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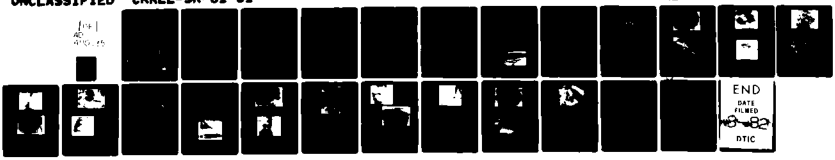

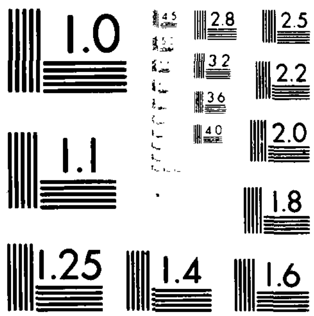

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ROOF MOISTURE SURVEY: RESERVE CENTER GARAGE, GRENIER FIELD, MANCHESTER, N.H.

W. Tobiasson, B. Coutermarsh and A. Greatorex

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An insulated roof with a badly blistered bituminous builtup membrane was surveyed with a hand-held infrared camera to locate areas of wet insulation. Several thermal patterns were observed. Core samples were taken to determine moisture contents. Core samples verified that one thermal anomaly was caused by the increased thickness of bitumen. All other anomalies were caused by wet urethane-perlite composite insulation. Some insulation boards contained much more moisture near the edges than at the center, but others were more uniformly wet. Dramatically different thermal patterns resulted. A few nuclear and capacitance

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readings, taken for comparison purposes, showed that extra bitumen adversely affects such sensing methods. Because of the amount of wet insulation and the condition of the membrane, both should be removed. The new roofing system for this building should have internal drains and be provided with a sloped surface.

PREFACE

This report was prepared by Wayne Tobiasson and Barry Coutermarsh, Research Civil Engineers, and Alan Greatorex, Civil Engineering Technician, of the Civil Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory.

The study was conducted under Intra-Army Order DFE 30-80 for the Directorate of Facilities and Housing, Fort Devens, Massachusetts.

C. Korhonen of CRREL and E. Subjek, Forces Command (FORSCOM) Civil Engineering Intern, technically reviewed this report.

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by

Wayne Tobiasson
Barry Coutermarsh
Alan Greatorex

INTRODUCTION

The garage roof at the Grenier Field Reserve Center had leaked since new insulation and a new membrane were installed there during the summer of 1979. We surveyed that roof with an infrared camera about 14 months later to determine how much insulation was wet, and to develop recommendations for corrective action. Two prior attempts to survey this roof in June and November 1979 could not be conducted because of ponded water (Fig. 1).

The steel frame of the building supports precast concrete deck panels. On the deck is a bituminous vapor retarder, 2-1/4-in.-thick urethane-perlite composite insulation, and a gravel-covered bituminous membrane. The main roof appears to be dead level and has no internal drains. An 8-ft-wide porch roof, also flat, runs along the 200-ft front of the building. This cold uninsulated roof is about 9 in. lower than the main roof and contains four internal drains. The leaders of these drains are on

Figure 1. Ponds on the flat roof of the Reserve Center garage, June 1979.

the outside of the building and extend through the pavement into a storm drainage system.

An AGA 750 Thermovision infrared camera was used for the thermal inspection during the evening of 26 August 1980. A Polaroid camera attachment photographically recorded the thermal information, and several of these photographs (called "thermograms") are included in this report. Bright areas on a thermogram indicate hotter portions of the roof than do dark areas. The procedure used to conduct infrared roof moisture surveys is discussed in Tobiasson et al. (1977a, 1977b) and Korhonen and Tobiasson (1978).

CORE SAMPLING

In conjunction with the infrared survey, 2-in.-diam. core samples were taken using a CRREL-designed coring device. The membrane, urethane insulation and perlite insulation from each sample were sealed separately in

Table 1. Core samples: moisture content (% of dry weight).

Sample	Membrane	Urethane	Perlite
C	1	41	228
D	12	482	275
I	6	827	533
L	19	304	137
M	2	99	94
N	0	3	20
O	1	7	42
P	9	209	No perlite

Table 2. Core samples: thickness (in.).

Sample	Membrane	Urethane	Perlite
C	3/8	1-1/2 (yellow)	3/4
D	3/8	1-5/8 (yellow)	3/4
I	3/8	1-5/8 (green)	3/4
L	3/8	1-3/8 (green)	1*
M	1/4	-- (green)	1†
N	3/4	1-1/2 (green)	1/4-3/8**
O	3/8	1-1/2 (green)	1
P	3/8	2-3/8 (yellow)	None

* With vapor retarder.
† 1/4- to 3/8-in. vapor retarder.
** Apparently all perlite not removed.

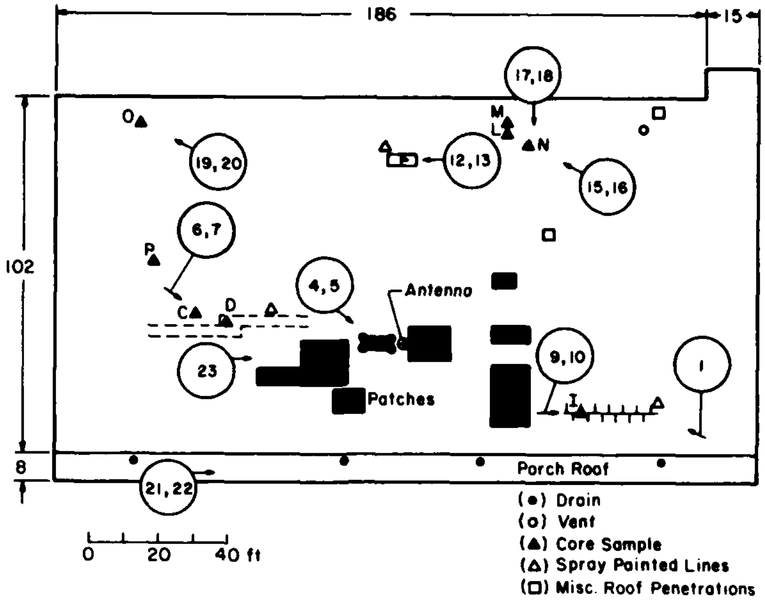

Figure 2. Plan view of roof. Circled numbers refer to figures in this report; arrows indicate viewing direction.

plastic bags and returned to the laboratory where they were weighed, oven dried at 120°F and reweighed. Moisture contents thus determined are presented in Table 1 and the thickness of each component is presented in Table 2. Sample locations are shown in Figure 2 along with the viewing direction of each photograph and thermogram included in this report.

During the infrared survey several possible sample locations were marked alphabetically. Samples were not taken at each location. Instead, visual findings from the extracted samples were used to make judgments about the moisture present at other locations with similar thermal images, thereby eliminating the need to sample there. On this roof we sampled at only half the locations marked, because once we had taken eight samples, the meaning of each type of thermal pattern had been defined and no surprises had been encountered.

ROOF MOISTURE SURVEY

The thermal image of the roof was quite complex. Spots, bands, lines and rectangular areas of varying brightness appeared on the infrared camera's monitor. Much of the roof also contained very dark areas a few inches wide and a few feet long. These dark areas coincided with tunnel blisters in the membrane (Fig. 3).

Figure 3. Tunnel blisters. The long one in the foreground is about 6 ft long.

Figure 4. Patch with corners outlined in white spray paint. Note antenna base behind patch.

Several large areas had been patched prior to our survey (Fig. 4). These patches did not significantly influence the thermal image of the roof, as shown in Figure 5. On some other roofs that we have surveyed, patches have had a thermal masking effect.

Figure 6 is a thermogram of the area of the roof shown in Figure 7.

Figure 5. Thermogram of area shown in Figure 4. The dashed white lines define the corners of the patch. Bright rectangle at rear of patch is the antenna base visible in Figure 4.

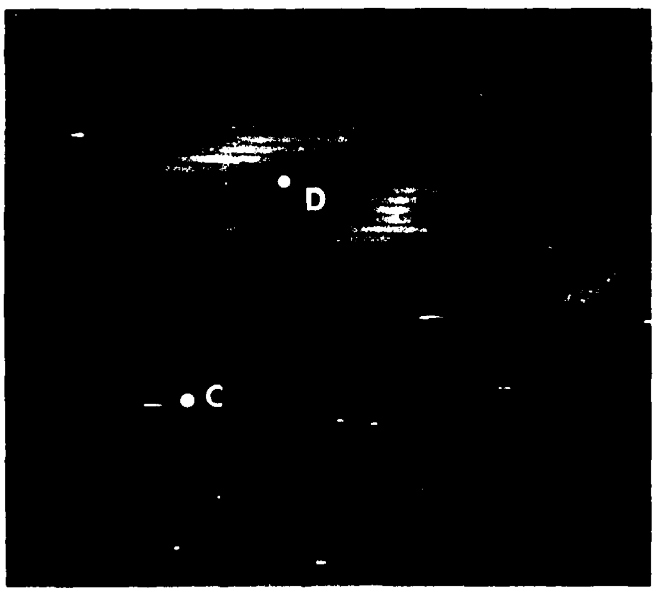

Figure 6. Thermogram showing sample D in a bright area and sample C in a dark area.

Figure 7. Painted outline of thermal image shown in Figure 6.

Figure 8. Over 2 in. of standing water in core hole D.

The thermogram shows a well-defined bright area with straight edges about 4 ft apart. Such patterns are usually a sure indication of wet board insulation. Moisture contents of samples C and D showed that 1) the perlite insulation was quite wet at each location, and 2) urethane insulation above contained substantially more moisture in the bright area (482% at D) than

Figure 9. Thermal pattern of bright lines. White dot is location of sample I.

Figure 10. Photograph of area shown in Figure 9.

in the dark area (41% at C). Figure 8 shows that the core hole at D contained over 2 in. of standing water.

Figure 9 shows a pattern that appeared over much of this roof. The bright lines were marked with paint in a few areas such as shown in Figure 10. Daytime inspection indicated nothing unusual on the surface there, but

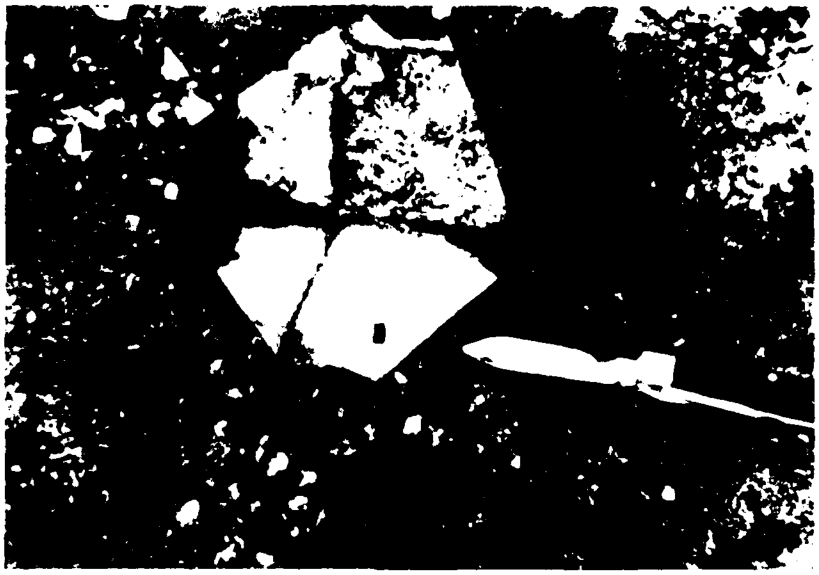

Figure 11. Core hole I and adjacent cut showing insulation seams. Note that the core hole is nearly full of water.

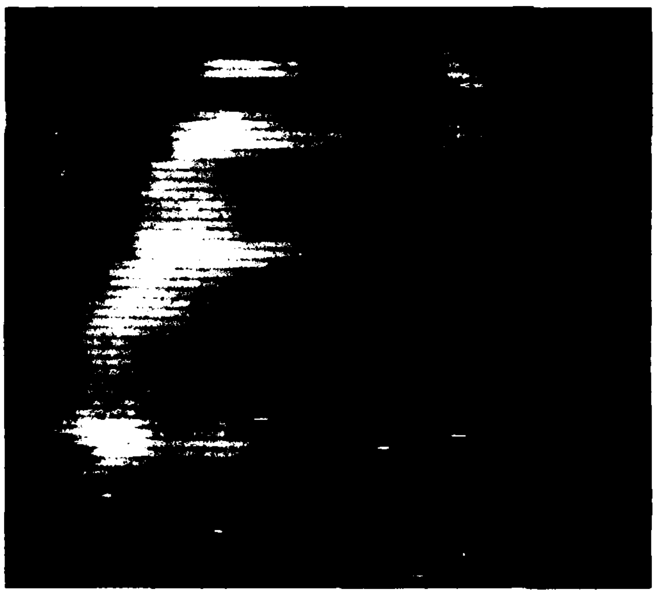

Figure 12. Thermogram of typical "hot" board outlines. The six black dots are from spray paint used to mark the intersections of the outline. The entire outline was subsequently painted as shown in Figure 13.

Table 3. Moisture content of urethane insulation (% of dry weight) (see Fig. 13 for sample locations).

Sample	Moisture content
1	1091
2	152
3	86
4	93
5	85
6	113
7	394

Figure 13. Photograph of the area shown in Figure 12 showing the location of samples 1-7.

core samples in that area (Fig. 11) verified that the bright lines coincided with insulation seams and that the insulation was wetter there. Core hole I nearly filled with water (Fig. 11) immediately after the core was removed.

On some other surveys we have done, seams have shown up as bright lines even when the insulation was dry. We attribute this to increased heat loss at the thermally poor seams. Consequently, when insulation board boundaries are seen as bright lines by the infrared camera, the insulation may not be wet.

Figures 12 and 13 show a thermogram and photograph, respectively, of another area where a well-defined board outline was present. Samples of the urethane insulation were taken where shown in Figure 13 to determine the variation of moisture content with distance from the edge of the board. These samples were knife-cut cubes about 1-1/2 in. on a side. Their moisture contents are presented in Table 3. Figure 14 shows that extra moisture was concentrated near the edges of the board. This created the dramatic thermal outlines shown in Figure 9 and 12.

Sample locations L, M and N are shown in Figure 15 through 18. Without core samples for verification, the Figure 15 thermogram might be misread by assuming that sample M is in a dry area and sample L in a wet area. In fact, both samples were found to be wet, with sample L wetter

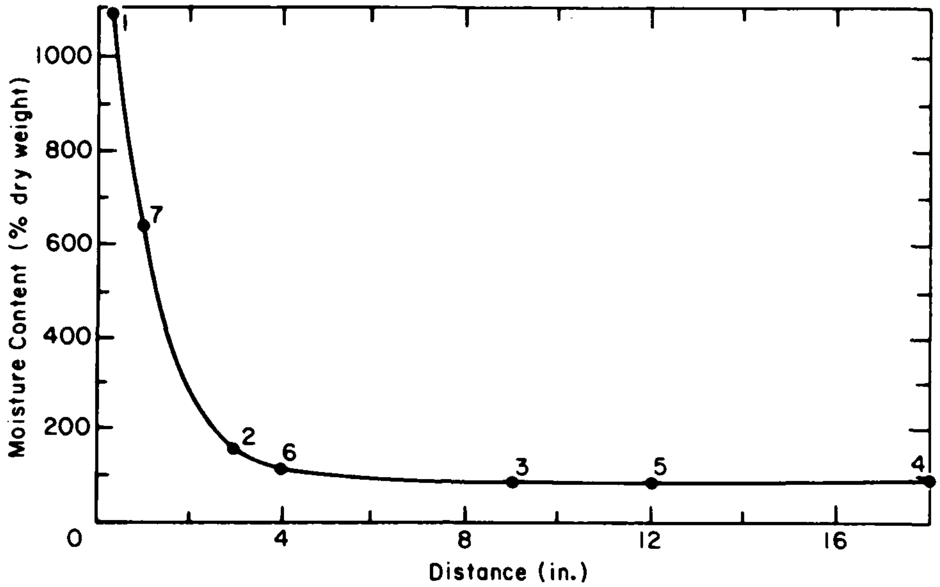

Figure 14. Variation of moisture content in urethane insulation with distance from edge of board.

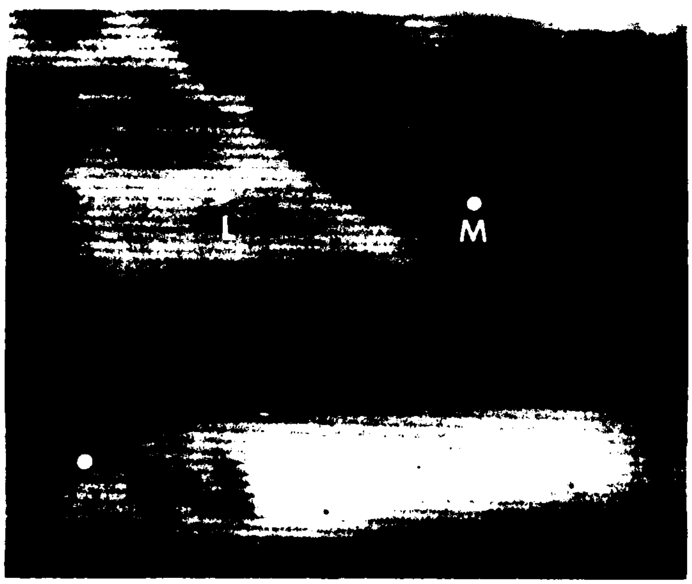

Figure 15. Thermogram showing samples L, M and N.

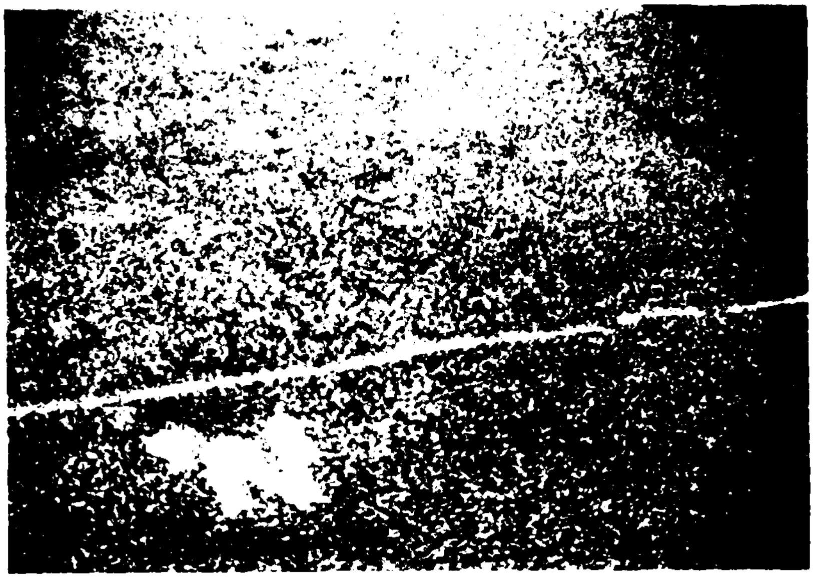

Figure 16. Photograph of area shown in Figure 15.

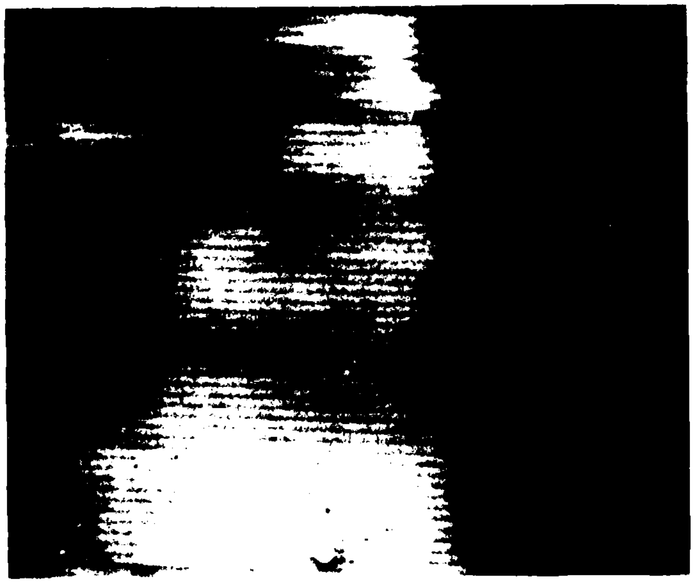

Figure 17. Thermogram of bright stripe with sample N in the foreground.

Figure 18. Photograph of the area shown in Figure 17.

than sample M. Sample N was taken within the bright stripe shown in Figures 15 and 17, but the insulation at sample N was relatively dry. Table 2 shows that the sample N membrane was almost twice as thick as other membrane samples. The extra solar energy stored in the thick membrane during the day resulted in a warmer membrane surface there during the evening. We expect that this may have been a work termination point during construction.

Half-minute measurements were taken with a nuclear moisture meter adjacent to locations L, M and N. Two types of capacitance meters were also used at these three locations and the results are given in Table 4.

Table 4. Nuclear and capacitance readings adjacent to sample locations L, M and N.

Meter	L	M	N
Nuclear (Troxler Model 2401)	451	319	424
Capacitance (Sentry Model HM-104)	37	37	26
Capacitance (Moisture Register Model PM-8F)	64	66	33

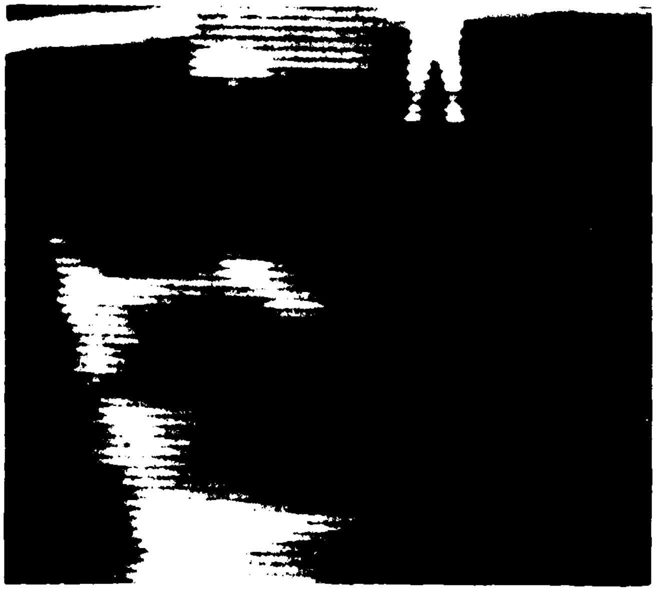

Figure 19. Thermogram with man straddling point O. Bright rectangle at the top of this picture is the sign visible in Figure 20.

Figure 20. Photograph of area shown in Figure 19.

Although sample N contained far less moisture than sample M, it had a much higher nuclear reading due to the extra bitumen there. This confirms prior observations we have made (Tobiasson and Korhonen 1978) that both infrared and nuclear systems are adversely affected when extra bitumen is present in an area. For both capacitance meters the lowest reading was at N where the insulation was relatively dry. However, each capacitance meter gave similar, if not identical, readings at locations L and M even though the moisture contents there varied widely. The L, M and N comparisons point out the value of core samples for verification purposes.

Figures 19 and 20 show the area surrounding sample location O. The

Figure 21. Thermogram of man standing by two dark spots which extended from the edge of the upper roof onto the lower porch roof.

insulation board outline in the foreground tapers off, giving way to a uniform gray tone in the background of the thermogram. Sample O showed this background area to have a relatively low moisture content. Sample P was taken in a brighter area about 40 ft from sample O. The insulation contained more moisture at P than at O.

Visually, the uninsulated lower porch roof appeared in good condition. The infrared camera detected a few dark spots on it extending out from the upper roof-lower roof intersection (Fig. 21). These dark (cool) areas were caused by water from the insulation of the main roof that had seeped out at the edge, down along the flashing and out onto the porch roof. The porch roof was moist during the infrared survey and the following day (Fig. 22).

The membrane of the main roof contained several patches (Fig. 23) and tunnel blisters (Fig. 3). A cut into a blister adjacent to sample D revealed evidence of poor installation. The blister contained water between the plies and areas of bare felt (Fig. 24). The bitumen had a glossy appearance, which is a good indication that it had cooled and not adhered to the felt above. During sampling we noticed two types of urethane-perlite insulation present. Some urethane was yellow and some green, as indicated in Table 2. In addition, at sample P the insulation

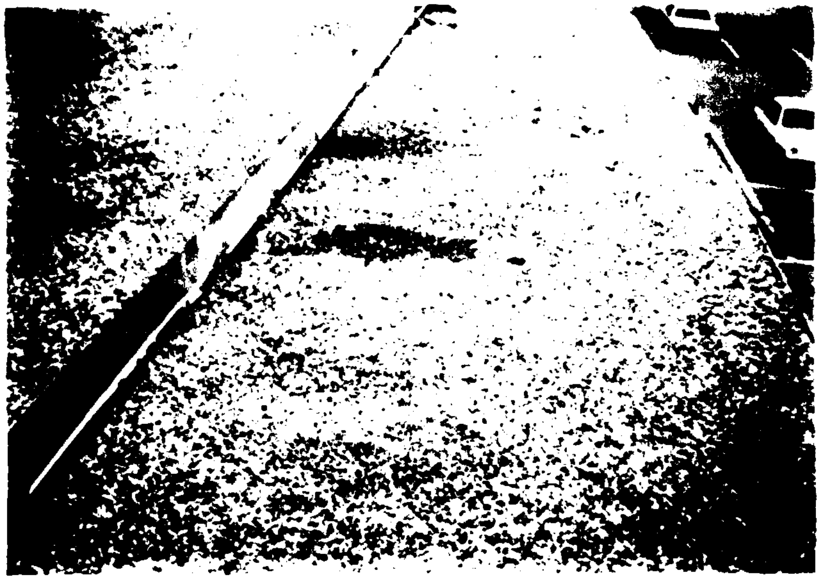

Figure 22. The two moist areas of gravel on the porch roof that appear cold in the Figure 21 thermogram.

Figure 23. Some of the large patches on the main roof.

Figure 24. Blister adjacent to sample D showing 1) areas of bare felt, 2) glossy appearance of bitumen, and 3) water.

was not a urethane-perlite composite but rather 2-3/8-in.-thick urethane. Therefore, at least three different types of insulation board were installed on the main roof.

CONCLUSIONS AND RECOMMENDATIONS

Shortly after beginning this infrared survey, it seemed obvious that this roof contained much wet insulation, as the thermograms graphically displayed a complex distribution of moisture. However, without several core samples for verification purposes the thermal images could have been misinterpreted and some wet insulation not found. Core samples are an essential ingredient of any roof moisture survey.

Thermographically this roof was interesting for several reasons:

1. Well-defined, "board stock" wet areas were detected (Fig. 6).
2. Although the roof was patched in several areas, these patches had no significant thermal masking effect (Fig. 4 and 5). On most other roofs we have examined thermographically, patches have had a significant masking effect.
3. Wet seams between insulation boards were bright and easy to locate (Fig. 9, 12 and 19).
4. A large anomaly (Fig. 17) was present that might well have been called wet insulation if core samples had not been taken. The

extra thickness of the membrane in that area was the cause of the thermal anomaly.

A nuclear or capacitance grid survey, with core samples for verification, would probably have also concluded that most of this roof contained wet insulation. The large variation of moisture from the edge to the middle of boards and the localized nature of many wet areas, along with the extra thick membrane in one area, would have complicated numerical results of such a survey and may have resulted in complex, confusing contour maps.

There is no hope of saving the membrane and insulation in this roof. Both should be removed as soon as possible. From Tobiasson and Ricard (1979) we estimate that overall about half the thermal resistance of the insulation has been lost. Tobiasson (1981) indicates that there is no way to dry such insulation in place.

The membrane contains construction flaws, is blistered and patched, and contains moisture. We expect that its rate of deterioration is increasing rapidly.

The lack of internal drains on the main roof and the apparent lack of slope to drain cause water to pond over most of the roof, as shown in Figure 1. When water is allowed to pond on a roof the risk of premature failure is greatly increased. If this roof had been sloped to drain, much less water would have entered the insulation through membrane and flashing flaws.

Our recommendations are as follows:

1. Remove the existing membrane and insulation.

2. Repair the existing vapor retarder or install a new one towards the warm side of the roofing system.

3. Install internal drains on the main roof. Internal drains are expensive in a retrofit operation, but they are much preferred to over-the-eaves drainage for low-slope roofs in areas where it snows. Ice dams at the eaves can cause significant ponding loads on low-slope roofs in such areas.

4. On the main roof provide a positive slope to drain, of about 1/4 in./ft, using either tapered insulation or a wet fill. Use crickets in valleys to assure lateral flow of water to the drains.

5. Install curbs on which the antenna and guy wire anchors can be located, or side-mount the antenna on an exterior wall.

6. Install new insulation and a new membrane.

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