clip design (permitted movement), color of panels (dark colors absorb more solar load), climate, and metal used. (Aluminum has roughly double the coefficient of thermal expansion of steel.)

(2) Panel Movement. Expansion in the transverse direction is accommodated within the trapezoidal or vertical side lap itself. Panels must be anchored at some point to resist the down-slope component of design loads. Panels are usually pinned at the eave. They expand up-slope towards flexible ridge covers. Pinning or fixing at eaves makes waterproofing a simpler task at that critical location over which all water flows and ice dams may form.

(3) Restrained Panels. Through-fastened panels, as opposed to clipped, are restricted to relatively short runs. As runs increase, the accumulated thermal movement may increase stresses at through-fasteners resulting in elongated fastener holes or panel buckling. With time this results in leakage and corrosion.

g. Re-entrant Corners. At such locations points of fixing may shift among adjacent panels. Design details are needed; special closures may be necessary.

h. Roof Access. Roof hatches must be treated like other curbed penetrations. Most metal roofs can resist only light foot traffic. Walkways may be needed if more than casual traffic is expected.

i. Roof Venting. Architectural systems are relatively easy to ventilate when an attic space is present below the deck or by airways created in a cathedral ceiling. For hot, humid environments installation of a plastic film directly beneath the roof panels minimizes the potential for bottom-side corrosion. Structural systems that contain batt insulation between the panels and the frame are difficult to ventilate. This limits their applicability in very cold regions and for high humidity occupancies.

j. Roof Decks. Architectural systems require decks for continuous support; structural systems do not. However, decks may be used with structural systems for other reasons (e.g., to provide diaphragm action).

k. Vapor Retarders. With a SSSMR system with no roof deck, batt insulation faced with a plastic film vapor retarder is frequently used. In a cool climate, the vapor retarder will be a facing on the bottom of the blanket insulation; in a warm climate, the vapor retarder may be a facing on top of the blanket insulation with a separate insulation support system. A slipsheet is required. Vapor retardancy can be greatly improved by sealing all laps and penetrations to minimize air exfiltration.

l. Thermal Insulation and Heat Flow.

(1) Batt Insulation. When glass fiber blankets are used in SSSMR systems, they are supported by draping them over the frame before the roofing is placed or by supporting them on wires or metal bands strung beneath the roof panels. Slightly compressed batt insulation inserted between the substrate and new metal panels helps dampen wind-generated noise.

(2) Thermal Spacer Blocks. At locations where the batt is squeezed between the frame and metal panel (resulting in a loss of thermal efficiency) thermal spacers are used. These are relatively incompressible blocks of polystyrene or polyisocyanurate.

(3) Limited Clearance. The height of the concealed clip limits the thickness of batt insulation that can be installed.

(4) Rigid Insulation. When installed over a metal subdeck, noncompressible board insulations such as polyisocyanurate foam are used.

(5) Insulation for Architectural Panels. For architectural systems, insulation may be placed under the deck between rafters or as a rigid board on top of the structural deck.

m. Membranes. In this Chapter, the metal panels themselves are the roof membranes. Refer to ASTM E1514 Standard Specification for *Structural Standing Seam Steel Roof Panel Systems* and CEGS 07416 *SSSMR*.

n. Roof Penetrations.

(1) Allowance for Thermal Movement. Lightweight skylights and lightweight HVAC curbs may be supported by (and float with) the structural roof panels themselves. Structural members beneath the roof panels support heavier air handling units. A double curb with a *floating* base and a stationary inner base flashing attached to the panel, fixed to the buildings structure frame allows differential movement (figure 9-5). Large units may be mounted on pipe stands supported by other parts of the structure.

(2) Pipes. Pipe penetrations are flashed with rubber boots (figure 9-6). They should penetrate the flat pan, not the raised seam. To minimize damage to metal roofs, large mechanical items should be ground-mounted whenever possible.

o. Historical Roof Restoration. If the existing system is metal, new metal systems can duplicate the color and seam style relatively inexpensively. Structural systems can be used as a *retrofit* over existing systems improving slope and thermal efficiency.

p. Aesthetics. The numerous configurations of metal panel systems can achieve a variety of appearances. Because panels often have a broad flat area they are prone to oil canning. Fluting (deformations in the flat area between seams) are sometimes used to reduce oil canning effects. Trapezoidal ribs may be either distinctive or distracting on highly visible applications. Trapezoidal rib closure components at eaves may be unsightly.

q. Gaps, Flashings, Joints, Fasteners, and Sealants.

(1) Wall Flashing with Wall Parallel to Panel Seams. Parapets that parallel the standing seams require floating flashings. The base component of such flashing is anchored to the metal panel and moves with it. A counterflashing anchored to the wall covers the base flashing and provides additional protection (figure 9-7).

(2) Wall Flashing with Wall Perpendicular to Roof Panels (Headwall Transition). Roof to head wall transitions must have a gap between the panel and wall to allow for thermal movement. The gap is covered with a flexible flashing membrane for watertight performance or covered by a two piece metal wall flashing system (figure 9-8).

(3) Sealants. Sealants are used in all waterproof seams. Factory sealant is installed into the female seam of factory formed panels. Sealant in tape form is used at endlaps and other places specified by the manufacturer. Pumpable sealant (caulk) is used to supplement the other types. In general, butyl-based materials are preferred because they tolerate finishing oil that may be present on the panels or coil stock and they retain their adhesive properties for many years when protected from the weather.

(a) Additional field applied sealants are necessary in hydrostatic side seam design where attachment clips are located to restore continuity of the seam sealant.

(b) Refer to the weather tightness requirements of ASTM E1514.

(4) Fasteners. Many different fasteners are used in metal roof systems. Coarse threads (Type A) are best for joining two thin sheets of metal together (stitching), while finer threads for lower tapping torque are used when engaging thicker materials. The elastomeric washers provided as part of the integral head serve a waterproofing function and should not be overtorqued. For color metal panels matching colored fastener heads are available.

(5) Clips. Clips are designed for each proprietary type of panel. For SSSMR, CEGS 07416 stipulates: "clips shall be made from multiple pieces with the allowance for the total thermal movement required to take place within the clip. Single piece clips may be acceptable when the manufacturer can substantiate that the system can accommodate the thermal cyclic movement under sustained live or snow loads." Typically, clips are designed to accommodate thermal movement on the order of 25 mm (1 in.) to 38 mm (1.5 in.).

(6) Accessories. Accessories include prefabricated curbs with flanges matching the rib and seam configuration of the panel and roof jacks i.e., pipe penetrations, which also match the panels.

r. Drainage, Valley and Intersection Details.

(1) Water Flow. Water must run parallel to all standing seams. At down-slope curbs and penetrations that block water flow, the standing seams must be truncated short of the curb and a diverter installed so that water can move around the penetration.

(2) Gutters. Internal gutters can be problematic especially in cold regions. If roof geometry necessitates internal gutters other kinds of roofing should be considered.

9-3. DESIGN CONSIDERATIONS AND ALERTS. Refer to specific design details for each metal panel system being considered. In addition, refer to the NRCA Roofing and Waterproofing Manual, Volume 2 and the SMACNA *Manual for Guide Details*. Caution—Most SMACNA details are watershedding and should not be used in watertight applications.

a. Sealants. The sealing compound must be a nonskinning, noncuring, nonhardening type compound (typically butyl) acceptable to the panel manufacturer. It must be kept under compression within the joint by either seam folding or by use of mechanical fasteners (screws). Location of the sealant must be on the weather side (i.e., down-slope side) of end joint fasteners (figure 9-9).

b. Joint Movement. Differential thermal movement must not occur between the components of sealed joints. Expansion joints are typically required when runs exceed 40 m (135 ft.) for steel and 30 m (100 ft.) for aluminum.

c. Oil-canning. Some distortion of metal panels is unavoidable. Oil-canning can be minimized by proper adjustment of the roll forming equipment. Transverse embossing is available on some panel configurations.

d. Noise. Noise caused by wind, hail, or thermal movement can be muffled by inserting blanket insulation.

e. Air Exfiltration. Seal all laps and penetrations of faced blanket insulation to minimize air exfiltration.

f. Minimum Slopes for Cold Regions. In cold regions, EI 01S908 recommends a minimum slope of 12% (1-1/2 in. in 12).

9-4. CONSTRUCTION CONSIDERATIONS.

a. General. Each pre-engineered metal panel system has its own clips, end closures, terminations and transitions. Everything from the fasteners used to anchor the concealed clips, through the stiffener plates, sealants, panels, and closures must be from a single source and UL listed in order to meet UL wind requirements.

(1) Erection Sequence. Many pre-engineered systems can be installed in one direction only. For example, from the lower right tier towards the left, followed by the second tier, etc. In addition, seaming machines vary among systems.

(2) Gutters and Panel Closures. Exterior gutters (where appropriate) must be designed so that water cannot back up under the panels. When a trapezoidal closure is used it must be adequately sealed to resist wind driven rain or dislodgment by birds or insects.

(3) Allowance for Thermal Movement. Gable trims, end wall transitions, and ridge assemblies must be designed to move with the panel.

(4) Underlayment. For watershedding systems decking and underlayment must meet code and manufacturer requirements. Rubberized (modified bituminous) underlayment is needed along eaves and in valleys in cold regions where ice damming is likely.

(5) Sealant. Sealant is essential in low-slope metal panel systems. Seam sealant should be factory installed in the female seam. However, field sealant must be used to supplement the factory sealant to insure continuity of the waterproofing at clips, endlaps, terminations, and penetrations. Such details are critical to the integrity of the finished roof.

(6) Alkali Attack. Avoid contact between wet cementitious (alkaline) materials (such as fresh mortar) with aluminum-coated and zinc-aluminum alloys.

(7) Temperatures During Construction. Consider the temperatures during construction to verify that the clips can accommodate the maximum thermal expansion expected when the building is put into service.

b. Pre-roofing Conference. A conference should be held prior to construction especially for unusual applications. Representatives of the designer, user, roofing contractor, general contractor, materials manufacturer, field inspector, and other related subcontractors should be present. Discussion should include support of mechanical equipment, penetrations, transitions, and terminations.

c. Shop Drawing Submittals. The manufacturer will normally provide detailed drawings of all connections. These should be appropriate for the project's wind and structural design requirements. See NRCA *Roofing and Waterproofing Manual* and the SMACNA Manual for typical details required.

d. Design Submittal Requirements and Checklist. The designer should specify design loads, resource documents (e.g., ANSI/ASCE 7-95), and system type (e.g., structural vs. non-structural, watershedding vs. waterproof) using the guidelines in this EI. The metal system should be designed as a complete system to meet these requirements. Evidence of meeting ASTME1592 and UL 580 should also be required.

e. Field Review and Observation. These systems each have unique application techniques and tool requirements. A copy of the manufacturer's erection manual should be provided to the field inspector for examination.

9-5. MAINTENANCE CONSIDERATIONS.

a. General.

(1) Coatings. Zinc-aluminum, aluminum, and PVDF (poly-vinylidene difluoride) coated steel should remain corrosion free for 20+ years. However, gouges and scratches that remove the coating can result in corrosion if not field coated. Manufacturers can provide touchup materials.

(2) Surface Contamination. Ferrous debris left on the roof panels (such as iron shavings from metal cutting operations) will corrode and cause staining of the zinc-aluminum and all-aluminum coatings. Periodic cleaning of leaves, pine needles, and other debris is recommended.

(3) Copper Salts. Copper salts, such as that carried by HVAC condensate water, will attack zinc, aluminum, and zinc-aluminum alloy coatings. Because of this, run condensate lines from copper cooling coils directly into drains. Washing of copper salts from up-slope copper flashings will also degrade zinc alloys.

(4) Durable Metals. Avoid the use of galvanized steel counterflashings as they are far less durable than zinc-aluminum and Polyvinylidene Fluoride (PVDF) coated materials. Galvanized iron will become unsightly as it rusts and stains the zinc/aluminum coating. Only durable fasteners recommended by the manufacturer should be used for the same reason.

b. Repair or Replace. The most common problems with metal roofing are:

(1) Corrosion. When the protective coatings fail the base steel will rust. Clean by sandblasting or sanding followed by rust inhibiting primer and topcoat. For PVDF coatings, adhesion of retreatments is a problem. Consult with the system manufacturer for suitable primers and coatings.

(2) Differential Panel Movement. Differential panel movement may cause fastener hole enlargement of through-fastened panels. A variety of treatments are available, most of which embed

polyester mat or butyl tape over the hole, followed by coating. Others involve oversized weather sealing washers and fasteners.

(3) Differential Movement at Ridge Covers, Side Wall or End Wall Conditions. Differential movement at ridge covers, side wall or end wall conditions may fatigue fastenings. Reflashing with flexible membrane under the metal flashing may be needed.

(4) Endlap Leakage. Endlap leakage may be caused by a gap in the sealant within the lap. Top coating with reinforcement provides only temporary protection. The lap may have to be disassembled and resealed.

(5) Rooftop Penetrations. Rooftop penetrations, especially those installed after completion of the roof membrane, may be incorrectly installed. Finished installations must accommodate thermal movement of the panel. Flexible boots or proper curbs are needed to accommodate this movement.

(6) Replacement of Panels. Replacement of installed panels can be very difficult, especially those which are machine seamed.

(7) Replacement of Fasteners. If fasteners have backed out or the washers have failed, replacement of fasteners is appropriate. If fasteners have stripped the threads in the underlying metal, replace with larger diameter fasteners.

(8) Suitability in Reroofing Applications. Structural metal roofing systems can sometimes be used to replace or recover poorly draining membrane roofs. On relatively narrow buildings a watershedding system and attic can be created by applying elevated lightweight structural supports through the old membrane into the roof deck or structural members below.

c. Repairs: Emergency, Temporary, and Permanent

(1) Emergency repairs. Emergency repairs are sometimes done with duct tape, asphalt mastic or butyl tape with foil facing.

(2) Temporary repairs. A temporary repair would be to embed a piece of sheet metal in butyl sealant, screwed into the metal panel. The life of such a temporary repair will not match that of the rest of the roof.

(3) Permanent repairs. A permanent repair would be to install identical metal with corrosion resistant fasteners embedded in the proper sealant, or if the damage is extensive enough, to replace the affected panels.

d. Repair Work by User. Exposed sealant applied to laps, flashings, etc., that are suspected of leakage is not durable. The butyl sealants that are installed between metal panels are extremely durable because they are protected from sun exposure and dirt pickup. Recoating of metal panels is similar to painting metal in general. However, flexible membranes are sometimes installed over fasteners, laps, and penetration joints prior to coating.

e. Maintenance Checklists.

(1) Membrane. Inspect panels and seams for deformation damage. Use feeler gauge to determine if sealant is present under endlaps on wet side of fasteners (figure 9-11). Look for corrosion caused by the presence of ferrous materials, copper salts, or chemical aerosols.

(2) Flashings. Look for signs of buckling, wear, or fatigued fastening caused by inadequate provisions for expansion. Look for corrosion caused by improper fasteners or incompatible metals.

(3) Penetrations. Look for evidence of excessive thermal movement or damage caused by sliding snow and ice. Check the base of roof jacks (boots) for tightness.

(4) Ridges. Since low-slope metal roof panel systems generally expand towards the ridge, check ridge for damage. Check the ends of the ridge to see if movement along the ridge is accommodated.

(5) Gutters and Valleys. Remove debris; examine for corrosion and staining behind the gutter. Check for bent-over or open seams in valleys caused by moving snow. Check eaves for gaps and tears created by sliding snow and accumulating ice.

(6) Metal Trim. Examine for loose metal, backed out fasteners, and loss of sealant.

(7) Interior. Look for water stains or sagging insulation, which might be evidence of condensation or leakage. Remove sagging insulation and examine back of panels for evidence of corrosion.

(8) Exterior. Look for icicles or evidence of sliding snow, damaged fascia, gutter, or downspouts.

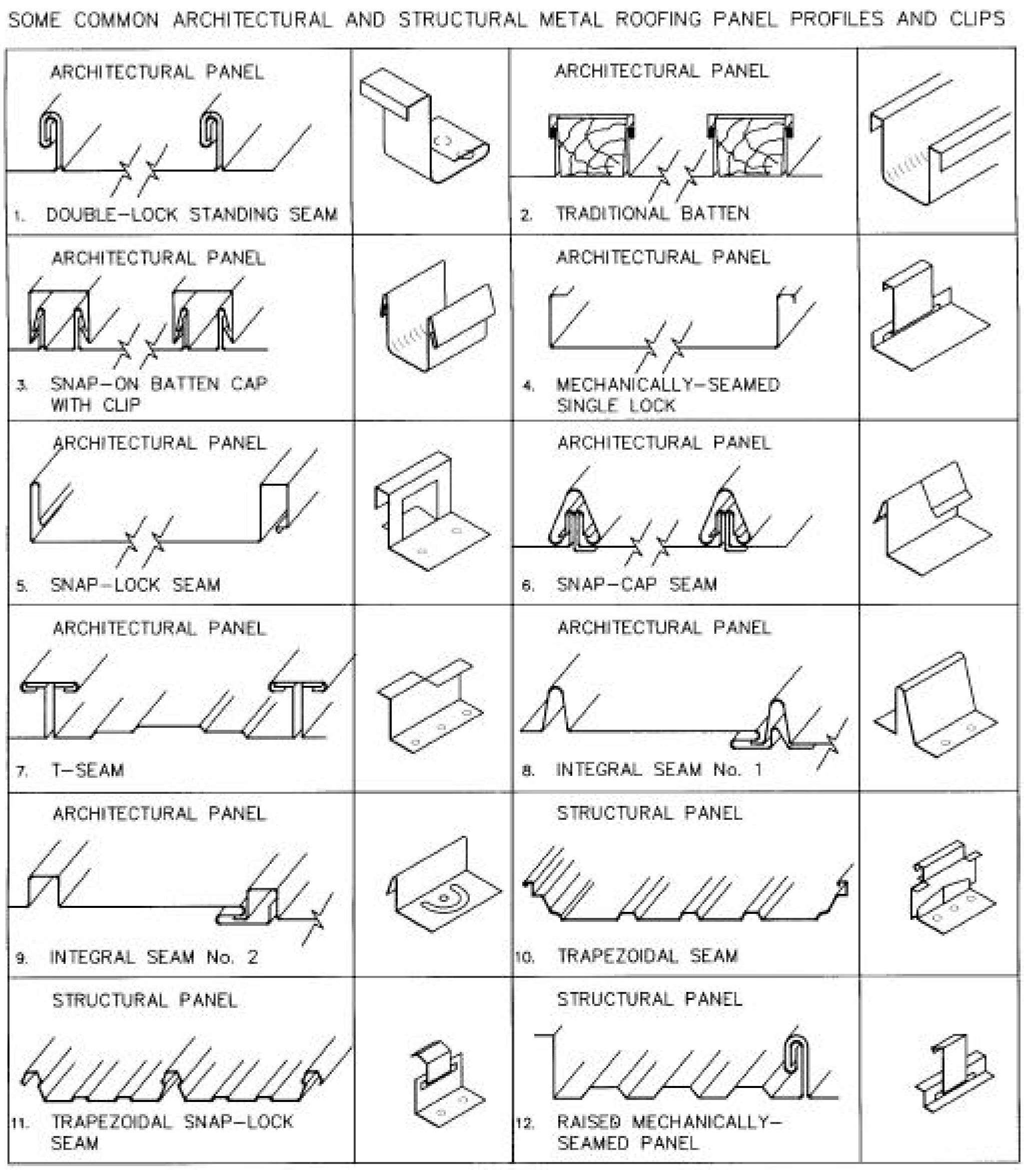


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Figure 9-1. Metal Roof Panels and Clips

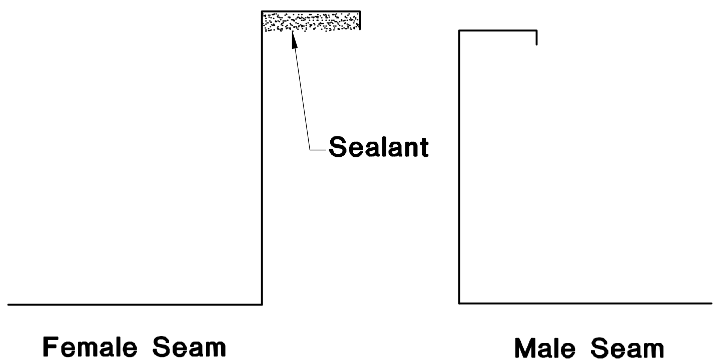
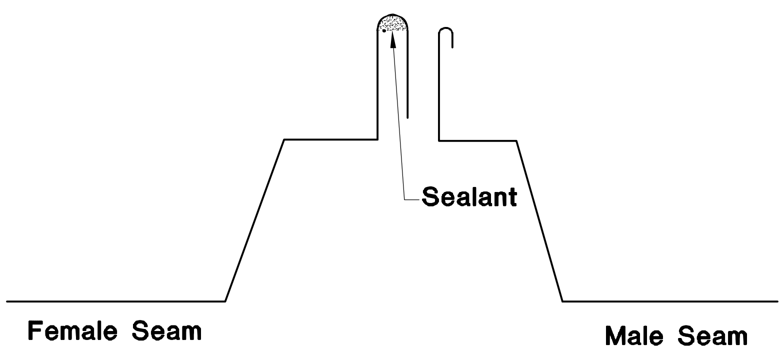


Figure 9-2a. Factory Sealant in Vertical Rib System



Note: If clip *tab* component interrupts continuity of seam sealant, the *tab* must receive field-applied sealant to restore continuity of the *hydrostatic* design.

Figure 9-2b. Factory Sealant in Trapezoidal Rib System

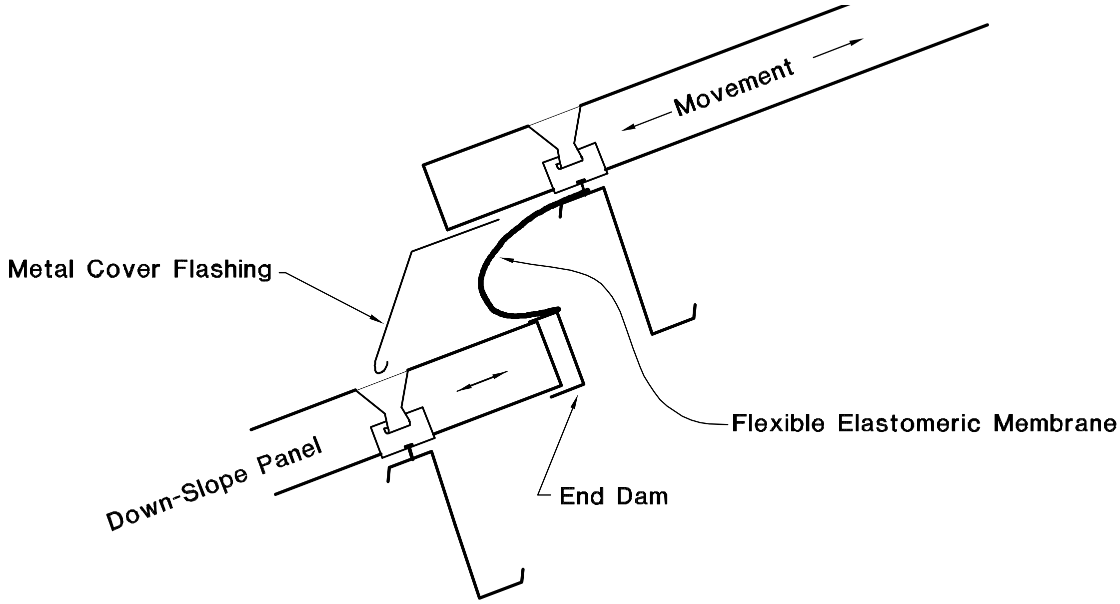


Figure 9-3. Expansion Joint with Step

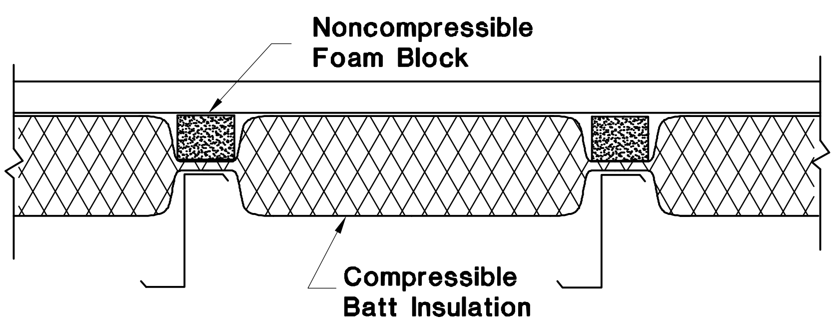


Figure 9-4. Rigid Foam Thermal Spacer Blocks

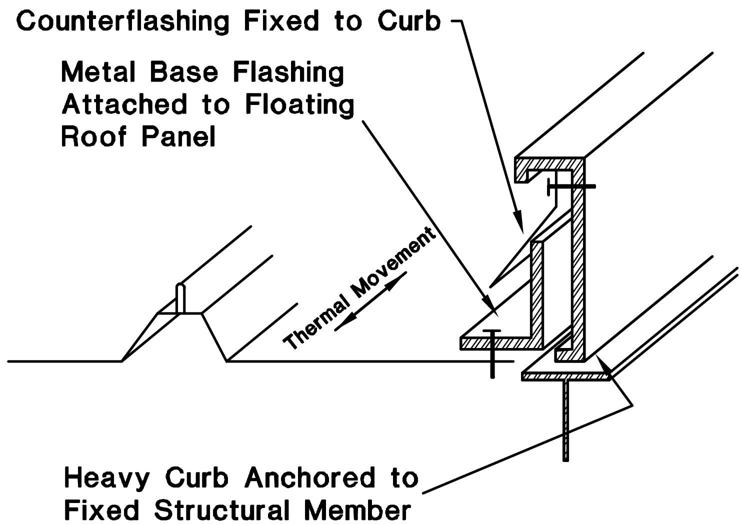


Figure 9-5. Fixed Curb to Support Heavy Rooftop Units with Floating Base Flashing

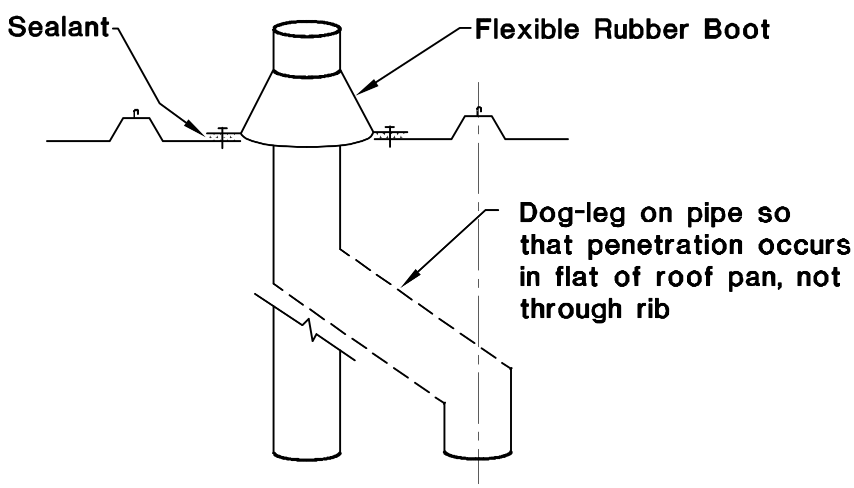


Figure 9-6. Pipe Penetration Boot for Standing Seam Roof Panel

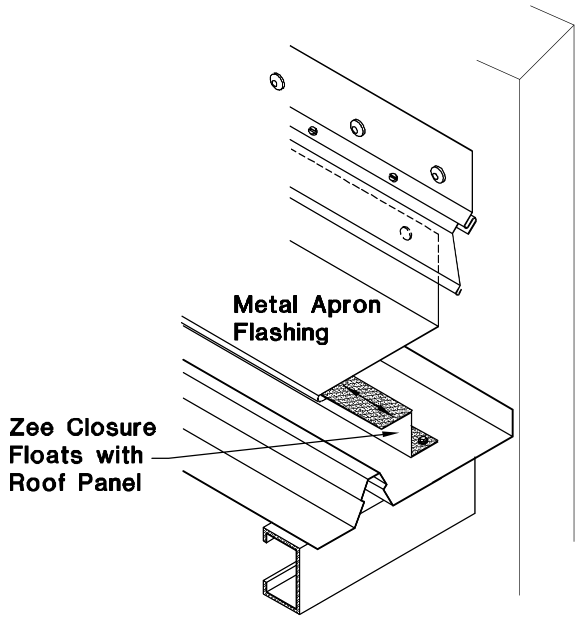


Figure 9-7. Wall Flashing with Wall Parallel to Panel Seams

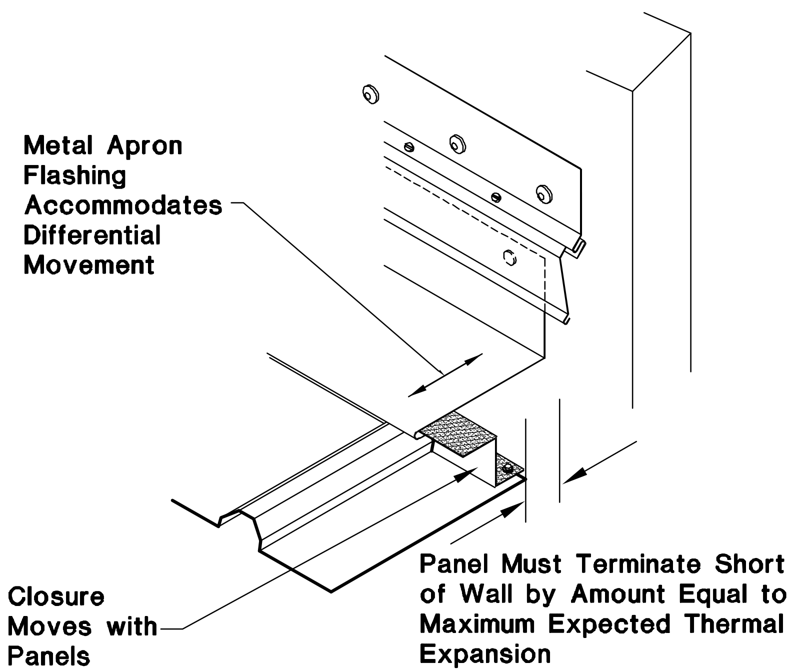


Figure 9-8. Headwall Transition

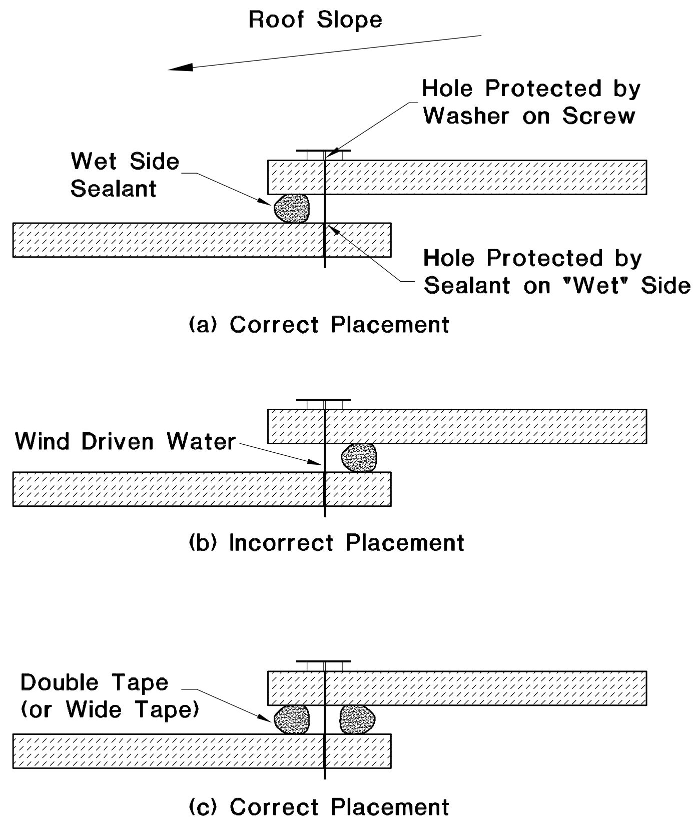


Figure 9-9. Placement of Endlap Sealant

CHAPTER 10

COPPER AND OTHER CRAFTED METALS
REFERENCE
CEGS 07610 (Copper Roof Systems)

10-1. COPPER AND OTHER CRAFTED METALS.

a. Overview. Copper, lead-coated copper, terne coated steel (lead-tin alloy), terne-coated stainless steel (TCS), zinc, and lead roofing are more formable and ductile than steel and aluminum panels and are generally used in crafted systems where hand forming and/or soldering is required (Table 10-1). Most are extremely durable with records of roofs in service for centuries. These metals tend to be relatively soft and are used in nonstructural applications where solid roof decking is used. Copper metal gradually changes from a bright metallic copper color to brown, and eventually green (*patina*). In areas of low air pollution (sulfur), lead, lead-coated copper and TCS may suffer from a red coloration (lead oxide) rather than the expected dark gray patina. Because of their high material costs and intensive labor requirements early historical uses of these metal roof systems were in cathedrals and civic buildings. Typically, small flat pans with folded edges are formed. Cleats engage the folded-over edge of the pan and are nailed to the substrate. The adjacent panel with a folded-under edge engages the installed pan concealing the installed clip (figure 10-1). On low-slopes the seams are soldered together for waterproofness. Crafted metal roofings are generally shop-fabricated by the contractor for each specific application rather than factory formed. However, some automatic pan formers and mechanical seamers are also used. Copper roofs include locked and soldered flat seam, standing seam, batten seam, and custom design.

Table 10-1. Properties of Crafted Metals

Metal	Fastener Compatibility	Ability to Solder, Weld, or Braze*	Corrosion Resistance/Durability	Weathering Characteristics of Unfinished Material
Copper	Copper, Brass, or Stainless Steel	Solder-Yes Weld-Yes	Limestone, stucco, concrete, and other light colored porous materials can show staining from moisture run-off from copper. Iron, galvanized metal, and acidic solutions from some trees can stain copper. Acid leaching from cedar roofing can impede patina development and in severe cases cause localized thinning of the copper. Bitumen and fire-treated woods containing salt are corrosive to copper. Copper should not be in contact with steel or galvanized steel.	Brown tones developing into a green-gray patina.
Lead-Coated Copper	Copper, Brass, or Stainless Steel	Solder-Yes	Used to avoid staining associated with copper. However, lead oxide can cause staining (see "Lead" below).	Dark gray to gray black.
Lead	Copper, Brass, or Stainless Steel	Solder-Yes Weld-Yes	Inert, atmospheric corrosion has little effect. Lead oxide can stain glass, stainless steel, and other materials. Lead is attacked by free lime (found in fresh concrete). Lead can be stained by rust from steel.	Dark gray to gray black.
Terne-Metal (Terne-Coated Carbon Steel)	Stainless Steel Cadmium Plated or Galvanized	Solder-Yes	Do not nail through metal; use cleats. Avoid contact with aluminum, copper or acidic materials. Must be painted.	Dark gray.
Terne-Coated Stainless Steel (TCS)	Stainless Steel	Solder-Yes	Does not stain.	Medium to dark gray.
Zinc	Galvanized or Stainless Steel	Solder-Yes	Not compatible with bituminous roofing materials. Copper generates a corrosion compound that attacks zinc. Sulfur dioxide inhibits the development of zinc's carbonate film. Wood preservatives can corrode zinc.	Dark bluish gray.

*When welding or brazing metal components, the gauge of the metal will affect the level of difficulty in achieving a proper weld (i.e., thicker materials are generally easier to weld or braze).

b. General. Crafted metal roof systems require a solid roof deck for support. Both underlayments and slipsheets are generally used. No. 30 asphalt saturated roofing felt (ASTM D226) is normally used as sheathing paper. Self-adhering polymer-modified bituminous sheet materials are also used (ASTM D1970). Rosin sized building paper is used as a separator and slipsheet.

(1) Climate/Weather. These systems are suitable for all climate conditions; however, careful attention to joints and details are necessary. Eave flashings and sealed underlayments are used where there is danger of ice damming. Self-adhering modified bituminous sheets can be used but the softening point of the bitumen must be greater than 93°C (200°F). Otherwise, the hot metal roof could cause bitumen drippage. Cold roofs in which the eave beneath the roof membrane is adequately ventilated can be used where eave icing and snow buildup are of major concern. Designs should include snow guards and steep slopes (generally 50% [6:12] or greater).

(2) Logistics. Crafted metals can be furnished to the shop or job site in coils or flat sheet stock. Portable roll formers are sometimes used to form panels.

(3) Familiarity with the System and Site. Crafted metals are a dying art. Master craftsmen are essential to successful installations. Experience of the installers should be part of the prequalification of the contractor.

(4) Life Expectancy. Many of these systems have a documented life in excess of 100 years. Crafted systems use expensive metals as well as considerable labor. These costs are normally justified by a strong desire for the roof's particular appearance and longevity. The metals are recyclable.

10-2. BUILDING ELEMENTS.

a. Slope. Crafted metals have been used from 2% (1/4 in./ft.) to vertical.

b. Low-Sloped Roofs. At flat or lowest recommended slopes, locked and soldered flat seam design provides waterproofness. Some architectural systems use waterproof underlayments to lower the permitted slopes. Provision should be made for any water that reaches the underlayment to weep out on the down-slope side.

c. Steep Roofs. At slopes well above the minimum recommended slope, watershedding provides adequate water protection and sealed underlayments are omitted (except where ice damming is likely).

d. Structural Considerations. Some of these systems such as lead are very heavy and the weight must be considered in the overall design.

e. Expansion and Seismic Joints. Roof panel expansion joints are formed of intermeshed hooked flanges not less than 25 mm (1 in.) deep. Membrane expansion must be part of the roof design. Refer to *Copper and Common Sense* for a discussion. Structural expansion joints generally utilize raised curbs. For roof runs that exceed 9 m (30 ft.), expansion cleats should be used. Over 14 m (45 ft.), expansion joints are necessary.

f. Re-entrant Corners. (See SMACNA, Revere *Copper and Common Sense*, and NRCA Manuals for details.)

g. Roof Access. Steep roof systems utilizing crafted metals normally will not accommodate mechanical equipment and associated rooftop traffic. Designs may incorporate a flat roof area hidden from view by mansard roofs. This hidden roof area may utilize membrane roofing rather than more expensive metal roofing. This equipment area requires easy access preferably by an internal roof hatch.

h. Roof Venting. Steep roof configurations are relatively easy to ventilate when an attic space is present below the deck or by airways created in a cathedral ceiling. Inadequate ventilation may cause moisture sensitive roof decking to expand, buckle, or degrade. In general, half of the required net free ventilating area should be placed at the eaves through means of soffit vents, and half at the ridge through ridge or gable vents to take advantage of the chimney draft. Condensation on the underside of terne metal can result in corrosion and painting the underside is recommended prior to installation. Zinc metal must have underside venting to avoid *white rust* corrosion.

i. Roof Decks. Plywood and Oriented Strand Board (OSB) are commonly used. There have been problems with fire retarded plywood (degradation due to accumulated heat and moisture). When fire retarded plywood is necessary the APA recommends AWPA C27 low hydroscopic Interior Type A fire retardant be used. Lumber and plywood in contact with copper should be non-treated or have a *non-corrosive* fire retardant.

j. Underlayment

(1) Functions. The underlayment can keep the deck dry until the roofing is installed. It also provides secondary water resistance for unsoldered systems. Sealed underlayments can reduce leaks from wind driven or ice-dam water which may back up under the panels. The underlayment and rosin paper forms a cushion for the clips and fasteners.

(2) Icings. At eaves and other locations where ice dams could cause temporary water backup felts can be sealed together with asphalt mastic, or more commonly, a self-adhesive modified bituminous sheet meeting ASTM D1970, or a plastic sheet conforming to ASTM D4397. The self-adhesive sheets have the advantage of forming a watertight seal where roofing fasteners penetrate the sheet. Self-adhesive sheets should have a melt point above 200°F to avoid bitumen melting.

k. Vapor Retarders. If poly film is used as a vapor retarder, a fully compatible tape with equal or better water vapor permeance must be used. Under most conditions with steep roof system designs, the vapor retarder will be on the attic floor slowing (but not completely stopping) moisture penetration into the insulation. Unfortunately, most vapor retarders are not very effective at stopping air exfiltration as little attempt is made to seal them at edges and penetrations. However, in more severe cases or for high humidity buildings it is essential to severely limit air exfiltration. If a separate cold-side air barrier is used, it should have a *high* vapor permeability.

l. Penetrations. Round pipe penetrations through the metal roofing are handled with soldered cones or formed metal sleeves. Refer to SMACNA, CDA, Revere Copper and Common Sense, and NRCA manuals for details. Hot pipes are flashed using isolation details (see NRCA and SMACNA manuals for details).

m. Historical Roof Restoration. Since by definition steep metal roofings are very visible, efforts should be made to retain historical accuracy. In many cases lighter metals can give a less expensive replica of the original metals. Artificial patination is sometimes done to help match the appearance of adjacent panels but natural weathering will give the best match. See the Copper Development Association's *Copper in Architecture* for discussion. Also refer to the SMACNA reprint of its 1929 *Standard Practice in Sheet Metal Work*.

n. Aesthetics. In addition to the rich color of many of these crafted metals various batten and seam techniques give the designer a wide number of choices. See CDA, SMACNA, *Copper in Common Sense* and NRCA manuals for illustrations.

o. Gaps, Flashings, Joints, and Sealants. Each system has specific details for hip and ridge closures. References include NRCA, SMACNA and *Copper and Common Sense*. Elastomeric sealants, caulks and closure components should not be relied upon for roof integrity; these materials will not have life expectancies consistent with these metals. Some sealants are incompatible with copper. Acid curing silicones may be unacceptable. Verify compatibility with the manufacturer for sealant recommendations. Endlaps must be designed for thermal movement.

p. Drainage, Valley and Intersection Details

(1) Drains and Gutters. Roof drainage systems are discussed in detail in Chapter 1 of the SMACNA *Architectural Sheet Metal Manual*. Gutters are also discussed in detail in *Copper and Common Sense.* Two distinct types are described:

(a) Built-in gutters may be installed level for strength. Maximum safe distance from any fixed point such as outlets or downspouts depends upon cross section shape and thickness of the copper used. See chart in *Copper and Common Sense*.

(b) Hung molded gutters should be 20 ounce copper with expansion joints not more than 48 ft apart, 24 ft from corners. Spike and ferrule method is not recommended.

(c) Roof gutters should be designed so the front edge of the gutter is lower than the back and any overflow will spill over the front of the gutter. The elevation difference should be 1/12 of the gutter width, 25 mm (1 inch) minimum.

(2) Sliding Snow. Snow guards are necessary on most steep metal roofs in cold climates subjected to snow accumulation.

10-3. DESIGN CONSIDERATIONS.

a. Guide Details/Resources. Guide details are provided in the SMACNA *Architectural Sheet Metal Manual*, the NRCA Metal Roofing Section of their *Roofing and Waterproofing Manual*, *Copper and Common Sense* by Revere Corp., and the Copper Development Association *Copper in Architecture*.

b. Substrates. The surface to receive the metal roofing should be dry and smooth, free from projecting nail heads or other obstructions. The underlayment should be No. 30 saturated roofing felt (ASTM D226) lapped at least 50 mm (2 in.) and secured with copper, brass, or Series 300 stainless steel. A layer of smooth building paper should be laid over the felt immediately preceding the application of the metal roofing.

c. Nailers. When decks other than plywood are used, it may be necessary to provide wood nailing strips for securing cleats. The nailers are run perpendicular to the standing seams and spaced 300 mm (12 in.) apart.

d. Pan Clearance. When standing and batten seam pans are used a minimum of 1.6 mm (1/16 in.) space should be allowed between the base of adjacent pans.

e. Low-Slope Locking Strip. For slopes between 8% (1:12) and 25% (3:12) the transverse seam of the upper panel is locked into a locking strip soldered to the lower pan. For steeper slopes (>25%) the separate locking strip is not used (figure 10-2).

f. Military References/Guide Specifications. Refer to CEGS 07610-Copper Roofing.

10-4. CONSTRUCTION CONSIDERATIONS.

a. General. The skill of the applicator is extremely important to *crafted* metals. Knowledge of techniques and possession of correct tools is needed.

(1) Zinc. Zinc metal cannot be formed or bent at temperatures below 5°C (40°F).

(2) Solder. Soldered seams should be uniform and neat with a minimum of exposed solder.

(3) Cutting. Cutting of panels by torch is not permitted.

b. Pre-roofing Conference. It is strongly recommended that a pre-roofing conference be held prior to construction. Representatives of the designer, user, roofing contractor, general contractor, materials manufacturer, field inspectors and other related subcontractors should be present.

c. Shop Drawing Submittals. Submittals for historical restoration should indicate attempts to match the original material. The use of cold rolled copper will permit replacement of the original heavier copper with thinner, stronger sheets.

d. Design Submittal Requirement, Checklists and Design Alerts. Design and erection drawings of the system should be provided containing data necessary to clearly describe design, materials, sizes, layouts, seam configuration, construction details, provisions for thermal movement, line of panels, fastener sizes and spacing, sealants, and installation procedures. Coordination checklists. Numbers in parenthesis refer to CSI Masterformat number system (1995 edition).

(1) Concrete substrates should be made smooth with a wash of neat cement (CEGS 07610). Refer to the *substrate* section of the NRCA *Roofing and Waterproofing Manual, Metal Roofing Systems*.

(2) Underlayments should be designed so that any water that penetrates below the metal roofing panels will drain outside of the building envelope.

(3) Snow guards (07720). Specified if needed?

(4) Gutters (07710). Expansion joints, slopes, materials and details—are gutters sloped towards leaders (exception for box gutters)? For lengths over 10.7 m (35 ft), are two downspouts used? Is outer face of gutter lower than roof face so that overflow is away from structure? Are wire strainers provided at leaders?

(5) Downspouts and Rain Water Leaders (07710). Are strainers specified for leaders? Splash blocks specified? Leaders firmly anchored to structure?

(6) Materials. Sheet metal (07610). Preformed metal roofing (07412)

(7) Plumbing stacks (15405). Where snow is likely to slide are stacks placed near or at the ridge or protected by diverters?

(8) Roof mounted HVAC (15650/15800).

(9) Chimneys. Masonry (04210). Prefab (10300). Flashing (07608). Are saddles, crickets installed to divert water flow around projections?

(10) Solar heat collection panels (13980). Solar water heaters (13980/15431).

(11) Prefabricated roof specialties. Steeples (10341). Spires (10342). Cupolas (10343)

(12) Anchorage. Fasteners, cleats as specified? Metals compatible? Fasteners long enough for specified penetration? (Min 12 mm [1/2"] into [or all the way through] decking). High wind or seismic details applicable?

e. Field Review and Observation.

(1) Seam Formation and Soldering. Flat pans require pre-tinning prior to application. After seam engagement seams should be malleted or dressed down and thoroughly sweated full of solder.

(2) Sealant. If sealant is specified, observe that specified sealant is used and is compatible with the metals used.

(3) Valleys and Drains. Valley construction is critical. Review details and specified lapping.

10-5. MAINTENANCE CONSIDERATIONS.

a. General.

(1) Joints. Thermal expansion can cause fatigue of intersections where sufficient clearance has not been provided. Soldered joints provide little strength. Use rivets for strength and solder for waterproofing.

(2) Corrosion. Corrosion caused by contact with dissimilar metals requires replacement with compatible materials or the use of separators.

(3) Housekeeping. Cleaning gutters every spring and autumn is beneficial to all sloped roofing systems.

b. Repair or Replace. The systems discussed in this Chapter are extremely durable and most decisions will be to repair rather than replace. All the metals are valuable and recyclable.

c. Repairs: Emergency, Temporary, and Permanent.

(1) Emergency repairs. Emergency repairs would imply loss of watertight integrity. An emergency patch could consist of self-adhesive EPDM or MB materials, roofing felts, a plastic film, or metal plate set in asphalt mastic.

(2) Temporary repairs. A temporary repair would be to install metal of similar form even if the appearance does not visually match the rest of the roof.

(3) Permanent repairs. A permanent repair would be to install identical material making certain that new material is installed as appropriate for the original system.

d. Repair Work by User. A common repair would be at a penetration or flashing that has loosened or failed. Each type requires specific skill. See the SMACNA manual for recommended details and proper gauges of metal for various applications.

e. Corrosion. *Corrosion* may be due to galvanic action such as from the use of the wrong fasteners. Replace with copper, stainless, brass, etc., as recommended in the SMACNA Manual. Water flow from up-slope copper roofs or flashings that contain copper salts will be corrosive to zinc and zinc-aluminum coated steel.

f. Maintenance Checklists.

(1) Joints. Transitions, penetrations, and flashings are subject to damage from movement, wind, and foot traffic. Panel splices may be subject to leakage if roof traffic causes stress or distortion.

(2) Fasteners. Fasteners are subject to back out; washers to weather degradation or overtorquing. Replace when necessary.

(3) Recoating. Terne coated metal requires field coating for corrosion protection. Recoat as needed. (TCS does not require field coating.)

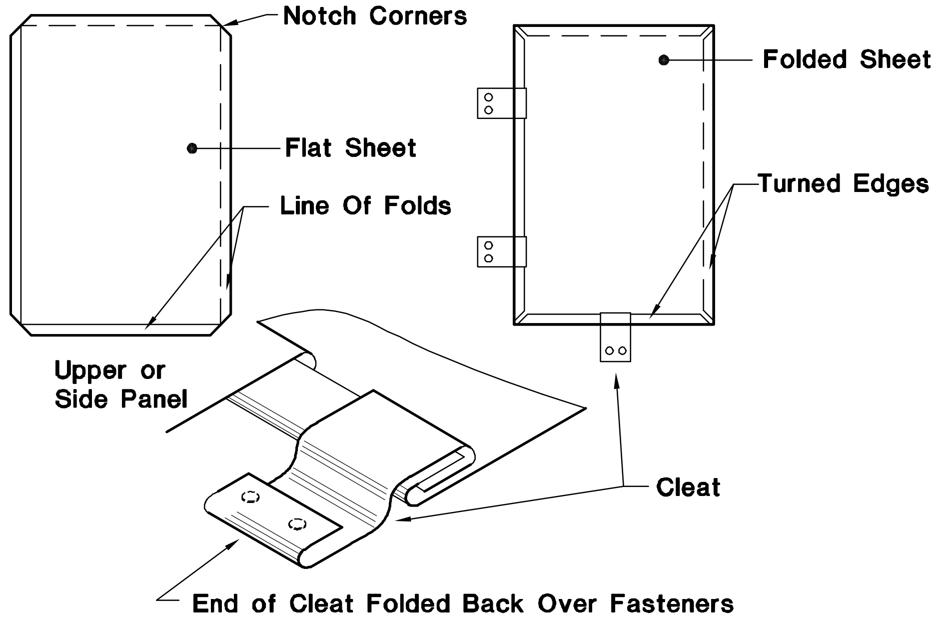


Figure 10-1. Flat Pan Roofing System

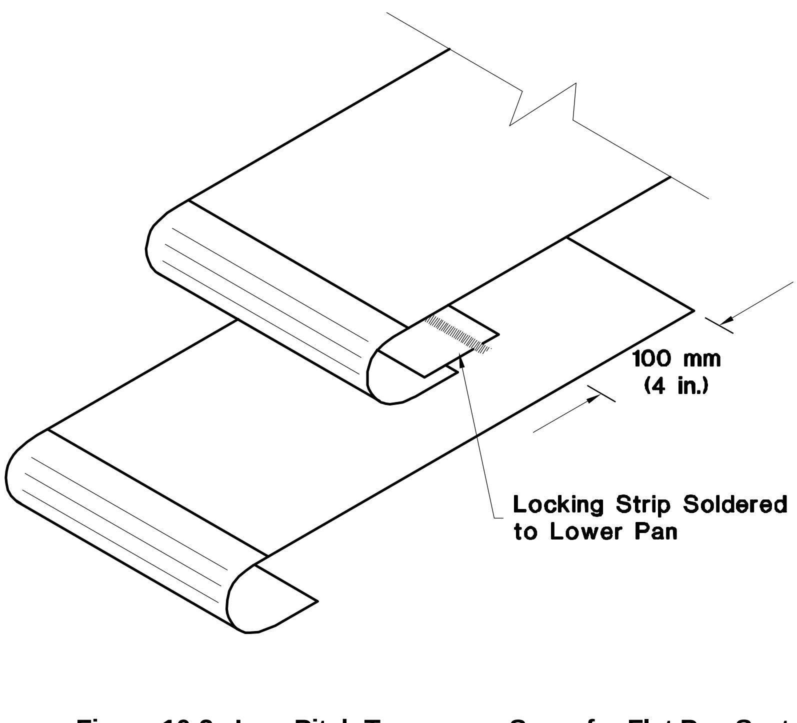


Figure 10-2. Low Pitch Transverse Seam for Flat Pan System

CHAPTER 11

REROOFING CONSIDERATIONS AND CRITERIA

11-1. OVERVIEW OF REROOFING. Eventually every roofing system will reach the end of its economic life. Reroofing options include *removal and replacement*, *re-cover* (where a new system is superimposed over what is already there), and *partial replacement.* Reroofing decisions begin with a careful survey of existing conditions. This may include visual inspection, moisture surveys, and roof cut analysis. Structural analysis may also be in order especially if a different type of roof is contemplated which changes dead load, drainage, or seismic behavior. Reroofing is both a problem and an opportunity. It is a problem because work has to be done on an occupied structure. There are concerns with noise, fumes, access, and interruption of use. It is an opportunity as there is no better time to upgrade the roof. These changes may be mandated by revisions to ANSI/ASCE 7-95 for calculating loads or by needed improvement in drainage or thermal performance. It is an opportunity to elevate or redesign problem roof elements, to install deck supported curbs that are flashed independently of the wall (resolving persistent flashing problems due to differential movement) and to resolve condensation problems or thermal insulation deficiencies.

a. General. Reroofing of poorly draining low-slope roofs may take the form of adding structural members (and a new deck if needed) and converting to a steep roof (refer to USACERLTechnical Report M85/05 Steep Roof Conversions) for small, flat-roof buildings. However, slope conversions are often more expensive than in-kind reroofing. There are a number of *pressures* that push for leaving a troublesome existing roofing system in place. It is important to remember the best thing to do technically is remove the problem rather than build up on it. It is wrong to re-cover over wet or deteriorated materials.

(1) SSSMR for Slope Conversion. Metal roofing is frequently selected for steep roof conversion since new lightweight structural members easily accommodate increased slope requirements; the new metal roof does not need a new deck (figure 11-1). FM Data Sheet 1-31 expresses concerns related to fire hazards when creating an attic space with metal roofing. Metal roofing can be installed over existing metal roofing.

(2) New Trusses and Decking. Adding trusses or rafters and a nailable deck permits the use of conventional steep roofing. Steep roof conversions can be both costly and cost effective.

(3) Recovering Steep Roofing. Re-covering of steep roofing such as asphalt shingles is easily done. Building codes permit either one or two direct recovers with missing shingles replaced first and curled shingles flattened. Generally, underlayment is not required in shingle re-covers. Wood shakes are not a suitable substrate for new shingles or shakes but wood shingles (which are flatter) can be acceptable if they are still sound.

(4) Recovering Existing Bituminous Flat Roofing. Re-cover of existing built-up and modified bitumen roofing may take the form of mechanically or spot attaching a base sheet (to aggregate-free substrates), or mechanically or spot attaching re-cover insulation when aggregate is present (where only the loose aggregate is removed). Full attachment to an old troubled membrane is never recommended.

(5) Recovering Existing Single-Ply Systems. When re-covering old single-ply systems it is preferred that the old membrane be removed especially if it is shrinking or otherwise experiencing dimensional instability. Otherwise, it may drag and distort the new membrane. At this time most plastic and rubber membranes are not recyclable.

Table 11-1. Typical Code—Allowable Reroofs Over Existing Roofing
(Inspection and Written Approval Required by Code Official Prior to Application)

	New Overlay Roofing							
	Built-Up	**Wood Shake**	**Wood Shingle**	**Asphalt Shingle**	**Tile Roof**	**Metal Roof**	**Modified Bitumen**	**SPF**
Existing Roofing								
Built-Up	Yes	NP	Yes (3:12)	Yes (2:12)	Yes (2.5:12)	Yes	Yes	Yes
Wood Shake[1]	NP	NP	NP	NP	Yes[2]	Yes[2]	NP	NP
Wood Shingle[1]	NP	Yes[3] (4:12)	Yes[4]	Yes[4]	Yes[2]	Yes[2]	NP	NP
Asphalt Shingle[1]	NP	Yes[3] (4:12)	Yes[4] (3:12)	Yes	Yes (2.5:12)	Yes	Yes	NP
Asphalt Over Wood	NP	NP	NP	Yes	Yes[2]	Yes[2]	Yes	NP
Asphalt Over Asphalt	NP	NP	NP	Yes	Yes	Yes	Yes	NP
Tile Roof	NP	NP	NP	NP	NP	NP	NP	NP
Metal Roof	NP	NP	NP	NP	NP	Yes	NP	NP
Modified Bitumen	Yes	NP	Yes (3:12)	Yes	Yes (2.5:12)	Yes	Yes	NP

NP = Not Permitted
Note: (Minimum Roof Slope)
[1]See specific requirements
[2]Board and batten leveling system must be firestopped
[3]One layer 500 mm (18-in.) Type 30 nonperforated felt interlaced between shake courses required.
[4]Type 30 nonperforated felt underlayment required for reroofing.

b. Climate/Weather. A complete tear off requires good weather as the building is occupied and nightly tie-offs are not perfect. The demands of protecting the building sometimes result in accepting phased construction especially when a thicker insulation system is being added and it is unfeasible to run from eave to ridge in a single day.

(1) Nightly Seal-Off of New Penetrations. When new structurals are added it is necessary to carefully seal where the anchor bolts penetrate the old roof system. This seal might be little more than asphalt mastic (figure 11-2). Verify that the old drains are in working order until the new sloped roof and associated drainage system is completely functional.

(2) Upgrading Insulation. Adding new insulation and/or an air space above the existing roof will change snow-melting characteristics and will generally reduce, not create vapor condensation problems.

c. Logistics. Tear off is complicated especially if asbestos-bearing materials are present or if landfill or recycling rules and regulations require separation of construction materials. Chutes are efficient for material removal provided that dust management is used. Vacuuming of aggregate-surfaced roofs prior to tear-off removes a great deal of surface dirt as well as loose aggregate. Staging of new materials is difficult when existing materials are being torn off. Protecting the newly applied membrane from tear-off debris and construction traffic is critical.

d. Familiarity with the System and Site. Safety is of paramount importance. Occupants must be protected from fumes by coordinating the shut down of air handling units. Areas where roofing work is taking place directly overhead must be cordoned off especially if deck repairs are taking place. Entrances to the building must be protected from falling materials. Underground tanks and the like must be identified so that heavy vehicles do not overload these areas.

e. Life Expectancy and Costs. It is likely that a re-cover will not last as long as a total tear-off and replacement. Avoidance of a tear off is cost effective but re-cover is limited by most codes to one or two layers so eventually total roof replacement must be faced. Costs are greatly affected by ease of access, whether slope buildup is necessary, and mechanical equipment must be raised for access. Reroofing is an excellent time to remove obsolete equipment and stacks from the roof.

f. Occupancy Considerations.

(1) Protecting the Building. Reroofing invariably means disruption of building operations. For some sensitive occupancies (e.g., top floor computer rooms, surgical suites, laboratories or telephone equipment) a total tear off may be an unacceptable risk. In design of such buildings it is prudent to install a secondary roof membrane and drainage at the deck level. This membrane keeps the building in the dry in the event of leaks in the primary membrane as well as during roof replacement. It can also serve as a vapor retarder.

(2) Deck Replacement. If deck replacement is necessary the operations beneath will require shut down for safety and leakage reasons. It also may be impossible to maintain HVAC services, humidity control, and air exchange with the building open.

g. Low-Sloped vs Steep Roofs. The presence of an attic space provides separation of construction activities from the interior of the building. On steeper slopes scaffolding may be a major construction item as well as protected access to the building.

11-2. BUILDING ELEMENTS.

a. Slope. The first decision is whether a watershedding or waterproof system is wanted.

b. Low-Sloped Roofs. Recessing internal drains is beneficial. It may be appropriate to add crickets to divert water away from curbs and flashings towards drains.

c. Steep Roofs. It is important to give special attention to flashing and valley design. Interior gutters are a problematic feature, particularly for metal systems.

d. Structural Considerations.

(1) Adding Weight. Addition of new structurals or using a replacement roof that is much heavier than the previous requires analysis by a structural engineer. Re-cover and reroofing operations add significant weight to a structure.

(2) Deck Integrity. At the time of reroofing, the existing deck should be carefully examined to verify that it is capable of receiving a new roofing system. Damaged decking must be replaced or repaired and loose decking reattached. Tear-off down to the deck permits careful examination of the deck, re-

covering does not. Pull-out capacity of fasteners should be determined per TI 809-29 Paragraph 7.k or SPRI recommended practice.

(3) Upgrading. Review of ANSI/ASCE 7-95 may indicate that strengthening of the system is required to meet new load requirements. Consider adding new roof- or overflow-drains.

(4) Rooftop Equipment. Assess whether rooftop equipment can be relocated or removed. Consider raising the height of curbs to accommodate thicker insulation or changes in slope.

e. Expansion and Seismic Joints.

(1) Roof Joints. Are existing joints adequate? Are more needed? Consider adding new joints where differential movement or stress accumulation has been noted.

(2) Fire Stop at Joints. If a steep roof conversion is done which bridges an existing structural expansion joint and now places it within the newly created attic space, it may be necessary to convert the joint into a fire stop. Refer to Factory Mutual Loss Prevention Data Sheet 1-31 for details.

f. Re-entrant Corners. Examination of the existing system will help establish whether area dividers are needed at these locations.

g. Roof Access. If access has been inadequate, this is the time to improve it. In addition, attic spaces created in slope roof conversions may require access if the attic height is 760 mm (30 inches) or greater.

h. Roof Venting. Ventilation of attics and cathedral ceilings is often appropriate to control building moisture. When reroofing steep systems the attic space must be examined for evidence of condensation problems as well as roof leakage. Continuous intakes along eaves in combination with soffit vents are quite effective. Most compact low-slope membrane roofs should not be ventilated.

i. Roof Decks. When the existing deck is to be reused it should be examined for conditions. Refer to *Structural Safety Issues in Reroofing* in ORNL CONF-9405206.

j. Underlayment. In steep roof designs such as with tile and slate, the underlayment may be the first element to fail. Replacement along with deck repair may permit reuse of the tiles or slates. In membrane re-cover, use re-cover boards to separate the new membrane system from the old.

k. Vapor Retarders. Examination of the existing system may be the best way to decide what is needed when reroofing. Existing vapor retarders may be poorly attached, may not have edges sealed, or may be full of holes. Consider installation of new retarder either at deck level or on top of a new thin layer of rigid underlayment board.

l. Thermal Insulation and Heat Flow. Most existing buildings are underinsulated by today's energy standards.

(1) Reinsulating of Attics. For steep roofing systems with an attic space insulation can be superimposed over existing insulation. The new materials should be *unfaced* to avoid creating a second vapor retarder. However, installing a vapor-permeable air barrier may be beneficial. Care should be taken to keep the insulation from blocking attic ventilation airways at eaves.

(2) Separator Board of Membrane Roofing. For low-slope roofing systems, if additional thermal resistance is not needed, a thin re-cover board may be used to separate the old roof system from the

new. This might be rigid glass fiber, perlite, or wood fiber board mechanically attached or mopped to an old bituminous roof system.

(3) Upgrading Thermal Insulation for Low-Slope Roofing. If additional thermal insulation is needed rigid foam plastic insulations are highly efficient. Compatibility with the new roof system is of primary concern.

(4) PMR Conversion. It may be feasible to convert a conventional low-slope roof to a protected membrane by adding extruded polystyrene foam insulation (XEPS), a filter fabric, and ballast on top of the existing system. A structural analysis is required if dead loads will increase. Lightweight insulation/paver composites are available to reduce the amount of dead load added.

m. Membranes. For low-slope systems, compatibility may be an important design factor. For example, if existing walls and penetrations are contaminated with bitumen it may be simpler to use a bituminous re-cover rather than to install separators to keep the incompatible membrane and flashing materials apart. Membrane choice may also be determined by the nature of the problems with the roof system currently being replaced.

n. Penetrations.

(1) Upgrading Roof Details. Reroofing is an excellent time to replace pitch pockets and other high maintenance items with more durable details such as curbs with removable, watershedding covers. The NRCA construction details provide examples.

(2) Maintaining Ventilation. When a steep roof conversion is done, existing roof vents must be extended through the new roof system.

o. Historical Roof Restoration. CEGS 02226 covers the requirements for removal and salvage of historic building materials. Often it is appropriate to carefully remove and reuse terra cotta, clay tile trim, cast architectural ornaments, slate tiles, clay tiles, gutters, leaders, and downspouts. Replacement materials can be expensive and difficult to obtain.

p. Aesthetics. Reroofing affords an opportunity to maintain or upgrade roof appearance. This EI has touched on the many roof choices available to the designer. Examination of the existing system may suggest secondary problems such as wind scour, chemical attack, corrosion or the like that should also be resolved.

q. Gaps, Flashings, Joints, and Sealants. Reroofing may solve problems caused by failure or inappropriate use of these elements.

r. Drainage, Valley and Intersection Details. Reroofing is an excellent time to improve on these critical elements by adding crickets or saddles.

11-3. DESIGN DETAILS AND ALERTS.

a. Assessment. Reroofing and re-cover require a careful analysis of existing conditions. Assessments should include:

(1) Roof Deck

(a) Steel: Rusting? Differential deflection at side or end laps? Excessive deformation? Sound welds?

(b) Wood: Rotting? Warped? Shrunk? Excessive joint gaps? Unanchored?

(c) Structural Concrete: Excessive deflection or wide cracks? Sharp *fins* (raised knife-like edges or folds in the concrete)?

(d) Precast Concrete: Excessive joint gaps? Differential deflection at adjacent units?

(e) Poured Gypsum: Excessive deflection of subpurlin bulb tees? Cracking? Evidence of excess moisture or loss of binder strength? (Can create a reroofing hazard.)

(f) Adequate fastener withdrawal resistance?

(g) Corrugated Steel Supporting Lightweight Insulating Concrete: Underside venting slots present? Efflorescence at slots or laps?

(h) Structural Wood Fiber: Excessive deflection? Differential deflection between adjacent units? Excessive joint gaps? Evidence of moisture degradation or loss of binder?

(2) Roof Insulation.

(a) Use destructive tests (roof cuts) to determine condition and attachment of components.

(b) Conduct moisture surveys using infra-red (IR), nuclear, or capacitance techniques.

(3) Rooftop Assessment.

(a) Ponding? Drains plugged? Drains located properly, not blocked by curbs?

(b) Flashing height adequate? Flashing damage? High enough to accommodate increased insulation or slope?

(c) Evidence of accumulated stress at re-entrant corners, flashings, penetrations, or joints?

(d) Punctures or repairs indicating chemical attack, abuse or excessive roof traffic?

(e) Equipment mounted properly? Clearances adequate?

b. Roof Replacement.

(1) Can a new system comply with Factory Mutual, UL, and other requirements?

(2) Are all flashings to be replaced?

c. Roof Re-cover.

(1) Should new membrane be isolated from existing? Should loose aggregate be removed? Has a moisture survey or core cutting revealed wet insulation?

(2) Is the structural design capable of supporting the weight of an additional roof system?

11-4. CONSTRUCTION CONSIDERATIONS AND ALERTS.

a. General. The big difference between reroofing and new roofing is the fact that the building is now occupied. The designer must not only consider the technical aspects of the new roof but disturbance and safety considerations as well. Appendix 11-1 provides examples of concerns that must be addressed in a reroofing project.

(1) Hidden Damage. It is likely that previously undetected substrate damage will be discovered during the tear off. Replacement decking and lumber for curbing should be readily at hand.

(2) Construction Damage. Control of debris is difficult. Routes for demolition should avoid tracking over newly applied roofing.

(3) Substrate Integrity. Re-covering requires a sound deck and adequate adhesion of the existing system (unless the new system will be fastened through the old system). The existing insulation must be strong enough to withstand construction loads and must not be wet.

(4) Weather. Anticipate bad weather. Tear-off only as much area as can be completely replaced that day.

(5) Fasteners. Verify that fasteners are penetrating the deck as specified. On steel decks, fasteners should penetrate the top flange of the deck, not ribs. Run pull out tests to confirm specified withdrawal strength.

(6) Through-Fastening. Installation of new structurals for conversion to standing seam metal roof requires anchorage into building structural members. Penetrations must be sealed daily.

b. Pre-roofing Conference. A conference should be held prior to construction. Representatives of the designer, user, roofing contractor, general contractor, materials manufacturer, field inspector and other related subcontractors should be present. Discussions should include protection of the new membrane after installation and how nightly water cutoffs will be installed. (Refer to suggested Agenda Items in Appendix 11-1.)

c. Shop Drawing Submittals. Drawings of intersections of expansion joints, curbs, edging, flashing and coping should be required. These should be dimensioned, not copies of manufacturer’s standard details.

d. Design Submittal Requirements and Checklist. The reroof system should be provided as a complete system, including anchorage through the existing system if applicable, fire ratings for total roof system (re-cover and existing), replacement of base flashings, reuse of counterflashing metal, and separation of new and old work.

(1) Manufacturer Acceptance. Require the manufacturer to verify in writing that the proposed system is compatible with the roof deck, vapor retarder, insulation and is appropriate for this specific application.

(2) QA Inspections. On major roofing projects require quality assurance inspection.

(3) Code Compliance. Require evidence of compliance with fire ratings, wind loads, or other specified code requirements.

(4) Metal Reroofing Checklist.

(a) If installing a new metal roof over an existing metal roof, design should indicate method of anchoring the new system.

(b) Verify compatibility of metals especially if existing structures use copper copings, eaves or flashings.

(c) Field testing on the actual roof should confirm pull-out strength of the fasteners planned for the new roof system.

(d) Penetrations must be extended through new metal panel roof. Use oversize holes with flexible boots to accommodate movement of panels. Penetrations must pass through the flat portion of panel, not the standing seam.

(5) Nonmetal Checklist.

(a) Loose-laid Ballasted Single Ply Checklist

1/ Check for compatibility problems.

2/ Establish ballast retention methods at eaves, drains and scuppers.

3/ Determine quantity and size of ballast required for corners, perimeters and field.

4/ Verify that roof edge height conforms to ANSI/SPRI RP-4 recommendations.

5/ Verify that river washed rounded ballast is available. If crushed stone is used, is stone-mat used for membrane protection?

(b) Bituminous (BUR and MB) Checklist:

1/ If bituminous adhesives will be used verify that the existing roof surface is free of dirt and loose gravel.

2/ If mechanical fasteners will be used to secure re-cover insulation verify that their length will be adequate. This is especially critical when tapered insulation is used.

(c) Sprayed Polyurethane Foam (SPF) Checklist:

1/ If SPF will be applied directly to the surface of an existing gravel surfaced BUR the surface should be thoroughly cleaned with high pressure/low volume water jets and vacuumed, then allowed to dry.

2/ Repair splits to existing BUR, and remove blisters, buckles, wrinkles, and fishmouths. Use hot mopped or torch-applied repairs. Do not use asphalt mastics for repairs.

3/ Take precautions to avoid overspray of surrounding buildings, automobiles, shrubs, and so forth.

4/ Coat all exposed foam within four hours.

e. Field Review and Observation. Care should be taken to assure that the interior is protected at all times. New penetrations must be sealed as work progresses, and nightly tie-offs must be well constructed.

(1) Hazardous Materials. Limit the quantity of hazardous materials stored on site. Propane bottles may need to be removed from the site each evening. If torching has been done a fire watch with fire fighting equipment must be established for at least 1-hour after the last torch is extinguished. Kettles and other dangerous equipment must be placed behind fenced pedestrian barriers.

(2) Drain Function. Remove drain plugs each evening and make sure construction material does not block water flow to the drains.

11-5. MAINTENANCE CONSIDERATIONS.

a. General. Evaluation of the existing roofing system should highlight defects in the current maintenance program. These may have a bearing on the selection of the new system.

b. Repair or Replace. It is a good rule to replace base flashings of membrane roof systems even if the rest of the roof is only going to be re-covered. If metal counterflashings and copings can be removed and replaced without sustaining excessive damage, they may be reused.

c. Repairs: Emergency, Temporary, and Permanent. This category pertains to the new roof system selected (see appropriate Chapters in this EI).

d. Maintenance Checklists. This category pertains to the new roof system selected (see Chapter 12).

Appendix 11-1.

SUGGESTED AGENDA FOR A REROOFING CONFERENCE

SECTION 01201 – PRECONSTRUCTION CONFERENCE (Refer to CEGS 01201)

1. Not less than 14 days prior to commencing work, representatives of the architect and owner will meet with the contractor, his superintendent or foreman who will be engaged full time on the project, and subcontractors, to review the materials and procedures to be followed in performing the work.

SECTION 01014 – WORK SEQUENCE

1. Sequence of operations. Generally sequencing is the contractor's option provided it maintains the building dry during the life of the contract. Discuss schedule and execution of work to prevent problems.

2. The building is occupied. Discuss how to minimize disruption of activities in occupied spaces.

SECTION 01015 – CONTRACTOR USE OF THE PREMISES

1. Before beginning work, discuss the following:

a. Areas permitted for personnel parking.
b. Access to the site during and after hours.
c. Areas permitted for storage of materials and debris.
d. Areas permitted for location of cranes, hoists, and chutes.
e. Whether interior stairs and elevators may be used for removing debris or delivering materials.
f. Responsibility for soiling or damaging access ways.
g. Approval from owner's representative for the use of a designated elevator.
h. Location of underground tanks and tunnels. Avoid these locations for parking or moving tankers or cranes.

2. From the date that work commences until completion and acceptance of work, the contractor should assume full responsibility for maintaining the roof watertight; this includes both new and existing.

SECTION 01019 – EXISTING CONDITIONS

1. Information noted on the drawings as *existing* generally has been obtained from construction drawings and inspections. Following demolition, confirm that drains, flashing, blocking and similar concealed work conforms to that expected. Report variations that would preclude installation of new work in accordance with the drawings and specifications.

2. Discuss what steps will be taken if discrepancies are discovered between the existing conditions and those noted on the drawings.

3. Note areas that have been fireproofed. Use care in removing the roofing system to avoid dislodging the fireproofing.

SECTION 01300 – SUBMITTALS

1. Shop Drawings and Samples

   1.1 Review details of fabrication, assembly, and erection.

   1.2 Examine samples for identification.

2. Tests

   2.1 Review test reports and how installation will be done to conform with published results.

   2.2 Review field tests, approval and correction of work if found necessary.

3. Material Safety Data Sheets (MSDS) (See Safety Manual EM 385-1-1)

Each Contractor should comply with *Right to Know* requirements concerning notification of the use of toxic substances.

Any product or substance used by the contractor or its subcontractors which is listed in Subpart Z of OSHA Part 1910, Title 29 of the Code of Federal Regulations entitled, *Toxic and Hazardous Substances* should be identified to the owner by the contractor's submission of a Standard Material Safety Data Sheet.

Submit the following MSDS or a manufacturer's standard form (OSHA-20) to the owner's representative to advise the owner of the use of such material during the project before the material is brought on site.

SECTION 01510 – TEMPORARY UTILITIES

1. Discuss details of use of water and power that exists at the site.

2. Indicate that the contractor will provide all hoses, valves, vacuum breakers, and connections for water from sources designated by the owner's representative.

3. Discuss voltage, phase and amperage of power available. Indicate that the contractor is to provide all trailers, connections, ground fault protection and fused disconnects and special feeders if service required is larger than that available.

4. Resolve if building power may be used for electrically seaming single-ply membranes, heating modified bitumen sheets or for spraying foam roofing.

5. Discuss removal of all temporary utilities after job completion.

SECTION 01516 – TEMPORARY SANITARY FACILITIES

1. Discuss whether building toilets designed by the owner may be utilized or whether temporary chemical toilets conforming to local heath regulations are required.

SECTION 01520 – TEMPORARY HOISTS, CRANES, CHUTES

1. Discuss exterior hoisting equipment for moving materials and equipment to work level.

2. Indicate that completely enclosed canvas, metal or plastic chutes of sufficient size for transfer of demolition products to ground level containers are required. Indicate that chutes should be dust-tight and patched or replaced as required to maintain this condition.

3. Protect building and site from damage. Restore damaged surfaces and elements. Remove hoists, cranes, chutes and containers from site after completion.

4. Make scaffold available to owner’s and architect’s representatives for inspections. Provide hard hats, safety belts and insurance to cover these people.

SECTION 01590 – FIELD OFFICES

1. Indicate if the contractor is required to provide a weathertight, climate controlled field office on the site at a specified location.

2. Indicate field office utilities required.

3. All equipment, furniture, etc., will remain the property of the contractor and should be removed from the site when the job is completed.

—or—

1. The owner will provide lockable space within the building to serve as a field office. The contractor should provide a phone and all furniture and furnishings which should be removed from the site when the job is completed.

SECTION 01620 – STORAGE AND PROTECTION

1. Protect paved areas from damage and staining. Provide canvas, boards and sheet materials, properly secured. At completion, remove protection and return damaged elements to their original condition.

2. Take precautions to prevent spread of dust and debris, particularly where they may enter into the building. Give ample notice to the owner’s representative so that building contents can be protected. Provide temporary cloth filters on air intake openings. Provide temporary plastic sheets over operable windows within 3 m (10 ft.) of chutes.

3. Do not overload any portion of the building, either by use of equipment, storage of debris or storage of materials. Where trucks, tankers or heavy equipment traverse landscaped areas, verify location of oil tanks, utilities, tunnels and similar subsurface items. Avoid traffic over them.

4. Protect against fire and fire spread. Maintain proper and adequate fire extinguishers. When torches are present provide one fire extinguisher for each torch on the roof plus one additional.

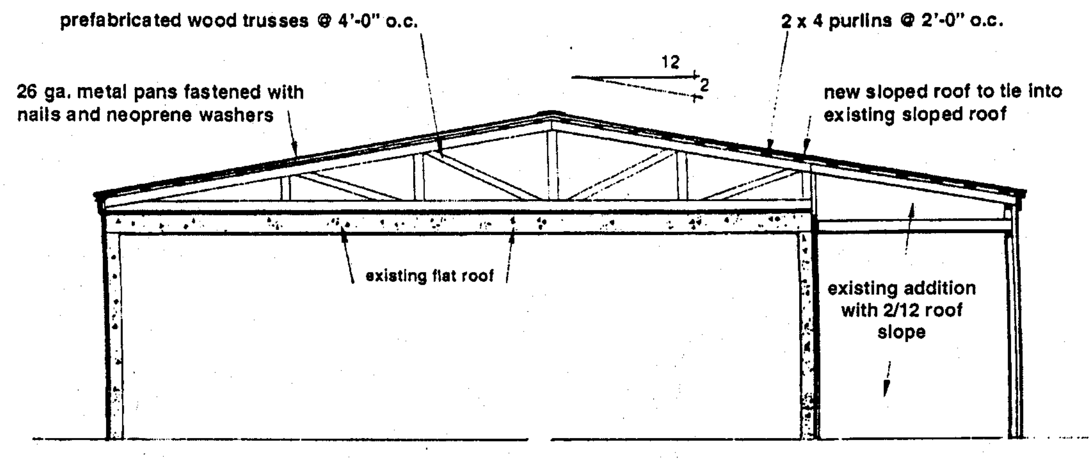
5. Take precautions to prevent drains from clogging during execution of this contract. Remove strainers and plug drains In areas where work is in progress. Install flags or other telltales on plugs. Remove plugs each night and screen the drain. Remove debris at the completion of each day’s work and clean drains, if required. At completion of the contract, test drains to insure that they are free-running and watertight.

6. Remove all traces of piled bulk materials and return site to its original condition.

7. Do not close or obstruct passageways, drives, streets or entrances without permission from the owner’s representative. Erect barriers, lights required for safety and as required by local laws and regulations.

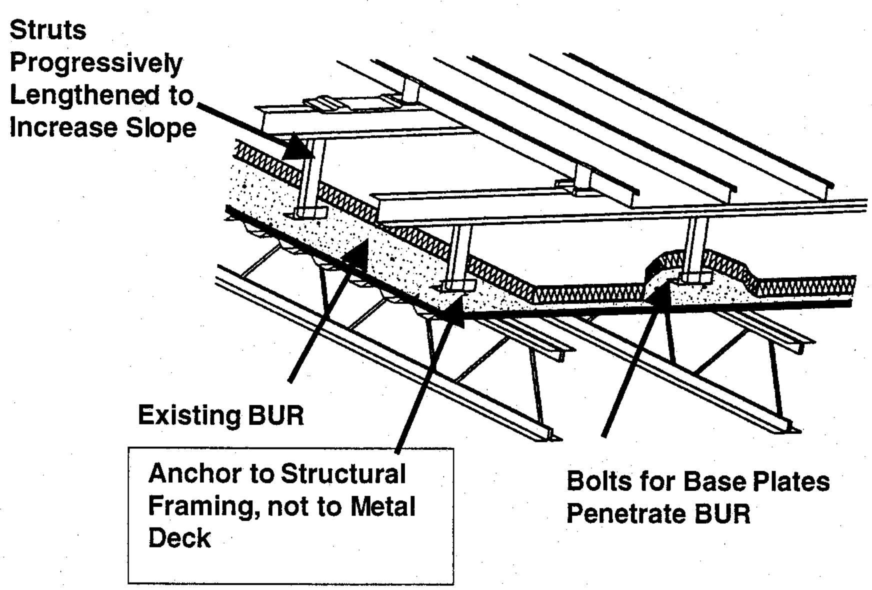
8. When work is in progress on parapets maintain suitable sidewalks, closed passageways, fences, lights, sidewalk bridges, nets and other structures as required by local laws and regulations to avoid obstruction or interference with traffic in public streets, alleyways and private rights-of-way. Leave access to hydrants, stand pipes and entrances.

9. Erect temporary protection covers over pedestrian walkways and at entrances for persons and vehicles which must remain in operation during course of masonry restoration work.



Reprinted from: US Army Corps of Engineers Construction Engineering Research Laboratory (CERL) Technical Report M-85/05, Sloped Roof Conversions for Small, Flat Roof Buildings, dated December 1984, Figure 50, Page 57.

Figure 11-1. Sloped Roof Conversion



Note: Anchor bolt holes in BUR must be sealed to protect the building.

Figure 11-2. SSSMR Reroof over Built-Up Roof

CHAPTER 12

ROOF MAINTENANCE

12-1. OVERVIEW OF ROOF MAINTENANCE. *All* roofing systems require maintenance. While this EI is primarily intended for the selection and design of roofing systems, maintenance must be kept in mind since even the best roofing system will fail prematurely if not maintained. The primary intent of this Chapter is to enumerate those things a designer can do to improve the performance and longevity of roofing systems. As mentioned in Chapter 11, good roof design anticipates maintenance, reroofing or re-covering. Providing positive slope within the structure itself assures the roof will drain properly. Adequate clearance is needed so that these functions can be performed. Counterflashings should be high enough to accommodate additional roof insulation.

a. General.

(1) Separation of Rooftop Units. Roof penetrations should be spaced a minimum of 305 mm (12 in.) apart (see figure 12-1). If this minimum spacing is impossible, then penetrations should be clustered and brought through a curbed opening (figure 12-2).

(2) Removable Counterflashing. Providing two-piece counterflashings permits removal of the snap-in piece so that the roof may be more easily reflashed (figure 12-3).

(3) Eliminate Pitch Pans. Use watertight sheet metal rain collars instead of pitch pans to reduce the need to periodically refill the pans to assure watertightness (figure 12-4).

(4) Anticipate Movement. Where differential movement is expected between roof and wall, use nonwall-supported base flashing designs (figure 12-5).

(5) Design Coping System to Shed Water. Slope all copings to shed water back onto the roof. Provide a watertight membrane at least under the coping joints and preferably under the entire coping (figure 12-6).

(6) Avoid Metal Flashings Embedded Within Roof Membrane. Avoid embedded metal such as illustrated in figure 12-7a. Use raised metal such as illustrated in figure 12-7b.

(7) Operations and Maintenance Manual. The Operations and Maintenance Manual given to the owner should contain copies of any roof warranty with attention drawn to occupant obligations and notification requirements. Accurate and comprehensive records such as those used in the ROOFER program are recommended. Any requirements for special tools or materials should be noted as well as references, instructions, or training needed. Excellent references are available on maintenance of each type of roof system discussed in this EI.

b. Inspection and Maintenance.

(1) Roof Surveys. Visual inspection should follow checklists similar to those provided in the RIEI Roof Maintenance Manual, the NRCA/ARMA Manual of Roof Maintenance and Repair, or when applicable, used in the ROOFER program. Moisture surveys are recommended at 3-5 year intervals on insulated roof systems. Such surveys are required to properly analyze insulated low-slope roofs using ROOFER.

(2) Inspection Techniques. As indicated in each of the preceding Chapters, the specific characteristics of each system define the inspection and maintenance techniques necessary. Periodic visual inspections and debris removal are essential to all. Material manufacturers and trade associations provide information on needed inspection and maintenance.

(a) Low-slope inspections done while the membrane is still wet from recent rain help locate areas that are not draining well. Applying foot pressure can sometimes force air or water back out of laps, seams, or blisters finding defects that would otherwise not be detected. Caution: Wet roofs are slippery, especially metal, coated SPF, and single-ply membranes.

(b) Maintenance will require compatible repair materials and tools. Refer to Chapters 3-10 and references in Appendix A for materials and equipment required.

(c) Roofs that are still under warranty should have leak repairs made by manufacturer-authorized contractors only. Emergency repairs to a warranted system can be done by anyone but must be reported to the manufacturer shortly thereafter.

(d) All roofing systems are dependent upon inspection and maintenance to reach their design life. It is clear that periodic inspection and preventative maintenance greatly increase the life expectancy of roofing system and reduces life-cycle costs. Maintenance, inspection, and minor repairs should cost somewhere between 2 and 5% of the replacement cost per year. This will vary with accessibility to the site, details of the survey, and amount of maintenance needed.

12-2. BUILDING ELEMENTS.

a. Slope. Drainage is essential.

(1) Drains. Roof drains should be recessed below the drainage plane of the roof. Drains must be sized properly to carry away the designed water flow. The addition of new drains, especially in areas where deflection has resulted in ponding, is sometimes feasible and more cost effective than resloping the entire roof.

(2) Ponding. Correction of ponding is generally beyond the scope of a maintenance program. However, the addition of crickets or filling in a low spot on a BUR with bitumen and aggregate might be appropriate. Major slope correction will be done at the time of reroofing.

b. Low Sloped Roofs. Punctures and open seams/laps can result in water entry. Water should drain away from laps and seams i.e., laps and seams should not *buck* water.

c. Steep Roofs.

(1) Damaged Roofing. Broken and missing units should be replaced. While underlayment may protect the building against water entry for some period of time, unprotected underlay will gradually deteriorate.

(2) Access. Permanent ladders and walkways will reduce foot traffic damage on tiled roofs.

d. Structural Considerations. Damage to the roof deck from leakage will endanger the structure. When leaks are reported, or when moisture is discovered during a moisture survey, the deck should be checked to see if rotting, corrosion, or softening has occurred.

e. Expansion and Seismic Joints. Flush joints are a high-risk feature. Joints should be at least 200 mm (8 in.) up on curbs. Use short legs at crossover corners and terminations to allow for differential movement (figure 12-8).

f. Re-entrant Corners. On fully adhered membrane systems re-entrant corners can be high stress points likely to suffer splitting. Permanent repairs may require the installation of a curbed expansion joint or area divider. Flexible single ply systems are more capable of handling stress concentrations and differential movement than BUR systems.

g. Roof Access. Roofs won't get inspected if they can't be accessed. Interior roof hatches or permanent ladders are best.

(1) Ladders. Permanent ladders are sometimes installed to accommodate climbing on very steep roofs.

(2) Walkways. Walkways may help protect the roof against foot traffic especially at access points and around mechanical equipment that must be serviced. These are available for metal roofs as well as for membrane systems.

(3) Controlled Access. Gates, locks, or ladders that can only be reached by other ladders must control unauthorized roof access.

h. Roof Venting. Attic ventilation reduces the accumulation of moisture and the formation of icings at the eaves of steep roofing systems. Inadequate ventilation may result in growth of mold and mildew and cause roof decking to buckle resulting in an uneven roof appearance. New soffit and ridge vents may be needed if inspection indicates there are moisture problems. It is also very important to reduce air exfiltration up into the roof by installing or improving air barriers and vapor retarders. Topside venting of compact roofing systems is of dubious benefit.

i. Roof Decks and Nailers. Secure attachment of the roof deck to structural members is critical. Refer to references on roof decks for details. For steel decks screw fastening is preferred over rewelding as a method of repairing failed welds. Anchorage of nailers is very important. Additional fastening, especially at perimeters, may be needed if evidence of deck movement or wind damage is found. Nailers should be installed to meet Factory Mutual Data Sheet 1-49, even if FM Approval is not specified (CEGS 06100-Rough Carpentry).

j. Underlayment. In some long life steep roofing systems such as slate and tile the valley metal and underlayment may deteriorate before the primary covering. In this case removal of the roofing, replacement of the flashing and underlay, and reinstalling the roofing may be appropriate. However, localized leakage might indicate that only underlay repairs are needed.

k. Vapor Retarders.

(1) Sealed Retarders. When steep roof system require vapor retarders, the retarders (or air barriers) will not be effective unless serious attempts are made to seal them at penetrations, edges, and ends of batts. Unsealed penetrations at light fixtures and vent pipes can cause serious moisture problems.

(2) Low-Slope System Retarders. In adhered low-slope membrane systems air exfiltration is near zero. Since moisture problems are the result of air exfiltrations these systems have few moisture problems. However, some may still require vapor retarders.

l. Penetrations. Periodic inspections and repairs are required for penetrations. Pitch pockets must be periodically refilled to function properly.

m. Historical Roof Restoration. Buildings of historical significance should be repaired with matching (not necessarily identical) materials to maintain their original appearance.

n. Aesthetics. When the appearance of a built-up roof system is not an issue it is sometimes best not to reapply aggregate to patches for at least a year or so. On future inspections the patch can be easily found and examined for integrity.

o. Gaps, Flashings, Joints, and Sealants

(1) Sealants. Exposed sealants such as at termination bars and laps of some single-ply systems may need rework due to deterioration. Protected sealants, such as the butyl, used where two metal sheets lap deteriorate very slowly.

(2) Joint Covers. Splices of elastomeric expansion joint covers may disbond with aging. Where shrinkage or movement has caused a joint cover to collapse, crack, or tear consider installing a wider joint cover.

p. Drainage, Valley and Intersection Details.

(1) Maintaining Proper Drainage. Roof drainage systems are discussed in detail in Chapter 1 of the SMACNA *Architectural Sheet Metal Manual*. Roof drains must be kept free of debris in order to function. Overflow provisions are essential since the primary drains may become blocked.

(2) Pressure Washing. On steep roofing systems such as wood shakes, periodic pressure washing to remove silt and pine needles from between individual shakes and at flashings is beneficial.

(3) Rusting. Galvanized sheet metal will rust when the zinc coating erodes. Recoat exposed metal with a durable rust inhibiting paint.

12-3. DESIGN CONSIDERATIONS FOR ROOF MAINTENANCE.

a. Roof Traffic. Provide access, railings and traffic-ways as needed.

b. Low Maintenance Details. Avoid pitch pockets and other details that require periodic service to perform properly. Avoid embedded metal gravel stops at membrane level in bituminous systems. (See NRCA recommendations and construction details.)

c. Periodic Inspection. Establish inspection and maintenance protocols. Use ROOFER or a similar system to record inspections and repairs and to program future work.

12-4. CONSTRUCTION CONSIDERATIONS.

a. General. Roof membranes are relatively fragile elements and are easily damaged by other construction trades. Controlled access to the roof is extremely important.

b. Pre-roofing Conference (new construction or reroofing). An agenda item should include protection of adjacent roofing and the newly constructed roofing from damage by other trades.

c. Shop Drawing Submittals. Drawings of complicated details such as through-wall flashings, layout of single-ply sheets, and calculations of load information should be assembled into a permanent roof maintenance file and turned over to the building manager when construction is completed. This file should also contain the roof warranty as well as maintenance recommendations provided by the roofing materials manufacturer.

d. Design Submittal Requirements and Checklist. If a roofing system requires periodic recoating to maintain reflectance, screen UV, preserve components (e.g., wood shingles or shakes), or maintain a fire rating, this information must be supplied to the building manager as part of the roofing file.

e. Field Review and Observation. Trained personnel should perform inspection and repair of roofing. Tools and techniques vary with the kind of roofing present. The manufacturer's authorized contractor should perform repairs required on a roof still under a warranty.

12-5. MAINTENANCE CONSIDERATIONS.

a. General. Each of the many different ways to roof a building has unique characteristics that affect maintenance requirements. Fortunately, literature on maintenance of most systems is available from trade associations and materials manufacturers. Of all the considerations, positive drainage and flashing details probably have the greatest impact on roof performance.

b. Repair or Replace. This subject is discussed in Chapters 3 through 10.

c. Repairs: Emergency, Temporary, and Permanent. Having trained personnel and establishing an adequate maintenance file will help greatly in making repair decisions. ROOFER has an analysis program to help decide whether to repair or replace a roofing system.

d. Checklists. Refer to industry literature for checklists appropriate to specific systems.

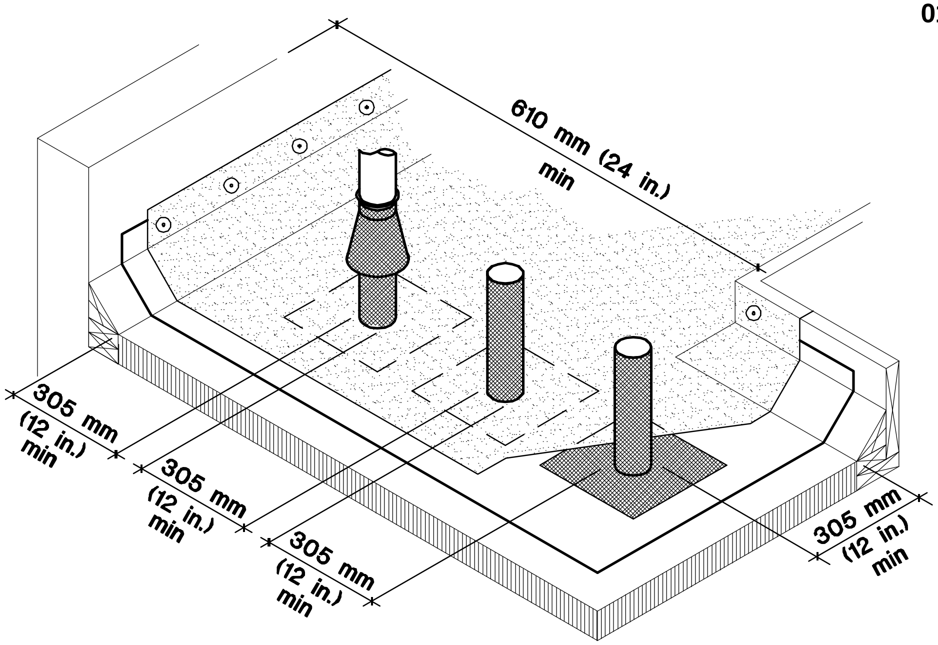


Figure 12-1. Clearances Between Pipes/Walls/Curbs

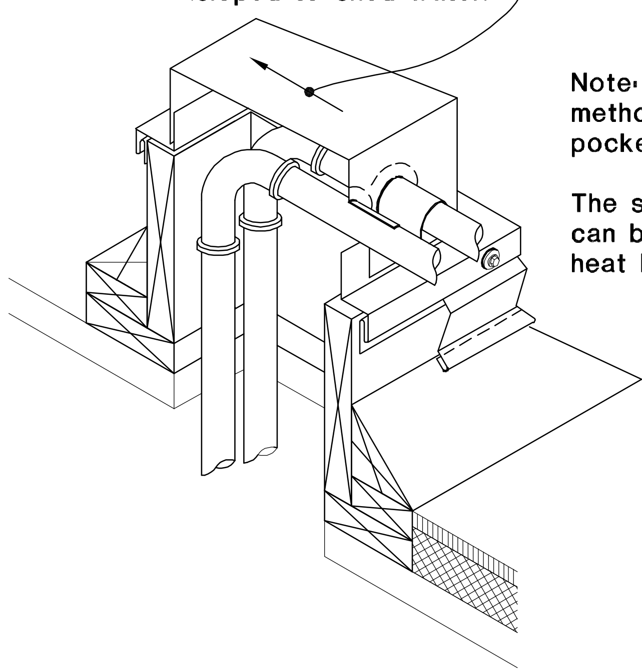


Figure 12-2. Curbed Enclosure for Piping Through Roof Deck

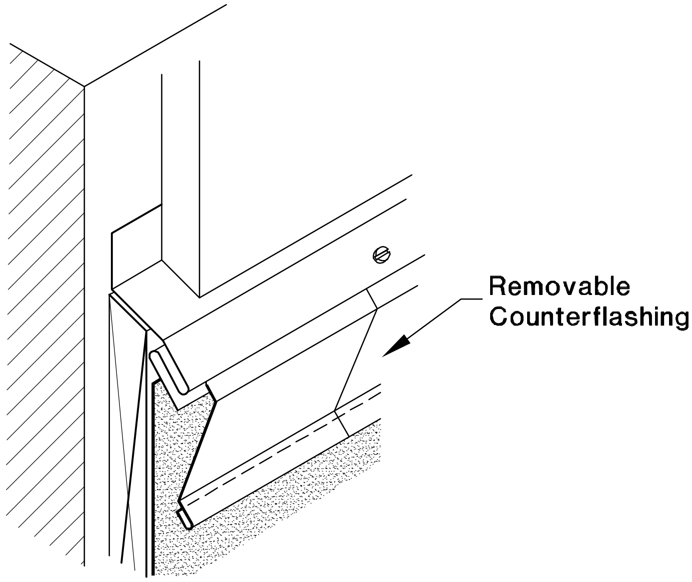


Figure 12-3. Use of Two-Piece Metal Counterflashing

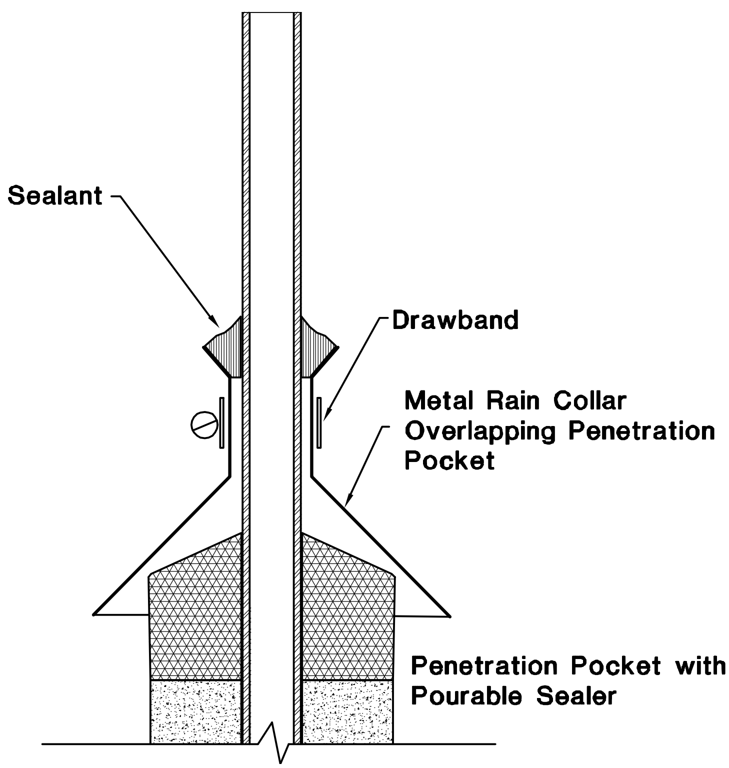


Figure 12-4. Water-Shedding Rain Collar for a Penetration (Pitch) Pocket

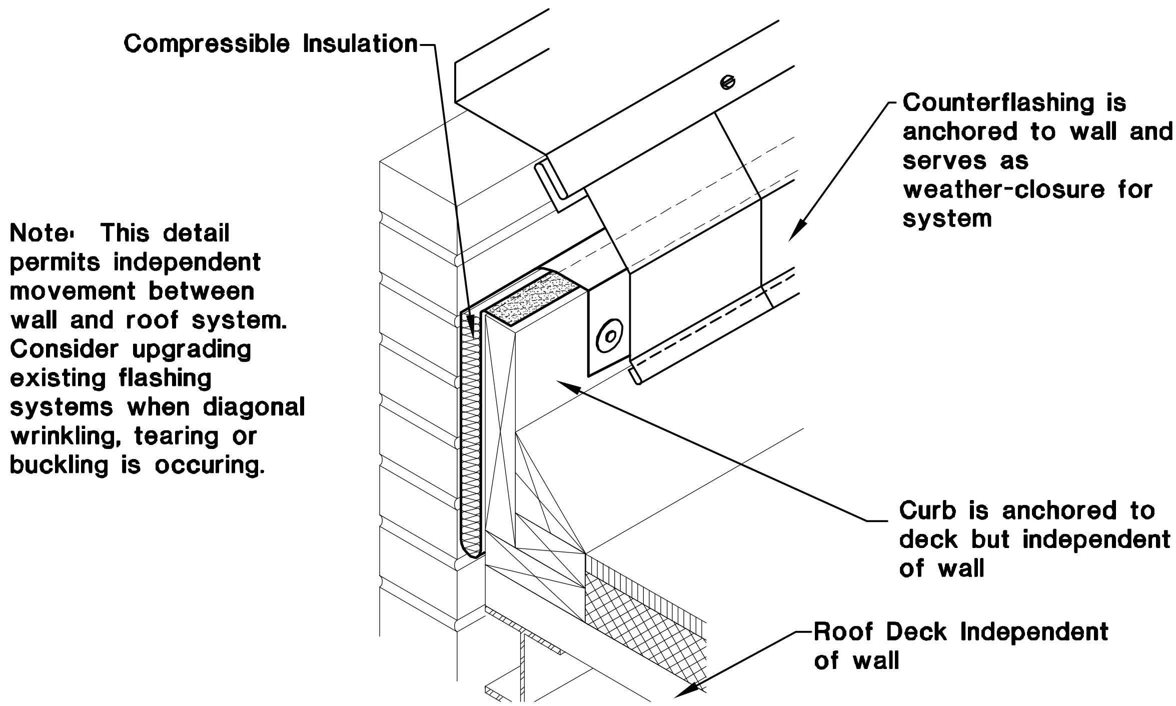


Figure 12-5. Use of Curb for Base Flashing, Independent of Wall Movement

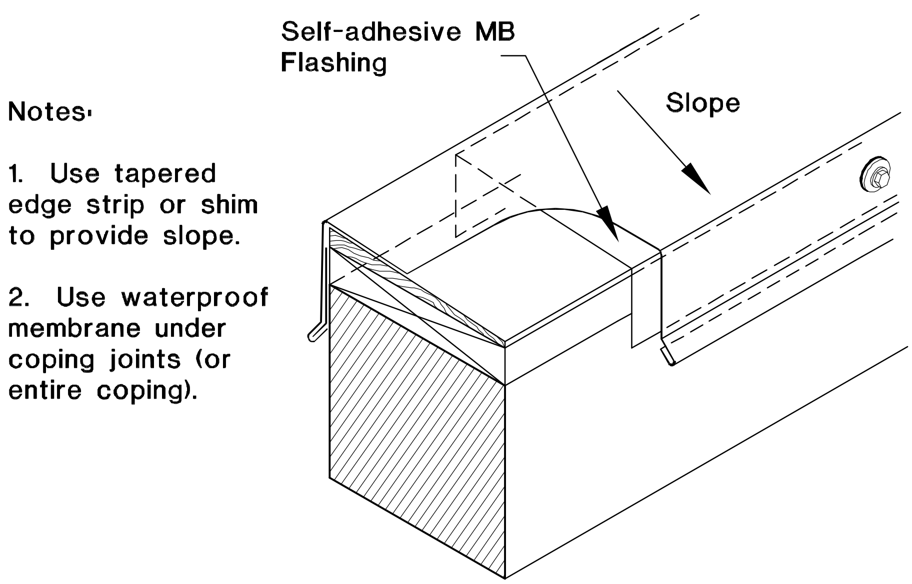


Figure 12-6. Coping Sloped to Shed Water

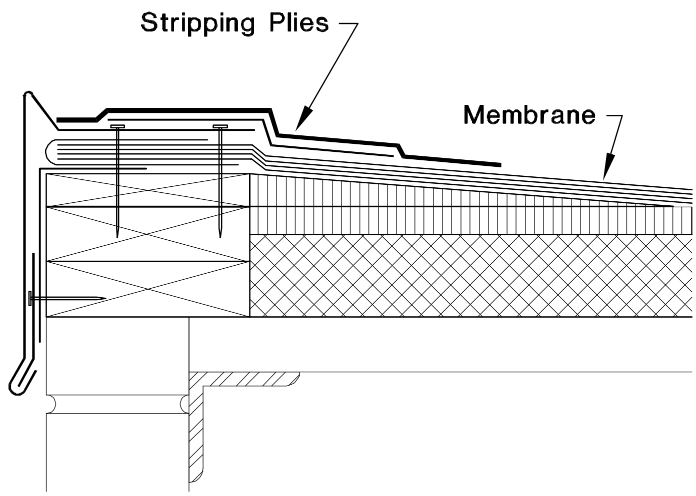


Figure 12-7a. Metal Gravel Stop/Fascia Embedded Between Membrane Plies and Stripping Plies.

<u>Not Recommended</u>

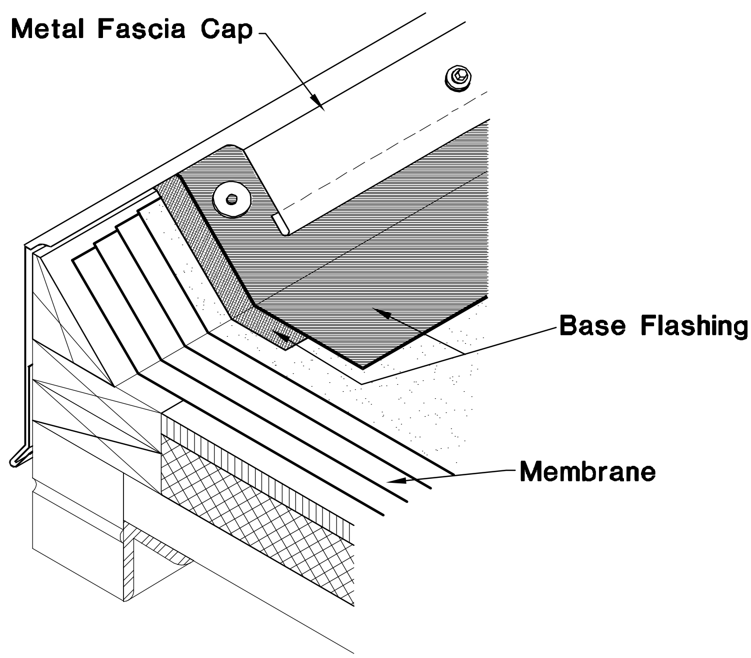


Figure 12-7b. Metal Fascia Cap Placed Over Completed Membrane and Base Flashing.

<u>Recommended</u>

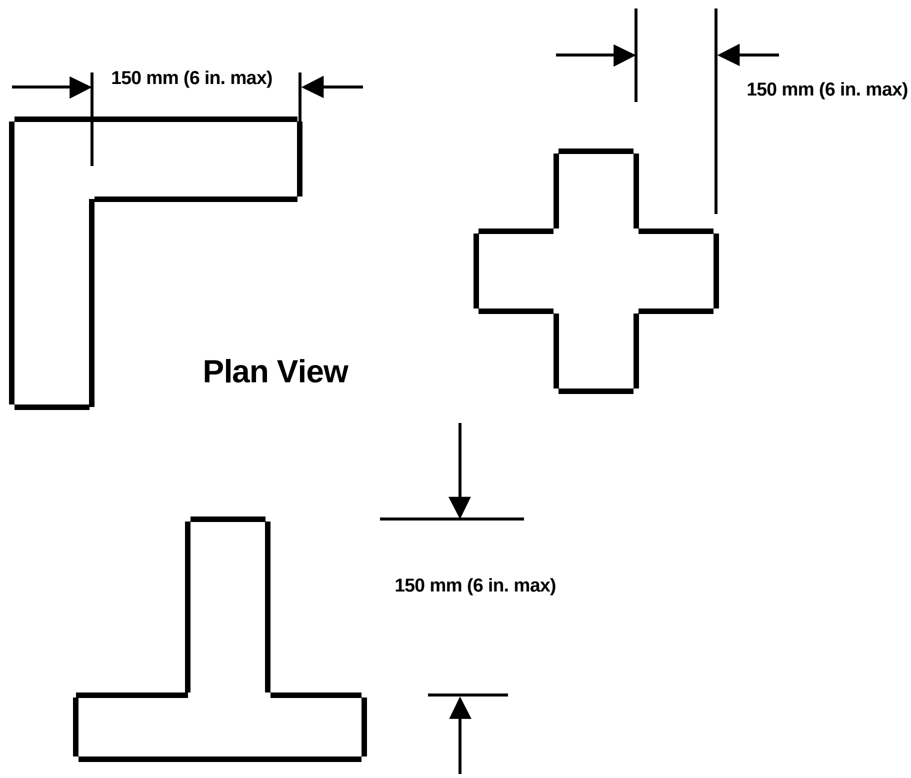


Figure 12-8. Metal Intersections (Expansion Joint Covers, Gravel Stops, etc.) Require Short *Legs* to Accommodate Differential Movement

APPENDIX A

REFERENCES

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Department of the Army

TM 5-805-14	Roofing and Waterproofing
TM 5-617	Inspection, Maintenance and Repair of Roofing Systems
TI 809-01	Load Assumptions for Buildings
TI 809-52	Commentary on Snow Loads
TI 809-29	Structural Considerations for Metal Roofing
TI 809-30	Metal Building Systems
CEGS 02226	Removal and Salvage of Historic Building Materials
CEGS 03300	Cast-In-Place Structural Concrete
CEGS 03410	Precast/Prestressed Concrete Floor and Roof Units
CEGS 03414	Precast Roof Decking
CEGS 03510	Roof Decking, Cast-in-Place Lightweight Concrete
CEGS 03511	Gypsum Plank Decking
CEGS 03340	Precast/Prestressed Concrete Floor and Roof Units
CEGS 05300	Steel Decking
CEGS 06100	Rough Carpentry
CEGS 07220	Roof Insulation
CEGS 07310	Slate Roofing
CEGS 07311	Roofing, Strip Shingles
CEGS 07320	Clay Tile Roofing
CEGS 07412	Non-Structural Metal Roofing

CEGS 07416	Structural Standing Seam Metal Roof (SSSMR) System
CEGS 07510	Built-up Roofing
CEGS 07530	Elastomeric Roofing (EPDM)
CEGS 07548	Polyvinyl Chloride (PVC) Roofing
CEGS 07550	Protected Membrane Roofing (PMR)
CEGS 07551	Modified Bitumen Roofing
CEGS 07571	Sprayed Polyurethane Foam (SPF) Roofing
CEGS 07610	Copper Roof System
CEGS 07650	Copper Sheet Metal Flashing
MILHDBK 1008C	Fire Protection for Facility for Engineering Design and Construction

Cold Regions Research & Engineering Laboratory (CRREL)
72 Lyme Rd., Hanover NH 03755
(Order Publications from NTIS—www.dtic.mil/stinet)

MP 1498	(1981) Venting of Built-Up Roofs
MP 2489	(1989) Vapor Retarders for Membrane Roofing Systems
MP 3443	(1994) General Considerations for Roofs
MP 3527	(1994) Ventilating Attics to Minimize Icings at Eaves
MP 3858)	(1996) Snow Guards for Metal Roofs
MP (In Prep)	(1998) Roof Ventilation to Prevent Problematic Icings at Eaves

Construction Engineering Research Laboratories (CERL)
5285 Port Royal Rd
Springfield, VA 22161
(Order Publications from NTIS—www.dtic.mil/stinet)

M85/05	(1985) Sloped Roof Conversions for Small, Flat-Roofed Buildings
M87-13	Vol. II (1987) Membrane and Flashing Condition Indexes for BURs, Inspection and Distress Manual

M-90/04	(1989) ROOFER: An Engineered Management System (EMS) for Bituminous Built-Up Roofs
FM-93/11	(1993) ROOFER: Membrane and Flashing Condition Indexes for Single-Ply roofs—Inspection and Distress Manual

Air Force Engineering & Services Center
Tyndall Air Force Base, Florida 32403

ORNL-6520	(1988) Decision Guide for Roof Slope Selection
Instruction 32-1051 (1994)	Roof Systems Management
Eng. Tech Letter 90-1	Built-Up Roof Repair/Replacement Guide Specification
Eng. Tech Letter 90-8	Guide Specific for Ethylene-Propylene Diene Monomer (EPDM) Roofing

National Institute for Standards and Technology (NIST)
Structures and Materials Division/Center for Building Technology
Gaithersburg, MD 20899
(Order Publications from NTIS—www.dtic.mil/stinet)

NISIR 88-4638	(1991) Performance Approach to the Development of Criteria for Low Sloped Roof Membranes
NBS Report 86-3418	(1986) Performance Criteria for Load-Elongation of Bituminous BUR Membranes; Alternative to the Tensile Strength Criterion
NIST Special Publication 811 (SI)	(1995) Guide for the Use of the International System of Units

Oak Ridge National Laboratories
PO Box 2008
Oak Ridge, TN 37831-2008

ORNL CONF 9405206	(1994) Low Slope Reroofing

NONGOVERNMENT PUBLICATIONS

APA—The Engineered Wood Association
7011 S, 19th St., P. O. Box 11700
Tacoma, WA 98411-0700

SPE-1025	Guidelines for Proper Installation for APA Rated Sheathing for Roof Applications

	Residential and Commercial Manual
	Design/Construction Guide

American National Standards Institute (ANSI)
11 W. 42nd St. New York, 10036

ANSI/ASCE-7	(1995) Minimum Design Loads for Buildings and Other Structures
ANSI/SPRI RP-4	(1997) Wind Design Standard for Ballasted Single Ply Roofing Systems

American Society for Testing and Materials (ASTM)
100 Barr Harbor Drive, W. Conshohockern PA 19428-2959

Manual 18	(1994) Moisture Control in Buildings

Asphalt Roofing Manufacturers Association
6000 Executive Blvd., Suite 201
Rockville, MD 20852-3803

#105-BUR-82	(1993) Recommendations Regarding Built-up Roofing Asphalt
#108-BUR-93	(1993) Quality Control Guidelines for Application of Built-up Roofing
#109-BUR-88	(1994) Deck Recommendations for Built-Up Roofing and Modified Bitumen Membranes
#110 RR-96	(1996) Quality Control Guidelines for Application of Polymer Modified Bitumen Roofs
#111-BUR-88	(1993) Cold Weather Recommendations for Built-Up Roofing
#115-BUR-93	(1994) The Effects of Ponding Water
#117-BUR-94	(1994) Aggregate Retention Enhancement for Built-up Roofing in Extreme Wind Zones
#210-RR-71	(1993) Color Shading of Asphalt Shingle Roofs
#207-RR-85	(1993) Plain Facts About Buckled Shingles
#209-RR-86	(1996) Ventilation and Moisture Control for Residential Roofing
#300 MBS-86	(1986) Torch Applied Roofing—Do’s and Don’ts

#301 MBIT-10	(1993) Guide to Preparing Modified Bituminous Roofing Specifications
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Cedar Shingle and Shake Bureau
515 116th Ave, N.E., Suite 275
Bellevue, WA 98004-5294
(360) 753-4647
www.cedarbureay.org — Design & Application Manual for New Roof Construction

Copper Development Association
260 Madison Ave
New York, NY 10016 — Copper in Architecture

Factory Mutual System (FM)
1151 Boston-Providence Turnpike
Norwood, MA 02063

FP7825c	(1997)FMRC Approval Guide Current Listing of Approved Roofing Systems
Loss Prevention Data Sheets	
1-28	(1996) Wind Loads to Roof Systems and Roof Deck Securement
1-29	(1996) Above-Deck Roof Components
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1-31	(1992) Metal Roof Systems
1-49	(1985) Perimeter Flashing

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McGraw Hill Publications P. O. Box 545 Blacklick, OH 43004-0545	
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National Roofing Contractors Association (NRCA) 10255 W. Higgins Rd, Suite 600, Rosemont, IL 60018-5607	
	(1996) Roofing and Waterproofing Manual 4th Edition
	(Annual) Commercial Roofing Materials Guide
	(1996) Manual of Inspection and Maintenance of Built-up and Modified Bitumen Roof Systems
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National Tile Roofing Manufacturers Association, Inc. P. O. Box 40337 Eugene, OR 97404	
	(1998) Concrete and Clay Tile Roof Design Criteria Manual for Cold, Snowy Regions
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PO Box 148, Morin Heights, PQ
Canada, J0R 1H0

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Revere Copper Products, Inc.
P.O. Box 300
Rome, NY 13440

(1982) Copper and Common Sense

Roofing Industry Educational Institute (RIEI)
14 Inverness Dr. E, H-110, Englewood, CO 80112

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Sheet Metal and Air Conditioning Contractors National Association (SMACNA)
4201 Lafayette Center Drive
Chantilly, VA 22021

(1993) Architectural Sheet Metal Manual, 5th Ed.

Standard Practice in Sheet Metal Work (Reprint of 1929 Edition)

Steel Deck Institute
PO Box 25
Fox River Grove, IL, 60021

#29 — Design Manual for Composite Decks, Form Decks, Roof Decks and Cellular Deck Floor Systems with Electrical Distribution

Manual of Construction with Steel Deck

Underwriters Laboratories (UL)
333 Pfingsten Rd
Northbrook, IL 60062

Roofing Materials & Systems Directory (Current Date)

Building Materials Directory (Current Date)

Vermont Structural Slate, Inc.
P. O. Box 98
Fair Haven, VT 05713

Slate Roofs

Western States Roofing Contractors Association (WSRCA)
8000 Airport Blvd. Suite 412
Burlingame, CA 94010

Clay Roof Tile Manual
Roofing Details on Tile

APPENDIX B

BIBLIOGRAPHY

GOVERNMENT PUBLICATIONS

Cold Regions Research & Engineering
Laboratory (CRREL)
72 Lyme Rd., Hanover NH 03755
(603) 646-4100
www.crrel.usarmy

Report 76-2 Protected Membrane Roofs in Cold Regions (1974)	Explains PM roof principles and presents performance measurements from 3 PM roofs. Justifies cost premium on much improved performance.
MP 1498 Venting of Built-up Roofing Systems (1984)	Explains why ventilating compact roofing systems accomplishes very little and may do more harm than good.
MP 1509 Can Wet Roof Insulation be Dried Out?(1984)	Quantifies the very slow drying rates of most roof insulations using breather vents and such
MP 2040 Roof Moisture Surveys—Yesterday, Today and Tomorrow (1985)	Overviews nuclear, capacitance and infrared techniques and promotes periodic moisture surveys in conjunction with visual inspections
MP 2489 Vapor Retarders for Membrane Roofing Systems (1988)	Provides a method of deciding if a roof requires a vapor retarder and where it should be placed
MP 2866 New Wetting Curves for Common Roof Insulations (1989)	Quantifies the loss in insulating ability for roof insulations as they become wet.
MP 3233 Standing Seam Metal Roofing Systems in Cold Regions (1990)	Overviews strengths and weaknesses of standing seam metal roofs. Discusses sliding snow, ice damming, electrical heaters.
MP 3441 Installation of a Protected Membrane Roof at the Windiest Place on Earth (19940	Overviews PM principles and describes how problems with a loose-laid PM were solved by installing a fully-adhered MB membrane. The XEPS insulation was reused.
MP 3443 General Considerations for Roofs	Provides excellent discussion of water shedding and water proof roof designs, especially as related to moisture

MP 3527 Ventilation of attics to minimize Icings at Eaves (1994)	Presents findings from several instrumented attics, before and after retrofits and provides design guidelines for avoiding such problems
MP 3858 Snow Guards for Metal Roofs (1996)	Overviews available types and provides design guidelines.
Videotape—Reroofing with Protected Membranes (1989)	Explains the design and documents the construction of a variety of PMR systems in Alaska.
Freeze-Thaw Durability of Common Roof Insulations	Defines the adverse effect of repeated freezing and thawing on various roof insulation boards
Roof Ventilation to Prevent Problematic Icings at Eaves (1998)	Presents case studies of steep roofs having chronic icings at their eaves which were eliminated by ventilation improvements.
Electric Heating Systems for combating Icing Problems on Metal Roofs (1997)	Presents findings from test installations on several instrumented buildings.
Special Report 95-19 (1995) Roof Blisters—Cause and Cure	Discusses blistering mechanism in BUR and MB

Construction Engineering Research Laboratories (CERL)
1-800-872-2375
(Order Publications from NTIS)
5285 Port Royal Rd
Springfield, VA 22161)
www.dtic.mil/stinet/

M85/05 Sloped-Roof Conversions for Small, Flat Roofed Buildings (1984)	Examines cost-effectiveness of converting flat-roofed buildings to sloped-roof buildings as an alternative to repair or replacement in kind. Actual projects studied. Includes costs.
M86/03 Initial Investigation of Three Uncured Elastomeric Materials used in Military Construction (1986)	CSPE, CPE and PIB are investigated. It was concluded that they should not be used in Corps Projects (at this time).
M86/10 (1986) Investigation of Standing Seam Metal Roofing	Reviews the design and application of SSSMR
M86/14 (1986) Field Test Results of Aluminum Standing Seam Rfg.	Discusses design defects and corrections

M86/21 (1986) Initial Investigation of MB Roofing for use in Military Construction	Lists products and observations on performance
M87/04 Experimental PVC Roofing Field Performance	This work set the basis for the Corps CEGS on PVC
M87-13: ROOFER :Membrane and Flashing Condition indexes for BURs (1987)	Details on inspection of BUR systems using ROOFER procedures
M90/04 ROOFER: and Engineered Management System for BURs (1989)	Gives background on a roof management program for BUR and Single Ply
M90/09 Long Term Field Test Results of Experimental DPDM and PUF Roofing (1990)	Documents a seven year field test program
M93/05 Three Year Field Test Summary for Experimental Modified Bituminous Roofing	Results of three modified bituminous systems at Fort Polk, LA
FM 92/05 Cleaning Aged EPDM Rubber Roofing Membrane Material for Patching (1992)	Describes cleaning techniques and a droplet test for cleanliness
FM 93/11 ROOFER: Membrane and Flashing Condition Indexes for Single-Ply roofs—inspection and Distress Manual (1993)	Details on inspection of Single Ply roofing systems using ROOFER procedures

Corps of Engineers— Ft. Belvoir
www.usacpw.belvoir.army.mil/librarie/riss/riss/m-gen.htm

Corps of Engineers-Huntsville
www.hnd.usace.army.mil\techinfo\

Air Force Engineering & Services Center
Tyndall Air Force Base, Florida 32403

Air Force Civil Engineer Support Agency Field Guides: Single-Ply Roofing Systems; Pitched Roofing Systems; BUR Systems.	Three pocket-sized booklets with color photographs of roofing defects and discussion of problems. Also includes inspection check sheets.

Department of the Interior

BUREC Technical Service Center
Material Engineering and Research Group
PO Box 25007, Code D-8180
Denver Federal Center
Denver, CO 80225

R-94-18 Maintenance and Repair of Sprayed Polyurethane Foam Roofing. (1994)	Contains Introduction to foa systems, materials, coatings, defects, inspection and repair

EPA Energy Star Cool Roofs Program www.eetd.lbl.gov/CoolRoof	Information of High Albedo Roofs, results on many tested materials.

National Institute for Standards and Technology (NIST)
(Order publications from NIST)
http://.DTIC/mil/stinet
Building Science Series

#3 Wind Loads on Buildings (1970)	Covers proceedings of technical meeting concerning wind loads of buildings
#9 Thermal Shock Resistance for BURs (1967)	The resistance of BURs to thermally induced forces is discussed
#23 Hail Resistance of Roofing Products	Discusses hail test with synthetic hailstones. Most prepared roofings suffer damage when stones >37 mm (1-1/2 in.) dia. are used. Solidly supported systems are better than soft substrates. Aggregate surfacing is beneficial.
#37 Effects of Moisture on the Heat Transfer Performance of Insulated Flat Roof Constructions (1971)	A solution to the problem of unwanted moisture in the thermal insulation of flat roofs was found. The best insulation and moisture performance was obtained by utilizing the heat of the summer sun to vaporize and transfer to the room beneath any free moisture contained within the construction.
#55 Preliminary Performance Criteria for BUR (1974)	Develops a performance approach based upon testing of successful BUR membranes. Recommends levels of performance for nine attributes including low temperature tensile strength.
#92 Viscosities of Roofing Asphalts at Application Temperatures (1976)	Indicates how fluidity of asphalt can relate to good handling as observed by experienced contractors. This report lead to the establishment of EVT.
#123 Effect of Moisture on the Thermal Conductance of Roofing	Five types of rigid board insulations with BURs had moisture induced into the roof specimens.

Systems (1980)	Measurements were taken of moisture gain and thermal conductivity.
#167 Interim Criteria for Polymer Modified Bituminous Roofing Membrane Materials (1989)	Results of a study for the selection of polymer-modified bituminous materials. Dimensional stability, fire, flow resistance, hail impact, moisture content and absorption, pliability, strain energy, uplift resistance and weathering resistance (sun exposure) are identified
#169 Strength and Creep Rupture Properties of Adhesive Bonded EPDM Joints Stressed in Peel (1990)	Discusses the major defect in EPDM—field seams. Cure time and level of cleanliness have the greatest effect on joint strength, while the thickness of the adhesive and the mechanical load have the greatest effect on a joint's creep rupture time to failure
#175 Performance of Tape-Bonded Seams of EPDM Membranes: Comparison of the Peel Creep Rupture Response of the Tape-Bonded and Liquid Adhesive Bonded Systems (1996)	Continues the work of BSS #167 and #169. The industry has gradually shifted from neoprene-based adhesives to butyl-based adhesives to primer and tape systems. This paper concludes that the tape systems are at least as good as the earlier adhesive systems.
NBSIR 85-3239 Roof Management Programs (1985)	Three general types of management programs are identified and discussed: total management, new construction, and maintenance management. Reference is made to USAF Manual 91-36, which includes chapters on general information, data base, rating the serviceability of existing roofs and alternatives, repair procedures, design and construction management.
NISTIR 88-4008 Corrosion of Metallic Fasteners in Low Sloped Roofs: A Review of the Available Information and Identification of Research Needs(1989)	The potential for corrosion-induced problems is of concern. Mechanical fasteners have gained acceptance for fastening components to roof decks. Three main areas are addressed: the field performance of fastener systems; fastener system materials and the possibility of corrosion; and evaluation techniques for corrosion resistance.
NISTIR 89-4155 Report of Roof Inspection—Characterization of Newly Fabricated Adhesive Bonded Seams at an Army Facility (1991)	Specimens of EPDM field seams were analyzed for peel strength and surface condition. Voids and release agent may contribute to low peel strength.
NISTIR 4504 A Field Study of the Performance of EPDM Roofing at	About 1/3 of the roofs surveyed had minor defects which were readily repairable, but which had gone

Air Force Facilities (1991)	without repair. This confirms a key concern expressed by field personnel that they had lacked the ability to perform routine maintenance.
NISTIR 4638 A Performance Approach to the Development of Criteria for Low-Sloped Roof Membranes (1991)	Continues the Work of BSS #167 and includes progress of an international task force on roofing performance (CIB/RILEM)
NBS 231 Solar Heating, Radiative Cooling and Thermal Movement / Their effects on BUR (1961)	Twenty-five different BUR specimens were subjected to natural solar heating and night-time cooling. The data indicates that the temperature attained in a roof membrane is influenced by the absorptance and emmisivity of the surface, as well as the properties of the substrate. Insulated roofings may be heated to as much as 44°C (80°F) above ambient due to solar heating and 11°C (20°F) below ambient due to radiative cooling. Thermal expansion data is presented.
NBS 473 Lab/Field Comparisons of BUR membranes (1961)	Field Specimens tend to have thinner moppings and better thermal shock resistance
NBS 965 Effects of Moisture in BUR—State of the Art Literature Survey (1978)	A literature review of the effects of moisture on BUR, including quantitative data on permeability, absorption, tensile strength and fungus attack resistance
NBS 1135 Cooling of Bitumen during Construction of BUR systems—a Mathematical Model (1981)	Provides a model of how bitumens cool, which will help in the development of better application guidelines
NBSIR 76-987 Effect of Insulation on the Surface Temperature of Roof Membranes	This paper, published after the oil embargo of 1972-73, resolved the issue of whether membrane roofing would fail prematurely due to excessive thermal load on highly insulated membranes. It found that after about the equivalent of 25 mm (1 in.) of insulation the temperatures only increased slightly with increased R value.
NBSIR 86-3418 Strain Energy of Bituminous BUR Membranes: An Alternative to the Tensile Strength Criterion (1986)	This document proposed a minimum strain energy of 13 N•m/m (3 lbf•in/in) @ -18°C (0°F)
NBS Report 10950 Slippage of BUR Membranes—Causes and Prevention (1972)	Identified major reasons why BURs can slip: wrong asphalt for slope, asphalt degraded by overheating, roof lacking nailers to back-nail the felts, excessive

	gravity force for the slope, hot climate, use of coated sheets and/or phased construction. All-ply constructions without a coated base sheet were less likely to slip. Excessive interply bitumen (likely due to asphalt too cool when applied) was a major factor, and this observation led to the development of the EVT concept.
NBS Report M-89 Effects of Thermal Shrinkage of BUR	Gives insight into why BURs shrink. Anchorage to the substrate to avoid shear planes in important. Ratchet effect with organic materials show that they contract when the roof is cooling and the interply bitumen is still relatively fluid. However, when felts take up moisture and try to expand, the bitumen is stiff and resists expansion Results of this cyclic effect is non-restorable shrinkage. This effect is far less significant on glass fiber felts.
NBS Report 86-3418 Performance Criteria for Load Elongation of Bituminous BUR membranes; Alternative to the Tensile Strength Criterion (1986)	Modified bituminous roofs differ from BUR. Specimens were tested in tension to determine load elongation properties and to measure strain energy. As an alternative to the conventional BUR criterion for a minimum tensile strength of 35 kN/m) 200 lbf, it was recommended that the strain energy should be a minimum of 13 Nm/m (3 lbf) when tested at -18°C (0°F) in the weakest direction.
NBS Report 9381 Exposure of New Roofing Systems (1966)	Provided excellent insight into the first generation of new roofing systems.
NBS Technical Note 972 Elastomeric Roofing: A Survey (1978)	Good insight into the second generation of single ply systems including PVC, Hypalon® and EPDM. Guidelines for selection and application and a summary of references is included.
NBS Technical Note 778 Guidelines for Selection of and Use of Foam Polyurethane Roofing Systems	Provides for the selection and use of SPF and suggests performance specifications for foam and protective coatings. Most of the guidelines are still valid today. Use in conjunction with ASTM D-5469 Application of New Spray-Applied Polyurethane Foam and Coated Roofing Systems.
CIB/RILEM Joint Report Elastomeric, Thermoplastic and MB Roofing Technical Report (1986)	Shine the 1970's, a phenomenal proliferation of materials, composites and systems employing elastomers, thermoplastics and MBs has occurred. It was agreed that criteria, test methods and standards could be developed. (See following report)
CIB-Rilem Joint Report Performance Testing of Roofing	This report gave recommendations for a test protocol comprising a set of performance test methods for

Membrane Materials, Recommendations of the Committee (1988)	characterizing and evaluating sheet roof membrane materials. Four test parameters were concentrated on: puncture testing; tear resistance, cyclic fatigue and thermal analysis.

Oak Ridge National Laboratory (ORNL)
PO Box 2008
Oak Ridge, TN 37831-2008
(615) 576-5454
www.ornl.gov/roofs&walls

Conf 9405206 Low Slope Roofing Workshop (1994)	Collection of papers relating to reroofing and re-cover issues.
Conf 9610200 Sustainable Low-Slope Roofing Workshop (1996)	Collection of papers on durability and recyclability
ORNL 89-SD350/1 Moisture Control Handbook — New, Low-rise Residential Construction(1989)	Discusses designs for various climate situations

NONGOVERNMENT PUBLICATIONS

Arizona Roofing Contractors Association

Concrete Tile Roof Specifications (1998)	Covers Tile Installations in the Western U.S. Directed towards cement tile, but applicable to clay as well

APA—The Engineered Wood Association
7011 S. 19th St., P.O. Box 11700
Tacoma, WA 98411-0700
(253)565-6600

Guidelines for Proper Installation of APA Rated Sheathing for Roof Applications	Provides checklist for deck preinspection, panel application and fastening hints
Residential and Commercial Manual	Comprehensive guide to panel construction systems for both residential and commercial/industrial buildings

American National Standards Institute (ANSI)
11 W. 42nd St. New York, 10036
(212) 642-4900
www.ansi.org

ANSI/ASCE 7-95 Minimum Design Loads for Buildings and Other Structures (1996)	Provides wind, snow ice and seismic maps and other information to be used by building designers
ANSI/SPRI RP-4 Wind Design Standard for Ballasted Single Ply Roofing Systems (1998)	Updated to be consistent with ANSI/ASCE-7-95. Provides design information on ballasted single-ply roofs.

American Society of Civil Engineers
Book Orders A 803, PO Box 831
Somerset, NJ 08875-0831
(800)-548-2723
www.asce.org

Guide to the use of the Wind Load Provisions of ASCE 7-95	Written by Texas Tech. University to assist readers of ASCE-7-95

American Society of Heating, Refrigerating
& Air Conditioning Engineers (ASHRAE)
1791 Tullie Circle, NE
Atlanta, GA 30329
(404) 636-8400

Handbook of Fundamentals	Voluminous reference book includes chapters on psychrometrics and condensation, steam tables, thermal insulation calculations and resistance; climate data.
Proceedings on Thermal Performance of Exterior Envelopes, PMRs	
A Water-Ballasted Life-time Energy Saving Roof System, Economic Projections	

American Society for Testing and Materials (ASTM)
100 Barr Harbor Drive, W. Conshohocken
PA 19428-2959
(610) 832-9500
www.astm.org

STP 603 Roofing Systems (1977)	Eight papers, including cold process BUR and moisture in PMR insulation
STP 790 Single-ply Roofing Technology (1982)	Seven papers including wind effects on ballasted and spot attached systems. Also EPDM seam adhesion

STP 959 (1987)	Nine papers including heat transfer through mechanically fastened single plies; MB testing; cold adhesives
STP 1088 Roofing Research & Standards Development (1990)	Fourteen papers-Includes paper on EPDM adhesives, comparing open time. Adhesive thickness and surface cleanliness on peel strength; PVC roofing; testing
Moisture Control in Buildings Manual 18	Comprehensive overview of issues and data related to moisture control in buildings. Ch. 16 covers roofing.

Asphalt Roofing Manufacturers Association
4041 Powder Mill Road, Suite 404
Calverton, MD 20705-3106
www.asphaltroofing.org

Butterworth Architecture
80 Montvale Ave
Stoneham, MA 02180

Problems in Roof Design (1991)	Textbook by H. McCampbell, listing types of roofing (mostly west coast design), avoiding failures, details that work.

Cedar Shingle and Shake Bureau
515 116th Ave, N.E., Suite 275
Bellevue, WA 98004-5294
((800) 843-3578
www.cedarbureau.org

Design & Application Manual for New Roof Construction	General Design and Application Details using Plywood and OSB, Specification Guidelines

Construction Specification Institute (CSI)
601 Madison St.
Alexandria, VA 22314
(703)684-0300
www.csinet.org

Copper Development Association 260 Madison Ave New York, NY 10016 (212) 251-7220 www.copper.org	6-part video series for architects: Copper in Architecture, Standing seam Roofs, Batten Seam Roofs, Flat Seam and Shingle Roofs, Horizontal Seam Roofs and Gutters, Flashing and Roof Details
Copper in Architecture Manual	3-ring Binder with fundamentals, and details. Also contains 6-floppy disc with details and specifications

Council of Forest Industries of British Columbia
1500/1055 West Hastings St.
Vancouver, Canada V6E 2H1
(604) 684-0211
www.cofi.org/wrcla

Western Red Cedar Shingles and Shakes Used in Heavy Snowfall Areas	Number of recommendations on location of stacks, ventilation of roof system, layers of shingles or shakes

Factory Mutual System (FM)
1151 Boston-Providence Turnpike
Norwood, MA 02063

P7825c Approval Guide Building Materials (Annual)	Lists Approved Materials and Systems
Approval Standard 4435 for Roof Flashing	Booklet describing basis for listings of Flashing Materials
Approval Standard 4450 Class 1 Insulated Steel Deck Roofs (1989)	Booklet describing basis for listings including fire, wind, heat damage and fasteners
Approval Standard 4451 for Steel Roof Decking (1996)	Booklet describing basis for listings, including wind, welds, corrosion
Approval Standard 4454 for Lightweight Insulating Concrete Roof Deck	Booklet describing basis for listings when using Lightweight Insulating Concrete
Approval Standard 4470 Class 1 Roof Covers (1986)	Booklet describing basis for listings including fire, wind, corrosion of fasteners, hail, leakage
Approval Standard 4471 Class 1 Panel Roofs (1995) (1994)	Defines criteria for acceptance of metal and plastic panel roofs, including fire, wind, foot traffic, hail damage resistance and water leakage resistance.
1-7 Wind Forces on Buildings and Other Structures	Data sheet with wind maps and procedures for estimating uplift forces
1-22 Maximum Foreseeable Loss Fire Walls	Use of fire walls in construction
1-28 Wind Loads to Roof Systems and Roof Deck	Data sheet on roofing materials installation

Securement	
1-28/1-29R Roof Systems	Data sheet on roofing procedures
1-29 Above Deck Roof Components	Vapor retarders, insulation, singleply and BUR
1-29* Safeguarding Torch-Applied Roof Installations	Safety procedures
1-29* PVC Roof Coverings	
1-31 Metal Roof Systems (1996)	Recover of and Recover by metal roofing
1-47S.1 Hail Damage (1985)	Recommendations to minimize hail damage
1-49 Perimeter Flashing (1985)	Both BUR and single ply details are provided, including installation of edge nailers
1-52 Field Uplift Tests (1986)	Data sheet on evaluating wind damaged roofing using tripod or suction panel apparatus.
1-54 Roof Loads for New Construction (1994)	Snow and rain loads and roof drainage

Florida Roofing, Sheet Metal And Air Conditioning Contractors Association, Inc.
PO Drawer 4850
Winter Park, FL 32792
(407)671-3772

Concrete and Clay Roof Tile Installation Manual (2nd Ed) (Jointly with National Tile Roofing Manufacturers Association)	Covers direct deck installations, battens, mortar and adhesive-set and execution using tile roofing.

2000 International Building Code order from ICBO, SBCCI or BOCA	New code intended to replace Uniform, Basic and Standard Codes.

McGraw Hill Publications
PO Box 545
Blacklick, OH 43004-0545

Manual of Low Slope Roofing Systems (1996)

Means, R.S Co. 100 Construction Plaza Kingston, MA 02364 (617) 685-7880	Text Book by C.W. Griffin and R.L. Fricklas covering the roof as a system, drainage, decks, thermal insulation, vapor control, fire and wind resistance, BUR, MB, Elastomeric and Thermoplastic systems,

	Flashings, PMRs, SPF, metal, inspections, reroofing, specifications and warranties.
Roofing-Design Criteria Options, Selection	
Estimating Guides	Text Book by R. D. Herbert, listing types of roofing, avoidance of failure, accessories, maintenance, warranties, codes, system selection and estimating. Several different guides available for construction estimating

Metal Building Manufacturers Association (MBMA)
1300 Sumner Ave
Cleveland, OH 44115-2561
(216) 241-7333

Midwest Roofing Contractors Association (MRCA)
4840 W. 15Th St., Ste 1000
Lawrence, KS 66049
(913)843-7555
www.mrca.org

Safety In Torch Welding (1986)	

National Tile Roofing Manufacturers Association, Inc. (NTRMA)
PO Box 40337
Eugene, OR 97404
(541) 689-0366
www.ntrma.com

Concrete and Clay Tile Roof Design Criteria Manual for Cold, Snowy Regions	

National Roofing Contractors Association
10255 W. Higgins Rd, Ste 600
Rosemont, IL 60018-5607
(847) 299-9070
www.nrca@roofonline.org

Commercial Roofing Guide (Updated annually)	Directory of materials manufacturers, including membranes, adhesives, coatings, metals, insulations. Also includes analysis of manufacturer warranties
Residential Roofing Guide	Directory of materials, manufacturers for steep roofing

Conferences on Roofing Technology	Periodic publication of proceedings of joint conferences between NRCA, NIST and other sponsors
North American Insulation Manufacturing Association (NAIMA) 44 Canal Center Plaza, Suite 310 Alexandria, VA 22314 (703) 684-0084	
NAIMA 202-96 Standard for Flexible Fiber Glass Insulation Used in Metal Buildings	Gives guidance on R-values of compressible glass fiber insulation in service and in identification of products.
Polyscience Publications, Inc. PO Box 148, Morin Heights, PQ Canada, J0R 1H0	
Roofs—Design, Application, Maintenance	Text Book by M.C. Baker, physics of roofing, basic principles, materials that every designer should know.
Reston Publishing Co., Inc. Reston, VA (Prentice-Hall)	
Roofing Systems: Materials and Application	Text Book by John Watson, Historical usage, physical properties, substrate preparation, specs and installation methods, with emphasis on steep roofing
Revere Copper Products, Inc. PO Box 300 Rome, NY 13440 (800) 448-1776	
Copper and Common Sense	Compact but highly regarded manual on copper roof design and detailing
Roofing Industry Educ. Institute (RIEI) 14 Inverness Dr. E, H-110, Englewood, CO 80112 (303) 790-7200 www.riei.org	Conducts training seminars on flat and steep roofing. Course manuals available for purchase, as well as other training aids.
Sheet Metal and Air Conditioning Contractors Nat'l. Assoc. (SMACNA) 4201 Lafayette Center Drive Chantilly, VA 22021 (703) 803-2989 www.smacna.org	

1929 Standard Practice in Sheet Metal Work	Very useful reference in historical restoration of metalwork

Sheet Membrane and Component Suppliers to the Commercial Roofing Industry (SPRI)
200 Reservoir St., Ste 309A
Needham, MA 02194
(781) 444-0242
www.spri.org

ANSI/SPRI RP-4-1997 Wind Design Standard for Ballasted Single-ply Roofing Systems	Provides reference information on wind loads, edge securement, ballast type and quantity, as well as height/parapet recommendations.
Wind Design Guide for Edge Systems used with Low Slope Roofing Systems	Reference material on edge materials used with low slope roofing systems including securement of the substrate, holding power of the edge detail and materials specifications.

Steel Deck Institute
PO Box 25
Fox River Grove, IL, 60021
(847) 462-1930
www.sdi.org

# 29 Design Manual for Composite Decks, Form Decks, Roof Decks, and Cellular Deck Floor Systems with Electrical Distribution	Covers ribbed steel roof deck construction of varying configurations used for the support of roofing materials, design live load and SDI constructions loads.
Manual of Construction with Steel Deck	Intended as an aid and general guide for the proper erection of steel decks.

Underwriters Laboratories (UL)
333 Pfingsten Rd
Northbrook, IL 60062

Building Materials Directory	Lists non-roofing constructions (i.e. construction joints)
Roofing Materials and Systems Directory	Lists approved materials and systems for external fire and under-deck fire resistance, as well as wind uplift ratings
Fire Resistance Directory	Lists Time-Temperature ratings.
UL 55A Materials for BUR	Describes felts & bitumen

Coverings (1985)	
UL 55B Class C Asphalt Organic-Felt Sheet Roofing and Shingles (1983)	Properties of organic felts and shingles
UL580 Tests for Wind-Uplift Resistance of Roof Assemblies (1980)	Test Equipment and Procedures
UL 790 Tests for Fire Resistance of Roof Covering Materials (1983)	Class A,B,C test protocol for external fire
UL 2218 (1996) Impact Resistance of Prepared Roof Coverings	Impact procedure with steel ball impacts at room temperature
UL 1256 Fire Test of Roof Deck Constructions (1985)	Steiner Tunnel procedure for under-deck fire spread

Western States Roofing Contractors
Association (WSRCA)
8000 Airport Blvd. Suite 412
Burlingame, CA 94010
(800)725-0333

Roofing Details	Contains “Western” details for commercial roofing, for example uninsulated roofs and walls. Also contains details for flashing tile roofs.

APPENDIX C.
ACRONYMS

ANSI	American National Standards Institute
APA	The Engineered Wood Association
APO	Alpha-Polyolefin (Polymer used in MB Systems)
APP	Atactic (or Amorphic) Polypropylene (Used in MB)
ARMA	Asphalt Roofing Manufacturers Association
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BOCA	Building Officials and Code Administrators (Basic Building Code)
BUR	Built-up Roofing
CDA	Copper Development Association
CFC	Chlorofluorocarbon (Blowing Agent)
CPE	Chlorinated Polyethylene (Single Ply Polymer)
CSPE	Chlorosulfonated Polyethylene (Hypalon®)
ECO	Polyepichlorohydrin Rubber
EPDM	Ethylene Propylene Diene Monomer (or “m” class polymer)
EPS	Expanded Polystyrene
ETD	Equivalent Temperature Difference (ASHRAE)
EVT	Equiviscous Temperature
FM	Factory Mutual System
FMRC	Factory Mutual Research Corporation
FR	Fire-retarded
HCFC	Hydrogenated Chlorofluorocarbon (Blowing Agent)
HVAC	Heating, Ventilation, Air-conditioning

ICBO	International Congress of Building Officials (Uniform Building Code)
IPP	Isotactic Polypropylene
KEE	Ketone Ethylene Ester (Single Ply Polymer)
MB	(Polymer-) Modified Bitumen
MEPS	Molded, Expanded Polystyrene (Foam)
MRCA	Midwest Roofing Contractors Association
MSDS	Material Safety Data Sheets
NRCA	National Roofing Contractors Association
O&M	Operations & Maintenance Manual
ORNL	Oak Ridge National Laboratory
PIB	Polyisobutylene (Single Ply Polymer)
PMR	Protected Membrane Roof (System)
PVC	Poly(vinyl) Chloride (Single Ply Polymer)
PVDF	Polyvinylidene (di) Fluoride (Kynar 500®; Hylar 5000®)
RIEI	The Roofing Industry Educational Institute
ROOFER	Corps of Engineer Maintenance Data-Base Management System
SBA	Systems Builders Association (Formerly MBDA)
SBC	Standard Building Code (See SBCCI)
SBCCI	Southern Building Code Congress International, Inc. (Standard Building Code)
SBS	Styrene (or Sequenced) Butadiene Styrene
SDI	Steel Deck Institute
SMACNA	Sheet Metal and Air Conditioning Contractors National Association
SPF	Sprayed Polyurethane Foam
SPFD	Spray Polyurethane Foam Division (of SPI)

SPI	Society of the Plastics Industry
SPRI	Single Ply Roofing Institute
SPUF	Sprayed Polyurethane Foam
SSSMR	Structural Standing Seam Metal Roofing
TCS	Terne-Coated Stainless Steel
Tg	Glass Transition Temperature
TPO	Thermoplastic Polyolefin
UBC	Uniform Building Code (See ICBO)
UL	Underwriters Laboratories
UV	Ultraviolet Light
WSRCA	Western States Roofing Contractors Association
XEPS	Extruded (expanded) Polystyrene Foam

APPENDIX D

GLOSSARY OF ROOFING RELATED TERMS

Aggregate—(1) Crushed stone, crushed slag, or water-worn gravel used for surfacing a built-up roof; (2) Any granular mineral material.

Alligatoring—Shrinkage cracking of the surfacing bitumen on a built-up roof, producing a pattern similar to an alligator's hide. The cracks may or may not extend through the entire surfacing bitumen thickness.

Alloys, polymeric—A blend of two or more polymers, e.g., a rubber and a plastic to improve a given property, e.g., impact strength.

Asphalt—A dark brown to black cementitious material whose predominating constituents are bitumens that occur in nature or are obtained in petroleum processing.

Asphalt felt—An asphalt-saturated felt.

Asphalt, air blown—An asphalt produced by blowing air through molten asphalt at an elevated temperature to raise its softening point and modify other properties.

Asphaltene—A high molecular weight hydrocarbon fraction precipitated from asphalt by a designated paraffinic naphtha solvent at a specified temperature and solvent-asphalt ratio.

Note—The asphaltene fraction should be identified by the temperature and solvent-asphalt ratio used.

Atactic—A chain of molecules in which the position of the side methyl groups is more or less random. (Amorphic; Low Crystallinity)

Backup plate—A rigid plate to support an end lap to provide uniform compression.

Backnailing—*blind* (i.e., concealed by overlapping felt) nailing of roofing felts to a substrate in addition to hot-mopping to prevent slippage.

Ballast—Loose aggregate, concrete pavers, or other material designed to prevent wind uplift or flotation of a loose-laid roof system.

Base sheet—A saturated or coated felt placed as the first ply in a multi-ply bituminous roofing membrane.

Batten—Raised rib, in a metal roof, or a separate part or formed portion in a metal roofing panel.

Beaufort scale—A scale in which the force of the wind is indicated by numbers from 0 to 12. No.7 is "near gale" at 52-61 km/h (32-38 m.p.h.). No. 9 is "strong gale" at 76-87 km/h (47-54 m.p.h.).

Bitumen—(1) A class of amorphous, black or dark colored, (solid, semisolid, or viscous) cementitious substances natural or manufactured, composed principally of high molecular weight hydrocarbons, soluble in carbon disulfide, and found in asphalts, tars, pitches, and asphaltites; (2) A generic term used to denote any material composed principally of bitumen; (3) In the roofing industry there are two basic bitumens: asphalt and coal-tar pitch. Before application they are either (a) heated to a liquid state, (b) dissolved in a solvent, or (c) emulsified.

Bituminous emulsion—A suspension of minute globules of bituminous material in water or in an aqueous solution.

Bituminous, adj.—Containing or treated with bitumen. Examples: bituminous concrete, bituminous felts and fabrics, bituminous pavement.

Blanket insulation—Fiberglass insulation in roll form, often installed between metal roof panels and the supporting purlins.

Blister—An enclosed pocket of air-water vapor, trapped between membrane plies or between membrane and substrate.

Blister (Polyurethane Foam)—Undesirable rounded delamination of the surface of a polyurethane foam whose boundaries may be either more or less sharply defined.

Block copolymer—An essentially linear copolymer in which there are repeated sequences of polymeric segments of different chemical structure.

Block or board thermal insulation—Rigid or semi-rigid thermal insulation preformed into rectangular units.

Blocking—(1) wood built into a roofing system above the deck and below the membrane and flashing to (a) stiffen the deck around an opening, (b) act as a stop for insulation, (c) serve as a nailer for attachment of the membrane or flashing. (2) Wood cross-members installed between rafters or joists to provide support at cross-joints between deck panels. (3) Cohesion or adhesion between similar or dissimilar materials in roll or sheet form that may interfere with the satisfactory and efficient use of the material.

Blocking, wood—Treated wood members designed to help prevent movement of insulation.

Blowing agent—A compounding ingredient used to produce gas by chemical or thermal action, or both, in manufacture of hollow or cellular articles.

Blueberry—A small bubble or blister in the flood coating of a gravel-surfaced membrane.

Bodied solvent adhesive—An adhesive consisting of a solution of the membrane compound in solvent used in the seaming of membranes.

Bond—The adhesive and cohesive forces holding two roofing components in intimate contact.

Boot—A bellows type covering to exclude dust, dirt, moisture, etc., forming a flexible closure.

Breaking strain—% elongation at which a sheet or other tested component ruptures under tensile force.

Breaking stress—Stress (in force per linear or area units) at which sheet, or other tested component, ruptures under tensile force.

British thermal unit (BTU)—Heat energy required to raise the temperature of one pound of water by 1^0F (= 1055 joules).

Brooming—Embedding a ply by using a broom to smooth it out and ensure contact with the adhesive under the ply.

Btuh—Btu per hour.

Building code—Published regulations and ordinances established by a recognized agency describing design loads, procedures, and construction details for structures. Usually applying to designated political jurisdiction (city, county, state, etc.). Building codes control design, construction, and quality of materials, use and occupancy, location and maintenance of buildings and structures within the area for which the code was adopted. (See Model Codes)

Built-up roofing (BUR)—A continuous, semi-flexible membrane consisting of plies of saturated felts, coated felts, fabrics or mats assembled in place with alternate layers of bitumen, and surfaced with mineral aggregate, bituminous material, or a granule surfaced sheet (abbreviation, BUR).

Bull—Roofer's term for flashing or plastic cement.

Butyl rubber—A synthetic rubber based on isobutylene and a minor amount of isoprene. It is vulcanizable and features low permeability to gases and water vapor and good resistance to aging, chemicals and weathering.

Calender—A machine with two or more rolls, operating at selected surface speeds and controlled temperatures, for sheeting, laminating, skim coating (topping) and a friction coating to a controlled thickness or surface characteristic, or both.

Camber—A predetermined curvature designed into a structural member to offset the anticipated deflection under design load.

Canopy—Any overhanging or projecting roof structure with the extreme end usually unsupported.

Cant strip—A beveled strip used under flashings to modify the angle at the point where the roofing or waterproofing membrane meets any vertical element.

Capflashing—See Flashing.

Capsheet—A granule-surfaced coated felt used as the top ply of a built-up roofing membrane.

Caulk—To seal joints, seams, or voids by filling with a waterproofing compound or material.

Caulking—A composition of vehicle and pigment, used at ambient temperatures for filling joints, that remains plastic for an extended time after application.

Cavity Wall—A wall built of hollow masonry units arranged to provide a continuous internal air space.

Centistoke—unit measurement of viscosity-i.e., resistance to flow. 1 cS = 1 x 10^{-6} m^2/s.

Chain scission—Breaking of chemical bonds between carbon atoms by UV photo-oxidation, a reversal of the asphalt-blowing polymerization process that produces long chainlike hydrocarbon chains, resulting in embrittlement and cracking.

Chalk resistance—A measurement of performance for paint systems; the ability to resist a dusty/chalky appearance over time.

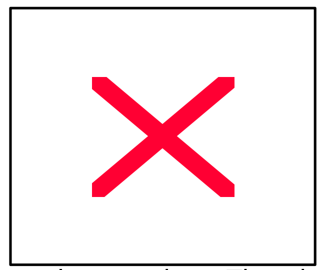
Chalking—A powdery residue on the surface of a material resulting from degradation or migration of an ingredient, or both.

Channel mopping—See Strip mopping under Mopping.

Chlorinated polyethylene (CPE)—Family of polymers produced by chemical reaction of chlorine on the linear backbone chain of polyethylene. The resultant rubbery thermoplastic elastomers presently contain 25-45% chlorine by weight and 0-25% crystallinity. CPE can be vulcanized but is usually used in a nonvulcanized form.

Chlorosulfonated polyethylene (CSPE)— Family of polymers that are produced by polyethylene reacting with chlorine and sulfur dioxide. Present polymers contain 25-43% chlorine and 1.0-1.4% sulfur. They are used in both vulcanized and nonvulcanized forms. Most membranes based on CSPE are nonvulcanized. ASTM designation for this polymer is CSM. Best known by the DuPont Tradename “Hypalon”.

Closure strip—A resilient strip such as neoprene, flat on one side and formed to the contour of ribbed sheets on the other, used to close openings created by joining metal sheets and flashings.



Coefficient of thermal expansion—The change in length per unit of length for a unit change in temperature. (Thus the coefficient per ^{0}F must be multiplied by 1.8 for the coefficient per ^{o}C.)

Coal tar—A dark brown to black cementitious material produced by the destructive distillation of coal.

Coal tar felt—A felt saturated with refined coal tar.

Coal tar pitch—Dark brown to black, solid cementitious material obtained as residue in the partial evaporation or distillation of coal tar.

Coated fabric—Fabrics impregnated and/or coated with a plastic material in the form of a solution, dispersion hot melt, or powder. (The term also applies to materials resulting from the application of a preformed film to a fabric by means of calendering.)

Coated sheet (or felt)—(1) An asphalt felt that has been coated on both sides with harder, more viscous asphalt; (2) A glass fiber felt that has been simultaneously impregnated and coated with asphalt on both sides.

Coating weight—Weight of coating on surface (both sides), usually expressed in ounces per sq. ft. or grams per sq. meter.

Coil coating—The application of an organic finish to a coil of metal using a continuous process.

Cold flow—Slow deformation, under gravitational force, at or below room temperature. (See Creep)

Cold process roofing—A continuous, semi-flexible membrane consisting of plies of felts, mats, or fabrics laminated on a roof with alternate layers of roof cement and surfaced with a cold-applied coating.

Condensation—The conversion of water vapor or other gas to liquid as the temperature drops or atmospheric pressure rises. (See also Dew Point)

Condensation polymerization—Polymerization in which monomers are linked together with the splitting off of water or other simple molecules.

Conductance, thermal—The thermal transmission in unit time through unit area of a particular body or assembly having defined surfaces, when unit average temperature difference is established between the surfaces. $C=(W/m^2 \bullet K)$ $C=(Btu/h \bullet ft^2 \bullet {}^0F)$.

Conductivity (Thermal)—The time rate of transfer of heat by conduction through a unit thickness across unit area for unit difference of temperature.

Conductivity, thermal—The thermal transmission, by conduction only, in unit time through unit area between two isothermal surfaces of an infinite slab of a homogeneous material of unit thickness, in a direction perpendicular to the surface, when unit temperature difference is established between the surfaces. $k=(W/m \bullet K)$ $k=(Btu/h \bullet ft^2 \bullet {}^0F)$.

Coping—A covering on top of a wall exposed to the weather, usually sloped to carry off water.
Copolymer—A mixed polymer, the product of polymerization of two or more substances at the same time.

Counterflashing—Formed metal or elastomeric sheeting secured on or into a wall, curb, pipe, rooftop unit, or other surface, to shield the upper edge of a base flashing and its associated fasteners.

Coverage—The surface area to be continuously covered by a specific quantity of a particular material.

Covering—The exterior roof and wall covering for a metal building system.

Cream Time—This is the time, measured in seconds at a given temperature, when the “A” and “B” components of a polyurethane foam compound will begin to expand after being mixed through the spray gun.

Creep—The dimensional change with time of a material under load, following the initial instantaneous elastic deformation. Creep at room temperature is sometimes called cold flow.

Creep modulus—The ratio of initial applied stress to creep strain.

Creep strain—The total strain, at any given time, produced by the applied stress during a creep test.

NOTE: The term creep, as used in this method, reflects current plastics engineering usage. Plastics have a wide spectrum of retardation times and the elastic portions of strain cannot be separated in practice from nonelastic.

Cricket—A relatively small, elevated area of a roof constructed to divert water from a horizontal intersection of the roof with a chimney, wall, expansion joint or other projection.

Cross-linking—A general term referring to the formation of chemical bonds between polymeric chains to yield an insoluble, three dimensional polymeric structure. Cross-linking of rubbers is vulcanization, qv.

Curb—A raised member used to support roof penetrations such as skylights, hatches, etc.

Cure—To change the properties of a polymeric system into a more stable, usable condition by the use of heat, radiation, or reaction with chemical additives.

NOTE: Cure may be accomplished, for example, by removal of solvent or cross-linking.

Curing—See Vulcanizations.

Curled felt—BUR membrane defect characterized by a continuous, open longitudinal seal with top felt rolled back from underlying felt.

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 used to isolate sections of the roofing system, usually removed before the continuation of the work.

Dampproofing—Treatment of a surface or structure to resist the passage of water in the absence of hydrostatic pressure.

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

Dead level asphalt—A roofing asphalt conforming to the requirements of Specification D312, Type I.

Deck—The structural surface to which the roofing or waterproofing system (including insulation) is applied.

Degree-days—The difference between a reference temperature (usually 18°C [65°F]) and the mean temperature for the day times 24 hours times the number of days in the period. Degree-days are used to compare the severity of cold or heat during the heating or cooling season.

Delamination—Separation of the plies in a membrane or separation of insulation layers after lamination.

Denier—A unit used in the textile industry to indicate the fineness of continuous filaments. Fineness in deniers equals the mass in grams of 9,000 meter length of the filament.

Depth of measurement—The maximum thickness of a roof system upon which a given moisture survey method is effective.

Design loads—The "live load" (i.e. super-imposed loads) that a structure is designed to resist (with appropriate safety factor) plus "dead load" (i.e., weight of permanent loads).

Dew point—The temperature at which water vapor starts to condense in cooling air at the existing atmospheric pressure and vapor content.

Double pour—Doubling of flood-coat, graveling-in operation, to provide additional waterproofing integrity for a BUR membrane.

Downspout—A conduit used to carry water from the gutter of a building to the ground or storm drain.

Dry (n.)—A material that contains no more water than one would find at its equilibrium moisture content.

Duckboard—A boardwalk or slatted flooring laid on a wet, muddy or cold surface.

Eave—The line along the sidewall formed by the intersection of the planes of the roof and wall.

Eave height—The vertical dimension from finished floor to the eave.

Edge stripping—Application of felt strips cut to narrower widths than the normal felt roll width to cover a joint between flashing and built-up roofing.

Edge venting—The practice of providing regularly spaced protected openings at a roof perimeter to relieve water vapor pressure in the insulation. (It is of doubtful efficacy.)

Efflorescence—A deposit or encrustation of soluble salts, generally white and most commonly consisting of calcium sulfate, that may form on the surface of stone, brick, concrete, or mortar when moisture moves through and evaporates on the masonry. Often caused by free alkalies leached from mortar, grout, or adjacent concrete.

Elasticity—The property of matter by virtue of which it regains its original size and shape after removal of stress.

Elastomer—A macromolecular material that returns rapidly to its approximate initial dimensions and shape after subsequent release of stress.

Embedment—(1) the process of pressing a felt, aggregate, fabric, mat, or panel uniformly and completely into hot bitumen or adhesive to ensure intimate contact at all points; (2) the process of pressing granules into coating in the manufacture of factory prepared roofing, such as shingles.

Emulsion—A dispersion of fine particles or globules of a liquid in a liquid. Asphalt emulsions consist of asphalt globules, an emulsifying agent such as bentonite clay and water.

Endlap—The overlap where one panel or felt nests on top of the end of the underlying panel or felt.

Envelope—A continuous edge seal formed by extending one ply of felt beyond the edge of the assembly. After other plies or insulation are in place, the extended ply is turned back and adhered.

EIP (Elastoplastic)—pertaining to polymeric materials, including thermoplastic and elastomeric categories.

EPDM—A synthetic elastomer based on ethylene, propylene, and a small amount of a non-conjugated diene to provide sites for vulcanization. EPDM features excellent heat, ozone and weathering resistance, and low temperature flexibility.

Epichlorohydrin rubber—A synthetic rubber that includes two epichlorohydrin-based elastomers of saturated high molecular weight, aliphatic polyethers with chloro-methyl side chains. The two types include a homopolymer (CO) and a copolymer of epichlorohydrin and ethylene oxide (ECO). These rubbers are vulcanized with a variety of reagents that react difunctionally with the chloromethyl group, including diamines, urea, thioureas, 2-mercaptoimidazoline, and ammonium salts. This rubber offers excellent oil resistance.

Equilibrium moisture content—(1) Moisture content of a material stabilized at a given temperature and relative humidity, expressed as percent moisture by weight; (2) The typical moisture content of a material in any given geographical area.

EVA—Family of copolymers of ethylene and vinyl acetate used for adhesives and thermoplastic modifiers. They possess a wide range of melt indexes.

EVT (Equiviscous Temperature)—Temperature at which the viscosity of an asphalt is appropriate for application. Viscosity units are generally expressed in centipoise or centistokes. Tolerance on EVT is usually ± 1400 (± 25°F).

Exotherm—Heat generated in a chemical reaction.

Expansion joint—A structural separation between two building elements that allows free movement (expansion or contraction) between elements without damage to the roofing or waterproofing system.

Exposure—(1) The transverse dimension of a roofing element not overlapped by an adjacent element in any roofing system. The exposure overlapped by an adjacent element in any roofing system. The exposure of any ply in a membrane may be computed by dividing the felt width minus 51 mm (2 in.), by the number of shingled plies; thus, the exposure of 914 mm (36 in.) wide felt in a shingled, four ply membrane should be 216 mm (8-1/2 in.); (2) The time during which a portion of a roofing element is exposed to the weather.

Extra steep asphalt—See Super Steep Asphalt.

Extractables—Components or substances removable from a solid or liquid mixture by means of an appropriate solvent.

Extruder—A machine with a driven screw that forces ductile or semi-soft solids through a die opening of appropriate shape to produce continuous film, strip, or tubing.

Fabric—A woven cloth of organic or inorganic filaments, threads, or yarns.

Fabric reinforcement—A fabric, scrim, etc., used to add structural strength to a 2 or more ply polymeric sheet. Such sheeting is referred to as "supported".

Fabrication—(1) The manufacturing process performed in a plant to convert raw material into finished metal building components. The main operations are cold-forming, cutting, punching, welding, cleaning, and painting; (2) the creation of large panels of rubber from smaller calendar width sheets as in EPDM.

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

Fascia—A decorative trim or panel projecting from the face of a wall, serving as a weather closure at gable and endwall.

Felt—A flexible sheet manufactured by the interlocking of fibers through a combination of mechanical work, moisture, and heat, without spinning, weaving, or knitting. Roofing felts are manufactured from vegetable fibers (organic felts), glass fibers (glass fiber felts) or polyester fibers (synthetic fiber mats).

Felt mill ream—The mass in pounds of 480 ft^2 of dry, unsaturated felt, also termed "point weight."

Fiber glass insulation—Blanket insulation, composed of glass fibers bound together with a thermoset binder, faced or unfaced, used over or under purlins to insulate roofs and walls, semi-rigid boards, usually with a facer.

Field—The "job site," "building site," or general market area.

Fill—As used in textile technology refers to the threads or yarns in a fabric running at right angles to the warp. Also called filler threads.

Filler strip—See Closure Strip.

Film—Sheeting having nominal thickness not greater than (0.25 mm) 10 mils.

Fin—A sharp, raised edge capable of damaging a roof membrane.

Fine mineral surfacing—Water insoluble inorganic material, more than 50% of which passes the 500 micrometer (No. 35) sieve, used on the surface of roofing.

Fishmouth—(1) A half cylindrical or half conical opening formed by an edge wrinkle or failure to embed a roofing felt; (2) In shingles, a half conical opening formed at a cut edge.

Flashing—The system used to seal membrane edges at walls, expansion joints, drains, gravel stops, and other places where the membrane is interrupted or terminated. Base flashing covers the edges of the membrane. Cap or counter-flashing shields the upper edges of the base flashing.

Flashing cement—A trowelable mixture of cutback bitumen, mineral stabilizers and fibers.

Flash point—Temperature at which a test flame ignites vapor above a liquid surface.

Flat asphalt—A roofing asphalt conforming to the requirements of Specification D312, Type II.

Fleece—Term used to describe mats or felts of usually nonwoven fibers.

Flood coat—The top layer of bitumen used to hold the aggregate on an aggregate surfaced roofing membrane.

Fluid-applied elastomer—An elastomeric material, fluid at ambient temperature, that dries or cures after application to form a continuous membrane. Such systems normally do not incorporate reinforcement.

Fluorocarbon films—Substituted ethylene polymers, featuring outstanding formability, heat resistance, color retention, and resistance to solvents and chalking.

Framed opening—Frame work (headers and jambs) and flashing which surround an opening in the wall or roof of a building; usually for field-installed accessories such as overhead doors or powered roof exhausters.

"Free carbon" in tars—The hydrocarbon fraction precipitated from a tar by dilution with carbon disulfide.

Friability—The tendency of a material or product to crumble or break into small pieces easily.

Gable roof—A ridged roof that terminates in gables.

Galvalume—Trade name for steel coated with aluminum-zinc alloy for corrosion protection.

Galvanic cell—A cell in which chemical change is the source of electrical energy. It usually consists of two dissimilar conductors in contact with each other and an electrolyte.

Galvanized steel—Steel coated with zinc for corrosion resistance.

Glass felt—Glass fibers bonded into a sheet with resin and suitable for impregnation in the manufacture of bituminous waterproofing, roofing membranes, and shingles.

Glass mat—A thin mat of glass fibers with or without a binder.

Glass transition—The reversible change in an amorphous polymer or in amorphous regions of a partially crystalline polymer from (or to) a viscous or rubbery condition to (or from) a hard and relatively brittle one.

Glaze coat—(1) The top layer of asphalt in a smooth surfaced built-up roof assembly; (2) A thin protective coating of bitumen applied to the lower plies or top ply of a built-up membrane, when application of additional felts, or the flood coat and aggregate surfacing are delayed.

Gloss—Subjective term describing the relative amount and nature of mirror-like reflection from a surface

Grain—Weight unit equal to 1/7000 lb, used in measuring atmospheric water vapor content.

Granule—See Mineral Granules.

Gravel—Coarse, granular aggregate, with pieces larger than sand grains, resulting from the natural erosion of rock.

Gravel stop—Flanged device, usually metallic, designed to prevent loose aggregate from washing off the roof and to provide a continuous finished edge for the roofing.

Green building technology—Utilizing technology to reduce impact on the earth. Includes recyclability, reduction in carbon dioxide, ozone or other atmospheric pollutants, and reduction of urban heat islands.

Grout—Mixture of cement, sand, and water used to fill cracks and cavities. Often used under base plates or leveling plates to obtain uniform bearing surfaces.

Gutter—A channel member installed at the eave of the roof for the purpose of carrying water from the roof to the drains or down spouts.

Haunch—The deepened portion of a column or rafter, designed to accommodate the higher bending moments at such points. (Usually occurs at connection of column and rafter.)

Header—A horizontal framing structural member of a door, window, or other framed opening.

Headlap—The minimum distances measured at 90 degrees to the eave along the face of a shingle or felt as applied to a roof, from the upper edge of the shingle or felt, to the nearest exposed surface.

Heat capacity—The amount of energy required to raise the temperature of a unit substance $1^{o}F$ (or $1^{o}C$).

Heat seaming—The process of joining two or more thermoplastic films or sheets by heating areas in contact with each other to the temperature at which fusion occurs. The process is usually aided by a controlled pressure. In dielectric seaming, the heat is induced within films by means of radio frequency waves.

Heat transfer—The transmission of thermal energy from a location of higher temperature to a location of lower temperature. This can occur by conduction, convection or radiation.

Hip roof—A roof which rises by inclined planes from all four sides on the building. The line where two adjacent sloping sides of a roof meet is called the Hip.

Homopolymer—A natural or synthetic high polymer derived from a single monomer.

Holiday—An area where a liquid applied material is missing, a void.

Hot-dip metallic coating—Adherent protective coating applied by immersing steel in a molten bath of coating material.

Hood—Cover, usually light gage metal, over piping or other rooftop equipment.

"Hot stuff" or "hot"—A roofer's term for hot bitumen.

Humidity—The amount of moisture contained in the atmosphere. Generally expressed percent relative humidity. (The ratio of the vapor pressure to the saturation pressure for given conditions times 100.)

Humidity test—A test involving exposure of specimens at controlled levels of humidity and temperature.

Hydrocarbons—An organic chemical compound containing mainly the elements carbon and hydrogen. Aliphatic hydrocarbons are straight chain compounds of carbon and hydrogen. Aromatic hydrocarbons are carbon-hydrogen compounds based on the cyclic or benzene ring. They may be gaseous (CH_4, ethylene, butadiene), liquid (hexene, benzene), or solid (Natural rubber, napthalene, cispolybutadiene).

Hygroscopic—Attracting, absorbing, and retaining atmospheric moisture.

Incline—The slope of a roof expressed in percent or in the number of vertical units of rise per horizontal unit of run.

Inorganic, adj—Comprising matter other than hydrocarbons and their derivatives, or matter not of plant or animal origin.

Insulation—See Thermal Insulation.

Internal pressure—Pressure inside a building, a function of wind velocity, building height, and number and location of openings.

Isocyanate—A highly reactive chemical grouping composed of a nitrogen atom bonded to a carbon atom bonded to an oxygen atom; =N=C=O; a chemical compound, usually organic, containing one or more isocyanate groups.

Isoboard—Abridgement of polyisocyanurate foam insulation board.

Joist — Any of the small timbers or metal beams arranged parallel from wall to wall to support a floor, ceiling or roof of a building.

Kesternich test—Simulates acid rain conditions by subjecting samples to a sulfur dioxide atmosphere as well as condensing moisture.

Kick-out (Elbow)—(Turn-Out) A lower downspout section used to direct water away from a wall.

Laitance — An accumulation of finer particles on the surface of fresh concrete due to an upward movement of water (as when excessive mixing water is used).

Lap—Dimension by which a felt covers an underlying felt in BUR membrane. "Edge" lap indicates the transverse cover; "End" lap indicates the cover at the end of the roll. These terms also apply to single-ply membranes.

Lapped joint—A joint made by placing one surface to be joined partly over another surface and bonding the overlapping portions.

Layer (Plywood)—A layer is a single veneer ply or two or more plies laminated with parallel grain direction. Two or more plies laminated with grain direction parallel is a "parallel laminated layer".

Leno fabric—An open fabric in which two warp yarns wrap around each fill yarn in order to prevent the warp or fill yarns from sliding over each other.

Live load—Live load means all loads including snow, exerted on a roof except dead, wind, and lateral loads.

Loose-laid membrane—A unadhered roofing membrane anchored to the substrate only at the edges and penetrations through the roof and ballasted against wind uplift by loose aggregate or payers.

Macromolecule—A large molecule in which there is a large number of one or several relatively simple chemical units, each consisting of several atoms bonded together.

Masonry—Anything constructed of materials such as bricks, concrete blocks, ceramic blocks, and concrete.

Mastic—Caulking or sealant normally used in sealing roof panel laps.

Membrane—A flexible or semi-flexible roof covering or waterproofing whose primary function is the exclusion of water.

Memory—Tendency of a material to regain a previous configuration—notably, the tendency of glass-fiber felts not to lie flat on their substrate after unrolling; the retraction of single-ply roll goods which were stretched during production or winding.

Mer—The repeating structural unit of any high polymer.
Mesh—The square opening of a sieve.

Metal flashing—See Flashing—frequently used as through-wall cap, or counterflashing.

Mineral Fiber—Inorganic fibers of glass, asbestos or mineral wool (slag).

Mineral Granules—Natural or synthetic aggregate, ranging in size from 500µm (1µm = 10^{-6}m) to 1/4 in. diameter, used to surface BUR or modified bitumen cap sheets, asphalt shingles, and some cold process membranes.

Model Codes—Codes established to provide uniformity in regulations pertaining to building construction.
Examples:
Uniform Building Code published by ICBO
National Building Code by BOCA
Standard Building Code by SBCCI
International Building Code (New)

Modulus of elasticity—The ratio of stress (nominal) to corresponding strain below the proportional limit of a material, expressed in force per unit area based on the minimum initial cross sectional area.

Moisture conduction—Migration by wicking as contrasted to vapor movement.

Moisture contour map—A map with lines connecting continuous levels of moisture. When drawn by computer the wettest areas are often indicated by darkest symbols and the driest areas left blank.

Mole run—A meandering ridge in a membrane not associated with insulation or deck joints.

Monomer—A simple molecule which is capable of combining with a number of like or unlike molecules to form a polymer.

Mop-and-flop—A procedure in which roof components (insulation boards, felt plies, cap sheets, etc.), are initially placed upside down adjacent to their ultimate locations, are coated with adhesive, and are then turned over and adhered to the substrate.

Mopping—Application of hot bitumen with a mop or mechanical applicator to the substrate or to the plies of a built-up or modified-bitumen roof. There are four types of mopping: (1) solid—a continuous coating; (2) spot—bitumen is applied in roughly circular areas, generally about 460 mm (18 in.) in diameter, leaving a grid of unmopped, perpendicular area, (3) strip—bitumen is applied in parallel bands, generally 200 mm (8 in.) wide and 300 mm (12 in) apart; (4) sprinkle—bitumen is shaken on the substrate from a broom or mop in a random pattern.

Mud cracking—Surface cracking resembling a dried mud flat.

Nail-type concrete anchor—A hammer-driven fastener with spiral or annular rings that provides pullout strength.

Nailer—Wood member bolted or otherwise anchored to a nonnailable deck or wall to provide nailing anchorage of membrane or flashing.

Nailing—(1) Exposed nailing of roofing wherein nail heads are bare to the weather; (2) Concealed nailing of roofing wherein nail heads are concealed from the weather. (See also Blind Nailing)

Needle punched—A mechanical entanglement of dry laid (usually cross-lapped, carded staple fiber) webs where barbed needles achieve, in multiple punches, mechanical bonding.

Neoprene—Synthetic rubber (polychloroprene) used in liquid or sheet-applied elastomeric roofing membranes or flashing.

Neutral sealants—Acid-free and amine-free sealants.

Nitrile rubber—A family of copolymers of butadiene and acrylonitrile that can be vulcanized into tough oil resistant compounds. Blends with PVC are used where ozone and weathering are important requirements in addition to its inherent oil and fuel resistance.

Nondestructive testing (NDT)—Methods for evaluating the strength or composition of materials without damaging the object under test.

Nonwoven fabric—A structure produced by bonding or interlocking of fibers (or both) by mechanical, thermal or solvent means (or combinations thereof).

Off-ratio mix—When the mixture of isocyanate and resin does not conform to the manufacturer's recommended mixing ratio. The acceptable ratio for most systems is when the two components are combined in equal volumes.

Olefin—An unsaturated open-chain hydrocarbon containing at least one double bond: ethylene or propylene.

Olefin plastics—Plastics based on polymers made by the polymerization of olefins or copolymerization of olefins with other monomers, the olefins being at least 50 mass %.

One-on-one—See Phased Application.

Organic, adj.—Composed of hydrocarbons or their derivatives, or matter of plant or animal origin.

Organic coating—Coatings that are generally inert or inhibited. May be temporary (e.g., slushing oils) or permanent (paints, varnishes, enamels, etc.).

Organic content—Usually synonymous with volatile solids in an ashing test; e.g., a discrepancy between volatile solids and organic content can be caused by small traces of some inorganic materials , such as calcium carbonate, that lose weight at temperatures used in determining volatile solids.

Panel clip—Independent clip used to attach roof panels to substructure.

Panel creep—Tendency of the transverse dimension of a roof panel to gain in modularity due to spring-out or storage-distortion.

Parapet—Portion of wall above the roof line.

Pascal—SI unit of measure for force per unit area (N/m^2).

Pea gravel—Small gravel with a diameter approaching that of a pea. Size roughly defined by ASTM D448, Number 7 or smaller.

Peak—The uppermost point of a gable.

Penetration—The consistency of a bituminous material expressed as the distance in tenths of a millimetre (0.1 mm) that a standard needle or cone vertically penetrates a sample of material under specified conditions of loading, time, and temperature.

Percent elongation—In tensile testing, the increase in the gauge length, measured after fracture of the specimen within the gauge length.

Percent water by volume—

$$= \frac{\text{Volume of Water in Sample}}{\text{Volume of Sample}} \times 100$$

Percent water by weight—

$$= \frac{\text{Sample Weight Wet-Sample Weight Dry}}{\text{Sample Weight Dry}} \times 100$$

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

Perm—(vapor transmission) Unit to measure water vapor transmission—one grain of water vapor per square foot per hour per inch of mercury pressure difference. 1 Perm = 1 grain/h•ft^2•in. Hg = 5.74 x 10^{-11} kg/Pa•s•m^2.

Permeability—(1) The capacity of a porous medium to conduct or transmit fluids; (2) The amount of liquid moving through a barrier in a unit time, unit area and unit pressure gradient not normalized for but directly related to thickness; (3) The product of vapor permeance and thickness (for thin films, ASTM E96—over 3.2 mm (1/8 in.), ASTM C355). Usually reported in perm inches or grain/h•ft^2•in. Hg per inch of thickness. 1 perm inch = 1.46 x 10^{-12} kg/Pa•s•m.

Permeance—The rate of water vapor transmission per unit area at a steady state through a membrane or assembly, expressed in ng/Pa•s•m^2 (grain/ft^2•h•in. Hg).

Petroleum pitch—A dark brown to black, predominantly aromatic, solid cementitious material obtained by the processing of petroleum, petroleum fractions, or petroleum residuals.

Phased application—The installation of a roofing or waterproofing system during two or more separate time intervals; a roofing system not installed in a continuous operation.

Phenolic plastics—Plastics based on resins made by the condensation of phenols, such as phenol and cresol, with aldehydes.

Picture framing—A rectangular pattern of ridges in a membrane over insulation or deck joints.

Pig spout—A sheet metal flashing designed to direct the flow of water out through the face of the gutter rather than through a downspout.

Pinhole—A tiny hole in a film, foil, or laminate comparable in size to one made by a pin.

Pitch—See Incline; Coal Tar Pitch; or Petroleum Pitch.

Pitch pocket—A flanged, open bottomed container placed around a column or other roof penetration and filled with hot bitumen, flashing cement or pourable sealer.

Plastic—A material that contains as an essential ingredient one or more organic polymeric substances of large molecular weight. It is solid in its finished state and at some stage in its manufacture or processing into finished articles can be shaped by flow.

Plastic cement—See Flashing Cement.

Plasticizer—Material, frequently solvent-like, incorporated in a plastic or a rubber to increase its ease of workability, flexibility, or extensibility. Adding the plasticizer may lower the melt viscosity, the temperature of the second order transition, or the elastic modulus of the polymer.

Plasticizers—May be monomeric liquids (phthalate esters), low molecular weight liquid polymers (polyesters) or rubbery high polymers (EVA). The most important use of plasticizers is with PVC where the choice of plasticizer dictates under what conditions the membrane may be used.

Plastisols—Mixtures of resins and plasticizers that can be cast or converted to continuous films by the application of heat.

Ply—A layer of felt in a roofing membrane; a four-ply membrane should have at least four plies of felt at any vertical cross section cut through the membrane.

Ply (Plywood)—A single veneer lamina in a glued plywood panel.

Plywood—A flat panel built up of sheets of wood veneer called plies, united under pressure by a bonding agent to create a panel with an adhesive bond between plies as strong as or stronger than, the wood. Plywood is constructed of an odd number of layers with grain of adjacent layers perpendicular. Layers may consist of a single ply or two or more plies laminated with parallel grain direction. Outer layers and all odd numbered layers generally have the grain direction oriented parallel to the long dimension of the panel.

Pointing—(1) Troweling mortar into a joint after masonry units are laid. (2) Final treatment of joints in cut stonework. Mortar or a putty-like filler is forced into the joint after the stone is set.

Polyester fiber—Generic name for a manufactured fiber in which the fiber-forming substance is any long chain synthetic polymer composed of an ester of a dihydric alcohol and terephthalic acid. Scrims made of polyester fiber are used for fabric reinforcement.

Polyisobutylene—The polymerization product of isobutylene varying in consistency from a viscous liquid to a rubberlike solid, with corresponding variation in molecular weight from 1,000 to 400,000.

Polyisocyanurate—Thermoset polymer formed by polymerization of isocyanate; rigid foam insulation meeting ASTM C1289; a thermal insulation similar in appearance to polyurethane foam, but with improved fine resistance or rating.

Polymer—A macromolecular material formed by the chemical combination of monomers having either the same or different chemical composition. Plastics, rubbers, and textile fibers are all high molecular weight polymers.

Polyols—A polyhydric alcohol, i.e., one containing three or more hydroxyl groups.

Polypropylene $(C_3H_5)_n$—A synthetic thermoplastic polymer, with a molecular weight of 40,000 or more.

Polyvinyl Chloride (PVC)—A synthetic thermoplastic polymer prepared from vinylchloride. PVC can be compounded into flexible and rigid forms through the use of plasticizers, stabilizers, filler, and other modifiers; rigid forms used in pipes; flexible forms used in manufacture of sheeting.

Pond—A roof area that retains water instead of draining after rainfall.

Ponding—Water in low or irregular roof areas that remains longer than 48 hours after the cessation of rainfall.

Pot Life—The working time once a product has been reacted (catalyzed).

Pre-painted coil—Coil steel which receives a paint coating prior to the forming operation.

Press brake—A machine used in cold-forming metal sheet or strip into desired cross-section.

Prestressed concrete—Concrete in which the reinforcing cables, wires, or rods in the concrete are tensioned before there is load on the member, holding the concrete in compression for greater strength.

Preventive maintenance—The regular, scheduled, inspection for and the repair of normal, expected breakdown of materials and equipment.

Prime coat—First liquid coat applied in a multiple coat system.

Primer (bituminous)—A thin liquid bitumen applied to a surface to improve the adhesion of heavier applications of bitumen and to absorb dust.

Protected membrane roof (PMR)—Roof assembly with insulation on top of membrane instead of vice versa, as in conventional roof assembly (also known as inverted or upside-down roof assembly).

Puncture resistance—Index of a material's ability to withstand the action of a sharp object without perforation.

R-Factor—Resistance to heat flow. The summation of individual thermal resistances in an assembly.

Racking—To stretch or strain by force, such as by the thermal or wind action.

Raggle—See Reglet.

Rake—The sloped edge of a roof at the first or last rafter.

Rake angle—Angle fastened to purlins at rake for attachment of endwall panels.

Rake trim—A flashing designed to close the opening between the goof and endwall panels.

Re-covering—The process of covering an existing roof system with a new roof.

Reentrant corner—An inside corner of a surface, where stress concentrations may occur.

Reglet—A groove in a wall or other surface adjoining a roof surface for the attachment of counterflashing.

Reinforced membrane-A roofing or waterproofing membrane reinforced with felts, mats, fabrics, or chopped fibers.

Relative humidity—The ratio of the mass per unit volume (or partial pressure) of 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, expressed as a percentage.

Relative saturation—

$$= \frac{\text{Volume of Water in Sample}}{\text{Maximum volume of water sample could hold}} \times 100$$

Remedial roofing—The repair of selected isolated portions of the roof system to return the roof to uniform condition. This normally involves the removal of wet materials along with correction of the original cause of the problem.

Reroofing—The removal of all roof system components down to the structural deck followed by installation of a completely new roofing system.

Resistance, thermal—See Thermal Resistance.

Retrofit—the modification of an existing building or facility to include new systems or components.

Ridge—Highest point on the roof of the building, a horizontal line running the length of the building.

Ridge cap—A transition of the roofing materials along the ridge of a roof. Sometimes called ridge roll or ridge flashing.

Ridging—An upward, tenting displacement of a membrane, frequently over an insulation joint.

Roll goods—A general term applied to rubber and plastic sheeting, usually furnished in rolls.

Roll roofing—Coated felts, either smooth or mineral surfaced.

Roof cement—See Flashing Cement.

Roof covering—The exposed exterior roof skin.

Roof curb—An accessory used to mount and level units (such as air conditioning and exhaust fans) on the sloped portion of the building roof.

Roof jack—An accessory used to cover pipes (such as vents or flues) that penetrate the roof panel.

Roof overhang—A roof extension beyond the endwall/sidewall of a building.

Roof seamer—Machine that crimps panels together or that welds laps of E/P systems using heat, solvent or dielectric energy.

Roof slope—The angle a roof surface makes with the horizontal, measured in the number of inches of vertical rise in a horizontal length of 12 inches. (Or as a ratio such as 1:48, or as a per cent.)

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

Rubber—A material capable of quickly recovering from large deformations, normally insoluble in boiling solvent such as benzene, methyl ethyl ketone, and ethanol toluene azeotrope. A rubber in its modified state retracts within 1 mm to less than 1.5 times its original length after being stretched to twice its length.

Sacrificial protection—Reducing the extent of corrosion of a metal in an electrolyte by coupling it to another metal that is electrochemically more active in the environment, i.e., galvanic protection.

Saddle—A small structure that helps to channel surface water to drains. Frequently located in a valley, a saddle is often constructed like a small hip roof or like a pyramid with a diamond-shaped base (also see Cricket).

Sandwich panel—A panel assembly used as covering; consists of an insulating core material with inner and outer skins.

Scarf—To scrap or abrade a surface to remove degraded or wet polyurethane foam.
Scupper—Channel through parapet, designed for peripheral drainage of the roof, usually a safety overflow to limit accumulation of ponded rainwater caused by clogged drains.

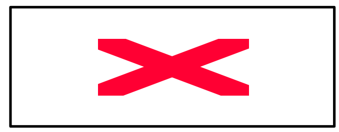
Scrim—A woven, open mesh reinforcing fabric made from continuous filament yarn. Used in the reinforcement of polymeric sheeting.

Sealant—Any material used to close up cracks or joints to protect against leaks. Lap sealant is applied to exposed lap edges in E/P systems.

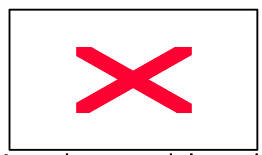
Sealing washer—A metal-backed rubber washer assembled on a screw to prevent water from migrating through the screw hole.

Seam strength—Strength of a seam of material measured either in shear or peel modes, reported either in absolute units, e.g., pounds per inch of width--or as a percent of the sheeting strength.

Self-drilling screw—A fastener that drills and taps its own hole, used as a fastener for attaching panels to purlins and girts.



Self-tapping screw—A fastener that forms receiving threads when turned into a previously drilled hole. It is for attaching panels to purlins and girts and for connecting trim and flashing.



Selvage—An edge or edging which differs from the main part of: (1) a fabric, or (2) granule surfaced roll roofing.

Service life—Anticipated useful life of a building, building component or building subsystem (e.g., roof system).

Shark fin—Curled felt projecting upward through the flood coat and aggregate of a BUR membrane.

Shear—The force tending to make two contacting parts slide upon each other in opposite directions parallel to their plane of contact.

Sheeting—A form of plastic or rubber in which the thickness is very small in proportion to length and width and in which the polymer compound is present as a continuous phase throughout, with or without fabric.

Shelf life—Maximum safe time to store a fluid construction material before use.

Shingle—(1) A small unit of prepared roofing designed for installation with similar units on overlapping rows on inclines normally exceeding 25%; (2) To cover with shingles, and (3) To apply any sheet material in overlapping rows like shingles.

Shingling—(1) The procedure of laying parallel felts so that one longitudinal edge of each felt overlaps, and the other longitudinal edge underlaps an adjacent felt. (See also Ply). Normally, felts are shingled on a slope so that the water flows over rather than against each lap; (2) The application of shingles to a sloped roof.

SI—The international symbol for the metric unit (Le Systeme International d'Unites).

Sidelap—The continuous overlap of closures along the side of a panel.

Sieve—An apparatus with square apertures for separating sizes of material.

Sill—The bottom horizontal framing member of an opening such as a window or door.

Single slope—A sloping roof with one surface. The slope is from one wall to the opposite wall of rectangular building.

Siphon break—A small groove to arrest the capillary action of two adjacent surfaces.

Skylight—A roof accessory to admit light, normally mounted on a curbed, framed opening.

Slab—A semi-finished steel product, intermediate between ingot and plate, with the width at least twice the thickness.

Slippage—Relative lateral movement of adjacent felts (or sheets) in a roof membrane. It occurs mainly in roofing membranes on a slope, sometimes exposing the lower plies or even the base sheet to the weather.

Slope—Tangent of the angle between the roof surface and the horizontal plane, expressed as a percentage, or in inches of rise per foot of horizontal distance. (See also Incline)

Smooth surfaced roof—A roof membrane without mineral aggregate surfacing.

Soffit—The underside covering of any exterior overhanging section of a roof, gable or sidewall.

Softening point—Temperature at which a bitumen becomes soft enough to flow as determined by an arbitrary, closely defined method.

Softening point drift—Change in softening point during storage or application. (See also Fallback)

Solid mopping—See Mopping.

Sprinkle mopping—See Mopping.

Spud—To remove the roofing aggregate and most of the bituminous top coating by scraping and chipping.

Spudder—Heavy steel implement with a dull, bevel-edged blade for removing embedded aggregate from a BUR membrane surface.

Spunbonded—A generic name for nonwoven fabrics formed directly from polymer chips, spun into continuous filaments which are laid down and bonded continuously, without an intermediate step.

Spunlaced—A hydroentangled nonwoven fabric whereby a dry laid staple fabric is mechanically bonded by water jet which entangles the individual fibers.

Square—A roof area of 9.29 m^2 (100 ft^2), or enough material to cover 9.29 m^2 of deck.

Stack vent—A vertical outlet designed to relieve pressure exerted by water vapor between a membrane and the vapor retarder or deck.

Stainless steel—An alloy of steel which contains a high percentage of chrominum. Also may contain nickel or copper. Has excellent resistance to corrosion.

Standing seam—Watertight seam type featuring an upturned rib, which may also be structural. It is made by turning up the edges of two adjacent metal panels and then folding them over in one of a variety of ways.

Standing water test—Evaluations in which test panels are submerged in aqueous solutions and alternately dried in air.

Starting platform—A movable platform used to support a seaming machine as it begins to roll-seal a metal seam.

Steep asphalt—A relatively viscous roofing asphalt conforming to the requirements of Specification D312, Type III.

Strain—Deformation under stress.

Strawberry—See Blueberry.

Stress—(1) A measure of the load on a structural member in terms of force per unit area (Mpa) (kips per sq. in.); (2) The force acting across a unit area in solid material in resisting the separation, compacting or sliding that tends to be induced by external forces. Also the ratio of applied load to the initial cross sectional area, or the maximum stress in the outer fibers due to an applied flexural load.

Stress concentration—A condition in which stress is highly localized, usually induced by an abrupt change in the shape of a member or at a substrate joint (e.g., between insulation joints) Stress relaxation—The time-dependent change in the stress resulting from application of a constant total strain to a specimen at a constant temperature. The stress-relaxation at a given elapsed time is equal to the maximum stress resulting when the strain is applied minus the stress at the given time.

Strikethrough—A term used in the manufacture of fabric reinforced polymeric sheeting to indicate that two layers of polymer have made bonding contact through the reinforcing scrim.

Strippable films—Added protection sometimes applied to continuous strip in coil coating process. Applied after prime and topcoats to resist damage prior to and during erection.

Stripping—Strip flashing: (1) The technique of sealing a joint between metal and bituminous 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 panels.

Substantial Completion—The stage in the progress of the work when it is sufficiently complete for the owner to occupy or utilize the work for its intended use.

Substrate—Surface upon which a roof component is placed (structural deck or insulation).

Super-steep asphalt—A high viscosity roofing asphalt conforming to the requirements of Specification D312, Type IV.

Supported sheeting—See Fabric Reinforcement.

Surface cure—Curing or vulcanization which occurs in a thin layer on the surface of a manufactured polymeric sheet or other items.

Surfactants—Surface active agents that reduce surface tension when dissolved in water or water solutions, or reduce interfacial tension between two liquids, or between a liquid and a solid.

Susceptibility—When not otherwise qualified, the degree of change in viscosity with temperature.

Tack-free—A film is considered tack-free when the finger, with a slight pressure, will not leave a mark. The surface will not be sticky.

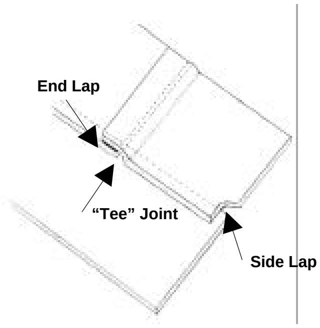
Tapered edge strip—A tapered insulation strip used to elevate the roofing at the perimeter and at penetrations of the roof.

Tar boils—Bubbles of moisture vapor encased in a thin film of bitumen, also known as blueberry, blackberry, etc.

Tear strength—The maximum force required to tear a specified specimen, the force acting substantially parallel to the major axis of the test specimen. Measured in both initiated and uninitiated modes. Obtained value is dependent on specimen geometry, rate of extension, and type of fabric reinforcement. Values are reported in stress, e.g., pounds, or stress per unit of thickness, e.g., pounds per inch.

Tearoff—Removal of a failed roof system down to the structural deck surface.

Tee joint—the condition created by the overlapping intersection of three or four sheets in the membrane.



Tensile strength—(1) The maximum tensile stress per unit of original cross sectional area applied during stretching of a specimen to break; units: SI-metric—Megapascal or kilopascal, customary—pound per square inch; (2) The longitudinal pulling stress a material can bear without tearing apart; (3) The ratio of maximum load to original cross-sectional area. Also called ultimate strength.

Tensile test—A test in which a specimen is subjected to increasing longitudinal pulling stress until fracture occurs.

Therm—A unit of heat commonly used by utilities, equivalent to 100,000 BTU = 1.05 x 10^8 joules.

Thermal block—A spacer of low thermal conductance material, designed to prevent formation of a thermal bridge.

Thermal bridge—Interruption of a layer of thermal insulation by a material of high thermal conductivity (e.g. metal).

Thermal conductance (C)—The rate of heat flow through a material whose surfaces have stated a temperature differential Btu•in./h•ft4^{0}F(W/m^2•^{0}C).

Thermal conductivity (k)—The rate of heat flow through a stated thickness of material with a stated temperature differential Btu/h.ft^2•^{0}F (W/m^2•^{0}C).

Thermal insulation—A material designed to reduce the conductive heat flow.

Thermal resistance (R)—Resistance to heat flow. The reciprocal of conductance (C).

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

Thermogram—A visible light record of the display of an infrared camera system via a Polaroid print, 35 mm film, or videotape.

Thermography—A technique for producing heat pictures from the invisible radiant energy emitted from stationary or moving objects at any distance and without in any way influencing the temperature of the objects under view. The electronic generation and display of a visible image of an infrared spectrum.

Thermoplastic—Capable of being repeatedly softened by increase of temperature and hardened by decrease in temperature. The thermoplastic form allows for easier seaming both in the factory and in the field.

Thermoplastic elastomers—Polymers capable of remelt, but exhibiting elastomeric properties; related to elasticized polyolefins. They have a limited upper temperature service range.

Thermoplastic resin—A material with a linear macromolecular structure that will repeatedly soften when heated and harden when cooled.

Thermoset—A material that will undergo (or has undergone) a chemical reaction by the action of heat, catalysts, ultraviolet light, etc., leading to a relatively infusible state.

Through-wall flashing—A water-resistant membrane or material assembly extending totally through a wall and its cavities, positioned to direct any water within the wall to the exterior.

Toggle bolt—A two-piece assembly consisting of a threaded bolt and an expanding clip that can fit through a drilled bolt hole, then spring outward to provide anchorage from the blind side.

Trim—The light gauge metal used in the finish of a building, especially around openings and at intersections of surfaces. Often referred to as flashing.

Tuck pointing—The filling in with fresh mortar of cutout or defective mortar joints in masonry.

U-Factor—The heat flow across an entire assembly e.g., from air within a building to outside air; the inverse of R-Factor.

Ultimate elongation—The elongation of a stretched specimen at the time of break. Usually reported as percent of the original length. Also called breaking strain.

Unsupported sheeting—A polymer sheeting one or more plies thick without a reinforcing fabric layer or scrim.

Uplift—Wind load on a building which causes a load in the upward direction. (See Suction)

Valley gutter—A channel used to carry off water at the intersection of two sloping roof planes.

Vapor barrier—See Vapor Retarder.

Vapor migration—The flow of water vapor from a region of high vapor pressure to a region of lower vapor pressure.

Vapor pressure—The pressure exerted by a vapor that is in equilibrium with its solid or liquid form.

Vapor retarder—A material that resists the flow of water vapor.

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

Ventilator—An accessory usually used on the roof that allows air to pass through.

Vermiculite—An aggregate used in lightweight insulating concrete, formed by heating and expanding a micaceous mineral.

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

Viscosity—Index of a fluid's internal resistance to flow, measures in centistokes (cSt) for bitumens. (Water has a viscosity of roughly 1 cSt, light cooking oil 100 cSt.)

Vulcanization—An irreversible process during which a rubber compound, through a change in its chemical structure, e.g., cross-linking, becomes less plastic and more resistant to swelling by organic liquids, and elastic properties are conferred, improved, or extended over a greater range of temperature.

Warp—In textiles, the lengthwise yarns in a woven fabric.

Water vapor transmission—(WVT)—Water vapor flow normal to two parallel surfaces of a material, through a unit area, under the conditions of a specified test such as ASTM E96. Customary units are g/h•m^2 (grains/h•ft^2). 1 grain/h•ft^2 = 0.697 g/h•m^2.

Waterproofing—Treatment of a surface or structure to prevent the passage of water under hydrostatic pressure.

Weatherometer—An instrument used to subject specimens to accelerated weathering conditions, e.g., rich UV source and water spray.

Wicking—The process of moisture movement by capillary action as contrasted to movement of water vapor.

Yield strength—(1) The longitudinal stress a material can bear before plastic deformation (i.e., elongation under constant stress); (2) The stress at which a material exhibits a specified reduction in the constant stress/strain ratio is the elastic range.

Yield strength—The stress at which a material exhibits a specified deviation from proportionality of stress and strain.

APPENDIX E
METRIC PRACTIC GUIDE FOR ROOFING INDUSTRY
Conversion Factors

Property	to Convert from	Symbol	to	Symbol	Multiply by	Remarks
Application rate	U.S. gallon per square	gal (U.S.)/ 100 ft²	litre per square metre	litre/m²	0.4075	= 0.4075 mm thick
	U.K. gallon per square	gal (U.K.)/ 100 ft²	litre per square metre	litre/m²	0.4893	= 0.4893 mm thick
Area	square inch	in.²	square millimetre	mm²	645.2	1 000 000 mm² = 1 m²
	square foot	ft²	square metre	m²	0.092 90	
	square	100 ft²	square metre	m²	9.290	
Breaking Strength	pound force per inch width	lbf/in.	kilonewton per metre width	kN/m	0.175	
Coverage	square foot per U.S. gallon	ft²/gal	square metre per litre	m²/litre	0.024 54	
	square foot per U.K. gallon	ft²/gal	square metre per litre	m²/litre	0.020 44	
Density, or mass per unit volume	pound per cubic foot	lb/ft³	kilogram per cubic metre	kg/m³	16.02	water = 1000 kg/m³
Energy or work	kilowatt-hour	kWh	megajoule	MJ	3.600*	J=W•s = N•m
	British thermal unit	Btu	joule	J	1055	
Flow, or volume per unit time	U.S. gallon per minute	gpm	cubic centimetre per second	cm ³/S	63.09	or 0.0631litre/s
	U.K. gallon per minute	gpm	cubic centimetre per second	cm ³/S	75.77	or 0.0758litre/s
Force	pound force	lbf	newton	N	4.448	
	kilogram force	kgf	newton	N	9.807	N = kg•m/s²
Heat flow	thermal conductance, C	btu/h•ft²•oF	watt per square metre kelvin	W/m²•K	5.678	
	thermal conductivity, k	btu•in./ h•ft²•°F	watt per metre kelvin	W/m•K	0.1442	

Incline	inch per foot	in./ft	percent	%	8.333	3 in./ft = 25%
Length, width, thickness	mil inch (up to ~48 in. foot (~4 ft and above)	0.001 in. in. ft	micrometre millimetre metre	um mm m	25.40* 25.40* 0.3048*	1000 um =1mm 1000 mm=1m
Mass (weight)	ounce pound short ton	oz lb 2000 lb	gram kilogram megagram	g kg Mg	28.35 0.4536 0.9072	1000 g = 1 kg 1000 kg = 1 Mg
Mass per unit area	pound per square foot	lb/ft^2	kilogram per square metre	kg/m^2	4.882	
	pound per 100 square foot (roofing square)	lb/sq	kilogram per square metre	kg/m^2	488.2	
	pound per square foot	lb/ft^2	gram per square metre	g/m^2	4882	
	pound per square	$lb/100\ ft^2$	gram per square metre	g/m^2	48.82	
	ounce per square yard	$0z/yd^2$	gram per square metre	g/m^2	33.91	
Permeability at 23°C	perm inch	grain•in./ ft^2•h•in. Hg	nanogram/pascal second metre	ng/Pa•s•m	1.459	ng = 10^{-12} kg
Permeance at 23°C	perm	grain/ ft^2•h•in. Hg	nanogram/pascal second square metre	ng/Pa•s•m^2	57.45	1 grain = 64.8 mg

Power	horsepower	hp	watt	W	746	W = N•m/s + J/s
Pressure or stress	pound force per square inch	$lbf/in.^2$ or psi	kilopascal	kPa	6.895	Pa = N/m^2
	pound force per square foot	lbf/ft^2 or psf	pascal	Pa	47.88	
Temperature	degree Fahrenheit	°F	degree Celsius	°C	$(t_{°F}-32)/1.8$*	32°F = 0°C
	degree Celsius	°C	kelvin	K	$t_{°C}+273.15$•	273.15 K = 0°C
Thread count (fabric)	threads per inch width	threads/in.	threads per centimetre width	threads/cm	0.394	
Velocity (speed)	foot per minute	ft/min or fpm	metre per second	m/s	0.005 080*	
	mile per hour	mile/h or mph	kilometre per hour	km/h	1.609	
Volume	U.S. gallon U.K. gallon cubic foot cubic yard	gal (U.S.) gal (U.K.) ft^3 yd^3	cubic metre cubic metre cubic metre cubic metre	m^3 m^3 m^3 m^3	0.003 785 0.004 546 0.028 32 0.764 6	or 3.785 litres or 4.546 litres