PROTECTED MEMBRANE FLASHINGS DESIGNED TO WORK

DOUGLAS C. FISHBURN
Fishburn Roofing Sciences Group Ltd.
Toronto, Canada

The protected membrane roof design is more than 20 years old. This design places the insulation over the membrane to protect it from the degrading effects of the environment and damage from traffic.

Regardless of the type of roofing system, the flashing elements often account for the majority of roofing problems. This paper primarily discusses how the detrimental effects acting upon bituminous flashings can be mitigated by the external use of insulation. This practice protects the flashing from the detrimental effects of the environment and damage from roof traffic, simplifies construction, reduces maintenance and increases the roof's life expectancy.

PROTECTED MEMBRANE FLASHINGS

Low-slope roofs in Canada can be generally classified into two types, conventional and protected. The conventional built-up roof has been used for more than 100 years. The protected membrane roof was introduced to Canada and Europe in 1969 and the United States in 1970.

While the conventional built-up roof places the insulation component under the membrane, the protected membrane roof places the insulation above it. In this configuration the insulation becomes a critical component and requires good physical and moisture-resistant properties. While this new arrangement of materials protects the roof membrane, the flashings continue to be unnecessarily exposed to temperature cycling, physical damage, solar radiation and water vapor pressure.

Figures 1 and 2, taken from the Canadian Roofing Contractors' Association manual, show the similarities of a typical eave for both a conventional and a protected bitumen membrane roof assembly.

Traditionally, flashings are the most problem-prone element of the roof assembly in both their ability to render the roof watertight and in their maintenance requirements.

A roof flashing is a vertical continuation of the waterproofing membrane and is found at intersections such as roof-to-wall junctions and at roof openings. While the manner in which they are designed and constructed poses limitations to their function, they are also subject to a number of other limiting factors.

The flashing, like a roof and wall, must protect the building from sun, wind and precipitation. Flashings may also be required to provide strength, rigidity or flexibility. They must also be durable and fire resistant. In many cases, the final finish or counterflashing may be required to complement the aesthetics of the roof or building.

The flashing elements are also subject to the laws of physics and chemistry such as vapor pressure, moisture migration, air and heat flow, radiation and reflection, dimensional change and electrolytic action.

While volumes have been written on how these factors have affected the performance of roof membranes, their effect on flashings has largely gone unreported.

In order to understand why flashings continue to be a problem and how protection of the flashing with insulation addresses many of these concerns, we need to look at some of the more important factors acting upon them.

DESIGN AND CONSTRUCTION

Flashings have always presented a challenge to both designer and contractor. Trade associations such as the Canadian Roofing Contractors Association (CRCA) and the National Roofing Contractors Association (NRCA) provide guidelines for their design and construction. These guidelines are considered minimum requirements and designers must use their knowledge and experience to ensure that the flashing design and materials employed are suitable for the intended application.

The design and selection of materials for their construction should be based on the following: their ability to render watertightness; how well they integrate into the overall construction of the building; and their durability.

While it is enough to say that flashings must be prudently designed and properly installed if they are to be watertight and afford durable service, it is evident that not all flashings are created equal. Otherwise, flashings would not continue to be a problem.

While the insulated flashing design can simplify design and construction practices, improper air sealing and placement of insulation can negate many of its benefits.

Good workmanship is an important consideration, but can be difficult to achieve. The following scenario uses bitumen roof flashings as an example.

It is difficult, particularly during cold weather operations, to keep high-melting-point bitumen at equiviscous temperature (EVT) at point of contact during the installation of membrane flashings. During this phase of the operation, the bitumen is usually held for longer periods on the roof, resulting in a temperature fall-back. While the requirements for interply quality are the same for both the membrane and membrane flashings, due to gravitational forces, maintaining a continuous layer of bitumen at the proper quantity on vertical flashings can be difficult.

While the subject of interply voids in flashings has not been studied and any comment would be speculative, voids appear to occur with common regularity, especially if the flashing is installed during colder weather. Poor interply adhesion appears to contribute to this problem.

While the protected membrane flashings cannot overcome design and construction errors, it appears that the use of Type II in lieu of Type III asphalt for protected membrane flashing construction may improve quality of construction. Fixing the flashings to prevent slippage is an important consideration. Because protected flashings will be shielded from the extreme impact of the environment, the use of more expensive flashing materials than the traditional felt and bitumen may not afford any great advantage.

Type II asphalt has been shown to be an acceptable waterproofing material for the construction of built-up roof membranes and is recommended when installing glass felts. The use of Type II for both membrane and flashings in a protected membrane roof application would ease application and provide some cost advantages since it would eliminate the necessity of duplicating asphalt heating and handling equipment. Since only one type of asphalt is used, error in using the wrong type of asphalt would be greatly reduced.

Regardless of the approach and type of materials employed, the flashings should be designed and installed to act in concert with the roof membrane to render the roof watertight and provide long-term service.

RADIATION AND REFLECTION

It is recognized that temperature affects the durability and service life of roofs. The same phenomenon is also true for roof flashing components.

High temperatures will generally increase the rate of deterioration of all flashing materials, accelerate compatibility problems, accelerate the loss of plasticizers in PVC sheets, accelerate the photo oxidation process and harden bitumen.

Because flashings are not covered with a protective layer of aggregate whose weight must be overcome to allow for expansion, even a small temperature rise can produce sufficient expansion for the small quantity of air trapped between the layers to cause blistering and delamination of the membrane flashings.

Figure 3 shows blistering of exposed flexible flashing due to the expansion of trapped air from solar heating. This photo was taken on a protected membrane roof that was 14 years old.

The roof is often exposed to extreme temperatures. It is not uncommon to have variations with daily cycles of 30 °C and seasonal cycles of 80 °C. Roof flashings are also exposed to solar heating and emissive cooling. Depending upon color and heat storage capacity of the substrate, it has been established that roof surface temperature in the summer can reach 90 °C. Color plays a major role in the amount of solar absorption since black, dark green and brown have a solar absorption coefficient of 0.95 and white, 0.45.

Even higher temperatures can be experienced due to reflective heat. This may occur, for example, when dark flashings are used on a south wall, and results from the combined effect on solar absorption and reflection.

These extreme temperatures can cause drying and shrinkage of materials. This may cause thermal stress in the various building materials which can act adversely on the flashings' performance. In addition, each of the building's materials has chemical and physical properties that must be satisfied if all elements are to work together to provide the desired results.

While the laws of nature are the same for the roof and flashings, their effect can vary. For example, while the combination of heat and gravity is beneficial and contributes to the flow of coal tar pitch to fill in cracks and crevasses on the roof's flat surface, it can act adversely on sloped surfaces. This can result in bitumen between the plies of membrane installed up the cant and vertical to flow down the slope from between the interply layers. Because of this phenomenon, when flashings are uninsulated, the correct choice of bitumen such as Type III or IV is usually employed in an attempt to offset these forces. Since the interply bitumen contributes significantly to both the membrane and flashing watertightness and strength, the flow of asphalt at elevated temperatures can dramatically affect the flashings performance and maintenance characteristics.

As an example, it is not unusual to find older coal-tar pitch roofs in good condition except for where the bitumen has leached from between the interply layers turned up the cant strip or verticals. In order to offset these forces on roofs constructed from coal-tar pitch, it has become standard practice to construct the membrane flashings with high-melting-point asphalt. The perceived risk of slippage and accelerated deterioration is far less than that of any non-compatibility that may exist between these two dissimilar products.

Since bituminous membrane roofs in Canada are generally constructed with Type I asphalt, they are subject to a similar phenomenon.

Both the CRCA and the National Building Code in Canada recognize the requirements for roofing asphalt as set out by the Canadian Standard Association (CSA), which sets standards for the slopes for asphalt types. While Type III asphalt is usually employed with the construction of most bituminous flashings, the use of insulation to protect the flashings from elevated temperatures makes the use of lower melting point asphalt possible with little undesirable effects. Studies are now being completed to confirm these findings.

In order to show the effect of heat build up on the flashings, the flashings of a 6-year-old roof was examined. Figures 4 and 5 show slippage and general deterioration of the bitumen membrane flashings on an inverted roof where the flashings were uninsulated. These photographs were taken after the counterflashing was removed.

While metal flashings can be used to shield uninsulated membrane flashings from ultraviolet rays, physical damage and fire, they do little to protect them from excessive heat build up, particularly where dark-colored counterflashings are used. The effect of the environment on flashings has not gone unnoticed, for over the years the demand for more durable flashing materials has continually increased.

To use a bituminous built-up roof as an example, the flashings on this type of assembly were initially constructed of a multi-ply organic felt and bitumen capped with metal counterflashings. Subsequently, higher-melting-point asphalts were used in their construction. In many cases, and in order to improve their durability, organic felts were substituted for asbestos felt. Mineral-surfaced cap sheets were also employed, as well as glass, cotton or jute mesh incorporating clay-filled or asphalt cutback mastic. While many of these materials are still employed, in Canada there is a trend toward the use of EPDM, PVC or modified bitumen membranes as the final flashing material in a bitumen membrane roof's construction.

The types of flashing material will vary with the type of membrane employed, such as the use of modified bitumen flashing when using glass fiber roofing felts to construct the roof membrane. Regional differences also exist. Compliance with manufacturers' recommendations for warrantee requirements will impact on the type of flashing material selected.

While there have been improvements in the design and durability of materials, they have not solved the problem. As a result, flashings continue to be the most problem-prone element limiting the ability of most roofs, protected or otherwise, to reach their service potential. As the strength of the chain is determined by the weakest link, so is the watertightness and performance of the roof. The external protection of the flashings and membrane place both in similar environments and provides for integrated design and shared benefits.

Figure 6 shows a detail of a protected membrane flashing at the roof's exterior edge and highlights the major features of construction.

The impact of the environment to which flashings are exposed can be demonstrated by a close-up view of the flashings shown in Figure 7. This photo depicts a roof after 14 years of service. The protected membrane roof was constructed with bitumen membrane flashings and one ply of butyl flashings.

Where the membrane flashings were covered by the roof insulation and shielded from the external environment, there was no sign of membrane separation, slippage or blistering. Where the membrane was exposed, the flashings were blistered, delaminated and bitumen slippage was evident.

While it is recognized that a flashing constructed from a properly installed modified bitumen cap sheet or one covered with light-colored counterflashing might not have shown the same degree of deterioration, the photograph does serve to demonstrate that changing the environment can enhance a flashing's performance.

Figure 8 shows a roof that was constructed with a protected membrane roof and flashings. This photograph was taken after the metal counterflashings and insulation were removed. An examination of the flashings after seven years of service showed no visual sign of change as compared to that normally seen for uninsulated flashings. Figure 8 is typical of many insulated flashings observed after many years of service. This is due to the flashings being placed in a more forgiving environment and shielded from the effects of severe temperature exposure in both winter and summer. Heat flow measurements are being completed so that comparisons can be made with previous data reported for roof membranes.

AIR AND MOISTURE PROTECTION

Because flashings form part of the building envelope, they must also provide resistance to air and moisture flow and provide thermal continuity. While it is recognized that vapor retarders protect a roof from vapor diffusion, studies completed by the National Research Council showed significantly higher levels of moisture in roof assemblies that can be accounted for by vapor diffusion alone. This difference is due to air leakage.

While the membrane in a protected membrane roof fulfills the function of both an air and moisture barrier, air leaks at roof-to-wall junctions have continued to be a problem.

While the membrane provides air and moisture protection for the roof, it does not do so at the cant. As a result this area is subject to moisture accumulation due to diffusion and air leakage.

In order to prevent this occurrence, protection is required such as underlaying all cants with a vapor retarder sealed to the roof and wall. If the cants are not employed, as in the case of most single plies, the sealing of the membrane to the wall could provide the air barrier function. The vapor retarder under the cants must be continuous and of sufficient strength and stiffness to accommodate the imposed loads of air pressure and movement without failure. This pressure difference across the vapor retarder is influenced by wind speed, direction, stack effect and mechanical pressure.

Figure 9 shows moisture deterioration of an unprotected fiber cant on a protected membrane roof due to moisture ingression from below. Figure 10 shows deterioration of a wood blocking on an exterior wall on a protected membrane roof.

An examination of the flashings showed air leakage at the roof-to-wall junction due to the lack of an air seal. The examination showed the flashings and roof to be free of external leakage. A properly designed and insulated flashing would place both the building material and flashing in their proper configuration, and prevent this occurrence. The effect of vapor diffusion can be seen in Figure 11.

Figure 11 shows the effect of air leakage and vapor diffusion. The image was taken during the removal of an existing protected membrane roof. Figure 11 shows a wood curb that was built over a steel column penetrating through a concrete deck that was to be used for a building addition. The curb was built directly on top of the concrete deck and the roof membrane carried up and over the curb.

The curb showed no signs of extensive leakage. There was no evidence of membrane failure or water migration from adjacent roof areas. It is concluded that the lack of an air or vapor retarder at the deck level allowed water vapor to become trapped inside the curb allowing dry rot to occur.

Recognizing that air leakage contributes significantly to building energy costs, the National Building Code in Canada began requiring the use of air barriers in 1985.

Dependent upon the type of building construction, the air barrier and vapor retarder may be constructed from a single material or combination of materials and can be located in the same or different positions within a roof or wall assembly. As represented in Figure 6, a properly designed and installed protected membrane roof can easily be constructed to fulfill these functions and ensure continuity between the roof and wall. As shown in Figure 6, the membrane roofing and flashings provide a barrier to moisture and air flow, the insulation component keeps the wall, flashings and roof membrane above the dew point to prevent vapor traps that can be detrimental to both the roof and wall. This configuration also allows proper phasing of construction and coordination of the various trades.

Figures 12 and 13 show thermal gradients through a typical protected and unprotected flashing. While this calculation has not accounted for construction variations, thermal bridges and solar gain, it shows that the exterior wrapping of the roof, walls and flashings keeps both the air barrier and roof membrane above the dew point, whereas the uninsulated flashing does not.

While these calculations work for the 400mm-high masonry wall shown, walls will vary in configuration and type of materials employed. As a result, each design must be evaluated on its own merit. As an example, it would be difficult to keep all of a 1200mm masonry exterior wall sufficiently warm to prevent the dew point from falling below that of the membrane with exterior insulation alone. In this regard, alternative design solutions are required as shown in Figure 14. Regardless of the approach, improved performance in both energy and long-term maintenance performance will be obtained from the use of the insulated flashing approach.

A research project is being organized to obtain accurate information under field conditions.

Figure 14 depicts an insulated flashing of a high parapet utilizing a protected modified bituminous membrane roof assembly.

THERMAL PROTECTION

With conventional design and construction practices, the roof-to-wall junctions are thermally weak due to discontinuity and thermal bridging, which can interfere with building performance. The interconnection of metal tie, columns, beams, and the roof structure provides not only thermal bridges across the building envelope, but provides a direct path for air and water vapor to enter the roof and wall cavity.

While total destruction of the wall and roof seldom occurs through air leakage and diffusion alone, it is not uncommon to find deteriorated metal ties, rusting structural joints and moisture damage to the wall and roofing materials. The problems associated with continuity and thermal bridges is overcome as shown in Figure 6 by placing the insulation continuously over the exterior of the building envelope.

While the roof-to-wall junction does not constitute a major portion to the building exterior, uninsulated functions at the roof and wall provide thermal bridges that contribute to the building's heating and cooling costs.

Infrared examination of the roof-to-wall junctions under winter conditions shows that the cold bridge from uninsulated flashings can extend more than a meter into the building's interior. These cold bridges through a wall can often be visually detected as dirt trails on a building's interior.

While the prime benefit of insulated flashings focuses on performance and durability issues, the thermal performance of the building is also improved, so their use will contribute to the reduction of building energy costs.

In order to provide continuity of design and performance, all flashings such as curbs, soil pipes, expansion joints and roof-to-wall functions should be air-sealed and insulated. Figures 15, 16, 17 and 18 illustrate insulated flashings.

Since the majority of protected membrane roof assemblies employ Type IV polystyrene insulation, its use for covering the vertical portion of the flashings is a preferred choice. While this type of insulation offers good physical and moisture-resistant properties, it is subject to ultraviolet deterioration and must be shielded from the sun.

While short-term protection is not required since the insulation is usually friction fit, the wrapping of the insulation by the water permeable fabric offers some immediate sun shielding and prevents the insulation from being dislodged by the wind prior to the installation of metal counterflashings. On soil pipes and sleeves, glass fiber insulation or polyurethane insulation is often employed.

CONCLUSION

While the protected membrane roof might be more applicable for use with protected membrane flashings, their ability to overcome problems associated with the environment and construction are applicable for most roofing systems. The protected membrane flashings offer many advantages over the more traditional approach to flashings. These advantages are:

Primary Advantages

- Protected membrane flashings shield the base flashing from the stress induced by extreme cold and from the detrimental effects of elevated temperatures which could increase compatibility problems, bitumen slippage, degradation and delamination of interply layers.
- They provide protection of the flashing during phase construction and against damage from roof traffic or wind-blown debris.
- They substantially reduce the frequency and cost of maintenance.
- They enhance the ability of protected membrane roofs to provide long-term service by matching the service-life potential of the roof membrane and flashings.

Secondary Advantages

- Depending upon design configuration, they help to prevent vapor traps within the roof-to-wall junction by allowing each component to be placed in its proper arrangement.
- They shield the flashing assemblies' structural components from undue stress that could result in excessive movement by moderating the rate of change and temperature extremes.
- Insulated protected flashings will improve the building's thermal performance by eliminating the thermal bridge which occurs at most roof and wall connections.
- They allow for the flashing membrane to be constructed from less durable materials since they are placed in a more forgiving environment.
- They allow for the use of lower-melting-point asphalt, which can speed and simplify construction, improve quality and reduce cost.

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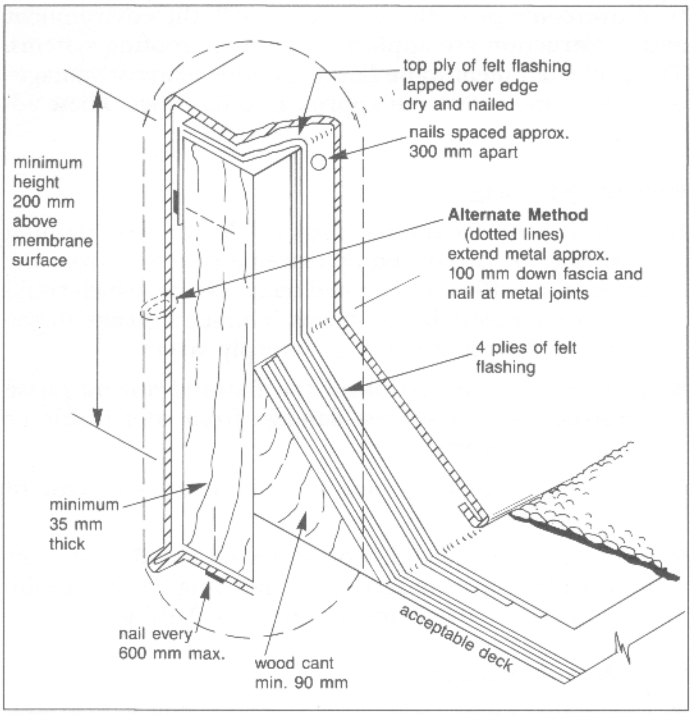

Figure 1 Conventional roof.

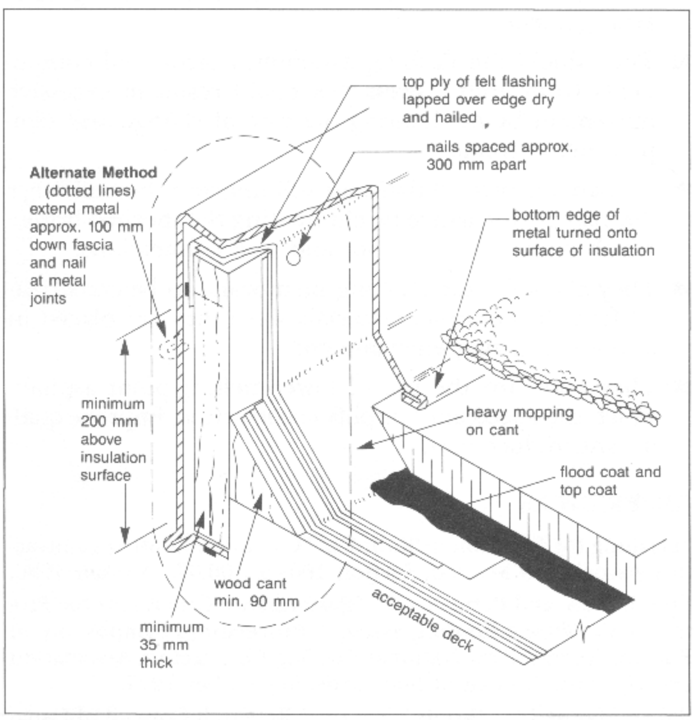

Figure 2 Protected membrane roof.

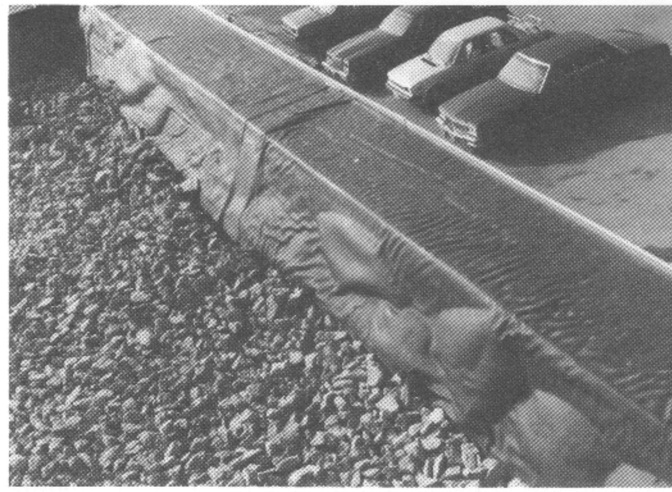

Figure 3 Blistered base flashing.

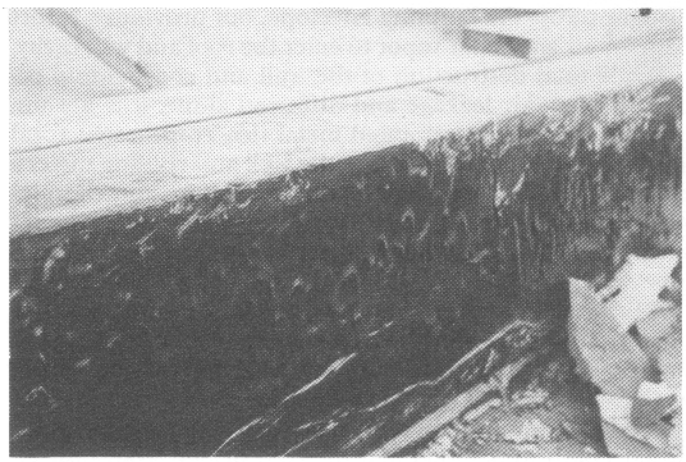

Figure 4 Deterioration of bitumen flashings.

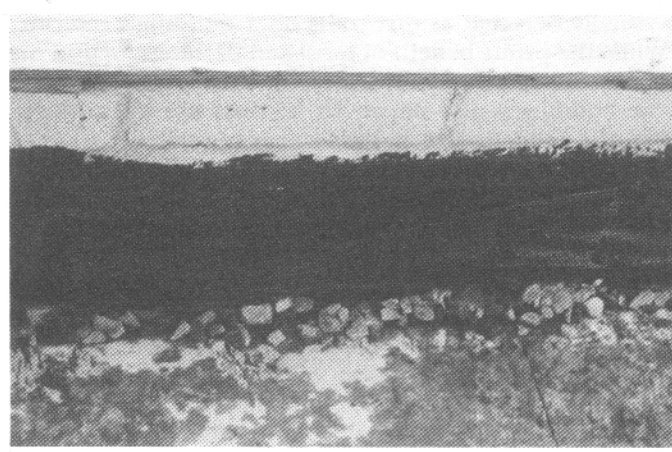

Figure 5 Deterioration of bitumen flashings.

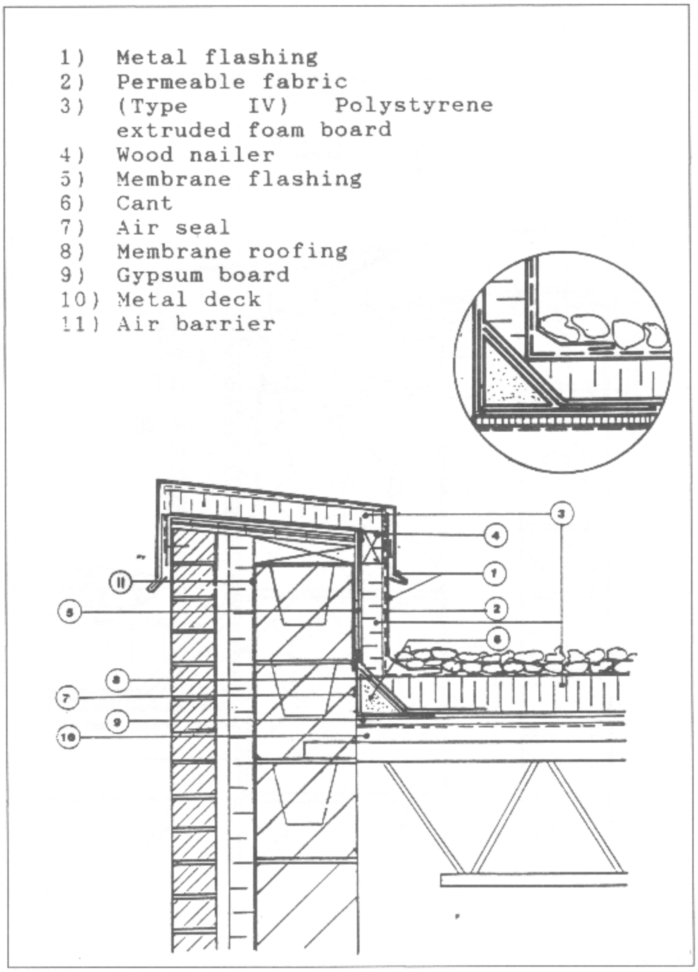

Figure 6 Parapet eave.

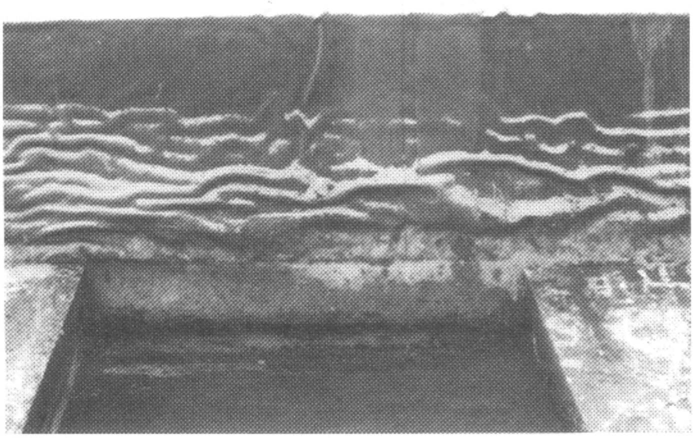

Figure 7 Flashing after 14 years of service.

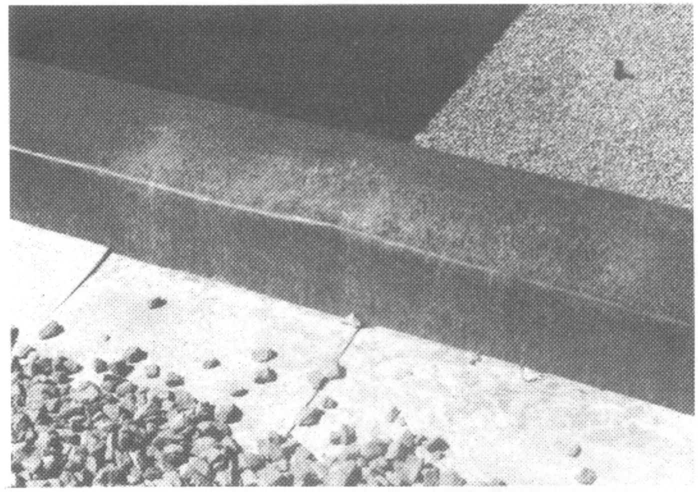

Figure 8 Roof constructed with protected membrane and flashings.

Figure 9 Moisture deterioration of an unprotected fiber cant.

Figure 10 Deterioration of a wood blocking on an exterior wall.

Figure 11 Wood curb built over a steel column.

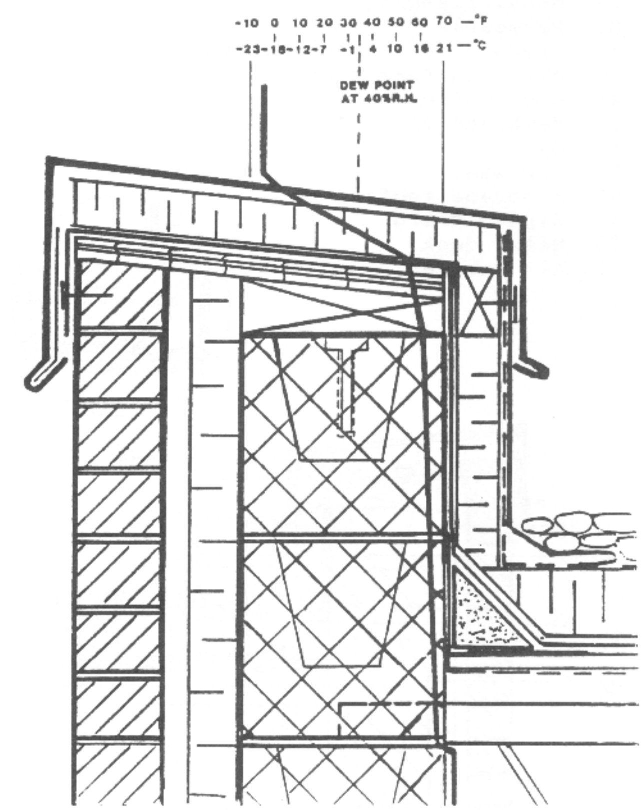

Figure 12 Protected membrane flashing.

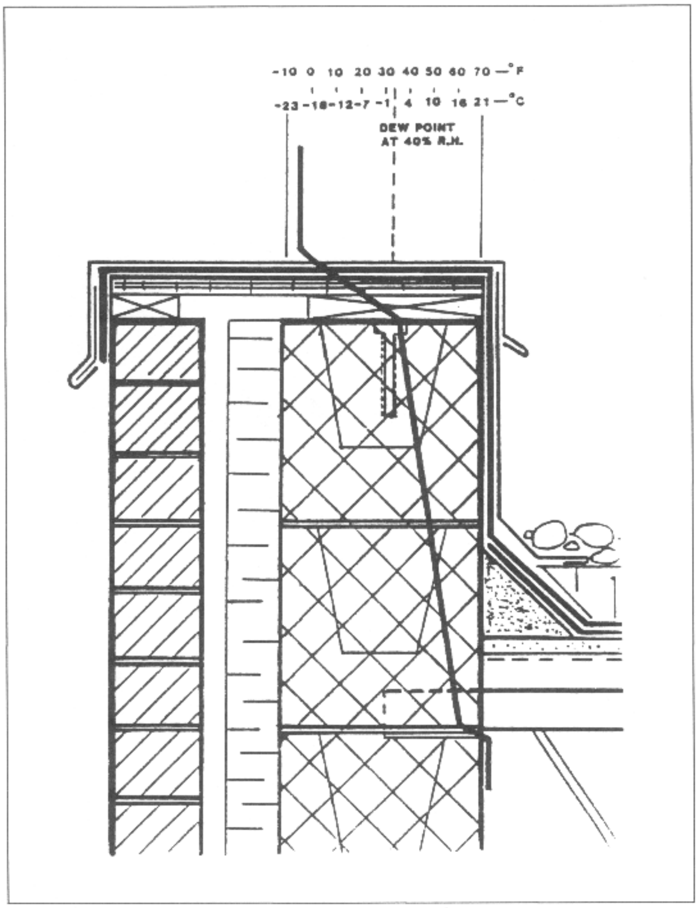

Figure 13 Unprotected membrane flashing.

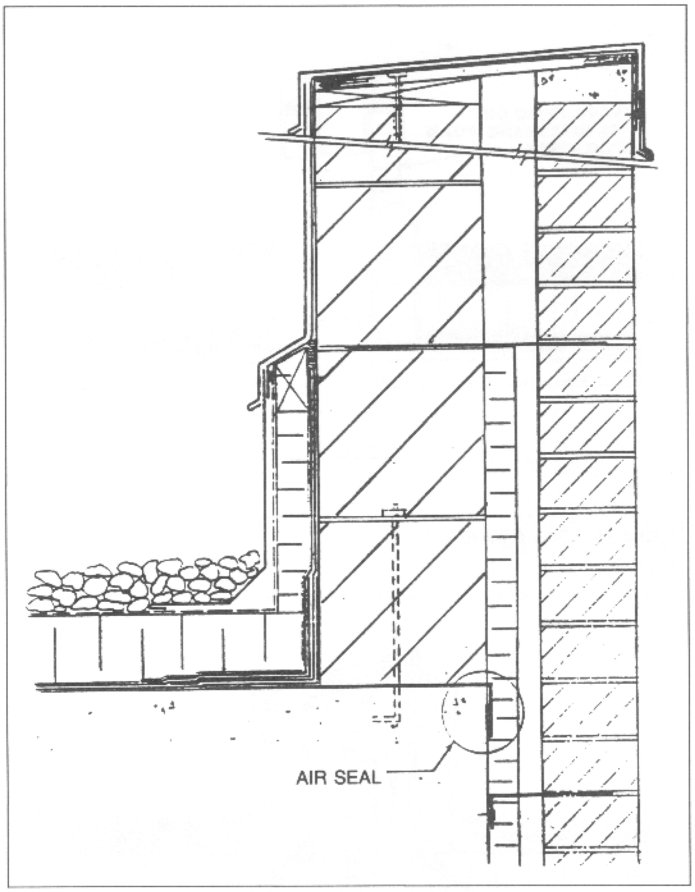

Figure 14 Insulated flashing of a high parapet.

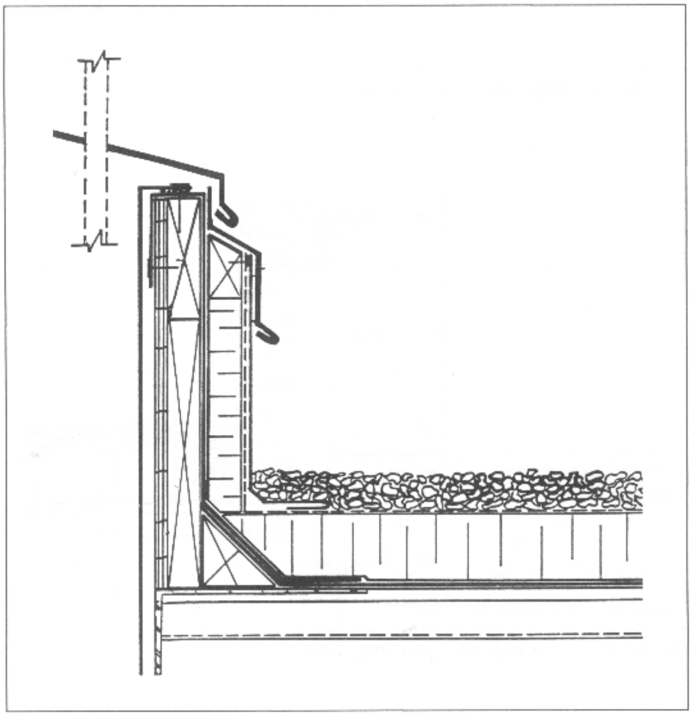

Figure 15 Curb detail.

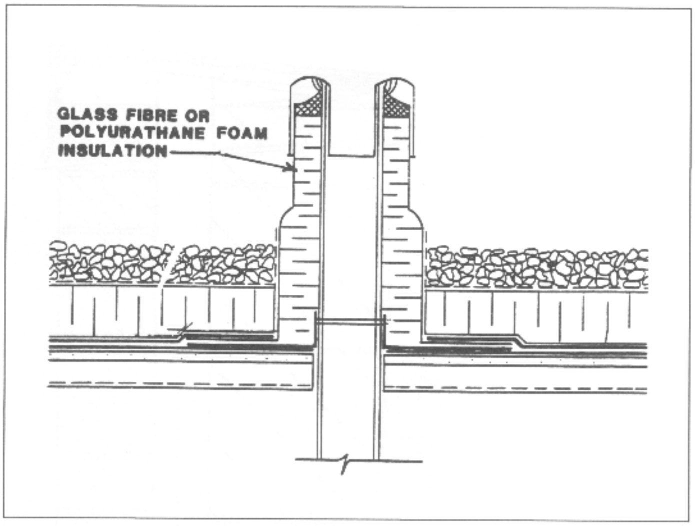

Figure 16 Soil pipe detail.

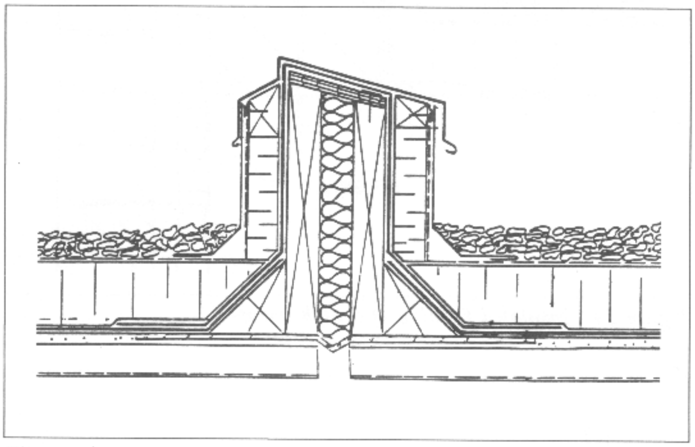

Figure 17 Expansion joint detail.

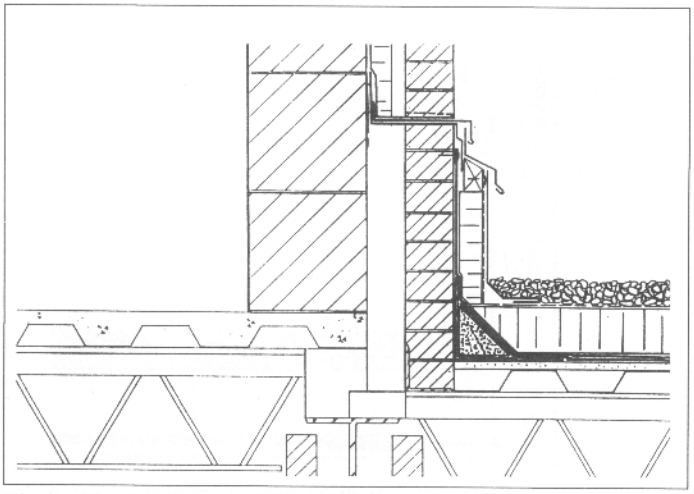

Figure 18 Through wall flashing detail.