

ROOF MOISTURE SURVEYS: YESTERDAY, TODAY AND TOMORROW

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Since it is virtually impossible to visually determine the extent of wet insulation, roof moisture surveys are used to complement visual inspection. Such surveys are conducted with nuclear meters, capacitance meters or infrared scanners.

Nuclear meters (*Figure 1*) and capacitance meters (*Figure 2*) take readings at the spots on the roof where they are placed. It is common to mark a grid on the roof with points spaced from 5 to 10 feet apart. Nuclear meters sense the amount of hydrogen in the roofing system at each spot. Since most dry roofs contain hydrocarbons, they do not give zero readings. When water also is present on the roof, nuclear readings increase since water is part hydrogen.

Capacitance meters create an alternating current electrical field in the roofing system below. When there is water in the roof, its dielectric properties change and the reading on the capacitance meter increases. Capacitance meters do not "see" deeply (a few inches at most) into the roofing system.

An infrared scanner (*Figure 3*) senses the temperature of the surface of the roof. Wet insulation changes the ability of the roofing system to store and conduct thermal energy, thereby causing changes in its surface temperature which the infrared scanner can detect. Instead of a meter reading, the infrared results are presented as shades of brightness on a video monitor. This qualitative visual image provides information about every square inch of the roof, but the information is more subjective than the numbers generated at grid points by nuclear or capacitance meters.

YESTERDAY

Nuclear and capacitance grid surveys and airborne infrared techniques for finding wet insulation in built-up roofing systems were introduced commercially in the 1970s. Because of their proprietary value, details on instrument accuracy and the methods of analysis were not made available, so it was difficult to determine the absolute or relative value of each technique. This prompted the U.S. Army and Air Force to fund research aimed at evaluating these techniques on real roofs.^{1,2} Contracts were let for airborne roof moisture surveys, which are covered by U.S. Patent 3,791,097, and capacitance grid surveys, which are covered by U.S. Patent 3,967,197. Nuclear meters were purchased and used on roofs. Comparison studies were conducted, and numerous core samples were taken to provide a sound basis for providing recommendations. Grid surveys conducted with capacitance meters could find wet insulation, but the results were not as accurate as grid surveys conducted with nuclear meters. The airborne infrared surveys did not produce meaningful results, but we attributed this to the fact that they were done in the daytime when solar interference

created a significant amount of thermal "background noise" on the roof. Rather than reject infrared systems from further consideration, we conducted infrared roof moisture surveys at night by walking on roofs with a hand-held infrared scanner. Excellent results were obtained.

At this time, we also evaluated various airborne infrared systems including line scanners in fixed-wing aircraft and hand-held scanners used from helicopters. We concluded that those systems were quite valuable for reconnaissance purposes, but they could not be used to locate accurately all wet insulation in roofs (i.e., follow-up on-the-roof surveys also were required).

Because of the magnitude of the U.S. Army's roofing problem (we have over 300,000 roofs to maintain), the Army roof-moisture research team recommended in 1978 that Army teams be established and trained to use hand-held infrared scanners to survey roofs at Army installations across the nation.³ While the initial investment in an infrared system greatly exceeds that of a nuclear system (i.e., about \$30,000 vs \$3,000), the increased speed of conducting infrared surveys can return that investment in short order if numerous roofs must be surveyed. The Army's Facilities Engineering Support Agency (FESA) has been surveying Army roofs with infrared scanners ever since.

The U.S. Air Force developed a detailed visual inspection method that may be supplemented with an optional airborne infrared roof moisture survey.⁴ The Navy purchased several nuclear moisture meters for use at their installations across the country.

Concurrently, additional firms began to offer nuclear grid surveys and on-the-roof infrared surveys. The firm that holds the patent for airborne roof moisture surveys switched most of its work from the airborne to on-the-roof surveys. Many building owners purchased their own nuclear meters and used them periodically to survey their inventory of roofs. Capacitance survey franchises developed across North America.

Since the late 1970s, numerous case study reports have been written that document the technique for conducting on-the-roof moisture surveys with infrared scanners.⁵⁻¹³ Those reports have shown the value of core samples for verification and the importance of sampling areas expected to be dry as well as areas expected to be wet. In addition, a guide has been written on how to conduct airborne infrared roof moisture surveys.¹⁴

A statistical method for analyzing nuclear readings is described in an instructional report on how to conduct nuclear surveys.¹⁵ A simpler empirical method of analysis based on the relationship between nuclear readings and core-sample-moisture contents also has been promoted. It

has been recommended that at least four core samples are needed per roof to establish the empirical relationship.¹⁶ Nuclear methods also have been evaluated in Canada.¹⁷

Several trade journal articles have been written promoting nuclear, capacitance, and infrared techniques.¹⁸⁻²⁹

In 1981, the National Bureau of Standards (NBS) compared nuclear, capacitance, and infrared techniques under controlled laboratory conditions.³⁰ Nuclear meters seemed best able to detect low levels of moisture in roof insulation, with infrared a close second and capacitance a distant third. Nuclear and infrared devices proved to be about equal in their ability to distinguish increasing levels of moisture, but capacitance meters were inconsistent. As more moisture was encountered, some capacitance readings first increased then decreased, with the result that readings for very wet specimens and dry specimens were identical. The laboratory study concluded that nuclear and infrared hardware have about the same sensing ability, which exceeds that of capacitance meters. The laboratory study acknowledged that when these sensing systems (infrared in particular) are used on roofs, additional variables are introduced that must be considered. Since the 1981 NBS study improved nuclear and capacitance meters have become available.

State-of-the-art reports on roof moisture surveys were published in 1981³¹ and 1983.³² The 1983 report states, "It is generally agreed that it is technically unwise and fiscally irresponsible to develop plans for the maintenance, repair and/or replacement of a roof without first conducting a roof moisture survey."

TODAY

General

Today, numerous building owners, facility maintenance personnel, roofing contractors, roofing material manufacturers, designers, consultants, lawyers, and others use roof moisture surveys to help them do their jobs better. However, there are individuals that remain unconvinced of the value of roof moisture surveys, and there are others who have had a bad experience with one of the techniques and would not consider using it, or perhaps any other such technique again. The forces of competition continue to keep the few bad surveys in the limelight to the ultimate detriment of all.

There are successful and unsuccessful example of surveys with each technique. Problems and limitations are more strongly related to the people involved than the equipment used. Training courses are available for the individuals that operate the hardware. Those individuals that analyze the data and then generate findings and recommendations require much more knowledge since they also must know a great deal about roofing technology. Many of them have attended short courses offered by the Roofing Industry Educational Institute (RIEI) or the University of Wisconsin-Extension.

To verify surveys, we developed a two-inch-diameter coring device (*Figure 4*) that now is commercially available. Our instructions for sampling and patching roofs with built-up membranes³³ have been updated.

Some consultants refuse to cut holes in the roofing system to verify their results because of the liabilities they would incur. Others require the building owner to hire a roofing contractor to make the cuts. However, most firms take core

sample to verify their findings. Some consultants take a cut in each suspected wet area to verify that it is, indeed, wet. We are strong advocates of a few core cuts.

Several firms take only one or two core cuts to define the materials present in the roofing system, then use a resistance probe (*Figure 5*) for additional verification. This reduces verification costs but also reduces accuracy. In addition, some probe holes have not been properly patched and problems have resulted. The effort required to patch the two small holes at each resistance probe reading should be about the same as that required to patch a two-inch-diameter core hole.³⁵

Roof moisture surveying hardware and services are advertised in trade magazines, and booths promoting various techniques are present at trade shows, conventions and seminars.

Increasing use is being made of roof moisture surveys as evidence in legal proceedings, and on a few occasions, legal action has been brought against the surveyors themselves for providing information that someone judged to be incorrect.

The Roof Consultants Institute (RCI) has been established to foster professionalism.³⁴ RCI plans to develop standards, certifications, licensing programs and educational materials. The Institute of Roofing and Waterproofing Consultants (IRWC) also is active in this area.

Roof moisture surveys are discussed in American Society for Testing and Materials (ASTM) Standard E936-83, "Practice for Roof System Assemblies Employing Steel Deck, Preformed Roof Insulation and Bituminous Built-up Roofing." A task group within ASTM Subcommittee D8.20 (Non-Structural Roofing Systems) of the D8 Committee (Roofing, Waterproofing and Bituminous Materials) is developing a standard for non-destructive methods for detecting moisture in roofing systems.

Numerous specifications have been written by government and the private sector for roof moisture surveys. RIEI has developed a checklist for procurement of roof moisture survey services.³⁵ That checklist stresses the importance of survey team experience and core cuts for verification.

The Division of State Construction of North Carolina has mandated the use of roof moisture surveys on state-owned buildings before they are re-roofed, before new buildings are accepted, and two months prior to the expiration of any roofing guarantee.³⁶ The Department of General Services of Virginia requires roof moisture surveys before new state-owned roofs are accepted and before state agencies contract for repair of existing state-owned roofs.

Nuclear

Today there are several commercially available nuclear gauges designed specifically for surveying roofs. They have switches and handles that preclude the need to bend over at each reading (*Figure 1*) and they are relatively light. Some have buzzers that notify the operator when the count time has ended. Instead of having to wait 30 to 60 seconds for a reading, the new roof gauges provide a reading in 4 to 15 seconds.

Programs are available commercially that statistically analyze the field data and plot contour maps of the roof showing zones of wetness.

Nuclear gauges can be purchased with removable chips that store the field data (i.e., the grid coordinates and the reading), thereby eliminating the need to record this infor-

mation in a field book or on a clipboard. The chip can transfer the field data directly into a computer that has contour mapping capability.

The Naval Civil Engineering Laboratory (NCEL) has developed a method to input nuclear moisture survey information directly into a portable computer terminal on the roof.¹⁷ Phone lines can be used to transmit this data to a central computer that prepares a contour map, which is immediately mailed back to the surveyor. The map, together with the findings of core cuts, define where wet insulation is located. NCEL feels it can cut the cost of nuclear surveys in half using this procedure, making nuclear surveys cost-competitive with infrared surveys.

The manufacturers of nuclear gauges have developed systems to facilitate the licensing and periodic safety testing requirements of the Nuclear Regulatory Commission. They also offer operator training programs.

Nuclear meters are not allowed on passenger flights, but they can be moved by air freight. We have had exceptionally bad luck moving nuclear meters this way, but others have had no major problems.

Firms that have been surveying roofs with nuclear meters for years have developed guidelines that predict the magnitude of readings to expect for various roofing systems. They claim to be able to use this data base to greatly enhance their ability to interpret the information collected on their next job. Some claim that they can distinguish as many as five different wetness levels. Unfortunately, supporting data is not in the open literature because of its competitive value.

Extra bitument in a bituminous membrane increases nuclear readings which may be mistakenly diagnosed as wet insulation. The uniformly thick single-ply membrane systems do not have this problem and thus nuclear meters may do a better job on a single-ply membrane than on a bituminous built-up membrane. If the single-ply is ballasted, it is best to push aside the ballast at each grid point and take the reading with the meter resting directly on the membrane. Moisture on the membrane has little adverse effect on nuclear readings. The components of some single-plys (e.g. carbon black and metal foils) do not adversely affect nuclear readings, but they do affect capacitance readings.

Capacitance

Because of the extreme sensitivity of capacitance meters to surface moisture, it is essential that the roof surface be dry when capacitance surveys are made.

The firm that holds the patent on roof moisture surveys with capacitance meters offers this service through franchised dealers. The central office of that organization analyzes the grid survey findings and prepares the investigative report. Because of its proprietary value, their data base has not been divulged and thus little quantifiable information on capacitance surveys has been published. Claims that capacitance meters can distinguish between moisture within the plies of a bituminous built-up membrane and wet insulation remain unsubstantiated. The meters used by this firm are not for sale.

Recently, a family of capacitance meters designed for surveyed roofs has been introduced in the USA. They are advertised in roofing trade magazines and can be purchased by anyone. The largest of these devices can be pushed across a

roof like a lawn mower (*Figure 2*); its meter operates continuously and is watched for signs of wet insulation (i.e., significant increases in meter reading). The device also emits beeps which are infrequent when the meter reading is low and more frequent when high readings are obtained. We have had some success using this device to find wet insulation.

The ingredients of certain single-ply roofing systems, such as the carbon black fillers in EPDM membranes and the metal foils laminated to some of the modified bitumens, distort the electrical field, and effectively "short-circuit" capacitance meters.

Capacitance readings taken through the ballast of a single-ply system are of little value. However, as with nuclear meters, it is possible to survey a ballasted single-ply system by pushing the ballast aside where the reading is to be taken and placing the capacitance meter directly on the membrane. Of course, the membrane there must be dry.

If a metal fastener lies directly below the membrane where a capacitance reading is taken, the metal will adversely affect the reading. However, it is usually easy to see where mechanical fasteners are located below single-ply membranes and simply to move the meter away from those points.

Infrared

Today there are several hand-held infrared scanners on the market that are suitable for roof moisture surveys. They fall into two price ranges, \$10,000-15,000 and \$25,000-40,000. Their differences are primarily related to a combination of thermal and spatial resolution, image clarity, and their ability to capture the thermal image on film or videotape.

Some infrared scanners detect electromagnetic radiation with wavelengths between 2 and 5 microns while others detect between 8 and 14 microns. A roof emits more energy in the 8- to 14-micron range, but enough is emitted in the 2- to 5-micron range to permit location of wet areas with equipment sensitive to those wavelengths. We have found that on-the-roof surveys with systems that operate at wavelengths from 2 to 5 microns have, in fact, a slight advantage because a spot of light on the roof from a powerful flashlight can be seen on the monitor. This makes it easier for the thermographer to guide the spray painting activities of his assistant.

We continue to feel more comfortable with the results from the more sophisticated (i.e. higher-priced) devices, but we also have examined some very convincing, well-documented reports prepared by surveyors who use the less sophisticated hardware.

Perhaps the less expensive devices have a smaller operational "window" than do the more expensive devices. Qualitative guidelines on when to conduct infrared surveys have been established,^{11,10,14} and a one-dimensional transient heat transfer model recently has been developed to predict the temperature difference that exists on a roof's surface above wet and dry insulation.¹⁴ The model considers solar radiation, daily outdoor temperature variation, indoor temperature, and the dynamic thermal properties of the roof. Where the primary thermal driving force is solar radiation (e.g., a sunny summer day), the model indicates that the best time to conduct a survey is shortly after sundown. On a cold overcast day the best time to survey is somewhat later, perhaps after midnight. The model also indicates that a five

mile-per-hour wind can reduce the wet-to-dry surface temperature gap under calm conditions by one-half. Before these guidelines are followed, the model requires field validation.

Army teams from FESA have surveyed hundreds of roofs at Army installations across the nation. They began several years ago by using hand-held infrared scanners on a few problem roofs at each installation. Now they often comprehensively survey an installation with scanners mounted in helicopters because of the speed at which airborne surveys can be accomplished.³⁹

Recently, we conducted a comparison study of various airborne infrared techniques for finding wet insulation.⁴⁰ That study confirmed our earlier finding that oblique imagery from helicopters was of reconnaissance value only. We found that we could do a reasonable job of mapping using imagery from high-resolution line scanners in fixed-wing aircraft, but we could do an even better job using straight-down imagery taken by a pointable imaging system mounted on a helicopter (*Figure 6*). We concluded that it is better to have the instant results of a videotape from an imaging system than to wait for the negatives made from a line scanner. We recommended that airborne missions be designed so that the instantaneous field of view (i.e., the spot on the roof) is no larger than 0.15 square feet. We also found that photographs taken the day before the infrared survey were quite valuable in interpreting infrared findings. The best airborne system we evaluated was able to locate 82 percent of the wet areas found by on-the-roof surveys on the same roofs. We expect that, with practice, few wet areas will be missed by this state-of-the-art airborne system. We also observed that some "mottled thermal anomalies" were easier to detect from the air than on the roof.

We are in the process of demonstrating the value of this airborne survey technique at Army installations in Alaska, Massachusetts, Maryland and Texas.

Another recent study⁴¹ included a comparison of oblique airborne and on-the-roof infrared findings with a visual inspection and roof rating done according to the method developed by the U.S. Air Force.⁴ That study found that 82 percent of the oblique airborne infrared findings were corroborated by the subsequent on-the-roof infrared survey. Wet areas with a diameter of less than one foot were missed, as were some anomalies adjacent to mechanical equipment and higher roofs. They also found that there was no correlation between visual appearance and the presence of wet insulation for the 38 gravel-covered bituminous built-up membrane roofs of a large factory-warehouse complex. Their findings provide an important reminder of the limitations of visual inspections.

Verified roof moisture surveys complement visual inspections. Both are quite valuable (many of us feel both are essential) for diagnosing the condition of insulated roofing systems.

Some individuals responsible for building maintenance were somewhat skeptical that they would be able to use the airborne infrared results without expert interpretation. One report⁴² indicates that they have become "true believers" and now utilize the videotapes to develop their roof maintenance management plans. Such surveys are being promoted as fast, inexpensive, and accurate ways of surveying roofs.⁴³

We have estimated that airborne surveys become more economical than on-the-roof surveys when 250,000 to 500,000 square feet of roof is to be surveyed in one area.⁴⁴

Because of the high cost of mobilizing for airborne roof moisture surveys and their decreased accuracy, on-the-roof infrared surveys still are more popular.

Although most roof moisture surveys are conducted on existing roofs, an increasing number of new roofs are being surveyed. The value of conducting a roof moisture survey eight to 10 months into the one-year workmanship warranty period on new roofs has been established⁴⁵ and is being demonstrated on Army roofs. Because of the relatively slow wetting rate of cellular plastic insulation and the concentration of wetness around the perimeters of the insulation boards (*Figure 7*), grid surveys are not expected to be very successful for this purpose. We have recommended infrared surveys for new roofs.⁴⁶ We hope that, before long, such surveys will become part of the U.S. Army Corps of Engineers Guide Specifications.

The patterns of wetting for various insulation boards (e.g., free forms, board-by-board, picture framing, and shattered) have been reported.^{44,45}

When insulation contains enough moisture to reduce its insulating ability to less than 80 percent of its advertised "dry" value, it is unacceptable and should be removed. Legal precedent is being established that wet insulation and decreased thermal efficiency, as well as roof leaks, constitute failure of a roofing system.

The ballast over loose-laid single-ply roofing systems significantly decreases the amount of solar energy that reaches any wet insulation in such roofs. For this reason, infrared surveys on ballasted systems should be done when it is cold outside, since heat from within the building then is flowing up through the roof. Even so, it may be difficult for the infrared scanner to find wet insulation under a ballasted membrane.

Membranes with a reflective top surface are difficult or impossible to survey with an infrared scanner.

Combinations

Little has been written on the value of cross-checking infrared findings with spot nuclear readings, capacitance readings, or core samples. Several firms routinely use this technique and feel it greatly improves their ability to locate wet insulation. Nuclear generally is the preferred cross-checking method even though it is understood that extra bitumen may be mistaken for wet insulation by both the infrared scanner and the nuclear device.

Differences in Opinion

Proponents of nuclear and capacitance grid surveys promote the lasting value of the grid marked on the roof and the value of the numerical result obtained at each grid point, as opposed to the qualitative pictorial infrared information. They also suggest that infrared surveys miss damp areas that are defined on the moisture contour maps generated by grid surveys.

Infrared proponents promote the value of examining every square inch of the roof. They argue that numbers can be generated by infrared devices, but they are not needed because the pictorial information suffices to locate problem areas. They also indicate that grid surveys are apt to miss small wet areas, since they examine less than 10 percent of the roof area.

One point of agreement is that if the people performing the roof moisture survey are not conscientious and knowledgeable, a bad survey is likely to result.

Costs

The cost of commercial roof moisture surveys varies from less than one cent per square foot to over 20 cents, but generally falls between two and six cents. The size and type of roof, the number of different levels, and the distance the survey crew must travel will affect the cost. Much of the variation in cost is related to the scope of work, not the technique used. For the same scope of work, the three techniques are often cost-competitive. The scope of work can range from a superficial, unverified examination with one of the instruments to a comprehensive survey in combination with a visual inspection and core cuts for verification purposes. The product can be as simple as marks on the roof, a few thermograms, or a tabulation of grid readings, or it can include a comprehensive report that analyzes the information collected and provides technical and economic recommendations for maintenance, repair and replacement.

A low-cost unverified roof moisture survey usually is not recommended. A comprehensive visual inspection and core cuts usually are needed to define the location of wet insulation, to understand why it is wet, and to determine what should be done about it.

TOMORROW

We expect that increasing use will be made of roof moisture surveys in future years to diagnose periodically existing roofs and to determine whether new roofs and those about to leave their warranty period are acceptable.

We expect that roof moisture surveys will be conducted on many new roofs six to 10 months after they are built, and periodically thereafter to detect flaws while problems still are small. Considering the way many of the newer insulations become wet (Figure 7), we believe that infrared systems will prove to be best at detecting small moisture problems in new roofs.

It is likely that government and industry will mandate some roof moisture surveys before funds are approved on large construction projects and major reroofing jobs.

Guide specifications for conducting roof moisture surveys also will be developed. The time now is right to foster cooperative development of these documents to avoid creating a plethora of conflicting, inconsistent guidelines.

We expect that nuclear, capacitance, and infrared specifications will be developed separately and individuals will use only the technique with which they are most comfortable. A single performance specification may be better.

Increased use of computer-aided data reduction, analysis, mapping and report preparation is inevitable.

New instruments and techniques are likely to be introduced that are better able to find moisture in ballasted and single-ply systems whose ingredients adversely affect the sensing ability of existing hardware.

While nuclear, capacitance, and infrared hardware can help locate the flaw that allowed moisture access to the insulation, improvements are needed in our ability to find flaws, especially in loose-laid single-ply roofing systems.

We see great promise in the expanded use of straight-down thermal imagery using pointable infrared scanners in helicopters. We hope that several firms will develop this

capability so that competitive bidding for such services is possible.

Once an initial airborne infrared survey is done and a roof plan and data file are generated, it is quite simple and relatively inexpensive to conduct repeat airborne surveys. It will be economically feasible to repeat airborne infrared surveys of many roofs at least every three years.

In government, roof maintenance management systems are being developed that rely on periodic visual inspections and moisture surveys to keep ahead of roofing problems and reduce roof life cycle costs. As the experience of government with these systems becomes better known, private industry will make increased use of the information.

Roof moisture surveys have been around for about a decade. They have helped us solve many roofing problems and better understand roofing systems. We have not yet come close to using these new tools to their full potential, but we have the opportunity to move in that direction in the years ahead.

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