NATIONAL BUREAU OF STANDARDS REPORT

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THE EFFECT OF INSULATION ON THE DURABILITY OF A SMOOTH-SURFACED, BUILT-UP ROOF

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U. S. DEPARTMENT OF COMMERCE
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Building Research Division

Sponsored by

Office of the Chief of Engineers
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NBS

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THE EFFECT OF INSULATION ON THE DURABILITY OF A SMOOTH-SURFACED, BUILT-UP ROOF

1. INTRODUCTION

During the past 25 years or more, insulation in many forms has been used to separate the roof membrane from the roof deck. This has been the accepted practice for several reasons, but primarily for its thermal insulating properties which ultimately contribute to the comfort of the building occupants. As early as 1935, Rogers [1][1/] stated that all roofs should be insulated and normally insulation should be placed above the roof deck on a flat roof. He further indicated that above deck insulation, thoroughly waterproofed at all points, prevents solar heat from reaching the roof deck so that the mass will not continually radiate heat within the structure during a protracted period of hot weather. The use of insulation above deck also reduces the maximum temperature reached by the deck and this in turn reduces the chances of structural cracking due to temperature changes in a concrete deck. In addition, insulation is often used for economical reasons; less power is utilized to cool the interior during the summer and less fuel is used to heat the structure in the winter. Further, the use of insulation is mandatory in many cases to provide a suitable surface for the application of a built-up roof.

There is no doubt that the accomplishment of these ends dictates the necessity for insulating above a roof deck. However, how does the use of insulation above a deck affect the durability of a built-up roof?

At the request of agencies of the Department of Defence, as a task under Project 10447, Performance of Roofings, Tri-Service Engineering Investigations of Building Construction and Equipment, NBS, a program was conducted to study roof temperatures and their effect on the durability of a built-up roof.

Previous studies under this project indicated temperature differences among various roofing systems on various types of decks and deleterious effects of the higher temperatures on the durability of an insulated, smooth-surfaced, built-up roof. In the continuation of these studies, the following experimental work was undertaken.

1/ Figures in brackets refer to list of references at the end of this report.

2. BACKGROUND

A number of investigations relating to the mechanisms of degradation of roofing asphalts carried out at the National Bureau of Standards have shown that a chemical reaction occurs within a bitumen during the weathering process. Based on extensive laboratory tests, Greenfeld [2] has established that when asphalts are exposed to light (ultraviolet), heat, and water, numerous and complex changes take place. Other investigators [3,4,5] connected with these studies, describe in detail the various chemical and photochemical reactions which occur during weathering.

The effect of rise in temperature on the speed of a chemical reaction is rather astonishing. It is generally accepted that a rise of 10°C (18°F) may double or even triple the velocity of a chemical reaction [6].

If these statements are valid, the temperatures attained by a built-up membrane, other factors being similar or equal, will have a definite effect on the durability of the bitumen and felt comprising the membrane.

In addition to the chemical changes which occur within the bitumen, another factor must be considered in the degradation of a built-up roof, i.e., the thermal stresses produced in the membrane and surfacing bitumen during the temperature changes which occur. A combination of the hardening effect on the surfacing asphalt due to oxidation and to the thermal stresses due to temperature change result in an alligatoring and cracking of this component and differential movements in the various components of the roof system. These events may develop to such an extent that water eventually enters the waterproofing membrane. Therefore, two factors should be considered in relating temperature to the degradation of a built-up roof as follows: (1) the acceleration of the rate of degradation by increasing the temperature, and (2) the effect of thermal stresses and movements due to rapid temperature changes.

Little information regarding the temperatures attained by an insulated built-up roof membrane has been published. In 1957, Ballantyne and Spencer [7] reported the results of a study of temperatures attained by bituminous roofs coated with black, white, and aluminum surfaces. Their results indicated that appreciable (15°F or more) reductions in temperatures were obtained by treating a black, bituminous surface with a suitable white reflective coating, and to a lesser extent with an aluminum paint. In comparing the placement of the insulation above the deck versus that placed below the deck, Stephenson [8] reported that the maximum surface temperature and the rates of change of temperature are higher with the insulation placed between the roof deck and the waterproof layer. Martin [9] recognized the effects of the high temperatures built up in an insulated

roofing membrane and stated that it was essential to provide a reflective surface in such cases. He further reported the coefficients of solar reflectivity of different surfaces and the approximate values are listed in Table 1.

TABLE 1. COEFFICIENT OF SOLAR REFLECTIVITY*

Material	Coefficient of Solar Reflectivity
Asphalt and Bituminous Compounds	0.07
Bituminous Roofing Felt	0.10
Asbestos Cement, old and dirty	0.17
Asbestos Cement, new	0.39
Galvanized Iron, old and dirty	0.10
Galvanized Iron, new	0.35
Slate, blue-grey	0.15
Marble, white	0.56
Sand, fine and white	0.59
Paint, light grey	0.25
Paint, red	0.26
Paint, aluminum	0.46
Paint, light green	0.50
Paint, light cream	0.65
Paint, white	0.75
White wash	0.80
Aluminum Foil, new	0.87

*Coefficient of reflectivity is defined as the numerical ratio of radiant energy reflected to the radiant energy impinging on a surface.

In a paper on the thermal movements and stresses in concrete slabs in relation to tropical conditions, Hendry and Page [10] enumerated eight factors on which the rate of temperature use will depend and discussed their significance. They are as follows:

1. The intensity of short-wave radiation received from the sun and sky.

2. The rate of increase of outside air temperature.

3. The velocity of wind blowing over the surface.

4. The heat loss back to the atmosphere in the form of long-wave radiation.

5. The surface absorbtivity for short-wave solar radiation.

6. The surface emissivity for long-wave radiation.

7. The thermal properties of the roof system.

8. The interior thermal conditions.

In discussing roof insulation, they further state that insulation on the top of the reinforced concrete deck decreases the temperature of the concrete, but raises the temperature of the built-up membrane, which may lead to its accelerated deterioration.

3. EXPERIMENTAL RESULTS

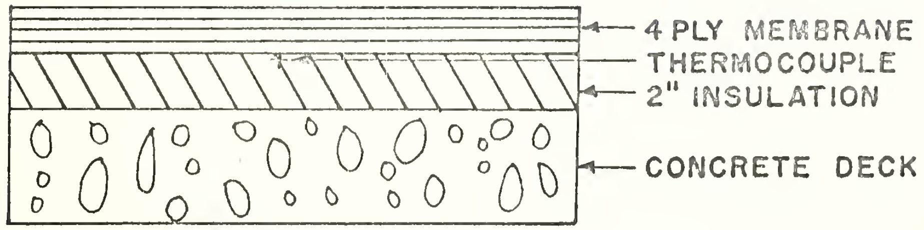
In planning the experiments, it was decided to use asphalt-surfaced, built-up membranes, since a black surface absorbs nearly all the radiant energy falling upon it and consequently attains higher temperatures when exposed to solar radiation than most surfaces of other kinds under the same conditions.

Identical specimens of a roof system were constructed using a four-ply, asphalt, built-up roof membrane on a concrete deck. The membrane was separated from the concrete deck by two inches of cork insulation on one specimen, while the membrane was applied directly to the deck on the other. A copper-constantan thermocouple was placed directly beneath and in contact with the roof membrane. The construction details of the specimens are shown in Figure 1.

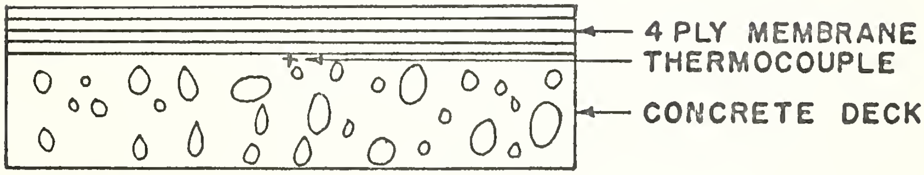
The specimens were exposed at a zero slope on the roof of the Industrial Building, National Bureau of Standards, and the temperatures attained in the respective membranes were recorded continuously on a Brown Recorder.

The results obtained during the exposures, expressed as time-temperature curves as they were recorded on summer days in 1961, are illustrated in Figures 2 and 3. The illustrated curves were selected from the many obtained, since they represented the extremes in temperatures and temperature changes which occurred.

In addition to the above results, the temperature determinations made on clear, cool nights indicated significant differences varying from 5°F to 15°F below the ambient for the insulated membrane during the summer and winter, respectively, and from 2°F to 5°F below ambient for the non-insulated specimen. On the other hand, no apparent temperature difference was observed among the ambient, the insulated specimen, and the non-insulated specimen when the sky was cloudy and overcast.



INSULATED SPECIMEN



NON-INSULATED SPECIMEN

FIGURE 1.

CONSTRUCTION DETAILS OF BUILT-UP ROOF SPECIMENS

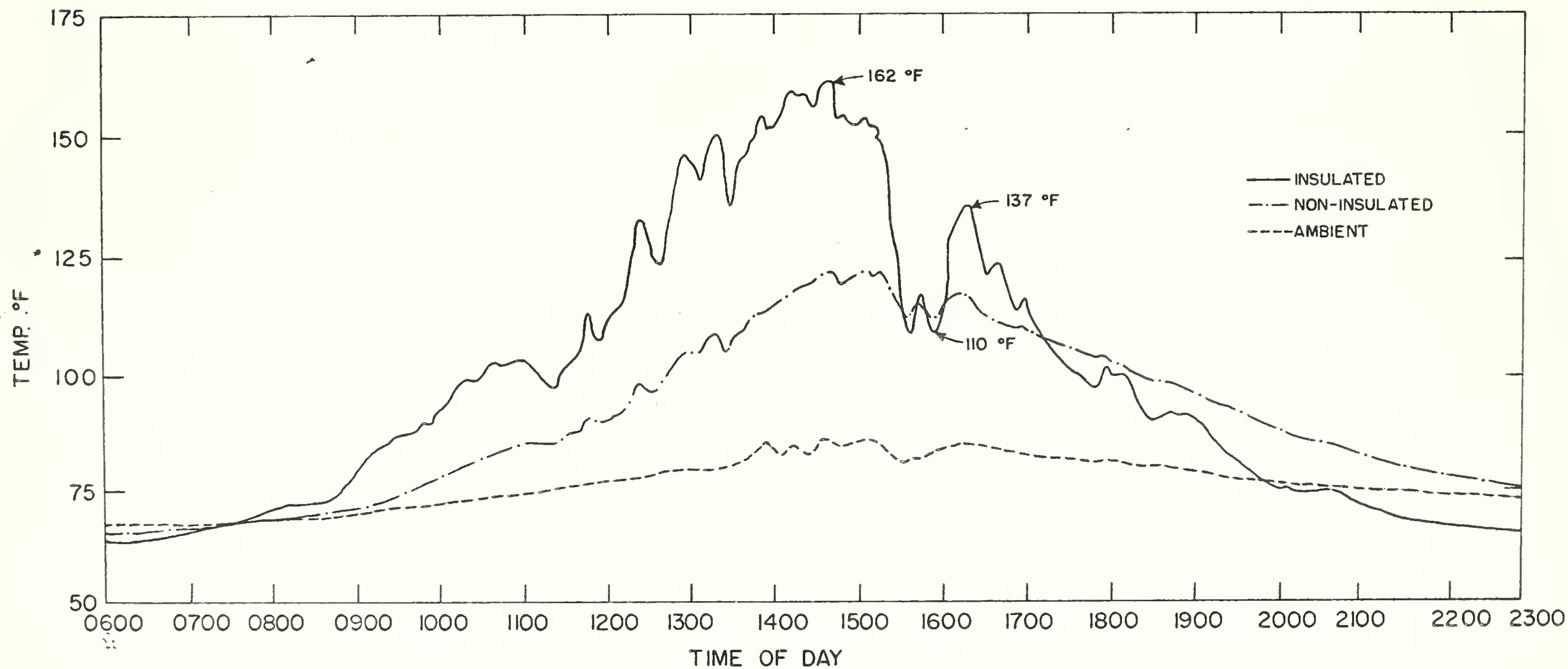


FIG. 2 TIME - TEMP. CURVES OF INSULATED AND NON-INSULATED BUILT-UP ROOF SPECIMENS

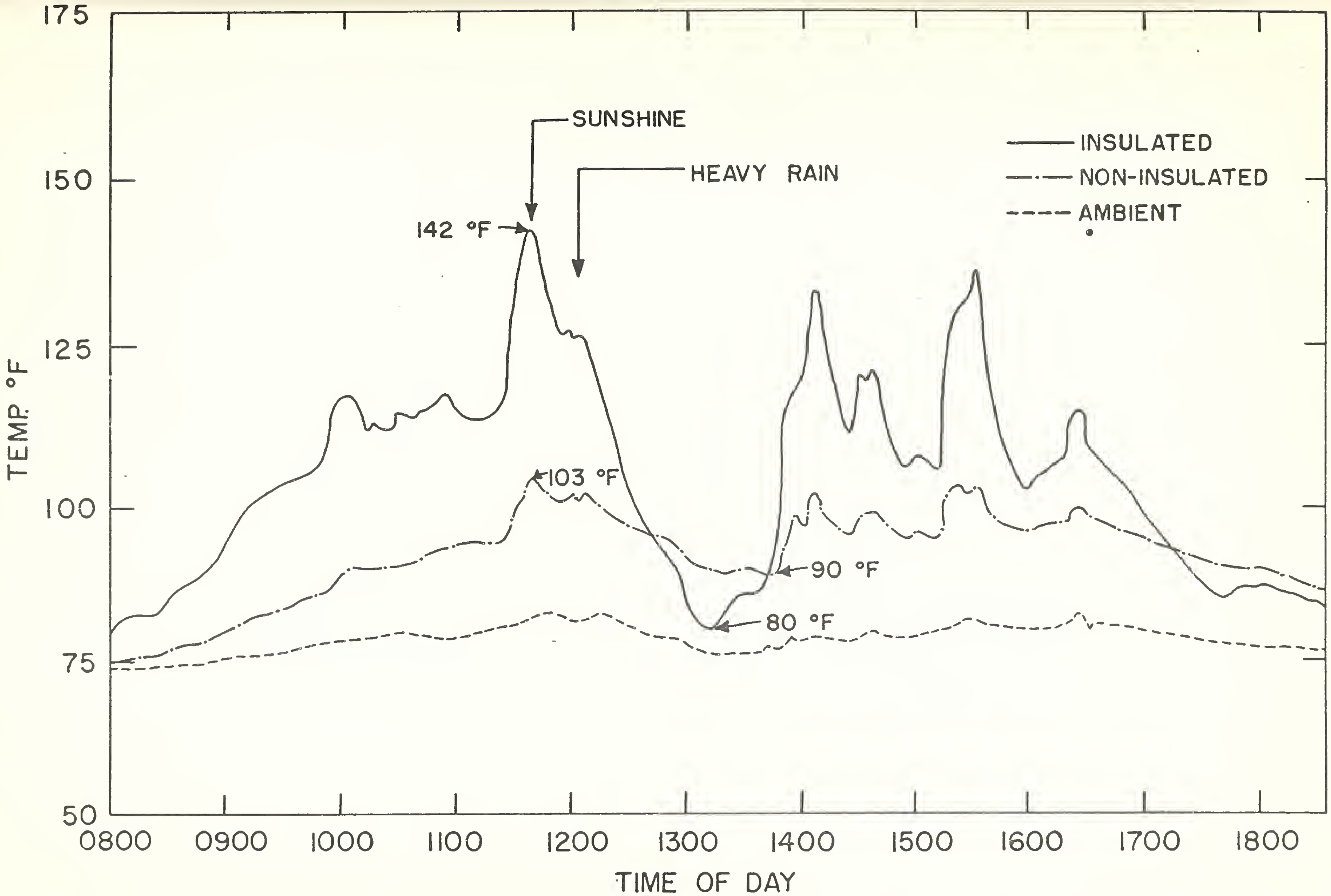


FIG.3 TIME-TEMP. CURVES OF INSULATED AND NON-INSULATED BUILT-UP ROOF SPECIMENS

4. DISCUSSION OF RESULTS

A study of the time-temperature curves in Figure 2 shows that not only was a temperature differential of 42°F (162°F vs. 120°F) observed between the insulated and the non-insulated specimen, but also that greater temperature changes occurred in the insulated specimen over short periods of time due to varying weather conditions (clouds, winds, etc.).

The time-temperature curves presented in Figure 3 represented the conditions as recorded on a day which included sunshine, clouds, and heavy rains. The curves illustrate the extremes in temperature evidenced by the insulated specimen as opposed to those observed in the non-insulated specimen. The morning was generally cloudy with intermittant sunshine and, it should be noted, that these conditions were reflected to a much greater extent by the insulated specimen. This specimen reached a maximum temperature of 142°F at 11:30 A.M. when a heavy rain occurred. The temperature of the insulated specimen declined 62 degrees to 80°F in a period of only 1-1/2 hours, and after the rain ceased, the temperature climbed 45 degrees to 125°F in a matter of 30 minutes. In contrast, the temperature of the non-insulated specimen declined only 13 degrees and rose about 10 degrees in the same period of time.

It was observed that the temperatures of both the insulated and non-insulated specimens were generally below the ambient on clear, cool nights, with the insulated specimen showing the greatest declination. In this connection, it is generally accepted that surfaces which radiate energy at long wave lengths are coolest at night. However, since identical surfaces were employed in these experiments, the deviation in the temperatures of the specimens observed on clear, cool nights was attributed solely to the use of insulation.

The results which were observed in these series of experiments were not entirely unexpected, since it was felt that a concrete deck would act as a stabilizing influence to the built-up membrane. It was predicted that the insulated membrane would not only exhibit the higher maximums and lower minimums in temperature, but also an increased rate of change since it is divorced from the concrete deck by an insulating medium. The insulation, of course, prevents the heat absorbed by solar energy from being dissipated by the roof deck during the day and, conversely, allows the energy to be readily emitted to the sky on a clear, cool night.

It is further expected that the temperature differential between an insulated and non-insulated membrane will depend on the density of the roof deck. For example, this differential will probably be somewhat less on a wood deck than on a concrete deck.

The data which were obtained in these studies indicated that the insulated membrane will not only degrade chemically more rapidly due to the higher temperatures attained, but will also deteriorate physically at a faster rate. The greater temperature changes in short periods of time result in large thermal stresses being set up. In the laboratory specimens, the differential weathering of the surfacing asphalt on an insulated membrane versus that protecting a non-insulated membrane was readily apparent as illustrated in Figure 4. The specimens were photographed after 2 years exposure side by side.

The performances of insulated and non-insulated built-up roofs have also been observed during a number of field surveys carried out under this project. Generally, the non-insulated roofs gave the more trouble-free performance and longer durability. For example, Figure 5 illustrates the weathering of an insulated section (left) and an uninsulated section (right) of an aluminum painted, asphalt-surfaced, asbestos felt, built-up roof exposed on Guam Island after about 2 years. It was readily apparent that the insulated section had undergone the greater degree of weathering as evidenced by the alligatoring, cracking, and general deterioration.

Temperature and rate of change of temperature will, no doubt, have an affect on other changes which occur in built-up roofs such as blistering, wrinkling or buckling, cracking, membrane ruptures, etc. Each of these conditions is caused or accelerated by thermal movements or stresses and changing air and/or vapor pressure which are, of course, directly related to temperature and temperature changes.

5. CONCLUSIONS

The following conclusions may be drawn based on this study:

1. Smooth surfaced built-up roofs insulated from the roof deck attained appreciably higher temperatures under solar radiation than their non-insulated counterparts.

2. The average temperature of an insulated membrane was recorded at about 15°F below the ambient and about 10°F below the temperature of its non-insulated counterpart when exposed to a clear, cold, night sky.

3. The insulated specimen registered the greater fluctuations in temperature when exposed to varying weather conditions when compared to the non-insulated specimen.

4. Evidence of greater deterioration of the bitumen protecting the insulated membranes was observed both in laboratory experiments and in field exposures.

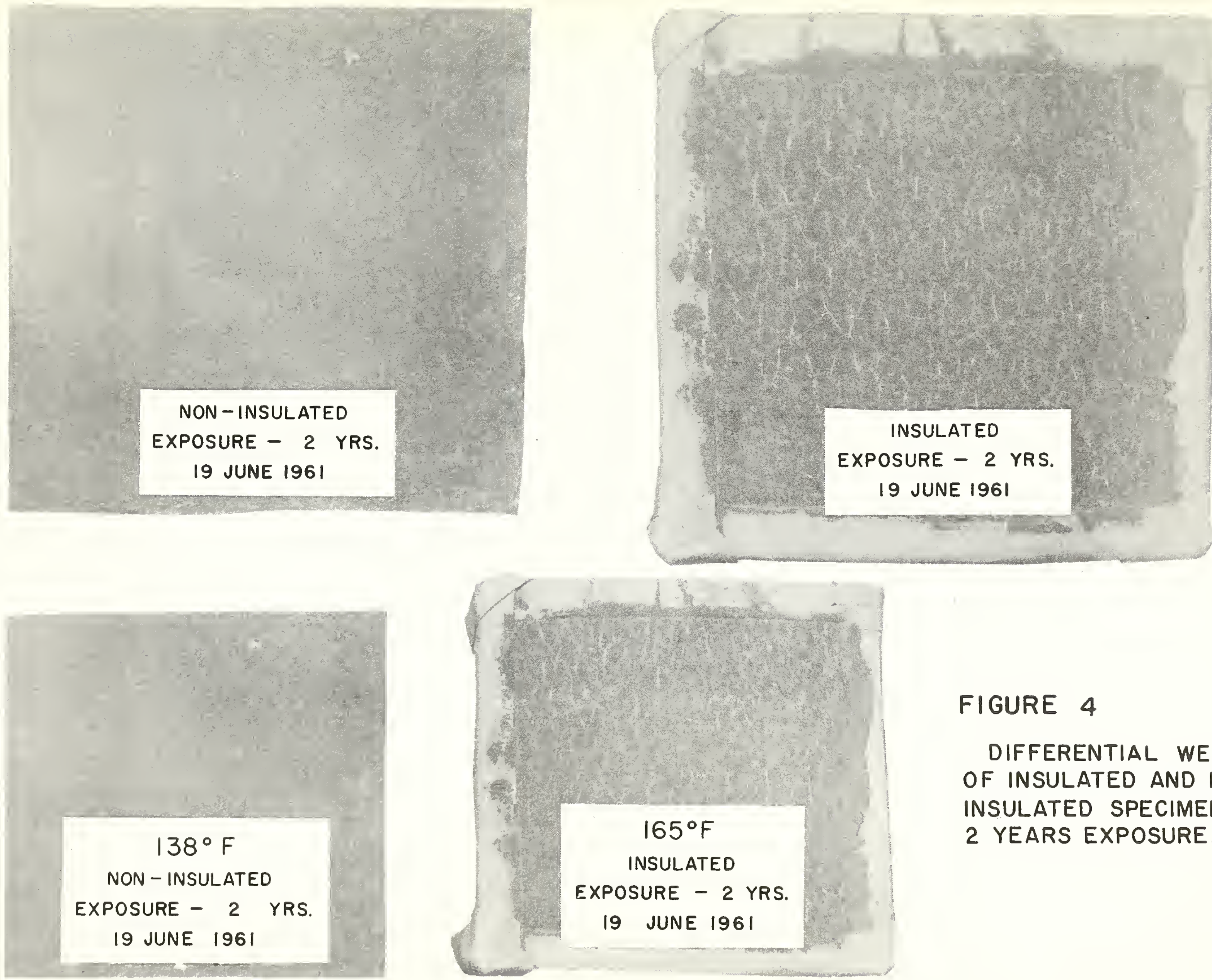


FIGURE 4

DIFFERENTIAL WEATHERING OF INSULATED AND NON-INSULATED SPECIMENS AFTER 2 YEARS EXPOSURE.

INSULATED NON-INSULATED

FIGURE 5. DIFFERENTIAL WEATHERING OF AN INSULATED VERSUS A NON-INSULATED SECTION OF A BUILT-UP ROOF.

5. The greater deterioration of the surface protecting the insulated membranes apparently resulted from both the higher sustained temperatures and the thermal stresses produced by rapid temperature changes.

6. RECOMMENDATIONS

Because of the wide variety of roofing systems, insulations and surface treatments available for use in the construction and maintenance of built-up roofs, it is recommended that additional studies be conducted to gather information about how these factors influence the performance of a roof over both insulated and non-insulated decks.

7. NOTE

This paper deals with the effect of temperature on the performance and degradation of a built-up membrane and not with the performance of the entire roof system; therefore, it should not be construed to imply that insulation should, in every case, be eliminated between the roof deck and the membrane. This is especially true where there is a risk of failure in some other component of the roof, such as the deck, due to thermal stresses and movements.

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