THE USES AND PERFORMANCE REQUIREMENTS OF STEEP-SLOPE ROOF UNDERLAYS IN NORTH AMERICA AND THE UNITED KINGDOM

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The use and performance requirements for underlays used in steep-slope roof systems differ depending on the type of roof system, materials used and climate.

The terms used to describe roof underlays include underlayment, sarking and underslating.

Underlayment *is an asphalt-saturated felt or other sheet material (it may be self adhering) installed between a roof deck and roof system, usually used in a steep-slope roof construction. Underlayment is primarily used to separate a roof covering from a roof deck, shed water, and provide secondary weather protection for the roof area of a building* [1].

Underlay *is a material, usually felt, used in covering a roof deck before the roofing material is applied.* **Underlayment** *is a medium to heavy breather-type building paper or felt, usually asphalt treated, secured to a roof deck before the application of the covering material. It is most commonly used under shingles in residential construction* [2].

Sarking *is a timber or felt cladding placed over the rafters of a roof before the tiles or slates are fixed in place* [3]. *Traditional sarking materials are asphalt felts laid across the slopes of roof. Plastic sheet products have been recently introduced.*

Typical North American roof underlays are fully supported on roof decks, sandwiched between the roof deck and shingles, and thoroughly penetrated with shingle nails or staples. Typical roof underlays in the United Kingdom are supported on rafters, separated from the roofing tile, and not penetrated with nails (except at rafters). The performance requirements from the underlays in these two types of roof systems are different.

There is ongoing debate in North America about the value of underlays in asphalt shingle roof systems. The balance of published technical opinion supports the use of underlays but there is little scientific information on the subject.

There is no debate about the value of underlays in tile[1] roof systems; they are a necessary and indispensable part of a roof system. Technical opinion and scientific studies unreservedly support the use of underlays in tile roof systems.

The introduction of new underlay materials has improved the performance of some roof systems. The advantages of some new materials appear to be exaggerated, and there are performance properties inherent in traditional materials that may have been overlooked in the development of new products.

Rotting of untreated pine shakes in some areas of Canada has provided insight into the interaction between roof design and material durability.

The uses and performance requirements of underlays in the most common types of roof systems in North America and the United Kingdom are reviewed in separate sections of this paper. Design and installation guidance for underlays is available from contractor associations and manufacturers (e.g., 1, 4).

KEYWORDS

Condensation, Ice Damming, Sarking, Shakes, Shingles, Steep Roofs, Roof Materials, Roof Systems, Tiles, Underlay, Underlayment, UV Resistance, Ventilation, Water-shedding, Wood Rot.

WATER-SHEDDING ROOFS

The primary roofing material on water-shedding roof systems usually consists of small units (e.g., shingles, tiles) that shed rain from one unit to the next, thus rainwater flows down and off the roof. The individual roofing materials (e.g., shingles, tiles) may be waterproof but their ends and edges are generally not sealed, and they could not prevent rainwater entry on a flat roof.

Preventing roof system leaks

Preventing roof leaks is conceptually simple according to the National Research Council of Canada's, *Fundamentals of Roof Design*. It says, "Rain penetration occurs when there is water on the roof surface, openings through which it can flow, and forces acting to move it inwards. If any one of these conditions is eliminated, water cannot enter" [5].

Keys to a quality roof system are to direct water off the roof, minimize holes in roofing materials and control all forces that act to move water through these holes. Roof underlays can help to control the forces or help reduce damage if the primary roof leaks.

Asphalt shingle systems

Asphalt shingles supported on roof sheathing (i.e., a roof deck) over a ventilated attic space is the most common form of steep-sloped roof system in the United States and Canada. There are no roof battens, and the asphalt shingles are nailed directly through the underlay to the roof deck. Consequently, the underlay is perforated with shingle nails or staples about every 8 inches (203 mm).

[1] Throughout this paper, tile refers to individual watershedding elements of all types of materials, such as stone, ceramic, concrete, metal and wood.

Steep-sloped shingle roof systems seldom leak, despite their many openings, because there is no net force acting to move water inward. Overlapping the shingles limits the direct entry of rain. Capillary suction acts to draw and hold water into the capillary spaces between the shingles, and an air-pressure drop through the roof acts to move water toward the interior, but this is resisted by the force of gravity pulling the water out and down the slope [6].

Leakage of shingled roof systems will occur if the air pressure difference measured in inches of water is greater than the height through which the water must be raised to pass over the head-lap of the shingles. Leakage can also occur if shingles are blown off a roof or when the gravity flow on the surface is interrupted by skylights, snow, ice or other obstacles that cause water damming. Underlays will not prevent any of this leakage, but they may mitigate the damage if leaks occur.

Tile Roof Systems

In the United Kingdom the most common watershedding roof system is concrete tile with an air gap between the underlay and tiles. These roof systems are not as resistant to wind blown rain as asphalt shingles over plywood sheathing are, but tile roof systems generally have longer service lives. Windblown rain is a significant consideration for tile roof systems. Water can be blown through gaps at sides and ends of the tiles. The watershedding performance of underlays is critical to the performance of tile roof systems in exposed locations.

Leakage through joints in some tile roof systems can be prevented by the inclusion of spaces that are too large to produce capillary suction, which connect the outside air with a pressure equalized ventilation space beneath the tiles [5]. In this "rain screen" approach, the battens provide the cavity and the underlay provides the inner air barrier for pressure equalization. In this system, there is no air pressure difference on either side of the tiles nor capillary suction at the wetted ends of the tiles. Air pressure equalization can be employed effectively so long as continuous and rigid air barriers are used. This usually necessitates the inclusion of a continuous rigid underlay, and not one that is draped between roof rafters.

In this paper, the uses and performance requirements of underlays in two commonly used steep-slope roof systems; asphalt shingles and tile roof systems are reviewed.

ASPHALT SHINGLE UNDERLAYS

Asphalt shingle underlays are commonly used throughout North America. The National Roofing Contractors Association's (NRCA's) definition of underlay(ment) includes some important functions:

- To separate the roof covering from the roof deck
- To shed water
- To provide secondary weather protection

Resins from green lumber roof decks have been known to interact with roof shingles, and a separation layer of underlay can be useful. Underlays are quickly applied and they can provide temporary roofing before the roof shingles are installed. Underlays have remained intact after shingles have blown away, thereby providing temporary roofing [7]. Underlays provide secondary weather protection in ice-dam situations, when water backs up over the head-laps of shingles.

Other functions of underlays have been reported [8]. Two of the more important ones are air-flow resistance and moisture storage. Air-flow resistance reduces windblown water penetration from the outside and moist air penetration from the inside of a roof. Moisture storage provides temporary storage for small amounts of leak water, which subsequently evaporates in dry weather. We know of no experiments that quantify these advantages.

There are disadvantages to underlays. Felt materials can wrinkle and buckle, and these imperfections can telegraph through the finished shingle layer [8,9]. Peterson reported that underlays reduced the life of roof shingles in California due to heat build-up [10]. Explaining how an underlay will act as secondary weather protection when it has shingle nails through it every 8 inches (203 mm) or so can be a challenge. The liquid water transmission test in ASTM D 4869 for asphalt felt underlayments for shingles [11] includes the following note: *"Take care to ensure that the staples do not protrude at the front surface of the plywood board so as not to puncture the test specimen,"* this is hardly realistic. Slipperiness and poor ultraviolet (UV) resistance can be problems with some underlay materials.

Three types of underlays are used in asphalt shingle roof systems: general (full roof), eave protection and low slope underlays.

General (full roof) asphalt shingle underlays

In 1989, Arlan Peterson said that support for the use of underlays was long on opinions and short on facts [10]. The situation has not changed much in 10 years.

NRCA recommends underlays on all shingle roof systems without exception [1]. A 1990 survey indicated that 79 percent of U.S. roofing contractors always used underlays [12]. The absence of underlays can invalidate some manufacturers' warranties and roof system fire classifications [13].

Canadian building codes do not require general (full roof) underlays under roof shingles. Many Canadian roofing contractors use general underlays, while others do not. Typically, underlays are used more over wood plank roof decks and less over plywood. Underlays are more likely to be used on lower-sloped roof systems than on steeper sloped roofs. There also are provincial preferences, for example, Ontario roofing contractors tend to use underlays less than their neighbors in Québec.

The possibility of roof leaks increases as roof slope decreases. Some underlays have the capacity to absorb small amounts of backed-up water and subsequently release the water in drier weather [8,14,15]. Underlays are commonly used when roof slopes are less than 20 degrees (4.4 in 12). Unless specially manufactured low-slope shingles are used, low-slope underlays (two ply No. 15 felt, heavier felts or self-adhering modified bitumen) are required by Canadian building codes for roofs with slopes less than 18.4. degrees (4 in 12). NRCA has similar low-slope recommendations. NRCA also recommends reducing shingle exposures as roof slopes decrease, but it does not recommend the use of shingles on slopes of less than 14 degrees (3 in 12) [1].

With steeper roofs some of the benefits of shingle underlays decrease and some of the problems increase. Secondary weather protection is less useful, and slipperiness is more of a problem on steep-slope roof systems. Also, rolls are more difficult to lay straight and wrinkles and buckles from that are more visible on steeper roof systems. Some roofing experts believe that the potential problems of general underlays outweigh the benefits on roof systems over plywood decks with slopes exceeding 23 degrees (5 in 12).

Fully adhered modified bitumen underlays are believed to perform better than traditional felt underlays. Some of these materials are able to seal around nail shanks [16], increase wind resistance, and, because they are fully adhered, decrease the spread of water over a roof deck [17]. Higgs noted that these products should not be used as full roof coverings over high humidity occupancies because they may trap water between the deck and roof system [18]. These materials have little water storage capacity, and some have limited UV resistance.

Underlay Protection Against Ice Damming on Asphalt Shingle Roofs

In cold climates, the eaves of sloped roofs' overheated buildings are prone to ice damming.

Ice damming results from a combination of snow (or ice) on a sloping roof, below freezing outside air temperatures, and sufficient heat loss from the building's interior and/or solar radiation that causes the snow to melt [19].

The main reason for snow melting is heat loss from the building. Heat loss through the roof will depend on the interior temperature, the amount of insulation, the integrity of the air-vapor barrier between the interior and roof, and the ventilation of the space underneath the roof system. Heat loss through the double top plate at the exterior wall/ceiling junction can be a particular problem if provision is not made for full-depth (or full R-value) insulation.

In Ottawa, enough sunlight can be transmitted through a 5.9-inch (150-mm) snow cover on a clear winter day to cause melting at the roof surface, even when the outside temperature is as low as 10.4°F (-12°C) [20]. A roof slope facing south will become bare of snow more quickly than one facing north. Absorption of heat energy from the sun on the bare south slope can heat the attic space and cause melting of snow on the north slope.

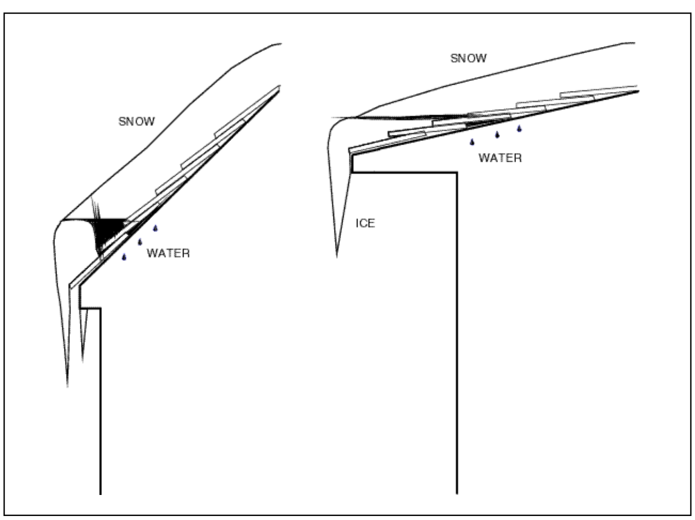

Figure 1. *Formation of ice dam.*

Water from melting snow will flow down the roof over the attic spaces of heated buildings until it meets cooler roof surfaces over the eaves; then melted snow starts to form ice. The ice formation can continue to build, with water backing up behind the ice dam. This water can penetrate underneath the shingles and leak into the interior.

The prevention of ice damming is largely in the hands of nonroofing trades. Ice damming can be almost totally prevented [21] by:

- ensuring that the entire ceiling, including the area above the top plates of the exterior walls, is protected by a full-depth layer of insulation.
- eliminating heat loss from air leakage into the attic or roof space.
- ventilating the attic space to prevent heat build-up under the roof sheathing.

The consequences of roof leaks due to ice damming can be reduced, but not prevented,[2] by eave protection underlay.

NRCA recommends eave protection on all roof systems regardless of slope when the January mean temperature falls below freezing [1].

Canadian building codes require eave protection underlay for most roof systems: exceptions include nonheated buildings and roofs with slopes exceeding 34 degrees (8 in 12) [22]. Approved eave protection materials include two plies of continuously asphalt bonded No. 15 felt, coated base or cap sheets, or self-adhering modified bitumen sheets. These materials are waterproof before shingles are applied, but do not necessarily remain waterproof when shingle nails have passed through them. Self-adhering modified bitumen membranes are preferred for eave protection because they can re-seal around shingle nail shanks [16].

Underlays for Low-slope Shingle Roofs

The minimum recommended low-slope limit for asphalt shingles is 14 degrees (3 in 12) in the United States [1] and 9.4 degrees (2 in 12) in Canada [22].

Asphalt shingles used on roof slopes from 9.4 degrees to 18.4 degrees (2 to 4 in 12) are applied differently than shingles on slopes above 18.4 degrees (4 in 12). Specially manufactured low-slope shingles that are solidly adhered with asphalt roof cement have been used successfully with and without underlays. These shingles are larger (more head-lap, less exposure) than regular asphalt shingles. Essentially this is a waterproofing, not watershedding, roof system.

The specially manufactured low-slope roof shingles are not as widely available as regular self-sealing shingles. The idea of laying two plies of No. 15 felt underneath regular asphalt shingles on low-slope roof was introduced about 20

[2] In the severe ice storm of January 1998, some roofs in eastern Canada had ice dams that ran halfway up their roofs. Water backed up well beyond the minimum requirements for eave protection specified by building codes. Eave protections were short-circuited. Water damage inside many houses was reduced by continuous vapor barriers in attic spaces.

years ago. This type of roof system has experienced problems in Canada, and the roofing industry is in the process of reviewing the situation [23]. A mandatory use of self-adhering modified bitumen underlays (in place of dry laid felts) may result in a more acceptable performance of this roof system. Special attention will have to be given to adequate underdeck ventilation when airtight underlays are used because attic spaces underneath low-slope roof systems can be awkward to ventilate effectively.

The Function of Asphalt Shingle Underlays

Asphalt shingle underlays reduce water damage in the interior of a building by providing temporary weather protection during construction and secondary watershedding protection in the event of leaking shingles.

Performance Requirements

In an asphalt shingle roof system, the strength of the underlay is largely "donated" by the roof sheathing. After shingles are applied, the watertightness of the underlay is compromised by the shingle nails.

1. **Tear resistance**
   Roof underlays can be exposed to high winds before shingles are applied. Tear strength is specified in ASTM D 4869 [11].

2. **Resistance to liquid water transmission**
   The ASTM D 4869 standard test for liquid water transmission of underlay material requires that there be no staples or nails through the upper surfaces. This is unrealistic. Ideally materials should be tested with nails through the underlay to better know their weather protection effectiveness.

3. **Resealing around nails**
   The test method described in ASTM D 1970 appears appropriate [16]. Resealing around nail shanks is more critical for low-slope and eave-protection underlays.

4. **Compatibility with asphalt shingles and roof deck**
   Some plastic sheets are reported to degrade when in contact with certain wood exudates.

5. **Wrinkle and buckle resistance**
   Some asphalt felts wrinkle and buckle [9]. Plastic sheet products appear to be relatively free of buckles and wrinkles as long as they are applied properly.

6. **UV resistance**
   Underlay material must retain adequate properties when exposed prior to shingle application. Some plastic and plastic surfaced sheets appear to be prone to UV damage.

7. **Water storage**
   The ability to absorb small amounts of backed-up water and then release it through evaporation during dry weather can reduce interior water damage.

8. **Fire resistance**
   Many underwriters' approvals for asphalt shingle roof systems include specific types of underlay.

9. **Thickness**
   Thick products can cause unsightliness in the finished shingle layer; however, products that are very thin may not seal or cushion staples or nail heads [24].

TILE ROOF UNDERLAYS

The most common watershedding roof systems in the United Kingdom are tiles nailed to timber battens, over underlays and timber rafters. These roof systems are not as resistant to windblown rain as asphalt shingles over underlays and solid wood sheathing, but tile roof systems generally have service lives of more than 50 years. Windblown rain is a significant consideration for tile roof systems, especially in exposed western locations, and the watershedding performance of underlays is important to their performance.

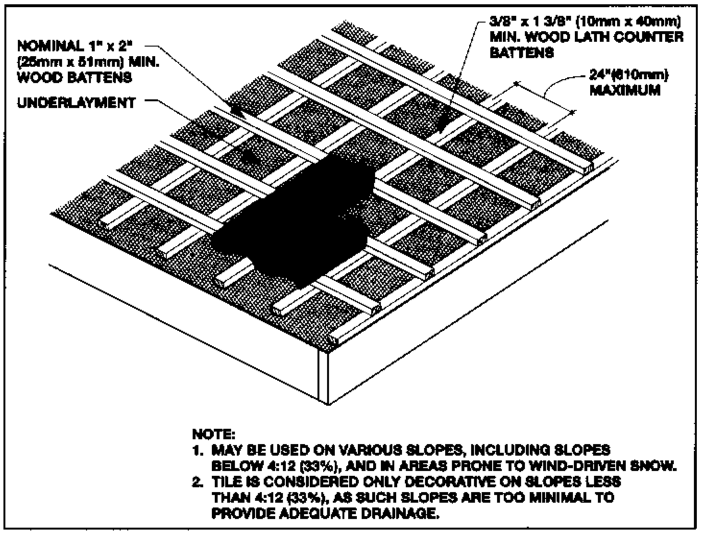

Figure 2. *Example of wood batten and counter batten system. [1]*

The Function of Tile Roof Underlays

Paraphrasing the U.K. National Federation of Roofing Contractors Limited (NFRC) bulletin on "Pitched Roof Underlays" [25]: *"The principle function of the underlay is to reduce the effect of wind loading on the tiles, and a secondary function is to provide a waterproof barrier to allow safe disposal of water to prevent damage to the interior."*

Windblown rain and snow that finds its way underneath or through side laps in tiles drips onto the continuous underlay and drains safely down into the gutter and out of the building. Underlays should have good nail holding capabilities, and should not sag much or exhibit the "canvas tent effect" (i.e., contact the material beneath and allow moisture to soak through).

During construction, and if damage to tiles occurs after construction, the underlay protects the insulation and building below so that the worst of the rain runs free.

If the ceiling below the pitched roof is not convection-tight. warm moist air can rise up into the attic space. Unless the attic space is ventilated adequately, this can result in condensation on cold surfaces and ultimately the decay of the building.

Performance Requirements

Underlays in typical tile roof systems in the United Kingdom are supported on roof rafters but unsupported in-between, so the material strength, tear and nail holding capabilities of underlays in tile roofs are more critical than they are for (fully supported) underlays in asphalt shingle roof systems.

1. **Strength and Nail Tear Resistance**
   On roofs without timber sarking boards, the underlay has to be able to withstand significant wind pressures.

2. **Water resistance**
   The ability to shed water off the roof system, for the service life of the roof system, is critical.

3. **Noise resistance**
   Wind blowing up into the eaves of a roof system can cause a drumming or chattering noise in some types of underlay which can disturb building occupants.

4. **Resistance to "tent effect"**
   When you touch the inside face of a canvas tent on a rainy day, the surface tension is broken and rainwater comes in. The same is also true for some types of breather underlays that need to be draped between rafters, otherwise water may penetrate through where the membrane touches the supports.

5. **Resistance to UV degradation**
   If the underlay is to be used for temporary weather protection before the tiles are laid, then it is essential that the underlay is not damaged permanently by extended exposure to direct sunlight.
   Some U.K. manufacturers of plastic sheets have claimed that their products are UV resistant and can be exposed for up to four months on site. As a result, some underlays are being put on early in projects and left as exposed temporary roofing. This practice may partly explain why there is significant leakage in some roofs [26].

6. **Electrical Conductivity**
   Electrical conductivity should be low, so as not to attenuate radio or television signals.

7. **Animal Attack**
   Underlay materials should not encourage such attack.

8. **Chemical Resistance**
   Especially its resistance to wood preservatives.

CURRENT ISSUES

Condensation Control

There is an active technical debate within the U.K. roofing press regarding the use of "breathing" underlays and the need for ventilation underneath tile and slate roofing. [27, 28, 29]. Design uncertainties about where best to position ventilation openings without compromising the water-shedding properties of the roof system, combined with concerns about the longevity of the plastic ventilation openings and installation costs, have encouraged specifiers to look at breathing underlays. Claims have been made that the use of water vapor permeable underlays can eliminate the need for attic ventilation [27].

Nonwoven polyethylene and polypropylene products have the lowest resistance to water vapor and comply with BS5534 British Standard Code of Practice for Slating and Tiling (including shingles) requirements.

Doubts have been raised about the test conditions used for determining the water vapor resistance of underlay materials. The low water vapor resistance values quoted by many manufacturers result from tests made at low mean relative humidities and warm conditions: typically 38 percent RH and 75 F (24 C). Condensation in attics is likely to occur at cool temperatures when the relative humidity approaches 100 percent. When tested at lower temperatures and higher mean relative humidities the water vapor resistance of many "low resistance" underlays increases by 20 times. [28]

There is also concern about the long term in-service permeability of materials in dusty environments such as roof spaces. Some researchers claim that even if water vapor permeable underlay materials retained their breathability, the rate of water vapor entering a typical attic space would exceed that of the underlay's ability to "breathe" it out [28, 29].

Recognizing this situation, the U.K. NFRC states: *"The water vapor permeability of the material is not an important requirement for pitched roof underlays as this cannot on its own be relied upon to eliminate roof space condensation. NOTE: Any water vapor transmission benefit should be treated as fortuitous."* [25]

The best current advice appears to be to provide ventilation openings and an underlay with low vapor resistance if money allows.

Roof System Ventilation and Roof Cladding Ventilation

Asphalt shingle roof systems are compact and relatively vapor-tight; condensation of interior humidity is controlled by effective air and water-vapor sealing of interior spaces,

WATER VAPOR RESISTANCE			
Statutory Requirements			**BS5534**
	(1/Perm)	(MNs/g)	<0.33 (1/Perm) <5.7 (MNs/g)
Type 1F bitumen felt	2.9	50	Fail
Microperforated polyethylene	0.6	10	Fail
Microperforated kraft paper	0.08	1.4	Pass
Nonwoven polypropylene	0.005	0.08	Pass

coupled with attic ventilation.

These vapor-tight roof systems work well for asphalt shingles, which survive well in damp environments; however, most roof cladding materials need ventilation and these compact systems allow little ventilation of the roof cladding.

Wood shakes are normally applied to roofs over battens, although they are applied directly on underlays over roof decks in some areas. A problem with untreated pine wood shakes appears to have highlighted the benefits of ventilation underneath shake roof systems.

Untreated pine shakes were introduced in Canada about 10 years ago and are reported to have performed adequately when installed on battens [30], however the performance of untreated pine wood shakes applied directly over underlays on roof decks has been poor, with reports of wood rot being seen after as little as three years [31]. It appears that untreated pine shakes perform well enough if properly ventilated on the underside (i.e., applied to battens) but not if they are applied directly to underlays on roof decks. The problem severity appears to be exacerbated on low-sloped roofs.

Wood rot in Canadian buildings is not expected unless the building design is inappropriate [32]. A case of inappropriate roof design appears to have been highlighted by the introduction of an inferior material. Premature rotting of cedar shakes applied directly over underlays and roof decks also has been reported [30, 33].

Wardell [17] discussed how wood shakes could be successfully applied on lower-sloped roof systems.

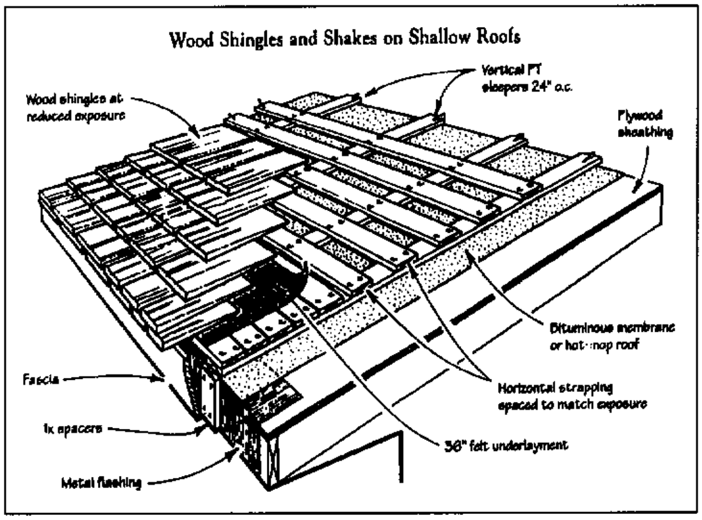

Figure 3. On shallow slopes, install wood shingles and shakes over a watertight subroof and a framework of pressure-treated strapping. The fascia is spaced out from the metal flashing at the eaves to allow any water that gets under the roofing to drain from the subroof. From Wardell [17].

NOTE. Although not shown in this figure, interlayment between the shakes should be installed.

FUTURE RESEARCH NEEDS

Designers and specifiers seek reliable and balanced guidance based on authoritative and independent research studies. Research on roof underlays, as opposed to experience and opinion, is lacking. Some of the test methods used in material standards are unrealistic and may be misleading to specifiers. Long-term monitoring of in-service roof constructions subjected to real weather conditions would greatly assist our understanding of roof underlays.

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