



Standard Practice for Thermographic Inspection of Insulation Installations in Envelope Cavities of Frame Buildings¹

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1. Scope

1.1 This practice is a guide to the proper use of infrared imaging systems for conducting qualitative thermal inspections of building walls, ceilings, roofs, and floors, framed in wood or metal, that may contain insulation in the spaces between framing members. This procedure allows the detection of cavities where insulation may be inadequate or missing and allows identification of areas with apparently adequate insulation.

1.2 This practice offers reliable means for detecting suspected missing insulation. It also offers the possibility of detecting partial-thickness insulation, improperly installed insulation, or insulation damaged in service. Proof of missing insulation or a malfunctioning envelope requires independent validation. Validation techniques, such as visual inspection or *in-situ* R-value measurement, are beyond the scope of this practice.

1.3 This practice is limited to frame construction even though thermography can be used on all building types.^{2,3}

1.4 Instrumentation and calibration required under a variety of environmental conditions are described. Instrumentation requirements and measurement procedures are considered for inspections from both inside and outside the structure. Each vantage point offers visual access to areas hidden from the other side.

1.5 The values stated in SI units are to be regarded as standard. The inch-pound units given in parentheses are for information only.

1.6 *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 appro-*

priate safety and health practices and determine the applicability of regulatory limitations prior to use. In particular, caution should be taken in the handling of any cryogenic liquids or pressurized gases required for use in this practice. Specific precautionary statements are given in Note 1 and Note 3.

2. Referenced Documents

2.1 ASTM Standards:

C 168 Terminology Relating to Thermal Insulation⁴

E 1213 Test Method for Minimum Resolvable Temperature Difference for Thermal Imaging Systems⁵

3. Terminology

3.1 *Definitions*—Definitions pertaining to insulation are defined in Terminology C 168.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *anomalous thermal image*—an observed thermal pattern of a structure that is not in accordance with the expected thermal pattern.

3.2.2 *envelope*—the construction, taken as a whole or in part, that separates the indoors of a building from the outdoors.

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

3.2.4 *framing spacing*—distance between the centerlines of joists, studs, or rafters.

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

3.2.6 *infrared thermography*—the process of generating thermal images that represent temperature and emittance variations over the surfaces of objects.

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

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² *ISO/TC 163/SC 1/WG N31E Thermal Insulation—Qualitative Detection of Thermal Irregularities in Building Envelopes—Infrared Method*, available from American National Standards Institute, 25 W. 43rd St., 4th Floor, New York, NY 10036.

³ *Guidelines for Specifying and Performing Infrared Inspections*, Infraspection Institute, Shelburne, VT, 1988.

⁴ *Annual Book of ASTM Standards*, Vol 04.06.

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

3.2.8 *masonry veneer*—frame construction with a non-load bearing exterior masonry surface.

3.2.9 *minimum resolvable temperature difference (MRTD)*—a measure of the ability of the 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 discriminate the pattern with that infrared imaging system at a defined distance.

3.2.10 *thermal pattern*—a representation of colors or tones that indicate surface temperature and emittance variation.

3.2.11 *thermogram*—a recorded image that maps the apparent temperature pattern of an object or scene into a corresponding contrast or color pattern.

3.2.12 *zone*—a volume of building served by a single ventilation system. For buildings with natural ventilation only, the whole building shall be considered a zone with all interior doors open.

4. Summary of Practice

4.1 This practice is a guide to the proper use of infrared imaging systems for conducting qualitative thermal inspections of building walls, ceilings, roofs, and floors, framed in wood or metal, that may contain insulation in the spaces between framing members. Imaging system performance is defined in terms of instantaneous field of view (IFOV) and minimum resolvable temperature difference (MRTD). Conditions under which information is to be collected and compiled in a report are specified. Adherence to this standard practice requires a final report of the investigation. This practice defines the contents of the report.

5. Significance and Use

5.1 Although infrared imaging systems have the potential to determine many factors concerning the thermal performance of a wall, roof, floor, or ceiling, the emphasis in this practice is on determining whether insulation is missing or whether an insulation installation is malfunctioning. Anomalous thermal images from other apparent causes may also be recorded as supplemental information, even though their interpretation may require procedures and techniques not presented in this practice.

6. Instrumentation Requirements

6.1 *Environmental Factors*—The environment has a significant impact on the heat flow through the envelope. As a result, the requirements on thermal imaging instrumentation vary with the interior to exterior air temperature gradient for both interior and exterior inspections and also vary with wind speed for exterior inspections.

6.2 *Infrared Imaging System Performance*—The ability of an observer to detect thermal anomalies depends on the imager's powers of thermal and spatial resolution. The practical test for these qualities is whether the operator can distinguish the framing from the envelope cavities under the prevailing thermal conditions with the infrared imaging system at a distance that permits recognition of thermal anomalies. For

planning an equipment purchase or a site visit, the following qualities may be considered: The minimum resolvable temperature difference (MRTD) defines temperature resolution. Instantaneous field of view (IFOV) is an indicator of spatial resolution. Appendix X1 explains how to calculate IFOV and how to measure MRTD.

6.2.1 *Spectral Range*—The infrared thermal imaging system shall operate within a spectral range between 2 and 14 μm .

6.2.2 *Field of View (FOV)*—The critical minimum dimensions for discriminating missing insulation in frame construction is two framing spacings wide and one framing spacing high. Outdoors, it is typically convenient to view at least one floor-to-ceiling height across and one-half that distance high. The FOV of the chosen imaging system should encompass these minimum dimensions from the chosen indoor viewing distance, d_i , and outdoor viewing distance, d_o . For planning purposes, the angular value of FOV may be calculated for either d (m) by the following equations:

$$FOV_{\text{vertical}} \geq 2 \tan^{-1}(h/2d) \quad (1)$$

$$FOV_{\text{horizontal}} \geq 2 \tan^{-1}(w/2d) \quad (2)$$

where:

h = vertical distance viewed, m, and

w = horizontal distance viewed, m.

7. Knowledge Requirement

7.1 This practice requires operation of the imaging system and interpretation of the data obtained. The same person may perform both functions. The operator of the infrared imaging system shall have thorough knowledge of its use through training, the manufacturer's manuals, or both. The interpreter of the thermographic data shall be knowledgeable about heat transfer through building envelopes and about thermography, including the effects of stored heat, wind, and surface moisture.

7.2 The instrument shall be operated in accordance with the published instructions of the manufacturer.

8. Preferred Conditions

8.1 The criterion for satisfactory thermal conditions is the ability to distinguish framing members from cavities. Appendix X2 gives some guidelines for determining whether the weather conditions are likely to be suitable.

9. Procedure

9.1 *Preliminary Inspection*—A preliminary thermographic inspection may be performed to determine whether a thorough inspection, and report, is warranted.

9.2 *Background Information*—Prepare for the report by collecting information on the building. In order to evaluate the structure, collect the following preliminary data where practical and necessary:

9.2.1 Note each type of building cross section, using visual inspection, construction drawings, or both, to determine what thermal patterns to expect.

9.2.2 Additions or modifications to the structure.

9.2.3 Thermal problems reported by the building owner/occupant.

9.2.4 Note differences in surface materials or conditions that may affect emittance, for example, metallic finishes, polished

surfaces, stains, or moisture. Such differences in emittance cause thermal patterns that are independent of temperature differences.

9.2.5 Orientation of the building with respect to the points of the compass.

9.2.6 Heat sources, such as light fixtures, mounted in or close to the exterior construction.

9.3 *Performing On-Site Equipment Check and Settings:*

9.3.1 Set the instrument gain or contrast to allow the observer to distinguish a framing member from the envelope area around it. In addition, set the imager's sensitivity so that any anomalies or areas to which they are referenced are not in saturation (maximum brightness or white) or in suppression (minimum brightness or black) on the display.

9.3.2 Verify proper operation of the recording system, if any.

9.3.3 Make a sketch or photograph of each envelope area with references for locating framing members.

9.4 *Performing the Inspection:*

9.4.1 A complete thermographic inspection of a building may consist of an exterior or interior inspection of the complete envelope, or both. Both types of inspection are recommended because each offers access to areas that may be difficult for the other.

9.4.2 Inspect all surfaces of interest from an angle as close to normal to the surface as possible, but at least at an angle that permits distinguishing framing members. Make inspections from several angles, perpendicular, if possible, and at two opposite oblique angles in order to detect the presence of reflected radiation.

9.4.3 Make scans from a position that allows a field of view that encompasses at least two framing spacings wide and one framing spacing high for an interior inspection and a floor-to-ceiling height wide and one-half that distance high for an exterior inspection.

9.4.4 Effective corrective action requires a precise definition of the areas with apparent defects. Record each anomaly with annotation regarding the location of all recognizable building characteristics such as windows, doors, and vents. The record may accommodate any requirement for calculations of envelope areas with anomalies.

10. Thermographic Interpretation

10.1 If apparent defects in insulation are not confirmed, corrected, and reinspected at the time of the thermographic survey, then thermograms or other precise identification of the locations and types of apparent defects are required. The interpretation of the thermogram allows determination of the following information:

10.1.1 Locations of the regions where insulation is apparently missing or defective and their total area.

10.1.2 Locations of the regions where the insulation is apparently intact and their total area.

10.1.3 Location and total area of added insulation (if 10.1.1 and 10.1.2 were performed in a thermographic inspection prior to adding insulation).

10.1.4 Estimated total area of surfaces that cannot be inspected.

10.2 Interpretation of thermographic images requires awareness of the following types of patterns:

10.2.1 *Intact Insulation*—As seen from the warm side of the construction: dark parallel lines, representing the framing; uniformly lighter areas between the framing lines, representing the insulation. As seen from the cool side of the construction: the framing lines are light. The areas containing insulation are uniformly dark.

NOTE 1—Metal framing with no insulation may fit this description. See Note 2.

NOTE 2—Metal framing conducts heat better than both air and insulation. If insulation is present, the thermal contrast between metal framing and the spaces between may be very strong. Independent verification may be needed for metal-framed buildings to establish typical patterns for insulated and uninsulated areas.

10.2.2 *Insulation Missing Completely*—As seen from the warm side of the construction: light parallel lines, representing the framing; darker areas between the framing lines, representing the empty space between framing members. Convection may be visible in vertical framing, as evidenced by a gradient from dark (cooler) at the bottom of the space to light (warmer) at the top. As seen from the cool side of the construction: the framing lines are dark, the areas between framing are light and convection is still lighter at the top of vertical spaces.

NOTE 3—Metal framing with no insulation may not fit this description. See Note 2.

10.2.3 *Insulation Partially Missing*—The dominant effect is as described in 10.2.1, except that missing insulation shows as a well-defined dark region, as seen from the warm side and as a light region as seen from the cool side.

10.2.4 *Other Thermal Patterns*—Irregular variation of the thermal pattern in the spaces between framing members may indicate a combination of possible causes, including varying density of insulation, convection or air leakage, moisture, or thermal bridges. A partial list of examples follows:

10.2.4.1 Variable density insulation often allows air leakage and convection and thereby creates intruding areas of surface temperature variation.

10.2.4.2 Areas where insulation contains significant moisture conduct heat much more readily than dry insulation or no insulation. Within the moist region there may be a mottled and diffused thermal pattern. Temperature variations within the pattern are not extreme.

10.2.4.3 Thermal bridges may be caused by the presence of fasteners or framing members.

10.2.4.4 Air leakage, usually at joints and junctions in the building envelope, typically produces irregular shapes with uneven boundaries and large temperature variations. Air leakage can be detected thermographically when air of a different temperature than the surface viewed comes from the side of the envelope opposite the observer.

10.2.4.5 Indoor temperatures may vary from room to room. This can result in large areas showing brighter than others, as seen during an exterior survey. Independent verification of indoor temperatures can determine whether such variations are due to variations in indoor temperatures or to differences in the thermal qualities of the envelope.

10.2.4.6 If an object has been removed from a surface, there may be a thermal signature where the object insulated the surface. This effect diminishes with time after removal of the object.

10.3 If possible, the cause of the anomalous thermal image shall be determined. This may be done by calculations, ancillary measurements, experience, or by comparing the actual thermogram with reference thermograms for structures with known anomalies. The report should substantiate such determinations.

11. Report

NOTE 4—Much of the report may be recorded on a standard form devised by the user of this practice.

11.1 The report on a thermographic survey shall contain, at a minimum, the following information:

11.1.1 Brief description of the essential construction features of the building. (This information can be based on drawings or other construction documents when available).

11.1.2 Note any unusual surface conditions, such as moisture or reflective materials, and note the means used to account for these conditions.

11.1.3 Geographic orientation of the building with respect to the points of the compass, and a description of the surrounding buildings, vegetation, landscape, and microclimate. This may be done with photographs of each side of the building.

11.1.4 The equipment used, including model and serial number, and any critical settings used during the inspection.

11.1.5 Date and hour of the inspection.

NOTE 5—This practice does not rely on detailed weather information. The ability to distinguish framing members is the critical criterion. Weather records from a nearby weather station should provide sufficient data, when desired.

11.1.6 Sketches/photographs of the building showing the positions of the thermograms. If no thermograms were made, then the following may be substituted:

11.1.6.1 Scale or dimensioned drawings that locate areas with apparently missing insulation, defective installations of insulation, or other anomalies.

11.1.6.2 Markings on the building envelope, for example with tape, that delineate the apparently defective areas.

11.1.7 Thermograms (if obtained) from the inspection with identifications of the region represented and with any interpretations of the thermal images.

11.1.8 Identification of the examined parts of the building envelope and of those not examined.

11.1.9 Results of any analysis dealing with the type and extent of each apparent defect that may warrant remedial action. This may be a simple reference to outlined areas on the thermograms.

11.1.10 Results of any supplementary measurements and investigations.

11.1.11 *Optional*—Estimate of the total area and location where no insulation is apparent.

11.1.12 *Optional*—Estimate of the total area and location where full insulation is apparent.

11.1.13 Names of members of inspection team and team leader.

12. Precision and Bias

12.1 This practice is qualitative in nature. Therefore, the data determined is subject to interpretation. It requires the user to be able to distinguish framing members before proceeding. The appendixes detail the equipment specifications and weather conditions that are likely to meet the criterion of distinguishing framing members. Users can expect to obtain anomalous thermal images from phenomena that are about the size of a framing member or larger. Section 1.2 describes what types of suspected problems the user can expect to detect.

13. Keywords

13.1 building envelope; infrared; in-situ; thermal insulation; wall systems; workmanship

APPENDIXES

(Nonmandatory Information)

X1. HOW TO DETERMINE SPATIAL AND THERMAL RESOLUTION OF AN INFRARED THERMAL IMAGING SYSTEM

X1.1 The user can determine in advance whether an imaging system has an adequate IFOV and MRTD for the conditions of use. First the user must establish typical distances for indoor and outdoor inspections that are compatible with the imaging system (see X1.1.1); secondly, an IFOV calculation may be performed (see X1.1.2); then, MRTD experiments must be performed for those distances (see X1.1.3).

X1.1.1 *Criterion Distances*—The user may choose convenient distances to be probable maximums for indoor and outdoor scanning. Indoors the distance, d_i , might be 3 m (about

10 ft). Outdoors, d_o , might be 5 m (about 16 ft). These distances shall conform to the FOV (see section 6.2.3), IFOV (see X1.1.2), and MRTD (see X1.1.3) of the equipment chosen.

X1.1.2 *Instantaneous Field of View (IFOV)*—To ensure adequate spatial resolution, the instrument must discriminate a width, s , of one piece of framing from the distance, d , chosen in X1.1.1. The same width, s , pertains to determining MRTD in 6.2.5. The instrument should have an IFOV defined by the following equation:

$$IFOV \leq 500 \text{ s/d} \quad (X1.1)$$

In the USA a typical value of s would be 0.0381 m (1.5 in.), when viewed from $d = 5$ m (about 16 ft) would require an IFOV of less than 3.8 milliradians.

X1.1.3 Minimum Resolvable Temperature Difference (MRTD)—Depending on the construction subject to inspection and the thermal conditions, the instrument shall have an MRTD, as defined by the following equation at the distance, d , chosen in X1.1.1:

$$MRTD \leq \frac{|\Delta R| * |\Delta T|}{h * R_1 * R_2} \quad (X1.2)$$

where:

- $|$ = the absolute value symbol,
- R = thermal resistance, $\text{m}^2\text{K/W}$ (or $\text{ft}^2\text{h}^\circ\text{F/Btu}$),
- h = the surface film coefficient, $\text{W/m}^2\text{K}$ (or $\text{Btu/}^\circ\text{Fh ft}^2$),
- l = properly insulated area,
- 2 = defectively insulated area,
- ΔT = difference between inside and outside ambient temperatures, K (or $^\circ\text{F}$), and
- $\Delta R = R_1 - R_2$.

Tables X1.1-X1.3 list the MRTD required for the imaging system assuming that the imager is located inside the building being tested and the building's interior temperature is at $25 \pm 5^\circ\text{C}$ ($77 \pm 9^\circ\text{F}$). The MRTD requirement for the imaging system can also be estimated, using Eq X1.2. For exterior surveys the film coefficient, h , changes with wind speed.

X1.1.4 Test for MRTD—MRTD of the thermal imaging system is defined by the following test conditions:

X1.1.4.1 Instrument Setting—The thermal imaging system shall be set at the sensitivity that detects the smallest temperature variations.

TABLE X1.1 Required MRTD for R-0.352 (R-2) to R-1.76 (R-10) Difference at $25 \pm 5^\circ\text{C}$ Ambient Temperature

Required Minimum Resolvable Temperature Difference at 0.52 cycles/cm (1.3 cycles/in.)		Inside to Outside Air Temperature Difference	
$^\circ\text{C}$	$^\circ\text{F}$	$^\circ\text{C}$	$^\circ\text{F}$
1.0	1.8	7	13
1.2	2.0	8	14
1.4	2.5	9	16
1.6	3.2	11	20

TABLE X1.2 Required MRTD for R-0.88 (R-5) to R-2.64 (R-15) Difference at $25 \pm 5^\circ\text{C}$ Ambient Temperature

Required Minimum Resolvable Temperature Difference at 0.52 cycles/cm (1.3 cycles/in.)		Inside to Outside Air Temperature Difference	
$^\circ\text{C}$	$^\circ\text{F}$	$^\circ\text{C}$	$^\circ\text{F}$
0.4	0.78	8	14
0.6	1.1	12	22
0.8	1.4	16	29
1.0	1.8	20	36

TABLE X1.3 Required MRTD for R-1.76 (R-10) to R-2.64 (R-15) Difference at $25 \pm 5^\circ\text{C}$ Ambient Temperature

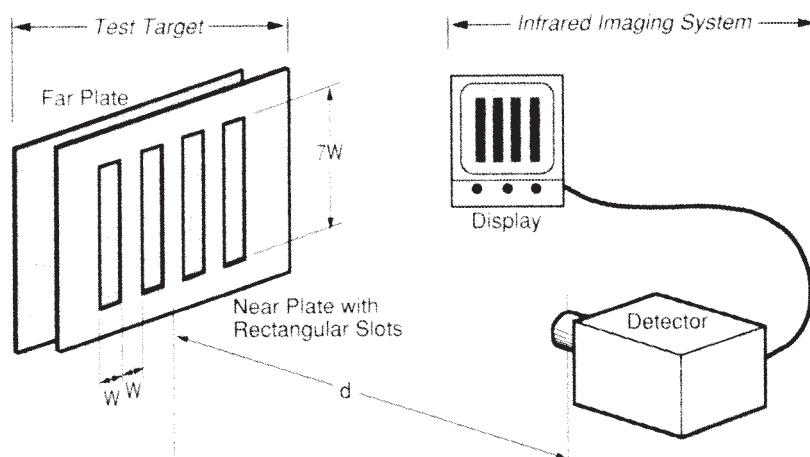
Required Minimum Resolvable Temperature Difference at 0.52 cycles/cm (1.3 cycles/in.)		Inside to Outside Air Temperature Difference	
$^\circ\text{C}$	$^\circ\text{F}$	$^\circ\text{C}$	$^\circ\text{F}$
0.2	0.4	16	29
0.4	0.7	32	58
0.6	1.1	48	86
0.8	1.4	64	115
1.0	1.8	80	144

X1.1.4.2 Criterion Distance—MRTD shall be determined for indoors and outdoor applications at the distances d_i and d_o , chosen in X1.1.1.

X1.1.4.3 Test Target Pattern—The test target shall consist of two plates with controlled, known temperatures, located at the criterion distance, d , in front of the imaging system. The near plate shall have a four-bar test pattern of $w = (s/2)/\text{cycle}$ and a 7:1 aspect ratio. The dimension, s , is the same value as in X1.1.2, defined as the width of a single piece of framing. Other size patterns of the same aspect ratio may be used as long as w/d remains constant. See Fig. X1.1 for an illustration of the MRTD experimental set-up.

X1.1.4.4 MRTD Test Procedure—Someone slowly increases the temperature difference between the two plates of the target without communicating with the observer of the display on the imaging system. The observer announces when the test pattern comes into view. The difference in temperature at this point is the MRTD for that test condition.

X1.1.4.5 Test Replicates—A minimum of three separate observers shall perform the procedure in 6.2.6.4 to establish an average value for MRTD.



NOTE—A test pattern, consisting of four rectangular slots, permits a comparison of the temperature of the near plate of the test target with the far plate. The plates are initially at the same temperature. Someone increases the temperature difference between plates until an observer announces when the test pattern comes into view on the display. The difference in temperature at this point is the MRTD for that test condition.

FIG. X1.1 Test for Minimum Resolvable Temperature Difference (MRTD) of Infrared Imaging System

X2. PREFERRED CONDITIONS FOR PERFORMING INFRARED INSPECTIONS OF FRAME CONSTRUCTION

X2.1 Infrared inspection requires a sufficient difference in temperature from inside to outside (ΔT) for a sufficiently long period of time, as described in this section, to produce discernible differences between areas with studs and areas that may contain insulation. The preferred measurement of ΔT is *surface to surface*, because this minimizes problems with accounting for solar and wind effects. Air-to-air measurements are also permitted under this practice. The following environmental conditions are suggested for thermographic inspections:

X2.2 *Minimum ΔT* —Minimum temperature difference (ΔT) of 10°C (18°F) between interior and exterior surface or ambient air temperatures for a period of 4 h prior to test.

X2.3 *Using Ambient Air Temperature Measurements*—Ambient air temperature measurements cannot account for the strong radiative effects of the sun or for convective effects from wind, so the following precautions should be taken when using air temperature measurements for ΔT :

X2.3.1 *Avoid Solar Radiation*—No direct solar radiation on the inspected surfaces for approximately 3 h previous to the

inspection for light frame construction and approximately 8 h for masonry veneer construction. ΔT s greater than 10°C reduce these times. Direct sunlight and other strong sources of thermal radiation make discrimination of uninsulated areas unreliable. Exterior surveys should be performed after sunset and before sunrise for best results.

X2.3.2 *Avoid Wind*—For exterior surveys, the wind speed should be less than 6.7 m/s (15 mph) and the building surface should be dry.

X2.4 *Other Conditions*—Although it is recommended that the conditions in X2.3-X2.3.2 prevail at the time of inspection, it is recognized that the thermographic inspections can be performed under other conditions if sufficient knowledge is used in taking and interpreting the thermograms. For example, a wall exposed to direct solar radiation will experience a temperature reversal; the studs and voids will appear warm and the insulated section cold on interior inspections. Interior surveys may be possible on veneer surfaces or ceilings under attics an hour or two after sunrise.

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