

[54] **METHOD OF DETECTING AND REPAIRING
A STRUCTURAL ROOF DAMAGED BY
SUBSURFACE MOISTURE**

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[56] **References Cited**

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[57] **ABSTRACT**

A method under the title of the application, which involves generating an infrared image of a roof from an airborne position, from infrared radiation emitted by the roof in the spectral band from about 2 to about 14 microns, preferably from about 8 to 14 microns, thus locating roof portions corresponding to areas of anomalous radiation which are potentially moisture laden areas of the roof, and effecting repairs of those roof portions where the presence of subsurface moisture is confirmed by coring or other inspection procedures.

7 Claims, No Drawings

METHOD OF DETECTING AND REPAIRING A STRUCTURAL ROOF DAMAGED BY SUBSURFACE MOISTURE

This invention relates to the roofing art and, more particularly, to a method of detecting and repairing roof systems damaged by subsurface moisture. The invention is particularly applicable to the large flat, and sloped roofs commonly found on industrial, commercial, and educational buildings, including manufacturing plants, apartments, office buildings, warehouses, schools, hospitals, and the like.

Most of these roofs are built-up roofs and will vary to some degree on their exact construction. Roofs are fabricated from a series of superposed layers of materials on the job site. Starting from the inside out, a conventional built-up roof construction starts with a roof deck which could be steel, concrete, wood, wood fibres, gypsum, concrete planks, or any one of the many other decking materials now available. Applied over the roof deck is a vapor barrier with the prime purpose of preventing moisture laden air from within the building from penetrating into the roof system. The material used for the vapor barrier could be polyvinyl chloride sheeting, one or several sheets of roofing felts, mopped in with hot asphalt, or one of the many other types of vapor barriers commercially available.

Disposed over the vapor barrier is the insulation, with the primary purpose of insulating the building, i.e., preventing heat losses in the winter and cooling losses in the summer. Commercially available insulation materials include fiberboard, fiberglass, foam glass, mineral aggregate, urethane board, sprayed urethane, polystyrene, epoxy, and various combinations of these and other materials.

Disposed on top of the insulation is the roof membrane which conventionally consists of a series of alternate layers of roofing felts and a bituminous laminate. The laminates may consist of one of the many types of asphalt or coal-tar pitch. The felts comprise of fibrous material such as asbestos, or fiberglass. They may be saturated, for example with an asphalt or coal-tar pitch, or unsaturated, perforated or imperforate, granulated surfaced or nongranulated surfaced. The topmost surface of the roof membrane is usually provided with a heavy mopping of bitumen, or a coating of one or more of the various roof paints or new elastomers now on the market, such as silicone, urethane, epoxy, or other synthetic elastomers. Where the roof is heavily mopped it may be covered with slag, gravel, marble chips, or other types of aggregate.

Moisture may infiltrate a roof system during the construction of the built-up roof. Roofing materials on the job are frequently stored unprotected from the elements. Inclement weather such as rain, snow, sleet, fog, or even high humidity in the atmosphere will dampen the materials before and during installation, resulting in "built-up" wet insulation.

Moisture may also infiltrate the roof system if the vapor barrier is omitted, not specified, damaged during construction, or damaged by movement after construction.

As the roof membrane ages, the exposed surfaces tend to become brittle and dry through the deleterious effects of weathering, e.g. exposure to ultraviolet and infrared radiation, moisture, gases, and pollutants. In addition, thermal movement of the various roofing

components, due to temperature changes, aggravates the aging condition by exerting forces capable of producing cracks and breaks in the roof membrane, through which water may be admitted into the roofing system. The water may penetrate the outer layer through the roofing felts, down through the insulation, then down through the vapor barrier and into the building below. The presence of a reliable vapor barrier may prevent the water from entering the building interior, but in this event, the water would be trapped within the insulation of the roof system.

Moisture trapped in the roof insulation tends to proliferate throughout the roof system due to gravity, atmospheric conditions, and the vaporizing effect of solar heat. Vapor pressures intensify in the roof system with solar heat causing blisters, felt delamination, breaks, holes, etc. This enhances the already deleterious effects of weathering and thermal movement and hastens the eventual failure of the roof system.

As the insulation within the roof system becomes water laden, the insulating value of the roof insulation decreases. Even moderately damp insulation has little insulating value. Unless and until water actually leaks into the interior of the building under the roof system, building owners generally remain unaware of the wet insulation. Wet insulation not only fails to insulate, but when subjected to wet-dry cycles, loses adhesion to the vapor barrier on the interior side and adhesion to the roof on the outside. This creates a further problem of movement, shrinkage, and expansion of all components of the roof system since the roof membrane and insulation are not restrained.

The more devastating stage of extended wet insulation can completely deteriorate the structural roof deck underneath, resulting in wood rotting, steel rusting, concrete spalling, and gypsum and wood fibers crumbling. Weights from traffic, snow, standing water, etc. can cause a complete collapse of any roof under these conditions.

In order to forestall the advancement of roof deterioration, it is necessary to make periodic visual inspections of the roof surface to discern anticipated sources of water entry into the roof system and visible evidence of the actual presence of water in the insulation. Historically, these inspections have been conducted by one or more men touring the roof looking for breaks, holes, dry exposed felts, blisters, fishmouths, or other openings which could allow water to enter the roof system. Visible earmarks of water or moisture already trapped within the roof system's insulation include blisters, delaminated roofing felts, and sponginess underfoot.

Water or moisture which has infiltrated the roof system's insulation as described above is normally not detectable by conventional visual inspection unless the deterioration has progressed to more advanced stages. Thus, a perfectly sound appearing roof may be completely saturated. Therefore, for a complete and thorough analysis of the condition of the roofing system, the roof membrane must be cut and opened to visually observe the extent of moisture invasion. This method of inspection is generally known as "coring," and can also be supplemented by an electrical probe, which must be verified due to the changes in the electrical current produced by small flashlight batteries. Coring of a roof should involve, at a minimum, the cutting of cores each 20 feet in all directions with additional cores being cut to define precise areas of wet insulation.

The aforementioned technique for a thorough inspection of the roof has a number of imperfections and inadequacies. The cutting of cores requires making holes in the water-proofing roof membrane, which are potential situses of moisture penetration. The cutting of even the minimum number of cores, i.e., 20 foot intervals, is a costly, time consuming procedure. Further, there is no way of determining with any certainty the precise location of the wet insulation, since it is possible that the insulation may be wet between the dry cores.

Due to the expense and time involved, proper examinations cannot always be conducted although most building owners, at a minimum, conduct or have conducted a visual inspection of the roof. The practice of cutting cores is either completely ignored, due to the time element, or it is minimized to only the suspected areas observed through visual inspection. As a result, areas much larger than the probable wet area are replaced "just to be sure." In some instances an entire roofing system may be replaced rather than spending the time and cost for a more thorough inspection. This practice can double the costs of repairing the roof system.

Another possible consequence of incomplete inspections is the risk of making repairs over water damaged but undetected roof portions. Such repairs usually will fail prematurely forcing the owner to expend additional monies to effect proper repairs.

Although some of these problems are minimized if all roof inspection techniques are utilized, the inspection falls short of adequacy due to the guesswork inherently involved in such inspections.

It should be apparent from the foregoing discussion that the present methods of detecting and repairing roof systems damaged by moisture are less than satisfactory, and that there is a need for improved methods for accomplishing these objectives. The present invention is addressed to filling this need.

In accordance with the present invention, an entire roof can be inspected for any moisture laden areas below the surface of the roof and identified in a matter of minutes, regardless of the size of the building, through the recording of thermal imagery. More specifically, in accordance with the present invention, there is provided a method of detecting and repairing roof systems damaged by subsurface moisture, comprising, detecting and recording, from an airborne position, infrared radiation emitted by a roof in the range of about 2 to 14 microns in wavelengths, generating a visual image from the emitted infrared radiation, photographing the visual image to provide a permanent record thereof, locating roof portions corresponding to anomalous radiation, confirming the presence or absence of subsurface moisture in the corresponding roof portion and repairing those roof portions where the presence of subsurface moisture is confirmed.

It is therefore an object of the present invention to provide an improved method of detecting and repairing a roof system damaged by subsurface moisture.

A further object of the present invention is to provide a method of detecting and repairing roof systems damaged by subsurface moisture by employing infrared imagery to detect the damaged roof areas to identify the metes and bounds of the areas to be repaired.

These and other objects and advantages will become apparent from the following detailed description of the

invention which includes the best mode presently contemplated for practicing it.

As is well known, all bodies of matter at temperatures above 0° K emit electromagnetic radiation. The magnitude and wavelength of this thermal radiation, emitted per unit area, is a function of the temperature and emittance characteristics of the emitting body. It has been found that the infrared emission of black or gray bodies, at approximately 300° K (room temperature), peaks at approximately 10 microns and, in general, covers the infrared spectral region of wavelengths from above about 2 microns to about 14 microns. This region embraces two bands of wavelengths about 3 to about 5.5 microns and about 8 to about 14 microns, which cover the wavelengths of most of the emitted infrared radiation.

For purposes of the present invention, it has been found that operation in the 8 to 14 micron band has been the most successful, since this band embraces the maximum emission wavelength at about 10 microns. However, this does not preclude operating successfully within the 2 to 14 micron region.

In practice of the present invention, the inclusion of water in the roof insulation alters the thermal properties of the insulation, primarily, in two ways, by increasing its thermal capacity and thermal conductivity.

An increase in the thermal capacity of a roof portion will result in a lag in the time it takes for that portion of the roof to show a temperature response to varying heat loads, such as occur during the daytime due to solar radiation. Specifically, as the sun rises and a roof is subjected to an increasing heat input, the wet insulation areas will warm at a slower rate than dry insulation areas due to the increased heat capacity and thus appears cooler in infrared images. Conversely, after the sun sets and the roof is cooling, the wet insulation areas will in time appear warmer than the surrounding roof areas.

An increase in the thermal conductivity of an area of a roof can be detected from infrared imagery if there exists a thermal gradient across the thickness of the roof. Specifically, if the outside air temperature is substantially lower than the inside air temperature as in winter, then the more conductive wet areas of the roof will be characterized by a reduced temperature gradient across the thickness of the roof. Thus, the wet areas will be warmer than the surrounding roof areas and can be observed on the infrared images as areas of increased radiation.

Visible images can be prepared which correspond to the infrared images. The visible images can be processed so that the areas of increased infrared radiation can appear as either lighter or darker than areas of low infrared radiation.

In the practice of the invention, the roof to be inspected and repaired is flown over either in a helicopter or fixed wing aircraft at an elevation within the range of about 300 feet minimum for a helicopter, and about 1,000 feet minimum for fixed wing aircraft. Maximum height would be approximately 800 feet for the helicopter, and 1,500 feet for the fixed wing aircraft. Although air speed will vary, generally the average speed for our purposes for helicopter is 50 mph, and on fixed wing aircraft, 100 mph.

The equipment used to detect and record infrared imagery comprises a remote sensing instrument which may, for example, comprise a liquid nitrogen cooled

semiconductor infrared detector placed at the focus of an optical collector which is caused to scan the roof, as the aircraft moves forward, by means of a rotating mirror optical system.

The detector senses consecutive scan lines across the flight path. The electronic signal from the detector is amplified and used to modulate a glow tube, the light from which is a visible representation of the intensity of sensed infrared energy. This light is scanned across photographic film in a process which duplicates the original scanning motion. Advancing the film duplicates the forward motion of the aircraft.

Alternatively, the amplified signal may be recorded as a digital or analog signal, for example on magnetic tape, and then translated into a visible image on a CRT (cathode ray tube) glow tube modulator laser beam or the like. A permanent photographic record would then be made of the visible image. To minimize the amount of equipment which must be airborne it is preferred to do no more than record the digital or analog signal aloft and process the signal into a permanent visible record on the ground. Even the digital or analog signal may be recorded on the ground by telemetry.

Remote sensing instruments, useful in the practice of the invention, are commercially available. Examples are Thermal Mapper LN-2LW and Thermal Mapper LN3, both utilizing a HgCdTe detector which senses radiation in the 8 to 13 micron spectral region. Thermal Mapper TM-LN-3 also provides for the interchangeability of detector modules for sensing radiation in the 0.2 to 13 micron spectral region. Both models are manufactured by the Aerospace Systems Division, Bendix Corporation.

Coupled with the remote sensing instrument is an oscilloscope, which serves as a monitoring device and as a data collection checkpoint. It enables the scanner technician to make adjustments in the contrast and brightness of a visible representation of the applied signal from the detector. One example of the oscilloscope is the Tektronix Model No. 422.

At the same time that the remote infrared sensing instrument is detecting and recording a visible image of infrared radiation, it is highly desirable to photograph, by conventional photographic means, the same target or areas being scanned by the infrared sensing equipment, for use as a reference for visual interpretive information. By using the photograph as a reference it is possible to include or exclude from further consideration certain areas of anomalous radiation as identifying potentially moisture laden areas. For example, by checking the actual photograph, an area of anomalous radiation on the infrared image may be explained by a shadow, ponded water, a boiler room, various colors of the roof surface with varying differences in emissivity, vaporized moisture from air conditioning units, or the like. These areas can then be excluded from further consideration as potentially subsurface moisture laden areas.

While the thermal image generally indicates the location of ventilators, vent pipes, sumps, and expansion joints by their recognizable anomalous radiation patterns which provides suitable "bench marks" for precise location of the suspected areas of subsurface moisture laden insulation radiation, the conventional photographs serve to verify the existence of the "bench marks."

After the anomalous areas on the photograph of the thermal imagery have been located, and those attributed to phenomena other than subsurface moisture eliminated from further or subjugated to secondary consideration, the roof is then inspected physically to confirm the presence or absence of subsurface moisture in the remaining areas of anomalous radiation. Since the metes and bounds of the anomalous radiation area are generally well defined in the photograph of the thermal imagery, it is necessary to cut and inspect only a very few core samples of the roof to confirm the presence or absence of moisture. This examination procedure not only confirms the presence or absence of moisture, but assists in making the determination of the extent of the damage, type of construction, and the type of repair which should be made.

Repairs can be divided into two broad categories; rehabilitation of the existing roof system, and replacement of the roof system. It is possible to utilize both categories on one roof. If moisture infiltration has been nominal, and the insulation lends itself to "breathing" it may be possible to rehabilitate the roof system in the installation of insulation vents to relieve the vapor pressure, and to eventually dry out the insulation. When this procedure is followed, all breaks and openings where water had or still could penetrate the roof system, must be repaired and sealed tightly to preclude a reoccurrence of the original problem.

Depending on the severity of the aging process, the roof may also receive either a rejuvenating or penetration application, or one of the various surface coatings, depending on the type and/or condition of the roof involved.

Where moisture infiltration has reached a point closer to saturation, where entrapped moisture has damaged the surface of the roof, or where damage to the deck is suspected, it is necessary to remove the roofing system down either to the roofing deck or the vapor barrier, depending on individual conditions, and replace the roof with a new roof system. Deterioration or unsafe roof decks must also be replaced.

It will therefore be seen that the present invention provides an improved method of detecting and repairing roof systems damaged by subsurface moisture. The method not only permits a very rapid identification of potentially moisture laden areas of the roof under consideration, but substantially reduces the amount of actual roof inspection needed to confirm the presence or absence of subsurface moisture and evaluate the amount of damage done by the moisture. Practice of the method also provides a clear delineation of the area of moisture damage, greatly simplifying estimating and specifying the areas to be replaced, thus effecting a substantial savings in time and materials, and the elimination of waste.

Having thus described our invention, we claim:

1. A method of detecting and repairing a roof damaged by subsurface moisture comprising
 - detecting from an airborne position infrared radiation emitted from the roof in the range of about 2 to about 14 microns in wavelength
 - generating a visible image from the detected radiation
 - photographing the image to provide a permanent record thereof

7

locating roof portions of said image corresponding to areas of anomalous radiation potentially attributable to subsurface moisture confirming the presence or absence of subsurface moisture in said roof portions and repairing those roof portions where the presence of subsurface moisture is confirmed.

2. The method as defined in claim 1 wherein said detecting step is conducted at an elevation within the range of from about 300 to about 1,500 feet above the roof.

3. The method as defined in claim 1 wherein said step of confirming the presence or absence of subsurface moisture comprises cutting one or more cores from the roof and examining the subsurface structure for moisture.

4. The method as defined in claim 1 wherein the step

8

of locating roof portions corresponding to said areas of anomalous radiation comprises generating an actual photograph of the roof and locating on it roof portions corresponding to said areas of anomalous radiation.

5. The method as defined in claim 4 wherein said detecting step and said step of generating an actual photograph of the roof are both conducted at an elevation within the range of from about 300 to about 1,500 feet above the roof.

6. The method as defined in claim 1 wherein said detecting step is conducted with respect to emitted radiation in the range of about 8 to about 14 microns.

7. The method as defined in claim 5 wherein said detecting step is conducted with respect to emitted radiation in the range of about 8 to about 14 microns.

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