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Standard Specification for Heat Meter Instrumentation[1,2]

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1. Scope

1.1 This specification defines general specifications for heat meters. Heat meters are instruments that measure heat in heat exchange circuits in which energy is absorbed (cooling) or given up (heating) by a flowing liquid.

1.2 For this specification, the necessary elements of a heat meter consist of a sensor to measure flow of the heat-conveying liquid, a pair of temperature sensors that measure the temperature differential across the heat exchange circuit, and a device that receives input from the flow and temperature sensors and calculates energy.

1.3 Electrical safety is not a part of this specification.

1.4 Mechanical safety (including pressure safety) is not a part of this specification.

1.5 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *CCT Standard:*[3]

ITS-90 International Temperature Scale of 1990

2.2 *IAPWS Standard:*[4]

IAPWS-IF97 Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam

2.3 *IEC Standards:*[5]

IEC 61000 Part 4-2 Electrostatic Discharge Immunity Test

IEC 61000 Part 4-3 Radiated, Radio-Frequency, Electromagnetic Field Immunity Test

IEC 61000 Part 4-4 Electrical Fast Transient/Burst Immunity Test

IEC 61000 Part 4-5 Surge Immunity Test

IEC 60068: Environmental Testing Part 2.1 Test A: Cold

IEC 60068: Environmental Testing Part 2.2 Tests B: Dry Heat

IEC 60068: Environmental Testing Part 2-30 Tests Db: Damp Heat, cyclic

IEC 60529 Degrees of protection provided by enclosures (IP Code)

IEC 60751 Industrial platinum resistance thermometer and platinum temperature sensors

IEC 60870 Part 5-1 Telecontrol equipment and systems

IEC 61107 Data exchange for meter reading, tariff and load control—Direct local data exchange

IEC TR 61000 Electromagnetic compatibility—Part 2: Environment—Section 7: Low frequency magnetic fields in various environments

2.4 *NEMA Standards:*[6]

NEMA 250 Enclosures for Electrical Equipment (1000 Volts Maximum)

2.5 *OIML Standards:*[7]

OIML D11 General Requirements for measuring instruments—Environmental conditions

OIML R 49 Part 2 Water meters intended for the metering of cold potable water and hot water

[1] This specification is under the jurisdiction of ASTM Committee E44 on Solar, Geothermal and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.25 on Heat Metering.

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[2] Through a mutual agreement with ASTM International (ASTM), the International Association of Plumbing and Mechanical Officials (IAPMO) contributed its technical expertise to ASTM, leading to the development of this ASTM Standard. IAPMO and its membership continue to play an active role in providing technical guidance to the ASTM standards development process.

[3] Available from the Consultative Committee for Thermometry, www.its-90.com.

[4] Available from the International Association for the Properties of Water and Steam, www.iapws.org.

[5] Available from the International Electrotechnical Commission, www.iec.ch.

[6] Available from National Electrical Manufacturers Association (NEMA), 1300 N. 17th St., Suite 900, Arlington, VA 22209, http://www.nema.org.

[7] Available from the International Organization of Legal Metrology, www.oiml.org/en.

OIML R75-1 Part 1 General requirements

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *conventional true value, n*—value of a quantity, which for the purpose of this specification, is considered as a true value. **OIML R75-1 2002**

3.1.1.1 *Discussion*—A conventional true value is regarded, in general, as sufficiently close to the true value for the difference to be insignificant for the given purpose. **OIML R75-1 2002**

3.1.2 *disturbance, n*—influence quantity having a value outside the rated operating conditions. **OIML R75-1 2002**

3.1.3 *electronic device, n*—device using electronic components and performing a specific function. **OIML R75-1 2002**

3.1.4 *equipment under test, n*—subassembly, a combination of subassemblies, or a complete meter subject to a test. **OIML R75-1 2002**

3.1.5 *error types, n*—

3.1.5.1 *durability error, n*—difference between the intrinsic error after a period of use and the initial intrinsic error. **OIML R75-1 2002**

3.1.5.2 *error (of indication) of a measuring instrument, n*—indication of the measuring instrument minus the conventional true value of the corresponding input quantity. **OIML R75-1 2002**

3.1.5.3 *initial intrinsic error, n*—intrinsic error of a measuring instrument as determined before performance and durability tests.

3.1.5.4 *intrinsic error (of a measuring instrument), n*—error of a measuring instrument determined under reference conditions. **OIML R75-1 2002**

3.1.5.5 *maximum permissible error, MPE, n*—extreme values of the error (positive or negative) permitted by this specification. **OIML R75-1 2002**

3.1.6 *fast response meter, n*—heat meter designed for use in heat exchange circuits in which sudden or rapid changes, or both, in flow or temperature are a normal condition. **OIML R75-1 2002**

3.1.7 *fault types, n*—

3.1.7.1 *fault, n*—difference between the error of indication and the intrinsic error of the instrument. **OIML R75-1 2002**

3.1.7.2 *significant fault*—fault greater than the absolute value of the MPE that is not a transitory fault, for example, if the MPE is ±2 %, then a significant fault is a fault larger than 2 %. **OIML R75-1 2002**

3.1.7.3 *transitory fault*—momentary variations in the indication that cannot be interpreted, memorized, or transmitted as measurements. **OIML R75-1 2002**

3.1.8 *flow direction, n*—indication of directionality for a flowing liquid within a piping system leading to and exiting from a heat exchange circuit.

3.1.8.1 *Discussion*—The term supply (or inlet) is used to indicate liquid traveling to the heat exchanger and the term return (or outlet) describes the liquid exiting the heat exchanger. In heating systems, supply liquids will normally have a higher temperature than return liquids. In cooling systems, supply liquids will normally have a lower temperature than return liquids.

3.1.9 *flow sensor, n*—subassembly of a heat meter designed to measure the volume or mass of a flowing liquid in a heat exchange circuit.

3.1.10 *heat calculator, n*—heat meter subassembly that receives flow and temperature signals from flow and temperature sensors and calculates and displays energy.

3.1.11 *influence factor, n*—influence quantity having a value within the rated operating conditions. **OIML R75-1 2002**

3.1.12 *influence quantity, n*—quantity that is not the measurand but that affects the result of the measurement. **OIML R75-1 2002**

3.1.13 *meter model, n*—different sizes of heat meters or subassemblies having a family similarity in the principles of operation, construction, and materials. **OIML R75-1 2002**

3.1.14 *minimum immersion depth of a temperature sensor, n*—depth of immersion in a thermostatic bath with a temperature of 80 ± 5°C [176 ± 9°F] at an ambient temperature of 25 ± 5°C [77 ± 9°F], beyond which deeper immersion changes the output value by an amount corresponding to less than 0.1 K [0.18°F]. **OIML R75-1 2002**

3.1.15 *platinum resistance thermometer, PRT, n*—temperature responsive device consisting of one or more sensing platinum resistors within a protective sheath with internal connecting wires and external terminals to permit connection of electrical measurement instruments.

3.1.15.1 *Discussion*—Mounting means and connection heads may be included. Not included is any separable protection tube or thermowell.

3.1.16 *platinum resistor, n*—resistor made from platinum wire or film with defined electrical characteristics, embedded in an insulator (in most cases glass or ceramic), designed to be assembled into a resistance thermometer or an integrated circuit.

3.1.17 *rated operating conditions, n*—conditions of use for which specified metrological characteristics of a measuring instrument are intended to lie within the specified maximum permissible errors. **OIML R75-1 2002**

3.1.18 *rated voltage, U_n, n*—voltage of an external power supply required to operate a heat meter.

3.1.19 *reference conditions, n*—conditions of use prescribed for testing the performance of a measuring instrument or intercomparison of results of measurements. **OIML R75-1 2002**

3.1.20 *reference values of the measurand, RVM, n*—specified set of values of the flow rate, the return temperature, and the temperature difference fixed to ensure valid intercomparison of the results of measurements. **OIML R75-1 2002**

3.1.21 *response time, τ0.5, n*—time interval between the instant when the flow, the temperature, or the temperature difference is subjected to a specified abrupt change and the instant when the response reaches 50 % of its final steady value. **OIML R75-1 2002**

3.1.22 *self-heating effect, n*—increase in temperature signal that is obtained by subjecting each temperature sensor of a pair to a continuous power dissipation of 5 mW when immersed to the minimum immersion depth in a water bath having a mean water velocity of 0.1 m/s [0.328 ft/s]. **OIML R75-1 2002**

4. Significance and Use

4.1 This document is based, in part, on OIML R 75-1 Edition 2002, Heat meters Part 1: General requirements and OIML R 75-2 Edition 2002, Heat meters Part 2: Type approval tests and initial verification tests. R 75 is an International Recommendation published by OIML. International Recommendations are model regulations that establish the metrological characteristics required of certain measuring instruments and which specify methods and equipment for checking their conformity. As an OIML Member State, The United States is obligated to utilize these recommendations, where possible, when developing standards that meet the needs of the market and may result in either terminology or definitions specific to this standard and deviations in standard form and style.

5. Using this Specification

5.1 This specification is intended to provide both manufacturers and users of heat meters with important information.

5.2 Manufacturers will use this specification to certify that their products conform to industry standards for accuracy, performance, and reliability.

5.3 End users and specifying engineers will use this specification as a guide in understanding how heat meters are defined based on performance and accuracy classifications for flow, temperature, and energy. They will also use this specification to ensure that the meter will be suitable for use in the operating environment in which it will be installed.

5.4 End users are strongly encouraged to review carefully the requirements of their specific application and then select a heat meter that will meet their needs based on the following criteria:

5.4.1 *Flow Sensor Accuracy Class*—Class 1, Class 2, or Class 3;

5.4.2 *Lower Limit of the Temperature Difference Range*—1, 2, or 3 K [1.8, 3.6, or 5.4°F]; and

5.4.3 *Environmental Class*—A, B, C, or D.

5.5 Overall accuracy of the heat meter is defined as the additive maximum permissible errors (MPE) of the flow sensor, the temperature sensor pair, and the heat calculator. See Section 7 for additional information on maximum permissible errors.

5.6 *Flow Sensors:*

5.6.1 The three flow sensor accuracy classes are Class 1, Class 2, or Class 3. In each class, the accuracy is determined by the MPE at the manufacturer's stated minimum (Q_i) and maximum permanent flow rate (Q_p). See 8.2 for additional information on flow sensor operating limits.

5.6.2 The MPE for each flow sensor varies with the flow sensor accuracy class and the ratio of the Q_p to the actual operating flow rate (Q). This is the turndown for the sensor. When selecting a flow sensor, it is necessary to identify first the maximum flow rate for the application. This maximum flow rate shall be compared to the upper flow limit (Q_s) and the Q_p as stated by the flow meter manufacturer for the flow sensor under consideration. Next, identify the minimum flow rate for the application. Compare this value to the Q_i as stated by the flow meter manufacturer. Flow sensors should be selected that will operate within these upper and lower flow limits. Once the upper and lower flow limits are defined (turndown), the accuracy limits by class can be determined from Table 1.

5.6.3 Table 1 shows the range of allowable error (E_f) for the flow sensor by class and turndown range for use in MPE equations in 8.3. For clarity, turndown is expressed as Q_p/Q_i in Table 1.

5.7 *Temperature Sensor Pairs and Heat Calculator:*

5.7.1 The MPE of the temperature sensor pair is a function of the lower limit of the temperature difference as described in 9.4 and 9.5. The three lower limits for the temperature difference range are 1, 2, and 3 K [1.8, 3.6, or 5.4°F]. As with the flow sensor, the highest percentage measurement error will occur at the minimum operating level. In this case, it is the lowest differential temperature.

5.7.2 The heat calculator MPE is also defined by the lower limit of the temperature difference range (1, 2, or 3 K) as described in 10.4. As is the case with the temperature sensor pair, the highest percentage measurement error will occur at the minimum temperature differential.

5.7.3 When selecting a temperature sensor pair, it is necessary to identify the minimum and maximum operating temperatures for the application and confirm that they fall within the operating limits of the individual temperature sensors. Next, identify and compare the maximum and minimum temperature difference for the application with the upper limit of temperature difference (Δt_{max}) and lower limit of temperature difference (Δt_{min}) as stated by the manufacturer. Temperature sensor pairs should be selected that will operate within the Δt_{max} and Δt_{min} at least 75 % of the time while never exceeding the Δt_{max}. Once the Δt_{max} and Δt_{min} are defined, the accuracy limits can be determined from Table 2.

TABLE 1 Allowable Flow Rate MPE by Accuracy Class and Turndown

Class	Turndown	E_f at Minimum Flow ($Q = Q_i$), %	E_f at Maximum Flow ($Q = Q_p$), %
Class 1	10:1	1.10	1.01
	25:1	1.25	1.01
	50:1	1.50	1.01
	100:1	2.00	1.01
	250:1	3.50	1.01
Class 2	10:1	2.20	2.02
	25:1	2.50	2.02
	50:1	3.00	2.02
	100:1	4.00	2.02
	250:1	5.00	2.02
Class 3	10:1	3.50	3.05
	25:1	4.25	3.05
	50:1	5.00	3.05
	100:1	5.00	3.05
	250:1	5.00	3.05

TABLE 2 Temperature Sensor Pair MPE % in -16.6°C [2°F] ΔT Increments for the Three Lower Limits of the Temperature Difference Range

Measured ΔT, °F[A]	1 K, %	2 K, %	3 K, %
2	4.60	***8.20***	***11.80***
4	2.80	4.60	***6.40***
6	2.20	3.40	4.60
8	1.90	2.80	3.70
10	1.72	2.44	3.16
12	1.60	2.20	2.80
14	1.51	2.03	2.54
16	1.45	1.90	2.35
18	1.40	1.80	2.20
20	1.36	1.72	2.08

[A] 1°F = –17.2°C.

5.7.4 Table 2 shows the combined allowable error percentages for the temperature sensor pair and the heat calculator for measured difference temperatures (ΔT) in –17°C [2°F] increments.

5.8 *Environmental Classes*—Heat calculators and complete heat meters are defined by one of the four environmental classifications: A, B, C, or D. These are summarized in 10.10. Heat calculator and heat meter environmental classes should be selected according to the needs of the application in which they will be used.

6. Types of Instruments

6.1 This specification defines heat meters as complete or combined instruments.

6.1.1 *Complete Instrument*—A heat meter that does not have separable subassemblies as defined in 6.1.4.

6.1.2 *Combined Meter*—A heat meter that has separable subassemblies as defined in 6.1.4.

6.1.3 *Hybrid Meter*—A heat meter that, for the purpose of type approval and verification, can be treated as a combined instrument as defined in 6.1.2. However, after verification, its subassemblies will be treated as inseparable.

6.1.4 *Subassemblies of a Heat Meter that is a Combined Instrument*—The flow sensor, the temperature sensor pair, and the heat calculator or a combination of these.

6.1.4.1 *Flow sensor*—A subassembly installed at either the supply or return of a heat exchange circuit and that emits a signal, which is a function of the volume or the mass or the volumetric or mass flow rate.

6.1.4.2 *Temperature sensor pair*—A subassembly (for mounting with or without thermowells) that senses the temperatures of the heat-conveying liquid at the inlet and outlet of a heat exchange circuit.

6.1.4.3 *Heat calculator*—A subassembly that receives signals from the flow sensor and the temperature sensors and calculates and indicates the quantity of heat exchanged.

6.1.5 *Equipment under Test*—A subassembly, a combination of subassemblies, or a complete meter subject to a test.

7. Metrological Characteristics

7.1 *General*—Flow sensors of heat meters and complete instruments belong to one of the following three accuracy classes: Class 1, Class 2, and Class 3.

7.1.1 The class of the complete instrument is determined by the class of the flow sensor.

7.1.2 The maximum permissible errors of heat meters, positive or negative, in relation to the conventional true value of the heat, are defined as relative errors varying as a function of the temperature difference and flow rate.

7.1.3 The maximum permissible errors of subassemblies, positive or negative, are calculated from the temperature difference in the case of the heat calculator and the temperature sensor pair and from the flow rate in the case of the flow sensor.

7.2 *Relative Error*—The relative error, E, is expressed as:

$$E = \frac{X_d - X_c}{X_c} * 100\ \% \quad (1)$$

where:

X_d = indicated value, and
X_c = conventional true value.

7.3 *Values of Maximum Permissible Errors (MPEs)*—The MPEs of a complete instrument are calculated as a function of the temperature difference ratio ($\Delta t_{min}/\Delta t$) and the flow rate ratio (q_p/q). The MPEs of the complete instrument of accuracy Classes 1, 2, and 3 are the arithmetic sums of E_f (in 8.3), E_t (in 9.5), and E_c (in 10.4). The classes of heat meters are defined by the class of the flow sensor.

7.3.1 *Class 1, Class 2, and Class 3:*

$$E = E_f + E_t + E_c \quad (2)$$

where:

E = maximum permissible error,
E_f = flow sensor error,
E_t = temperature sensor error, and
E_c = heat calculator error.

8. Flow Sensor

8.1 *General*—Flow sensors measure the volume or mass of a flowing liquid in a heat exchange circuit. Flow sensors are defined by the following parameters:

8.1.1 Flow sensor operating limits,
8.1.2 Flow sensor accuracy classes,
8.1.3 Operating pressure,
8.1.4 Pressure drop,
8.1.5 Minimum and maximum liquid temperature,
8.1.6 Flow sensor operation outside the stated operating limits,
8.1.7 Process connection type,
8.1.8 Flow sensor installation restrictions,
8.1.9 Materials of construction,
8.1.10 Protection against fraud, and
8.1.11 Flow sensor verification of design.

8.2 *Flow Sensor Operating Limits:*

8.2.1 *Lower Flow Limit*—The lower limit of the flow rate, q_i, is the lowest rate the sensor can operate at without exceeding the maximum permissible error. The manufacturer shall clearly indicate the limit, q_i.

8.2.2 *Upper Flow Limit*—The upper limit of the flow rate, q_s, is the highest flow rate the sensor can operate at for short periods without exceeding the maximum permissible error.

Short periods are defined as less than 1 h/day and as less than 200 h/year. The manufacturer shall clearly indicate the limit, q_s.

8.2.3 *Permanent Flow Rate*—The permanent flow rate, q_p, is the highest rate the sensor can operate at continuously without exceeding the maximum permissible error. The manufacturer shall clearly indicate the limit, q_p.

8.2.4 *Flow Rate Range*—The manufacturer shall clearly indicate the ratio of the permanent flow rate to the lower flow limit, and the ratio shall be at least 10.

8.3 *Flow Sensor Accuracy Classes*—Flow sensors of heat meters and complete instruments belong to one of the following three accuracy classes: Class 1, Class 2, and Class 3.

8.3.1 The class of the complete instrument is determined by the class of the flow sensor.

$$\text{Class1}: E_f = \pm\left(1 + 0.01\frac{q_p}{q}\right), \text{ but not more than } \pm 3.5\ \% \quad (3)$$

$$\text{Class2}: E_f = \pm\left(2 + 0.02\frac{q_p}{q}\right), \text{ but not more than } \pm 5\ \% \quad (4)$$

$$\text{Class3}: E_f = \pm\left(3 + 0.05\frac{q_p}{q}\right), \text{ but not more than } \pm 5\ \% \quad (5)$$

where:

E = flow sensor error,
q_p = maximum permanent flow rate, and
q = actual flow rate.

8.4 *Operating Pressure:*

8.4.1 *Minimum Operating Pressure*—The manufacturer shall state the minimum operating pressure that shall be maintained at the meter when operating at the upper flow limit.

8.4.2 *Maximum Operating Pressure*—The manufacturer shall state the maximum internal pressure that can be applied to the flow sensor when operating at the maximum liquid temperature.

8.5 *Maximum Pressure Loss*—The loss of pressure in the heat-conveying liquid passing through the flow sensor when the flow sensor is operating at the permanent flow rate, q_p, shall not exceed 28 kPa [4 psi].

8.6 *Minimum and Maximum Liquid Operating Temperature*—The manufacturer shall state the minimum and maximum temperatures at which the flow sensor will operate without exceeding the maximum permissible error, E_f.

8.7 *Flow Sensor Operation outside the Stated Operating Limits*—When the flow rate is less than a threshold value declared by the supplier, no registration is allowed.

NOTE 1—The flow rate through a "nominally" closed valve or the movement of liquid in the pipe behind a closed valve caused by thermal expansion and contraction shall not be recorded.

8.7.1 For flow rates greater than q_s, the behavior of the meter, for example, the production of spurious or zero signals, shall be declared by the manufacturer. Flow rates greater than q_s shall not result in a positive error greater than 10 %.

8.8 *Flow Sensor Process Connections*—Complete heat meters and flow sensor subassemblies are provided with threaded or flanged process connections as required by the application. Process connections shall comply with National Pipe Thread (NPT), American National Standards Institute (ANSI), American Water Works Association (AWWA), or other applicable U.S. standards. For instruments with threaded process connections that do not meet this requirement, it will be acceptable to supply heat meters with thread adapters that meet the applicable U.S. standards.

8.9 *Flow Sensor Installation Restrictions*—The manufacturer shall declare any limitations with regard to installation of the flow sensor including straight, unobstructed pipe lengths required upstream and downstream of the meter. Any restrictions relating to its orientation with respect to the vertical shall also be declared.

8.10 *Flow Sensor Materials of Construction*—Flow sensor subassemblies and complete heat meters shall be of durable construction from materials designed to resist wear and corrosion that may be expected to result from prolonged exposure to the heat transfer liquid.

8.10.1 The enclosure for the flow sensor shall protect the interior against the ingress of water and dust. The minimum level of protection shall conform to NEMA 3R or IP54 (heating) or IP65 (cooling) (see IEC 60529 or NEMA 250).

8.11 *Protection against Fraud*—Flow sensors shall be protected in such a way that, after the sensor has been correctly installed, there is no possibility of dismantling or altering or adjusting the sensor without evident damage to the sensor or a security seal(s).

9. Temperature Sensor Pair

9.1 *General*—Temperature sensor pairs measure the temperature of the flowing liquid in the heat exchange circuit. The sensors are installed such that one sensor measures the liquid temperature at supply (inlet) and the other sensor measures temperature at the return (outlet) of the heat exchange circuit. Temperature sensor pairs are defined by the following parameters:

9.1.1 Limits of temperature measurement range,
9.1.2 Temperature sensor accuracy,
9.1.3 Limits of temperature difference,
9.1.4 Temperature sensor pair accuracy,
9.1.5 Direct insertion sensors and sensors used with thermowells,
9.1.6 Minimum insertion depth,
9.1.7 Sensor lengths,
9.1.8 The influence on a temperature sensor pair when installed in thermowells,
9.1.9 Materials of construction,
9.1.10 Protection against fraud,
9.1.11 Process connection type,
9.1.12 Maximum operating pressure,
9.1.13 Sensing element types, and
9.1.14 Restrictions on the use of platinum resistance temperature sensors.

9.2 *Limits of Temperature Measurement Range:*

9.2.1 *Lower Temperature Limit*—The lower temperature limit of the temperature measurement range, t_{min}, is the lowest temperature of the heat-conveying liquid at which the heat meter will function without exceeding the maximum permissible errors. This temperature limit shall be clearly stated by the manufacturer.

9.2.2 *Upper Temperature Limit*—The upper temperature limit of the temperature measurement range, t_{max}, is the highest temperature of the heat-conveying liquid at which the heat meter will function without exceeding the maximum permissible errors. The manufacturer shall clearly indicate the upper temperature limit, t_{max}.

9.3 *Temperature Sensor Absolute Accuracy*—The relationship between the output of each individual temperature sensor of a pair and the conventional true value of temperature shall not be greater than 2 K [3.6°F].

9.4 *Limits of Temperature Difference*—The temperature difference, Δt, is the absolute value of the difference between the temperatures of the heat-conveying liquid at the supply and return of the heat-exchange circuit.

9.4.1 *Lower Limit of Temperature Difference*—The lower limit of the temperature difference, Δt_{min}, is the lowest temperature difference at which the heat meter shall clearly function without the maximum permissible errors being exceeded. The manufacturer shall indicate the lower limit of the temperature difference, Δt_{min}.

9.4.2 *Upper Limit of Temperature Difference*—The upper limit of the temperature difference, Δt_{max}, is the highest temperature difference at which the heat meter shall function without the maximum permissible errors being exceeded. The manufacturer shall clearly indicate the upper limit of the temperature difference, Δt_{max}.

9.4.3 *Temperature Difference Range*—The ratio of the upper and lower limits of the temperature difference shall clearly not be less than ten, with the exception of heat meters intended for cooling applications. The manufacturer shall indicate the lower limit of the temperature difference as 1, 2, or 3 K [1.8, 3.6, or 5.4°F].

9.5 *Temperature Sensor Pair Accuracy*—Temperature sensor pair accuracy is defined as:

$$E_t = \pm\left(0.5 + 3\ \frac{\Delta t_{\min}}{\Delta t}\right) \quad (6)$$

where:

E_t = temperature sensor pair accuracy,
Δt_{min} = lower limit temperature difference, and
Δt = temperature difference measured across the heat exchange circuit.

9.6 *Direct Insertion Sensors and Thermowells*—Direct insertion temperature sensors are designed to be immersed directly into the heat-conveying liquid. They are provided with a process connection suitable for installation into the heat exchange piping system. Direct insertion sensors should be used for heat exchange pipes with a nominal diameter of less than 3 cm [1¼ in.] (DN32) whenever possible as they provide the most accurate temperature measurement.

9.6.1 Thermowells are tubes closed at one end that are inserted into the heat exchange circuit pipes. The temperature sensors are inserted into the open end of the tubes. The heat-conveying liquid flowing in the pipes transfers heat to the thermowell and the thermowell transfers heat to the temperature sensor.

9.6.2 The manufacturer shall declare if the temperature sensor pair provided is designed for use with thermowells.

9.6.3 Temperature sensor pair installation methods shall be symmetrical. The use of one direct insertion sensor and one thermowell is not permitted.

9.6.4 The use of clamp-on temperature sensors is not permitted.

9.6.5 *Temperature Sensor Pair Immersion Depths*—The minimum allowable insertion depth for temperature sensors shall be stated by the manufacturer based on the nominal pipe diameter and the length of the insertion temperature sensors. The preferred immersion depth is to the center of the pipe. This may not be practical in larger pipes. In all cases, the minimum insertion depth shall be sufficient to ensure that further increases in the insertion depth will not produce a change in temperature measurement greater than 0.1 K [0.18°F]. (Refer to Annex A2.)

9.6.6 *Temperature Sensor Lengths*—The manufacturer shall provide the appropriate length temperature sensors according to 9.6.5 based on the nominal pipe diameter in use in the heat exchange piping system where the sensors are installed.

9.6.6.1 *Temperature sensor dimensions*—Sensor dimensions are not defined by this specification.

9.6.6.2 *Thermowell dimensions*—The temperature sensor manufacturer shall specify the length and diameter of thermowell(s) to match the temperature sensor(s) if used.

9.6.6.3 *Influence on a temperature sensor pair when installed in thermowells*—The difference in the temperature measurement with and without thermowells shall not exceed one third of the maximum permissible error.

9.7 *Methods and Materials of Construction*—Direct insertion sensors and thermowells shall be constructed from materials designed to resist wear and corrosion that may be expected to result from prolonged exposure to the heat-conveying liquid. The materials shall be suitable for use at the heat-conveying liquid's operating temperatures and pressures. The sensors and thermowells shall be designed to withstand the forces applied from the flowing liquid, and they shall have the requisite thermal conductivity for the application.

9.8 *Protection against Fraud*—Temperature sensors shall be protected in such a way that, after the sensor has been correctly installed, there is no possibility of dismantling, altering, or adjusting the sensor without evident damage to the sensor or a security seal(s).

9.9 *Process Connection Type*—The temperature sensor process connection type is not defined by this specification. NPT, ANSI, or AWWA process connections are preferred. For instruments with threaded process connections that do not meet this requirement, it will be acceptable to supply heat meters with thread adapters that meet the applicable U.S. standards.

9.10 *Maximum Operating Pressure*—The manufacturer shall state the maximum operating pressure for the temperature sensor or thermowell when operating at maximum fluid temperature.

9.11 *Sensing Element Types*—The type of temperature sensing element is not defined by this specification.

9.11.1 *Restrictions on the Use of Resistance Temperature Sensors*—Resistance temperature sensors may be used in two-, three-, or four-wire resistance bridge circuits.

9.11.2 *Resistance Temperature Sensor Signal Leads*—Stranded or solid wire leads may be used. Stranded wire lead ends shall be trimmed and provided with lead end sleeves. Signal wire lead ends coated with solder to prevent fraying are not permitted.

9.11.3 *Two-Wire Resistance Temperature Sensors*—The length and cross-sectional area of signal wires of paired sensors of separable subassemblies shall be equal. The maximum lead length shall be as shown in Table 3. For sensors with a higher nominal resistance, the lead lengths can be proportionally longer.

10. Heat Calculator

10.1 *General*—Heat calculators receive signals from the flow sensor and the temperature sensors and calculate and indicate the quantity of heat exchanged. Heat calculators are defined by the following parameters:

10.1.1 Limits of thermal power,
10.1.2 Heat calculator accuracy classes,
10.1.3 Maximum permissible error,
10.1.4 Types of temperature sensors,
10.1.5 Limits of ambient temperature,
10.1.6 Heat-conveying liquid type,
10.1.7 Heat transmission formula,
10.1.8 Supply voltage,
10.1.9 Environmental class,
10.1.10 Protection against fraud,
10.1.11 Display, and
10.1.12 Materials of construction.

10.2 *Limits of Thermal Power*—The upper limit of thermal power, P_s, is the highest power at which the heat meter shall function without the maximum permissible errors being exceeded. The manufacturer shall clearly indicate the upper limit of thermal power, P_s.

10.3 *Heat Calculator Accuracy Classes*—Heat calculators and heat meters are defined by the accuracy class of the flow sensor and shall be Class 1, Class 2, or Class 3.

10.4 *Heat Calculator Maximum Permissible Error*—The heat calculator maximum permissible error is defined as:

$$E_c = \pm\left(0.5 + \frac{\Delta t_{\min}}{\Delta t}\right) \quad (7)$$

where:

E_c = maximum permissible heat calculator error,
Δt_{min} = lower limit temperature difference, and
Δt = temperature difference.

TABLE 3 Maximum Lead Cross Section and Length Requirements

Lead Cross Section in mm^2 [cmil]	Minimally Acceptable AWG Wire Sizes	Maximum Length for 100 Ω Sensors in metres [feet]
0.22 [434.2]	22	2.5 [8.2]
0.5 [986.7]	20	5.0 [16.4]
0.75 [1480.1]	18	7.5 [24.6]
1.50 [2960.3]	16	15.0 [49.2]

10.5 *Types of Temperature Sensors*—The manufacturer shall clearly indicate the type of temperature-sensing element that shall be used with the heat calculator.

10.6 *Limits of Ambient Temperature*—The manufacturer shall clearly indicate the allowable ambient temperature range that the heat calculator can operate in without exceeding the maximum permissible error.

10.7 *Heat-Conveying Liquid Type*—For heat calculators intended for use with heat-conveying liquids other than water, the manufacturer shall clearly state the heat coefficient(s) used as a function of temperature and pressure.

10.8 *Heat Transmission Formula*—Heat transmitted to or from a body of liquid can be determined from knowledge of its mass, specific heat capacity, and change in temperature.

10.8.1 In a heat meter, the rate of change of enthalpy between the supply and return through a heat exchanger is integrated with respect to time. The equation for its operation is:

$$Q = \int_{t_0}^{t_1} q_m \Delta h \, dt \quad (8)$$

where:

Q = quantity of heat given up,
q_m = mass flow rate of the heat-conveying liquid passing through the heat meter,
Δh = difference between the specific enthalpies of the heat-conveying liquid at the supply and return temperatures of the heat-exchange circuit, and
t = time.

10.8.2 If the instrument determines the volume instead of the mass, its equation becomes:

$$Q = \int_{V_0}^{V_1} k \Delta t \, dV \quad (9)$$

where:

Q = quantity of heat given up,
V = volume of liquid passed
k = function of the properties of the heat-conveying liquid at the relevant temperatures and pressure, called the heat coefficient, and
Δt = temperature difference between the flow and return of the heat exchange circuit.

10.8.3 Where water is used as the system heat-conveying liquid, the conventional true value of the heat coefficient, k, shall be obtained from the formulas from Annex A1, where the pressure shall be set to 1.6 MPa [232.1 psi].

10.8.4 For heat calculators intended for use with heat-conveying liquids other than water, the manufacturer shall clearly declare the heat coefficient used as a function of temperature and pressure.

10.9 *Supply Voltage*—Heat calculators shall be powered from batteries, low-voltage ac or dc supplies, or from ac mains.

10.9.1 *Battery Power*—If a heat calculator has interchangeable batteries, they shall be replaceable without damaging verification seals. The battery(s) lifetime shall be clearly stated by the manufacturer.

10.9.2 *Remote Low-Voltage Power (<50 V)*—Heat calculators intended for use with remote low-voltage ac/dc power shall operate at a nominal voltage and shall tolerate the following variations:

10.9.2.1 Voltage variations of ±10 % of the nominal stated value, or

10.9.2.2 ac frequency variations of ±2 % from the nominal stated frequency.

10.9.2.3 The manufacturer shall clearly indicate the maximum input current.

10.9.3 *ac Mains Power*—Heat calculators intended for use with ac mains power shall operate at a nominal voltage of 120 V and shall tolerate the following variations:

10.9.3.1 Voltage variations of -15 to +10 % of the nominal stated value or

10.9.3.2 ac frequency variations of ±2 Hz from the nominal stated frequency.

10.9.3.3 The manufacturer shall clearly indicate the maximum input current.

10.10 *Environmental Class*—Heat calculators and complete heat meters shall conform to one or more of the following environmental classifications according to the application.

10.10.1 *Environmental Class A (Domestic/Light Commercial Use, Indoor Installations):*

10.10.1.1 *Ambient temperature*—5 to 55°C [41 to 131°F].

10.10.1.2 Low-level humidity conditions as defined in OIML D11, Section 8.2.2, at a test level index for Class H1.

10.10.1.3 Normal electrical and electromagnetic conditions as defined in OIML D11, Section 8.4, at a test level for Class E1.

10.10.1.4 Low-level mechanical conditions as defined in OIML D11, Section 8.3, at a test level index for Class M2.

10.10.1.5 NEMA 12 or IP52 or better enclosure (off the pipe) (see IEC 60529 or NEMA 250).

10.10.1.6 NEMA 3R or IP54 (heating) or IP65 (cooling) (on the pipe) or better (see IEC 60529 or NEMA 250).

10.10.2 *Environmental Class B (Domestic/Light Commercial Use, Outdoor Installations):*

10.10.2.1 *Ambient temperature*— -25 to 55°C [-13 to 131°F].

10.10.2.2 Normal level humidity conditions as defined in OIML D11, Section 8.2.2, at a test level index for Class H2.

10.10.2.3 Normal electrical and electromagnetic conditions as defined in OIML D11, Section 8.4, at a test level for Class E1.

10.10.2.4 Low-level mechanical conditions as defined in OIML D11, Section 8.3, at a test level index for Class M2.

10.10.2.5 NEMA 3R or IP54 (heating) or IP65 (cooling) or better enclosure (see IEC 60529 or NEMA 250).

10.10.3 *Environmental Class C (Industrial Installations):*

10.10.3.1 *Ambient temperature*— -25 to 55°C [-13 to 131°F].

10.10.3.2 Normal level humidity conditions as defined in OIML D11, Section 8.2.2, at a test level index for Class H2.

10.10.3.3 High electrical and electromagnetic conditions as defined in OIML D11, Section 8.4, at a test level for Class E2.

10.10.3.4 Low-level mechanical conditions as defined in OIML D11, Section 8.3, at a test level index for Class M2.

10.10.3.5 NEMA 3R or IP54 (heating) or IP65 (cooling) or better enclosure (see IEC 60529 or NEMA 250).

10.10.4 *Environmental Class D (Domestic/Light Commercial Use, Outdoor Installations):*

10.10.4.1 *Ambient temperature*— -40 to 55°C [-40 to 131°F].

10.10.4.2 Normal electrical and electromagnetic conditions.

10.10.4.3 Low-level mechanical conditions.

10.10.4.4 NEMA 3R or IP54 (heating) or IP65 (cooling) or better enclosure (see IEC 60529 or NEMA 250).

10.11 *Protection against Fraud*—Heat calculators shall be protected in such a way that, after the device has been correctly installed, there is no possibility of dismantling, altering, or adjusting it without evident damage to the sensor or a security seal(s).

10.12 *Display (Indicating Device)*—The heat calculator shall include a device that indicates the quantity of heat. The display shall include a numerical or semi-numerical scale and shall provide an easily read, reliable, and unambiguous indication. The real or apparent character height shall be at least 4 mm [0.16 in.]. The quantity of heat shall be indicated in Btus, watt-hours, or decimal multiples of those units. The figures indicating decimal fractions of a unit shall be separated from the others by the decimal divider. The name or symbol of the unit in which the quantity of heat is given shall be indicated adjacent to the display.

10.12.1 *Retention of Data*—Heat calculators shall be so designed that, in the event of an external power supply failure (mains or external ac or dc), the meter indication of energy at the time of failure is not lost and remains accessible for a minimum of one year.

NOTE 2—Compliance with 10.12.1 will not necessarily ensure that the heat meter will continue to register the heat consumed in the event of a power supply failure.

10.12.2 *Scaling and Resolution*—The display indicating the quantity of heat shall be able to register, without overflow, a quantity of heat at least equal to the transfer of energy that corresponds to a continuous operation for 3000 h at the upper limit of the thermal power, P_s, of the heat meter.

10.12.2.1 The quantity of heat, measured by a heat meter operating at the upper limit of the thermal power for 1 h shall correspond to at least one digit of lowest significance of the display.

10.13 *Materials of Construction*—The heat calculator shall be constructed from materials designed to resist wear and corrosion that may be expected to result from exposure to the heat-conveying liquid. The materials shall also be suitable for the environmental class of the instrument. The heat calculator enclosure shall meet NEMA 3R or IP54 (heating) or IP65 (cooling) requirements when installed on the piping system (see IEC 60529 or NEMA 250).

11. Data Exchange and Communications Protocols

11.1 *General*—Heat meters may use either none or a number of interfaces to communicate with remote readout devices.

11.1.1 *Hardware Interface and Communications Protocols*—The hardware interface and communications protocols should meet internationally recognized standards for interoperability. Recognized standards organizations include the Institute of Electrical and Electronics Engineers (IEEE), the International Organization for Standardization (ISO), American National Standards Institute, (ANSI), the European Telecommunications Standards Institute (ETSI), the European Committee for Standardization (CEN), and the International Electrotechnical Commission (IEC).

11.1.2 *Data Element Structure and Definitions*—Heat meters that use one or more communications interfaces shall at least, at a minimum, transmit values for heat and volume totals. Other recommended values would include volume flow, temperature(s), and heat rate.

12. Heat Meter Testing

12.1 Heat meters that comply with the general requirements of this specification and are submitted for type approval and undergo initial verification shall comply with the specified tests in this section. Initial verification is intended to ensure that instruments that are put into service will have specified metrological characteristics within the limits of the maximum permissible errors and will function properly.

12.2 *Type Approval Tests*—The type approval procedure will ascertain that the design and construction of the instrument type conforms to the metrological requirements of this specification. In addition to verifying documentation provided by the manufacturer (see 14.18) and comparison of the type with the metrological requirements of this specification, the tests in Section 14 shall be performed. When testing the heat meter as a combined instrument, the flow sensor, the temperature sensor pair, the heat calculator, or a combination of these each will be tested separately.

12.3 *Initial Verification Tests:*

12.3.1 Initial verification of a measuring instrument consists of a series of tests and visual examinations carried out during the manufacturing process to determine whether an instrument manufactured to replicate a given type conforms to that type and regulations and that its metrological characteristics lie within the limits of the maximum permissible errors. Initial verification is divided into metrological, technical, and administrative phases. If the instrument passes all required tests and examinations in Section 15, it is given legal character by its acceptance as evidenced by stamping, or issue of a certificate of verification, or both. Unless otherwise stated in the type approval certificate, the verification shall be carried out in accordance with this specification, the provisions of which also apply to the subsequent verification of heat meters.

12.3.2 *Combined Instrument*—When verifying a heat meter as a combined instrument, the flow sensor, the temperature sensor pair, the heat calculator or a combination of these shall each be verified separately.

12.4 *Requirements*—Under rated operating conditions, the errors of heat meters or their subassemblies shall not exceed the MPE specified in Section 7. When heat meters or their subassemblies are exposed to disturbances, significant faults shall not occur.

13. Specification of Operating Conditions During Testing

13.1 *Rated Operating Conditions*—The rated operating conditions are those given in Table 4.

13.2 *Reference Conditions:*

13.2.1 *Range of Ambient Temperature*—15 to 35°C [59 to 95°F].

13.2.2 *Range of Relative Humidity*—25 to 75 %.

13.2.3 *Range of Ambient Air Pressure*—86 to 106 kPa [12 to 15 psi].

13.2.4 The actual temperature and relative humidity within the specified range may not vary by more than ±2.5 K [±4.5°F] and ±5 %, respectively, during the period of one measurement.

13.2.5 The reference conditions for a subassembly will be the conditions under which it would operate if it was a part of a combined heat meter.

13.3 *Reference Values for the Measurand (RVM):*

13.3.1 *Reference Values for RVM for $q_p \leq 3.5$ m^3/h [15.4 gal/min]:*

13.3.1.1 *Range of temperature difference:*

$$\Delta t \pm 40\ K \text{ if } \Delta t \geq 40\ K \text{ or } \Delta t_{max} + 0 \text{ or } -2\ K \text{ if } \Delta t_{max} < 40\ K \quad (10)$$

$$[\Delta t \pm 72°F \text{ if } \Delta t \geq 72°F \text{ or } \Delta t_{max} + 0 \text{ or } -2.4°F \text{ if } \Delta t_{max} < 72°F] \quad (11)$$

13.3.1.2 *Range of flow rate*—0.7 to 0.75 q_p.

TABLE 4 Rated Operating Conditions

	Environmental Class			
	A	B	C	D
Ambient temperature °C	+5 to +55 [41 to 131°F]	–25 to +55 [-13 to 131°F]	+5 to +55 [41 to 131°F]	-40 to +55 [-40 to 131°F]
Relative humidity, %	<93			
Mains supply voltage, V	v_{nom} – 15% to v_{nom} + 10%			
Mains frequency, Hz	f_{nom} ± 2%			
External low voltage (<50 V)				
Ac, V	v_{nom} ± 10%			
Dc, V	v_{nom} ± 10%			
Battery voltage	The voltage of a battery in service under normal conditions.			

13.3.1.3 *Return temperature*—50 ± 5°C [122 ± 9°F] or the upper limit of the return temperature, if the limit is less than 50°C [122°F].

(1) The conditions mentioned in 13.3.1.3 are reference values for a complete heat meter. Reference values for subassemblies are the relevant parts of the above-mentioned condition.

13.3.2 *Reference Values for RVM for q_p > 3.5 m^3/h [15.4 gal/min]:*

13.3.2.1 Flow rate simulation of the flow sensor electronics is allowed, but testing with water is always preferred and is carried out in accordance with 13.3.1.

13.3.2.2 If flow rate simulation is used, the following RVM values apply:

(1) Range of temperature difference:

$$\Delta t \pm 40\ K \text{ if } \Delta t \geq 40\ K \text{ or } \Delta t_{max} + 0 \text{ or } -2K \text{ if } \Delta t_{max} < 40\ K \quad (12)$$

$$[\Delta t \pm 72°F \text{ if } \Delta t \geq 72°F \text{ or } \Delta t_{max} + 0 \text{ or } -2.4°F \text{ if } \Delta t_{max} < 72°F] \quad (13)$$

(2) Water temperature in flow sensor—50 ± 5°C [122 ± 9°F] or ambient.

(3) Range of flow rate—0.7 to 0.75 q_p.

13.3.2.3 The power supply to and the signal wires from the flow sensor shall be connected.

13.3.2.4 The flow sensor including flow sensor electronics will be operated at zero flow rate (without low flow cutoff device).

14. Type Approval Tests and Measurements

14.1 *General*—Unless otherwise stated in this specification, the test requirements apply irrespective of the heat meter's environmental class (see 10.10).

14.1.1 *Measurement*—All measurements will be carried out under the installation conditions (for example, straight sections of piping upstream and downstream of the meter) stipulated by the supplier for their type of meter. For all tests, the heat-conveying liquid should be water unless otherwise specified.

14.1.1.1 If a temperature sensor can be installed in the flow sensor, this shall be done during the performance tests of the flow sensor. When a filter or strainer is an integral part of the flow sensor, it shall be included in all the tests.

14.1.1.2 If the error determined lies outside the MPE, the test shall be repeated twice unless otherwise stated.

14.1.1.3 The test is then declared satisfactory if both:

(1) The arithmetic mean of the result of the three tests are within or at the MPE, and

(2) At least two of the test results are within or at the MPE.

14.1.2 *Required Tests*—Depending on the flow sensor size, the tests and measurements to be carried out are described in 14.1.2.1 – 14.1.2.4.

14.1.2.1 The tests in 14.4, 14.16, and 14.7 can be carried out on a limited number of sizes according to an evaluation by the testing laboratory. This evaluation shall be included in the type testing report.

14.1.2.2 The test in 14.8 shall be carried out only for those sizes of a type for which the highest wear is expected.

14.1.2.3 For sizes DN > 200, the tests in 14.17 shall be carried out at t_{min}.

14.1.2.4 For each meter model, the following tests shall be carried out on one size only: 14.5 – 14.7 and 14.9 – 14.15.

14.2 *Test Program*—Samples of a heat meter, or its subassemblies, submitted for type approval will be subject to tests to verify that underrated operating conditions, the errors of heat meters, or their subassemblies shall not exceed the MPE as defined in Section 7. Unless otherwise stated, the tests shall be carried out at reference conditions and the samples shall be exposed to the influence factors or disturbances specified for the respective tests, as stated in Table 5.

14.2.1 The test sequence and the number of items used will be either as described in Table 5 or as agreed between the supplier and the testing laboratory (assuming three samples numbered by the testing laboratory).

14.2.2 Only one influence quantity will be applied at a time.

14.2.3 If the equipment under test (complete, combined, or subassemblies) has test outputs for quantity of water, temperature difference, or energy, or combination thereof, these outputs may be used to test such parameters.

14.3 *Expand Uncertainty of Test Equipment (for Type Approval and Initial Verification Tests)*—Standards, instruments, and methods used in type approval tests or initial verification tests shall suit the purpose, be traceable to U.S. standards or international standards that are traceable to national standards, and be part of a reliable calibration program.

14.3.1 The uncertainties associated with these standards, methods, and measuring instruments shall always be known. They shall either:

14.3.1.1 Not exceed one third of the maximum permissible errors of the heat meter or the subassemblies (recommended provision), or

14.3.1.2 When Δ*t* ≤ 3 K [Δ*t* ≤ 5.4°F] shall be subtracted from the maximum permissible errors of the heat meter or the subassemblies to obtain a new MPE.

14.4 *Performance Test*—The initial intrinsic error shall be determined at least at the conditions stated in 14.4.1 – 14.4.4.

14.4.1 *Flow Sensor*—All performance tests shall be carried out three times at the flow rates according to 13.2.1.

14.4.1.1 *General*—Flow rates: q_1 + 0 % – 10 %, q_2 ± 5 %, q_3 ± 5 %, q_4 ± 5 %, and q_5 + 10 % – 0 % where $q_1 = q_s$ and $q_5 = q_i$ and $q_1/q_2 = q_2/q_3 = q_3/q_4 = q_4/q_5 = K$.

$$K = \sqrt[4]{\frac{q_s}{q_i}} \quad (14)$$

where:

K = just a ratio used to derive flow rates in the range from q_i to q_s,
q_s = maximum permissible flow rate, and
q_I = lowest allowable flow rate.

14.4.1.2 The point nearest to 0.7-0.75 q_p will be changed to be within 0.7-0.75 q_p to obtain one point within RVM conditions.

14.4.1.3 *Water temperatures:*

(1) t_{min} to t_{min} + 5°C, but not less than 10°C [t_{min} to t_{min} + 9°F, but not less than 50°F];