Discussion and Comparison of Test Methods ASTM C236 and ASTM C1363

Executive Summary

ASTM C1363 was first published in 1997 as a replacement for two earlier hot-box test methods, C236 and C976. C1363 provides a wealth of technical discussion especially for the design of a test apparatus and determination of extraneous heat flow. The basic heat-transfer principles remain unchanged as the testing community migrated from the earlier test methods to C1363.

A comparison of C236 and C1363 shows that the two test methods are the same in most respects. C1363 requires more attention to "flanking loss", heat that travel though a test specimen but not across the test specimen. Flanking lose represents a small (estimate 0-3%) correction to the determination of heat flow across a test specimen. The second difference is determination of the environment temperatures on the two sides of a test specimen rather than the air temperature. The environmental temperature includes the impact of the surroundings on the heat transfer process. A shift from air temperatures to environmental temperatures when it can be accomplished affect the measured U value but not the thermal resistance of the test specimen (the surface-to-surface R-value). Since air-flow conditions in the hot-box chambers are not like actual environmental conditions, practical heat-flow calculations use surface-film resistances characteristic of actual environments to calculate U-value rather than the U-value reports from a hot box. The surface-to-surface thermal resistance results are the useful result obtained from a hot-box measurement.

The anticipated improvement in reproducibility for the migration from C236 to C1363 did not occur. Recently published precision and bias data (C1363-19) shows the reproducibility for C236 and C1363 to be approximately the same.

Documents

ASTM C236-89 (1993), "Standard Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box", 1998 Annual Book of ASTM Standards, Volume 04.06, pages 62-72.

ASTM C1363-11, "Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus", 2017 Annual Book of ASTM Standards, Volume 04.06, pages 784-827. C1363-19 will appear in the next edition of 04.06. C1363-19 is available but not in a printed volume.

Introduction

The following is a discussion and comparison of ASTM test methods C236 and C1363. The elements of heat transfer theory are the same for both tests. The thermal properties that result are calculated from steady-state heat flux and temperature difference across a test specimen. The temperature difference can be between the surfaces of the test specimen or between the air on the two sides of the test specimen. The area perpendicular to the direction of heat flow is also used in the calculation of thermal properties. The area is normally determined from length and width measurements. The following two figures show the extent to which the test configurations are the same. Figure 1 is from C236 while Figure 2 is from C1363-19. The diagrams in the figures are nearly identical with minor changes in nomenclature. Metering box in C236 becomes "metering chamber" in C1363. Test panel in C236 becomes "specimen" in C1363. Cold box in C236 becomes climatic chamber in C1363.

ASTM C1363 includes both the "guarded hot box" and the "calibrated" versions of a hot-box test method in one standard. The primary difference between the two versions is that the guarded version controls the temperature difference across the metering box walls other than that facing the specimen to zero or a small negative value so that no heat will be lost across the metering box walls to the guard area or the amount of heat transfer is readily calculated. If this is accomplished, then heat into the metering chamber minus heat loss will equal heat across the test specimen. There could be an additional adjustment due to flanking losses (heat transfer from the metering chamber to the guard chamber through the test specimen but not across the specimen).

Figure 1 is a diagram of a guarded hot box apparatus copied from C236. The key elements are a metering box (hot region), cold box (climate chamber), and a guard box that encloses a temperature controlled region around the metering box. The test specimen (or panel) separates the hot region from the cold region. The heat flux across the test panel and the temperature difference between the two sides are used to calculate the thermal resistance. Figure 2 is the C1363 representation of a guarded hot box. The two test methods describe the same apparatus.

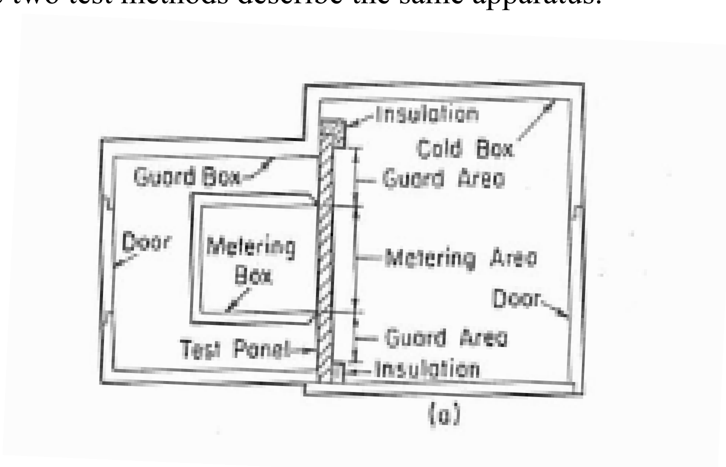

Figure 1. Diagram of Guarded Hot Box from ASTM C236

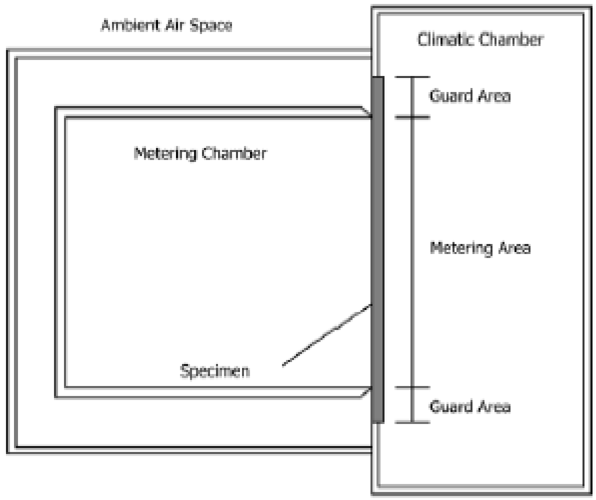

Figure 2. Diagram of Guarded Hot Box from C1363

Results Obtained from C236 and C1363

The same thermal properties are determined in the two hot box test methods. The equations used to calculate thermal properties using the two test methods are the same as illustrated by the following side-by-side comparison. The only difference in the list of equations is the introduction of environmental temperatures $t_{env,h}$ and $t_{env\ cold}$ in place of air temperatures measured in a plane 75 mm or more from the test specimen surfaces.

C236	C1363
t_h and t_c are air temperatures at least 75 mm from specimen surface	$t_{env,h}$ and $t_{env,c}$ are calculated values similar to the mean radiant temperature
$U=Q/A(t_h - t_c)$	$U=Q/A\cdot(t_{env,h} - t_{env,c})$
$C=Q/A(t_1 - t_2)$	$C=Q/A\cdot(t_1 - t_2)$
$R = (t_1 - t_2)A/Q$	$R= A\cdot(t_1 - t_2)/Q$

$R_U = (t_h - t_c)A/Q$ $R_U = A\cdot(t_{env,h} - t_{env,c})/Q$

$r_h = (t_h - t_1)A/Q$ $R_{h,env} = A\cdot(t_{env,h} - t_1)/Q$

$r_c = (t_2 - t_c)A/Q$ $R_{c,env} = A\cdot(t_2 - t_{env,c})/Q$

$h_h = Q/A(t_h - t_1)$ $h_{h,env} = Q/A\cdot(t_{env,h} - t_1)$

$h_c = Q/A(t_2 - t_c)$ $h_{c,env} = Q/A\cdot(t_2 - t_{env,c})$

$\lambda = QL/A(t_1 - t_2)$ $\lambda = Q\cdot L/A(t_1 - t_2)$

In both cases, the equations are the same, and they involve Q, A, and temperatures. The thermal properties in the list depend on a determination of heat flow through the test specimen, Q, the area of the test specimen, A, and a pair of temperatures of which there are four; temperatures of the hot and cold surfaces and temperatures of the hot and cold air regions in the hot box. In cases where the hot-box operator is able to calculate the environmental temperatures there will be a small difference in properties other than R, C, and λ from the two test methods. In practice, if the hot box apparatus does not have baffles (plane parallel to the surface of the test specimen), then the laboratory will typically report results obtained using the measured air temperatures rather than the environmental temperatures. The result for R is of primary importance since a practitioner adds surface resistance that is characteristic of actual operating conditions to obtain U for a real structure.

Temperature Measurements

Test Specimen Surfaces

The average temperatures of the hot and cold test specimen surfaces or the average temperatures of the air spaces adjacent to the test specimen appear in all of the equations for the thermal property evaluations. Test specimen surfaces are relatively large and, as a result, require multiple temperature sensors, usually thermocouples, to establish an average value. In the case of non-homogeneous test specimens, there is often a need to determine average temperatures for specific areas of the surface. The need in some cases to determine average temperatures for specific regions is recognized in both C236 and C1363 and required, for example in ASTM C1224, the product specification for reflective insulations.

In general, the instructions about sensor placement in both standards direct that sensors on the hot and cold sides be installed to be “in line” i.e. directly opposite. C1363 requires that sensors be selected and applied in such a manner that the indicated temperature is within +/- 0.2 K of the temperature that would be present in the sensor was not present. Since verification is an impractical requirement for a routine measurement, the standard provides a set of conditions that are deemed to satisfy this condition. The temperature measurement requirements for the two standards are compared below.

C236	C1363
Maximum diameter for thermocouple wire: 0.25 mm	same
special limit of error wire required	same
sensor shielded i.e. match the emittance of the surrounding surface	same
locations of sensors depend on the type of test specimen, uniform versus non-uniform specimens	same
requirements for air space temperature measurement	same
number of sensors for a surface (N). This will be repeated for each surface and air space	
N no less than [$A/(0.07+0.08\cdot\sqrt{A}) +1$] where A is area in m^2. (rounding up)	N at least 2 per m^2 of area and N at least 9

A	Minimum N		A	Minimum N
4	18		4	9
6	23		6	12
8	27		8	16

Actual number of sensors to be with 10% of N.

Not addressed	Thermocouple junctions no larger than two times the wire diameter.
Not addressed	Sensors electrically insulated

Both standards have text containing discussions about temperature measurement including factors to consider. The discussions in the two standards are equivalent.

C236 requires more temperature sensors that C1363 (perhaps significant). No obvious justification is provided in C1363 for the difference. Each metallic lead (a TC sensor has two) is a highly conductive path with very small area that can transport heat and change the temperature at the point of contact. This is implied in C1363 in the discussion about not changing the surface temperature by attaching thermocouples. C236 appears to have an advantage in the precision of temperature measurement since the variance of the mean varies with $1/\sqrt{N}$. The requirements in both standards are for the minimum number of sensors. Hot-box operators exercise judgement on this issue and often exceed the minimum requirements

C1363 requires a limit on the thermocouple bead size. No quantitative impact, however, is provided. Maintenance and attachment of thermocouples to a test specimen is a significant factor in obtaining valid temperature measurements. Good practice on the part of the hot-box operator is assumed by the test methods.

It is obvious that judgement (or experience) is required for successful testing with a hot box facility. This is the case with most ASTM test methods. This is stated in the scope statement of both test methods. C236 section 1.3.2, "Persons applying this test method shall be trained in the methods of temperature measurement, shall possess a knowledge of the theory of heat flow, and shall understand the general requirements of testing practice". C1363 section 1.12 "If no applicable standard exists, sound engineering judgement that reflects accepted heat transfer principles must be used and documented".

The conclusion here is that both test methods require knowledge of factors to consider in making surface temperature measurements.

Air Temperature

When overall R (air-to-air thermal resistance), U, or surface film resistances are to be calculated, then the average temperature of the air space adjacent to the hot and cold surfaces or environmental temperatures are required. The requirement in both test methods is that number and positioning of air-temperature sensors is the same as used on the adjacent surface. Baffle temperatures are required in C1363 for the calculation of environmental temperatures as mentioned earlier. Baffle temperature is used in the calculation of radiant heat transfer rates. If baffles are not present, then air temperatures are often used.

C236	C1363
Thermocouple wire no greater than 0.51 mm in diameter	Sensor requirements same as for surface
Thermocouples shielded with bright metallic material	Shielded to minimize thermal radiation exchange
Distance from surface at least 75 mm	75 mm minimum unless the air velocity is high. Then the distance should be increased.
Thermocouple precision +/- 0.05 K (+/-0.09 °F)	readable to +/- 0.05 K

The requirements for surface and air or environmental temperature measurements are basically the same for the two standards. C236 requires more thermocouples than C1363. But this is overshadowed by hot-box operator skill and experience in instrumenting a test specimen. C1363 has more discussion about factors to be considered than C236. This is especially valuable for design work. Routine test projects and standardization rely on specific requirements.

Heat Flux (Q/A)

The ratio Q/A, heat flux, appears in every thermal property equation listed at the start of this discussion. (A/Q = 1/(Q/A)). The precision of a hot box test depends on the precision of the heat-flux measurement. The heat flux across the test specimen is obtained from the electrical input to the metering box corrected for extraneous heat loses. The heat input to the metering chamber is the sum of the electrical heater input, heat generated by fans, and heat generated by instruments (if any). The total power input is reduced by heat loss across the walls of the metering box, flanking loss around the test specimen, and possible air leaks in the hot box assembly. The metering box wall correction receive the most attention. C236 is a "guarded" hot box. This means that the metering box is surrounded by a temperature controlled air space. The thermal resistance of the metering box walls must be known as a function of average temperature so that the metering box walls can serve as a heat flux transducer. This means that a temperature difference measurement can be used to calculate heat flux which in turn can be used to calculate a heat flow or in this case an extraneous heat loss. Extraneous heat loses are subtracted from the total input to the metering box to obtain the heat flow and heat flux across the test specimen.

The specification of power input measurement is the same for the two test methods: +/-0.5 %.

The determination for determination of metering wall heat transfer is the same for the two standards.

Differences in the control strategy for the guard area is not covered in the standard. The implication is that the temperature difference across the metering box wall is controlled to zero. This means that the direction of heat flow will likely change as controlled temperatures inside and outside the metering box change. This would require a time average value be determined, a complex operation. If the guard region control space is offset to a temperature less than the metering box temperature, then the heat flow will be consistently from inside to outside. Steady-state temperatures can then be used to determine the heat-flow correction for the metering box walls. The size of the correction depends on the magnitude of the off-set, difference in temperatures, the area of the metering box walls, and the thermal resistance of the walls.

Both test methods require five differential thermocouples per square meter of test specimen area. This number was not determined by analysis, rather it was determined by survey. C236 adds a requirement that there must be at least one differential thermocouple per side (there are five sides). The differential thermocouples are connected in series to form a thermopile. This is required in both test methods. The result is a single electrical signal that provides a single temperature difference across the walls. The requirements and technical discussions in the two standards are the same. The success of this measurement (precision) depends on uniform temperature in the guard area and equality of the thermal resistance for the five sides of the metering box. This fuzziness in the test methods likely is a major factor in the relatively large differences observed between laboratories during round-robins. Some of this uncertainty is removed by the requirement for a verification/calibration step. As far as specific requirements, the two test methods have two minor differences. C1363 requires, when possible, the use of environmental temperatures in place of air temperatures and flanking lose calculations. C1363 has more discussion than C236 to guide design of an apparatus.

C1363 requires a determination of and accounting for flanking heat loss (heat transfer through the specimen to the guard area but not across the test specimen. This is obtained by extensive hot box characterization since it is not directly measured. The magnitude of the flanking loss depends on the composition and dimensions of the test specimen and the temperature off-set between the interior air of the metering box and the air in the guard chamber. C1363 Annex 6 contains an example of a procedure to establish a correlation for flanking loss. C236 does not have a corresponding requirement. The test matrix required in C1363 shows 18 hot-box tests required for the correlation. This matrix, however, even though extensive does not cover the range of operating possibilities.

There are testing assignments in which the test specimen is smaller than the metering area of the metering chamber. In this case a mask of known properties is used to completely enclose the metering side of the metering chamber. It is then necessary to instrument the masked area to determine the het flow across this region which is an extraneous heat flow that must be subtract from the total metering box heat input. This aspect of hot box operation is discussed in Annex A1 of C236. The techniques described in the two standards are the same with C1363 containing more explanation and detail.

It should be obvious that the determination of the net heat flow across the test specimen installed in a hot box apparatus is complex. Both C236 and C1363 discuss the various factors with C1363 providing more theoretical explanation than C236. It is not possible to determine the magnitude of differences (if any) that could result from reading and following the requirements and suggestions in the two standards. The uncertainty and differences are reduced by a final calibration/verification based on the test of a panel with known thermal resistance.

Climate Chamber/Cold Side

Cold side temperature controlled to +/- 0.25 K required in C236. C1363 requires determination of the environmental temperature (discussed earlier).

Verification/Calibration

Verification or calibration is a final requirement in both standards. The requirement is based on the realization that all of the data needed to determine the heat flux and temperature differences are not measured or calculated with absolute certainty. A test panel (usually homogeneous) with previously determine thermal resistance is measured using representative conditions. The results of the hot-box test are compared with the known value for thermal resistance to determine an adjustment in heat flux (a mathematical factor) that will make the hot box result the same as the known values. Is some case this is a determination or adjustment of the flanking lose. The calibration / verification required in both standards tends to eliminate minor difference is temperature determinations or net heat-flows determinations between the two methods.

Unfortunately, the uncertainty in hot-box testing as documented in interlaboratory comparisons is about the same for both test methods. Differences in results due the flanking loss estimates, or air temperature determinations are small (0-5%) in comparison with the results reported below for precision. (opinion)

Precision and Bias

Precision and bias statements have been published for both C236 and C1363. The anticipation was that the improved discussion of theory and details of operation would result in reduced test uncertainty. A comparison of the statements or reproducibility do not show improvement.

TABLE 2 Reproducibility Test Results—Homogeneous Specimens—ASTM Hot Box Round Robin (19)

Mean Temperature (°C)	Reproducibility Interval (%)		Difference In Resistance (m^2K/W)
	Calibrated	Guarded	
4	13.6	14.6	± 0.22
24	14.4	15.6	± 0.22
43	15.4	17.2	± 0.22

Figure 3. Results published in ASTM C236

TABLE 2 Wall Condition Results

Analysis	Average[A]	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility	
	$\bar{x}$	Sr	SR	r	Limit R	%
Conductance, (W/m²K)	0.291	0.003	0.018	0.009	0.051	17.5
R-value, (m²K/W)	3.446	0.039	0.208	0.109	0.581	16.9
U-factor, (W/m²K)	0.278	0.003	0.017	0.009	0.046	16.5

[A] The average of the laboratories' calculated averages.

Figure 4. Results published in ASTM C1363

The R-value interval (reproducibility) at mean temperature 24 °F published for C236 is 15.6 %.

The R-value interval (reproducibility) at mean temperature 24 °F published for C1363 is 16.9 %.

Section 13.4 in ASTM C1363-19 reports a difference in 8.8% between the C1363 result for the R-values of reference materials and the direct measurement using ASTM C518. Bias.

The final conclusion is that the possible 0-5% difference between C236 and C1363 results is small compared to the large bias and very serious lack of reproducibility of the test methods.

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October 4, 2019