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Recommended Asphalt Mixture Temperature Specifications for Paving Projects

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1. Executive Summary

Temperature is a key element of every outcome in the asphalt paving chain. At the plant, for example, the mix discharge temperature determines whether a warm mix asphalt additive is performing as intended and whether the mix will remain workable through the haul. At the project site, the mix temperature at delivery defines the available compaction window. Behind the screed, mat surface temperature reveals whether thermal segregation is present and whether rollers are operating within the effective compaction range. Temperature is also the basis on which incentive payments, rejection decisions, and quality documentation sometimes rest.

Despite this centrality, the current national specification framework treats temperature measurement as a secondary concern. No AASHTO standard specifies a minimum instrument class for thermometers used to measure asphalt mixture temperature. No national standard requires calibration or verification of field infrared (IR) thermometers at production temperatures. No standard requires a plant to log asphalt mixture discharge temperature electronically, identify whether the measurement represents surface or bulk temperature, or deliver that record to the agency. The practical consequence is a system in which temperature reading can mean very different things depending on the instrument, location, and inspector, and in which neither the agency nor the contractor can reliably determine whether two readings measure the same physical quantity.

This report documents what those gaps look like in practice, quantifies their magnitude, and provides draft specification language to improve consistency, safety, and reproducibility. The proposed revisions distinguish between asphalt mixture surface temperature measurements and bulk temperature measurements and suggest that agencies identify which measurement type applies to specification compliance.

Approach

The study drew on five sources of information.

1) A review of AASHTO and ASTM standards that govern asphalt mix production, temperature measurement, and calibration.
2) A review of published literature and state DOT specifications identified the technical principles governing temperature measurement and the current range of state practice.
3) A national survey of State DOT materials and pavement engineers, with 29 respondents, quantified how agencies specify, verify, and use temperature data in their acceptance programs. This survey was supplemented by a one-on-one interview with a State Bituminous Engineer.
4) A parallel survey of the State Asphalt Pavement Associations (SAPAs), with 23 respondents, shared field measurement practices and industry perceptions. This survey was supplemented with eight one-on-one interviews of asphalt paving contractors from across the United States.
5) Field measurement data, including an in-house NCAT Test Track study in which seven handheld IR thermometers measured the same mat, provided empirical evidence of inter-instrument variability under controlled conditions.

Key Findings

Table ES-1 summarizes the study's key findings. Together, they describe a widely used measurement system that lacks nationally consistent standards for instrument selection, calibration, documentation, and interpretation of surface and bulk temperature measurements.

Table ES-1. Key Findings

No.	Finding
1	85% of DOT respondents use handheld IR thermometers (IR guns) as their primary field temperature measurement tool, yet IR guns received the lowest agency acceptance-risk rating (2.84 out of 5.0) of any measurement method. No current national standard defines a minimum instrument class or spectral band for IR guns used in acceptance decisions.
2	In an NCAT Test Track in-house study with seven IR thermometers measuring the same mat location during track construction, inter-instrument temperature spreads ranged from 12°F to 53°F across measurement sets, with an average spread of approximately 30°F. This variability occurred under controlled conditions with an experienced operator.
3	70% of DOT respondents do not compare IR thermometer readings with contact probe readings at the same location or follow a defined measurement hierarchy. No national standard currently establishes whether contact probe or IR thermometer readings govern acceptance decisions.
4	Contact probes received the highest instrument accuracy rating (4.3 out of 5.0), but measurement safety in the paver hopper received the lowest safety rating (62 out of 100).
5	IR thermometers measure exposed asphalt mixture surface temperature; contact probes measure asphalt mixture bulk temperature at the point of insertion. These are not the same physical quantity. No current national standard defines whether specification limits apply to surface temperature measurements, bulk temperature measurements, or both, or requires documentation of which measurement type produced the recorded temperature.
6	No state DOT surveyed requires calibration of field IR thermometers or contact probes at production temperatures (250–350°F). The most common calibration check is a boiling-water test at 212°F, which falls outside the production temperature range.
7	AASHTO M 156 requires a thermometric device at the plant discharge but specifies no instrument class, accuracy requirements, calibration requirements, logging obligations, archive duration, or data format.
8	95% of contractor and supplier respondents report no active temperature-incentive program for warm mix asphalt (WMA) production. Minnesota is the only U.S. state with an operational tiered temperature incentive (MnDOT SP 2360, piloted in 2025), which pays a 2 to 4 percent incentive of the plant mix unit price for production at or below 275°F and 250°F, subject to a verified plant sensor and continuous electronic recording.

Recommendations

Recommendations address the findings above and are organized into five topic areas.

Instrument standards: Bimetal dial thermometers *should not* be used for acceptance temperature measurements. Contact probes used for acceptance should meet a minimum class of Type K thermocouple at Special Limits of Error, or Resistance Temperature Detector (RTD) Class A. Handheld IR thermometers used for acceptance measurements should be verified in accordance with the manufacturer's recommendations and applicable ASTM standards.

Calibration and verification: Contact probes and IR thermometers used for process control, quality control, or acceptance activities should be calibrated or verified at temperatures representative of asphalt mixture production and placement. Records should include device identification, verification date, reference device, and results.

Surface and bulk temperature measurements: Specifications should clearly distinguish between surface temperature measurements and bulk temperature measurements. Infrared thermometers and thermal imaging devices measure the surface temperature of exposed asphalt mixtures. Contact probes measure the bulk temperature of the asphalt mixture at the point of insertion. When both measurements are obtained at the same location, the contact measurement should be used as the reference for determining bulk temperature.

Safe access and plant logging: Temperature measurements should be obtained using safe work practices. Personnel should not be required to climb onto haul trucks solely for temperature measurement purposes. Temperature at the designated reporting point should be electronically recorded and archived, with the date and time recorded, and recording intervals not exceeding 10 minutes during production.

WMA incentives: MnDOT's special provision WMA incentive program demonstrates that temperature-based incentives can be successfully implemented when supported by verified plant sensors, continuous electronic temperature records, and an in-place density quality gate. Agencies wishing to encourage lower-temperature production should consider adopting a similar framework.

Draft Specification Language

Section 8 of this report provides proposed specification language for AASHTO standards. The proposed M 156 revisions (Section 8.1) add provisions on instrument class, accuracy, electronic recording, calibration and verification, data integrity, and safety to the existing plant thermometric equipment provision. The proposed R 97 revisions (Section 8.2) add temperature observation requirements at the time of sampling, clarify the distinction between surface and bulk temperature measurements, establish contact measurements as the reference for determining bulk temperature when both measurements are obtained, and add verification and safety language. The paver-mounted thermal profile (PMTP) agency contract language (Section 8.3) provides a special provision (SP-P1) that invokes AASHTO R 110, defines an applicability threshold, establishes a decision framework, and specifies data delivery requirements.

The M 156 and R 97 revisions are intended for adoption through the AASHTO Committee on Materials and Pavements (COMP), a process that typically takes 1 to 2 years. Agencies that wish to act sooner can incorporate the field measurement requirements as project-level special provisions without waiting for a national standard revision. The PMTP special provision and the WMA incentive provision can be adopted by any agency under a contract special provision.

Conclusions

The central conclusion of this study is that the challenge of temperature measurement in asphalt paving is not a technological problem. The instruments exist. ASTM E2847 provides a field-practical verification method for IR thermometers. AASHTO R 110 provides a rigorous PMTP framework. Minnesota has demonstrated that a WMA temperature incentive can be administered. The challenge is that the national specification framework has not kept pace with the measurement tools that are now routinely used in the field, and the gap between what is measured, what is documented, and which measurement type governs specification compliance has grown large enough to produce acceptance decisions that may not be reproducible.

Closing that gap requires minimum instrument standards, a clear distinction between surface and bulk temperature measurements, calibration and verification at relevant temperatures, safe field measurement practices, and plant temperature records that agencies can access and trust. The draft language in Section 8 provides a practical mechanism for implementation through AASHTO standards and agency special provisions.

2. Background

Asphalt mix temperature is one of the most consequential and least standardized measurements in pavement construction quality assurance (QA). Every state transportation agency requires it, yet the instrument used, the location where it is taken, the frequency of measurement, and the tolerance applied vary substantially across jurisdictions. To understand why standardization matters, and why it has proven elusive, it is necessary to understand what temperature measurement controls, where along the production-to-placement chain each measurement is most meaningful, and how each class of instrument obtains its reading.

2.1 Why Mix Temperature Matters

The workability, compactability, and long-term performance of an asphalt mixture are all directly tied to the temperature of the asphalt binder at each stage of production and placement. Asphalt binder is a viscoelastic material: at high temperatures, it behaves as a viscous liquid, and at lower temperatures, it transitions to an elastic solid. Mixing, coating, transport, placement, and compaction each require the binder to be within a specific viscosity window, and viscosity is controlled almost entirely by temperature.

During mixing and coating at the plant, both the aggregate and the binder must be within the range where the binder is sufficiently fluid to uniformly coat every aggregate particle. Too low a production temperature results in an incomplete coating and a mix potentially prone to raveling and moisture damage. Too high a temperature accelerates oxidative aging of the binder; binder molecules react with atmospheric oxygen, increasing stiffness and brittleness and potentially causing cracking in service. For polymer-modified binders, excessive temperature can degrade the polymer network, reducing the performance benefits the modifier was selected to provide. For open-graded and stone-matrix asphalt (SMA) mixes, elevated temperatures increase the risk of binder drain-down during transport and storage.

During compaction, the binder must remain sufficiently fluid to allow aggregate particles to reorient under roller compaction loads. As the mix cools below the commonly cited cessation temperature, approximately 80–85°C (175–185°F) for most dense-graded mixes, the binder stiffens to the point where further densification becomes difficult without aggregate degradation. Any delay between placement and breakdown rolling that allows the mat to cool below this threshold may result in an under-compacted mat, increased in-place air voids, accelerated moisture infiltration, and shortened pavement service life.

Temperature also provides the operational link between mix design and field production. The job mix formula (JMF) specifies a target production temperature based on binder viscosity requirements; the field tolerance applied around that target (typically ±20°F to ±30°F) defines the acceptable window within which the mix can be produced and delivered while remaining workable. When temperature-based acceptance criteria are inconsistently applied, or the instrument used to measure compliance is not verified for accuracy, the specification loses its intended protective function.

For warm mix asphalt (WMA) technologies, temperature control takes on additional significance. WMA additives and processes *(foaming, chemical additives, organic waxes)* are designed to reduce production and compaction temperatures by 20–55°C (35–100°F) compared with conventional hot-mix asphalt (HMA). At lower temperatures, worker exposure to asphalt fumes is reduced, plant fuel consumption decreases, and the compaction window can be extended. However, WMA must still meet the minimum viscosity and compaction temperatures specified by the mix design, and verification depends on accurate, representative temperature measurements.

2.2 The Temperature Measurement Chain

Temperature is not a fixed property of an asphalt load. It decreases continuously from the moment the mix exits the drum or pugmill until the mat reaches ambient temperature after rolling. This means that where a temperature is measured determines what it represents, and no single measurement location captures the full thermal history of a load. Table 2-1 summarizes the five primary measurement locations in current practice and their relationship to the production-to-placement chain.

Table 2-1. The Asphalt Mix Temperature Measurement Chain

Location	Typical Temp. Range	What It Represents	Primary Instrument(s)	Primary User
Plant mixer discharge	130–180°C (265–355°F)	Production temperature, as defined by NAPA SUST-008; measures mix quality at the point of manufacture; the highest temperature in the chain	Fixed plant pyrometer (IR); fixed thermocouple in mix stream	Plant operator / QC
Haul truck at the plant	125–175°C (255–350°F)	Mix temperature at load-out; first point where DOT inspector can access the mix; verifies temperature has not dropped excessively during silo or truck loading	Handheld IR gun (over truck bed); contact probe (truck-side port, if available)	Plant QC; DOT inspector
Haul truck at the project site	115–165°C (240–330°F)	Temperature after haul reflects heat loss during transport; the most common DOT acceptance point represents what the paver will receive	Handheld IR gun; contact probe inserted into truck bed	DOT inspector
Paver hopper	110–160°C (230–320°F)	Temperature at point of placement; verifies mix is workable when it enters the auger and screed system; reflects the combined effect of haul and wait time	Handheld IR gun; contact probe in hopper	DOT inspector
Behind the screed/mat surface	95–150°C (200–305°F)	Temperature at point of compaction; most critical for density achievement; must exceed cessation temperature (~80–85°C) before breakdown rolling is complete; only location suitable for thermal profiling	Handheld IR gun; PMTP system (IR camera array)	DOT inspector; Contractor QC

Note: Temperature ranges are approximate and vary with binder grade, WMA technology, ambient conditions, lift thickness, and haul distance. °C and °F conversions rounded for readability.

Table 2-2. Surface and Bulk Temperature Measurement Technologies

Instrument	Measurement Type	Typical Location	Primary Use
Handheld IR thermometer *(IR Gun)*	Surface	Truck, hopper, mat	Screening, field documentation, and rapid temperature checks
Fixed IR pyrometer	Surface	Plant discharge or mix stream	Continuous plant monitoring of the exposed mix surface temperature
PMTP system	Surface	Behind screed	Continuous thermal uniformity and thermal segregation evaluation
Type K thermocouple	Bulk	Plant discharge, truck, paver, sample	Process control, verification, and reference bulk temperature measurement
RTD / Pt100 probe	Bulk	Sample, truck, laboratory reference	High-accuracy reference or verification measurement

Surface-temperature instruments and bulk-temperature instruments measure different physical quantities. Surface temperature measurements characterize the exposed asphalt mixture surface. Bulk temperature measurements characterize the internal temperature of the asphalt mixture at the point of probe insertion or sensor contact. These measurements should not be assumed equivalent, especially when the mix is cooling during transport, placement, and compaction.

Each measurement location answers a different question. Plant discharge temperature answers: Is the mix being produced correctly? Haul truck at the project answers: Did the mix maintain heat during transport, and is it acceptable to place? Behind-screed temperature answers: Is compaction achievable before the mat stiffens? A specification that requires measurement at only one location, or that fails to distinguish between what each location is meant to verify, provides incomplete quality assurance coverage of the production-to-placement chain.

An important distinction that current specifications often blur is between surface and bulk temperatures. IR instruments, whether handheld guns, fixed plant pyrometers, or paver-mounted profilers, measure the thermal radiation emitted from the surface of the material. Contact probes measure bulk temperature through conduction. These two quantities are related but not equivalent: the surface of a haul-truck load or a freshly placed mat will cool faster than the interior, particularly in wind or at low ambient temperatures, meaning that an IR reading may underestimate the temperature experienced by the aggregate at the core of the mix. Specifications that set acceptance criteria without specifying the measurement method implicitly assume that surface and bulk temperatures are interchangeable, an assumption that is not always valid.

Key Concept: One Load, Multiple Temperatures
Asphalt mixture temperature is not a single fixed value. A load has a production temperature at plant discharge, a delivery temperature at the project, a placement temperature at the paver, and a compaction temperature behind the screed. Each location answers a different quality question; specifications should identify which point in the production-to-placement chain governs compliance.

2.3 Temperature Measurement Instruments: How They Work

Five classes of temperature measurement instruments are currently used in asphalt production and placement operations. Each operates on a different physical principle, measures a different temperature quantity (bulk vs. surface), and has distinct accuracy characteristics, calibration requirements, and practical limitations. Understanding these differences is essential to evaluating which instrument is appropriate for a given measurement purpose and to writing specification language that is technically sound.

2.3.1 Contact Probe Thermometers

Contact probe thermometers measure temperature via direct physical contact: a sensing element inserted into the asphalt material equilibrates with the surrounding temperature, and the instrument reads the equilibrated temperature. Three types of sensing elements are commonly used.

Bimetal Dial Thermometers. The simplest contact thermometer consists of two metals with different thermal expansion coefficients bonded into a coil or helix. As temperature changes, the differential expansion and contraction of the two metals cause the coil to rotate, mechanically moving a needle across a calibrated dial. Bimetal thermometers are inexpensive, require no batteries, and are highly robust in harsh plant environments. Their drawbacks are significant for quality assurance purposes: they have no electronic output, cannot be integrated into a data logging system, are subject to mechanical drift over time, and have the lowest inherent accuracy of any contact thermometer type, typically ±2 to ±5°C (±4 to ±9°F) at best. In modern QA contexts, they are most appropriate as a rough field check rather than an acceptance instrument. (Image 1)



Image 1. Example of a bimetal dial thermometer used for field temperature measurements.

Type K Thermocouple Probes. The thermocouple is the most common contact temperature sensor in the asphalt field. It operates through the Seebeck effect: when two dissimilar metals are joined at a hot junction inserted into the mix and connected to a meter at a cooler reference junction, a small electromotive force is generated and converted to temperature. For Type K thermocouples, ASTM E230/E230M provides reference EMF-temperature tables, and ASTM E608/E608M covers the mineral-insulated, metal-sheathed configuration commonly used for rugged field probes and fixed plant sensors. Calibration is performed by comparison to a NIST-traceable reference per ASTM E220. (Image 2)



Image 2. Example of a Type K thermocouple probe used for measuring asphalt mixture temperature.

Digital Contact Probes Using Platinum Resistance Thermometers (RTDs/PRTs). The platinum resistance thermometer operates on the principle that the electrical resistance of pure platinum increases with temperature in a highly stable, predictable relationship described by the Callendar-Van Dusen equations. A standard Pt100 sensor has a resistance of exactly 100 Ω at 0°C and increases by approximately 0.385 Ω per degree Celsius. An ASTM E1137 Class A Pt100 sensor has an accuracy of ±(0.15 + 0.002|T|)°C, at 150°C (302°F) this equates to ±0.45°C (±0.8°F), the tightest accuracy of any practical field thermometer. The instrument measures the sensor resistance by passing a small excitation current (typically 1 mA or less) through the platinum element and measuring the resulting voltage. A known limitation is self-heating: the



Image 3. Example of digital RTD thermometer with probe sensor.

excitation current itself generates a small amount of Joule heat in the sensing element, slightly elevating its reading above the true ambient temperature; this is minimized by using the lowest practical excitation current. RTD-based digital probes are standard for laboratory reference measurements. (Image 3)

2.3.2 Fixed Plant Thermometric Systems

Modern asphalt mixing plants are equipped with thermometric devices that continuously monitor and display temperature at the drum or pugmill discharge. These systems typically include two complementary sensor types: a contact thermocouple embedded in the mix flow, and a non-contact infrared pyrometer aimed at the surface of the material stream.

Fixed Thermocouples. A Type K or Type N thermocouple is permanently installed so that its sensing junction contacts the flowing mix at the discharge chute or in the pugmill. Because the junction is in direct contact with the moving material, it measures bulk mix temperature, the most physically meaningful temperature from a mix design and quality standpoint. The reading can be displayed continuously on the plant's human-machine interface (HMI) monitor and is the temperature that the plant operator uses to control production. In some plants, this reading is recorded only as a display value and is not electronically archived to a time-stamped data file accessible to the QA record. AASHTO M 156 currently requires a thermometric device but does not mandate data logging of the contact sensor output.

Fixed Infrared Pyrometers. A fixed IR pyrometer is aimed at the surface of the mix stream as it exits the drum or pugmill, typically from a mounting point on the chute structure or discharge hood. It operates on the same Stefan-Boltzmann radiation physics as handheld IR thermometers, but in a permanently aligned, stationary configuration. Pyrometers typically operate in a spectral response range of 8 to 14 *μm*. Because the measurement geometry is fixed, field-of-view alignment and distance-to-spot ratio are set once and do not vary with operator technique. Modern drum plants typically log pyrometer data continuously to a time-stamped record. The pyrometer measures the surface temperature of the flowing mix stream, not the bulk temperature, and is subject to potential bias from steam at the drum discharge, optical path contamination by dust or bitumen vapor, and spectral bandwidth differences relative to handheld field instruments. (Image 4)



Image 4. Example of a fixed Infrared Pyrometer installed for continuous asphalt mix temperature monitoring.

2.3.3 Handheld Infrared Thermometers (IR Guns)



Image 5. Example of a handheld infrared thermometer used for non-contact surface temperature measurements.

The handheld infrared thermometer, commonly called the IR gun on paving projects, is the dominant field temperature-measurement tool in asphalt QA, used by 85 percent of state DOTs surveyed in this study. Its appeal is practical: it provides instantaneous, non-contact reading from a safe distance, requires no physical insertion into hot material, and is inexpensive enough for every inspector to carry one. Its limitations are equally important and less universally understood. (Image 5)

How an IR Gun Works. Every object above absolute zero (−273°C) continuously emits electromagnetic radiation across a spectrum of wavelengths, with the peak emission wavelength shifting toward shorter wavelengths as temperature increases. At temperatures relevant to asphalt paving (90–180°C, 195–355°F), peak emission occurs in the mid-infrared range, roughly 6.4-7.0 *μm*. An IR gun's optical system focuses the emitted radiation from the target surface onto a thermopile detector, an array of tiny thermocouple junctions arranged in series that generate a voltage proportional to the absorbed radiation intensity. The instrument's electronics then apply the Stefan-Boltzmann law, adjusted by the user-configured emissivity setting, to back-calculate the target's surface temperature. The entire measurement is effectively instantaneous; the thermopile responds in milliseconds, which is both the instrument's greatest advantage and a potential source of error if the target surface is not thermally representative of the bulk material.

Emissivity and Why It Matters. Emissivity (ε) is the ratio of thermal radiation emitted by a real surface to the radiation that would be emitted by an ideal, perfect emitter (known as a *blackbody*) at the same temperature. A perfect blackbody has ε = 1.0; real materials have ε < 1.0. Fresh dense-graded HMA has an emissivity of approximately 0.95 in the 8–14 *μm* wideband, depending on surface texture, aggregate mineralogy, and binder content. Open-graded mixes have an apparent emissivity that is effectively higher because the IR instrument "sees" into the void structure, potentially reading deeper. If the IR gun's emissivity setting does not match the material's actual emissivity, the instrument will compute an incorrect surface temperature. A 0.05 error in emissivity setting, for example, using ε = 0.95 when the true surface emissivity is 0.90, introduces a temperature error of approximately 2°C to 4°C (4°F to 7°F) at asphalt production temperatures. ASTM E1933 provides procedures for measuring surface emissivity in the field using a contact-probe comparison or surface modification with a known-emissivity tape, though this level of rigor is rarely applied in asphalt QA practice. Standard practice should specify a default emissivity setting of 0.95 for fresh dense-graded HMA in the 8–14 *μm* wideband.

Distance-to-Spot Ratio (D:S). Every IR thermometer has a defined distance-to-spot (D:S) ratio, specified per ASTM E2758, that describes the relationship between the measurement distance and the diameter of the surface area being integrated. A gun with a D:S ratio of 12:1 measures a circular spot 1 inch in diameter when held 12 inches from the target, or a 2-inch spot at 24 inches. If the measured spot is larger than the target material, for example, if the instrument is pointed down into a haul truck and the field of view includes the truck bed walls or gate in addition to the mix, the reading will be a weighted average of the hot mix and the cooler surrounding surfaces, biasing the result low. Managing the D:S ratio requires that inspectors know their instrument's specific ratio and maintain an appropriate measurement distance. *This is not addressed in most state DOT specifications.*

Environmental Interference. The optical path between the IR gun and the target surface can be compromised by several field conditions common to asphalt paving. Steam driven off from aggregate moisture at drum discharge absorbs and scatters infrared radiation, causing the

instrument to partially measure the cooler steam cloud rather than the hotter mix surface, which biases the readings low. Asphalt fumes, smoke, dust, and condensation on the instrument's lens have similar attenuating effects. Ambient wind accelerates the mat's surface cooling, increasing the difference between the surface temperature (what the IR gun reads) and the bulk temperature of the mix beneath. Rain or dew changes the surface emissivity to that of water rather than asphalt. *None of these interference factors is currently required to be documented or corrected for in standard asphalt QA temperature recording.*

Calibration and Accuracy Verification. ASTM E2847 *(elevated from Standard Guide to Standard Test Method in 2026)* specifies two schemes for verifying the accuracy of wideband IR thermometers.

- **Scheme I** compares the instrument's reading with a contact thermometer reading of the same surface, requiring an emissivity correction and a surface-to-probe temperature offset calculation.
- **Scheme II** uses a recently calibrated reference IR thermometer as a transfer standard, both pointed at the same surface.

Both schemes require knowledge of the target surface emissivity and are more rigorously applicable in a controlled calibration laboratory than in the field. *The critical point for asphalt QA is that most state DOT programs currently have no formal requirement to verify handheld IR thermometers against a reference before field use. Annual calibration at boiling water (212°F), when required, constitutes a single-point check far below the production temperature range of 250–355°F.*

The aggregate effect of these limitations, emissivity uncertainty, D:S management, environmental interference, and absent calibration requirements, is reflected directly in the NCAT Test Track field study (Section 5.4.1).

2.3.4 Paver-Mounted Thermal Profile (PMTP) Systems

Paver-mounted thermal profile systems extend the single-point IR measurement principle to a continuous, geo-referenced thermal map of the entire mat surface during placement. AASHTO R 110-22 is the governing practice for these systems and defines equipment requirements, data management protocols, and procedures for thermal segregation analysis. (Image 6)

How PMTP Systems Work. A PMTP system consists of an array of IR sensors or a scanning line-detector assembly mounted at the rear of the paver, 1.0–3.5 m (3–12 ft) behind the trailing edge of the screed plate. The sensor array covers the full lane width being paved and records surface temperature readings at longitudinal intervals of 305 mm (12 inches) or less at all paving speeds. Each temperature reading is tagged with a GNSS coordinate from the system's integrated GPS/GNSS receiver, creating a continuous spatial record of the mat surface temperature. Data is transmitted in near-real time to cloud storage and visualized as a color-coded temperature contour map that the paver operator can monitor on an in-cab display.

Data Analysis and Thermal Segregation Indices. Raw thermal profile data is processed in Veta software per AASHTO R 110 and PP114. The analysis divides each paving run into 45-meter (150-foot) data sublots, approximately one truckload, and computes four statistical indices for each sublot: standard deviation of surface temperature readings (StDev), the range between the 98.5th and 1st percentile readings, the thermal segregation index (TSI, a composite of StDev and transverse variability), and the transverse semivariogram index (TSV, which specifically identifies longitudinal thermal streaking patterns associated with auger-related segregation). Low TSI values

indicate thermally uniform placement; high TSI values identify areas of thermal segregation that correlate with density non-uniformity and are candidates for targeted field investigation.

Equipment Requirements and Accuracy. AASHTO R 110 specifies that the PMTP sensor must have a temperature measurement range of 60–250°C (140–480°F) and an accuracy of ±2°C (±3.6°F) or ±2.0 percent of the reading, whichever is greater. These requirements are stated as performance specifications. The standard does not prescribe a specific sensor type or spectral band, allowing manufacturers flexibility while establishing a minimum accuracy threshold. The system must also meet GNSS accuracy requirements of either ±1.2 m (±4 ft) or ±50 mm (±2 in.) in the X and Y directions, depending on the accuracy class selected by the specifying agency.

The primary limitation of PMTP systems is that they measure surface temperature only. While surface temperature immediately behind the screed is generally a reasonable proxy for the mat's compactable thermal state, thin lifts (less than 25 mm [1 in.]) are more susceptible to surface cooling from ambient wind and air temperature, and surface readings in these cases may underestimate the interior temperature available for compaction. For lifts of adequate thickness under typical production conditions, the correlation between PMTP readings and in-place density is well-supported in the research literature and was a key factor in AASHTO's adoption of R 110.

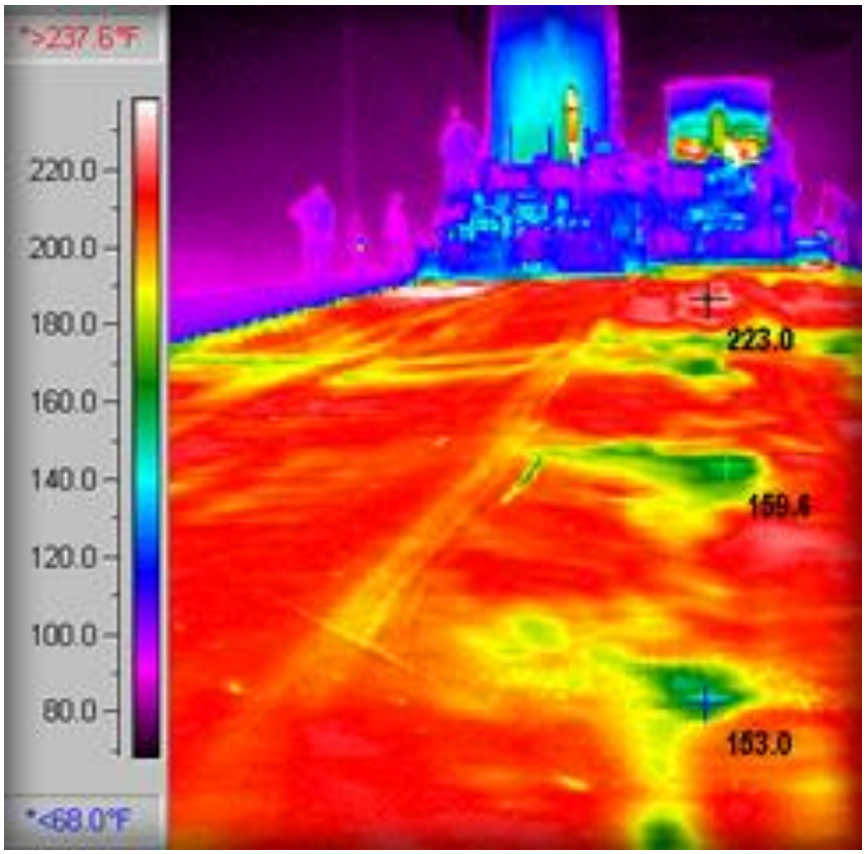

Image 6. Paver-mounted thermal profiling system used to monitor temperature uniformity across the mat. (Source: PavementInteractive.Org)

2.3.5 Instrument Summary

Table 2-3 summarizes the operating principle, measured quantity, typical accuracy, calibration standard, and primary field limitations of each instrument class. This comparison provides the technical basis for the instrument class requirements in the draft specification language (Section 8).

Table 2-3. Comparison of Temperature Measurement Instruments Used in Asphalt Mix Production, Transport, and Placement

Instrument	Measurement Principle	Measures	Typical Field Accuracy	Key Calibration Standard(s)	Primary Limitations for HMA Applications
Bimetal dial thermometer	Differential thermal expansion of two bonded metals rotates a needle	**Bulk (contact)**	±2 to 5°C (±4 to 9°F); lowest of contact types	ASTM E1, E2251	Mechanical drift; no electronic output; warm-up lag; no data logging
Type K thermocouple probe	Seebeck effect: dissimilar metal junction generates a voltage proportional to temperature	**Bulk (contact)**	±1.1 to 2.2°C (±2 to 4°F); Special Limits of Error ±1.1°C	ASTM E220, E230/E230M, E608/E608M	Warm-up time required; self-heating at low current; reference junction compensation needed
Digital contact probe (Pt100 RTD)	Electrical resistance of platinum increases linearly and predictably with temperature	**Bulk (contact)**	Class A: ±(0.15 + 0.002|T|)°C; highest accuracy of all probe types	ASTM E1137/E1137M, E644	Requires thermal stabilization; self-heating error at high excitation current; fragile sensing element
Fixed plant pyrometer (IR)	Detects thermal radiation emitted by mix stream surface; converts radiance to temperature using the emissivity setting	**Surface (non-contact)**	±1 to 2°C (±2 to 4°F) under stable conditions; varies with emissivity and path cleanliness	ASTM E2847 (wideband); manufacturer-specific for narrowband	Measures surface only; steam/dust path interference; lens contamination; spectral band may differ from field IR guns
Handheld IR thermometer (IR gun)	Thermopile detector integrates emitted IR radiation over	**Surface (non-contact)**	Manufacturer claim: ±1 to 2°C; field inter-instrument	ASTM E2847 (wideband, 8–14 *μm*)	Operator-dependent; emissivity setting critical; D:S ratio must be managed; environmental

Instrument	Measurement Principle	Measures	Typical Field Accuracy	Key Calibration Standard(s)	Primary Limitations for HMA Applications
	the field of view; D:S ratio defines spot size		spread documented at 18°C (32°F) on same mat		interference (steam, wind, fumes); lowest repeatability of all methods (DOT survey: 2.84/5.0)
Paver-mounted thermal profiler (PMTP)	2D IR sensor array or line scanner mounted behind screed; geo-referenced with GNSS; continuous spatial coverage	**Surface (non-contact)**	R 110 requirement: ±2°C (±3.6°F) or ±2.0% of reading	Manufacturer recommendations ASTM E2847 applicable to individual sensors	Surface temperature only; not suited for lifts <25 mm (1 in.); significant data management and software requirements (Veta); cost and setup time; not practical for small projects

Note: Accuracy values reflect manufacturer specifications and standards requirements under controlled conditions. Field accuracy is generally lower due to environmental factors, operator technique, and calibration state.

2.4 Current State-of-the-Practice and Identified Gaps

Despite the critical role that temperature plays in asphalt mix quality assurance, national guidance on how, where, when, and with what instrument mix temperatures should be measured is fragmented and incomplete. A review of current AASHTO and ASTM standards (Appendix A), 29 state DOT survey responses, 23 SAPA industry survey responses, and field empirical data identified the following principal gaps:

- No standardized instrument class. Any device, from an uncalibrated bimetal dial to a high-accuracy Pt100 RTD, is currently accepted in most specifications. Instrument class, spectral band (for IR instruments), and minimum accuracy are not specified in standard DOT contract documents.
- No calibration or verification frequency for field instruments. Most state programs do not require handheld IR thermometers or contact probes to be verified against a traceable reference before use. Where calibration is mentioned, it typically requires a single-point check at boiling water (212°F) at most once annually, which is 40–145°F below the normal production temperature range.
- No standardized access point. How inspectors physically access the mix for temperature measurement, particularly at the haul truck, is not specified. Over-the-top truck measurements expose inspectors to fall and burn hazards; truck-side access ports are not currently required by any national standard.
- Probe warm-up time not addressed. No standard specifies a minimum thermal stabilization period before recording a contact probe reading.
- Surface vs. bulk temperature distinction is absent from specifications. IR measurements (surface temperature) and contact probe measurements (bulk temperature) are treated as equivalent in most specifications, though the two quantities can differ by several degrees Fahrenheit depending on surface cooling conditions.
- No cross-method verification protocol. When an IR reading and a contact probe reading at the same location disagree, a situation that 70 percent of DOT survey respondents report they do not routinely investigate, there is no standardized method for resolving the discrepancy or determining which reading governs for acceptance purposes.
- Plant pyrometer data is not required to be logged. AASHTO M 156 requires plant thermometric devices but does not currently require that their data be time-stamped, electronically archived, or made available to the DOT inspector. The fixed thermocouple, the most accurate plant temperature reference, is typically display-only.
- Adoption of thermal profiling is limited to pilot projects. Only one of 29 DOT survey respondents uses thermal profiling routinely; one-third have piloted it. The lack of specification language, guidance on equipment procurement, and data management protocols is a barrier to the broader adoption of AASHTO R 110.
- WMA incentive structures are essentially absent. Only one SAPA respondent reported an active WMA production-temperature incentive program, despite WMA's documented benefits for worker safety, energy consumption, and extended paving seasons.

These gaps collectively define the technical scope of this study's recommendations and draft specification language. Each is directly addressed in Sections 7 and 8.

3. Objective

The objective of this work is to develop recommended temperature reading specifications for asphalt paving projects, grounded in a systematic review of existing practice, survey data from state DOTs and industry, and field and laboratory measurement data. The intent is to close specific, documented gaps in the current national specification framework, gaps that allow temperature readings used for acceptance decisions to vary significantly based on the instrument used, the measurement location chosen, and the verification practices applied, and to provide draft specification language that agencies and AASHTO technical committees can adopt directly.

This deliverable addresses the temperature reading component of the broader NAPA-funded project, *'Recommended Asphalt Mix Sampling and Temperature Reading Specifications for Paving Projects.'* The scope covers the full temperature measurement chain from plant discharge through mat placement: plant discharge sensors and recording systems (addressed in AASHTO M 156), field contact probe and IR thermometer practices during sampling and acceptance (AASHTO R 97), and paver-mounted thermal profiling as a spatial QA tool (AASHTO R 110). Recommendations for warm-mix asphalt temperature incentive programs are included as an optional extension of the plant temperature-recording framework, drawing on Minnesota's experience as an active U.S. model.

The work does not seek to change the temperature ranges used for mix acceptance; those are appropriately set by agencies based on local conditions, binder grades, and mix design. The work seeks to ensure that when a temperature is measured and used for an acceptance decision, the measurement is taken with an instrument of known, verified accuracy, at a defined location, with a documented method, so that the reading means the same thing regardless of who takes it.

4. Sources of Information

This study synthesizes information from four categories of sources: national standards developed by AASHTO and ASTM; a targeted literature review of published and unpublished technical documents bearing on temperature measurement in asphalt applications; state DOT construction specifications reviewed to characterize the current range of regulatory approaches; and primary data collected through stakeholder surveys, interviews, and field observations (Section 5). Each category is described below.

4.1 AASHTO and ASTM Standards

The relevant AASHTO and ASTM standards were identified through a systematic review of thermometry, infrared measurement, and asphalt plant and sampling practice standards. Full designation-level summaries and the temperature-relevant sections of each standard appear in Appendix A. The four AASHTO standards directly governing temperature measurement in asphalt production and paving are summarized in Table 4-1. Ten ASTM standards addressing instrument calibration, thermocouple specification, RTD specification, infrared measurement, and emissivity are summarized in Table 4-2.

A significant event affecting the normative landscape occurred during the preparation of this report. ASTM E2847, which previously carried the status of Standard Guide for Calibration and Accuracy Verification of Wideband Infrared Thermometers, was upgraded to a Standard Test Method in its 2026 edition. This distinction matters because AASHTO standards and state specifications cite a Test Method that references a normative, procedure-defining document rather than an advisory guide. Citing the 2026 edition of E2847 in revised AASHTO M 156 and R 97 language therefore provides a stronger, more enforceable verification requirement than citing the prior Guide edition.

The proposed 2026 ballot revisions to AASHTO M 156 (plant equipment requirements) and AASHTO R 97 (sampling practice) are treated in this report as expected-to-advance additions. These ballot items were developed separately from this study and are referenced throughout as a potential primary vehicle for implementing the report's recommendations. AASHTO R 110 and its proposed 2026 revisions are the governing standard for paver-mounted thermal profiling and are referenced in Section 8.3.

Table 4-1. AASHTO Standards Reviewed — Temperature Measurement Relevance

Designation	Scope Relevant to Temperature Measurement	Role in This Study
AASHTO M 156-13(2025) [Proposed 2026]	Requirements for asphalt mixing plant equipment, including thermometric devices at drum discharge, binder lines, and aggregate dryer. Proposed 2026 ballot adds continuous electronic data logging at ≥1 Hz, RTD Class A or Type K SLE instruments, ±1.5°C expanded uncertainty, NIST-traceable verification, and CSV archiving for ≥3 years.	Primary production-side standard; defines minimum equipment requirements. Proposed revisions are a central output of this study.
AASHTO R 97-19(2024) [Proposed 2026]	Standard Practice for Sampling Asphalt Mixtures. Specifies permitted sampling locations (haul truck, paver hopper, windrow, roadway pre-compaction). Proposed 2026 additions address temperature recording at time of sampling, measurement location, instrument documentation, and side-port access for truck sampling.	Governs sampling practice; temperature at time of sampling is a key data element for quality correlation.

Designation	Scope Relevant to Temperature Measurement	Role in This Study
AASHTO R 66-16(2024)	Sampling of Bituminous Materials. Covers liquid binder sampling; not directly applicable to mix temperature measurement but establishes chain-of-custody and documentation principles relevant to the broader QA framework.	Background context for documentation standards.
AASHTO R 110-22(2026)	Continuous Thermal Profile of Asphalt Mixture Construction Using Paver-Mounted Infrared Profiling Systems. Specifies equipment (2D IR array, GNSS), data management, Veta software analysis, and TSI/TSV segregation indices. Accuracy requirement: ±2°C or ±2.0% of reading. Proposed 2026 revisions refine equipment and data requirements.	Primary standard for paver-mounted thermal profiling; scope and accuracy requirements are benchmarks for discussion of PMTP capabilities and limitations.

Table 4-2. ASTM Standards Reviewed — Temperature Measurement Relevance

Designation	Scope and Temperature Measurement Relevance
ASTM E1 / E2251	Liquid-in-glass thermometers; ITSN-90 calibration. Baseline reference for calibration traceability of primary standards.
ASTM E220-25	Standard Test Method for Calibration of Thermocouples by Comparison Techniques. Applies to Type K sensors used in both fixed plant and handheld contact probes.
ASTM E230/E230M-23a	EMF-temperature reference tables for all standardized thermocouple types, including Type K (chromel–alumel). Basis for thermocouple readout electronics.
ASTM E608/E608M-24	Mineral-insulated, metal-sheathed (MIMS) base metal thermocouples. Covers Type K sensors in the rugged sheathed configuration used for both fixed plant sensors and field probes.
ASTM E1137/E1137M-08(2020)	Industrial platinum resistance thermometers (PRTs). Class A tolerance: ±(0.15 + 0.002|T|)°C. Relevant to the proposed RTD Class A requirement in M 156 §4.12.3.
ASTM E644-11(2025)	Test methods for testing industrial resistance thermometers. Verification and calibration procedures for RTD probes.
ASTM E2758-22	Standard Guide for Selection and Use of Infrared Thermometers. Defines distance-to-spot (D:S) ratio, field-of-view concepts, and selection criteria relevant to both handheld IR guns and fixed pyrometers.
ASTM E2847-21(2026)	Standard Test Method (upgraded from Guide in 2026) for Calibration and Accuracy Verification of Wideband Infrared Thermometers. Defines Scheme I (contact comparison) and Scheme II (radiometric comparison). Specifies 8–14 *μm* wideband response and emissivity = 0.95 for HMA worked examples. Upgrade to Test Method increases normative weight in AASHTO citations.
ASTM E1933-14(2022)	Standard Practice for Measuring and Compensating for Emissivity Using Infrared Imaging Radiometers. Procedures for field emissivity determination by contact comparison or known-emissivity tape.

Designation	Scope and Temperature Measurement Relevance
ASTM E563-22	Standard Practice for Preparation and Use of an Ice-Point Bath as a Reference Temperature. Single-point (32°F) verification reference; useful for contact probe baseline check but inadequate as sole calibration method for high-temperature asphalt applications.

Note: Full standard titles and temperature-relevant section summaries appear in Appendix A.

4.2 Literature Review

The literature review focused specifically on temperature measurement in asphalt mix production, transport, and placement. Sources were identified through a systematic search of AASHTO publications, FHWA technical reports, Transportation Research Board (TRB) proceedings, state DOT technical documents, and NAPA member organization resources. The review also incorporated two unpublished field datasets.

The published literature on temperature measurement in asphalt QA is notably sparse compared to the literature on sampling method effects, mix design, and compaction. Most available guidance is embedded in plant standards (M 156), sampling practices (R 97), and state construction manuals rather than in peer-reviewed research. The primary published and agency documents reviewed for this study, and their key relevance to temperature measurement, are summarized in Table 4-3.

Two recurring themes emerge from the reviewed literature.

> **First,** accuracy and calibration requirements for field temperature instruments are absent or minimal in virtually every available guidance document. NYSDOT's construction manual is an outlier for explicitly describing the IR gun as a screening tool that requires probe confirmation, but even this guidance does not specify a calibration protocol or an acceptable instrument class.
>
> **Second,** the connection between temperature measurement and performance outcomes, compaction achievement, binder aging, and in-place density is well established in the design and research literature but is not consistently operationalized in QA specifications. The NAPA SUST-008 temperature category framework and the MnDOT WMA incentive represent efforts to connect measurement to outcomes, and both are conditioned on having reliable, verifiable temperature data.

A gap identified early in the review and supported by the DOT survey results (Section 5) is the near-complete absence of published precision and bias (P&B) data for any temperature-measurement method used in asphalt paving applications. ASTM E2847 specifies a verification procedure for wideband IR thermometers but does not include a P&B statement for asphalt-specific conditions. The NCAT Test Track IR gun study (Table 4-3) fills part of this gap with field-measured inter-instrument variability data, and plant observation provides anecdotal evidence of probe warm-up bias, but neither constitutes a formal ASTM-style P&B study.

Table 4-3. Key Literature and Field Studies Reviewed

Source	Document Type	Temperature Measurement Relevance
NAPA SUST-008 (2024)	Industry Guideline	Defines five asphalt mix production temperature categories (0: ≥305°F; 1: 285 to 304°F; 2: 250 to 284°F; 3: 212 to 249°F; 4: ≤211°F). Defines production temperature as the temperature at the mixer exit. Establishes the industry communication framework for temperature reduction and WMA adoption. Explicitly cautions that temperature reduction should not be mandated and that mixture quality must be confirmed first.
Ingevity/TRF (2022 field study)	Industry Research Paper	Field study at five asphalt plants across the U.S. comparing dense-graded HMA at 154–163°C (310–325°F) to WMA with chemical additive at 19–39°C lower temperatures. Measured fugitive particulate matter (PM1, PM2.5, PM10) at silo, load-out, and paving site; stack emissions; and burner fuel consumption. Documents a direct link between measurable mix production temperature and quantifiable environmental and safety outcomes — motivating why accurate temperature measurement matters beyond routine QA.
MnDOT SP 2360 WMA Incentive (2025)	State Agency Specification Supplement	Optional temperature-based WMA incentive for plant mixing temperatures of ≤275°F (135°C). Four candidate projects contracted in 2025. Represents the most developed current U.S. example of a specification that directly links temperature measurement to a financial incentive, underscoring the need for standardized, verifiable measurement protocols at the designated reporting point.
FHWA HRT-23-047 (2023)	FHWA Technical Report	Documents effective e-ticketing implementation practices for asphalt paving. Relevant because e-tickets can include plant discharge temperature data (often drawn from the plant control system pyrometer), creating a digital temperature record tied to each load. Raises the question of which plant sensor feeds the e-ticket value, and whether that value is verified against a calibrated reference.
NYSDOT Section 402 Construction Guidance	State Training Document	Describes inspector protocols for both analog probe and IR gun temperature measurement at the paver hopper. Notable for explicitly characterizing IR guns as a 'screening tool' and requiring analog thermometer confirmation when IR indicates out-of-specification temperature. Provides practical basis for instrument hierarchy concept in the draft specification language.
WAQTC Meeting Notes (Fort, 2024)	Working Group Notes	Notes from a Western Alliance for Quality Transportation Construction (WAQTC) call identify inconsistent IR gun calibration practices across member agencies as a known issue, with some agencies performing no calibration at all. Supports the finding from the DOT survey that formal calibration requirements for field thermometers are absent in most programs.
Gong et al. (2023)	Peer-Reviewed Journal Article	Systematic review of strategies for reducing in-service asphalt pavement surface temperature (cool pavements, phase change materials, reflective coatings). Although focused on in-service surface temperature rather than production temperature,

Source	Document Type	Temperature Measurement Relevance
		provides context for the urban heat island effect as a driver of broader industry interest in asphalt temperature management.
Wurst (CTAA 2023)	Conference Paper / Presentation	Discussed at the project panel meeting; addresses temperature-related QA issues in the Canadian context. Provides a cross-border perspective on temperature measurement practices and instrument verification protocols.
NCAT Test Track IR Gun Variability Study (2024, unpublished)	Unpublished Field Study	Seven handheld IR thermometers of varying makes and models were used by separate observers to read the same mat surface simultaneously during 2024 NCAT Test Track construction. Across multiple measurement sets on seven days, inter-instrument spread ranged from 12°F to 53°F on the same surface, with an average spread of approximately 30°F. No formal precision and bias procedures were followed; instruments were not calibrated against a traceable reference prior to use. The study represents one of the only empirical datasets on IR gun inter-instrument variability in asphalt field applications.
Parker (1996)	Auburn University Research Report	Investigated residual moisture in HMA, with emphasis on porous, high-absorption chert gravels. Field results showed that surface moisture is removed rapidly, but internal moisture may continue to vaporize after the aggregate has been coated with asphalt binder and as the mixture moves from the drum to the truck and paver. The study found that residual moisture contents below approximately 0.2 percent were generally achievable with normal production procedures, except for mixtures containing highly absorptive chert gravel. The findings demonstrate that aggregate absorption, plant retention time, and measurement location can affect the temperature and moisture conditions observed at different points in the plant process.
Hossain et al. (2015)	FHWA/Illinois Center for Transportation Research Report	Applied thermodynamic and heat-transfer principles to the drying and heating of virgin aggregate, RAP, and RAS in batch and drum plants. The report quantified the sensible heat required to raise moisture to its boiling point and the latent heat required to vaporize the water, and used these energy requirements to predict the elevated virgin-aggregate temperatures needed to achieve a specified final mixture temperature. The analysis provides the theoretical basis for relating aggregate moisture content to an equivalent mixture-temperature reduction and demonstrates why intermediate aggregate or mixture temperatures may be higher than the final temperature measured later in the plant process.

Note: Unpublished field study (NCAT Test Track) is described in detail in Section 5.4.

4.3 State DOT Specifications

State DOT construction specifications were reviewed to characterize the current range of approaches to asphalt mix temperature measurement, limits, and instrument requirements. Specifications from 11 states were reviewed directly: Alabama, Minnesota, Missouri, North Carolina, New York, Oregon, South Carolina, Texas, Virginia, Washington State, and West Virginia. These states were selected to represent geographic diversity, varying levels of specification detail, and states with SAPA or DOT survey responses available for cross-reference. An AI summary of additional state specifications was used as a screening tool to identify states with notable or atypical requirements; all characterizations in this report are drawn from the primary specification documents.

The reviewed specifications reveal several consistent patterns and several important outliers. Most states establish maximum production temperature limits in the range of 325–350°F (163–177°C) tied to the JMF, with minimum delivery temperatures at the paving site between 220°F and 250°F (104–121°C), depending on mix type and whether WMA technology is in use. The instrument type required to measure compliance varies from unspecified (most states) to *"accuracy within 5°F"* (New York) to a recording thermometer or pyrometer at the plant discharge (Missouri, South Carolina, Texas). No reviewed specification requires calibration of handheld field instruments against a NIST-traceable reference prior to use, and none explicitly specifies an instrument class (e.g., Type K thermocouple vs. RTD vs. bimetal dial) for field acceptance measurements.

New York is the only state among those reviewed to have an explicit instrument hierarchy for field temperature measurement: IR guns are classified as screening tools, and probe confirmation is required when IR readings indicate noncompliance. NYSDOT also prohibits climbing on truck bodies to obtain samples or temperature readings, which is one of the clearest safety-driven measurement-protocol provisions in any of the reviewed specifications. Missouri and South Carolina are the strongest examples of plant-level recording requirements, both mandating continuous automatic recording of discharge temperature with defined chart intervals or electronic equivalents.

Minnesota stands apart from all other states reviewed in one critical respect: it is the only state with an active, tiered WMA temperature incentive payment linked to the plant discharge temperature record. The MnDOT supplemental provision to Spec 2360 (SP 2360, 2025 contracts) qualifies any mix produced with a non-wax-based warm mix chemical additive at 275°F or below, as measured at drum exit and recorded on the plant recordation system, for an incentive payment of 2 percent (250–275°F) or 4 percent (<250°F) of the HMA contract unit price. Critically, the provision requires documentation that the discharge temperature sensor has been calibrated for the current construction season, and the incentive is automatically denied if the sensor or the 20-minute recordation export is not functioning. The first 100 tons of daily production are excluded to allow for plant warm-up. MnDOT's approach demonstrates that a temperature-based incentive is operationally feasible but is explicitly conditioned on a verified, continuously logged plant temperature record.

Table 4-4 summarizes the key temperature provisions from each reviewed state specification. Additional state-specific information, particularly regarding accepted instruments, measurement frequencies, and dispute resolution protocols, is derived from the DOT survey responses described in Section 5.2.

Table 4-4. Temperature Provisions in Reviewed State DOT Specifications

State	Spec Reference	Production Temp Limit	Min Delivery / Placement Temp	Field Instrument Required	Plant Recording Required	Notable Provisions
Alabama	2022 Standard Specifications §410	≤350°F max	HMA: 250°F min WMA: 220°F min	Not specified by type	Not explicit	±25°F delivery tolerance for special mixes; rejection above 350°F for HMA or warm mix
Missouri	Draft §401 (2017) §404.2.8	Per JMF; surge bins within 25°F of designated temp; max 8-hr storage	Per JMF	Recording thermometer, pyrometer, or equivalent at discharge; binder feed thermometer at mixer	Yes, chart recorder; ≤15-min intervals; ≤10°F graduations	One of the most explicit plant recording requirements reviewed; chart must record both time and temperature continuously
North Carolina	2018 Std. Specs §610-5; 2024 QMS Asphalt Manual	≤350°F max at discharge	Not specified in sections reviewed	Not specified by type	Not explicit in §610-5	2024 QMS manual provides inspector guidance; discharge temperature limit is the primary control
New York	NYSDOT MP 401 (2022); Std. Spec §400	250–325°F (Permeable Base: 225–300°F)	240°F min at paver; ±20°F from pugmill discharge	All measuring devices accurate within 5°F; IR allowed as 'screening tool'; probe required for confirmation when IR indicates nonconformance	QCT records temperature on delivery ticket; QAT witnesses ≥1/day	Most prescriptive instrument hierarchy reviewed: IR as screen, probe as arbiter. Explicitly prohibits climbing on truck bodies.
Oregon	2024 Standard Specifications Division 5	Per JMF	Per JMF	Not specified by type in sections reviewed	Not explicit	Oregon is one of the few states permitting a sampling device at drum discharge (per survey); temperature measurement at that location is not separately specified

State	Spec Reference	Production Temp Limit	Min Delivery / Placement Temp	Field Instrument Required	Plant Recording Required	Notable Provisions
South Carolina	Supplemental Spec SC-M-401	Per JMF	Per JMF	Approved recording thermometer, pyrometer, or recording thermometric instrument required at dryer/drum discharge	Yes, automatic recording at discharge is required	Plant-level recording requirement matches Missouri in scope; no field instrument type specified
Texas	TxDOT Standard Specifications §300 series	275–350°F (varies by mix type and binder grade)	250°F min at paving site	Recording thermometer at discharge chute of drum plants	Yes, daily records of HMA discharge temperatures required; must be legible and submitted to Engineer	One of the most explicit delivery documentation requirements; daily temperature records are a contract requirement
Virginia	§211 (Plant Requirements); §315 (Placement)	Per JMF; max per §211	BM/IM: 250°F min SM-4.75: 290°F min 200°F absolute floor	Not specified by type	Not explicit	§315 requires compaction completion above 175°F; laydown temperature table governs minimum by base temperature and mix type; WMA minimum placement 290°F regardless of WMA use
Washington State	2025 Standard Specifications Division 5	≤JMF optimum + 25°F	Per JMF	Not specified by type in sections reviewed	Not explicit	Unique approach: production temperature tolerance referenced to JMF optimum rather than an absolute range
West Virginia	2023 Standard Specifications	Per JMF	Per JMF	Not specified by type in sections reviewed	Not explicit	Temperature requirements consistent with regional practice; specific limits not extracted from sections reviewed

State	Spec Reference	Production Temp Limit	Min Delivery / Placement Temp	Field Instrument Required	Plant Recording Required	Notable Provisions
Minnesota	MnDOT SP 2360 WMA Incentive (Supplemental Provision S-1, 2025)	≤275°F for WMA incentive eligibility; >275°F allowed first 100 tons/day (plant warm-up)	Per standard Spec 2360 (not modified by incentive provision)	Plant discharge temperature sensor (type not specified); must be calibrated for current construction season; 20-minute plant recordation export required	Yes, 20-minute plant recordation required; incentive automatically denied if sensor or recordation system is not functioning	Only U.S. state with an active tiered WMA temperature incentive payment: ≥275°F = 0%; 250–275°F = 2%; <250°F = 4% of HMA unit price. No incentive if >10% of daily discharge readings exceed 275°F (excluding first 100 tons). No incentive if >25% of project density lots fail minimum density.

Note: Entries are based on the primary specification documents listed in the Spec Reference column. 'Per JMF' indicates that the specification requires compliance with the job mix formula temperature rather than setting an absolute limit. 'Not specified by type' indicates that the specification does not identify an instrument class (e.g., probe vs. IR) for acceptance measurements.

The reviewed specifications fall into three general tiers. Minnesota, Texas, Missouri, South Carolina, and New York provide the clearest examples of first-tier practice, with explicit plant recording requirements, instrument hierarchy language, or temperature-linked incentives. Alabama, North Carolina, and Virginia specify temperature limits but generally do not prescribe instrument type or recording requirements for field measurements. Oregon, Washington State, and West Virginia largely rely on JMF compliance without additional measurement-protocol detail. The draft language in Section 8 is intended to establish a national baseline that brings greater consistency to all three tiers without exceeding what is currently practical for agencies or producers.

5. Surveys, Interviews, and Field Studies

Primary data collection for this study comprised two stakeholder surveys, supplemental stakeholder interviews, and field-based empirical studies conducted at an operating asphalt plant and the NCAT Test Track. Together, these sources capture the perspectives of state transportation agency inspectors and specification writers, asphalt contractors and their industry representatives, and independent researchers, providing a multi-perspective foundation for the recommendations and draft specification language that follow.

5.1 State DOT Survey

In May of 2026, a web-based survey was distributed to state highway agency materials and pavement engineers through AASHTO Technical Subcommittee 2c and related networks. The survey included both temperature-specific questions (11 Questions) and broader sampling questions; this section addresses only the temperature-related findings. Twenty-nine (29) state transportation agencies had submitted completed responses, representing approximately 57 percent of all 50 states plus the District of Columbia. Respondents are listed in Table 5-1 and Figure 5-1.

Table 5-1. State DOT Survey Respondents (n = 29)

Responding State Transportation Agencies
Alabama · Arkansas · California · Colorado · Connecticut · Florida · Hawaii · Indiana · Iowa · Kentucky · Maryland · Massachusetts · Michigan · Montana · Nebraska · New Jersey · New York · Ohio · Rhode Island · South Carolina · South Dakota · Texas · Utah · Vermont · Virginia · West Virginia · Wyoming (n = 27 named; 2 anonymous)

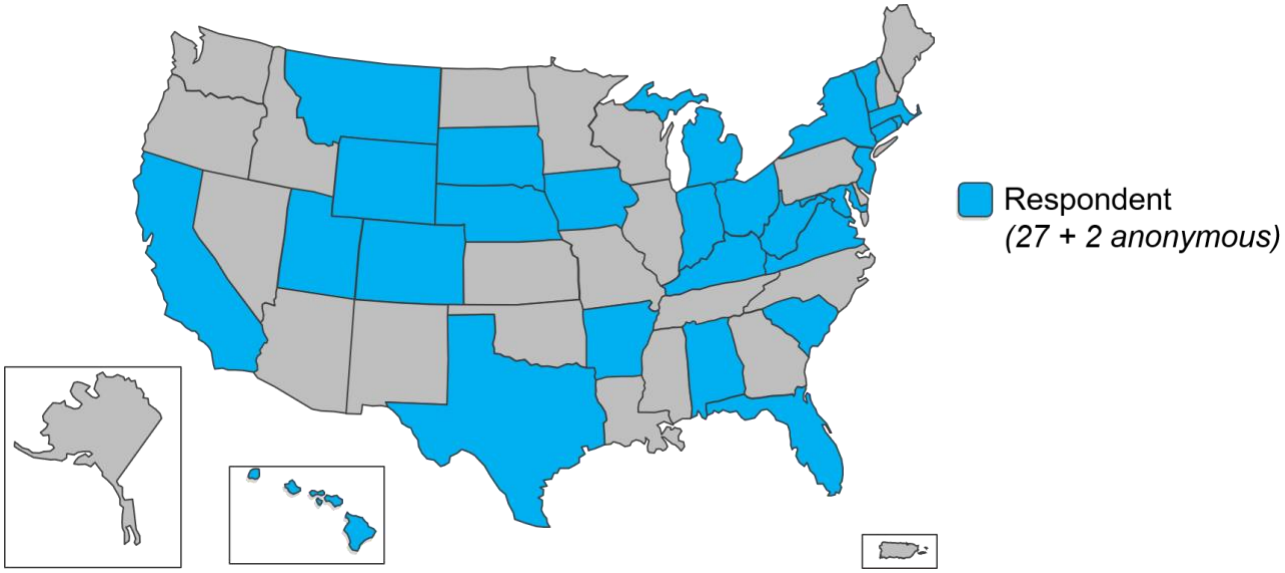

Figure 5-1. State DOT Survey Respondents

5.1.1 Temperature Measurement Devices Allowed

Respondents were asked which temperature-measurement devices their agency allows for documenting asphalt mixture temperature. As shown in Table 5-2, contact probe thermometers and handheld infrared (IR) thermometers dominate current practice, each permitted by more than 85

percent of responding agencies. IR cameras or thermal profiling systems are allowed by roughly one in four agencies, and fewer than one in four allow the asphalt plant pyrometer readout for official acceptance records.

Table 5-2. Temperature Measurement Devices Allowed by State DOTs (n = 29)

Device	Count (%)	% Agencies
Probe thermometer	**25 (93%)**	93%
Handheld IR thermometer (gun)	**23 (85%)**	85%
IR camera/thermal profiler	7 (26%)	26%
Plant readout/pyrometer	6 (22%)	22%

Note: Percentages based on 27 named respondents; totals exceed 100% because agencies may allow multiple devices.

5.1.2 Measurement Locations

Three out of four agencies take temperature measurements both behind the screed on the mat surface and at the haul truck at the project site: the two locations farthest from the plant and closest to the point of compaction. Just over half (52 percent) also record temperatures at the haul truck at the plant, providing a production-side data point for comparison. Fewer than one in four agencies measure temperature at the plant mixer discharge, potentially reflecting safety challenges and a lack of standardized access provisions at that location. Table 5-3 summarizes the results.

Table 5-3. Temperature Measurement Locations Required by State DOTs (n = 27)

Location	Count (%)	% Agencies
Behind the screed/mat surface	**20 (74%)**	74%
Haul truck at the project site	**20 (74%)**	74%
Haul truck at the plant	14 (52%)	52%
Paver hopper	10 (37%)	37%
Plant mixer discharge	6 (22%)	22%

5.1.3 Measurement Frequency and Timing

There is no consensus on when temperatures should be recorded. Engineer's discretion was the most common response (6 of 17), followed by periodic or hourly readings, each-truck measurements, and a catch-all "other" category that included start-up checks and condition-triggered readings. The open-ended responses revealed substantial variation even within the "periodic" category: frequencies ranged from every 20 minutes at discharge, to every fifth truck at the roadway, to once per hour of production. Several respondents noted that no frequency is formally specified in their agency's specification. Temperature is checked when problems are suspected. This absence of standardized trigger conditions represents one of the most actionable gaps identified by the survey.

5.1.4 Temperature Limits and JMF Tolerances

Temperature acceptance criteria vary considerably across agencies. Among the 17 respondents who answered directly, 10 selected "other" and provided open-ended descriptions rather than one of the standard tolerance bands. Of those who selected a numeric tolerance, ±25°F was most common (4 agencies), followed by ±20°F (2) and ±30°F (1). Representative limit structures reported in open-ended responses include:

- Maximum temperature at the designated reporting point tied to binder type: 315–325°F for unmodified grades; 325–355°F for polymer-modified binders.
- Minimum temperature at the paver: 225–250°F for HMA; 200–225°F for WMA.
- Asymmetric JMF tolerances: one agency specifies -20°F / +30°F at delivery to the road.
- Behind-screed minimum: 190–200°F before breakdown rolling.

5.1.5 IR Thermometer vs. Contact Probe Agreement

A critical finding of the survey is that agencies are not systematically comparing IR thermometer readings to contact probe readings at the same location. Of the respondents, 70 percent indicated they do not routinely compare the two methods. Among the eight agencies that do compare, most report differences of less than 5°F, though two agencies report differences exceeding 10°F. This result is consistent with the NCAT Test Track field study (Section 5.4), which found a 32°F spread among seven handheld IR guns measuring the same mat location simultaneously. The absence of routine cross-method comparison means that temperature-based acceptance decisions at most agencies rest on a single instrument whose accuracy relative to a contact reference is unknown.

5.1.6 Thermal Profiling of the Mat

Continuous thermal profiling using paver-mounted systems (per AASHTO R 110) remains an emerging practice. Of 27 respondents, 17 (63 percent) indicated that their agency does not use thermal profiling, 9 (33 percent) have conducted only pilot projects, and just 1 agency (Texas) reported routine use on production projects. Interest appears to be growing; nearly one-third of agencies have evaluated the technology, but a lack of specification language, data management requirements, and equipment procurement challenges are reported as barriers.

5.1.7 Method Performance Ratings

Respondents rated each temperature measurement method on four dimensions: accuracy, repeatability, practicality, and risk to acceptance decisions on a 1-to-5 scale (1 = poor/high risk, 5 = excellent/low risk). Table 5-4 summarizes mean ratings. Color coding reflects relative performance: green ≥ 4.0, amber 3.0–3.9, red < 3.0.

Table 5-4. DOT Ratings of Temperature Measurement Methods (Mean)

Method	Accuracy	Repeatability	Practicality	Acceptance Risk
Probe thermometer	**4.27**	**3.92**	3.77	**4.00**
Handheld IR thermometer	3.08	**2.84**	**4.68**	**2.80**

Method	Accuracy	Repeatability	Practicality	Acceptance Risk
IR camera / thermal profiler	3.53	3.21	3.18	3.24
Plant readout/pyrometer	3.12	3.47	**4.19**	3.06

Note: Higher scores indicate better performance. Acceptance Risk: 5 = low risk / reliable for acceptance; 1 = high risk / prone to disputes. Green ≥ 4.0; Amber 3.0–3.9; Red < 3.0.

The ratings reveal a central tension in current practice: the contact probe thermometer is rated highest for accuracy (4.27) and acceptance reliability (4.00), yet the handheld IR gun is rated nearly 1 point higher for practicality (4.68 vs. 3.77). The IR gun's low repeatability score (2.84), the lowest of any method, and its poor acceptance risk rating (2.80) confirm that agencies recognize its variability while still relying on it as the primary field instrument for reasons of speed and convenience. The plant pyrometer is rated relatively high for practicality and repeatability but low for accuracy, likely reflecting the fixed-instrument consistency it offers alongside concerns about calibration state and surface-temperature-only measurement.

Survey Takeaway: Practical Does Not Mean Acceptance-Ready
Handheld IR thermometers are highly practical and widely used, but DOT respondents rated them lowest for repeatability and acceptance reliability. Contact probes received the highest accuracy and acceptance-risk ratings, but they are less convenient and can introduce safety concerns when access is not well defined.

5.1.8 Primary Concerns

Respondents who had rated any method at 1 or 2 for acceptance risk were asked to identify their primary concerns. High variability between readings and method discrepancy were tied as the top concerns (10 responses each), followed by operator dependency (9) and environmental sensitivity to wind, smoke, and surface cooling (7). These findings reinforce the quantitative ratings: agencies are aware that their most practical tool, the handheld IR gun, is also their most variable one, and that readings from different methods at the same location can diverge without a defined protocol to resolve discrepancies.

Table 5-5. Primary Concerns about Temperature Measurement Methods

Concern	Responses	% of Respondents
High variability between readings	**10**	37%
Discrepancy with other measurement methods	**10**	37%
Operator dependency	9	33%
Environmental sensitivity (wind, smoke, surface cooling)	7	26%
Not representative of in-place mat temperature	6	22%
Measurement bias (systematic high or low readings)	5	19%

5.1.9 Emerging Use of Temperature-Based Incentives

MnDOT was the only agency identified in this study with an active WMA production-temperature incentive. The program ties incentive payments to measured plant discharge temperatures and conditions, and eligibility is based on satisfactory density performance.

In 2025, MnDOT included the WMA option with an incentive on four contracts, and contractors elected to use it on all four. For 2026, the provision was included in 12 contracts, with 9 contractors electing to participate. These results indicate that contractors will respond to temperature-based incentives when the provision is clear, optional, and paired with a density quality gate.

2025- In the first year of the MnDOT WMA Option with Incentive, four contracts were awarded. The percent of maximum possible incentive earned ranged from 52 percent to 90 percent, while achieving average mat densities of 93.1 to 94.5 percent of maximum specific gravity. The average daily plant temperature ranged from 262°F down to 239°F.

Table. Excerpt 2025 Minnesota Asphalt Conference & Trade Show (Bituminous Update)

Percent of Max. Possible Incentive Earned	Avg. Daily Plant Temperature (°F)	Avg. Mat Density
52%	254	93.1
65%	262	93.8
70%	255	93.4
90%	239	94.5

2026- The WMA option with an incentive provision was included in 12 contracts, with 9 contractors electing to use it.

5.2 Industry Survey: State Asphalt Pavement Associations (SAPA)

A parallel survey was distributed to state asphalt pavement association (SAPA) directors and technical directors to capture the contractor and industry perspective. Completed responses were received from 23 SAPA organizations representing states across all major regions of the country. Collectively, the responding SAPAs represent more than 1,750 asphalt mixing plants and their member contractors. Because SAPA respondents represent both plant operations and the field paving crew, their perspectives on safety, efficiency, and acceptance risk carry direct operational weight.

Unlike the DOT survey, the SAPA instrument was designed to elicit qualitative assessments of current requirements, such as what owners are asking of contractors, how safe and practical those requirements are, and where the industry sees gaps. Temperature-relevant questions covered methods used, measurement locations, frequency requirements, safety risk ratings by location, temperature limits, JMF tolerances, WMA incentives, surface temperature uniformity requirements, and calibration practices. Respondents are highlighted in Figure 5-2.

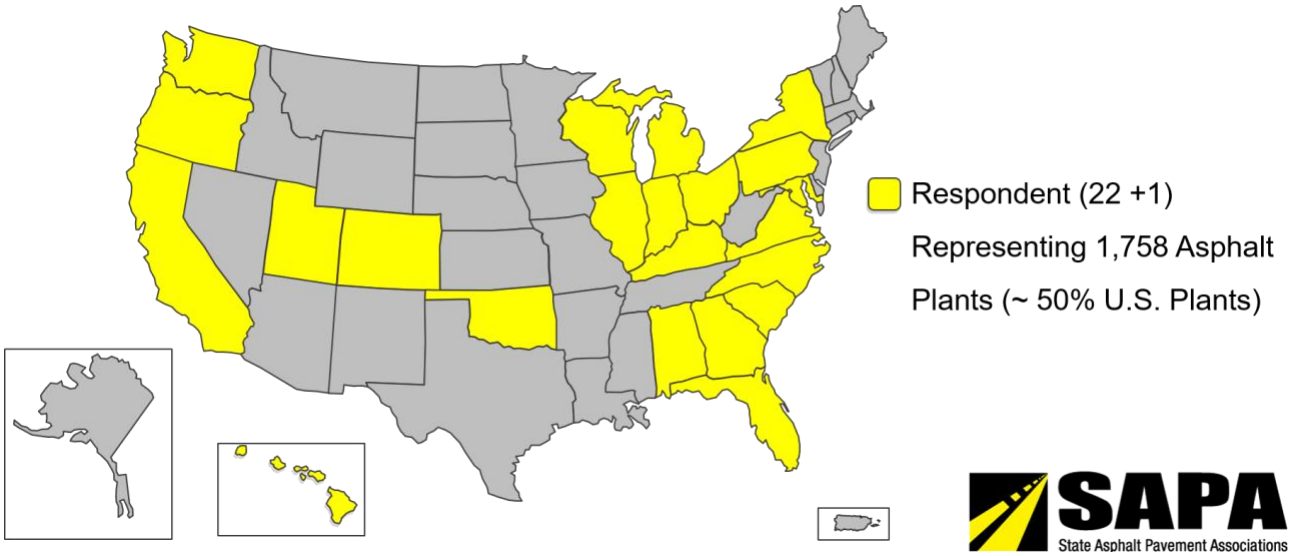

Figure 5-2. SAPA Survey Respondents

5.2.1 Temperature Measurement Methods in Use

The plant pyrometer and handheld IR thermometer were the methods most reported by SAPA respondents, followed by the calibrated contact probe. Embedded sensors (e.g., fixed RTDs in the mix discharge chute) were mentioned by two respondents, both in states with more advanced plant instrumentation programs. The majority of temperature measurements are performed by either the DOT inspector (handheld IR gun at the haul truck or mat) or the plant's fixed pyrometer—a split that creates potential for inter-instrument discrepancies in the official record.

5.2.2 Measurement Locations Required by Owners

SAPA respondents reported a wide variation in the locations where their primary owner, typically the state DOT, requires temperature documentation. The haul truck at the project site and behind the screed on the mat surface were the most frequently cited locations, consistent with the DOT survey. However, several respondents noted that temperature requirements vary by project type, mix type, and inspector, rather than being uniformly specified in the standard specifications. This

inconsistency creates compliance uncertainty for contractors operating across multiple DOT programs within or across states.

5.2.3 Measurement Frequency

Frequency requirements are even less standardized than measurement locations. Responses ranged from "each haul truck" (Alabama) to "no formal requirement" (Colorado, Washington). Common frameworks included: first five trucks and then every fifth truck (Florida); once per hour of production (Ohio); each time a sample is taken, plus whenever problems arise (Georgia); and per the QC protocol, with no state-specified minimum (Indiana). Several respondents noted that frequency is effective at the DOT inspector's discretion, with no written standard, making it difficult for contractors to plan or budget for temperature documentation as a formal QA activity.

5.2.4 Safety Risk at Temperature Measurement Locations

SAPA respondents rated the relative safety risk of taking temperature measurements at each location on a zero-to-100 scale. Results are summarized in Table 5-6. The paver hopper was rated the most hazardous location for temperature recording (mean 61.6 out of 100), followed by the MTV hopper (53.5) and the haul truck at the roadway (53.1). Both locations place the measurement taker in or adjacent to active traffic or heavy moving equipment. The haul truck at the plant was rated lowest (20.2), consistent with a controlled, off-road environment. These ratings are directionally consistent with the safety incident data: the one documented fatality associated with this type of fieldwork reported by respondents occurred during plate sampling at the roadway (Indiana, 2025), a work zone environment analogous to the high-risk temperature measurement locations.

Table 5-6. SAPA Safety Risk Ratings for Temperature Measurement Locations (0 = Low Risk, 100 = High Risk)

Location	Mean Risk Score	Relative Risk
Paver hopper	**61.6**	**High**
MTV hopper	**53.5**	**High**
Haul truck at roadway	**53.1**	**High**
Windrow	40.0	**Moderate**
Roadway before compaction	35.4	**Moderate**
Haul truck at the plant	**20.2**	**Low**

5.2.5 Temperature Limits and Acceptance Criteria

Temperature limits reported by SAPA respondents vary significantly across state programs. Maximum production temperatures at the plant ranged from 300°F (Colorado) to 360°F (Maryland), with most states setting a maximum of 325 to 350°F. Minimum delivery or placement temperatures ranged from 200°F (Virginia, warm mix) to 265°F (South Carolina, PG 64-22 mix). Several states apply asymmetric limits. For example, Florida specifies ±30°F from the compaction temperature at the roadway, but widens the lower bound to -40°F for windrow placements. JMF-based tolerances

range from ±15°F (Carolinas) to ±30°F (Florida, Washington). A notable outlier is New York, which requires delivery at 295°F using approved warm mix technology, a fixed target rather than a range.

5.2.6 Warm Mix Asphalt Temperature Incentives

Very few state programs provide financial incentives for producing asphalt at lower temperatures consistent with warm mix asphalt (WMA) classification. Of the respondents, 22 indicated that no WMA incentive exists; one respondent (Illinois) indicated that the concept is under consideration for a low-carbon transportation materials (LCTM) grant program. The absence of WMA incentive structures, despite WMA's documented benefits in reducing worker fume exposure, achieving fuel savings, and extending the paving season, represents a missed opportunity for policy alignment that several respondents identified as a priority for future specification development.

5.2.7 Calibration and Verification Requirements

Calibration requirements for temperature measurement instruments are poorly specified in most state programs. Of the 16 respondents who addressed this question area, the majority indicated that no formal calibration frequency or method is specified for handheld IR thermometers or contact probes used in field temperature documentation. South Carolina was cited as an exception, where SCDOT maintains calibration and verification procedures for thermometers as part of its laboratory accreditation framework. Georgia requires weekly calibration of thermometers at the plant. Pennsylvania specifies calibration at boiling water (212°F) at least annually, though this single-point check has not yet been updated to address IR thermometers. Washington noted that IR gun calibration has been "an issue on a few projects" with no clear resolution mechanism in the specification. The near-universal absence of instrument-specific calibration requirements is a structural gap that directly enables the inter-instrument variability documented in the field studies described in Section 5.4.

5.3 Synthesis: Convergence and Divergence between DOT and Industry Perspectives

Viewed together, the DOT and SAPA surveys reveal both shared concerns and meaningful differences in emphasis. Table 5-7 summarizes how each stakeholder group frames the six primary factors driving temperature measurement practice. The following narrative elaborates on each theme.

Table 5-7. Stakeholder Perspective Comparison: DOT vs. Industry (SAPA) Emphasis

Factor	State DOT Emphasis	Contractor / Industry Emphasis (SAPA)
Safety	Increasing importance; safety is not yet fully integrated into temperature measurement specifications, but is recognized as a concern at paver and work zone locations.	**Highest priority.** SAPA respondents rated the paver hopper and haul truck at the roadway as the most dangerous temperature measurement locations (>50/100). Prohibiting over-the-top truck measurements is an immediate, actionable request.
Representativeness	Primary driver. DOTs prioritize measurement locations close to placement: behind the screed (74%) and at the project site truck (74%), to capture the temperature the mix has when it goes down.	Important but balanced with safety. Industry recognizes the value of placement-side temperatures but raises concern that the safest practical access points (plant truck, discharge chute side port) may not align with what DOTs currently require.
Pavement Quality	Secondary consideration in survey responses; mix temperature is tracked primarily for specification compliance rather than explicit linkage to density or distress outcomes.	Major concern. SAPA respondents frame temperature control as a direct pavement quality driver; temperatures that are too high degrade the binder, and temperatures that are too low prevent proper compaction. The absence of minimum delivery temperature requirements in some states is seen as a quality risk.
QA Efficiency	Moderate concern. DOTs want data but do not universally specify frequency; engineer's discretion is the most common approach, which is practical for the agency but provides no consistent record.	Major concern. "Each haul truck" requirements in some states impose a significant labor burden with unclear quality benefits. Automation and digital data logging are strongly supported to reduce inspector workload while improving data coverage.
Acceptance Risk	Moderate concern. DOTs rate handheld IR as the lowest for acceptance reliability (2.80/5.0), but have no formal protocol to resolve discrepancies between IR and probe readings at the same location.	Major concern. Contractors face rejection or disputes based on a single IR reading from an uninspected, unverified instrument. The absence of calibration requirements and a cross-method verification protocol creates the

Factor	State DOT Emphasis	Contractor / Industry Emphasis (SAPA)
		potential for unfair or inconsistent acceptance decisions.
Automation / Digital Data	Growing interest. One-third of agencies have piloted thermal profiling; automated plant data logging is recognized as a gap in current M 156 requirements.	Strong support. Industry strongly endorses plant pyrometer data logging, automated timestamp-linked records, and thermal profiling as alternatives to labor-intensive spot measurements. Contractors see digital data as providing better-quality assurance evidence and reducing the potential for disputes arising from a single disputed reading.

Across both surveys, the clearest area of convergence is the inadequacy of current calibration and verification requirements. Neither DOT respondents nor SAPA respondents could point to a comprehensive, consistently applied protocol for verifying that the handheld IR thermometers used for temperature-based acceptance decisions are operating within acceptable accuracy limits. This gap is not a peripheral concern; it sits at the intersection of all six factors in Table 5-7, undermining safety-based decisions about where to measure, the representativeness of the recorded data, pavement quality assurance, QA efficiency, acceptance risk, and the reliability of any automated data record.

The second major convergence point is the disconnect between practical access to measurement and specification requirements. Both groups recognize that the safest and most practical temperature access point, the plant pyrometer or a truck-side port, is not consistently accepted by agencies for compliance documentation. Bridging that gap through standardized instrument-class requirements, a defined verification protocol, and formal recognition of side-port contact-probe access is the central task of the draft specification language developed in Section 8.

5.4 Field Study

5.4.1 NCAT Test Track — Handheld IR Thermometer Inter-Instrument Variability Study (2024)

During the 2024 NCAT Test Track construction cycle, seven (7) handheld IR thermometers of various makes and models were used simultaneously to measure surface temperature on the same asphalt mat at the same location during active paving operations. Temperature readings across the seven instruments ranged over 32°F on the same mat surface, with a mean spread that persisted across multiple measurement events. No single instrument was designated as the reference, and instruments were assumed to be within calibration. A single operator conducted all measurements consistently. The study was not designed as a controlled precision experiment; instruments were not randomized or blinded, but the magnitude of inter-instrument disagreement is practically significant. A 32°F spread is larger than the ±25°F JMF tolerance used by most DOTs, meaning that the choice of instrument alone could determine whether a load is accepted or rejected. This finding directly supports the recommendation to require pre-use IR thermometer verification and to establish an allowable inter-instrument agreement threshold before use in acceptance decisions (Figure 5-3).

Acceptance Risk: Instrument Choice Matters
In the NCAT Test Track field study, seven handheld IR thermometers measuring the same mat location produced temperature spreads ranging from 12°F to 53°F, with an average spread of approximately 30°F. That spread exceeds the ±25°F JMF tolerance commonly used by state DOTs.

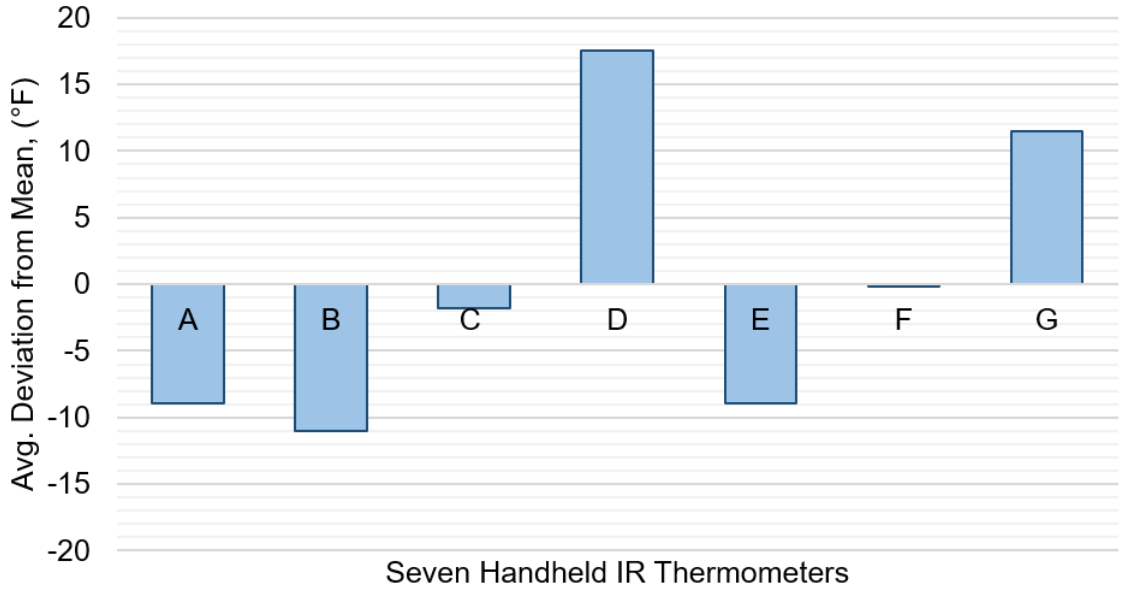

Figure 5-3. NCAT In-house Study of Handheld IR Thermometers

5.5 Relationship Between Aggregate Moisture and Resultant Temperature

Residual moisture retained within aggregate particles can affect asphalt mixture temperature after the aggregate has passed through the primary drying and mixing process. Surface moisture is generally removed rapidly in the dryer. Internal moisture contained within the pores of absorptive aggregate, however, may require additional time and energy to migrate to the particle surface, vaporize, and escape. Parker (1996) documented that internal moisture in porous chert gravel continued to vaporize after the aggregate had been coated with asphalt binder and as the mixture moved from the drum to the truck and paver.

At plant discharge, typical aggregate internal moisture content is usually very low, but it depends on the plant type and aggregate absorption. For most batch plants, aggregate moisture is less than 0.1 percent at dryer discharge. Even when the incoming aggregate is wet and highly absorptive, the moisture content leaving the dryer is generally less than approximately 0.3 percent, with additional moisture loss occurring in the hot bins. For counter-flow drum plants, aggregate entering the mixing zone typically contains little significant moisture when drying is complete. For parallel-flow drum plants, some moisture may remain when the binder is introduced and may continue to escape after the aggregate has been coated. High-absorption limestone, gravel, slag, or other porous aggregate may retain internal moisture even at normal production temperatures.

The effect of internal moisture on mixture temperature can be evaluated using a simplified heat balance derived from the thermodynamic relationships presented by Hossain et al. (2015). Energy is required to heat the internal water from its initial temperature to the boiling point, convert the liquid water to vapor, and heat the resulting vapor to the mixture discharge temperature. When that

energy is drawn from the heated aggregate and mixture, it results in an equivalent reduction in the mixture temperature. Equation 1 expresses this relationship.

$$\Delta T = \frac{m[C_w\,(T_b - T_i) + L_v + C_v\,(T_d - T_b)]}{C_{agg}} \qquad \text{Eq. 1}$$

Where:

ΔT	Equivalent asphalt-mixture temperature drop associated with heating and vaporizing the internal aggregate moisture, °F.
m	Internal moisture content expressed as a decimal fraction of the dry aggregate mass, lb. water/lb. dry aggregate.
C_w	Specific heat capacity of liquid water, Btu/lb.-water-°F.
T_b	Boiling temperature of water at the applicable atmospheric pressure, 212°F.
T_i	Initial temperature of the internal water before heating, °F *(assumed to be 60°F)*.
L_v	Latent heat of vaporization of water at approximately atmospheric pressure, Btu/lb. water *(970 Btu/lb.)*.
C_v	Specific heat capacity of water vapor, Btu/lb.-vapor-°F *(0.50 Btu/lb.-vapor-°F)*.
T_d	Asphalt mixture production discharge temperature, °F *(Figure 5-4 example ranges from 250 to 350°F)*.
C_{agg}	Specific heat capacity of the dry aggregate, Btu/lb.-aggregate-°F *(assumed to be 0.22)*.

Figure 5-4 shows the calculated equivalent temperature reduction over a range of internal aggregate moisture contents and mixture production temperatures from 250°F to 350°F. The relationship is nearly linear because the energy demand is directly proportional to the mass of internal water. The curves for the different production temperatures are relatively close because the latent heat of vaporization, approximately 970 Btu per pound of water, is much larger than the additional sensible heat required to raise the vapor from 212°F to the selected discharge temperature.

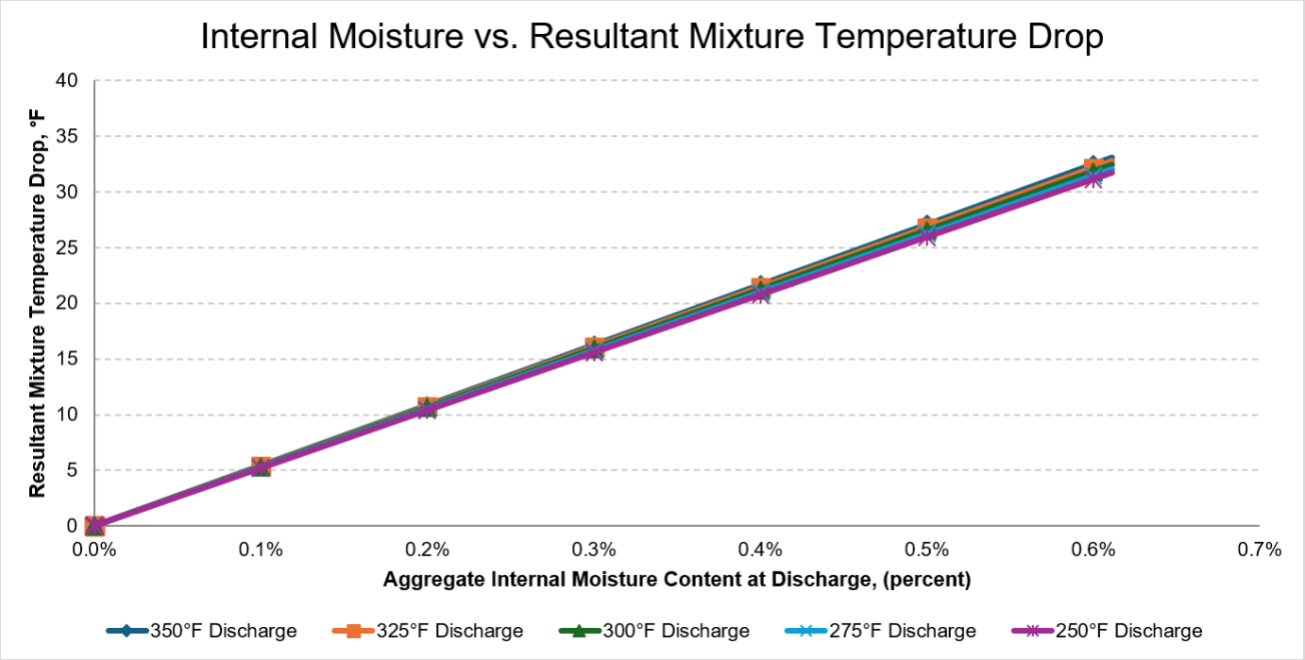

Figure 5-4. Relationship between Aggregate Internal Moisture at Discharge and Resultant Mixture Temperature Drop

For example, 0.5 percent internal moisture corresponds to approximately 10 lb. of water per ton of dry aggregate. Assuming an initial water temperature of 60°F and a mixture temperature of 300°F, approximately 1,520 Btu are required to heat the water from 60°F to 212°F, 9,700 Btu are required to vaporize it, and approximately 440 Btu are required to raise the vapor from 212°F to 300°F. The total energy absorbed is therefore approximately 11,660 Btu per ton of dry aggregate. Using a dry-aggregate heat capacity of approximately 440 Btu/°F per ton, this energy represents an equivalent mixture-temperature reduction of approximately 26.5°F, or about 27°F.

This relationship explains why a producer may intentionally operate at an elevated temperature at an intermediate point in the plant process. If internal moisture continues to vaporize after the drum, coater, or mixing device discharge, a mixture measured at approximately 327°F at that intermediate location could stabilize near 300°F by the time it reaches the silo discharge. The higher intermediate temperature does not necessarily represent unnecessary overheating; it may provide the thermal energy needed to remove the remaining internal moisture while still delivering the mixture at the temperature required for transport, placement, compaction, and satisfactory pavement performance.

The appropriate temperature-control location should therefore reflect the purpose of the measurement. An intermediate sensor may be appropriate for plant process control, while a downstream location where the mixture has approached a stable temperature may be more representative for documenting the temperature delivered to storage or load-out. A specification should not inadvertently prevent the producer from applying the thermal energy needed to manage residual internal moisture, provided that the mixture complies with applicable maximum-temperature limitations and reaches the specified temperature at the designated compliance location.

The calculations in Figure 5-4 are theoretical energy-equivalent estimates rather than predictions of the exact temperature decline that will occur in every plant. The relationship assumes complete vaporization of the specified internal moisture and uses the heat capacity of the dry aggregate as the thermal-mass basis. The actual temperature change will depend on aggregate absorption and pore structure, binder content, plant type, residence time, production rate, equipment heat losses, the location and timing of moisture release, and the amount of moisture remaining in the mixture. Post-coating vaporization may also result in stripping and even foaming.

Note: *An asphalt mixture made at 327°F at an intermediate point in the process and ending at 300°F requires the same amount of energy as a mixture made at 300°F and staying at 300°F throughout the plant process, where:*

For the same initial materials, moisture content, and final mixture temperature, the theoretical net heat required is approximately independent of whether the remaining internal moisture vaporizes before or after an intermediate temperature-measurement point. Thus, if delayed moisture vaporization consumes energy equivalent to a 27°F temperature reduction, a mixture measured at approximately 327°F upstream may stabilize near 300°F downstream. Actual burner energy may differ because plant heat losses, residence time, and equipment conditions vary with the temperature path.

6. Summary of Findings

The review of AASHTO and ASTM standards, 11 state DOT specifications, 29 state DOT survey responses, 23 SAPA industry survey responses, field observations, plant-manufacturer input, and the broader technical literature reveals a consistent pattern: the importance of asphalt mixture temperature to pavement quality and worker safety is widely understood, but the means of measuring it reliably, documenting it consistently, and identifying which measurement point governs compliance have not kept pace with the industry's technical capabilities or emerging needs. The additional evaluation of aggregate internal moisture also demonstrates that mixture temperature may change within the plant process as residual moisture vaporizes and the temperatures of individual aggregate particles equilibrate. This section synthesizes the principal findings by topic. Table 6-1 cross-references the findings to their evidence base and to the corresponding recommendations and proposed specification language.

6.1 Current Measurement Practice

Handheld IR thermometers dominate field temperature measurement practice. Among the 29 state DOT respondents to this study's survey, 85 percent allow IR guns for acceptance measurements, and the IR gun is effectively the de facto industry standard despite carrying the lowest DOT-rated acceptance risk (2.80 out of 5.0 on a scale where 5.0 = low risk). Contact probe thermometers received the highest accuracy rating (4.27 out of 5.0) but are used less frequently for acceptance decisions, in part because accessing hot mix by inserting a probe into a haul truck load requires physical proximity to a hazardous environment.

Measurement location is inconsistent across agencies. Most DOTs measure temperature at the haul truck at the project site or on the mat behind the screed because those locations are close to placement and compaction. However, a truck temperature measurement may be obtained from the exposed surface, from a sample after collection, through a truck-side access port, or by inserting a probe from an approved access platform. These methods do not measure the same physical quantity and do not present the same safety risk. At the plant, the appropriate monitoring location also depends on the intended purpose: an intermediate point may be suitable for process control, while a downstream point after mixing is complete may be more representative for agency documentation, acceptance, or incentive payment. No national standard currently requires the location, sensor type, measurement type, and intended use of each temperature reading to be documented consistently.

Measurement frequency is similarly variable. The majority of DOT respondents measure temperature periodically or at the engineer's discretion rather than on every truckload. Periodic measurement is a practical compromise, but it can allow out-of-specification loads to be placed undetected, particularly during startup, after extended haul delays, or when ambient conditions change rapidly.

6.2 Instrument Accuracy and Calibration

The most direct empirical evidence of IR gun inter-instrument variability was collected during construction of the 2024 NCAT Test Track. Seven handheld IR thermometers of varying makes and models, operated by separate observers who simultaneously read the same mat surface, produced inter-instrument spreads ranging from 12°F to 53°F across measurement sets, with an average spread of approximately 30°F. None of the instruments had been verified against a calibrated reference prior to use. These spreads exceed the ±25°F JMF tolerance commonly applied by state DOTs, meaning that two inspectors with different IR guns can obtain readings that support opposite acceptance decisions on the same truckload.

The sources of this variability are well understood individually but are rarely addressed together in practice. Emissivity settings vary across instruments and are rarely adjusted from factory defaults; manufacturers use different default values, and few inspectors know their instrument's emissivity setting when they take a reading. Distance-to-spot (D:S) ratios differ across instrument models, and inspectors do not routinely manage measurement distance to keep the spot size within the material boundary. Environmental interference from steam, dust, and wind affects readings without being corrected for. Thermal shock from cold ambient storage to a hot mix surface introduces transient errors before the instrument thermally equilibrates. These are not random errors; many are systematic and instrument-specific, which is why verification against a common reference before use is the only way to bound them.

No reviewed state DOT specification requires handheld IR thermometers to be verified against a NIST-traceable reference at production temperatures (250–355°F) before field use. Where instrument verification is addressed at all, it typically consists of a single-point check at boiling water (212°F) performed annually. ASTM E2847 (upgraded to Standard Test Method in 2026) specifies two schemes for wideband IR thermometer verification that are practical for field use, but no state or national standard currently cites E2847 as a required verification procedure for asphalt acceptance instruments.

Contact probes are more accurate under ideal conditions, but they carry their own field limitation: thermal stabilization. A probe stored at ambient temperature (say, 70°F in an inspector's truck cab) inserted into a 300°F mix must transfer heat through the probe housing, shaft, and wiring before the sensing element equilibrates to the surrounding material. Field observation at the Flanigan plant documented a low bias of approximately 105°F during the first minutes after insertion, with the reading gradually converging to the plant reference. No current standard specifies a minimum stabilization time before recording a probe reading, which means that a properly designed procedure, one that specifies a stabilization period, can yield substantially more accurate data than current practice without any change in instrument type.

Because surface and bulk temperature measurements represent different physical quantities, acceptance limits should identify which measurement type governs. This distinction is especially important for truck-load measurements, thin lifts, thick lifts, WMA operations, and decisions made near specification limits. When the tolerance is narrow relative to the surface-to-bulk temperature difference, the acceptance decision may reflect the measurement method rather than actual material quality.

Seventy percent of DOT survey respondents reported that they do not routinely compare IR and probe readings at the same location. Among those who do compare, the most commonly reported difference is 5-10°F. This difference is consistent with surface cooling effects under typical field conditions, but without a documented comparison procedure and a defined resolution protocol, discrepancies are resolved informally or not at all.

6.3 Plant Process Measurement Points and Aggregate Internal Moisture

Asphalt mixture temperature is not necessarily constant from the completion of mixing to the mixture loadout. Under normal production conditions, surface moisture is removed in the dryer, and residual moisture at discharge is generally very low. However, porous or highly absorptive aggregates may retain internal moisture that continues to migrate to the aggregate surface and vaporize after the dryer, coater, or mixing device discharge.

Vaporizing this internal moisture requires substantial thermal energy. The simplified heat balance presented in Section 5.5 indicates that 0.5 percent internal aggregate moisture can correspond to an energy-equivalent reduction in mixture temperature of approximately 27°F under the stated

assumptions. Consequently, a mixture measured at approximately 327°F at an intermediate process-control point could approach 300°F farther downstream as the remaining moisture vaporizes and the mixture approaches thermal equilibrium.

This finding reinforces the importance of distinguishing a plant process-control point from a designated reporting or compliance point. A higher intermediate temperature does not necessarily indicate unnecessary overheating if the additional thermal energy is needed to remove residual internal moisture and produce the required temperature at storage, loadout, delivery, and placement. The governing temperature location should therefore be specified according to the measurement's purpose, and temperature limits established at different plant locations should not be assumed interchangeable.

6.4 Plant Temperature Monitoring and Documentation

Asphalt plants may use fixed contact sensors, fixed noncontact infrared pyrometers, or a combination of sensors at different locations within the production process. The appropriate location and sensor technology depend on plant configuration, exposure to abrasion and material buildup, and the intended use of the data. An intermediate sensor may provide the information needed to control burner operation or mixing, while a separate downstream sensor may provide the representative temperature used for agency documentation, acceptance, e-ticketing, or incentive payment.

Contact and noncontact sensors measure different portions of the material. A fixed contact sensor measures temperature at the point where the sensor contacts the material stream. A fixed infrared pyrometer measures the exposed surface temperature within its field of view and may be affected by steam, dust, lens contamination, target area, and emissivity. Neither technology is universally preferable for every plant configuration. The critical requirements are that the sensor be appropriate for its intended use, have documented accuracy, be installed at a documented location, and be verified over the applicable operating range.

The revised M 156 language, therefore, distinguishes process-control monitoring points from a designated reporting point. Process-control points may be located where they provide useful information to the plant operator. When temperature data are used for agency documentation, acceptance, or incentive payment, the producer and agency should identify a designated reporting point after completion of mixing and before or at mixture loadout. The monitoring location, sensor type, measurement type, and intended use should be documented.

Among the state specifications reviewed, Missouri and South Carolina impose the most prescriptive automatic recording requirements, Texas requires daily temperature records to be submitted to the engineer, and New York requires temperature documentation on delivery tickets. These provisions represent a first tier of plant documentation practice. Most states reviewed do not define the sensor, reporting location, verification requirements, or electronic record needed to interpret the reported temperature consistently.

6.5 Warm Mix Asphalt and Temperature Incentive Structures

The asphalt industry has developed WMA technologies capable of reducing production temperatures by 35–100°F relative to conventional HMA. At lower temperatures, fugitive particulate matter emissions at the plant and the paving site decrease measurably, plant fuel consumption decreases, and worker exposure to asphalt fumes decreases. The Ingevity/TRF field study (2022) documented these reductions across five plants in multiple states, providing a quantitative basis for the industry's case that temperature reduction has real and measurable environmental and safety benefits.

Despite these benefits and the availability of proven WMA technologies, temperature incentive programs are nearly absent from state QA practice. 95% of SAPA survey respondents reported no active incentive program linked to production temperature, and only 1 DOT respondent identified an active WMA incentive in its specification. MnDOT's optional ≤275°F incentive provision in SP 2360, with four pilot contracts in 2025, is the only active U.S. example identified by this study. NAPA SUST-008 provides a five-category temperature framework intended to communicate industry efforts to reduce temperatures but explicitly cautions that temperature reduction should not be mandated and that mixture quality must be confirmed before temperature is considered.

Results from MnDOT's 2025 pilot projects suggest that lower production temperatures can be achieved without compromising pavement quality. One notable project, TH 73 (SP 6930-41), combined MnDOT's High RAP provision with the WMA incentive program. The contractor produced a SPWEB340C mixture containing approximately 38 percent RAP, targeted the highest incentive tier (<250°F), and achieved an average daily plant discharge temperature of 254°F. The project earned 52 percent of the maximum available incentive while achieving an average mat density of 93.1 percent and longitudinal joint density of 91.1 percent. MnDOT reported that the project met quality expectations and that compaction improved when mixture temperatures were maintained below approximately 250°F. Project personnel also noted operational benefits, including cleaner baghouse systems and reduced buildup on laboratory equipment. These observations suggest that temperature reduction, RAP utilization, and density performance can be achieved simultaneously when supported by appropriate mixture design and construction practices.

The fundamental barrier to WMA temperature incentives is not technical; it is the absence of a reliable, standardized, and auditable protocol that identifies the temperature sensor and location used for the incentive calculation. An incentive payment for producing mixture below a specified temperature requires confidence that the reported value is accurate, traceable, and representative of the point identified in the contract. An intermediate process-control temperature, a mixer or drum-exit temperature, and a silo-loadout temperature should not be treated as interchangeable because continued moisture vaporization and thermal equilibration may change the mixture temperature between those locations.

The revised M 156 language addresses this issue by requiring the agency and producer to identify a designated reporting point, document the sensor and measurement type, verify the sensor, and maintain an electronic temperature record. The MnDOT model is instructive because it ties the incentive to a defined plant recordation system. Any agency adapting that approach should similarly define the exact reporting point and establish temperature thresholds appropriate to that location.

6.6 Paver-Mounted Thermal Profiling

Paver-mounted thermal profiling (PMTP), as specified in AASHTO R 110, is the only temperature measurement method that provides continuous spatial coverage across the full mat width during placement. By tagging every surface temperature reading with a GNSS coordinate, PMTP systems produce a two-dimensional thermal map of each paving run, identifying truck-load-related hot and cold zones, auger-related longitudinal streaking, and transverse temperature gradients that single-point spot measurements cannot detect. The thermal segregation index (TSI) and transverse semivariogram index (TSV) computed from PMTP data in Veta software have demonstrated correlations with in-place density non-uniformity in multiple research studies.

Despite this capability, only one of 29 DOT survey respondents reported routinely using PMTP; one-third have conducted pilot projects. The primary barriers cited are equipment costs, the absence of specification language that creates an obligation to use the system, and the data management burden of processing and archiving continuous thermal profile datasets. The barrier is

not technical performance: AASHTO R 110 specifies clear accuracy requirements (±2°C or ±2.0% of reading), and the Veta software provides a standardized analysis platform.

The panel discussion in April 2026 noted that PMTP adoption is also limited by the gap between what the system measures (surface temperature behind the screed) and what contractors and DOTs are accustomed to making decisions on (spot temperature at the truck or hopper). Bridging this gap requires not just a specification but training and a clear decision framework: what TSI value triggers a density investigation, what evidence is required to confirm or refute a thermal segregation finding, and how PMTP data integrates with the existing acceptance process. Section 8.3 proposes draft language addressing these questions within the R 110 framework.

6.7 Measurement Uncertainty and Acceptance Risk

Temperature specifications often assume that the measured value is known with greater certainty than field practice supports. In reality, every asphalt mixture temperature measurement is subject to uncertainty due to the instrument, measurement location, operator, environment, and the difference between surface and bulk temperatures.

Measurement uncertainty poses an acceptance risk when it is large relative to the specification tolerance. For example, an IR reading taken from a wind-cooled truck surface, a handheld thermometer with an unknown distance-to-spot ratio, and a contact probe removed before stabilization may each produce a value that is technically recorded but not comparable to another inspector's reading. In those cases, the risk is not merely statistical; it can affect payment, rejection decisions, contractor-agency disputes, and confidence in quality assurance records.

The proposed specification language addresses this risk by requiring agencies and producers to document the monitoring location, intended use, sensor type, and measurement type; distinguish surface measurements from contact measurements; verify thermometric devices in accordance with applicable standards; identify a designated plant reporting point when temperature is used for acceptance or incentive payment; and maintain accessible electronic records. The proposed language also establishes a response when a device fails verification or the required recording system becomes unavailable. These provisions do not eliminate measurement uncertainty, but they make it visible, auditable, and manageable.

Table 6-1. Measurement Uncertainty Sources and Acceptance Risk Implications

Source of Uncertainty	Example Field Mechanism	Acceptance Risk Implication
Instrument accuracy	Unverified IR thermometer or contact probe drift	Measured value may not reflect true surface or bulk temperature
Surface vs. contact temperature	Wind-cooled truck crust or rapidly cooling mat surface	Specification decision may depend on measurement type rather than material quality
Distance-to-spot ratio	IR field of view includes cooler truck sidewall or gate	Surface reading may be biased low
Probe stabilization	Contact probe read before sensor equilibrates with mix	Bulk temperature may be under- or over-estimated
Environmental interference	Steam, smoke, dust, or lens contamination	IR reading may be biased or not reproducible
Operator technique	Different measurement angles, depths, or locations	Readings may not be comparable between inspectors
Plant measurement point	Process-control sensor is upstream of the silo or loadout point used for compliance	Temperatures from different plant locations may be compared as though they represent the same condition
Residual internal moisture	Moisture continues to vaporize after mixing, consuming thermal energy downstream	A higher intermediate temperature may be necessary to achieve the required temperature at the designated reporting or loadout point

7. Recommendations

The findings in Section 6 identify a system in which temperature is treated as a critical production and acceptance parameter but is often measured with instruments of unknown accuracy, at locations that are not consistently defined, and with incomplete documentation of what the reading represents. The findings also show that a temperature measured at an intermediate plant process-control point may differ legitimately from a downstream temperature because of residual internal moisture, thermal equilibration, or storage conditions. The recommendations below address these deficiencies and are designed to be implemented through the proposed M 156 and R 97 language, summarized in Section 8 and provided in Appendices B and C. Each recommendation is numbered R-1 through R-9.

The intent is not to add paperwork for its own sake. The recommendations are intended to eliminate sources of systematic error that can lead to incorrect acceptance decisions and to enable outcomes, such as WMA temperature incentives, that require a reliable measurement foundation.

7.1 Instrument Performance Requirements

Instrument requirements should be based on the measurement function rather than prescribing one sensor technology for every application. Fixed plant monitoring systems operate in a highly abrasive environment and may use either contact sensors or industrial noncontact infrared pyrometers. Field temperature measurements during sampling require portable instruments with documented accuracy appropriate to the measurement type.

Bimetal dial thermometers may remain useful for approximate operational checks, but they should not be used as the basis for required acceptance temperature documentation because of their comparatively low accuracy, slow response, mechanical drift, and lack of an electronic record.

Handheld IR thermometers used for acceptance should have a documented distance-to-spot ratio and an emissivity setting appropriate for an asphalt mixture. A wideband 8-14 µm instrument with asphalt emissivity set at 0.95 provides a consistent basis for field use and ASTM E2847 verification.

R-1. Digital contact thermometers used for required field sampling documentation or acceptance must have a documented accuracy of ±1°C (±2°F) or better over the anticipated measurement range. Bimetal dial thermometers should not be used for acceptance temperature measurements.

R-2. Permit fixed plant temperature-monitoring systems used for agency reporting, acceptance, or incentive payment to use RTD Class A sensors, Type K thermocouples meeting Special Limits of Error, sensors providing equivalent approved performance, or industrial infrared pyrometers suitable for the anticipated operating environment. Require the installed system to have a documented accuracy of ±2°C (±4°F) or better over the anticipated asphalt mixture production-temperature range.

R-3. Require handheld IR thermometers used for required field documentation or acceptance to have a documented accuracy of ±2°C (±4°F) or better, a known distance-to-spot ratio, and an emissivity setting appropriate for the asphalt mixture. Record the emissivity setting when the instrument is adjustable, and verify the instrument in accordance with ASTM E2847 when applicable.

7.2 Calibration, Verification, and Device Response

Calibration and verification serve related but different purposes. Calibration establishes the relationship between the device indication and a traceable reference and may be performed by the instrument manufacturer or by a competent calibration laboratory. Verification is a documented confirmation that the installed or portable device remains within the applicable tolerance and may be performed by trained personnel using traceable reference equipment and an applicable ASTM or manufacturer-recommended procedure.

Fixed plant sensors used for required reporting, acceptance, or incentive payment should be verified before initial use, before the first use of each construction season, and at intervals not exceeding 12 months, after repair, replacement, or relocation, and whenever damage, drift, or inconsistent readings create reasonable doubt regarding accuracy. Portable field instruments should be verified before first use during each construction season, after repair or damage, and whenever performance is questioned.

Verification requirements should also identify what occurs when a device fails. A failed device should not remain in service for required documentation or acceptance while its accuracy is unresolved. Production need not automatically stop when a verified backup device or an agency-approved contingency procedure is available.

> R-4. Require thermometric devices used for required reporting, quality control, acceptance, or incentive payment to be calibrated or verified using traceable reference equipment and applicable ASTM or manufacturer-recommended procedures. Records should identify the device, manufacturer, model, sensor type, monitoring location, intended use, person or organization performing the work, reference device, temperature points or verified range, measured error, acceptance tolerance, pass/fail result, corrective action, and next verification date. A device that fails verification shall be removed from required reporting or acceptance use until it is successfully repaired, adjusted, replaced, and reverified. A verified backup device or approved contingency procedure may be used during the interim.

7.3 Surface and Bulk Temperature Measurements

Agencies should identify whether specification limits apply to surface temperature measurements, bulk temperature measurements, or both. Surface measurements are practical and valuable for screening, documentation, and thermal uniformity assessment; bulk measurements are the more direct reference for internal mixture temperature at a specific location.

> R-5. Define the measurement type and location used for specification compliance. Agencies should identify whether a limit applies to an infrared surface-temperature measurement, a contact-temperature measurement, or both. When both measurements are obtained at the same location, the contact measurement should be used as the reference for determining asphalt mixture bulk temperature. The infrared measurement remains the applicable measurement when the specification requirement is explicitly based on surface temperature or thermal uniformity.

7.4 Measurement Location and Safe Access

Climbing onto a loaded haul truck to insert a thermometer into the mix is a common field temperature measurement practice and one of the most hazardous. Fall distances from typical haul trucks exceed 4 feet, truck beds are hot and slippery, and inspectors must lean over the side to reach the interior of the mix. NYSDOT explicitly prohibits over-the-top truck access in its materials

procedure, citing worker safety. No national standard currently contains this prohibition or requires truck-side access as an alternative.

Truck-side sampling and measurement ports have been used in some DOT programs and are commercially available. A port positioned in the upper third of the truck body sidewall allows an inspector to insert a probe horizontally into the interior of the mix from ground level, obtaining a bulk temperature reading without climbing. However, mandating truck-side ports in a national standard may be difficult for agencies to implement immediately. The more defensible national requirement is to prohibit over-the-top access and to require safe measurement procedures, with side-port systems identified as one acceptable approach when contact-probe measurements are specified.

R-6. Require safe work practices for all temperature measurements and samples. Personnel shall not climb onto a loaded haul unit to obtain a temperature measurement or sample unless access is provided by a fixed platform or another agency-approved system meeting applicable safety requirements. Acceptable alternatives include measuring the temperature of the sample immediately after collection, using a designed truck-side access port or other approved ground-level access system, or obtaining a noncontact infrared measurement from a safe ground-level position.

7.5 Plant Temperature Measurement Points, Documentation, and Logging

No single plant “discharge point” is universally appropriate for every temperature measurement or plant configuration. Depending on the equipment arrangement, temperature may be monitored at the dryer discharge, mixing device, coater, drag conveyor, silo inlet, silo discharge, or loadout. Each point may provide useful information, but the values are not necessarily interchangeable.

A producer may need an intermediate temperature measurement for process control. For example, the mixture may need to be hotter at the coater or mixing-device discharge so that residual internal moisture can vaporize and the mixture can reach the required temperature at the silo or loadout. Conversely, an agency evaluating the temperature delivered to storage or a haul unit may need a downstream reporting point where the mixture temperature has approached a more stable condition.

The plant quality-control plan should therefore identify the location and intended use of each fixed monitoring point. When temperature data are used for agency documentation, acceptance, e-ticketing, or incentive payment, the producer and agency should identify a designated reporting point after completion of mixing and before or at mixture loadout. The designated point should be representative of the intended decision, and the sensor type and whether the measurement is infrared surface temperature or contact temperature should be documented.

Electronic recording remains essential. Temperature data from the designated reporting point should include date and time information, identify the sensor or monitoring point, and be retained in accordance with agency requirements. The system should notify plant personnel of sensor malfunction or interruption of required recording, and the quality-control plan should include a contingency procedure.

R-7. Require the plant quality-control plan to identify the location and intended use of each fixed temperature-monitoring point. When temperature data are required for agency documentation, acceptance, e-ticketing, or incentive payment, require the agency and producer to identify a designated reporting point after completion of mixing and before or at mixture loadout. Document the location, sensor type, measurement type, and intended use.

R-8. Require temperature data from the designated reporting point to be electronically recorded with associated date and time information at intervals not exceeding 10 minutes during production, retained in accordance with agency requirements, and made available to the agency upon request. Require notification of sensor or recording-system malfunction and a documented contingency procedure for periods when the designated reporting system is unavailable.

7.6 Warm Mix Asphalt Temperature Incentive Programs

The asphalt industry has the technology to produce WMA at production temperatures 35–100°F below conventional HMA, with documented reductions in fugitive particulate emissions, stack emissions, and plant fuel consumption. NAPA SUST-008 provides a communication framework that categorizes production temperatures into five tiers, with Category 2 (250–284°F) representing the target range for most chemical additive WMA systems. However, 95 percent of SAPA survey respondents reported no active temperature incentive program, and only one DOT respondent identified an incentive provision in its contract specifications.

The barrier is not technical. Minnesota has demonstrated that a temperature-based incentive is operationally feasible. The MnDOT SP 2360 supplemental provision, deployed on four pilot projects in 2025, pays a tiered incentive of 2 percent of the HMA unit price for production at 250–275°F and 4 percent for production below 250°F, based on the day's average discharge temperature from the plant's 20-minute recordation system. Critically, the incentive is automatically denied if the temperature sensor or the recordation export is not functioning, and it is contingent on the concurrent requirement that no more than 25 percent of project density lots fail to meet minimum density requirements. This last condition is essential: it ensures that lower production temperatures are achieved without compromising compaction quality.

Case Example: TH 73 Demonstrates Successful Low-Temperature, High-RAP Production

Minnesota TH 73 (SP 6930-41) demonstrates how temperature-based incentives can support both sustainability and mixture performance objectives. The project incorporated MnDOT's High RAP provision and a Warm Mix Asphalt (WMA) incentive specification. The contractor produced a surface mixture containing approximately 38 percent RAP, targeted the maximum WMA incentive threshold of less than 250°F, and achieved an average daily plant discharge temperature of 254°F. Despite the reduced production temperatures and elevated RAP content, the project achieved an average mat density of 93.1 percent and longitudinal joint density of 91.1 percent. The contractor earned 52 percent of the maximum available WMA incentive payment. MnDOT reported that the project met quality expectations and that compaction improved when mixture temperatures were maintained below approximately 250°F. Additional benefits reported by project personnel included reduced thermal exposure of the asphalt binder, cleaner baghouse, and reduced buildup on laboratory equipment.

Key Takeaway: The TH 73 project demonstrates that reduced production temperatures can be successfully combined with high RAP contents while still achieving acceptable density and construction quality when supported by appropriate mixture design, plant controls, and field compaction practices.

The prerequisite is equally straightforward: the sensor at the contract-defined reporting point must be verified, the recordation system must be functional, and the agency must be able to access and audit the complete temperature record. The contract should identify whether the reporting point is located at the drum or mixer exit, downstream of the mixing device, at the silo discharge, or at another defined location. Incentive thresholds must be established for that location because

temperatures recorded at different plant points may not be directly comparable. Recommendations R-7 and R-8 establish the measurement-point and data infrastructure needed to support such a program.

The NAPA SUST-008 temperature category framework is a useful reference for setting incentive thresholds, but it is explicitly not intended as a specification range. Agencies designing incentive programs should set their own thresholds based on local conditions, binder grades, and the availability of WMA technology, using MnDOT SP 2360 and SUST-008 as starting points. The recommended incentive structure should always include a density quality gate and should exclude startup production (the first 100–200 tons of the day, as MnDOT does) to allow for plant warm-up without penalizing contractors for conditions outside their control.

R-9. Agencies wishing to incentivize WMA production should consider a tiered temperature incentive structure modeled on MnDOT SP 2360 and applicable to mixtures produced with an approved WMA technology. The contract should identify the designated plant reporting point and establish temperature thresholds appropriate to that location. The incentive should be conditioned on: (a) a temperature-monitoring system meeting the applicable accuracy and verification requirements; (b) a functioning electronic recording system; (c) current calibration or verification documentation; (d) a complete auditable temperature record; and (e) a density quality gate that voids or reduces the incentive when a specified percentage of density results fail the minimum requirement. The first 100–200 tons of daily production may be excluded to allow for plant warm-up. When an upstream process-control point is used for the incentive calculation, the contract should not characterize that reading as the loadout or delivery temperature unless the relationship has been established.

7.7 Paver-Mounted Thermal Profiling

Single-point temperature measurements at the haul truck or paver hopper tell the inspector nothing about the spatial distribution of temperature across the mat after placement. Auger-related longitudinal streaking, truck-to-truck temperature variation, and screed-edge cooling are common sources of thermal nonuniformity that cause density variations and premature distress, but they are invisible to spot IR measurements. Paver-mounted thermal profiling (PMTP) under AASHTO R 110 is the only method that provides continuous, geo-referenced surface temperature coverage of the full lane width, giving both the contractor and the agency a complete spatial record of thermal uniformity for every paving run.

Only one of 29 DOT survey respondents uses PMTP routinely. The barriers are not primarily technical: the equipment is commercially available, R 110 provides a clear specification framework, and Veta software provides a standardized analysis platform. The barriers are the absence of specification language that creates an obligation to use the system on suitable projects, the lack of a defined decision framework that translates TSI values into required actions, and uncertainty about how PMTP data integrates with existing acceptance processes. Agencies that have piloted PMTP consistently report that it identifies thermal segregation patterns not visible through conventional inspection and shifts the basis for density investigation from random spot checks to spatially targeted follow-up.

Broad adoption does not require mandating PMTP on every project. A size or complexity threshold, such as projects exceeding 5,000 tons per lot or 2-lane miles of continuous paving, would focus PMTP on areas where its spatial coverage provides the greatest quality-assurance benefit relative to its cost and setup time. The critical enabling steps are to provide specification language (Section 8.3 provides a starting point), define a TSI decision threshold that triggers a density investigation,

and establish a data management expectation that does not require agencies to invest in custom software or data infrastructure beyond what Veta and standard file formats already provide.

Draft specification language supporting PMTP adoption appears in Section 8.3, which adapts AASHTO R 110 for agency contract use and includes a proposed project size threshold, a TSI decision framework, and data management requirements.

Bottom Line
The temperature measurement challenge is not a lack of technology. Contact probes, RTDs, plant sensors, IR thermometers, ASTM verification methods, and paver-mounted thermal profiling systems already exist. The gap is the specification framework: clear requirements for instrument class, calibration, measurement type, safe access, electronic records, and data use.

The following pages present proposed specification language for three AASHTO standards: M 156 (Standard Specification for Requirements for Mixing Plants for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures), R 97 (Standard Practice for Sampling of Hot-Mix Asphalt Paving Mixtures), and R 110 (Standard Practice for Collecting Pavement Surface Temperature Data Using Paver-Mounted Infrared Temperature Scanning Equipment).

8. Proposed Specification Language

The following sections summarize the proposed specification changes developed from the study findings, stakeholder review, and plant-manufacturer input. The complete M 156 and R 97 redline drafts are provided in Appendices B and C. To avoid inconsistencies between the report narrative and the ballot drafts, the appendices should be treated as the authoritative proposed standard language.

8.1 AASHTO M 156 — Plant Temperature Measurement and Recording

AASHTO M 156 currently uses general “discharge point” terminology and provides limited guidance on sensor technology, measurement purpose, accuracy, verification, electronic records, and responses to sensor failure. Plant-manufacturer review identified that the term “discharge” can refer to different locations depending on the plant configuration and that a temperature measured at an intermediate process point may change downstream because of continued moisture vaporization and thermal equilibration.

The proposed revision in Appendix B replaces the existing Section 4.12 with a performance-based framework that:

1. requires fixed asphalt mixture temperature monitoring at one or more documented locations after completion of mixing;
2. separately addresses heated-aggregate temperature monitoring;
3. permits fixed contact sensors, approved equivalent sensors, and industrial infrared pyrometers;
4. establishes a documented accuracy of ±2°C (±4°F) for systems used for agency reporting, acceptance, or incentive payment;
5. distinguishes producer-selected process-control monitoring points from a designated agency reporting point;
6. requires electronic recording from the designated reporting point at intervals not exceeding 10 minutes;
7. recognizes that downstream temperature may change because of internal moisture, thermal equilibration, storage time, and other plant-process conditions;
8. establishes defined calibration and verification intervals and documentation requirements;
9. removes failed devices from required reporting or acceptance use until successfully reverified and permits a verified backup or approved contingency procedure;
10. requires electronic record retention and notification of sensor or recording-system malfunction; and
11. addresses safe access for inspection, verification, maintenance, repair, and replacement of fixed plant equipment.

The complete proposed M 156 redline is provided in Appendix B.

Proposed Optional Supplemental Provision: WMA Temperature Incentive

The following language is an optional supplemental provision for agencies wishing to implement a WMA temperature incentive program consistent with Recommendation R-9. It is designed to be incorporated as a contract special provision or as a supplement to the project-level Quality Assurance Plan. Agencies should set their own temperature thresholds and incentive rates based on local conditions, binder grades, and approved WMA technology.

> SP-T1.1 — Applicability. This provision applies to all Hot Mix Asphalt (HMA) produced with an approved Warm Mix Asphalt (WMA) technology listed on the agency's Approved Products List. Temperature incentive payments are in addition to the unit price for the applicable HMA bid item.

SP-T1.2 — Prerequisite Conditions. A temperature incentive payment is available only when all of the following conditions are met:

(a) The temperature-monitoring system at the designated reporting point complies with M 156 Sections 4.12.3 through 4.12.7, the reporting point has been documented in accordance with Section 4.12.4.2, and the system has been verified for the current construction season in accordance with Section 4.12.5.;

(b) The plant electronic recording system has been functional during the production day for which an incentive is claimed;

(c) The Contractor has submitted calibration or verification documentation per Section 4.12.5 for the current construction season prior to the incentive-eligible production day; and

(d) The density quality gate in SP-T1.5 is satisfied.

SP-T1.3 — Production Temperature Measurement. The temperature used for incentive calculations shall be the daily average of the asphalt mixture temperature recorded at the designated reporting point identified in the contract documents and documented in accordance with M 156 Section 4.12.4.2. The same reporting point and sensor shall be used throughout the incentive-eligible production unless a change is approved by the Engineer and documented. The first [100–200] tons of daily production shall be excluded as the plant warm-up quantity.

Note: The contract should identify the reporting location used for the incentive. Temperature thresholds established for a drum or mixer exit should not be automatically applied to a silo discharge or loadout measurement, and vice versa.

SP-T1.4 — Incentive Schedule. The temperature incentive shall be calculated as a percentage of the HMA unit price for the incentive-eligible quantity, per the schedule in Table SP-T1:

Table SP-T1. WMA Temperature Incentive Schedule (Example — Agencies Set Own Thresholds)

Daily Average Plant Temperature at the Designated Reporting Point	Incentive (% of HMA Unit Price)
≥275°F (≥135°C)	0%
250–274°F (121–134°C)	2%
<250°F (<121°C)	4%

Note: Temperature thresholds and incentive percentages are example values based on the MnDOT SP 2360 model. Agencies should calibrate these values to local conditions and approved WMA technology. Agencies should work with local contractors before finalizing thresholds.

SP-T1.5 — Density Quality Gate. No temperature incentive shall be awarded for a production day on which more than [20] percent of the density acceptance test results for mix placed that day fail to meet the minimum density requirement specified in the contract. The density failure percentage shall be calculated using all density lots for which mix was placed on the incentive-eligible production day.

SP-T1.6 — Incentive Denial Conditions. The temperature incentive shall be denied for any production period during which the designated reporting sensor or required electronic recording system was not functioning and no approved contingency procedure was implemented; when more than 10 percent of the individual eligible temperature records

exceed the applicable upper threshold; or when the Contractor cannot provide current calibration or verification documentation and a complete electronic temperature record.

SP-T1.7 — Submission. To claim a temperature incentive, the Contractor shall submit the following information within [5] business days of the applicable production day:

(a) the complete electronic temperature record from the designated reporting point identified in the contract documents and documented in accordance with M 156 Section 4.12.4.2. The record shall include the associated date and time information, identify the reporting point or sensor, and document any interruption in temperature monitoring or data recording;

(b) current calibration or verification documentation for the temperature-monitoring system at the designated reporting point in accordance with M 156 Section 4.12.5;

(c) when an approved contingency procedure was used, documentation identifying the period affected, the reason the designated reporting system was unavailable, the replacement instrument or alternative procedure used, and the associated temperature records;

(d) an incentive calculation worksheet identifying the designated reporting point, daily average temperature, warm-up exclusion quantity, incentive-eligible tonnage, percentage of eligible temperature records exceeding the applicable upper threshold, applicable incentive rate, and calculated incentive amount; and

(e) documentation demonstrating compliance with the density quality gate in SP-T1.5, including the applicable density acceptance results for mixture placed during the incentive-eligible production day.

Temperature records obtained from a monitoring point other than the designated reporting point shall not be substituted for the required record unless the Engineer approved the substitution under the contingency procedure before or during the affected production period.

8.2 AASHTO R 97 — Field Temperature Measurement During Sampling

AASHTO R 97 governs sampling of asphalt mixtures, but currently provides limited direction for documenting temperature at the time of sampling. The proposed revision in Appendix C makes temperature recording conditional on agency requirements and establishes minimum requirements for instrument accuracy, documentation, verification, and safe access.

Proposed Section 5.12 permits a digital contact thermometer with documented accuracy of ±1°C (±2°F) or an infrared thermometer with documented accuracy of ±2°C (±4°F). For haul-unit samples, temperature may be measured from the collected sample, through an approved truck-side access point, or using noncontact infrared measurement from a safe ground-level position. Personnel may not climb onto a loaded haul unit unless access is provided by a fixed platform or another approved system meeting applicable safety requirements.

The proposed language also requires documentation of the measured temperature, date and time, sampling and measurement location, instrument identification, measurement type, and adjustable infrared emissivity setting. Contact temperature is the reference for determining bulk temperature when both contact and surface readings are obtained, while an infrared measurement remains applicable when the specification is explicitly based on surface temperature.

Proposed Section 5.13 establishes verification before seasonal use, after repair or damage, and whenever performance is questioned. A device that fails verification must be removed from required documentation or acceptance use until repaired, adjusted, replaced, and successfully reverified.

The complete proposed R 97 redline is provided in Appendix C.

8.3 AASHTO R 110 — Agency Contract Language for Paver-Mounted Thermal Profiling

AASHTO R 110 (Standard Practice for Collecting Pavement Surface Temperature Data Using Paver-Mounted Infrared Temperature Scanning Equipment) provides a technically sound framework for PMTP equipment and data collection. The gap is not in R 110 itself but in the absence of agency contract language that creates an obligation to use PMTP on projects where it provides meaningful quality assurance value, defines a decision threshold for the Thermal Segregation Index (TSI), and specifies what the Contractor must deliver to the agency.

The following draft special provision is written for incorporation as an agency contract Special Provision or as a section of the project Quality Assurance Plan. Bracketed values (e.g., [XX,XXX]) are project-specific thresholds that the agency should set based on project size, mix type, and risk tolerance. The special provision is intentionally cross-referenced to R 110 rather than duplicating its equipment and collection requirements, so that future R 110 revisions automatically benefit any contract that incorporates this language.

Proposed Special Provision SP-P1: Paver-Mounted Thermal Profiling

SP-P1.1 — Applicability. This special provision applies to all paving operations under this contract involving [XX,XXX] or more tons of HMA or [X] or more lane-miles of continuous paving in a single pass, unless otherwise specified in the contract documents. The Contractor shall provide and operate paver-mounted thermal profiling (PMTP) equipment meeting the requirements of AASHTO R 110 on all applicable paving operations.

Applying PMTP above a project size or complexity threshold focuses the requirement where continuous thermal data provides the greatest quality-assurance value relative to setup cost. Agencies should calibrate the threshold to their own project portfolio and risk tolerance.

SP-P1.2 — Equipment. PMTP equipment shall conform to AASHTO R 110. The system shall provide:

(a) A 2D IR sensor array mounted at the rear of the paver, spanning the full paved width;

(b) GNSS positioning with a horizontal accuracy of ±1.0 m (±3.3 ft) or better;

(c) Temperature measurement at intervals not exceeding 305 mm (12 in.) in the direction of paving; and

(d) Sensor accuracy of ±2°C (±3.6°F) or ±2.0 percent of reading, whichever is greater, across the range 60–200°C (140–392°F), as documented by current calibration per AASHTO R 110.

SP-P1.3 — Operation. The Contractor shall operate the PMTP system continuously during all paving under this special provision. The system shall not be paused or disabled during normal paving operations. Interruptions due to equipment malfunction shall be noted in the PMTP data file per AASHTO R 110. PMTP data collection shall begin no later than [300 m / 1,000 ft] after the start of each paving run and shall continue to within [100 m / 330 ft] of the end of the run, or to the natural end of the run if shorter.

SP-P1.4 — Data Processing and TSI Calculation. The Contractor shall process PMTP data using Veta software (Version [X.X] or later) or agency-approved equivalent software capable of producing TSI and TSV outputs per AASHTO R 110. The Thermal Segregation Index (TSI) shall be calculated for each [500 m / 1,640 ft] analysis section per AASHTO R 110.

SP-P1.5 — Real-Time Monitoring. The Engineer shall have access to the PMTP display in real time during paving operations. The Contractor shall ensure the PMTP display is positioned and accessible so that the Engineer can observe thermal data without interrupting paving operations. If the Engineer observes a pattern of thermal segregation in real time, the Engineer may direct the Contractor to investigate the source of the pattern before continuing placement. Such direction shall not constitute a suspension of work unless the pattern persists after the Contractor has taken corrective action.

SP-P1.6 — TSI Decision Threshold and Density Investigation.

(a) For each analysis section where the TSI exceeds [TSI threshold, e.g., 3.0], the Contractor shall conduct supplemental density testing at a minimum of [3] additional test locations within the flagged section, positioned at locations identified by the PMTP data as having the lowest mat surface temperatures within the section.

(b) If supplemental density testing confirms that in-place density at PMTP-flagged locations is below the contract minimum density requirement, the Contractor shall address the root cause of the thermal segregation and shall not place additional mix until the root cause has been identified and corrective action has been taken or approved by the Engineer.

(c) If supplemental density testing at PMTP-flagged locations meets or exceeds the contract minimum density requirement, no corrective action is required, but the Contractor shall document the result and the PMTP flag in the project quality records.

The TSI threshold in Section SP-P1.6(a) is the key decision parameter for integrating PMTP into acceptance. The density investigation is intended as a confirmation step, not an automatic penalty, so that a thermal anomaly is evaluated based on whether it produces a density deficiency.

SP-P1.7 — Data Delivery. The Contractor shall deliver to the Engineer, within [5] business days of the completion of each paving day:

(a) The complete raw PMTP data file in the native format produced by the PMTP system;

(b) A processed TSI summary report in PDF or CSV format, including TSI values for each analysis section, a map or alignment plot showing flagged sections, and a log of any system interruptions; and

(c) For any section where supplemental density testing was conducted under SP-P1.6: the density test results and the Contractor's root cause assessment.

SP-P1.8 — Calibration. PMTP sensors shall be calibrated per AASHTO R 110 prior to the start of each paving season and after any sensor replacement or repair. Calibration records shall be available for agency review upon request.

SP-P1.9 — Measurement and Payment. PMTP, when required under this special provision, shall be considered incidental to the HMA pay item and shall not be measured or paid separately, unless a separate bid item for PMTP is established in the contract schedule of prices.

8.4 Implementation Notes

The proposed language in Sections 8.1, 8.2, and 8.3 is designed for adoption through different channels and at different speeds. The M 156 revisions require action through the AASHTO Committee on Materials and Pavements and establish requirements for plant monitoring points, sensor performance, designated reporting points, electronic records, calibration and verification, failed-device response, and fixed-equipment access. The R 97 revisions can follow the same AASHTO process and establish field instrument accuracy, measurement documentation, safe haul-unit access, seasonal verification, and removal of failed devices from required use. Agencies wishing to act before national adoption may incorporate the core provisions into project-level special provisions.

The R 110 agency contract language in Section 8.3 does not require any standard revision. It can be adopted as a contract special provision by any agency that chooses to do so. The most important implementation step for Section 8.3 is selecting a project-specific TSI threshold. NCAT and other research centers can assist agencies in calibrating that threshold to their local data using PMTP datasets from existing projects.

The WMA temperature incentive provision in Section 8.1 may be adopted as a project special provision without waiting for M 156 to be revised, provided the agency defines the designated reporting point, establishes temperature thresholds appropriate to that location, verifies the monitoring system, and requires a complete electronic record and an approved contingency procedure. MnDOT's experience demonstrates that a temperature incentive can be administered successfully, but its plant recordation location and thresholds should not automatically be transferred to a different plant location without evaluation.

Table 8-1 provides a consolidated implementation roadmap showing the recommended adoption pathway for each specification provision, the responsible party, and the estimated timeline.

Table 8-1. Implementation Roadmap for Proposed Specification Provisions

Section	Provision	Adoption pathway	Responsible party	Estimated timeline
8.1 / M 156 §§4.12.1–4.12.7	Plant monitoring points; contact and noncontact sensors; accuracy; designated reporting point; electronic records; verification; failed-device response; access and safety	AASHTO M 156 revision	AASHTO COMP / NCAT / NAPA	1–2 years
8.1 / SP-T1	Optional WMA incentive using a contract-defined reporting point and density quality gate	Agency special provision	Agency / Contractor	Immediate pilot
8.2 / R 97 §§5.12–5.13	Temperature observation during sampling; instrument accuracy; safe access; documentation; verification; failed-device response	AASHTO R 97 revision	AASHTO COMP / NCAT / NAPA	1–2 years
8.2 / R 97 model language	Immediate field-temperature measurement requirements pending national adoption	Agency special provision	Agency	Immediate
8.3 / SP-P1	PMTP applicability; TSI threshold; density investigation; data delivery	Agency special provision	Agency / Contractor	Immediate

References

AASHTO Standards

AASHTO M 156. Standard Specification for Requirements for Mixing Plants for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures. American Association of State Highway and Transportation Officials, Washington, DC. (Current edition.)

AASHTO R 97. Standard Practice for Sampling of Hot-Mix Asphalt Paving Mixtures. American Association of State Highway and Transportation Officials, Washington, DC. (Current edition.)

AASHTO R 110. Standard Practice for Collecting Pavement Surface Temperature Data Using Paver-Mounted Infrared Temperature Scanning Equipment. American Association of State Highway and Transportation Officials, Washington, DC. (Current edition.)

AASHTO T 316. Standard Method of Test for Viscosity Determination of Asphalt Binder Using Rotational Viscometer. American Association of State Highway and Transportation Officials, Washington, DC. (Current edition.)

AASHTO T 329. Standard Method of Test for Moisture Content of Hot-Mix Asphalt (HMA) by Oven Method. American Association of State Highway and Transportation Officials, Washington, DC. (Current edition.)

ASTM Standards

ASTM E230/E230M. Standard Specification for Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples. ASTM International, West Conshohocken, PA. (Current edition.)

ASTM E1137/E1137M. Standard Specification for Industrial Platinum Resistance Thermometers. ASTM International, West Conshohocken, PA. (Current edition.)

ASTM E1933. Standard Practice for Measuring and Compensating for Emissivity Using Infrared Imaging Radiometers. ASTM International, West Conshohocken, PA. (Current edition.)

ASTM E2758. Standard Guide for Selection and Use of Wideband, Portable Infrared Thermometers. ASTM International, West Conshohocken, PA. (Current edition.)

ASTM E2847. Standard Test Method for Calibration and Accuracy Verification of Wideband Infrared Thermometers. ASTM International, West Conshohocken, PA. 2026 edition.

ASTM E2847-21 Standard Test Method for Calibration and Accuracy Verification of Wideband Infrared Thermometers

Federal Regulations and Guidance

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National Asphalt Pavement Association. Asphalt Mix Temperature Categories. NAPA SUST-008. National Asphalt Pavement Association, Greenbelt, MD, 2024.

National Asphalt Pavement Association. Field Management of Hot Mix Asphalt. Information Series 124. National Asphalt Pavement Association, Lanham, MD, 1997. Reprinted 2002.

Young, T.J. Applying QIP-126 & QIP-127: Production Strategies for $aving Money and Reducing Emissions. QIP-132. National Asphalt Pavement Association, Greenbelt, MD, 2023.

State DOT Standard Specifications (Selected)

Alabama Department of Transportation. Standard Specifications for Highway Construction, Section 424 — Hot Mix Asphalt (HMA) Pavement. ALDOT, Montgomery, AL. 2025.

Missouri Department of Transportation. Engineering Policy Guide Section 403 — Plant Mixed Bituminous Pavement. MoDOT, Jefferson City, MO. 2025.

North Carolina Department of Transportation. Standard Specifications for Roads and Structures, Section 610 — Asphalt Concrete Pavement. NCDOT, Raleigh, NC. 2025.

New York State Department of Transportation. Materials Procedure MP 4.02 — Plant-Mixed Hot-Mix Asphalt Concrete (HMAC) Construction. NYSDOT, Albany, NY. 2025.

Oregon Department of Transportation. Standard Specifications for Construction, Section 00745 — Asphaltic Concrete Pavement. ODOT, Salem, OR. 2025.

South Carolina Department of Transportation. Standard Specifications for Highway Construction, Section 342 — Asphalt Concrete. SCDOT, Columbia, SC. 2025.

Texas Department of Transportation. Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges, Item 341 — Dense-Graded Hot-Mix Asphalt (Method). TxDOT, Austin, TX. 2025.

Virginia Department of Transportation. Road and Bridge Specifications, Section 315 — Bituminous Concrete Pavement. VDOT, Richmond, VA. 2025.

Washington State Department of Transportation. Standard Specifications for Road, Bridge, and Municipal Construction, Section 5-04 — Hot Mix Asphalt. WSDOT, Olympia, WA. 2025.

West Virginia Department of Transportation. Standard Specifications for Roads and Bridges, Division 400 — Bituminous Construction. WVDOH, Charleston, WV. 2025.

Research Literature

Gong, H., Liu, Q., Lv, Y., Chen, S, Wu, S. Ying, H., Strategies for Reducing Asphalt Pavement High-Temperature Climate Change Impacts. Elsevier/Case Studies in Construction Materials. 2023

The Road Forward, NAPA. Emissions and Fuel Savings Using WMA at Reduced Asphalt Mixture Production Temperatures, Ingevity Corporation, North Charleston, SC. 2024.

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Parker, F. Residual Moisture in Hot Mix Asphalt Concrete. Auburn University Highway Research Center, Auburn, AL, 1996.

Project Data Sources

National Center for Asphalt Technology. Infrared Thermometer Measurement Study During 2024 NCAT Test Track Construction. Unpublished data, Auburn University, Auburn, AL, 2024.

National Center for Asphalt Technology. State Agency Asphalt Mixture Sampling Survey. Survey data collected May–June 2026, Auburn University, Auburn, AL, 2026.

National Center for Asphalt Technology. NAPA Mix Sampling and Temperature Reading Specifications — Contractor/Supplier Survey. Survey data collected March–April 2026, Auburn University, Auburn, AL, 2026.

Appendix A — AASHTO and ASTM Standards

Proposed 2026 ballot revisions to AASHTO M 156 and R 97 are included in Appendices B and C and treated as proposed implementation language for the purpose of this report.

AASHTO Standards

Plant Equipment Requirements

The proposed 2026 ballot draft expands Section 4.12 to add instrument class and accuracy requirements, electronic recording, verification and calibration records, data integrity provisions, safety language, and a note distinguishing surface temperature measurements from bulk temperature measurements.

Designation	Title / Temperature-Relevant Sections & Notes
AASHTO M 156-13 (2025)	***Standard Specification for Requirements for Mixing Plants for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures*** §4.12 Thermometric Equipment: Requires recording thermometers at the mixture discharge point and at the dryer discharge chute. Thermometers shall be calibrated by the manufacturer for the full range of production temperatures and verified periodically during production. | Proposed 2026 additions (assuming ballot advance): §4.12.3 Instrument classes and accuracy — fixed discharge/dryer sensors shall be RTD (Pt100, ASTM E1137, Class A) or Type K thermocouple (ASTM E230, Special Limits of Error); expanded uncertainty ≤ ±1.5°C (±3°F) at 135–165°C (275–330°F). §4.12.4 Measurement locations — continuous recording (≥1 Hz) at mixture discharge, dryer discharge aggregate stream, and binder line; truck-side access port required. §4.12.5 Verification and calibration — NIST-traceable reference verification at start-up; handheld IR per ASTM E2847 and contact probes per ASTM E2877 verified weekly and at project start; calibration log required. §4.12.6 Data integrity — time-stamped CSV archived ≥3 years; export every 20 min during production; alarm/interlock on sensor failure. §4.12.7 Safety — prohibit over-the-top truck measurements; use side ports or non-contact IR from ground level.

Sampling

Temperature at the time of sampling is critical context for mixture quality evaluation. AASHTO R 97 governs sampling of asphalt mixtures at the plant, from transport units, and at the paver; proposed 2026 additions require recording temperature at the sampling location and time, documenting the measurement type, and applying safe work practices. AASHTO R 66 governs asphalt binder sampling and is referenced in M 156 plant requirements.

Designation	Title / Temperature-Relevant Sections & Notes
AASHTO R 97-19 (2024)	***Standard Practice for Sampling Asphalt Mixtures*** Currently silent on temperature recording. | Proposed 2026 additions (assuming ballot advance): §5.12 Temperature Observation at Time of Sampling — record mix temperature at the sampling location using a contact digital thermometer (ASTM E2877, ±0.5°C) or IR thermometer verified per ASTM E2847 (±1–2°C); for truck samples use side-port insertion; for mat samples record both IR surface reading and contact probe in loose material; log instrument ID, emissivity setting (IR), and stabilization time. §5.13 Verification and Safety — verify all thermometric devices per manufacturer and applicable ASTM standards before use; prohibit personnel from climbing on trucks; use side ports or IR from ground level.

Designation	Title / Temperature-Relevant Sections & Notes
AASHTO R 66-16 (2024)	***Standard Practice for Sampling Asphalt Materials*** Governs sampling of liquid asphalt materials (binders and emulsions) at production facilities, storage, or delivery. Temperature context: asphalt binder temperature at the time of sampling is a quality indicator; binder must be within the specified handling temperature range at the point of sample collection.

Thermal Profiling of the Mat (Placement)

AASHTO R 110 is the governing practice for continuous thermal profiling of the asphalt mat during placement. It specifies the paver-mounted thermal profile (PMTP) system — including sensor accuracy, GNSS requirements, data management via Veta software, and thermal segregation analysis — and provides the quantitative framework for identifying temperature-related construction defects at the placement stage.

Designation	Title / Temperature-Relevant Sections & Notes
AASHTO R 110-22 (2026)	***Standard Practice for Continuous Thermal Profile of Asphalt Mixture Construction*** Full standard for paver-mounted thermal profile (PMTP) systems measuring mat surface temperature immediately behind the trailing edge of the paver screed during placement. Key temperature requirements: §4.9.3 Equipment — temperature sensor range 60–250°C (140–480°F); accuracy ±2°C (±3.6°F) or ±2.0 percent of reading, whichever is greater; longitudinal and lateral readings at ≤305 mm (12 in.) intervals at all paving speeds. §4.9.3 GNSS — ±1.2 m (±4 ft) or ±50 mm (±2 in.) accuracy. §4.9.7 Data analysis — data sublots of 45 linear meters (150 ft); thermal segregation index (TSI), transverse semivariogram index (TSV), standard deviation, and range reported per Veta software. System must be calibrated per manufacturer recommendations; data archived to cloud storage until 90 days after final acceptance.

ASTM Standards

ASTM standards provide the performance specifications, calibration methods, and selection guidance for all classes of thermometric instruments used in asphalt temperature measurement. They are organized below by instrument or calibration function. Where AASHTO M 156 or R 97 proposed revisions cite a specific ASTM standard, that citation is noted.

Liquid-in-Glass Thermometers

Designation	Title / Temperature-Relevant Sections & Notes
ASTM E1-14(2025)	***Standard Specification for ASTM Liquid-in-Glass Thermometers*** Defines requirements for liquid-in-glass thermometers, including temperature ranges, graduations, immersion depth, and accuracy tolerances. Baseline reference for contact thermometer performance in field and laboratory settings.
ASTM E2251-14(2021)	***Standard Specification for Liquid-in-Glass ASTM Thermometers with Low-Hazard Precision Liquids*** Non-mercury alternative to ASTM E1 thermometers. Applicable where mercury-free thermometers are required. Same performance class; used as reference or field spot-check instruments.

Reference Temperature Verification

Designation	Title / Temperature-Relevant Sections & Notes
ASTM E563-22	***Standard Practice for Preparation and Use of an Ice-Point Bath as a Reference Temperature*** Provides the primary low-cost, NIST-traceable 0°C (32°F) reference point for verifying and calibrating thermometers in the field or laboratory. Cited as a calibration verification method for contact probes and digital thermometers used in asphalt temperature measurement.

Thermocouples (Contact Probes — Fixed Plant and Handheld)

Designation	Title / Temperature-Relevant Sections & Notes
ASTM E230/E230M-23a	***Standard Specification for Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples*** Provides EMF-temperature reference tables for standardized thermocouple types (J, K, T, E, N, B, R, S). Type K thermocouples are the most common contact probe type used in asphalt plant fixed sensors and handheld probes. Reference for instrument calibration and verification.
ASTM E608/E608M-24	***Standard Specification for Mineral-Insulated, Metal-Sheathed Base Metal Thermocouples*** Covers construction and performance requirements for sheathed thermocouples (Type J, K, T, E, N). The sheathed configuration is the standard form for fixed plant sensors and rugged field probes used at asphalt mix discharge and transport measurement points.
ASTM E220-25	***Standard Test Method for Calibration of Thermocouples by Comparison Techniques*** Specifies the comparison calibration procedure for thermocouples against a NIST-traceable reference. Required calibration method for fixed plant sensors and field-use contact probes to confirm accuracy within specified tolerances across the asphalt production temperature range (approximately 120–180°C [250–355°F]).

Resistance Temperature Detectors (RTDs / Platinum Resistance Thermometers)

Designation	Title / Temperature-Relevant Sections & Notes
ASTM E1137/E1137M-08(2020)	***Standard Specification for Industrial Platinum Resistance Thermometers*** Covers industrial-grade platinum resistance thermometers (PRTs/RTDs), including Pt100 sensors meeting IEC 60751 Class A requirements. Class A RTDs are the preferred fixed sensor type in AASHTO M 156 proposed §4.12.3 for drum/pugmill discharge and dryer discharge measurements due to their high stability, repeatability, and low drift.
ASTM E644-11(2025)	***Standard Test Methods for Testing Industrial Resistance Thermometers*** Provides test methods for evaluating the accuracy, stability, and response characteristics of industrial RTDs. Used to verify that fixed plant RTD sensors meet specified accuracy requirements (expanded uncertainty ≤ ±1.5°C [±3°F] as proposed in M 156 §4.12.3) prior to installation and at periodic verification intervals.

Infrared (IR) Thermometers and Imaging Radiometers

Handheld IR thermometers (IR guns) and fixed infrared pyrometers are the dominant field measurement tools for asphalt temperature monitoring based on the 29-response state DOT survey (85 percent of respondents allow IR guns). The ASTM standards below govern instrument selection, calibration verification, and emissivity compensation — the three primary sources of inter-instrument variability observed in field studies.

Designation	Title / Temperature-Relevant Sections & Notes
ASTM E2758-22	***Standard Guide for Selection and Use of Infrared Thermometers*** Provides guidance on selecting and using handheld IR thermometers, including distance-to-spot (D:S) ratio requirements, emissivity settings, and factors affecting accuracy (surface emissivity, atmospheric path, reflected background temperature). Critical reference for field use of IR guns on haul trucks and mat surfaces; directly applicable to operator training and procedural standardization.
ASTM E2847-21(2026)	***Standard Test Method for Calibration and Accuracy Verification of Wideband Infrared Thermometers*** Upgraded from 'Standard Guide' to 'Standard Test Method' in 2026 edition, increasing normative weight. Specifies calibration and accuracy verification procedures for wideband IR thermometers (handheld IR guns). Referenced in both AASHTO M 156 proposed §4.12.5 and R 97 proposed §5.12 as the required verification method for IR instruments used at plant, truck, and mat measurement locations. Weekly verification required at project start.
ASTM E1933-14(2022)	***Standard Practice for Measuring and Compensating for Emissivity Using Infrared Imaging Radiometers*** Covers emissivity measurement and compensation for infrared imaging systems (IR cameras and thermal profilers). Applicable to paver-mounted thermal profile systems used in AASHTO R 110 applications and to fixed plant infrared pyrometers. Proper emissivity setting is essential for accurate IR temperature measurement of asphalt surfaces (typical emissivity 0.90–0.95 for fresh HMA).

Note: ASTM E2847 was elevated from a Standard Guide to a Standard Test Method in its 2026 edition (E2847-21[2026]), increasing its normative standing as a calibration verification requirement when cited in AASHTO specifications. All ASTM standard years reflect the most current edition available as of the preparation of this report.

Appendix B — Proposed AASHTO M 156 Ballot Draft

Proposed 2026 Ballot Draft – NCAT/TS 2c Input

Redline additions shown in red underline (AASHTO M 156 §4.12 revisions)

AASHTO M 156 – Proposed Revision (2026 Ballot Draft)

Rationale: Current AASHTO standards provide limited guidance regarding instrument selection, calibration, documentation, and the distinction between surface and bulk asphalt mixture temperature measurements. These revisions establish minimum requirements for temperature measurement and documentation while recognizing that infrared and contact thermometers measure different physical quantities. The revisions improve consistency, safety, and reproducibility of asphalt mixture temperature measurements used for production control, sampling, and acceptance activities.

Section 4.12 Thermometric Equipment (Redline Draft):

4.12 *Thermometric Equipment: (Current)*

4.12.1 Provide appropriate recording thermometers, of suitable temperature ranges, to accurately assess the temperature of the asphalt mixture at or near the discharge point. Harden the thermometer mechanism as necessary to assure durability of the device and continuous operation. Thermometers should be calibrated by the manufacturer for the full range of mixture production temperatures. The thermometers should be verified periodically during production to assure their accuracy.

4.12.2 Provide appropriate thermometric devices to measure the temperature at the discharge chute of the dryer, to display the temperature, and to record the temperature data automatically. For batch plants, provide the same capability for thermometric devices in the hot fines bin.

4.12. *Thermometric Equipment:(Redline Draft)*

4.12.1. *Asphalt Mixture Temperature Monitoring*—Provide fixed thermometric equipment of suitable temperature range and durability to continuously measure and display the temperature of the asphalt mixture at one or more documented locations after completion of mixing. Equipment exposed to the material stream shall be designed or protected to withstand abrasion, material buildup, vibration, and the anticipated plant operating environment.

4.12.2. *Heated Aggregate Temperature Monitoring*—Provide thermometric equipment to measure and display the temperature of the heated aggregate at a documented location downstream of drying and before or during mixing, as applicable to the plant configuration. The thermometric equipment shall measure material temperature rather than surrounding air or exhaust-gas temperature. For batch plants, provide comparable temperature-monitoring capability for the hot aggregate system, including the hot fines bin, as applicable.

4.12.3. *Instrument Types and Accuracy*—Fixed temperature-monitoring systems may use contact or noncontact sensors.

a) Fixed contact sensors shall be resistance temperature detectors (RTD, Pt100) sensors meeting IEC 60751 or ASTM E1137, Class A or better; Type K thermocouples meeting ASTM E230 Special Limits of Error; or sensors providing equivalent performance approved by the agency.
b) Fixed noncontact sensors shall be industrial infrared pyrometers designed for aggregate or asphalt mixture monitoring and suitable for the anticipated temperature range, operating environment, measurement distance, target area, and material emissivity.

Sensors used for required agency reporting, acceptance, or incentive-payment determinations shall have a documented accuracy of ±2°C (±4°F) or better over the anticipated asphalt mixture production temperature range.

NOTE 4—Infrared thermometers and thermal imaging devices measure the temperature of the exposed material surface. Contact thermometers, thermocouples, and resistance temperature detectors measure the temperature of the material at the point of sensor contact. Surface and contact measurements are not necessarily equivalent because thermal gradients may exist within the material.

4.12.4. *Measurement Points and Data Collection*

4.12.4.1. The producer shall identify in the plant quality-control plan the location and intended use of each fixed temperature-monitoring point. Monitoring points used only for plant process control may be located where they provide the information needed to operate the plant effectively.

4.12.4.2. When plant temperature data are required for agency documentation, acceptance, or incentive payment, the producer and agency shall identify a designated reporting point after completion of mixing and before or at mixture loadout. The designated reporting point shall be selected to provide a representative measurement of the asphalt mixture temperature for its intended use. The monitoring location, sensor type, and whether the measurement represents surface or contact temperature shall be documented.

4.12.4.3. Temperature data from the designated reporting point shall be electronically recorded with associated date and time information. Recording intervals shall be established by the agency or producer and shall not exceed 10 minutes during production.

NOTE 5—Asphalt mixture temperature may change after an intermediate process-control point because of thermal equilibration within aggregate particles, continued vaporization of internal moisture, storage time, or other plant-process conditions. An intermediate process-control temperature may therefore be higher than the temperature measured downstream. Contract documents should identify the location and measurement type that govern compliance.

NOTE 6—Plant temperature monitoring supports production control and documentation. It does not replace temperature observations near placement when those observations are used to evaluate the available compaction window.

4.12.5. *Calibration and Verification—*

4.12.5.1. Calibration may be performed by the instrument manufacturer or by a competent calibration laboratory using reference equipment traceable to a national metrology institute. Verification may be performed by trained personnel using a traceable reference thermometer and an applicable ASTM procedure or manufacturer-recommended procedure.

4.12.5.2. Fixed temperature sensors used for required reporting, acceptance, or incentive determinations shall be verified:

a) before initial use;
b) before the first use of each construction season and at intervals not exceeding 12 months;
c) after sensor repair, replacement, or relocation; and
d) whenever damage, drift, inconsistent readings, or other conditions create a reasonable doubt regarding accuracy.

Applicable procedures include ASTM E220 for thermocouples, ASTM E644 for industrial resistance thermometers, and ASTM E2847 for infrared thermometers within the scope of that standard. Manufacturer-recommended procedures may be used when an ASTM procedure is not applicable to the sensor type or installation.

4.12.5.3. Calibration and verification records shall include, as applicable:

a) device identification, manufacturer, model, and sensor type;
b) monitoring location and intended use;
c) calibration or verification date;
d) person and organization performing the work;
e) reference-device identification and traceability information;
f) temperature points or verified temperature range;
g) measured error at each verification point;
h) acceptance tolerance and pass/fail determination;
i) corrective action, when required; and
j) the next scheduled verification date.

4.12.5.4. A device that does not meet the applicable verification tolerance shall not be used for required agency reporting, acceptance, or incentive-payment determinations until it has been repaired, adjusted, or replaced and successfully verified. A verified backup device or agency-approved contingency procedure may be used during the interim.

4.12.6. *Electronic Records and System Status*—For fixed electronic plant temperature-monitoring systems, temperature records shall be retained in an electronic format in accordance with agency requirements. Each record shall identify the designated monitoring point or sensor. The system shall notify plant personnel of a sensor malfunction or an interruption in required data recording. When the designated reporting system is unavailable, the producer shall follow the documented contingency procedure established under Section 4.12.5.4.

4.12.7. *Access and Safety*—Provide safe access for inspection, verification, maintenance, repair, and replacement of fixed thermometric equipment. Calibration and verification activities shall be performed in accordance with the plant's site-specific safety procedures. Safety requirements for obtaining field temperature observations from haul units and roadway samples are addressed in AASHTO R 97.

Appendix C — Proposed AASHTO R 97 Ballot Draft

Proposed 2026 Ballot Draft – NCAT/TS 2c Input
Redline additions shown in red underline (AASHTO R 97 Sampling revisions)

AASHTO R 97 – Proposed Revision (2026 Ballot Draft)

Rationale: Current AASHTO standards provide limited guidance regarding instrument selection, calibration, documentation, and the distinction between surface and bulk asphalt mixture temperature measurements. These revisions establish minimum requirements for temperature measurement and documentation while recognizing that infrared and contact thermometers measure different physical quantities. The revisions improve consistency, safety, and reproducibility of asphalt mixture temperature measurements used for production control, sampling, and acceptance activities.

Insertions proposed after Section 5.9 (Sampling from Roadway before Compaction):

5.12. *Temperature Observation at Time of Sampling*—When required by the agency, record the asphalt mixture temperature at the sampling location and at the time the sample is obtained.

Temperature measurements may be obtained using:

(a) a digital contact thermometer having a documented accuracy of ±1°C (±2°F) or better over the anticipated measurement range; or

(b) an infrared (IR) thermometer having a documented accuracy of ±2°C (±4°F) or better over the anticipated measurement range and verified in accordance with manufacturer recommendations and ASTM E2847 when applicable.

For samples obtained from haul units, the temperature may be measured:

(a) from the sample immediately after collection;

(b) through a designed truck-side access port or other approved ground-level access system; or

(c) using a noncontact infrared thermometer from a safe ground-level position.

Personnel shall not climb onto a loaded haul unit to obtain a temperature measurement or sample unless access is provided by a fixed platform or other agency-approved system meeting applicable safety requirements.

For roadway samples, an infrared surface-temperature measurement may be obtained at the sampling location. When safe and practical, a contact measurement may also be obtained in loose material immediately behind the screed or from the sample itself.

When both a surface-temperature measurement and a contact-temperature measurement are obtained at the same location, the contact measurement shall be used as the reference for determining the asphalt mixture bulk temperature. The infrared measurement remains the applicable measurement when the specification requirement is explicitly based on surface temperature.

Record, at a minimum:

(a) the measured temperature;

(b) date and time;

(c) sampling and measurement location;

(d) instrument identification;

(e) measurement type—surface or contact; and

(f) the emissivity setting when an adjustable-emissivity infrared thermometer is used.

NOTE 3—Infrared thermometers measure the temperature of the exposed asphalt mixture surface, whereas contact thermometers measure material temperature at the point of probe insertion or sensor contact. Surface and contact temperatures may differ during transport, placement, and compaction.

Agencies should establish acceptance criteria appropriate to the specified measurement type and location.

Proposed Section 5.13 — Verification and Safety

5.13. *Verification and Safety*—Thermometric devices used for required sampling documentation or acceptance shall be maintained and verified in accordance with manufacturer recommendations and applicable ASTM standards.

Devices shall be verified:

(a) before first use during each construction season and at intervals not exceeding 12 months;
(b) after repair or replacement;
(c) after damage or exposure that may affect accuracy; and
(d) whenever inconsistent readings or other conditions create reasonable doubt regarding performance.

A device that does not meet the applicable verification tolerance shall be removed from service for required documentation or acceptance until it has been repaired, adjusted, or replaced and successfully verified. A verified replacement device may be used.

Safe work practices shall be followed whenever obtaining temperature measurements from haul units, around pavers, from loose mixture, or within active work zones.