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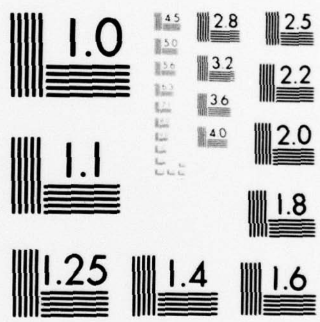
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SUMMARY OF CORPS OF ENGINEERS RESEARCH ON ROOF MOISTURE DETECTION AND THE THERMAL RESISTANCE OF WET INSULATION

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Nuclear, infrared, capacitance, microwave and impulse radar methods for nondestructively detecting moisture in roofs were evaluated. No system was reliable enough by itself or by cross-checking with another system to eliminate the need for a few core samples of membrane and insulation to verify findings. Airborne infrared surveys are a cost-effective way of reconnoitering numerous roofs at a major installation. However, follow-up on-the-roof surveys are necessary. Of the several *grid* techniques examined, nuclear surveys were the most reliable. Hand-held infrared surveys are the most accurate on-the-roof method studied. Although an infrared camera costs significantly more than a nuclear meter ($27,000 vs $3,000), infrared surveys can be conducted more rapidly. Where numerous roofs are to be surveyed,

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infrared surveys appear to be the most cost-effective method. In-situ measurements have been made of the thermal resistance of wet and dry portions of roofs. A laboratory apparatus has been built to subject 12 in. x 12 in. specimens of roof insulation to combined thermal and moisture gradients. Thermal resistance and moisture content are periodically determined and characteristic curves are being developed for various roof insulations.

PREFACE

This report was prepared by Wayne Tobiasson and Charles Korhonen, Research Civil Engineers, Civil Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL).

Corps of Engineers research on moisture detection in roofs is being conducted cooperatively by CRREL, the Waterways Experiment Station (WES), and the Facilities Engineering Support Agency (FESA). Dr. L.E. Link is conducting studies on nuclear moisture meters and fixed-wing airborne infrared surveys at WES. Alan Van den Berg is evaluating military infrared systems at FESA, and the authors are investigating hand-held infrared and capacitance systems along with microwave, impulse radar and other systems still in the early stages of development. These studies are conducted under DA Project 4A762730AT42, *Design, Construction and Operations Technology for Cold Regions*; Task A3, *Facilities Technology*; Work Unit 15, *Moisture Detection in Roofs*.

Research on the rate of moisture gain of various roof insulations and their concurrent decay in thermal resistance is being conducted at CRREL under DA Project 4A762730AT42, Task A3, Work Unit 12, *Improved Vapor Barrier Techniques in Cold Regions*.

William F. Quinn, Chief, Geotechnical Research Branch, Edward F. Lobacz, Chief, Civil Engineering Research Branch, and George W. Aitken, Research Civil Engineer, all of CRREL, technically reviewed this report.

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SUMMARY OF CORPS OF ENGINEERS RESEARCH ON ROOF MOISTURE DETECTION AND THE THERMAL RESISTANCE OF WET INSULATION

Wayne Tobiasson and Charles Korhonen

INTRODUCTION

The U.S. Army spends millions of dollars annually on the maintenance, repair and replacement of built-up roof membranes and insulation. Until recently, decisions to maintain, repair or replace roofs were based almost entirely on visual examinations frequently precipitated by complaints from occupants. Millions of square feet of sound membrane and dry insulation have been removed during the course of efforts to eliminate leaks.

A few years ago commercial firms began offering nuclear moisture surveys of roofs, and one firm was offering airborne infrared surveys from a helicopter. These commercially available systems were studied and it was apparent that at that time they had not developed to the point of reliability desired by the Corps of Engineers. Consequently, a research program was initiated to evaluate various methods for nondestructive detection of moisture in roofs.

The capabilities of commercially available surveys were determined by contacts with industry, by examination of the results of such surveys, by discussions with agencies that have contracted for such surveys, and by attendance at seminars. Some contracts have been awarded for commercial surveys of buildings. Such buildings were surveyed by several methods for comparison purposes and core samples of the membrane and insulation were taken to verify findings.

Other equipment and methodologies not commercially available but considered worthy of study by review and analysis of moisture-detection literature were also pursued.

The following methods have been investigated:

I. On-the-roof surveys
   A. Hand-held infrared systems
   B. Nuclear moisture meters
   C. Capacitance meters
   D. Microwave system developed by CRREL
   E. Impulse-radar system developed by CRREL.

II. Airborne surveys (all infrared)
   A. Fixed-wing aircraft
   B. Helicopters

GROUND TRUTH

Some commercial firms emphasize the point that their surveys can be conducted without the need for membrane cuts or core samples. Our studies indicate that no nondestructive moisture detection system evaluated was reliable enough by itself or by cross checking with another type of nondestructive system to eliminate the need to verify findings. A few core samples of the membrane and insulation on each roof are necessary to verify the findings of the nondestructive survey.

We have developed an inexpensive, accurate and reliable method of obtaining core samples from roofs and patching those locations after samples are taken. The sampling methods of the various commercial firms involved in roof moisture surveys vary considerably and are not as systematic or reliable as the one we have developed. Because the taking of samples can cause additional problems we consider it important to demand a highly reliable sampling-patching procedure. A report on our procedure is in preparation

ON-THE-ROOF SURVEYS

Systems still in the early stages of development

Microwave and impulse radar systems[6] developed at CRREL have been examined. Both systems are capable of differentiating between wet and dry insulation; however, they are large, complex, and in the development stage. Currently they are not commercially available. Data reduction and analysis are relatively difficult. Also, they are grid survey techniques, and as such have the inherent weaknesses of being time-consuming and of seeing only a small portion of the roof under study.

Research into the use of impulse radar and microwaves for various moisture detection applications should continue but neither system is considered appropriate for routine roof moisture surveys at this time.

Capacitance surveys

In this technique a capacitance meter detects changes in the dielectric properties of the roof. The dielectric constant of water is about 20 times that of the components of a dry roof. Grid surveys are conducted and maps of the dielectric constant are made. Unfortunately, some of the hardware currently in use for such surveys is not very precise. The indicator needle moves very little from a reading at a dry location to one at a wet location, but differences in gravel thickness alter the meter reading noticeably.

Comparison surveys we have sponsored indicate that although capacitance surveys are capable of locating wet insulation, they do not appear to be as accurate as nuclear or infrared surveys. Additional comparison surveys, recently conducted with other types of capacitance meters, offer promise of improved accuracy. The ability of capacitance surveys to detect moisture within the plys of a built-up membrane is seriously questioned.

Nuclear surveys

Nuclear surveys hunt out the hydrogen in a roof. Water contains hydrogen and so do bitumens. If the amount of bitumen in the roof does not change appreciably from place to place any extra counts on a nuclear moisture meter probably indicate moisture at that location.

Some of our early surveys showed moisture around most penetrations and along most flashings. But core samples revealed that many such areas were dry. The extra bitumen there, not moisture, caused counts to increase. WES has developed a formal method for correcting for this.[4]

Compared to capacitance surveys, nuclear surveys appear somewhat better able to locate wet insulation once the data are corrected for edge effects.

The absolute value of the numbers obtained from a nuclear survey is of little use, since differences in the thickness of the gravel, flood coat, built-up membrane, insulation and deck affect readings. An effort was made to develop standard "threshold" nuclear readings for each common type of roof to account for the position, thickness and composition of the deck, vapor barrier, insulation, membrane and gravel cover. The many materials present in roofs and their variability prevented the generation of useful results. Additional effort in this area is considered of low priority since nuclear meter readings can be used quite effectively when only their relative values are considered. A few core samples on the roof at low, medium and high nuclear readings are needed to give the relative numbers absolute significance in terms of moisture.

WES developed a systematic statistical method of handling nuclear readings to generate wet and dry threshold values for mapping. More recently WES has simplified the analytical method to eliminate the need for statistics. The simplified method requires that four cores be taken of each type of roof under study. This many would be required for normal verification purposes so this is a reasonable requirement.

Nuclear moisture meters are relatively low in cost (about $3000 each). Those that contain reactor-made radioactive material are controlled by the Nuclear Regulatory Commission (NRC), which regulates their use, storage and shipment. Devices that contain natural radioactive material (radium) are not controlled by NRC but may be controlled by individual states. Once personnel are trained, and in some cases licensed, to use these devices it is a relatively simple matter to obtain readings.

The principal drawback of a nuclear survey is that it is a time-consuming grid survey that only "sees" a small portion of the roof. For example, a nuclear survey done on a 10-ft grid "sees" only 2% of the roof. If the grid spacing is reduced to 5 ft, the work multiplies by a factor of four and 8% of the roof is "seen."[11]

Nuclear surveys are a viable means of detecting many wet roofs but they are not as accurate as infrared surveys, as discussed below.

Hand-held infrared surveys

To the best of our knowledge CRREL conceived the idea of using a hand-held infrared camera to survey roofs for entrapped moisture.[9] Working together, CRREL and FESA have developed the idea into a reliable moisture detection method.

Recently a few commercial firms have begun to use hand-held infrared cameras on roofs. Our published results have already found their way into manufacturers' literature. It is expected that commercialization of this technique will increase in the next few years. However, we do not expect competition will be so great that survey costs will decrease appreciably. The high cost of an appropriate infrared camera ($27,000 to $40,000) is a controlling factor.

Inexpensive radiation thermometers have been used on roof surveys without success.

Unlike the other roof survey techniques mentioned, infrared roof surveys must be conducted at night. Night work on roofs is somewhat more difficult, dangerous and expensive than daytime work.

CRREL and FESA's work with hand-held infrared instruments has shown that it takes a fair amount of experience to achieve accurate results consistently.

The infrared camera sees differences in the apparent surface temperature of a roof. The adjective *apparent* is necessary since the emissivity of the surface (i.e. its ability to emit electromagnetic radiation) and its reflectivity both influence the image seen by the infrared camera. The reflectivity of most roofs is very low and can be ignored. However, the reflectivity of water and ice is high and where they are present on a roof, anomalous readings can result. The emissivity variations over either a gravel-covered or a smooth-surfaced roof are minor, and when the infrared image of a roof contains a bright area, the surface there is quite likely warmer than at other locations on the roof. Many things can be responsible for warmer roof areas. Some of the more common are:

1. Hot air exhaust onto a roof from a fan or vent
2. Heaters suspended just below a roof with minimal insulation
3. Hot rooms below the roof (e.g. boiler rooms)
4. Differences in the amount and type of insulation in the roof
5. Wind shelter and radiated warmth from walls of higher portions of the same building
6. Significant differences in the thickness of the built-up membrane
7. Wet insulation

The cause of each thermal anomaly on a roof must be determined and all those that are not associated with moisture isolated from those that are. It is not a particularly difficult task but it takes some time to develop the ability to differentiate one type of hot area from another.

Comparison surveys have shown that where large wet areas exist, nuclear and infrared surveys generally give similar results. However, grid surveys conducted with a nuclear meter tend to miss small wet areas, which are detected by the infrared camera. The ability of an infrared camera to examine every square inch of a roof makes it quite valuable for the purpose of detecting wet roof insulation.

The ability to find wet areas when they are small is also considered quite important. When these "cancers" are small they can be removed at minimal cost. If they are not detected they can enlarge and generate major problems which are extremely expensive to resolve.[10] After examining numerous roofs with various nondestructive moisture detection systems we have concluded that the most accurate results can be obtained using infrared systems.

AIRBORNE INFRARED SURVEYS

Fixed wing aircraft

One commercial firm has a patent on detection of roof moisture from aircraft. This patent relates to 1) airborne sensing of roof moisture with an infrared camera to 2) verify wet areas for 3) the purpose of generating repair recommendations. On-the-roof infrared surveys obviously do not fall within the purview of this patent.

We have conducted *daytime* infrared surveys both on the roof and in various aircraft and have not been able to produce meaningful results. Shadows and solar effects are a big problem.

The patented aerial infrared surveys are conducted in the daytime and computer-enhanced to remove daytime "noise." We have examined recent surveys and they appear capable of delineating wet areas. Although we have not verified these results, that information looks convincing. However, night surveys appear to give somewhat better results.

WES has arranged several nighttime airborne infrared surveys of roofs using various military aircraft with infrared equipment on board.[3-5] That imagery has proven quite useful for reconnaissance purposes. However, comparison with on-the-roof surveys indicates that airborne infrared surveys do not see all of the smaller (e.g. 3 × 5 ft) anomalies.

Many wet areas uncovered by on-the-roof surveys during the past two years have been relatively small and associated with a drain, vent or other penetration.

Several relatively new roofs have been surveyed and they also have moisture problems. Current roofing technology does not appear capable of consistently delivering problem-free new roofs. Little flaws and associated problems appear inevitable. The ability to find and solve these little problems using the infrared camera may be the second step that is needed to provide a breakthrough in the performance of built-up roof systems.

It is conceivable that certain commercial and military airborne infrared imagery could consistently locate enough small wet areas to eliminate the need for on-the-roof surveys. Where many roofs in an area must be surveyed, it may be more economical to do an airborne survey than walk on each roof with infrared equipment. In order for airborne surveys to replace on-the-roof surveys during which wet areas can be outlined in white spray paint, it will be necessary to obtain high resolution mapping-quality airborne imagery. We are not convinced that currently available airborne imagery is consistently capable of accomplishing this. However, we are continuing to pursue this interesting possibility.

Where roof moisture surveys are needed for only a few buildings in an area, the high cost of mobilizing an airborne survey results in a very high unit cost (dollars/ft^2) for the roof survey. In such cases, even if airborne surveys would suffice, on-the-roof surveys would be more cost effective. It is believed that numerous situations will result in the need to survey a few buildings here and there. Consequently an on-the-roof surveying capability will always be needed.

Helicopters

FESA has flown in Army helicopters equipped with sophisticated night vision equipment available through the Night Vision Laboratories at Ft. Belvoir. Although the infrared equipment in those aircraft is very sensitive, and has some value for roof moisture surveys, it is only available in very limited numbers for research purposes.

CRREL has flown a hand-held infrared system in several Army OH-58 and "Huey" helicopters. Hardware has been developed to record results directly on videotape. The reconnaissance value of this method has been established. The possibility of reducing the number of on-the-roof surveys by using the helicopter survey is under investigation.

Where helicopters are available and numerous roofs are to be surveyed in an area this airborne method has the advantage of being something that a roof moisture team can do themselves their first night in the area. Contracting for a commercial airborne survey may take several weeks. Once such a flight is accomplished, a second set of arrangements for on-the-roof follow-up surveys, visual examinations and samples is then necessary.

Where helicopters are available the cost of placing a roof moisture survey team in the air their first night in an area is expected to be considerably less than the cost of a fixed-wing commercial overflight.

COSTS

Not surprisingly, most commercial roof moisture surveys cost about the same price per square foot of roof surveyed. Commercial firms are currently promoting the special features of their techniques above those of competitors rather than cutting costs to obtain customers. The price for a commercial roof survey ranges from 5 to 12 cents/ft². The range in cost is a function of the type of roof, the number of different levels, the distance the survey crew must travel, etc.

Airborne infrared surveys are not generally competitive unless several large roofs all located close together are surveyed concurrently. As more and more roofs are surveyed in an area the unit cost (dollars/ft²) of an airborne survey decreases.

SUMMARY OF ROOF MOISTURE SURVEY ALTERNATIVES

Valuable information can be obtained from nuclear and capacitance grid survey techniques. Because of the inherent weaknesses of grid surveys and the accuracy and the speed with which infrared surveys can be obtained, hand-held infrared surveys are preferred. If infrared equipment or services are not available, it may be appropriate to use grid surveying techniques. Of all the grid surveying techniques examined, nuclear moisture meters are preferred.

Airborne infrared surveys are quite valuable for reconnaissance purposes. Some of the latest high-resolution airborne imagery examined is of mapping quality and *may* be capable of eliminating the need for on-the-roof infrared surveys.

THERMAL IMPLICATIONS OF WET INSULATION

Alone, none of the nondestructive moisture detection methods can generate quantitative information on the amount of moisture in roof insulation. However, if core samples are obtained in conjunction with such surveys and moisture content determinations are made, a quantitative assessment of roof moisture is possible.

As the moisture content of an insulation increases, its thermal resistance decreases. An appreciation of the thermal performance of roof insulation as it becomes wet has been gained by in-situ measurement of heat flux and skin temperatures of roofs in areas of wet and dry insulation.[12] On one roof, readings were taken at 15-minute intervals for about two days to minimize errors caused by transient effects. The thermal resistance calculated from these measurements was for the entire roof sandwich at each instrumented location. The thermal resistances of the built-up membrane and the roof deck were subtracted out using thermal values in the ASHRAE Handbook.[1] The unit thermal resistance of the insulation (ft² · hr · °F/Btu · in.) was obtained by dividing the total thermal resistance of the insulation by the thickness of insulation present.

Core samples were taken at each instrumented location to determine the moisture condition of the insulation there.

Results for a perlite board insulation are presented in Table 1. A significant decrease in thermal performance at moisture contents as low as 32% is apparent. However, in-situ measurements subjected to diurnal temperature variations, wind effects, insolation and other variables are certain to be less accurate than controlled laboratory experiments.

Table 1. In-situ measurement of the unit thermal resistance of perlite board roof insulation as a function of its moisture content.

*Moisture content** *(%)*	*Unit thermal resistance†*
3	2.3
32	0.8
236	0.3

*Weight ratio of water to dry insulation
†ft² · hr · °F/Btu · in

The relationship between moisture content and thermal resistance has been studied in Scandinavia[7,8] and in the USA by one insulation manufacturer[2] for some roof insulations. However, a comprehensive survey of the moisture content-thermal resistance relationship for insulations in common use in the USA has not yet been conducted. Such a study is underway at CRREL.

Samples of the following types of roof insulation have been obtained and are being tested:

Wood fiber
Glass fiber
Foamed glass
Cork
Perlite
Polystyrene (extruded)

Polystyrene (expanded)
Urethane
Isocyanurate
Composites:
- Perlite-urethane
- Perlite-isocyanurate
- glass fiber-urethane

Twelve-inch by twelve-inch samples are edge sealed with a vapor barrier paint and then placed horizontally in a partitioned 3 ft × 6 ft cover which sits atop an 85°F high humidity box. Each box is located in a 40°F coldroom with a 60 to 70% relative humidity. Four boxes are in use: two are maintained at a relative humidity of 70% and two at 100%. The coldroom test conditions simulate the temperature and moisture gradients that exist across roof insulation.

The insulation samples are periodically removed from the coldroom, surface-dried if necessary, wrapped in plastic, weighed, and then placed in a Rapid-K Heat Flow Meter apparatus* preset with warm side and cold side temperatures of 85°F and 40°F respectively. Thermocouples and a heat flux meter are monitored until essentially steady state conditions are reestablished. The thermal resistance of the sample is then determined according to ASTM Standard C518-76. However, since the samples are wet and the distribution of moisture is unknown, all requirements of C518-76 are not met.

The insulation sample is reweighed, unwrapped and returned to the coldroom for additional wetting.

Some materials such as glass fiber are not at all resistant to moisture accumulation. They become wet and lose thermal resistance almost instantly. Others, like perlite and most cellular plastics, are in the wetting boxes for several weeks, during which time they accumulate enough water to significantly decrease their thermal resistance. Some insulations, notably foamed glass and extruded polystyrene, have little or no moisture gain or thermal decay after months under test.

The relationship between moisture content and thermal resistance differs for each type of insulation. Characteristic curves are being developed for each insulation investigated.

*Manufactured by Dynatech Corporation, 99 Erie Street, Cambridge, Massachusetts 02139.

LITERATURE CITED

1. ASHRAE (1977) Fundamentals. American Society of Heating, Refrigeration and Air-conditioning Engineers Inc., New York.
2. Epstein, K.A. and L.E. Putnam (1977) Performance criteria for the protected membrane roof system. Paper presented at the 1977 NBS-NRCA International Symposium on Roofing Technology.
3. Link, Lewis E., Jr. (1976) Demonstration of a new technique for rapidly surveying roof moisture. Mobility and Environmental Systems Laboratory, U.S. Army Engineer Waterways Experiment Station, P.O. Box 631, Vicksburg, MS 39180. Miscellaneous Paper M-76-14.
4. Link, L.E., Jr. (1977) Airborne thermal infrared and nuclear meter systems for detecting roof moisture. Paper presented at the 1977 NBS-NRCA International Symposium on Roofing Technology. Mobility and Environmental Systems Laboratory, U.S. Army Engineer Waterways *Experiment Station*, P.O. Box 631, Vicksburg, MS 39180.
5. Link, L.E., Jr. (1978) Guide for airborne infrared roof moisture surveys. Mobility and Environmental Systems Laboratory, U.S. Army Engineer Waterways Experiment Station, P.O. Box 631, Vicksburg, MS 39180. Instruction Report M-78-1.
6. Morey, Rexford and Austin Kovacs (1977) Detection of moisture in construction materials. U.S. Army Cold Regions Research and Engineering Laboratory, CRREL Report 77-25. AD A045353.
7. Paljak, Ivar (1973) Condensation in slabs of cellular plastics. *Materials and constructions*, vol 6, no. 31. National Swedish Institute for Material Testing (in Swedish).
8. Thorsen, Sven-Hakan (1973) Determination of the elongation coefficient, water adsorption, moisture diffusivity, as well as thermal conductivity at different moisture contents for polystyrene and urethane cellular plastics. Institute for Building Technology, Chalmers Technical University, Goteborg, Sweden (in Swedish).
9. Tobiasson, Wayne and Charles Korhonen (1975) Trip report — Alaska and Washington State. USACRREL.
10. Tobiasson, W.N., C.J. Korhonen and T. Dudley (1977) Roof moisture survey, ten State of New Hampshire buildings. CRREL Report 77-31. AD A0489 986.
11. Tobiasson, Wayne, Charles Korhonen and Alan Van den Berg (1977) Hand-held infrared systems for detecting roof moisture. Paper presented at the 1977 NBS-NRCA International Symposium on Roofing Technology. USACRREL.
12. Tobiasson, Wayne and Timothy Dudley (in prep.) Spot measurements of the thermal resistance of ten state buildings in Concord, New Hampshire. U.S. Army Cold Regions Research and Engineering Laboratory. CRREL Report.