

## THE DIRECT APPROACH TO RETROFITTING -

### PROTECTED MEMBRANE ROOFING

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Examination of the thermal performance of the building does not normally begin with the roof.

In a first attempt to save energy, the building owner has already reduced or increased temperature setpoints to comply with federal standards. The lighting efficiency may have been improved. Depending on the window arrangement of the building, increased efficiency and reduced area may be pursued. Air infiltration will have been examined. The walls may be thermally upgraded if insulation can be blown into a cavity, or if redecorating is a secondary objective.

These items deserve to be early considerations in examining ways to improve thermal efficiency. They require little investment, and often greatly improve the operation of the building from an energy use standpoint.

Normally, in the past, it was not until performance problems caused interior damage, or an expanding maintenance budget triggered a concern, that the owner seriously consider thermal upgrading of the roof itself. And yet a vast majority of today's industrial/commercial buildings have a high roof to wall area ratio making the roof the most important building component from an overall thermal efficiency perspective.

For many decision makers, this has been a justifiable position. The investment needed to add insulation to the roof was much greater than that of the earlier energy conservation decisions because a roof membrane performing in an acceptable fashion would either have to be removed, or covered and replaced by a new membrane.

But an alternative to thermal upgrading in this fashion exists--an alternative which allows the continued use of an existing performing membrane, but at the same time, provides an opportunity to add insulation.

#### PROTECTED MEMBRANE APPROACH TO RETROFITTING

The unique compressive strength and water resistant properties of extruded polystyrene allow the insulation to be placed above the roof membrane. Because of the closed-cell hydrophobic nature of the insulation, thermal efficiency is maintained even in this inverted position. After about two decades of development and refinement, the system was first commercialized in 1970. This inverted approach to insulating the roof has become known generically as the Protected Membrane Roof (PMR). The components of the PMR include

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the roof deck, a waterproofing membrane, extruded polystyrene insulation, and ballast (normally crushed stone). As can be seen in Figure 1, the order of components is unique from the conventional roof. The insulation is placed above the membrane where it serves as membrane protection, in addition to thermal insulation.

From a retrofit perspective, an additional component will be present in most cases. This will be the insulation used in the original roof located below the membrane. To accomplish a Protected Membrane Roof retrofit, 0.61 by 1.22m (2 by 4 ft) boards of rigid insulation are installed directly over the original membrane in a loose fashion. Sufficient crushed stone is installed over the insulation to prevent flotation of the insulation. The stone, because of its 19mm (3/4 in) typical size, provides stability against windstorm conditions even though it is not adhered as in a conventional gravel surfaced roof.

#### PROTECTED MEMBRANE ROOF COMPONENTS

The function of the deck and the waterproofing system is not much different than in a conventional roof. However, the demands placed on the insulation, and the expanded function of the ballast merit review.

While different insulations have been examined for use in Protected Membrane Roofing, only extruded polystyrene with densities above  $33.6 \text{ kg/m}^3$  ( $2.1 \text{ lb/ft}^3$ ) has demonstrated long term retention of thermal resistance. A paper entitled Thermal Transmission Measurements of Insulation (Ref. 1) summarizes the field performance of three types of insulations installed in PMR fashion. In the five to seven years of exposure examined, molded bead polystyrene picked up from 6 to 58% by volume water. Polyurethane picked up from 2 to 17% by volume water. Extruded polystyrene picked up from 0 to 1% by volume water. The resulting dramatic effect of moisture on thermal resistance when significant levels of moisture are absorbed is also reported in the above paper.

By being able to limit water absorption from direct contact, from freeze-thaw cycling, and from moisture vapor driving conditions, the rearrangement of components allows the insulation to protect the membrane, rather than requiring the membrane to protect the insulation.

The stone finish over a conventional roof is normally applied at a rate of  $14.5$  to  $24.5 \text{ kg/m}^2$  ( $3$  to  $5 \text{ lb/ft}^2$ ). A larger gradation stone, roughly 19mm (3/4 in) in diameter, is typically used as ballast in PMR systems. Its fundamental purpose is to resist the flotation of the insulation, so depending on insulation thickness, drainage, and adhesion, the rate of ballast required will vary. A minimum of  $48.8$  to  $58.6 \text{ kg/m}^2$  ( $10$  to  $12 \text{ lb/ft}^2$ ) is standard. This will be a depth of about 38mm (1-1/2 in) when 19mm (3/4 in) crushed stone is used. Additionally, the stone ballast provides an opaque shield for the insulation, thereby preventing ultraviolet light degradation.

#### ADVANTAGES OF PROTECTED MEMBRANE ROOFING

In conventional roofing, the introduction of the insulation layer between the deck and the membrane has placed the membrane in a more demanding position. In the conventional cross section the membrane is supported by a compressible material, rather than the more appropriate support of the structural deck itself. The membrane will experience greater extremes in temperature cycling, and these extremes will occur more rapidly as a result of the more thermally resistant insulation substrate. Often, the result is compromised performance of the waterproofing system, and in turn, the thermal efficiency of the moisture sensitive insulation below. The rearrangement of the roof components brings three significant improvements to the cross section:

- The larger ballast, in combination with the insulation, accomplishes complete shielding of ultraviolet light from the membrane.

- Improved physical protection is gained for the membrane.
- Thermal cycling is reduced and thermal shock (rapid fluctuation in membrane temperature) is completely eliminated.

#### PROTECTED MEMBRANE ROOF RETROFIT TECHNIQUES

New construction PMR specifications often call for adhesion of the insulation to a built-up roof. This adhesion is not practical when retrofitting over an existing membrane. In most cases an existing stone aggregate surface prevents adequate adhesion, but even a smooth surfaced roof will not allow the degree of adhesion that is required to use an adhered insulation approach as in new construction.

The Canadian Roofing Contractors Association describes this aspect of PMR thermal upgrading (retrofitting) in a technical bulletin by saying:

"It is CRCA's opinion that the roof membrane should not be subjected to possible weakening by using it as an anchor against flotation of the insulation. This is the function of the ballast." {Ref. 2}

Preparation of an existing gravel surfaced roof may be impacted by the structural capacity of the roof deck. If overall weight including the ballasted PMR retrofit approaches the total dead load capacity of the deck, removal of the loose stone may be achieved by power brooming the roof surface. This may also improve the ability to inspect the existing surface before insulation is installed.

It is the responsibility of the owner or his representative to see that the retrofit application does not exceed safe loading levels for each particular situation.

The roughness of the existing membrane surface may raise concern about heat loss occurring, either from convective air currents, or through conduction by draining rainwater at the membrane level. While some loss of heat energy will undoubtedly occur in this fashion, it is difficult to measure the degree of effect which occurs. Weather conditions, as well as building characteristics, make each situation a unique case. From a retrofit perspective, the existing insulation below the membrane will reduce the amount of thermal loss because the temperature of the membrane will be closer to that of outside conditions.

In work done at the U. S. Army Cold Regions Research and Engineering Laboratory (CRREL) to study the thermal efficiency of loose applied inverted systems, the size of the conductive heat losses due to rainwater runoff was estimated to be 10.6% of the total heat loss. In general, however, it was found that 80-90% of the time the overall efficiency exceeded design thermal efficiency. This occurs as a result of evaporation, solar radiation, and snow cover. {Ref. 3}

Heat loss due to conduction by rainwater should not be as large for retrofit applications. (In the CRREL study, the membrane was installed directly over a concrete deck followed by an insulation thickness of 82.6mm (3-1/4 in), making the percentage heat loss from conduction by rainwater higher than in a more typically insulated PMR and much greater than in a PMR retrofit.) Additionally, it should be noted that discussion of this phenomenon is in the context of heat loss during the heating season. During summer conditions rainwater runoff will cause beneficial conduction of heat out of the deck and membrane components.

The CRREL study represents one point of reference, but the real apples-to-apples comparison is between the annual thermal efficiency of the Protected Membrane Roof and its alternative--a conventional roof. More recent research at CRREL and other laboratories has been in the area of examining the annual thermal efficiency achieved by conventional roofs. No comprehensive re-

porting has been available up to this time, but the preliminary indications point to significant reductions in thermal efficiency as a result of the presence of moisture in conventional roofs.

Let's take a brief look at why real world thermal performance may not be as theoretically predicted for conventional roof systems.

#### DEW POINT LOCATION AS INFLUENCED BY INSULATION SYSTEM

The vapor pressure of air is dependent upon temperature. Because moisture vapor, like any gas, will seek an area of lower pressure, a diffusion force exists across building components whenever there is a temperature differential from inside to outside. The most severe diffusion conditions for most climates occur under winter temperatures when the inside air, at a higher vapor pressure, seeks the lower pressure condition on the outside of the building.

Figure 2 illustrates the plane of dew point condensation for a minimally insulated conventional roof. A vapor barrier would have to be as efficient as a waterproofing membrane to prevent the accrual of moisture under these winter conditions.

Figure 3 illustrates what occurs if additional thermal insulation is added over a suspended ceiling. Here condensation and loss of thermal efficiency are even more probable. {Ref. 4}

In Figure 4 a Protected Membrane Roof retrofit is illustrated using the same thermal resistance values as in Figure 3. Due to the inverted approach, internal moisture cannot reach the condensation plane. The membrane picks up the dual function of vapor barrier and waterproofing. Thermal efficiency is not compromised by water absorption.

#### RETROFIT CONSIDERATIONS

While the Protected Membrane Roof approach improves the environment of the membrane, other aspects may be just as important to the roof retrofit decision maker. The key in his mind is how much does it cost, how long will payback of the investment take, does it disrupt internal activities, and so forth. The answers to these questions shed even more light on the viability of adding roof insulation in an inverted sequence.

The cost effectiveness of PMR retrofit is centered in the directness of its approach. The main item to be purchased is insulation. No new waterproofing system is required. In this way, the dollars invested are as closely related to direct energy savings as possible.

Installation of the retrofit system does not interrupt internal activities. Hot asphalt equipment is not needed except where membrane repair is necessary. The insulation application can take place independent of weather conditions and by any crew of workmen even remotely familiar with construction techniques. The only material purchased in addition to the insulation is the stone ballast.

To fully evaluate the retrofit opportunity, a decision maker does need to take one preliminary, but prudent step in gathering information. The suitability of the existing membrane and flashings to provide continued service must be understood.

The historical performance of the roof should be reviewed. Rising maintenance costs or continued repairs in specific areas are clues that the repair of the membrane, before retrofit, is in order. A roofing contractor, or perhaps a consultant can help the building owner interpret the condition of the roof. Early warning signs, if properly corrected, may mean the energy conservation investment is accompanied by an even more critical investment which can assure the future utility of the existing roof.

It is necessary to point out that the PMR advantages cannot cure an existing membrane problem. The protection afforded by retrofitting is only advantageous to a membrane in suitable condition to provide continuing waterproofing service. In some cases, treatment of a weathered asphaltic surface may be necessary to prevent absorption of moisture into the surface felts.

An examination of the adequacy of the height of existing flashings is necessary. Insulation and ballast raise the effective roof surface several inches, often placing the flashings in a new environment relative to blowing rainwater.

Retrofitting reduces the ease with which the surface condition of the roof can be examined. However, because of loose installation of the insulation, accessibility can still be accomplished efficiently, and the materials can be reused once membrane inspection or repair is completed.

A seldom considered advantage is also available due to the non-attachment of the insulation--salvage value. Situations where membrane replacement eventually becomes necessary can still allow the reuse of the insulation and ballast over a new roof because neither is damaged during removal.

Extruded polystyrene insulation is combustible and should be properly installed. For roofing applications, it should be provided with an adequate protection. For specific instructions see literature available from your supplier.

#### VARIATIONS OF THE PROTECTED MEMBRANE RETROFIT APPROACH

The evaluation of the existing membrane to determine suitability for continued performance often requires some subjective analysis. Repairs of visible defects can relatively easily be specified and implemented, but the adequacy of the surface bitumen to prevent water absorption into the felts is not always obvious. To take a conservative approach to such situations is advisable. A new flood coat application may improve the condition, or additional plies of felt may be called for. A third alternative falls within the category of rehabilitation.

The first developmental installation of a rehabilitated Protected Membrane Roof took place on the Tremco Shaker Office Building in Cleveland, Ohio in 1975. Rehabilitation entails an application of a cold process reimpregnating bituminous coating, which is compatible with the built-up roof membrane being treated. To avoid degradation of the extruded polystyrene, a solvent barrier of approximately 0.15mm (0.006 in) thick annealed aluminum foil was placed over the treated membrane area after a 30 day flash off period.

There are situations where the reimpregnating treatment will not be of benefit to the asphaltic membrane. Its proper use is limited to built-up membrane situations which are basically sound, with plies well laminated together, but exhibiting symptoms of aging such as localized bare felts or fractures in the top bituminous coating. Underlying insulation should be in good condition.

Roof coatings have been used to upgrade existing membranes in the past. Following this roof coating with the installation of extruded polystyrene over the upgraded membrane provides a unique combination allowing continued utility of the existing waterproofing at the same time thermal efficiency is improved.

Two additional PMR variations are under development to allow broader applicability of the inverted system from a structural standpoint.

The first allows stone ballasting to be maintained at the minimum 48.8 to 58.6 kg/m<sup>2</sup> (10 to 12 lb/ft<sup>2</sup>), independent of insulation thickness. (Normally increased buoyant forces resulting from thicker insulation require higher ballasting rates.) This is accomplished with loose applied insu-

lation systems by rafting the insulation board stock in place with a porous fabric loosely laid over the top of the insulation. The 2.4m (8 ft) wide fabric is lapped sufficiently to allow it to perform as a continuous layer. Once installed this system allows flotation to occur, but in a controlled fashion. The stone is held above the insulation by the fabric. Displacement during temporary ponding is self-correcting. As rainwater is forced to the drains, the insulation settles to its original position.

A second truly lightweight variation of the Protected Membrane Roof involves the replacement of the stone ballast with a factory applied-integrally bonded layer of latex modified mortar. This durable surface applied at a nominal rate of 9.5mm (3/8 in) results in a ballast system weighing roughly 22.0 to 24.4 kg/m<sup>2</sup> (4.5 to 5.0 lb/ft<sup>2</sup>).

This system allows PMR retrofit to be considered virtually anywhere, because the ballast weight is approximately equivalent to the weight of conventional stone surfaced roof systems.

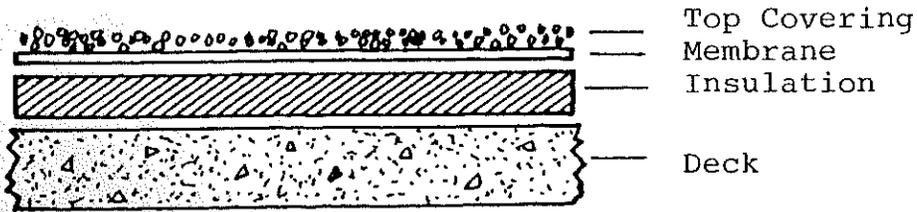
Because the insulation panels are under-ballasted, it is necessary that they be installed in a loose fashion and designed to float and maintain their position. This is accomplished by a tongue and groove edge configuration on the two long edges of the 0.61 by 1.22m (2 by 4 ft) board. Proper installation and roof edge treatment are necessary to maintain insulation system integrity and to provide sufficient resistance to windstorm conditions.

Energy conservation is not a short term problem. As we continue to explore alternatives available to improve our efficient use of energy, the building envelope will receive more and more attention. Low sloped industrial/commercial roofing will begin to be retrofitted in some fashion. Because Protected Membrane Roofing offers a direct approach to retrofitting, it may well become the equivalent of what additional attic insulation has become to the residential homeowner.

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### Conventional Roof



### Protected Membrane Roof

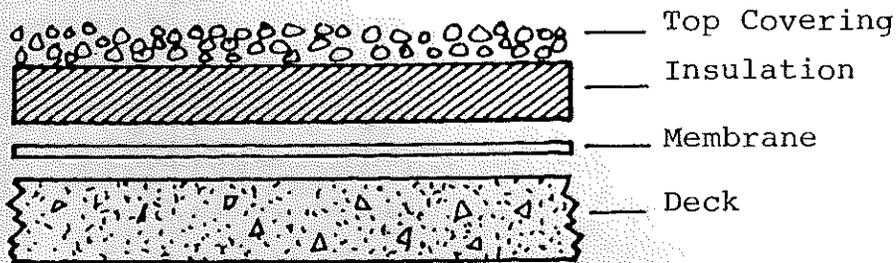
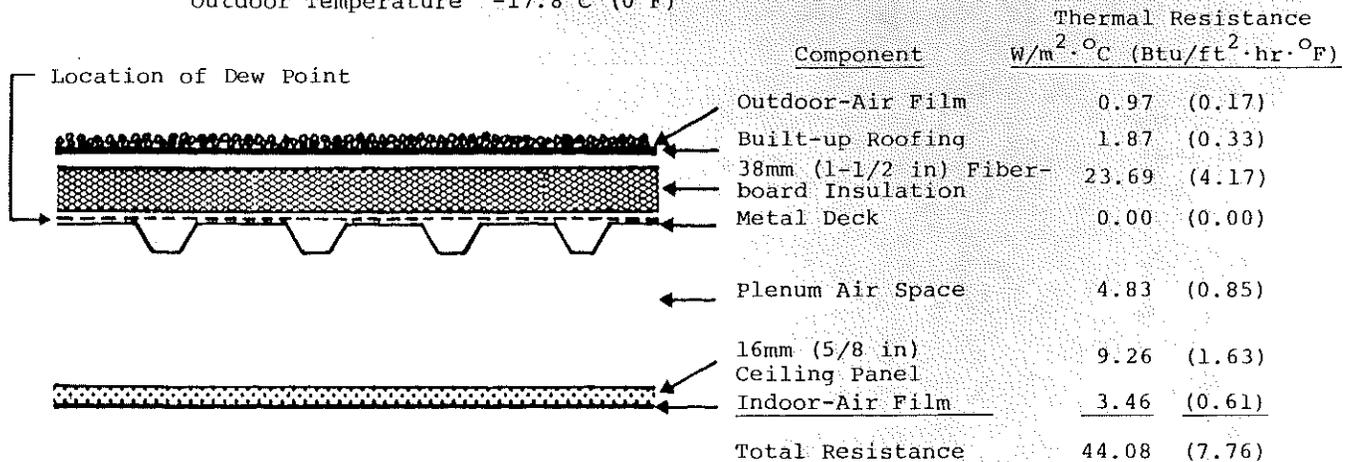


Fig. 1 Comparison of conventional roof to protected membrane roof

Outdoor Temperature  $-17.8^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ )



Indoor Temperature  $21.1^{\circ}\text{C}$  ( $70^{\circ}\text{F}$ )

Relative Humidity 38%

Dew Point Temperature  $26.2^{\circ}\text{C}$  ( $44^{\circ}\text{F}$ )

Fig. 2 Plane of dew point condensation; minimally insulated conventional roof

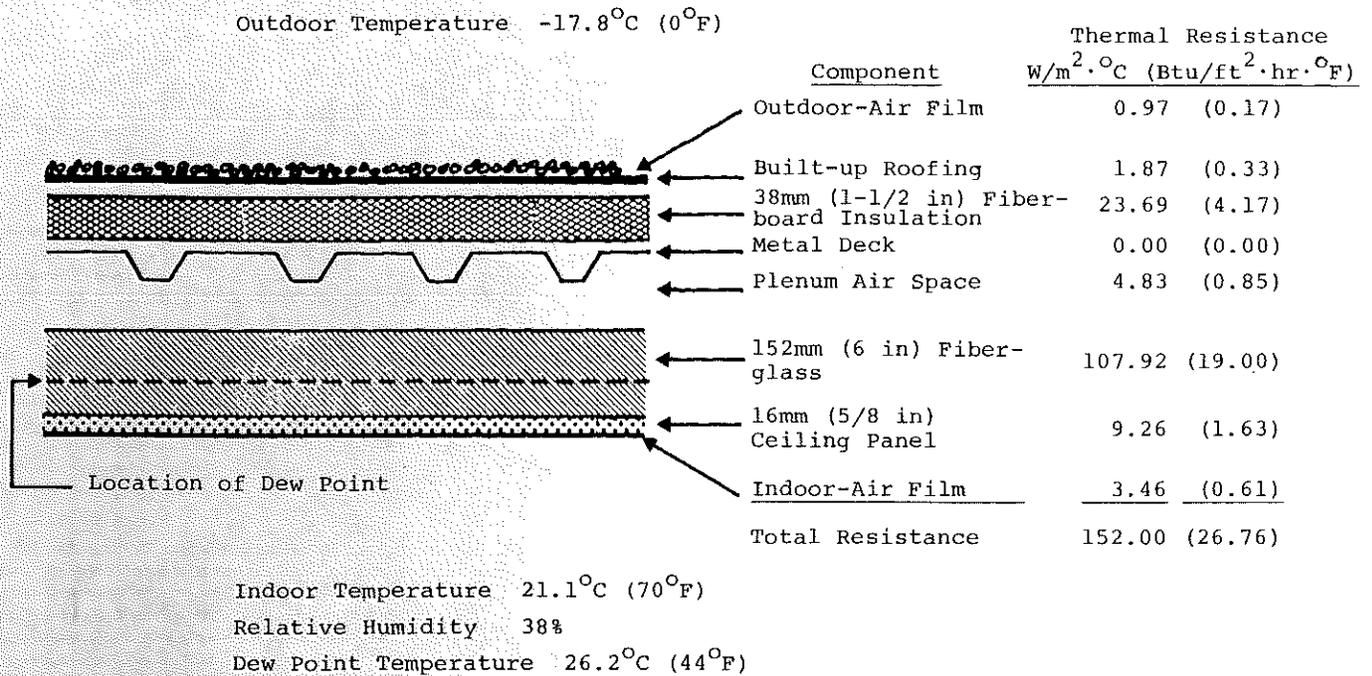


Fig. 3 Plane of dew point condensation; ceiling retrofit of conventional roof

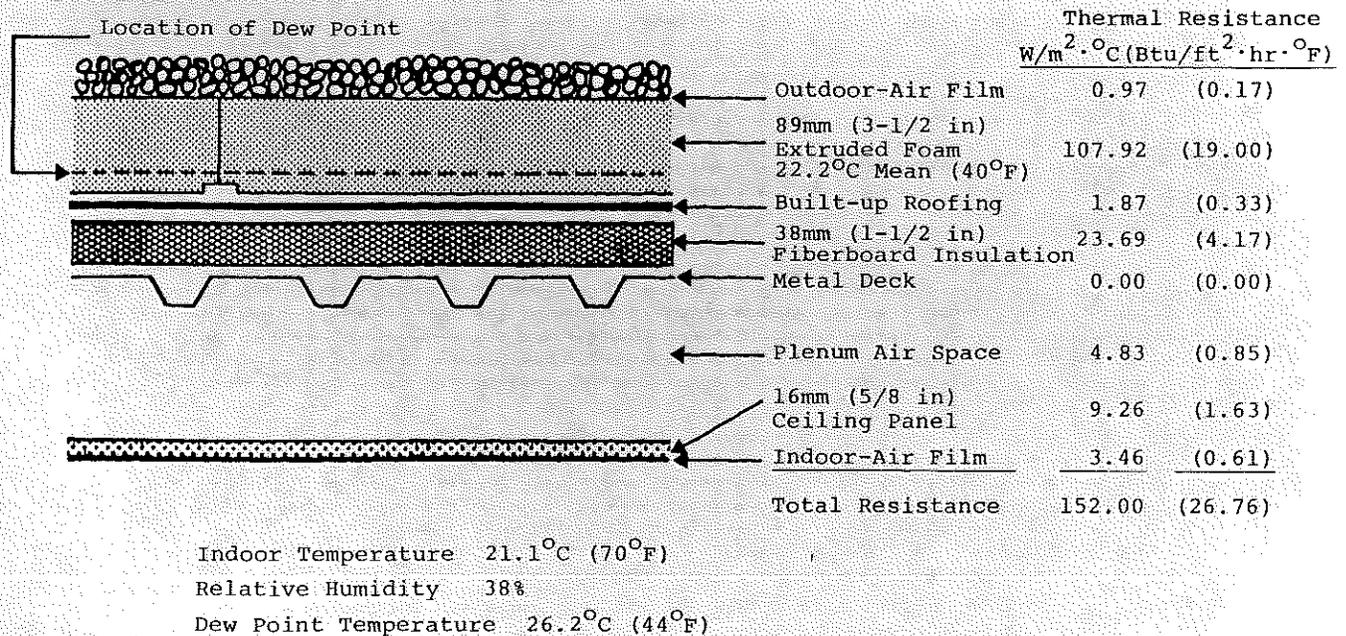
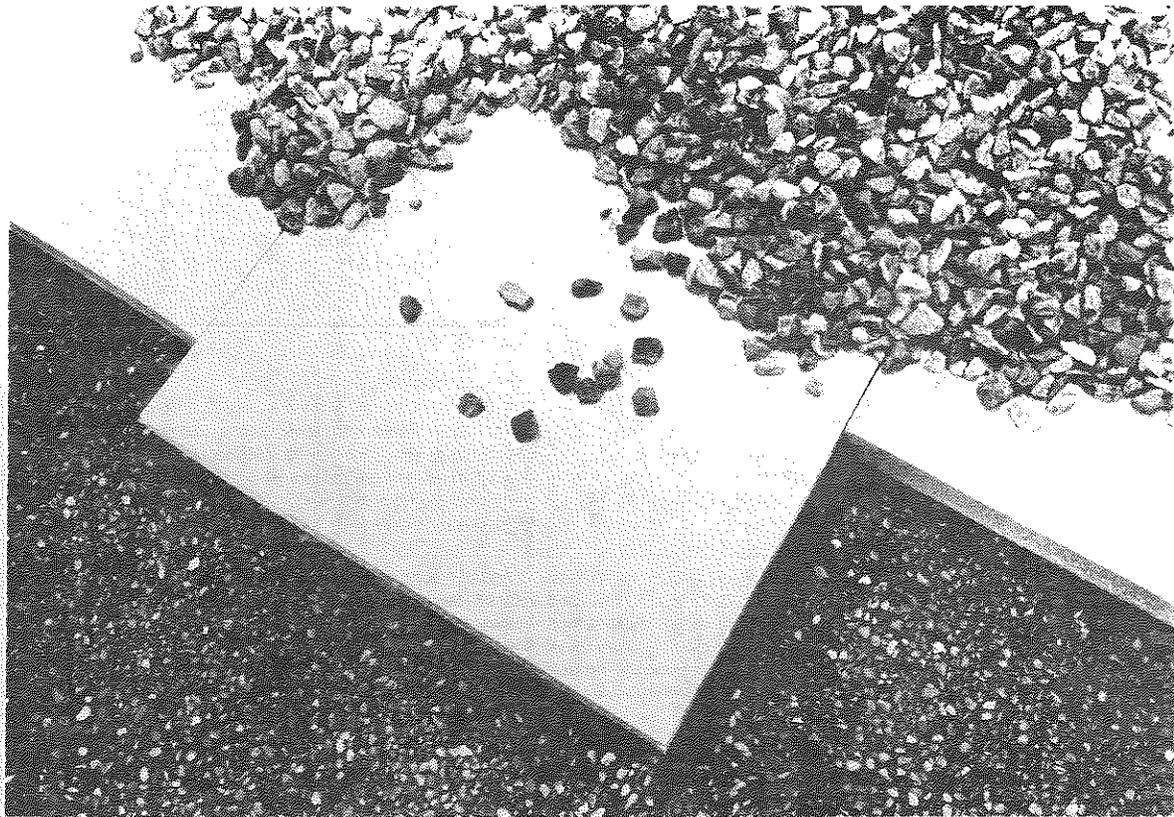
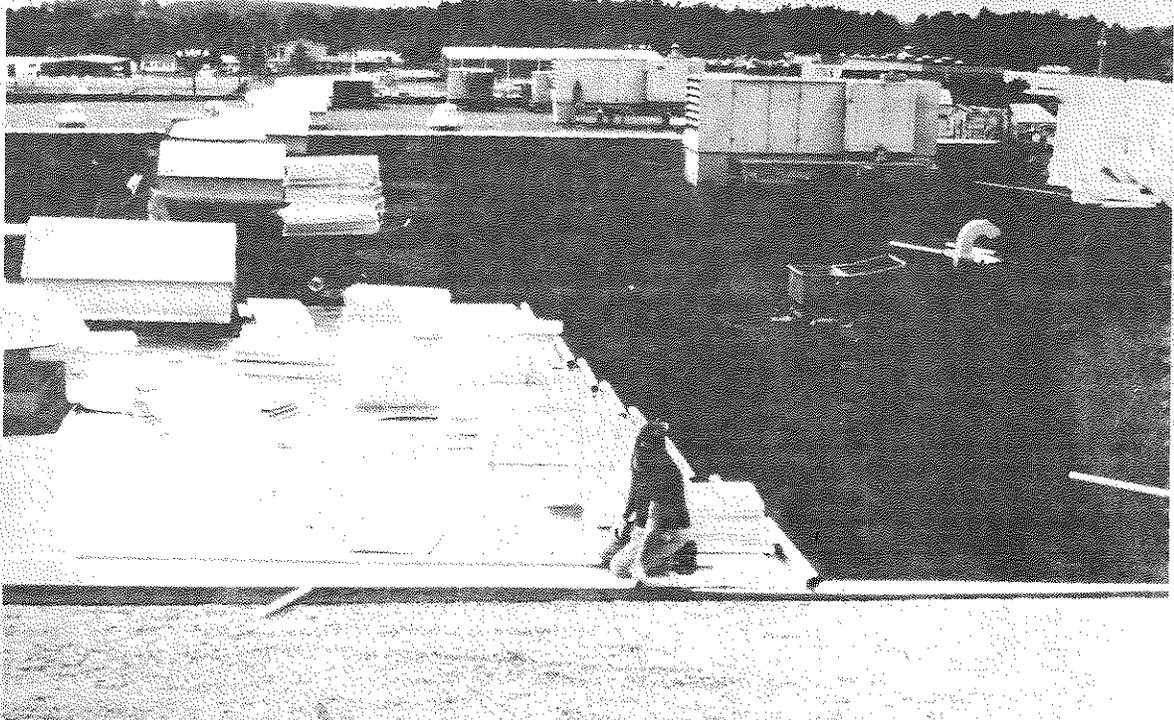


Fig. 4 Plane of dew point condensation; protected membrane retrofit



*Fig. 5 Protected membrane retrofit over existing gravel surfaced conventional roof*



*Fig. 6 Protected membrane retrofit after resaturation of existing membrane and installation of foil separation layer*