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Standard Practice for Location of Wet Insulation in Roofing Systems Using Infrared Imaging[1]

This standard is issued under the fixed designation C 1153; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ϵ^1 NOTE—Warning notes were editorially moved into the standard text in April 2003.

1. Scope

1.1 This practice applies to techniques that employ infrared imaging at night to determine the location of wet insulation in roofing systems that have insulation above the deck in contact with the waterproofing. This practice includes ground-based and aerial inspections. (**Warning—**Caution should be taken in handling any cryogenic liquids and pressurized gases required for use in this practice.) (**Warning—**Extreme caution should be taken when accessing or walking on roof surfaces and when operating aircraft at low altitudes, especially at night.) (**Warning—**It is a good safety practice for at least two people to be present on the roof surface at all times when ground-based inspections are being conducted.)

1.2 This practice addresses criteria for infrared equipment such as minimum resolvable temperature difference, spectral range, instantaneous field of view, and field of view.

1.3 This practice addresses meteorological conditions under which infrared inspections should be performed.

1.4 This practice addresses the effect of roof construction, material differences, and roof conditions on infrared inspections.

1.5 This practice addresses operating procedures, operator qualifications, and operating practices.

1.6 This practice also addresses verification of infrared data using invasive test methods.

1.7 The values stated in SI units are to be regarded as standard.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given in 1.1.

2. Referenced Documents

2.1 *ASTM Standards:*

C 168 Terminology Relating to Thermal Insulation[2]

D 1079 Terminology Relating to Roofing, Waterproofing, and Bituminous Materials[3]

E 1149 Definitions of Terms Relating to NDT by Infrared Thermography[4]

E 1213 Test Method for Minimum Resolvable Temperature Difference for Thermal Imaging Systems[5]

2.2 *ANSI-ASHRAE Standard:*

ANSI-ASHRAE Standard 101—Application of Infrared Sensing Devices to the Assessment of Building Heat Loss Characteristics[6]

2.3 *ISO Standard:*

ISO/DP 6781.3E—Thermal Insulation—Qualitative Detection of Thermal Irregularities in Building Envelopes—Infrared Method[6]

3. Terminology

3.1 *Definitions:*

3.1.1 *blackbody, n*—the ideal, perfect emitter and absorber of thermal radiation. It emits radiant energy at each wavelength at the maximum rate possible as a consequence of its temperature, and absorbs all incident radiance. (See Terminology C 168.)

3.1.2 *core, n*—a small sample encompassing at least 13 cm^2 of the roof surface area taken by cutting through the roof membrane and insulation and removing the insulation to determine its composition, condition, and moisture content.

3.1.3 *detection, n*—the condition at which there is a consistent indication that a thermal difference is present on the surface of the roof. Detection of thermal anomalies can be

[1] This practice is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.

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[2] *Annual Book of ASTM Standards*, Vol 04.06.

[3] *Annual Book of ASTM Standards*, Vol 04.04.

[4] Discontinued. Replaced by E 1316. See 1990 *Annual Book of ASTM Standards*, Vol 03.03.

[5] *Annual Book of ASTM Standards*, Vol 03.03.

[6] Available from American National Standards Institute, 25 W. 43rd St., 4th Floor, New York, NY 10036.

accomplished when they are large enough and close enough to be within the spatial resolution capabilities of the imaging system; that is, when their width is at least two times the product of the instantaneous field of view (IFOV) (see 3.1.10) of the system and the distance from the system to the surface of the roof divided by 1000.

3.1.4 *emittance*, ϵ, *n*—the ratio of the radiant flux emitted by a specimen to that emitted by a blackbody at the same temperature and under the same conditions. (See Terminology C 168.)

3.1.5 *expansion joint*, *n*—a structural separation or flexible connection between two building elements that allows free movement between the elements without damage to the roofing or waterproofing system. (See Terminology D 1079.)

3.1.6 *field-of-view, (FOV)*, *n*—the total angular dimensions, expressed in radians, within which objects can be imaged, displayed and recorded by a stationary imaging device.

3.1.7 *infrared imaging line scanner*, *n*—an apparatus that scans along a single line for variations in infrared radiance and is moved perpendicular to that line to produce a two-dimensional image of the region scanned.

3.1.8 *infrared imaging system*, *n*—an apparatus that converts the spatial variations in infrared radiance from a surface into a two-dimensional image, in which variations in radiance are displayed as a range of colors or tones.

3.1.9 *infrared thermography*, *n*—the process of generating images that represent variations in infrared radiance of surfaces of objects.

3.1.10 *instantaneous field of view, (IFOV)*, *n*—the smallest angle, in milliradians, that can be instantaneously resolved by a particular infrared imaging system.

3.1.11 *line scanner*, *n*—an apparatus that scans along a single line of a scene to provide a one-dimensional thermal profile of the scene. (See Terminology E 1149.)

3.1.12 *membrane*, *n*—a flexible or semiflexible roof covering or waterproofing whose primary function is the exclusion of water. (See Terminology D 1079.)

3.1.13 *minimum resolvable temperature difference (MRTD)*, *n*—a measure of the ability of operators of an infrared imaging system to discern temperature differences with that system. The MRTD is the minimum temperature difference between a four slot test pattern of defined shape and size and its blackbody background at which an average observer can discern the pattern with that infrared imaging system at a defined distance.

3.1.14 *moisture meter probe*, *n*—an invasive (electrical resistance or galvanometric type) test that entails the insertion of a meter probe(s) through the roof membrane to indicate the presence of moisture within the roofing system.

3.1.15 *radiance*, *n*—the rate of radiant emission per unit solid angle and per unit projected area of a source in a stated angular direction from the surface (usually the normal). (See Terminology C 168.)

3.1.16 *recognition*, *n*—the ability to differentiate between different types of thermal patterns such as board-stock, picture-framed and amorphous. Recognition of thermal anomalies can be accomplished when their width is at least eight times the product of the IFOV of the infrared imaging system and the distance from the system to the surface of the roof divided by 1000.

3.1.17 *roof section*, *n*—a portion of a roof that is separated from adjacent portions by walls or expansion joints and in which there are no major changes in the components.

3.1.18 *roofing system*, *n*—an assembly of interacting components designed to weatherproof, and normally to insulate, a building's top surface. (See Terminology D 1079.)

3.1.19 *survey window*, *n*—the time period during which roof moisture surveys can be successfully conducted according to the requirements of Section 10.

3.1.20 *thermal anomaly*, *n*—a thermal pattern of a surface that varies from a uniform color or tone when viewed with an infrared imaging system. Thermal anomalies may be caused by wet insulation.

3.1.21 *thermogram*, *n*—a recorded visual image that maps the apparent temperature pattern of an object or scene into a corresponding contrast or color pattern. (See Terminology E 1149 with the word "recorded" added.)

4. Significance and Use

4.1 This practice should be used to outline the minimum necessary elements and conditions to obtain an accurate determination of the location of wet insulation in roofing systems using infrared imaging.

4.2 This practice is not meant to be an instructional document or to provide all the knowledge and background necessary to provide an accurate analysis. For further information, see ANSI-ASHRAE Standard 101 and ISO/DP 6781.3E.

4.3 This practice does not provide methods to determine the cause of moisture or its point of entry. It does not address the suitability of any particular system to function capably as waterproofing.

5. Infrared Survey Techniques

5.1 *Ground-Based*:

5.1.1 *Walk-Over*—Walking on a roof using an infrared imaging system. The system may be hand-carried or mounted on a cart. Thermograms are taken of areas of interest. Areas that appear to contain wet insulation are identified and marked for verification.

5.1.2 *Elevated Vantage Point*—Use of an infrared imaging system from an elevated vantage point may provide an improved view of the roof.

5.2 *Aerial*:

5.2.1 *Real-Time Imaging*—Use of an infrared imaging system from an aircraft. Thermograms are obtained for the entire roof.

5.2.2 *Line Scanner Imaging*—Use of a line scanner from an aircraft to record thermal imagery for the entire roof.

6. Instrument Requirements

6.1 *General*:

6.1.1 *Objective*—Instrument requirements have been established in order to permit location of insulation that has lost as little as 20 % of its insulating ability because it contains moisture.

6.1.2 *Spectral Range*—The infrared imaging system shall operate within a spectral range from 2 to 14 µm. A spot radiometer or nonimaging line scanner is not sufficient.

6.1.3 *Minimum Resolvable Temperature Difference (MRTD)*—The MRTD at 20°C shall be 0.3°C.

6.1.3.1 The survey shall be conducted with the thermal imaging system only on sensitivity settings that meet this requirement.

6.1.4 *Test for Minimum Resolvable Temperature Difference*:

6.1.4.1 *Instrument Setting*—The thermal imaging system shall be tested at each sensitivity that the system will be used.

6.1.4.2 *Test Target Pattern*—The test target shall consist of two plates with known temperatures, located in front of the imaging system. The near plate shall have four equally spaced slots each having 7:1 height-to-width ratio (see Fig. 1).

6.1.4.3 *Test Geometry*—Refer to Fig. 1. The ratio of the width, (*w*), on the test pattern to the distance, (*d*), to the imaging system shall be established, using the maximum IFOV allowed for the type of survey being conducted, as follows:

$$w/d < 0.002\ (\text{IFOV})$$

where:
w and *d* are in the same units and IFOV is in milliradians. Maximum allowable values of IFOV are defined in 6.2.2, 6.3.2, and 6.4.2.

6.1.4.4 *Test Procedure*—In accordance with Test Method E 1213, the temperature difference between the two plates of the target is slowly increased without communicating with the observer. The observer announces when the test pattern comes into view on the display. The temperature at this point is recorded.

6.1.4.5 *Test Replicates*—Because of differences in visual acuity, more than one observer shall perform the procedure in 6.1.4.4. The average temperature difference is the MRTD for that test condition.

6.2 *Walk-Over Surveys*:

6.2.1 *Anomaly Size*—Instrument requirements have been established to permit recognition of areas of wet insulation as small as 0.15 m on a side.

6.2.2 *Recognition Distance, FOV and IFOV*—Recognition can be accomplished when the width of a thermal anomaly, in metres, is at least 0.008 times the product of the IFOV of the system and the distance, in metres, from the system to the anomaly. Since the walkover survey shall be accomplished at a maximum distance of 5 m, the IFOV of the apparatus shall be 3.8 milliradians, or less. The horizontal and vertical FOVs shall be at least 0.21 rad (12°) by 0.10 rad (6°), respectively.

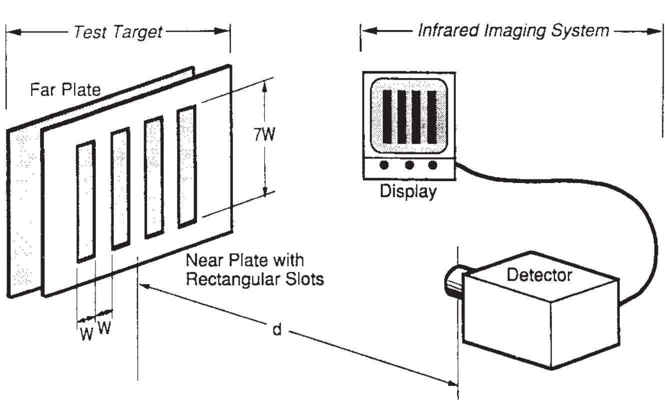

FIG. 1 Test Arrangement for Minimum Resolvable Temperature Difference (MRTD) of an Infrared Imaging System

6.3 *Elevated Vantage Point Surveys*:

6.3.1 *Anomaly Size*—Instrument requirements have been established to permit recognition of areas of wet insulation as small as 0.15 m on a side.

6.3.2 *Recognition Distance, FOV and IFOV*—Since recognition must be possible at distances greater than 5 m, the maximum allowable IFOV in milliradians is related to distance, (*d*), in metres from the infrared imaging system to the place on the roof being scanned as follows:

$$\text{IFOV} = 18.8/d$$

The minimum horizontal FOV shall be 1.0/*d* and the minimum vertical FOV shall be 0.5/*d*, both expressed in rad.

6.4 *Aerial Surveys*:

6.4.1 *Anomaly Size*—Aerial surveys shall be conducted with infrared imaging line scanners or infrared imaging systems that have the ability to detect areas of wet insulation as small as 0.3 m on a side directly below the system.

6.4.2 *Detection Distance, FOV and IFOV*—Detection can be accomplished when the width of a thermal anomaly, in metres, is at least 0.002 times the product of the IFOV of the system and the distance, in metres, from the system to the anomaly. The maximum allowable IFOV is related to the vertical distance (*d*), in metres, above the roof, as follows:

$$\text{IFOV} = 150/d$$

The FOV along the line of flight and across the line of flight shall be at least 0.05 rad by 0.10 rad, respectively. The usable field of view shall be within 0.35 rad of a point directly below the infrared imaging system.

7. Level of Knowledge

7.1 The proper conduct of a roof moisture survey using an infrared imaging system requires knowledge of how and under what circumstances the system can be used and a general understanding of roof construction.

7.2 Proper interpretation of infrared data requires knowledge of infrared theory, moisture migration, heat transfer, environmental effects, and roof construction as they apply to roof moisture analysis.

8. Limitations (Applicability of Constructions)

8.1 Applicable constructions include membrane systems containing any of the commercially available rigid insulation boards. This includes boards made of organic fibers, perlite, cork, fibrous glass, cellular glass, polystyrene, polyurethane, isocyanurate, and phenolic. Composite boards and tapered systems made from these materials can also be inspected as can roofs insulated with foamed-in-place polyurethane.

8.2 When extruded polystyrene insulation is placed under ballast and above a protected membrane, it is quite difficult to locate moisture in the insulation below the membrane by use of infrared thermography.

8.3 Wet applied insulations such as lightweight concrete and wet applied decks such as gypsum can be difficult to survey since they may retain significant quantities of construction water.

8.4 When moisture sensitive materials are located under pavers, stone ballast or insulating gravel (for example, scoria), or layers of dry insulation, thermal anomalies on the surface of the roof are diminished.

8.5 For roofs with highly reflective surfaces (that is, aluminized coatings or foils) in the spectral range of the infrared imaging system being used, infrared surveys are not practical until the surface is naturally or temporarily dulled.

8.6 The wetting rates of roof insulations vary according to the type of insulation and the environmental exposure. New roofs with insulations that wet slowly, such as cellular plastics or cellular glass, usually should not be surveyed until they are at least eight months old.

8.7 Infrared thermography can be used to locate wet roof insulation but will not always identify the source of the moisture.

9. Significant Environmental Parameters

9.1 Water retained in roofing systems decreases the thermal resistance and increases the heat storage capacity of such systems. This can lead to thermal anomalies on the surface that can be located using an infrared imaging system. These thermal anomalies depend upon the type of roofing system, the amount of moisture in the insulation, and the weather conditions. For a given roof, there are four weather related parameters that can cause significant changes in surface temperatures over wetted roof areas compared to dry areas. These are: inside to outside temperature difference, the rate of change of temperature in the hours prior to viewing, the amount of insolation (sunlight), and the wind speed.

9.2 Acceptable weather conditions for a nighttime infrared imaging inspection will be light winds with some combination of a large inside to outside temperature difference, a rapid decrease in temperature in the late afternoon and a sunny day before scanning. Typically, an infrared inspection during cold weather relies on a large inside to outside temperature difference and an infrared inspection during warm weather is best during a cool night after a hot sunny day.

9.3 *Inside to Outside Temperature Difference*—Thermal anomalies become more distinct as the inside to outside temperature difference increases.

9.4 *Rate of Change of Temperature*—The surface temperature over a wet roof area responds more slowly to a change in the air temperature than the surface temperature over a dry roof area. Thus, when the whole roof is cooling, wet areas will cool more slowly. The greater the rate of outside temperature change, the greater the difference in surface temperature between wet and dry areas.

9.5 *Insolation*—During the course of a sunlit day, wet roof areas will store more solar energy than dry areas, thus, they will cool more slowly during the evening. This effect increases as the insolation increases; that is, the effect is greater in the summer than in the winter and greater on a clear day than on a cloudy day. Shaded areas receive less insolation than unshaded.

9.6 *Wind*—Air flow over a roof surface increases the convective heat transfer to the surrounding air significantly. This causes all surface temperatures to approach the ambient air temperature. This, in turn, reduces any difference in temperature between wet and dry areas caused by other effects.

10. Required Conditions

10.1 No appreciable precipitation shall have fallen on the roof during the 24 h prior to the infrared survey.

10.2 At the time of the survey, the surface of the roof shall be free of ponded water, snow, ice, debris, and piles of aggregate except that these conditions may exist in a few areas provided that those areas are delineated as being unsurveyed in the report.

10.3 At the time of the survey, winds in the area shall be less than 25 km/h.

10.4 After a day of heavy overcast, surveys shall not be conducted unless the outside temperature is at least 10°C colder than the temperature of the space under the roof deck at the time of the survey and for most of the prior 24 h. In other weather, the indoor to outdoor temperature difference is not an issue except as indicated in 10.7 and 12.2.

10.5 Most surveys can be conducted from 1 h after sunset until sunrise. However, it may be necessary to delay the start of surveys after warm cloudy days since cloud cover reduces both daytime insolation and nighttime radiational cooling. To check that a sufficient delay has been allowed after such days, the first portion of the survey shall be repeated before leaving the roof.

10.6 The formation of dew or frost on the roof will reduce the intensity of thermal anomalies. It may not be possible to conduct surveys under these conditions.

10.7 Roofing systems ballasted with stone or pavers should only be surveyed when the outside temperature at the time of the survey and for most of the prior 24 h has been at least 18°C colder than the temperature of the space under the roof deck. If insulation is present above the roof membrane, the indoor/outdoor temperature difference should be at least 23°C to detect moisture in the insulation under the membrane.

11. Inspection Procedures

11.1 *Ground-Based Surveys*:

11.1.1 Whenever possible the underside of the roof should be examined visually. Room temperature, equipment, air movement, and changes in construction can affect thermal anomalies.

11.1.2 An infrared imaging system shall be maneuvered over the roof in an organized manner to ensure complete inspection viewing at an angle greater than 0.35 rad from the surface of the roof.

11.1.3 Areas containing wet insulation shall be delineated on the surface of the roof in a semipermanent manner such as with spray paint.

11.1.4 Infrared findings shall be verified in accordance with Section 13.

11.1.5 The location of all verification readings shall be marked on the surface of the roof.

11.2 *Aerial Surveys*:

11.2.1 *Compliance*—Before aerial surveys are conducted, the requirements of regulatory bodies such as the Federal

Aviation Administration (FAA) must be met with regard to installed equipment, flight safety, security, and noise.

11.2.2 *Execution*—The survey shall be conducted so as to meet the conditions in 6.2. Thermographic findings of line scanners shall be recorded on photographic film or magnetic media. The findings of infrared imaging systems shall be viewed on a monitor in the aircraft during the flight to ensure that the roof has been surveyed properly. The findings are also recorded for detailed study after the flight. The information required in Section 14 shall be obtained.

11.2.3 *Reconnaissance Surveys*—Surveys that do not meet all the requirements of 6.2 may be useful but are considered to be of reconnaissance value only.

11.2.4 *Visual*—The roofs surveyed shall be inspected visually during daylight hours within two days of when the aerial infrared survey is conducted in order to provide a visual record of roof surface conditions which may affect the infrared survey. The visual inspection can be accomplished by taking air photographs or by walking the roof. The condition of the roof surface shall not have changed appreciably in the period between the infrared roof moisture survey and the visual inspection.

11.2.5 *Verification*—Infrared data shall be verified according to Section 13.

11.2.6 The location of all verification readings shall be marked on the surface of the roof.

12. Data Interpretation

12.1 The interpretation of infrared data from a roof is a process of pattern recognition for the purpose of differentiating thermal anomalies caused by wet insulation from those caused by the following:

12.1.1 Variations in the type, thickness, density, or continuity of roof insulation.

12.1.2 Variations in membrane thickness, moisture content, or continuity.

12.1.3 Variations in the type or thickness of aggregate surfacing or ballast.

12.1.4 Variations within the roof deck or supporting structure.

12.1.5 Inconsistencies in the roofing system due to damage, repairs, coatings, or overlays.

12.1.6 Variations in temperature beneath the roofing system.

12.1.7 Fasteners, flashings, flanges, or projections from the roofing system or discontinuities within it.

12.1.8 Variations in roof surface emittance.

12.1.9 Infrared radiation from nearby sources.

12.1.10 Moisture or debris on the surface of the roof.

12.2 Most thermal anomalies associated with wet insulation observed at night will be warmer than adjacent areas of the roof that contain dry insulation. However, the reverse may be true for roofs over refrigerated areas.

12.3 Thermal anomalies associated with wet insulation generally fall into one of the following categories: board-stock, picture-framed, or amorphous.

12.3.1 Board-stock anomalies are comprised of solid rectangular patterns generally associated with board by board wetting of perlite, cork, wood fiber, and glass fiber or cellular plastic insulation.

12.3.2 Picture-framed anomalies are comprised of rectangular outlined patterns generally associated with slow-wetting insulation boards such as cellular plastic and cellular glass. However, insulation boards that do not abut adjacent boards may give similar patterns even though the insulation is not wet.

12.3.3 Amorphous anomalies are irregular in shape. They are generally associated with monolithic insulations such as lightweight concrete, gypsum, or foamed-in-place polyurethane. Such anomalies can also be associated with layers of water above or below any insulation.

12.4 Accurate interpretation of infrared data requires verification.

13. Verification

13.1 Verification of infrared data must be carried out by the following invasive test methods: Cores, or cores and moisture meter probes.

13.1.1 Cores shall be used to determine the composition and condition of the roofing system, and the quantity of moisture in the insulation.

13.1.2 Moisture meter probes may be used to indicate the presence of moisture in roofing systems provided that they are correlated with core moisture contents. (See 13.4.2.)

13.2 Noninvasive testing equipment such as nuclear and capacitance meters may be used to compliment, but not replace invasive verification.

13.3 The penetrated roofing system at invasive verification sites must be repaired in a manner that will not impair its waterproof integrity.

13.4 Minimum verification shall meet these requirements:

13.4.1 One core in each roof section (see 3.1.17) to determine the composition of that section. This core can be of either wet or dry insulation so as to verify with the minimum number of cores.

13.4.2 One core or correlated moisture meter probe reading in an area of dry insulation for each roof section. However, at least one core in an area of dry insulation is required for each roofing system of different composition.

13.4.3 One core in each type of thermal anomaly associated with wet insulation (see 12.3) for each roofing system of different composition.

14. Report

14.1 Reports are required for each infrared survey performed. Report the following information:

14.1.1 Building identification, location, and use.

14.1.2 Name, address, and telephone number of the organization providing the survey.

14.1.3 Type of survey performed (ground-based or aerial).

14.1.4 The make, model, and spectral range of the infrared imaging system used to perform the survey.

14.1.5 The wind velocity, outside air temperature, and cloud cover at the time of the survey and the cloud cover and precipitation during the previous 24 h. For roofing systems in which the insulation can dry rapidly, the date of the last appreciable precipitation shall also be provided.

14.1.6 Roof surface conditions at the time of the survey. (See 10.2.)

14.1.7 Date and time of the survey.

14.1.8 The composition and condition of the roofing system as determined from the cores.

14.1.9 Verification results including the quantity of moisture in the insulation as determined from the cores.

14.1.10 *Ground-Based Surveys*—A scaled drawing of the roof that shows the size and location of the areas of wet roof insulation and the location of the verification readings.

14.1.11 *Aerial Surveys*—The altitude of the aircraft above the roof when the infrared survey was performed. The size and location of the areas of wet roof insulation and the location of verification readings on a scaled drawing or on an air photograph of the roof.

14.1.12 Representative thermograms of each roof surveyed.

15. Precision and Bias

15.1 *Precision and Bias*—No information is present about either the precision or bias of this practice for location of wet insulation in roofing systems using infrared imaging since the test result is nonquantitative.

16. Keywords

16.1 infrared; in-situ; moisture; roofing systems; thermal insulation