A COMPARISON OF THREE DIFFERENT TECHNOLOGIES FOR PERFORMING NONDESTRUCTIVE ROOF MOISTURE SURVEY

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Nondestructive roof moisture surveys have been employed in the roofing industry since the late 1970s. Three different technologies, infrared thermography (IR), nuclear hydrogen detection (NHD) and electrical capacitance (EC) are used most commonly. Although the proponents of each method make claims of its efficiency and accuracy, the authors are not aware of any previous surveys in which all three methods were employed on the same roof assembly for the purpose of comparing data. The authors undertook such a survey and this paper will give the results of nondestructive evaluation (NDE) roof moisture surveys of each of three methodologies when all were employed on the same roof assembly. This paper will consider the accuracy, reliability and usefulness of the data gathered by these three different methods. Within the paper we also comment on some of the advantages and/or limitations of each testing method. We made no attempt to recommend one method over another, nor to prioritize these test methods in terms of best to worst.

KEYWORDS

Nondestructive Roof Moisture Surveys, NDE, Moisture Surveys, Nuclear Hydrogen Detection, Infrared Thermography, Electrical Capacitance, Reroofing Decision.

INTRODUCTION

Nondestructive Evaluation (NDE) roof moisture surveys have been employed in the roofing industry in the United States since the late 1970s to locate areas of moisture contaminated insulation below low-slope roof membranes [1, 2, 3, 4]. The information obtained by performing an NDE roof moisture survey is most often sought by building owners to help them decide whether:

1. The existing roof system is a candidate for long-term repair efforts.
2. To re-cover the existing system with additional insulation and a new roof membrane.
3. To remove an existing low-slope roof system (i.e., the membrane and insulation) prior to replacing them with new insulation and a new membrane.

The decision of whether to remove or re-cover an existing roof is critical because of the significant cost differential between roof removal and replacement (tear-off) and roof recovery. Although re-covering an existing roof system is less costly, there is a risk that moisture trapped within the original system, especially in the insulation, will have a negative effect on the overall roof assembly. Moisture contained in the insulation of the original roof system that is re-covered often leads to corrosion of fasteners and steel roof decks and may cause spalling damage to concrete decks. Furthermore, trapped moisture can cause structural damage to other types of roof decks (e.g., wood, gypsum, cementitious wood fiber).

Three different technologies—electric capacitance (EC), infrared thermography (IR), and nuclear hydrogen detection (NHD)—are commonly used to perform NDE roof moisture surveys. Although the proponents of each method make claims of its efficiency, sensitivity and accuracy, the authors are not aware of and previous project in which all three methods were employed on the same roof assembly for the purpose of comparing data.

This paper will give the results of a roof moisture survey the authors undertook that employed each of the three different moisture detection methodologies on the same roof assembly. The paper will consider the accuracy, reliability, sensitivity and usefulness of the data and comment on the advantages and limitations of each method. It should be noted that this study was intended to be a qualitative comparison and placed an emphasis on performing these surveys using the "real world" techniques that would typically be used by facilities managers, roof consultants and roofing contractors using one of these technologies.

The phrase "nondestructive moisture survey" is slightly misleading. These surveys are neither totally nondestructive nor moisture-detecting. All require some destructive testing (i.e., core sampling) to verify results. In addition, though the reason for performing these surveys is to find trapped water, none of the methods directly determines the presence of moisture in roof assemblies.

Instead, all methods indirectly determine the presence and location of trapped water by assessing roof assembly properties that may be caused by the presence of water. For example, when using IR, an operator uses a special camera to locate areas of temperature differences that may be caused by the presence of water in a roof assembly; under the right conditions, wet insulation will appear warmer than dry insulation. In addition, NHD devices measure relative quantities of hydrogen atoms present in roof assemblies; higher quantities of hydrogen atoms may be caused by the presence of water. An EC survey measures differences in a roof assembly's dielectric constant; moisture can cause changes in a roof assembly's dielectric constant.

BACKGROUND INFORMATION

The first step in undertaking this study was to identify the criteria that must be met by a roof assembly to be surveyed. The criteria established are as follows:

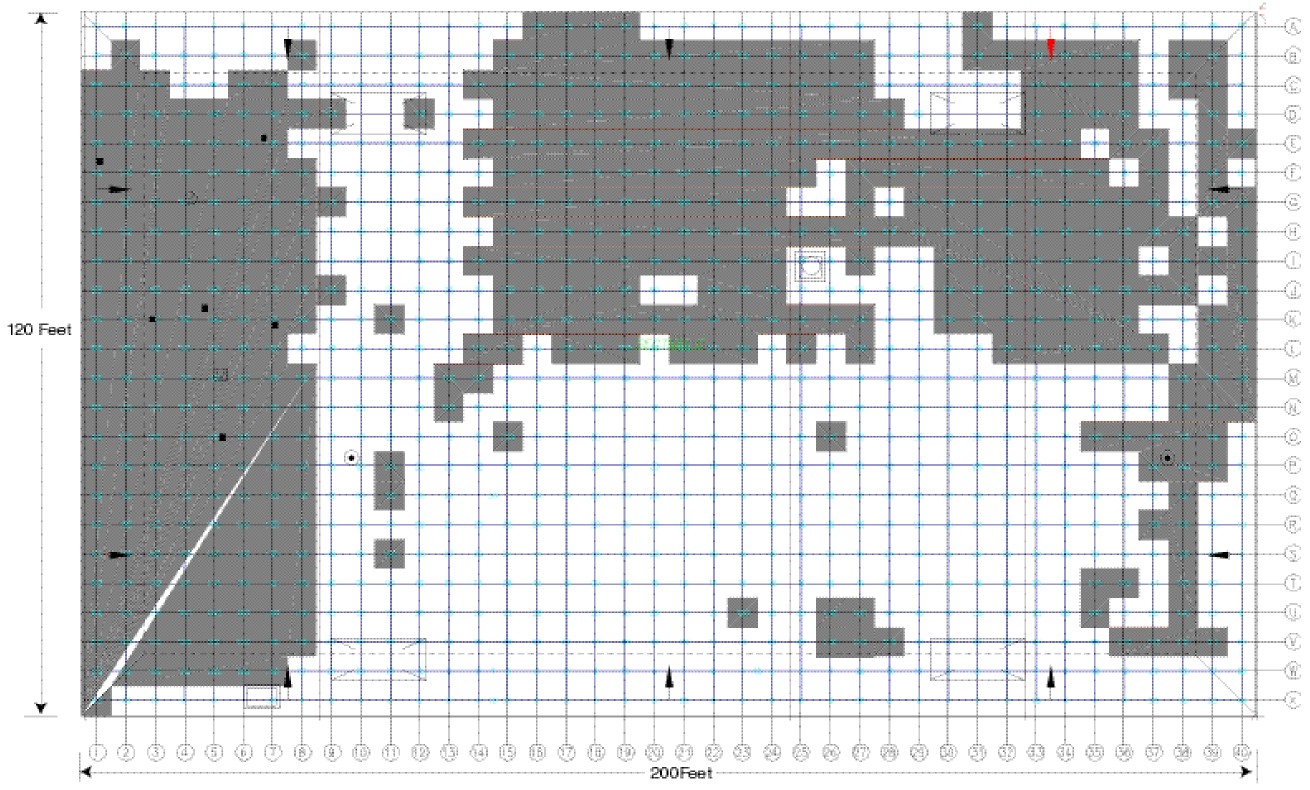
1. The roof assembly (i.e., deck, insulation and membrane) should be typical of a large population of low-slope roof assemblies.
2. The roof should be of sufficient size to allow for anomalies, but not so large to require a lot of time calculating data.
3. The building's owner would have to agree to the performance of the different NDE surveys and taking of test cores for verification of moisture content.
4. The roof assembly would have to have had some history of leaking, therefore increasing the probability that there would be wet insulation present.

The roof assembly that was selected for the study was found to meet all the above criteria is located in Dearborn, Mich., a Detroit suburb. The roof assembly consists of

- steel deck
- Two layers of ¾-inch-thick fibrous glass insulation (the lower course was mechanically fastened to the deck and the upper course was adhered to the lower course with hot asphalt)
- A four-ply, built-up membrane composed of type IV asphalt saturated glass fiber felts and Type I coal tar pitch
- A slag aggregate surface

The roof assembly is approximately nine years old and has experienced leaks, the most significant of which occurred in 1998 when a new curb unit was installed and the flashings were improperly installed. These flashings have since been repaired, and leaks are no longer reported near the new unit. The roof area that was the subject of this project is part of an extremely large facility that was surveyed in 1995 and 1998 using infrared thermography as part of an overall roof maintenance/management program. In 1995, the IR survey indicated no areas of moisture contaminated insulation. In 1998, following the serious roof leaks that were attributed to the new curb flashings, the IR survey indicated approximately 8,500 square feet (790 m^2) of wet insulation. The roof area surveyed encompasses approximately 120 feet by 200 feet (36.6 m by 61 m), or 24,000 square feet (2230 m^2) (see Figure 1). The building owner's representative agreed to allow the authors full access to the roof and take the required number of test cores for verification purposes.

For the purposes of this study, the authors had to agree on a definition of "wet insulation." It should be noted that the roofing industry has struggled with defining the level of moisture contamination at which roof insulation becomes "wet." In 1991, Tobiasson established Thermal Resistance Ratios (TRRs) for a number of common rigid roof insulation boards [5]. He defined TRR as the "ratio of a material's wet thermal resistivity to its dry thermal resistivity, expressed as a percentage." He proposed that "Insulation with a TRR of 80% or less is … 'wet,' and unacceptable." The authors have chosen to adopt the criterion of 80% TRR or less as wet and unacceptable for the purpose of this study. It should be noted, however, that Tobiasson also stat-



Shaded areas indicate where EC readings = 100

Figure 1. *EC results.*

ed that "for some insulations, less moisture than that required to reduce the TRR below 80% can be detrimental for other reasons (e.g., delamination, rot and corrosion of fasteners). It is not yet known what those 'moisture limit states' should be. Until it is known, the moisture content at which TRR equals 80% is proving to be a reasonable pass-fail criterion for judging when insulation is 'wet' and unacceptable."

ELECTRICAL CAPACITANCE SURVEY

Currently, there is no recognized standard protocol for performing NDE roof moisture surveys using electrical capacitance equipment. Tramex Ltd., the manufacturer of the EC device used in this study, suggests that readings be taken on a "convenient (i.e., 6-foot [2-m]) grid." The authors decided to take the EC readings on the same 5-foot (1.5-mm) grid basis as was employed for the NHD survey. This allowed direct comparisons between the EC and NHD readings. In fact, the protocol for the EC survey followed the protocol established for NHD surveys in the Roof Consultants Institute (RCI) Protocol for NHD Survey, except that the readings were taken by means of the EC device rather than by a NHD device [6].

The EC equipment used in this study was a moisture scanner provided by Tramex Ltd. The device was brought to the roof's surface and fresh batteries were installed. The moisture scanner was calibrated by placing it at a spot on the roof surface where the insulation below the membrane was believed to be completely dry (i.e., having a moisture content not exceeding its equilibrium moisture content [EMC]). The device was set to a reading of zero and a test probe was taken with a Delmhorst moisture probe to verify the "dry" condition. After completion of the calibration, the device was set to Scale 3, which is the scale suggested by the device manufacturer for obtaining readings on a 3- or 4-ply built-up roof system with aggregate surfacing.

The ambient temperature at the time of the EC survey was between 68°F and 75°F. (20°C and 24°C) with a relative humidity (RH) of 55%. The sky was clear and wind was northerly at 5 to 10 mph (2.2 to 4.4 m/s).

The readings were taken at 5-foot (1.5-m) intervals. A total of three test cuts were taken for the purpose of verifying the presence of moisture. At the time each of the test cores was taken, the insulation and membrane were visually observed for the appearance of moisture, and each was checked with a Delmhorst meter and the reading was recorded. Each of the test cores was divided into three samples: one sample contained the roof membrane (labeled as A), another contained the top layer of insulation (labeled as B) and the third contained the bottom layer of insulation (labeled as C). These samples were placed in plastic bags, sealed tightly and taken to a laboratory where they were subjected to gravimetric moisture content testing. The gravimetric moisture content testing consisted of removing the samples from the bags, weighing them and then placing them in an electric oven maintained at 220°F (104°C) for approximately 24 hours. Following the drying period, the samples were removed from the drying oven. The samples were then weighed again and the moisture content, expressed as a percentage of dry weight, was determined as follows:

$$\frac{\text{wet weight - dry weight}}{\text{dry weight}} \text{ x } 100 = \% \text{ moisture content by dry weight}$$

The Gravimetric Testing Results are shown in Table 1.

A total number of 939 readings were taken (960 grid points, less 21 grid points that coincided with skylights and/or curbs). The readings ranged from 0-100. All readings were recorded on a roof plan on which the grid points had been superimposed. Of the 939 readings, 450, or 47.9%, were 100. Based on the high number of readings of 100 and the results of the gravimetric testing, a contour map was developed indicating two levels of moisture content: dry and wet. All points at which the reading was less than 100 were designated as dry; all readings of 100 were designated as wet. (See Figure 1.)

The combined results of the gravimetric testing of the test cuts is shown in Table 2. The percent moisture content by dry weight is charted against the EC reading for the grid point at which the test cores were taken. This graph is shown in Figure 2. If the moisture content of the insulation at the test cores was directly and quantitatively related to the EC readings, then a straight line graph would be expected. The graph indicates little correlation between the EC readings and the moisture content of the insulation as determined by gravimetric testing. Where cores P-1 and P-3 were taken the EC readings were 100 and insulation samples at both points were shown to have a moisture content far higher than the 42% moisture by dry weight (i.e., the 80% TRR value for fibrous glass insulation) that we established as wet and unacceptable" (132% and 207%, respectively). However at core P-2, the EC device produced a reading of 100 but the gravimetric results rendered a moisture content of only 2%. Furthermore, at cores P-5 and P-6, EC readings of 50 were obtained and the gravimetric testing of these samples showed a moisture content of only 3% moisture by dry weight. Core P-7 was taken at a grid point where the EC reading was also 100, and the gravimetric testing showed a moisture content of 35%.

Analysis of the gravimetric results and the EC readings leads us to conclude that the point at which the insulation was truly wet (i.e., where the moisture content exceeded

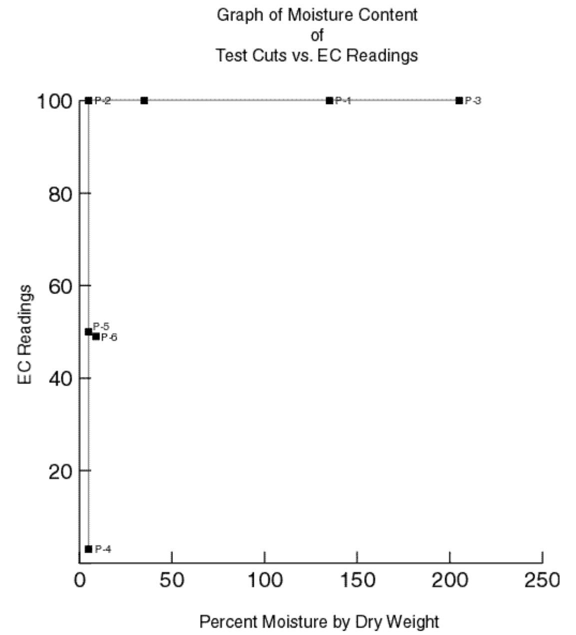


Figure 2.

42% by dry weight), was generally limited to those points where readings of 100 were obtained. However, not all readings of 100 indicated moisture content in the insulation. The moisture scanner was extremely sensitive to trace amounts of moisture that were present on the roof's surface or contained in the aggregate surfacing.

INFRARED THERMOGRAPHY

The IR roof moisture survey was conducted in general accordance with the American Society for Testing and Materials (ASTM) Standard Practices [7]. The infrared scanning camera used was an AGA model 720. ASTM C 1153 requires that the camera used for roof moisture surveys have a minimum resolvable difference of 0.3 degrees C at 68°F (20°C). ASTM C1153 also requires that the camera have an instantaneous field of view (IFOV) of 3.8 milliradians or less. The camera used for this study met these specifications, having a minimum resolvable temperature difference of 0.1 degrees C at 68°F (20°C), and an IFOV of 1.9 milliradians. The camera used detects infrared energy in the 2 micron to 5.6 micron wavelength range and has an adjustable thermal range from 2 degrees C to 1000 degrees C. The camera used for this survey meets the requirements of ASTM C 1153-97.

The AGA camera was set at a thermal range of 2 for this project (the most sensitive setting) and is equipped to take Polaroid still-film photographs of the scanning camera's black and white monitor (i.e., thermograms). (See Figure 6 for a typical thermogram taken during this survey.)

The IR survey was performed during the evening of May 20, 1999. At the time of the survey, the ambient temperature was between 55°F and 65°F. (18°C and 13°C) with an RH of approximately 50%. The wind was north/north-

Summary of Gravimetric Analysis

	A	B	C	D	E	F
Core Number and Sample Name	**Tare Weight**	**Tare + Sample**	**Tare + Sample "Dried"**	**Weight of Original Sample**	**Weight of Dried Sample**	**Percent Moisture by Dry Weight**
1 - A	21.5	200.0	194.4	178.5	172.9	3.24
1 - B	24.5	114.0	58.3	89.5	33.8	165.79
1 - C	23.5	36.0	33.6	12.5	10.1	23.76
1 - B+C				102.0	43.9	132.35
2 - A	23.0	73.7	72.8	50.7	49.8	1.81
2 - B	21.8	61.8	61.0	40.0	39.2	2.04
2 - C	22.0	38.8	38.6	16.8	16.6	1.20
2 - B+C				56.8	55.8	1.79
3 - A	22.1	73.0	69.2	50.9	48.1	5.82
3 - B	22.0	83.7	38.3	61.7	16.3	278.53
3 - C	19.4	40.3	30.0	20.9	10.6	97.17
3 - B+C				82.6	26.9	207.06
4 - A	17.8	35.9	35.4	18.1	17.6	2.84
4 - B	17.4	34.4	34.1	17.0	16.7	1.80
4 - C	18.5	29.1	28.6	10.6	10.1	4.95
4 - B+C				27.6	26.8	2.98
5 - A	17.8	43.7	42.6	25.9	24.8	4.36
5 - B	18.6	31.6	31.4	13.0	12.8	1.56
5 - C	18.9	27.3	26.8	8.4	7.9	6.33
5 - B+C				21.4	20.7	3.38
6 - A	20.0	36.0	35.7	16.0	15.7	1.91
6 - B	20.6	30.6	30.4	10.0	9.8	2.04
6 - C	17.7	28.4	28.0	10.7	10.3	3.88
6 - B+C				20.7	20.1	2.98
7 - A	13.5	34.8	33.6	21.3	20.1	5.97
7 - B	15.0	35.2	26.7	20.2	11.7	72.65
7 - C	15.8	31.8	31.0	16.0	15.2	5.26
7 - B+C				36.2	26.9	34.57

Notes: All "A" samples are roof membrane samples.
All "B" samples are the top layer of insulation.
All "C" samples are the bottom layer of insulation.
Samples 1, 4 and 5 were taken within the 12' taper area.
The top "tapered" insulation layer was dried along with the membrane sample.

Table 1.

west at 0 mph to 5 mph (0m/s to 4.4m/s). There were at least 12 hours of strong sunshine during the daylight hours preceding the IR survey.

The survey was performed using a two-man crew. The camera operator and his assistant both were experienced and knowledgeable in the performance of IR surveys and roof construction.

Many thermal anomalies (i.e., areas of higher temperature) were found during the IR survey. Two test cores were taken. One from an area suspected as having "wet"insulation and one from an area suspected as containing "damp" insulation. It should be noted that no core was taken in an area identified as having a "dry" substrate because one of the previously cored areas, identified as having "dry" insulation, was used to calibrate the thermal adjustment of the infrared scanning and imaging system prior to conducting the survey. The test cores taken during the IR survey were treated similarly to those obtained during the EC survey; that is, they were separated into membrane and insulation specimens, sealed in plastic bags and then taken to a laboratory for gravimetric testing. The reason for taking these cores was to verify that the elevated temperatures observed by the IR camera operator were caused by the presence of moisture in the insulation. During the IR survey, the EC equipment was also used to establish that the anomalies observed were moisture-related and not caused by other sources of infrared emissions, such as heavy coatings of bitumen or gravel, or underdeck heat sources, such as high-intensity lamps attached to the underside of the roof deck.

Three contiguous areas of moisture-related anomalies were identified with the IR equipment. It should be noted that within each of these three areas, many small (less than 10 feet [3 m] in any dimension) to large (more than 20 feet [6.1 m] in any dimension) moisture-related anomalies existed that were positioned in relatively close proximity to one another. All three contiguous areas marked on the surface of the roof's with spray paint (and shown on the roof plan in Figure 3) are areas that were deemed to have "unacceptable" concentrations of one or both of the following:

1) subsurface moisture in a large area, or
2) areas where several moisture-related anomalies existed in close proximity to one another (i.e., it would be impractical to remove each of these wet areas during any subsequent roof rehabilitation work)

The anomaly areas were measured and transposed onto the roof plan (see Figure 3). Collectively, the areas designated as "wet" in Figure 3 comprise 12,873 square feet (1196 m^2), or 53.6%, of the total roof area. The gravimetric tests of the test cores taken from within the suspect wet areas indicated that the moisture content of the insulation in the "wet" areas ranged from approximately 35% to 200+% of dry weight. This is generally close to or above the 42% moisture content that corresponds to the 80%TRR for fibrous glass insulation that the authors have established as wet and unacceptable. It should be noted that select cores taken from areas that were visually identified to have "spotty" substrate moisture (such as the P-5 core location), may have been in dry or "damp only" portions of the roof.

Although the IR camera is capable of detecting temperature differences in the roof assembly, the degree of temperature difference does not necessarily correlate to the amount of moisture present in the roof system. In other words, if two different anomaly areas were found where roof temperatures were observed to be 0.5 degrees C and 1.0 degrees C warmer than the "dry" areas, it would not necessarily follow that the area where the roof temperature is 1.0 degrees C warmer contains twice as much trapped moisture as the area with the 0.5 degrees C warmer temperature. However, areas where there is significantly more moisture trapped in the insulation, may in fact appear warmer than those areas that are less wet. The experienced IR technician can observe these differences and make a judgment regarding the relative, approximate moisture content of the anomaly areas. The technician can then categorize the anomalies into categories of "wet," "damp" or "dry" that should correspond to gravimetric results from test cores taken in the roof areas of the different categories.

NUCLEAR HYDROGEN DETECTION SURVEY

The NHD roof moisture survey was conducted in accordance with the Roof Consultants Institute protocol for NHD Survey [6]. The NHD survey was conducted using a Troxler Model No. 3216 roof reader nuclear gauge. It should be noted that some nuclear moisture gauges, those commonly used for asphalt paving or soil density and moisture testing, have small computer chips that not only give count type reading values, but can also calculate the percentage of moisture when given some input values. However, the roof reader gauge model gives only count readings. The roof reader gauge model does not need calibration because it provides data that are to be compared or interpreted by the user, rather than giving a calculated percentage of moisture.

When conducting an NHD roof moisture survey, it is most common to take readings in a set grid. Typical grid spacings are 10 feet by 10 feet (3 m by 3 m), 5 feet by 5 feet (1.5 m by 1.5 m), or 3 feet by 3 feet (9.4 mm by 9.4 mm). Obviously, the spacing of the grid points will greatly affect the number

Core #	EC Reading	NHD Reading	IR Results (Wet? Yes/No?)	% Moisture by Dry Weight	Comments
P-1	100	13	Yes	132	High moisture in top insulation layer, bottom layer was dry
P-2	100	6	Yes (near edge)	2	Trace moisture on insulation facer, else completely dry
P-3	100	20	Yes	207	Both top and bottom insulation had free moisture present
P-4	0	6	No	3	All materials were dry
P-5	50	6	Yes (damp only)	3	Slight moisture in flood coat. Membrane and insulation was dry
P-6	50	7	No	3	All materials were dry
P-7	100	9	Yes (near edge)	35	Moisture in top insulation layer. Bottom insulation layer was dry

Table 2.

of data collection points. For example, for every 10,000 square foot (9,290 m^2) of survey, a 10-foot-by-10-foot (3-m-by-3-m) grid would normally have approximately 100 data collection points. However, the same 10,000 square feet (9,290m^2) would need approximately 400 collection points for a 5-foot-by-5-foot (1.5-m-by-1.5-m) grid and approximately 1,111 collection points for a 3-foot-by-3-foot (914-mm-by-914-mm) grid. When performing a NHD survey, the taking of additional points (between the originally set grid points) can always be done to more fully investigate suspect areas (such as areas with leak histories or where unusual readings are obtained). For purposes of our survey, we used a 5-foot-by-5-foot (1.5-m-by-1.5-m) grid pattern.

Additionally, when conducting an NHD roof survey, the gauge can be set to make its readings, or "counts" at differing time intervals. Model 3216 has four separate time intervals, which include 7.5 seconds, 15 seconds, 30 seconds and 60 seconds. It should be noted that the "count" at each separate interval is the same (i.e., if a count of 15 is made at the 7.5-second interval, the count at a 60-second interval also would be expected to also be approximately 15). As with most testing, the 60-second time interval would provide the better "time-weighted" value, also the 7.5-second time results in a shorter count and essentially should be multiplied by a factor of eight to get the approximate reading that a 60-second reading would provide. To confirm this, we tested the same spot during our survey and at the 7.5-second and 60-second intervals, and at our test location the same reading was obtained. Because of the time involved to make the hundreds of readings typically needed for a NHD survey, the shorter count periods were most typically used. It should be noted that consecutive readings, especially "higher" readings, can vary slightly from one reading to the next. At the count time of 7.5 seconds, the counts can vary approximately 10% from one reading time to the next, even without moving the gauge. For purposes of this survey, a time count of 7.5 seconds was used to gather the data.

The NHD survey was conducted on May 11, 1999. At the time of the survey, the ambient temperature was 79°F (26°C) with a RH of 63%. The sky was clear and there was a breeze from the southwest at approximately 7 mph (3 m/s).

A total of approximately 939 readings (960 grid points, less 21 gridpoints that coincided with skylights and/or curbs) was taken. The readings ranged from 4 to 27. The readings were recorded on a roof plan that had the grid superimposed on it. As with the EC survey, a contour map was developed that connects points with similar readings (see Figure 5).

As we stated earlier, the gauge readings do not directly give the moisture contents of the materials below. Therefore, some destructive core sampling is needed to establish the correlation between the gauge readings and percentage of roof system moisture. Typically, three or four cores are taken to provide for a graph or curve to be developed that establishes the relationship between the reading values and roof system moisture content. It is not required to take cores at the absolute lowest, highest and middle count readings but, generally, a core should be taken from one of the lower

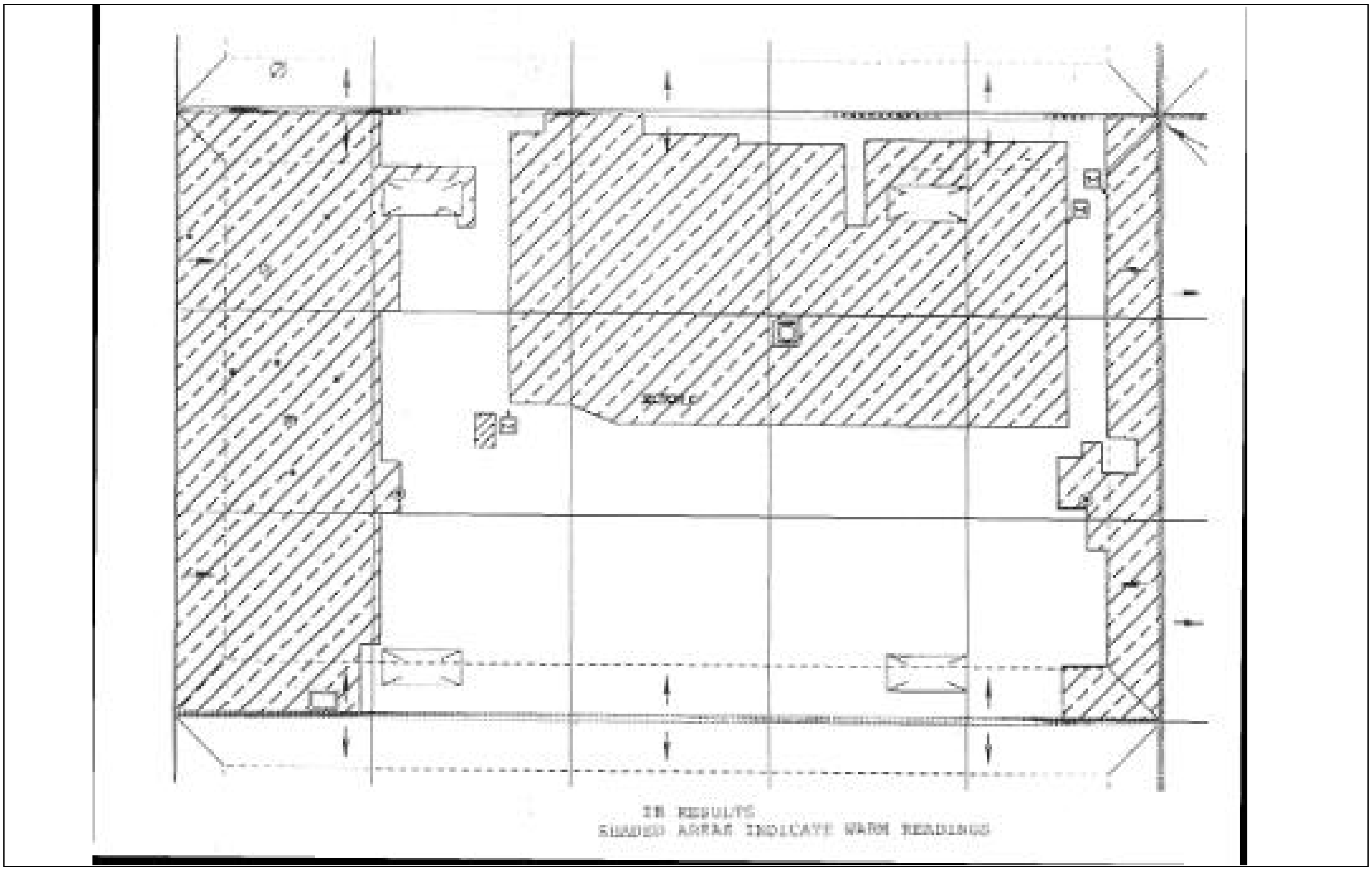


Figure 3.

reading grid points and another from a significantly elevated reading gridpoint. The selection of the third or fourth core location would typically be based upon the amount of substrate moisture visually identified at these first two cores. During the NHD field visit, we elected to take cores at three locations. These samples were taken at grid points where NHD readings of 6, 13 and 20, respectively, were obtained. These samples were separated into membrane, top-layer insulation and bottom-layer insulation samples and subjected to gravimetric testing. The results of the gravimetric testing are shown in Table 3. Because the field observations indicated that these three core locations were dry, damp/wet and nearly saturated, respectively, a fourth core was not taken at that time. With the reading of 20 indicating a nearly saturated insulation condition, cores at reading values of greater than 20 were determined not to be needed.

Similar to the practice employed in the EC survey, the moisture content of the samples was plotted vs. the NHD readings. This graph is shown in Figure 4. As with the EC survey, if the elevated NHD readings are attributable to trapped moisture, there should be a relatively straight line correlation between the NHD readings and the moisture content of the samples as determined by gravimetric testing. As shown in Figure 4, the relationship is very linear and the collected sample points all fall near to the plotted "relationship curve." (Note: The initial results of the gravimetric survey indicated a nearly uniform curve to represent the NHD reading and the percentage moisture by dry weight. Although no additional cores were needed, the additional core locations taken as part of the later-performed EC survey and IR survey were also plotted on our graph to provide additional data points on the curve.)

The findings of the NHD survey indicate that approximately 63.9% of the roof area has normal or dry substrate moisture (less than 5% moisture by dry weight). Another 10.3% of the roof was determined to have some above-normal moisture, but not yet sufficient to meet the selected threshold of 80% TRR (between 5% and 40% moisture by dry weight). The balance of the roof insulation, almost 26% of the roof section surveyed, was determined to have substrate moisture in an amount greater than that needed to fall below the 80% TRR level (above 40% moisture by dry weight). A chart of the various groupings of NHD meter readings with corresponding insulation moisture contents can be seen in Table 3. The grouped readings (of high NHD readings) on the roof plan appear to include three main sections of heavy substrate moisture with surrounding areas of less substrate moisture. It is likely that the areas of heaviest substrate moisture are areas that have defects in the roof system that are allowing the moisture to enter. It was noted during the coring operations that areas near heavily saturated insulation were found to have trace amounts of moisture on the underside of the roof membrane. This could be the result of lateral moisture movement during the hot/sunny portion of the day and condensation occurring in the evenings.

CONCLUSIONS

In evaluating these methodologies, it must be remembered that their primary uses are to provide guidance for repair, re-cover or removal and replacement of the existing roof system or determining whether the roof is a candidate for

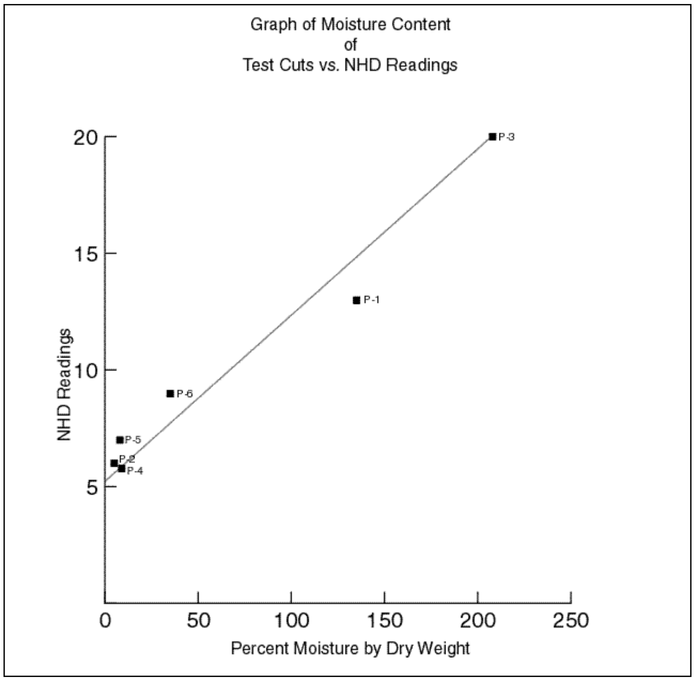


Figure 4.

	Estimated % Moisture by Dry Weight					
Nuclear Gauge Reading	Top Layer Insulation	Bottom Layer Insulation	Combined Insulation	Number of Readings within Range	Approx. Percent of Roof Area	Comments
4 -7	2 - 3	2 - 3	2 - 3	591	62.9	Both insulation layers have dry materials.
8 - 9	3 - 80	2 - 5	3 - 40	98	10.4	Some moisture, but combined moisture is less than "TTR".
10 - 12	80 - 150	5 - 20	40 - 120	59	6.3	Combined moisture is above TTR. Bottom layer is still dry.
13 - 15	150 - 200	20 - 50	120 - 160	59	6.3	Bottom layer damp, top layer very wet, but not yet saturated.
16 - 18	200 - 250	60 - 80	160 - 200	60	6.4	Bottom layer wet, top layer nearly saturated.
19 - 21	250+	80 - 120	200 - 250	44	4.7	Bottom layer wet, top layer is saturated.
> 21	250+	120+	225+	28	3.0	Based on core results, both layers would be expected to be nearly saturated.

Table 3.

long-term repairs. In either case, it is not important to know the amount of wet insulation to an extremely precise degree. Whether 12% or 15% of a roof's insulation is wet is not a significant difference in either a reroofing or repair decision. Whether 12% or 50% of the roof's insulation is wet is a significant decision in either case. The point is that fairly gross measurements of the extent of the wet insulation are still helpful in guiding these decisions.

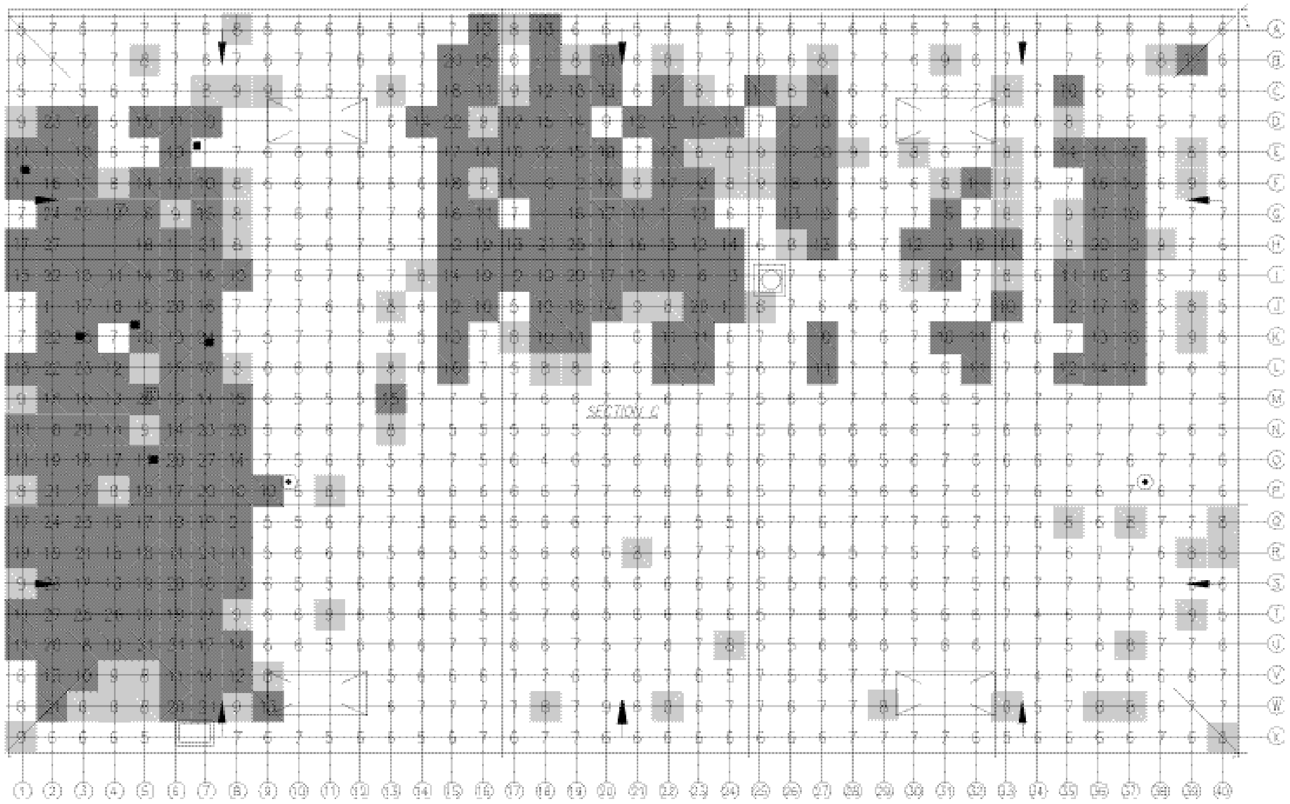
There was a relatively close correlation between the findings of two of the three NDE methods. The EC survey indicated that 47.8% of the total roof area was wet; the IR survey indicated that 53.6% of the roof was wet. The NHD survey indicated that 37.1% of the roof area was at least partially wet. (Readers should note that the area marked by the IR survey is already enlarged to show large squares/rectangles of roof. If we were to enlarge or "square-up" the areas identified as "wet" in the EC or NHD surveys, the percentage of "wet" roof area would be expected to be larger.)

It appears that all three technologies used to detect subsurface moisture in low-slope roof systems can successfully detect moisture contained in insulation below a roof membrane. In each of the cases, the measurements of the wet insulation are relatively broad and should not be relied on to be precise. Also, each of these technologies has limitations.

Although the EC method appears to be able to detect subsurface moisture in significant quantities (e.g., wet insulation), it appears that this technique has limited capability to detect substrate moisture that would be classified as damp but still be considered unacceptable (i.e., a percentage of moisture above the TRR). Additionally, the EC method may be useful in obtaining a gross approximation of the location and amount of wet insulation present, but its extreme sensitivity to trace surface moisture, invisible to the naked eye, may exaggerate the amount of area that is considered wet. Because more roof area may be classified as wet based up EC readings than actually is wet, using data from EC moisture surveys may result in more conservative reroofing decisions than may be made based on supporting data from NHD or IR surveys.

While the IR method appears to provide the best overview of substrate conditions, this method is the most sensitive to the experience, or lack thereof, of the operator of the equipment. Additionally, it appears that when substrate moisture is manifested by many small anomalies in a contiguous area, the time that it would take to mark all the anomalies independently somewhat negates the advantage of being able to identify these smaller areas of moisture. This is because the practical method dealing with these areas is to mark the boundary of the contiguous area in an effort to encompass all of the small anomalies within one or more wet areas.

The NHD method appears to have provided the best method of quantifying the percentage of roof moisture within the roof system. Because the readings of the nuclear meter are not limited between 0-100, as is the EC meter, the relationship curve of actual percentage of moisture by dry weight versus the NHD reading appears to be



☐ **Readings of 4 to 7**
Moisture % of 2 to 5

▨ **Readings of 8 to 9**
Moisture % of 5 to 40

■ **Readings of 10 to 27**
Moisture % of 40 to 225+

Figure 5. NHD results.

very linear through the entire range of possible substrate moisture amounts. That is to say that the results not only show that the roof is "dry" or "wet," but the gathered information also provides for the location of insulation that is "damp," as well as insulation that is nearly "saturated." This information could be very helpful in locating the source of the roof moisture entry. This method does not appear to be as "sensitive" as the other two methods, as it did not indicate high moisture in areas that were cored and were found to have only "trace" amounts of moisture.

In the case of all three of the methods used, the precision of the methods must be considered to be gross rather than fine. Often a decision is made to re-cover a roof area because a relatively small portion of the roof system is considered to be wet, based on the data provided by an NDE survey. In these cases, the wet areas are normally scheduled to be selectively removed and filled in with dry materials prior to the installation of the re-cover assembly. In these cases, roofing professionals should be aware that some small areas of wet insulation may not be addressed or that more area than is actually wet may be indicated. Additionally, all roofing practitioners must remember that NDE surveys are measurements of the insulation conditions at the time of the survey only. Conditions can change significantly between the time of the survey and the initiation of the repair or reroofing project. Good roofing practice would dictate planning to remove more wet insulation than the NDE surveys indicated. When selectively removing areas for repair or for infill prior to re-covering the roof system, the project should be guided by the actual conditions encountered as the roof assembly is removed.

Readers should also know that these three methods have significant differences in equipment cost and have general limitations in the types or sizes of roofs that can make each method more or less cost efficient. In general, all three methods work best when the roof is dry and clean, but the IR equipment must be operated at night and normally requires a two-person crew. The IR equipment is generally the most expensive to purchases and systems can cost from $15,000 up to $40,000 to buy new. Training of the operator in the proper usage and interpretation of the IR images is normally required, as many factors can result in heat anomalies. Nuclear gauges cost less than IR cameras, but because of the radioactive materials involved, these gauges are regulated, and licenses to operate the gauges are needed. Additionally, the transportation and administration of nuclear gauges is often complicated. The EC units are the least expensive and require no specialized training; however, as presented in this paper, the sensitivity of these units can provide false positive results. White roofs can be a problem, and IR surveys and aluminum coated roofs also can be a problem for both IR and EC surveys. Last, the use of an EC or NHD grid type of survey on roofs of more than 50,000 square feet can often take several days (if the readings are taken on a tightly spaced grid), whereas the IR camera can often survey 100,000 to 150,000 square feet (or more) of roof area in just a few hours. Conversely, small roof areas can often be more cost effectively assessed with grid surveys (done during the day by one person) than attempting night-time access (with two people).

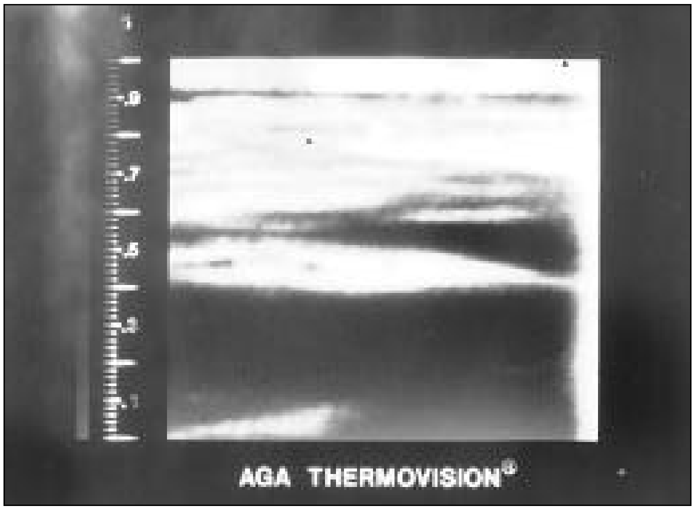


Figure 6.

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