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HAND-HELD INFRARED SYSTEMS FOR DETECTING ROOF MOISTURE

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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 to eliminate leaks. We now also know that many roofs that appeared to be in excellent condition actually contained wet insulation which was thermally ineffective.

In 1975, a few commerical firms were offering nuclear moisture surveys of roofs, and one firm was offering airborne infrared surveys from a helicopter. These 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. Portions of the early program were sponsored by the USAF. The current project is sponsored by the Chief of Engineers. Three Corps of Engineers facilities are involved in this program:

Cold Regions Research and Engineering Laboratory (CRREL). Hanover, New Hampshire.

Facilities Engineer Support Agency (FESA) Fort Belvoir, Virginia.

Waterways Experiment Station (WES), Vicksburg, Mississippi

The work being conducted by Dr. L. E. Link, Jr., of WES is described in the paper "Airborne Thermal Infrared and Nuclear Meter Systems for Detecting Moisture" which is also included in the Proceedings of this Symposium.

Since 1975 CRREL and FESA have used hand-held infrared systems to study roofs at various military installations from Eielsen AFB, Alaska, to Ft. McClellan, Alabama. Studies have been conducted throughout the year under a wide range of climatic conditions. Numerous problem areas have been uncovered and new approaches to the maintenance and repair of roofs have been generated based on the excellent results achieved to date.

CORE SAMPLES

Numerous cores have been taken of built-up roof membrane and insulation to verify infrared findings. A spudding bar or chipping hammer was used to dislodge any gravel cover from a 12-in. x 12-in. area of the membrane. Three-inch-diam. core samples of the membrane and insulation were obtained in the center of each cleared area using the CRREL-designed roof sampler shown in Figure 1. The samples were sealed in platic bags and later weighed, dried at 110°F, and reweighed to determine the amount of water present. Water contents mentioned in this paper are expressed as the weight ratios of water to dry insulation.

CRREL provided a 2¾-in.-diam. expanded polystyrene plugs to fill each hole after a sample was taken. Maintenance personnel at the installations being studied pushed these plugs into a bed of roofing cement placed in each hole, and then patched the membrane. Where roofs are under warranty, it has been necessary to involve roofing contractors approved by the warrantor in the cutting and patching operation.

INFRARED CAMERAS

Until recently, infrared cameras were quite large and seldom used out of doors. The portable, battery operated AGA Thermovision 750 Infrared System (Figure 2) was used for essentially all the studies discussed in this report. Some roof moisture studies have also been conducted with the Inframetrics Model 510 system, with a hand-held system developed for the Army by the Magnavox Corporation and type classified as the AN/PAS-10, and with the Probeye System developed by Hughes Aircraft.

It is not the intent of this paper to discuss in detail the relative merits of the various infrared camera systems that have been investigated. However, for the type of work discussed in this report, the inexpensive Probeye Camera (about $6,000) does not have sufficient resolution and the PAS-10 System (about $33,000) lacks a photographic recording capability. Only limited success has been achieved in adapting the PAS-10 to provide a photographic recording capability while retaining its desired hand-held portable features. The AGA (about $40,000) and Inframetrics (about $25,000) systems have both been used successfully in this work.

Both the AGA and Inframetrics systems require liquid nitrogen to cool the infrared detector. Although liquid nitrogen can be secured in most cities, it cannot be transported by commercial aircraft. It must be carried in special, vented Dewar flasks and handled with care, since the −321°F (−196°C) product can cause severe burns if it touches the skin.

The PAS-10 System uses an electric Peltier cell to cool the detector and has the advantage of not requiring liquid nitrogen. The Probeye System uses compressed argon gas in miniature bottles to cool its detector. When under pressure, these bottles are not allowed on commercial aircraft.

THERMOGRAPHY APPLIED TO ROOFS

Every object emits electromagnetic energy. That energy emitted between wavelengths of 0.37 microns* and 0.75 microns is seen as visible light. The near, middle and far infrared portions of the electromagnetic spectrum lie between 0.75 and 15 microns and cannot be seen by the naked eye. However, a radiation thermometer or scanning infrared camera can see this energy. The AGA system detects infrared radiation with wave lengths between 2 and 5.6 microns. The Inframetrics system detects infrared radiation with wavelengths between 8 and 14 microns. The PAS-10 and Probeye systems operate between wavelengths of 3 and 5 microns. Comparison tests have shown that the portion of the infrared band detected does not appear to significantly influence the results of roof moisture surveys.

The portable non-scanning radiation thermometers available commercially range in price from about $300 to a few thousand dollars. A few have been examined and although a comprehensive evaluation has not been conducted, those utilized were not able to consistently locate wet roof insulation. Radiation thermometers with a single line scanning capability have recently been introduced. They may have some potential in this work.

Scanning infrared cameras are complex electronic devices that accept infrared radiation through a special lens and convert it to a monochromatic tone on a cathode ray tube or light emitting diode (LED) viewing screen. The AGA equipment displays grey tones; the Probeye, red tones and the PAS-10 and Inframetrics systems, green tones. With the aid of a spinning or oscillating mirror or prism in the camera, many pictures per second are created on the screen. The resulting image is similar to what you might expect on an aged and somewhat poorly adjusted black and white television. By moving the camera about and viewing the screen, the observer can examine a roof in detail. Some infrared cameras have a photographic recording capability. When a particularly interesting scene is viewed by the operator, a conventional Polaroid photograph can be taken. Such photographs are called thermograms.

Different tones on a thermogram denote differences in the **apparent** surface temperature of all objects in view. The adjective "apparent" is necessary since the amount of electromagnetic radiation emitted by a surface (i.e., the brightness of its image on the thermogram) is not just a function of its temperature but also of its ability to emit heat by radiation.[3] This property of the surface is termed emissivity. If two objects have the same surface temperature but different emissivities, the object with the higher emissivity will appear brighter on the viewing screen. If two objects have the same emissivity, the warmer one will emit more electromagnetic radiation and appear brighter on the viewing screen.

Like a television, the infrared camera has a brightness control which can be used to vary the image on the screen from bright to dark through varying degrees of contrast. The camera is adjusted to give a middle tone (not bright, not dark) to the roof and a search is made for brighter areas. During the search it is quite easy to see drains, vents and other appurtenances on the viewing screen since their apparent surface temperatures are not identical to that of the roof because of temperature and/or emissivity differences.

The emissivity variations over either a gravel-covered or a smooth-surfaced roof are minor. Unless the emissivity changes (e.g., a smooth-surface patch on a gravel-covered roof), brightness variations on the viewing screen in-

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**A micron (micrometer) is one thousandth of a millimeter.*

dicate temperature differences on the roof. Many things can be responsible for these temperature differences. Some of the more common reasons for warmer roof areas are as follows:

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.

It takes a fair amount of experience to determine the cause of each area and to isolate those which are potentially moisture-caused. When it is suspected that an anomaly is moisture-caused, it is outlined in white spray paint.

Ice or ponded water on a roof reflects electromagnetic radiation like a mirror reflects visible light. Consequently, objects in the reflected background are visible in the thermal image. This can be confusing since the image on the viewing screen is then a combination of the apparent temperature of the ice or water and that of objects in the reflected background. Fortunately bare or gravel-covered roofs reflect relatively little electromagnetic energy, and that which is reflected is diffused. This avoids confusion by reflection when studying roofs, except those portions covered by ice or ponded water. Where ice or ponded water is present, no conclusions relative to moisture in the roof can be drawn from an infrared survey.

DAY VS. NIGHT SURVEYS

Daytime roof moisture surveys with an infrared camera are of little value since solar effects mask temperature variations caused by entrapped moisture. Figure 3 is a thermogram of a bare bitumen membrane in Alaska taken during a warm sunny day. Slight differences in membrane color caused by dirt in low spots caused it to heat up nonuniformly. Combined with solar effects, the result is a blotchy, confused thermogram of little value. At night, the same area provides a uniform tone as shown in Figure 4. If a wet area were present on this roof it would stand out as a white anomaly in a thermogram taken at night. Consequently all infrared roof surveys have been conducted at night, and except for Figure 3, all thermograms presented in this paper were taken at night.

Night work on a roof requires extra care. As a rule, daytime reconnaissance surveys of the roof are conducted prior to the nighttime infrared survey to locate any wires, debris, or unusual features that might create hazards at night. The individual operating the infrared camera has little trouble finding his way around in the dark, equipped as he is with the special night vision provisions of the camera. His assistant, who spray paints boundaries of bright anomalies, marks locations where core samples are to be taken, processes the Polaroid photographs, and sketches findings on a plan view of the roof, requires a flashlight. A headlamp has proved to be quite valuable for these tasks.

A thermogram taken during a cold spring night on a roof at Ft. Greely, Alaska, is shown in Figure 5. A man is standing with his feet at the far edge of a bright anomaly. The two dark objects behind him are roof vents. The picture the operator sees on the viewing screen of the infrared camera is of better quality than the fourth generation reproduction shown as Figure 5 in this report. The operator of the infrared camera provides verbal instructions on the location of the boundary of the bright anomaly to the man in Figure 5 who outlines the anomaly in white spray paint. A conventional photograph of the outlined area is shown in Figure 6. The two vents mentioned previously are also visible. Two core samples were taken within this anomaly (2 and 3 in Figure 6) and one just beyond its boundary (1 in Figure 6). Samples 1, 2 and 3 had water contents of 4, 83, and 187% respectively. The perlite board insulation within the anomaly was the consistency of fresh cow manure. The crosses shown on Figure 6 are locations where nuclear moisture meter readings were taken for comparison purposes.

Once wet areas are defined with the infrared camera, they are measured and located on a plan view of the roof. Cores taken on the roof are denoted on the plan and the water content of the insulation at each core is tabulated alongside the plan. The result for a building at Ft. Devens, Massachusetts is shown in Figure 7.

When cores are taken, a detailed visual examination of the roof is made to define the cause of problems and to develop recommendations for maintenance, repair or replacement. This aspect of the work requires individuals experienced in built-up roof inspection. Without their input, infrared roof surveys are of limited value to the owner of the building.

SUMMER VS WINTER SURVEYS

When a building is heated during cold weather, the surface of its roof in an area with wet insulation is hotter than the surface of a nearby area underlain by dry insulation (i.e., the dry insulation permits less heat to escape than does the wet insulation). With this in mind, it might be expected that roof moisture surveys with an infrared camera could be conducted only in cold weather. Fortunately, a second mechanism allows for essentially yearround detection of wet roof insulation with the infrared camera.

The second mechanism is the diurnal (day-night) variation in temperature even during summer months. Visualize the sun baking a flat built-up roof on a warm summer day. Where the insulation is dry and thermally effective, the membrane may be warmed to temperatures exceeding 180°F [1]. The insulation is also warmed but little solar energy is stored in the insulation. Where the insulation is wet, the membrane does not warm up quite as much, since a portion of the solar energy passes into the wet, conductive insulation and warms it. Appreciable energy can be stored in wet insulation since the specific heat of water is quite high (i.e., it takes a lot of energy to warm up the water).

As the sun goes down, the roof cools. There is relatively little energy stored in the dry area and although its surface was somewhat warmer during the day, it cools relatively fast. Because of the extra energy stored in the wet insulation it takes that area far longer to cool. In the late afternoon, the wet and dry areas might be about the same temperature. Later in the evening the roof surface above the dry insulation is colder than that above the wet insulation. The infrared camera can see this difference.

Therefore, it is possible to detect wet areas with the infrared camera throughout the year in essentially all parts of the country. Of course, there are some limitations. Although wet areas have been "seen" under light dustings of snow and during moderately heavy rains, the masking provided by rain and snow significantly reduces the value of such surveys. Practically speaking, infrared surveys should not be conducted on wet or snow-covered roofs.

COMPARISON WITH NUCLEAR MOISTURE SURVEYS

As mentioned when discussing Figure 6, nuclear moisture surveys have been conducted in conjunction with infrared surveys for comparison purposes. The hardware used in the nuclear surveys costs only a few thousand dollars, compared to the $25,000 and up cost of infrared equipment. However, the time and effort required to conduct a nuclear moisture survey, analyze the data and summarize the findings exceeds that required for an infrared survey. On a large scale, such as that required by the U.S. Army, infrared surveys are expected to be less expensive than nuclear surveys.

Nuclear devices containing reactor-made radioactive material are controlled by the Nuclear Regulatory Commission, which regulates their use, storage and shipment. Devices containing 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 principle on which nuclear meters operate is covered in the paper presented at this sympoisum by Dr. L. E. Link, Jr.[2] In essence the nuclear meter sees and counts hydrogen in the roof. The roof area sampled by a nuclear meter is about 2 square feet per reading. The built-up membrane, any bitumen used to adhere the insulation and any water in the roof all contain hydrogen. The portion of each nuclear meter measurement contributed by the bitumen in the roof must be known before the measurement can be related to moisture. Basic information on nuclear counts to be expected for dry roofs of various construction is not available. Consequently, the absolute value of nuclear readings taken on a roof is of little value: the variation in nuclear readings over a roof is used to determine if any wetness is present. If the membrane is uniform, variations in nuclear readings are quite likely indications of moisture in the roof.

Infrared surveys are also "relative" surveys since the gain on the infrared camera can be adjusted to vary the brightness of the image on the viewing screen.

Since a nuclear meter samples about 2 square feet of roof at each grid point and since nuclear surveys are commonly taken on a 10-ft x 10-ft grid, a nuclear moisture survey sees only about 2% on the roof. An infrared surveys sees essentially every square inch of the roof. The wet area in Figure 5 could have been completely missed by a nuclear survey on a 10 ft x 10 ft grid. Reducing the grid size to 5 ft x 5 ft reduces the chance of missing a wet area but multiplies the work by 4 and only increases the coverage to 8%.

Early comparison studies of moisture surveys conducted by nuclear meters and infrared cameras showed that both systems could consistently locate wet areas. However, many areas along flashings denoted as wet from nuclear surveys were dry according to the infrared camera. Core samples verified that these areas were dry. The extra layer of felts and bitumen at flashings provided extra hydrogen which the nuclear meter counted. Initially, the extra counts were attributed to water in the insulation. Dr. L. E. Link, Jr., of WES resolved this discrepancy by developing an equation which surcharges the "wet-dry threshold" nuclear meter reading at flashings to account for the extra bitumen there. When this is taken into consideration, the nuclear and infrared systems give essentially similar results where detailed comparisons are made. However, it is essentially impossible to produce a nuclear survey with as detailed coverage as an infrared survey.

The requirement for such detail can be questioned. Yet if a detailed survey using one technique is no more expensive than a grid survey using another technique, the detailed survey seems preferable. Even more important is the fact that detailed surveys allow little problems to be uncovered and solved before they become major failures.

HAND-HELD CAMERAS IN A HELICOPTER

In order to further speed up the survey of an entire military facility having dozens of large built-up roofs, the hand-held infrared camera has been used from large bucket trucks and helicopters. A considerable amount of time is associated with moving a bucket truck about and deploying it close to buildings. Although the difficulties of gaining access to roofs are eliminated, the ability to mark the roof is lost. The bucket truck work has not been that successful to this point but further evaluation of that technique is planned.

The capabilities of sophisticated infrared equipment installed in U. S. Army and U. S. Air Force fixed wing aircraft are discussed by Dr. L. E. Link, Jr., in the accompanying paper.[2] Since helicopters are available at most military insallations, the alternative of low level flights using the AGA hand-held infrared system with a telephoto lens has also been studied. Results have been quite good. At Ft. Devens, Massachusetts, a one-hour daytime familiarization flight at an elevation of 500 ft. established a flight pattern for examining 70 built-up roofs. The 70 roofs were examined with the infrared camera that evening during another hour of flying time. Of the 70 roofs, 16 were found to contain bright anomalies not obviously associated with roof vents. The causes of these hot areas were determined by subsequent on-the-roof infrared surveys and cores.

A daytime view of the gymnasium at Ft. Eustis, Virginia, is shown in Figure 8. A thermogram taken of that building from a helicopter at an elevation of about 500 ft. is shown in Figure 9. Several exhaust fans are visible in both the photograph and the thermogram. Core samples verified that the irregular white areas in Figure 9 contained wet insulation and the insulation under the dark areas of the roof was dry.

It is difficult to both study and photograph roofs while looping above them and looking out the open window of a noisy helicopter. Because of this, few thermograms have been taken during such flights. Instead, efforts have been devoted to studying the infrared viewing screen and noting comments in pencil on plan views of each roof. In an effort to improve upon this system, a video taping capability has been developed that permits recovery of the image on the viewing screen for future playback and copying under less strenuous conditions.

While airborne infrared studies have some significant advantages where numerous buildings must be surveyed, they do miss small wet areas. As discussed previously, such areas are important to find and correct if built-up roof performance is to be significantly improved. Consequently, airborne infrared studies are currently viewed as a method of finding large problem areas, not of locating all moisture problems on a roof. Once the big problems are solved, airborne studies will be of less value. However, our experience to date indicates that there are many roofs that currently have big problems and it will be some time before they are all found and corrected. In the interim, airborne surveys should have definite application.

FINDINGS

Many roofs have been surveyed with the infrared camera during the past two years. A few roofs have been found to contain massive amounts of water in the insulation throughout most of the roof. Often on such roofs the infrared survey has simply verified the strong suspicions of the personnel operating and maintaining the facility visited. However, on occasion, roofs that had not been causing any problems and appeared visually in good condition were found to contain massive amounts of wet insulation. Because of the energy losses associated with such roofs, the ability to find them with the infrared camera is significantly assisting the Army's energy conservation program.

A CRREL infrared roof moisture survey conducted for the State of New Hampshire[4] was supplemented by installing thermoelectric heat flux meters and temperature sensors to determine the in-place thermal resistance of insulation in several roofs. The quantitative thermal information obtained at a few specific locations, coupled with the infrared survey which defined the extent of moisture problems on each roof, was used to quantify the heat loss through the roof. This information, when used in an engineering economic study, defined the most economical alternative for extending the useful life of each roof.

Most wet areas uncovered during the past two years have been relatively small and associated with a drain, vent, or other penetration, or with flashings. Most roofs surveyed had several of these "little" problems. A visual examination the day after such wet areas were located often revealed the cause of the problem (e.g., cracked flashings, loose penetrations, deteriorated membrane). However, there were numerous occasions where no visual signs of a problem could be found.

The ability to find wet areas when they are small is a bit like early detection of a cancerous growth in a human. When the cancer is small, the expense of the operation and the trauma associated with it are relatively minor. Sometimes an operation is not even needed: medication in the form of minor maintenance may provide a solution. When a cancer grows unchecked for many years, major problems often result.

Several relatively new roofs have been surveyed and they also contain moisture problems. Current roofing technology does not appear capable of consistently delivering the 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.

SUMMARY AND CONCLUSIONS

Three agencies of the Corps of Engineers have teamed up to develop and evaluate various techniques for detecting roof moisture. This paper discusses the portion of that program involved with hand-held infrared systems. Infrared cameras see the thermal energy emitted by surfaces. Two portable hand-held scaning infrared camera systems with a photographic recording capability have been used successfully in this work. One is shown in Figure 1. Photographs of the image seen by an infrared camera are called thermograms (see Figures 3, 4, 5 and 9).

A roof area with a hot surface emits more thermal energy and shows up brighter on the viewing screen of an infrared camera than a cooler surface. A hot surface may indicate an area warmed by hot air from an exhaust fan, by a heater suspended below the roof or by other "normal" situations. However a hot area may also indicate the presence of wet insulation that is thermally deficient thereby warming the roof surface during cold weather.

Because wet insulation acts as a heat sink, storing solar energy during the day and liberating it slowly at night, wet insulation can also be located at night during warm weather.

Because of solar effects, all infrared roof surveys are conducted at night regardless of season.

A trained observer can determine which of the hot areas seen by the infrared camera are related to wet insulation. Problem areas are outlined with white spray paint. Numerous 3-in.-diam. core samples of membrane and insulation have been taken to verify infrared findings.

On a large scale such surveys are considered more accurate and potentially less expensive than roof moisture surveys conducted using nuclear moisture meters.

A hand-held infrared camera has been used from a helicopter to conduct preliminary surveys of numerous large built-up roofs at military installations. From the helicopter the camera sees many thermal anomalies but does miss some of the smaller ones. Because it is considered quite important to locate moisture problems when they are small, airborne infrared surveys should always be followed by on-the-roof surveys. The airborne survey is a fast way of finding the worst roofs so that detailed attention can then be directed to them.

Through the use of infrared techniques, numerous wet areas have been located on roofs. Most of the wet areas uncovered have been relatively small and associated with a penetration or flashing. The ability to find little "cancers" and remove them before they generate major problems has proven to be a very effective method for improving the long-term performance and reducing the life-cycle costs of built-up roofs.

REFERENCES

1. Griffin, C. W. (1970) *Manual of Built-up Roof Systems,* McGraw-Hill Book Co., New York, page 82.
2. Link, L. E. (1977) *Airborne Thermal Infrared and Nuclear Meter Systems for Detecting Roof Moisture.* Presented at the 1977 Roofing Technology Symposium, Gaithersburg, Md.
3. Paljak, I and B. Pettersson (1972) *Thermography of Buildings* [*In Swedish and English*]. Sangraf AB Stockholm, Sweden.
4. Tobiasson, W., C. Korhonen and T. Dudley (1977) CRREL Roof Moisture Survey: *Ten State of New Hampshire Buildings.* CRREL report in preparation.

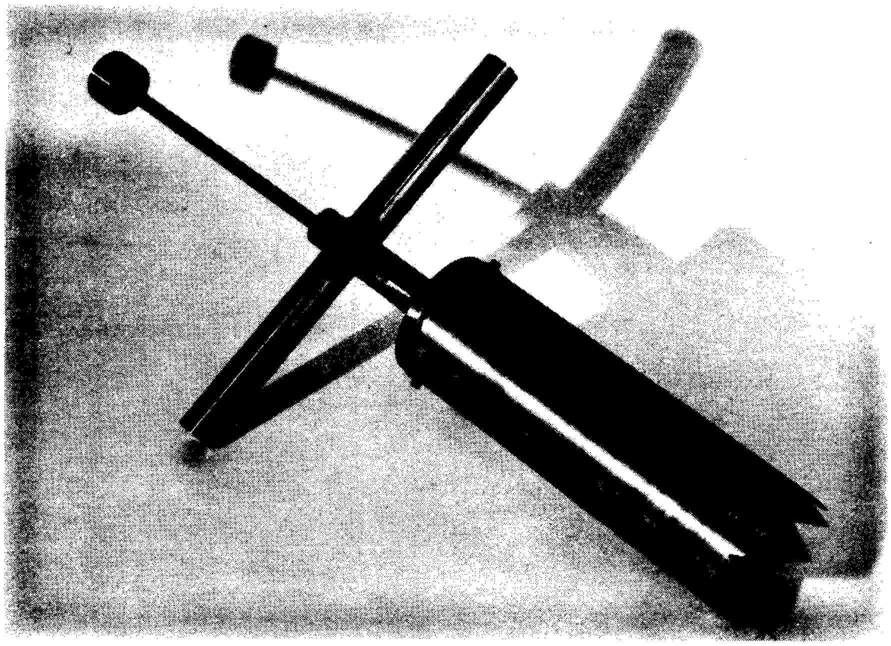


FIGURE 1 - THE CRREL ROOF SAMPLER USED TO OBTAIN 3-IN.-DIAM. CORES OF THE MEMBRANE AND THE INSULATION. THE PLUNGER IS USED TO PUSH THE MEMBRANE-INSULATION CORE SAMPLE OUT OF THE SAMPLER ONCE IT IS CUT OUT OF THE ROOF.

FIGURE 2 - THE AGA THERMOVISION 750 CAMERA SYSTEM.

1. Camera
2. Display unit
3. Polaroid camera and mount
4. Battery pack

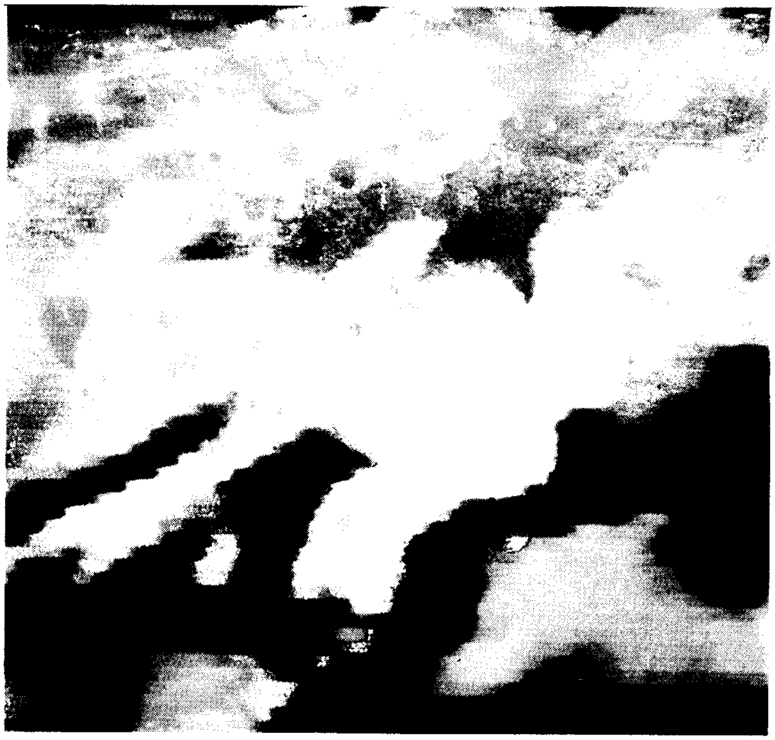


FIGURE 3 - THERMOGRAMS TAKEN OF ROOFS DURING THE DAYTIME ARE BLOTCHY AND CONFUSED BY SOLAR EFFECTS.

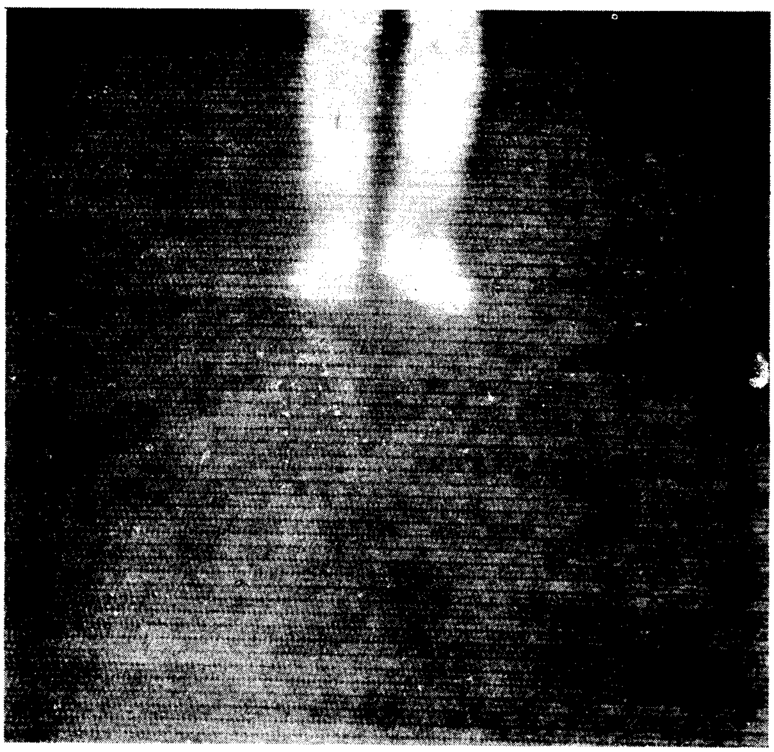


FIGURE 4 - A NIGHT TIME THERMOGRAM OF THE SAME AREA SHOWN IN FIGURE 3 IS A UNIFORM GRAY TONE. THE LEGS OF A MAN ARE VISIBLE IN THE THERMOGRAM.

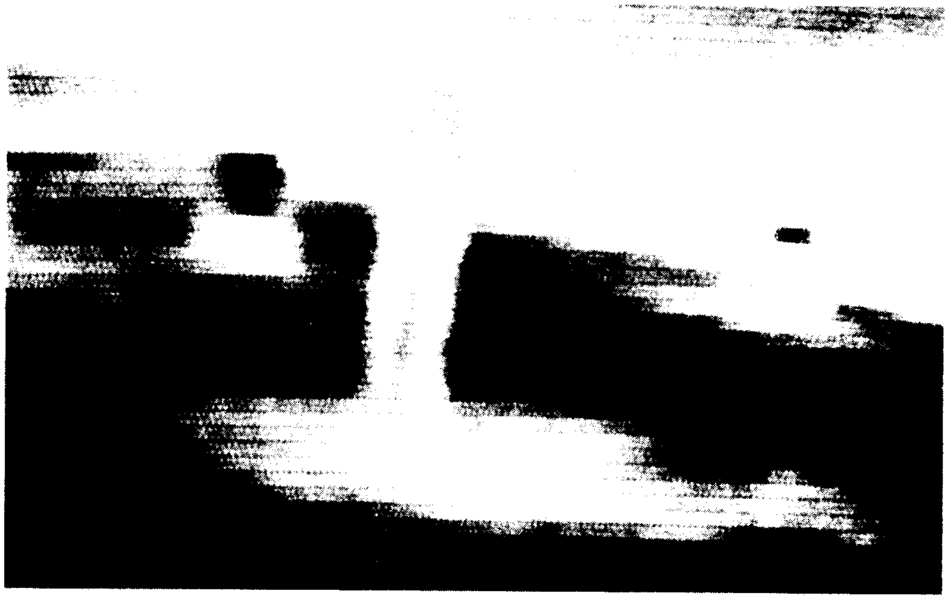
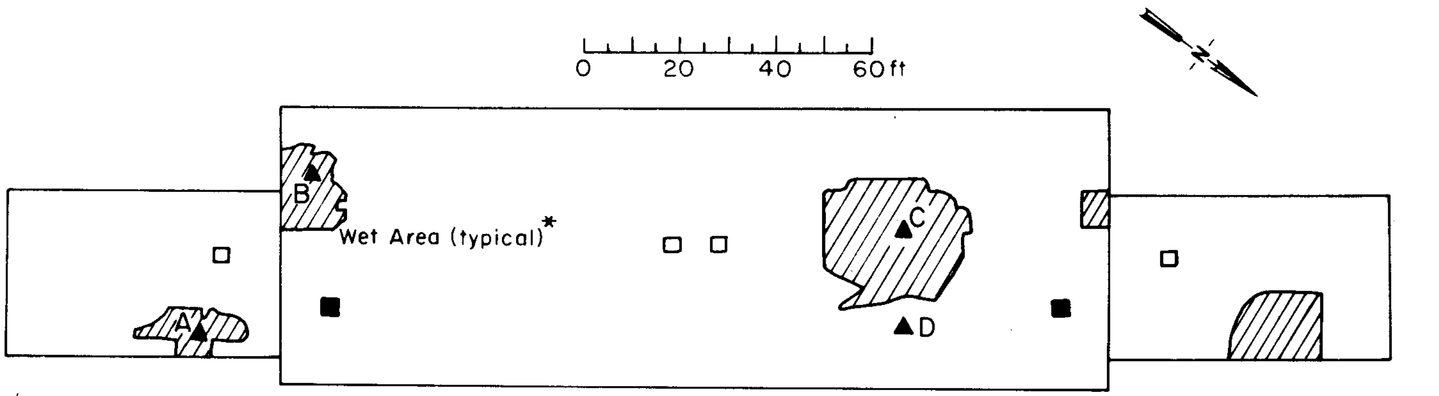


FIGURE 5 - THERMOGRAM OF AN ANOMALY ON A ROOF AT FT. GREELY, ALASKA. A MAN IS STANDING AT THE REAR OF THE ANOMALY. BEHIND HIM TWO ROOF VENTS ARE VISIBLE.

FIGURE 6 - A PHOTOGRAPH OF THE ANOMALY SHOWN IN THE FIGURE 5 THERMOGRAM. NOTE THE BOUNDARY SPRAY PAINTED THE NIGHT BEFORE AND THE LOCATIONS OF THREE CORES (1, 2 and 3).



Legend

- □ Vent
- ■ Hatch or skylight
- ▲ Core sample

Sample	Water Content (%)
A	377
B	319
C	404
D	4

*Boundary of each wet area is marked with white spray paint.

FIGURE 7 – PLAN VIEW OF A ROOF AT FT. DEVENS, MASSACHUSETTS, SHOWING SAMPLE LOCATIONS AND WET AREAS.

FIGURE 8 – AIRPHOTO OF THE GYMNASIUM AT FT. EUSTIS, VIRGINIA.

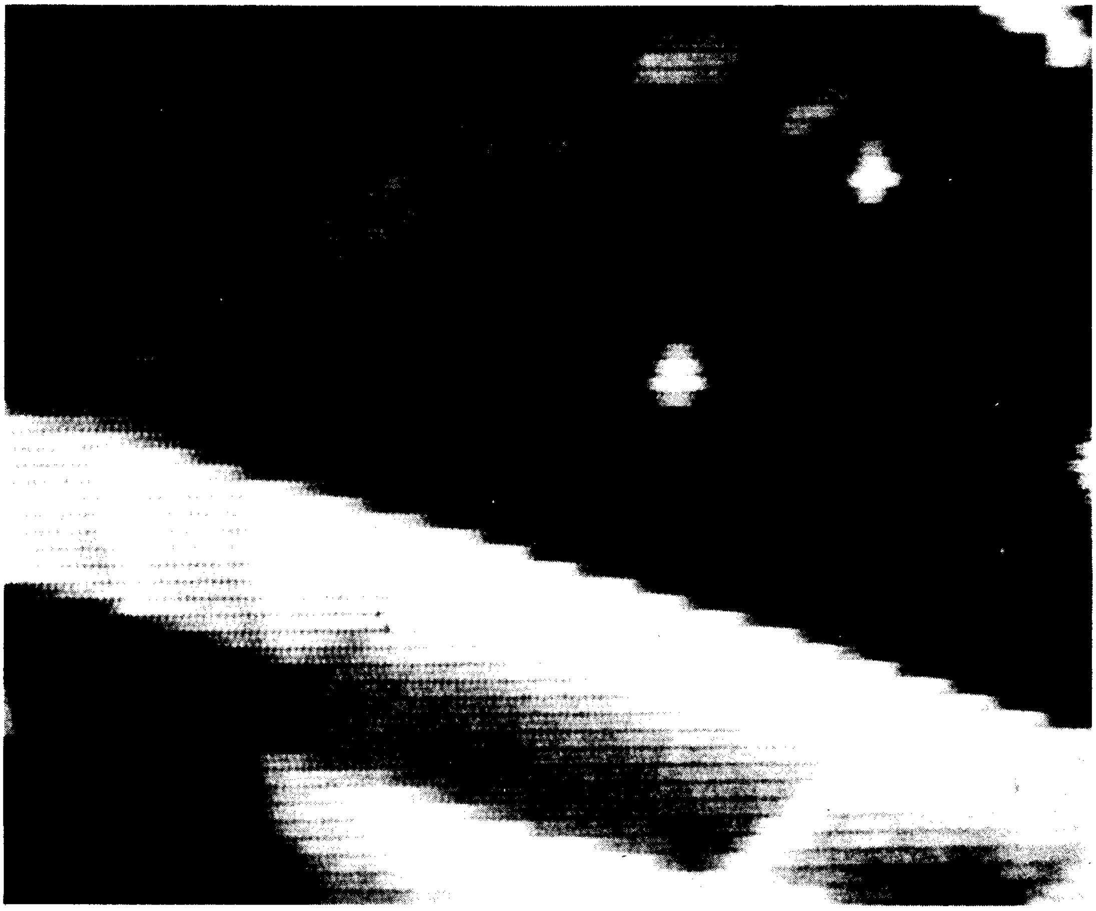


FIGURE 9 – THERMOGRAM TAKEN FROM A HELICOPTER OF THE GYMNASIUM SHOWN IN FIGURE 8. NOTE THE ENTRANCE STRUCTURE, EXHAUST FANS, AND WET (WHITE) ROOF AREAS.