# Method for Determining Suitability of Roofing over Roof Assemblies in Need of Repair

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## ABSTRACT

Engineering concepts are utilized to determine the suitability of applying roofing systems over existing commercial roof assemblies. The criteria for determining the need to remove the original roof assembly are identified. The effect of water in the cross section of the existing roof on the various elements of an added assembly are evaluated. The manner of ingress of water into this system; i.e., water that is built in during construction, water from the interior via moisture vapor movement or by roof leaks; the ability of the water to vent downward based on the vapor/pressure differential, and the existence of vapor retarders in the assembly are taken into account to determine the rate at which water can be removed from the system. These criteria are associated with the elements in basic types of new roofing systems, including the membrane, adhesives, mechanical fasteners, and insulation to determine their suitability.

These relationships provide the basis to preselect roofing systems. The next levels of selection criteria are discussed; i.e., code approval, fire and wind resistance, long term insulation value, and overall weight. Also discussed is the effect of water trapped within the new system that has two effective vapor retarders within the cross section.

This analysis indicates the need for future work to develop leak detection capability to protect roof elements from degradation by prolonged exposure to undetected trapped water.

KEY WORDS:

Condensation
Heat Exchange
Insulation
Moisture
Monitoring
Roof
Vapor
Vapor Barrier
Ventilation

## INTRODUCTION

The commercial roofing market, which is so large it is measured in billions of sq. ft. has become static in size in the last decade. The ratio of reroof to new roof construction has increased to 2 - 1 versus a more traditional 1 -

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1. Single ply roof systems usage have increased to an equal share of roof construction with built-up roof systems. Tearing off the old roof before installing a new roof has been common practice until recently. Now, recovering, (covering the old roof with a new roof) has increased to approximately 40% of roofing construction (Elseman 1989).

The rate of problems for roofs repaired by recovering is 50% greater than the amount constructed (Smith 1989). This has been the case for both built-up roofs (BUR) and single-ply systems. Based on this limited data, a more selective process is needed for repairing roofs by recovering.

The decision to recover should be made based on the compatibility of all the components of the added system with the potentially wet substrate of the existing system. This paper addresses that premise. After acceptable systems are identified to be used in specific recover situations, the best system can then be selected on the basis of design, material, installation, and competitive attributes.

The benefits of recovering are enticing. Saving the cost of the tear-off (which can approach the cost of a new system) the ability to continue operations within the structure in a safe and uninterrupted fashion, and saving the insulation in the existing system are prime examples. The concerns are essentially all involved with the potential problems trapped water can cause to the new system. They are the same problems that exist in the system under consideration for rehabilitation, that is, damage to the structural deck, insulation, and mechanical fasteners.

Mechanical fasteners are a major concern because of the great amount if ferrous based fasteners specified in all roof systems. This concern is emphasized in a report by Rossiter (1989) when corrosion of fasteners was documented and research needs outlined.

The purpose of this paper is to provide a rationale to determine what roofing systems are acceptable for recover situations on the basis that water is present in the existing system. Can the water be eliminated from the system in a timely fashion? Are the new roofing components sensitive to water? The first decision to be made is based on answers to these questions. Then, the important, but more perfunctory decisions related to design, installation, and cost can be made.

## HISTORICAL REVIEW

### Review Of Reroofing Practices

Built-up roofs (BUR) for commercial roof construction have been used for more than 100 years. Until the 1950s, properly installed roofs performed well and were relatively simple to repair when a leak in the roof membrane occurred. The roof membrane then became a roofing system, which included insulation, vapor barrier, and fasteners. When wetted, these components would deteriorate and eventually contribute to the degradation of the roofing membrane itself. Accordingly, the ratio of repairs to replacement began to favor replacement. The recover mechanism was not considered an acceptable means of rehabilitating a roofing system because the new roof system was composed of similar water- sensitive materials. Roof insulations were of organic composition as were reinforcing felts. Also, the cost for replacement was not prohibitive in that the buildings were generally small, low, and stable.

The 1950s through the 1970s saw the roofing industry essentially equally divided between new construction and reroofing. Water that went undetected within roofing systems, created a situation where repairs were not acceptable, making reroofing necessary. Buildings were larger and more complex so the cost of a tear-off became more meaningful. Also, some of the systems available were still considered somewhat water sensitive, even though material such as fibrous glass was introduced for the manufacture of insulation and roofing felt. The insulation materials, even with the advent of closed cell plastic foams, were still considered too sensitive to water to be acceptable in a recover system.

Single ply roofing membranes had garnered a large share of roof construction at the beginning of the 1980s. Because these membranes were insensitive to water a high percentage of the usage was in the reroofing area and installed using recover methods. Dependent on the type of roof system some of the components could be affected by trapped water, such as fasteners that penetrated the existing roof system.

The majority of existing roofs to this point were built-up roof systems, but obviously, the single ply membranes used in new construction were becoming eligible for reroofing, therefore candidates for recovering.

Single ply membranes are categorized as thermoset (elastomeric), thermoplastic, and modified bitumen. They are, by nature, water resistant materials. Water resistant materials for construction of BUR have been introduced into the industry using hot and cold applied built-up technology. Examples are; polyester based reinforcing felts and polymer modified bitumens.

__Drying of Wet Deck Systems__

Lightweight fills, such as insulating concrete and gypsum concrete, contain water in excess of 100% by dry weight. The excess water falls through the forms during construction and dries to approximately 80% by weight before a roofing system is installed. Based on a dry density for these concretes of 25 $lb/ft^3$ (407 $kg/m^3$) and cast in a thickness of approximately 3 in. (75 mm) the water content is 5 $lb/ft^3$ (25 $kg/m^3$). Based on the permeance of the substrate, these systems will dry in a few months or a number of years (Perrine 1982). Personal examinations of such roof structures 10 to 12 years after construction show that systems, where water has not intruded, have dried. The mechanical fasteners, which were often uncoated roofing nails or zinc coated fasteners, had not degraded. Where water had intruded, mechanical fasteners had degraded and water contents were found in excess of 100% by dry weight. These examples are sited because they are wet systems by design. The drying results would be similar for roofing systems that become wetted after construction. It indicates the importance of knowing as early as possible when a leak develops, and the drying rate when the water intrusion is stopped.

__ROLE OF SUBSTRATE IN DRYING TO INTERIOR__

The deck plays a major role in the drying rate for water trapped in a system during construction or that is not removed after a leak is repaired. Specific steps to follow to make a proper repair exist. They are difficult to perform with the least difficult step, repairing the leak, often the only action taken. The steps are:

-- knowing a leak exists
-- locating the leak
-- assessing the internal damage
-- repairing the internal damage
-- repairing the leak

The type of deck plays a major role in the ability to accomplish these steps. As examples, starting with the deck up:

-- porous formboard
-- lightweight concrete
-- mechanically attached membrane
-- no top surfacing

In this case, leak water would be easily located as it drops vertically through the entire cross section, so the problem with the waterproofing is directly associated with the point of entry into the building. The materials in the cross section would not be adversely affected by moisture as drying occurs quickly.

A similar example is:

-- structural concrete deck
-- liquid applied, fully adhered roof membrane
-- loose laid insulation
-- ballast

In this case, a leak probably does not exist, but if one did, no lateral movement of the water would occur within the cross section. The water would lay directly on the deck and eventually soak through. The leak would be vertically oriented with the point of entry into the building.

A more difficult example:

-- metal deck
-- rigid insulation board
-- vapor barrier
-- two layers of insulation (bottom layer closed cell; top layer porous)
-- loose applied ballasted membrane

In this case, water leaking into the system would be difficult to handle because it would move laterally and be trapped inside. There is no relationship of the origin of the leak with the point of entry or the time of entry into the building.

This latter case closely resembles the condition for recovering; that is, a new roofing system installed over an existing roof system. The new system would be designed to be compatible with water in the existing system, but subsequent leaks into the new system would be difficult to determine and locate. This could lead to destruction of components of the new system.

<u>ALTERNATIVES FOR RECOVERING</u>

The choice not to recover, but tear off, will not be examined. Recover for low slope commercial roofs is relatively new. Recovering steep roofs is an acceptable roofing practice based on experience. Design and installation criteria are readily available for water shedding types of roofs. Technology changes, usage changes, and economics have created a demand for utilizing the recover concept for low sloped roofing. Recover systems have been installed and, in many cases, for the wrong reasons including expediency and less expense. Often, a decision is made with no analysis of system performance. Additional information is needed. Additional information will be developed however, sufficient information exists at this time to select roof systems based on performance. The decision to recover revolves around the following choices:

-- eliminating the water within the existing system in a timely fashion so degradation will not occur to any components

-- using water insensitive materials

-- Using materials in a sequence where they will not be affected by the moisture in the system.

Currently available products and systems provide limited choices. In the future the choices can be extended by the development of new products and systems, and by the development of water detection methods for early and complete repair of the added roof system. Such developments also will be meaningful for new construction.

Many roofing systems are installed over decks, vapor or air barriers, and insulations that inhibit the egress of water into the building for negating both timely observance of a leak and rapid drying. This undetected trapped water eliminates the choice of using materials that cannot be exposed to water without degrading. Therefore, water sensitivity materials must be quantified. Materials without a quantified resistance to degradation should be considered water sensitive. A suggested format for classification is displayed in Table 1 (Resistance of Material to Water). The materials are aligned with the generic types of roofing systems to evaluate the acceptance of the system, Table 2 (Acceptability of New Systems for Installation Over Existing Roof Systems). These generic systems are divided into the basic underlying systems; with a vapor retarder, no drying to the underside - without a vapor retarder, predictable drying rate to the underside.

These procedural steps should be followed to analyze the suitability of recovering.

-- determine roof cross section

-- determine moisture content

-- compare moisture content to the equilibrium moisture content of insulation material

-- perform time-to-dry calculations based on moisture vapor drive considerations utilizing the multiples of permeance, moisture vapor pressure differential, and time.

-- relate time-to-dry with the moisture sensitivity of the roof components

Roof cross section and moisture content are determined using standard industry techniques. The cross section can be verified by reviewing roof plans and specifications. A core sample to verify the construction also can provide a better definition of the quality of the structure. Numerous methods exist to quantify moisture content. They vary from simple core cuts to roof surveys based on infra-red, capacitance, and nuclear technologies. (Jenkins 1981)

The excess water is the amount above the equilibrium moisture content (Anderson 1985), primarily of insulation materials. Typical values of equilibrium and maximum moisture content are listed in Table 3 (Moisture Content - Roofing Components). Equilibrium values vary considerably from organic fibrous products, that have a relatively high value, to closed cell plastic foams, with low values. Also, the maximum amount of water that can be held by these products is respectively high and low. The drying time should be predicated on drying to the equilibrium value. This provides a degree of safety with respect to the fibrous products because free water does not occur until a value somewhat higher than the equilibrium values is reached. For example, the equilibrium value for wood fiber products is 12% to 15%. Free water will not occur until about 35% moisture by weight, which occurs at 100% relative humidity (Baker 1969).

<u>Eliminating Water From Systems</u>

This discussion relates to interiors considered to be comfort conditions, such as 70°F (21°C) and 50% relative humidity. The same design criteria and decision making criteria can be used for low temperature space and high temperature/high humidity structures. When a roof is determined to be in need of repair it is assumed it is because water has leaked into the interior and also exists within the cross section from these leaks. The water that has leaked into the system most likely will be contaminated with sulphate and chloride ions (Riedel 1982). These will form the basis for an electrolite when in solution therefore, in addition to degradation by wetting products, rusting-and-galvanic induced degradation of ferrous materials is likely. Moisture from the interior via vapor drive is considered transient and not accumulative because the drive downwards is an order of magnitude greater downward than upward, i.e., summer versus winter; day versus night; sunny versus cloudy.

Once leak water is prevented from entering the system, drying to the interior will begin unless there is a vapor barrier (retarder) present. If a barrier is in place it is assumed it is performing as a vapor retarder so drying downward will not occur. Drying will not occur effectively by edge venting or through roof-top surface venting (Tobiasson 1981), therefore, drying will not occur. The new system components installed will have to be insensitive to trapped water or not penetrate into the area below the existing roofing membrane, such as fasteners extending into the structural deck. Water will not tend to move upward past the original membrane because it has effective barrier capability and the driving force upward is less than it is downward. So a ballasted new roof, conventional or protected membrane assemblies (PMA) are usable solutions. If fasteners are required, a viable solution is to tear off the existing roof assembly down to the vapor retarder. If it is not damaged during reroofing the interior operations need not be hampered.

Drying will take place if there is no vapor barrier. All roof decks will pass water at a rate dependent upon the permeance of the structure and the moisture vapor drive. Typical permeance rating for structures are listed (Table 4 'Permeance of Decks)

Once water has been removed from the cross section, the degradation potential will be terminated. Where drying can occur the time to dry must be compared to the time the components resist degradation.

The time the system will be wet can be estimated by the use of the moisture vapor transmission equation based on Fick's Law. The quantity of water per unit area that can be removed is directly proportional to the driving force and inversely proportional to the resistance to passage of moisture. Using available data with this rate equation and knowledge of the amount of water within the system, as noted by measurement, the time to remove the excess water can be determined.

The amount of water calculated to be removed from the existing roof cross section to the interior by moisture vapor transmission will be a conservative value. Construction tolerances, openings for projections, and edge effect at the wall/ceiling juncture will allow additional drying by air infiltration. Partially attached single ply membranes also may increase the benefits of drying by ventilation with the "pumping" action of the billowing membrane. These drying mechanisms are not included because they have not been quanitified.

The potential for drying is the difference between the vapor pressure within the wetted cross section and the space below. For comfort conditions of 70°F (21° C) and 50% relative humidity the vapor pressure is 0.37 in. Hg (1.25 kPa). The vapor pressure in a wetted system at 100% relative humidity is dependent upon the temperature the system would reach. To dry downward a higher vapor pressure is needed within the roof cross section. This relates to a high temperature, therefore, summertime develops drying versus wintertime. There is a reversal from summer to winter so water would tend to enter the roofing system during the winter. However this drive is much lower, as much as 1/10 of the driving force in the summer, with the net result of drying.

Assuming a non-insulated new roof system over the existing system, roof-top temperatures for graveled or black surfaces would reach 130°F (55°C) to 180°F (82°C). The work done by the National Bureau of Standards (Cullen 1981) has published time/temperature curves for summer conditions time for various surfaces ranging from light to dark Figure 1 (Effect of Surface Treatment on the Solar Heating of Built-up Membranes During Summer Exposure). A first approximation can be made by assuming an average temperature and associating that with the time it persists. For example, for a graveled surfaced membrane, a temperature of 130°F (55°C) for approximately 10 hours a day can be maintained. Use three months per year in the summertime, when the roof would be exposed to direct radiation, for a total drying time of 900 hours.

The quantity of water per unit of roof area removed per year would be equal to the permeability of the roof deck in question times the vapor pressure drive for this approximated drying season. A permeance of 1 perm (57.5 perm) is assumed for a sample calculation.

The difference in pressure is equal to the vapor pressure at 130°F (55°C) at 100% relative humidity, 4.5 in. Hg (15.2 kPa) less the pressure of the interior, which is .37 in. Hg (1.25 kPa). This provides a differential of 4.13, (14 kPa). The amount of water that can be dried per year would be equal to 0.53 $lb/ft^2$ (2.6 $kg/m^2$)

| | | | | | | |
|---|---|---|---|---|---|---|
| | WATER REMOVED | = PERMEANCE | X VAPOR PRESSURE | X TIME | X UNIT CONSTANT | (1) |
| I-P Units | $lb/ft^2$ yr. | = perm | X in. Hg | X hr./yr. | X $1.4 \times 10^{4}$ | (2) |
| | 0.53 | = 1.0 | X 4.13 | X 900 | X $1.4 \times 10^{-4}$ | (3) |
| SI Units | $kg/m^2$ yr. | = (perm) | X kPa | X hr,/yr. | X $3.6 \times 10^{-6}$ | (4) |
| | 2.6 | = 3.75 | X 14 | X 900 | X $3.6 \times 10^{-6}$ | (5) |

Insulation, such as organic fiber board with 100% water content in a 2 in. (50 mm) thickness would have an excess moisture content of approximately 2 $lb/ft^2$ (9.8 $kg/m^2$). With a deck permeance of 1 perm it could require 4 years to dry; at 10 perm (575 perm) it would take less than one year.

If the new system included insulation with a thermal resistance equal to 10 (1.8) the temperature difference of the existing system would be tempered. If the original insulation in its wetted state had an effective thermal resistance of 5 (0.9) the temperature drop across the original system would be 1/3 the total temperature difference. One third of the temperature drop, 130°F (55°C) - 70°F (21°C) divided by 3 is 20°F (11°C). This would reduce the temperature at the top of the original insulation to 90°F (32°C). The vapor pressure at that temperature and 100% humidity is reduced from 4.5 inch Hg (15.2 kPa) to 1.4 inch Hg (4.7 kPa) This reduces the difference in vapor pressure from 4.1 inch Hg (14 kPa) to 1 inch Hg (3.37 kPa) effectively increasing the drying time by four times. If there is no design requirement for additional insulation the drying time is significantly shorter and the thermal resistance of the original insulation can be retrieved.

Improving the decision making process to recover, when materials will be subjected to moisture for a limited time, requires the development of additional information:

-- permeance values for non-homogeneous roof decks

-- dynamic time/temperature relationships for various climates

-- quantifying the acceptable time of exposure of various roofing components, such as fasteners and insulations.

Alternatives are to use materials that are water insensitive; or not to have them exposed to water in the roof system.

<u>Selection Based on Water Insensitive Materials</u>

Roofing membranes that are insensitive to water are common in the market today. Insulations that are resistant to the ingress of water are also available in the form of closed cell plastic foams. The positioning of insulation above an existing roof membrane does not put it in a situation where there would be moisture. The moisture within the old system would be dried downward, even when slowed by the added insulation above. The barrier qualities of an existing membrane, if it is not intentionally damaged or perforated, retards the passage of water upward.

When mechanical fasteners are used to penetrate the existing roof membrane to hold the new roofing system in place the portion of the fastener that penetrates through the old system is in a hostile environment with respect to moisture. If the fastener materials are moisture sensitive, in all likelihood degradation will occur unless the drying time is short. For example, the drying rate will be essentially zero for a vapor retarder in place, but it could be very high for a porous deck, such as a gypsum deck or a wood fiber concrete panel deck system with a perm rating of 10 or more. The use of non-ferrous fasteners, which effectively resist the degrading effects of wet conditions, would be suitable.

Selection Based on Sequence of Construction to Place Materials Away from Trapped Water

The use of a protected membrane assembly concept eliminates the potential degradation of roofing membranes and the insulation. The insulation is designed to be in the weather and water above the new membrane. The requirement for mechanical fasteners to hold the system in place would be essentially the same as for conventional roof cross sections. The fasteners would be in a wetted area below the existing membrane, but there is less occasion for condensation to occur. This is because the temperature to which the new membrane is exposed is warmer in cold weather than that for a conventionally installed membrane. An interesting procedure would be to delay application of the insulation for a summer over a black membrane. This would enhance drying by heating the membrane by the sun.

## FOLLOW-UP CONSIDERATIONS

After the individual roof systems are identified for a specific recover project the best system is selected on the basis of design, installation, and cost considerations. Canon (1988) assembled a complete guideline of such considerations. Table 5 is a condensed version of the more important aspects to consider. The selected system must meet these requirements. For example, a ballasted system would meet the requirements for fire from above, but may be too heavy for the structure. Code requirements often require mechanically attaching the original roofing system which may necessitate the use of non-ferrous fasteners. The thickness of the total cross section may require changes in height of edges and projections to accept the new system. The items related to design must be met, and therefore can disqualify previously selected systems. Installation items for the most part are concerned with modifications to adapt the new system. Cost items are the result of meeting these criteria. The major bonus of the recover approach is the cost saving of eliminating the tear off of the original roof system. The tear off cost can equal the cost of a new roof.

## THE PROBLEMS ASSOCIATED WITH TRAPPED WATER ARE THE SAME FOR NEW CONSTRUCTION AS RECOVER

The application of roofing systems in the recover concept can be done, by following engineering logic. Often ignored but as important, the same logic must be followed for new construction, which includes tear off situations. New systems can become wet as systems installed over existing roof systems. New construction should be monitored because the same problems noted for the systems being recovered can occur. When leaks occur the problems are compounded because the old roof system provides a form of vapor retarder making it difficult to determine when and were the recover roof is leaking. This allows potential degradation of the products placed above the original roofing membrane before leaks are noted in the interior. Monitoring of all roofs through preventative maintenance programs is worthwhile. Leak detection concepts should be developed for all roofs that include some form of water barrier below the roof membrane to locate leaks before degradation occurs.

## CONCLUSIONS

1. The reroof segment of total roofing construction is large, 70%, and growing. Of this, recover installations account for 40%, compared to 30% for tear off. This change in the roofing market has been motivated by the favorable economics of recover, and the availability of a number of products considered to be water resistant.

2. When to recover is the initial decision to be made. Then the decisions of how best to implement the recover process are made.

3. Roofing systems can be selected for recover on the basis of:

    -- using materials that resist degradation while the system dries

    -- using water resistant materials

    -- Sequencing water sensitive materials to not be in a wet environment

4. The time to dry a system to the interior of a structure can be determined using moisture vapor transmission calculations.

5. The decision not to use certain systems for recover can be verified.

6. Increasing the number of systems for recover is dependent on the development of water resistant products, such as fasteners and adhesives.

7. The length of time roofing products can resist degradation when exposed to wet environments needs to be quantified.

8. The functions that control the drying rate should be defined in more detail:

    -- The permeability of non-homogenious and panelized roof decks.

    -- The drying energy with respect to time and temperature on a seasonal basis.

9. The drying effects of air infiltration and roof venting for non-rigid roof membrane systems should be quantified.

10. Leak detection and leak localizing concepts should be developed to protect roofing systems installed in recover systems and in new construction.

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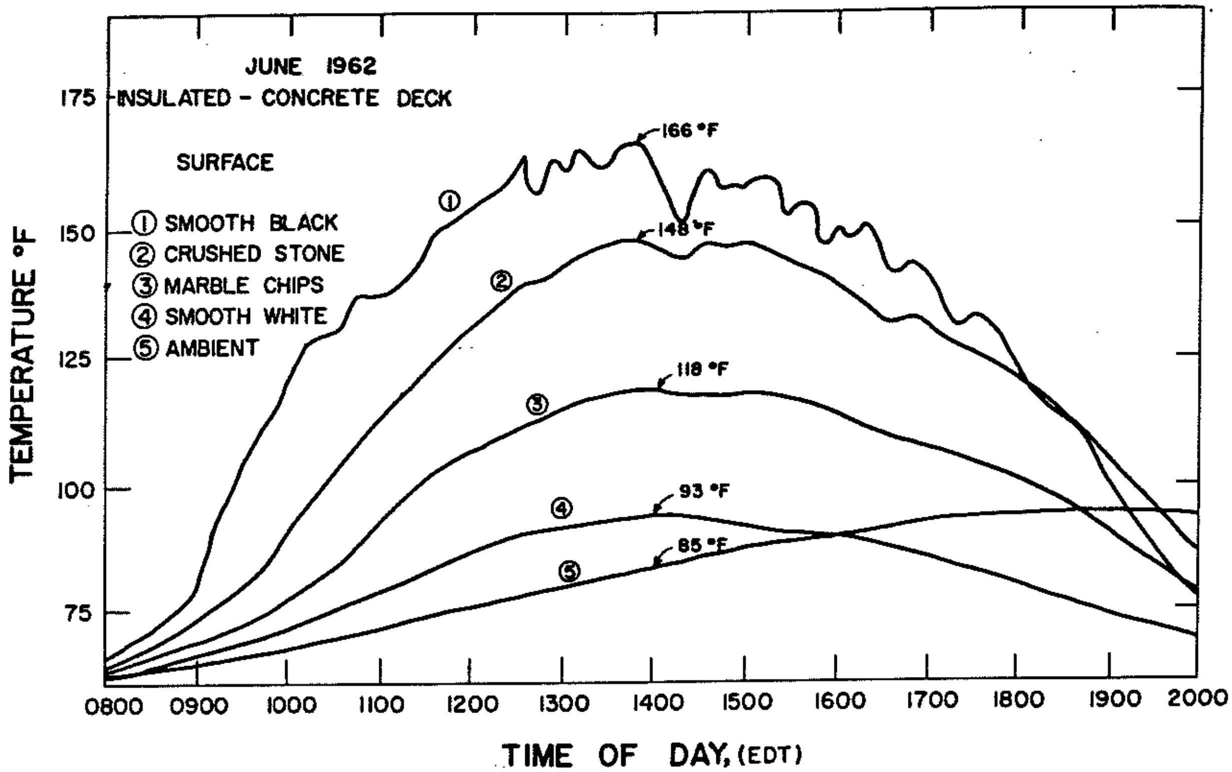


*Figure 1. Effect of surface treatment on the solar heating of built-up membranes during summer exposure*

*Table 1. Resistance of material to water*

| ITEM | YES | NO | LIMITED |
|---|---|---|---|
| ROOF MEMBRANE | | | |
| ADHESIVE TO: | | | |
| SEAM LAPS OF MEMBRANE | | | |
| ADHERE MEMBRANE TO INSULATION | | | |
| ADHERE INSULATION TO DECK | | | |
| FASTENERS TO: | | | |
| ATTACH INSULATION TO DECK | | | |
| ATTACH MEMBRANE TO DECK | | | |
| INSULATION: | | | |
| APPLIED BELOW MEMBRANE | | | |
| APPLIED ABOVE MEMBRANE | | | |
| OTHERS | | | |
| | | | |
| | | | |
| | | | |

*Table 2. Acceptability of new systems for installation over existing roof systems*

| NEW SYSTEM | EXISTING SYSTEM | |
|---|---|---|
| GENERIC DESCRIPTION | WITH VAPOR RETARDER | WITHOUT VAPOR RETARDER |
| **BUILT UP ROOF MEMBRANE (BUR):** | | |
| ADHERED WITH BITUMEN | | |
| MECHANICALLY FASTENED | | |
| **SINGLE-PLY MEMBRANE:** | | |
| BALLASTED | | |
| MECHANICALLY FASTENED | | |
| ADHERED | | |
| **PROTECTED MEMBRANE ASSEMBLIES (PMA):** | | |
| BALLAST 10# | | |
| BALLAST 15# | | |
| OTHER | | |
| **OTHERS:** | | |
| | | |
| | | |

*Table 3. Moisture content-roofing components (% dry weight)*

| TYPE MATERIAL | EQUILIBRIUM MOISTURE CONTENT AT 90% RH 75F | MAXIMUM MOISTURE CONTENT OBTAINED BY IMMERSION |
|---|---|---|
| ORGANIC FELT MEMBRANE | 1.0% | 20% |
| FIBERBOARD | 12.0% | 430% |
| PERLITE BOARD | 4.0% | 580% |
| GLASS FIBER | 2.0% | 610% |
| URETHANE | 6.0% | 520% |
| EXPANDED POLYSTYRENE | 3.0% | 540% |
| LIGHTWEIGHT CONCRETE | 6.0% | 110% |
| DRY ASPHALTIC FILLS | 0.1% | 60% |
| CELLULAR GLASS | 0.01% | 30% |
| EXTRUDED POLYSTYRENE | 0.5% | 10%-15% |

(ANDERSON 1985)

*Table 4. Permeance of decks*

| MATERIAL | PERM | (PERM) |
|---|---|---|
| CONCRETE (4.0 IN THICK) | 0.8 | 46 |
| CONCRETE PLANK | >0.8[1] | >46[1] |
| METAL PAN/CONCRETE | <0.8[1] | <46[1] |
| WOOD PLANK (1.0 IN THICK) | 0.4 - 5.4 | 23 - 310 |
| PLYWOOD (0.5 IN THICK) | 0.35 | 20 |
| SHREDDED WOOD/CONCRETE | >50[1] | 2860[1] |
| FORMBOARD FOR LIGHTWEIGHT DECKS | 50 | 2860 |
| METAL DECK | 1 (APPROX)[1] | 57 (APPROX)[1] |

(ASHRAE 1981)

NOTE: 1 = <, >, AND (APPROX) ARE AUTHOR'S MODIFICATIONS

*Table 5. Follow-up considerations*

## DESIGN CONSIDERATIONS

RESISTANCE TO FIRE - ABOVE
RESISTANCE TO FIRE - BELOW
RESISTANCE TO WIND
WEIGHT LIMITATIONS
THERMAL REQUIREMENTS
TRAFFIC LOADING
APPEARANCE
CODE REQUIREMENTS

## INSTALLATION CONSIDERATIONS

DRAIN HEIGHT
SLOPE CHANGES
FLASHING HEIGHTS AND SECUREMENT
FASCIA ATTACHMENT
ROOF EQUIPMENT INTERFERENCES
ROOF LOADING RESTRICTIONS

## COST CONSIDERATIONS

FIRST COST
MAINTENANCE COST
TOTAL COST - LIFE CYCLE CALCULATIONS
VALUE OF WARRANTY