Designation: F 1639 – 05

An American National Standard

Standard Test Method for Performance of Combination Ovens[1]

This standard is issued under the fixed designation F 1639; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the evaluation of the energy consumption and cooking performance of combination ovens. The food service operator can use this evaluation to select a combination oven and understand its energy consumption.

1.2 This test method is applicable to gas and electric combination ovens that are operated in the combination mode only. For evaluation of a combination oven operated in either convection only mode or steam only mode, apply either Test Method F 1496 or Test Method F 1484, respectively.

1.3 The combination oven can be evaluated with respect to the following (where applicable):

1.3.1 Energy input rate and thermostat calibration (10.2).

1.3.2 Preheat energy consumption and time (10.3).

1.3.3 Idle energy rate (10.4).

1.3.4 Pilot energy rate (if applicable) (10.5).

1.3.5 Cooking-energy efficiency, cooking energy rate, and production capacity (10.7).

1.3.6 Water consumption and condensate temperature (10.7).

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

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

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 3588 Practice for Calculating Heat Value, Compressibility Factor, and Relative Density of Gaseous Fuels

F 1484 Test Methods for Performance of Steam Cookers

F 1495 Specification for Combination Oven Electric or Gas Fired

F 1496 Test Method for Performance of Convection Ovens

2.2 *ASHRAE Documents:*[3]

ASHRAE Guideline 2-1986 (RA90) Engineering Analysis of Experimental Data

ASHRAE Guideline 2-1986 (RA90) Thermal and Related Properties of Food and Food Materials

3. Terminology

3.1 *Definitions:*

3.1.1 *combination oven*, *n*—device that combines the function of hot air convection (oven mode) and saturated and superheated steam heating (steam mode), or both, to perform steaming, baking, roasting, rethermalizing, and proofing of various food products. In general, the term combination oven is used to describe this type of equipment, which is self contained. The combination oven is also referred to as a combination oven/steamer, combi or combo.

3.1.2 *condensate*, *n*—mixture of condensed steam and cooling water, exiting the combination oven and directed to a drain.

3.1.3 *cooking-energy efficiency*, *n*—quantity of energy imparted to the specified food product, expressed as a percentage of energy consumed by the combination oven during the cooking event.

3.1.4 *cooking energy rate*, *n*—average rate of energy consumption (Btu/h (kJ/h) or kW) during the cooking-energy efficiency tests. Refers to all loading scenarios (heavy, medium, light).

3.1.5 *energy input rate*, *n*—peak rate at which a combination oven consumes energy (Btu/h (kJ/h) or kW).

3.1.6 *idle energy rate*, *n*—combination oven's rate of energy consumption (Btu/h (kJ/h) or kW), when empty, required to maintain its cavity temperature at the specified thermostat set point.

3.1.7 *oven cavity*, *n*—that portion of the combination oven in which food products are heated or cooked.

[1] This test method is under the jurisdiction of ASTM Committee F26 on Food Service Equipment and is the direct responsibility of Subcommittee F26.06 on Productivity and Energy Protocol.

Current edition approved Sept. 1, 2005. Published September 2005. Originally approved in 1995. Last previous edition approved in 2001 as F 1639 – 95 (2001).

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] See the *ASHRAE Handbook of Fundamentals*, available from the American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc., 1791 Tullie Circle, NE, Atlanta, GA 30329.

3.1.8 *pilot energy rate*, *n*—rate of energy consumption (Btu/h (kJ/h)) by a combination oven's continuous pilot (if applicable).

3.1.9 *preheat energy*, *n*—amount of energy consumed (Btu (kJ) or kWh), by the combination oven while preheating its cavity from ambient temperature to the specified thermostat set point.

3.1.10 *preheat time*, *n*—time (in min) required for the combination oven cavity to preheat from ambient temperature to the specified thermostat set point.

3.1.11 *production capacity*, *n*—maximum rate (lb/h (kg/h)) at which a combination oven can bring the specified food product to a specified "cooked" condition.

3.1.12 *production rate*, *n*—rate (lb/h (kg/h)) at which a combination oven brings the specified food product to a specified "cooked" condition. Does not necessarily refer to maximum rate. Production rate varies with the amount of food being cooked.

3.1.13 *uncertainty*, *n*—measure of systematic and precision errors in specified instrumentation or measure of repeatability of a reported test result.

4. Summary of Test Method

4.1 Accuracy of the combination oven thermostat is checked at a setting of 350°F (177°C). This is accomplished by comparing the oven's temperature control setting with the temperature at the center of the oven's cavity. If necessary, the control is adjusted so that the maximum difference between its reading and the temperature at the center of the cavity is no more than ±5°F (±2.8°C).

4.2 Energy input rate is determined to confirm that the combination oven is operating within 5 % of the nameplate energy input rate. For gas combination ovens, the pilot energy rate and the fan and control energy rates are also determined.

4.3 The time and energy required to preheat the oven from room temperature (75 ± 5°F (24 ± 3°C)) to a ready-to-cook state (350°F (177°C)) is determined.

4.4 Idle energy rate is determined the combination oven set to maintain a ready-to-cook state (for example, 350 ± 5°F (177 ± 2.8°C)).

4.5 Cooking-energy efficiency, cooking energy rate and production rate are determined during heavy and light-load cooking tests using whole chickens.

5. Significance and Use

5.1 The energy input rate test and thermostat calibration are used to confirm that the combination oven is operating properly prior to further testing and to ensure that all test results are determined at the same temperature.

5.2 Preheat energy and time can be useful to food service operators to manage power demands and to know how quickly the combination oven can be ready for operation.

5.3 Idle energy rate and pilot energy rate can be used to estimate energy consumption during non-cooking periods.

5.4 Cooking-energy efficiency is a precise indicator of combination oven energy performance under various loading conditions. This information enables the food service operator to consider energy performance when selecting a combination oven.

5.5 Production capacity can be used by food service operators to choose a combination oven that matches their food output requirements.

5.6 Water consumption characterization is useful for estimating water and sewage costs associated with combination oven operation.

5.7 Condensate temperature measurement is useful to verify that the condensate temperature does not violate applicable building codes.

6. Apparatus

6.1 *Analytical Balance Scale*, for measuring weights up to 20 lb (9.0 kg), with a resolution of 0.01 lb (0.005 kg) and an uncertainty of 0.01 lb (0.005 kg).

6.2 *Barometer*, for measuring absolute atmospheric pressure, to be used for adjustment of measured natural gas volume to standard conditions, having a resolution of 0.2 in. Hg (670 Pa) and an uncertainty of 0.2 in. Hg (670 Pa).

6.3 *Canopy Exhaust Hood*, 4-ft (1.2-m) in depth, wall-mounted with the lower edge of the hood 72 in. (2.0 m) from the floor and with the capacity to operate at a nominal exhaust ventilation rate of 300 cfm per linear foot (360 L/s per linear meter) of active hood length. This hood shall extend a minimum of 6 in. (150 mm) past both sides and the front of the cooking appliance and shall not incorporate side curtains or partitions.

6.4 *Flowmeter*, for measuring total water consumption of the appliance, having a resolution of 0.01 gal (40 mL) and an uncertainty of 0.01 gal (40 mL) at a flow rate as low as 0.2 gpm (13 mL/s).

6.5 *Gas Meter*, for measuring the gas consumption of a combination oven, shall be a positive displacement type with a resolution of at least 0.01 ft^3 (0.0003 m^3) and a maximum uncertainty no greater than 1 % of the measured value for any demand greater than 2.2 ft^3/h (0.06 m^3/h). If the meter is used for measuring the gas consumed by the pilot lights, it shall have a resolution of at least 0.01 ft^3 (0.0003 m^3) and a maximum uncertainty no greater than 2 % of the measured value.

6.6 *Pressure Gage*, for monitoring natural gas pressure, having a range from 0 to 15 in. H_2O (0 to 3.7 kPa), a resolution of 0.5 in. H_2O (125 Pa), and a maximum uncertainty of 1 % of the measured value.

6.7 *Stopwatch*, with a 1-s resolution.

6.8 *Temperature Sensor*, for measuring natural gas temperature in the range from 50 to 100°F (10 to 40°C), with an uncertainty of ±1°F (0.3°C).

6.9 *Thermocouple Probes*, with a range from 0 to 450°F (−18 to 232°C), with a resolution of 0.2°F (0.1°C), and an uncertainty of 0.5°F (0.3°C), for measuring temperature of the combination oven cavity, food product, and condensate water.

6.10 *Watt-hour Meter*, for measuring the electrical energy consumption of a combination oven, having a resolution of at least 10 Wh and a maximum uncertainty no greater than 1.5 % of the measured value for any demand greater than 100 W. For any demand less than 100 W, the meter shall have a resolution of at least 10 Wh and a maximum uncertainty no greater than 10 %.

7. Reagents and Materials

7.1 *Water*, shall have a maximum hardness of three grains per gallon. If the tester's water supply does not meet the specification, a water softener may be required.

7.2 *Chickens*, shall be fresh, ready to cook, whole chickens without giblets (WOG), with a nominal weight of 2½ to 2¾-lb (1.1 to 1.2-kg) per chicken.

7.3 *Chicken Racks*, for holding whole chickens, shall be of manufacturer's design or specification.

7.4 *Hotel Pans*, for capturing chicken juices, solid 12 by 20 by 2½ in. (300 by 500 by 65 mm) stainless steel weighing 2.8 ± 0.5 lb (1.3 ± 0.2 kg).

8. Sampling, Test Units

8.1 *Combination Oven*—Select a representative production model for performance testing.

9. Preparation of Apparatus

9.1 Install the appliance according to the manufacturer's instructions under a canopy exhaust hood. Position the combination oven so that a minimum of 6 in. is maintained between the edge of the hood and the vertical plane of the front and sides of the appliance. In addition, both sides of the combination oven shall be a minimum of 3 ft (1.1 m) from any side wall, side partition, or other operating appliance. The exhaust ventilation rate shall be 300 cfm per linear foot (360 L/s per linear meter) of hood length. The associated heating or cooling system shall be capable of maintaining an ambient temperature of 75 ± 5°F (24 ± 3°C) within the testing environment when the exhaust ventilation system is operating.

9.2 Connect the combination oven to a calibrated energy test meter. For gas installations, install a pressure regulator downstream from the meter to maintain a constant pressure of gas for all tests. Install instrumentation to record both the pressure and temperature of the gas supplied to the combination oven and the barometric pressure during each test so that the measured gas flow can be corrected to standard conditions. For electric installations, a voltage regulator may be required during tests if the voltage supply is not within ±2.5 % of the manufacturer's nameplate voltage.

9.3 For an electric combination oven, confirm (while the combination oven elements are energized) that the supply voltage is within ±2.5 % of the operating voltage specified by the manufacturer. Record the test voltage for each test.

NOTE 1—If an electric combination oven is rated for dual voltage (for example, 208/240 V), the voltage selected by the manufacturer or tester, or both, shall be reported. If an oven is designed to operate at two voltages without a change in the resistance of the heating elements, the performance of the oven (for example, preheat time) may differ at the two voltages.

9.4 For a gas combination oven, adjust (during maximum energy input) the gas supply pressure downstream from the appliance's pressure regulator to within ±2.5 % of the operating manifold pressure specified by the manufacturer. Make adjustments to the appliance following the manufacturer's recommendations for optimizing combustion.

9.5 Install a flowmeter to the combination oven water inlet such that total water flow to the appliance is measured.

9.6 Install temperature sensors at the point where the drain water exits the combination oven and in the drain line such that the sensor is immersed in the condensate water path just as it enters the drain.

10. Procedure

NOTE 2—Prior to starting these tests, the tester should read the operating manual and fully understand the operation of the appliance.

10.1 *General*:

10.1.1 For gas appliances, record the following for each test run:

10.1.1.1 Higher heating value,

10.1.1.2 Standard gas pressure and temperature used to correct measured gas volume to standard conditions,

10.1.1.3 Measured gas temperature,

10.1.1.4 Measured gas pressure,

10.1.1.5 Barometric pressure, and

10.1.1.6 Energy input rate during or immediately prior to test (for example, during the preheat for that days' testing).

NOTE 3—Using a calorimeter or gas chromatograph in accordance with accepted laboratory procedures is the preferred method for determining the higher heating value of gas supplied to the combination oven under test. It is recommended that all testing be performed with gas having a higher heating value of 1000 to 1075 Btu/ft^3.

10.1.2 For gas combination ovens, add electric energy consumption to gas energy for all tests, with the exception of the energy input rate test (see 10.3).

10.1.3 For electric combination ovens, record the following for each test run:

10.1.3.1 Voltage while elements are energized, and

10.1.3.2 Energy input rate during or immediately prior to test (for example, during the preheat for that days' testing).

10.1.4 For each test run, confirm that the peak input rate is within ±5 % of the rated nameplate input. If the difference is greater than ±5 %, terminate testing and contact the manufacturer. The manufacturer may make appropriate changes or adjustments to the combination oven.

10.2 *Energy Input Rate and Thermostat Calibration*:

10.2.1 Install a thermocouple at the geometric center (top to bottom, side to side, and front to back) of the combination oven cooking cavity.

10.2.2 Set the temperature control to 350°F (177°C); set the controls to operate in the combination mode; and turn the combination oven on. Record the time and energy consumption from the time when the unit is turned on until the time when any of the burners or elements (combination oven) first cycle off.

10.2.3 Calculate and record the combination oven's energy input rate and compare the result to the rated nameplate input. For gas combination ovens, only the burner energy consumption is used to compare the calculated energy input rate with the rated gas input; any electrical energy use shall be calculated and recorded separately as the fan/control energy rate.

10.2.4 Allow the combination oven to idle for 60 min after the burners or elements commence cycling at the thermostat set point.

10.2.5 After the 60-min idle period, start monitoring the combination oven cavity temperature, and record the average temperature over a 15-min period. If this recorded temperature is 350 ± 5°F (177 ± 3°C), then the combination oven's thermostat is calibrated.

10.2.6 If the average temperature is not 350 ± 5°F (177 ± 3°C), adjust the combination oven's temperature control following the manufacturer's instructions and repeat 10.2.5 until it is within this range. Record the corrections made to the controls during calibration.

10.2.7 In accordance with 11.4, calculate and report the combination oven energy input rate, fan/control energy rate where applicable, and rated nameplate input.

10.3 *Preheat Energy Consumption and Time*:

10.3.1 Verify that the combination oven cavity temperature is 75 ± 5°F (24 ± 3°F). Set the calibrated temperature control to 350°F; set the controls to operate in the combination mode; and turn the combination oven on.

10.3.2 Record the time, temperature, and energy consumption required to preheat the combination oven, from the time when the unit is turned on until the time when the combination oven cavity reaches a temperature of 350 ± 2°F (177 ± 1°C).

10.3.3 In accordance with 11.5, calculate and report the preheat energy consumption and time, and generate a preheat temperature versus time graph.

10.4 *Idle Energy Rate*:

10.4.1 With the temperature controls set to maintain the average cavity air temperature at 350 ± 5°F (177 ± 2.8°C) and the oven set to operate in full combination mode (maximum humidity), turn the combination oven on.

10.4.2 Allow the combination oven to stabilize at these settings for 60 min after the burners or elements commence cycling.

10.4.3 At the end of 60 min stabilization period, begin recording the elapsed time, oven cavity temperature, and combination oven energy and water consumption for a minimum of 3 h.

10.4.4 Repeat 10.4.1 through 10.4.3 with the oven set to operate at the lowest humidity setting, while still in combination mode. If additional humidity settings are possible, the combination oven may be characterized at these settings by repeating 10.4.1 through 10.4.4.

10.4.5 In accordance with 11.6, calculate and report the combination oven's idle energy rate and water consumption rate.

10.5 *Pilot Energy Rate*:

10.5.1 For a gas combination oven with a standing pilot, set the gas valve at the "pilot" position, and set the combination oven's temperature control to the "off" position.

10.5.2 Light and adjust the pilot according to the manufacturer's instructions.

10.5.3 Monitor gas consumption for a minimum of 8 h of pilot operation.

10.5.4 In accordance with 11.7, calculate and report the pilot energy rate.

10.6 *Chicken Preparation*:

10.6.1 Determine the number of chicken racks required to fill the oven to maximum capacity (or the manufacturer's recommended maximum capacity) while maintaining a minimum of ½-in. (13 mm) clearance around each loaded chicken rack. If the chicken racks are not designed to be placed inside standard hotel pans, then space must be reserved at the bottom of the oven for a standard 2½-in. (64-mm) deep hotel pan to catch the drippings.

NOTE 4—It is the intent of this procedure to load the oven to maximum capacity without having the chickens contacting each other, the oven walls, or adjacent racks. The number of chicken racks required to fill the oven to maximum capacity will vary depending on oven size and the manufacturer's design of the chicken racks.

10.6.2 Prepare enough chickens for a minimum of three runs each of both heavy- and light-load tests. For the heavy-load tests, use the maximum number of chicken racks allowable. For the light-load tests, use one rack of chickens.

10.6.3 If necessary, the chickens may be thawed by immersing them in cold running water. Thoroughly rinse the thawed chickens and then place them onto a drip rack on a sheet pan and cover with plastic wrap. Place the wrapped chickens into the refrigerator.

NOTE 5—It is important that the raw whole chickens be properly and consistently thawed and drained. Excess moisture in the pans will make it difficult to accurately determine the amount of product shrinkage.

10.6.4 Monitor the internal temperature of a sample chicken with a thermocouple probe. Its internal temperature must reach 37 ± 2°F (3 ± 1°C) before the chickens can be removed from the refrigerator and loaded onto the appropriate chicken racks. If necessary, adjust the refrigerator temperature to achieve this required internal temperature.

10.6.5 Trim any loose fat and skin from the bottom of each chicken.

10.6.6 Weigh and record the weight of each rack. If the chicken racks are designed to be held inside standard hotel pans, then weigh and record the weight of the individual hotel pans. To facilitate the testing, label the racks (and pans) for identification.

10.6.7 Load the chickens onto the appropriate racks, following the manufacturer's recommendations for orientation. Weigh and record the weight of each full-loaded rack (and pan).

10.6.8 Choose two chickens near the center of each rack for temperature measurement. Each chicken shall be instrumented with four thermocouples: one thermocouple in each thigh and one thermocouple in each breast.

NOTE 6—Each pair of thermocouples in the breasts and thighs can be mechanically averaged by joining two equal lengths of thermocouple wire into one wire, which is attached to the temperature measuring device. This method simplifies the procedure by reducing the number of thermocouple wires leaving the combination oven.

NOTE 7—It is recommended that the thermocouple wires be attached to the side of the chicken racks with clips or some other form of strain relief to ensure that the thermocouples remain in the same spot in the chickens during handling and loading of the racks.

NOTE 8—It was determined by the Food Service Technology Center that four thermocouple pairs for each chicken rack were sufficient to produce accurate and repeatable test results. Limiting the number of thermocouples simplifies the handling of the pans and reduces the chance that the wires will become tangled.

10.6.9 Cover the chickens with plastic wrap. Return the chickens to the refrigerator and allow them to stabilize at the 37

± 2°F (3 ± 1°C) refrigerator temperature. Do not store the thawed chickens in the refrigerator for more than one week.

10.7 *Cooking-Energy Efficiency and Production Capacity*:

10.7.1 This procedure applies to two possible loading scenarios: heavy and light. Each loading scenario shall be repeated a minimum of three times. Additional test runs may be necessary to obtain the required precision for the reported test results (Annex A1). The reported values of cooking-energy efficiency, cooking energy rate, production capacity, condensate temperature, and water consumption shall be the average of the replications (runs).

10.7.2 Set the temperature control to 350°F (177°C); set the controls to operate in full combi mode; preheat the combination oven; and then allow the combination oven to idle in full combi mode for 60 min.

10.7.3 If the manufacturer offers a recommended program for cooking whole chickens, then that program may be used, provided that the cooking time, temperature, and humidity settings are noted in the results reporting sheets. If no recommended cooking program is provided, then the chickens shall be cooked in full combi mode (temperature plus maximum humidity) at 350°F (177°C).

NOTE 9—Some oven manufacturers recommend cooking whole chickens using a staged or stepped program, using varying temperature and humidity settings. It is the intent of this test procedure to characterize the cooking performance of the combination oven as the manufacturer intends it to be used.

10.7.4 Remove the chickens from the refrigerator and remove the plastic wrap. Open the door of the combination oven and commence loading the racks of chickens into the oven. If the racks are designed to be loaded directly into the oven without pans, then place a standard 2½-in. (64-mm) deep hotel pan at the bottom rack position to catch any chicken drippings. For the light-load test, the rack shall be placed as close to the center of the oven cavity as possible For the heavy-load test, the racks shall be loaded from bottom to top. Allow 20 s to load each rack into the combination oven (for example, a heavy load of 3 racks times 20 s = 1-min maximum loading time). The initial average temperature of the chickens (all the racks together) when the test is started (the combination oven door is closed) shall be 40 ± 2°F (4 ± 1°C). Keep the door open for the entire load time, even if the loading is accomplished in less time.

10.7.5 Shut the door and start the oven cooking cycle to begin the test. Start monitoring time, temperature, energy consumption, water consumption, and condensate temperature.

10.7.6 End the test when the average temperature of the whole chickens (all the racks together) reaches 200°F (93°C). Stop monitoring time, temperature, energy, water consumption, and condensate temperature.

10.7.7 Remove the racks of chickens and hotel pan(s) from the combination oven and close the oven door. Remove the thermocouples from the chickens, and immediately weigh each rack of chickens while still in the hotel pans, including the juice in the pans (racks in pans). For stand-alone racks, include the weight of the hotel pan with drippings in the final chicken weight.

10.7.8 Subtract the weight of the chicken racks and the hotel pans to determine the total cooked weight of the whole chickens with the juices. Record the final temperature, the test time, the total cooked weight of the whole chickens, and the energy and water consumed during the test.

10.7.9 To quantify product shrinkage, remove the chickens from the racks, leaving any juice in the drip pans and shaking off any excess moisture that may have condensed on the chickens, then weigh and record the net weight of the whole chickens.

NOTE 10—The total cooked weight of the whole chickens will be subtracted from the total uncooked weight of the whole chickens in order to determine the amount of moisture evaporated during the test. It is crucial to include all of the moisture that is remaining in the drip pans when determining the total cooked weight so that the evaporation will not be exaggerated.

NOTE 11—The net weight of the whole chickens will be subtracted from the total uncooked weight of the whole chickens in order to determine the product shrinkage. The net weight is representative of the final product or the quantity of product that would be available to be served.

10.7.10 Perform runs No. 2 and No. 3 by repeating 10.7.3-10.7.9. Allow a minimum of 10 min for the oven to re-stabilize at its operating temperature (for example, 350°F (177°C) at full-combi mode) between subsequent tests. Follow the procedure in Annex A1 to determine whether more than three test runs are required.

10.7.11 In accordance with 11.8, calculate and report the cooking-energy efficiency, cooking energy rate, electric energy rate (if applicable for gas combination ovens), production capacity, product shrinkage, water consumption, and condensate temperature.

11. Calculation and Report

11.1 *Test Combination Oven*—Summarize the physical and operating characteristics of the combination oven, including method of steam generation, oven controls and different operating modes. If needed, describe other design or operating characteristics that may facilitate interpretation of the test results.

11.2 *Apparatus and Procedure*:

11.2.1 Confirm that the testing apparatus conformed to all of the specifications in Section 6. Describe any deviations from those specifications.

11.2.2 For electric combination ovens, report the voltage for each test.

11.2.3 For gas combination ovens, report the higher heating value of the gas supplied to the combination oven during each test.

11.3 *Gas Energy Calculations*:

11.3.1 For gas combination ovens, add electric energy consumption to gas energy for all tests, with the exception of the energy input rate test (see 10.2).

11.3.2 Calculate the energy consumed based on the following:

$$E_{gas} = V \times HV \quad (1)$$

where:

E_{gas} = energy consumed by the appliance,

HV = higher heating value,
= energy content of gas measured at standard conditions, Btu/ft^3 (kJ/m^3),
V = actual volume of gas corrected for temperature and pressure at standard conditions, ft^3 (m^3),
= $V_{meas} \times T_{cf} \times P_{cf}$

where:

V_{meas} = measured volume of gas, ft^3,
T_{cf} = temperature correction factor,

$$= \frac{\text{absolute standard gas temperature, °R (°K)}}{\text{absolute actual gas temperature, °R (°K)}}$$

$$= \frac{\text{absolute standard gas temperature, °R (°K)}}{[\text{gas temperature, °F (°C)} + 459.67\ (273)]\ \text{°R (°K)}}$$

P_{cf} = pressure correction factor,

$$= \frac{\text{absolute actual gas pressure, psia (kPa)}}{\text{absolute standard pressure, psia (kPa)}}$$

$$= \frac{\text{gas gage pressure, psig (kPa)} + \text{barometric pressure, psia (kPa)}}{\text{absolute standard pressure, psia (kPa)}}$$

$$= \frac{\text{gas gage pressure, psig} + \text{barometric pressure, psia}}{\text{absolute standard pressure, psia}}$$

NOTE 12—Absolute standard gas temperature and pressure used in this calculation should be the same values used for determining the higher heating value. Standard conditions using Practice D 3588 are 14.696 psia (101.33 kPA) and 60°F (519.67 °R, (288.71 °K)).

11.4 *Energy Input Rate*:

11.4.1 Report the manufacturer's nameplate energy input rate in Btu/h for a gas combination oven and kW for an electric combination oven.

11.4.2 For gas or electric combination ovens, calculate and report the measured energy input rate (Btu/h or kW) based on the energy consumed by the combination oven during the period of peak energy input according to the following relationship:

$$q_{input} = \frac{E \times 60}{t} \tag{2}$$

where:

q_{input} = measured peak energy input rate, Btu/h (kJ/h) or kW,
E = energy consumed during period of peak energy input, Btu (kJ) or kWh, and
t = period of peak energy input, min.

11.5 *Preheat Energy and Time*:

11.5.1 Report the preheat energy consumption (Btu or kWh) and preheat time (min).

11.5.2 Generate a graph showing the combination oven cavity temperature versus time for the preheat period.

11.6 *Idle Energy Rate*:

11.6.1 For the maximum humidity setting (combi mode), calculate and report the idle energy rate (Btu/h or kW) based on the following:

$$q_{idle} = \frac{E \times 60}{t} \tag{3}$$

where:

q_{idle} = idle energy rate, Btu/h (kJ/h) or kW,
E = energy consumed during the test period, Btu (kJ) or kWh, and
t = test period, min.

11.6.2 For the maximum humidity setting (combi mode), report the water consumption rate (gal/h (l/h)) during the idle test period.

11.6.3 If additional humidity settings were evaluated, report the idle energy rate and water consumption rate for each setting.

11.7 *Pilot Energy Rate*—Calculate and report the pilot energy rate (Btu/h) based on the following:

$$q_{pilot} = \frac{E \times 60}{t} \tag{4}$$

where:

q_{pilot} = pilot energy rate, Btu/h (kJ/h),
E = energy consumed during the test period, Btu (kJ), and
t = test period, min.

11.8 *Cooking-Energy Efficiency, Cooking Energy Rate, Production Capacity, Product Shrinkage, Water Consumption, and Condensate Temperature*:

11.8.1 Calculate the cooking-energy efficiency, η_{cook}, for heavy- and light-load cooking tests based on the following:

$$\eta_{cook} = \frac{E_{food} + E_{racks} + E_{pans}}{E_{appliance}} \times 100 \tag{5}$$

where:

η_{cook} = cooking energy efficiency, %,
E_{food} = energy into food, Btu (kJ),
= $(Wraw \times Cp\ (C) \times (T_2 - T_1)) + ((Wraw - Wcooked) \times Hv)$,
E_{racks} = energy into the chicken rack(s), Btu (kJ),
= $Wr \times Cp\ (R) \times (T_2 - T_1)$,
E_{pans} = energy into the hotel pan(s), Btu,
= $Wp \times Cp\ (P) \times (T_2 - T_1)$
$Wraw$ = total weight of uncooked chickens,
$Wcooked$ = total weight of cooked chickens including juice,
Wr = weight of rack(s),
Wp = weight of hotel pan(s),
$Cp(C)$ = specific heat of whole chickens,
= 0.800 Btu/lb·°F,
$Cp(R)$ = specific heat of chicken rack(s),
= 0.11 Btu/lb·°F,
$Cp(P)$ = specific heat of hotel pan(s),
= 0.11 Btu/lb °F,
Hv = heat of vaporization of water (Btu/lb) based on the table of thermodynamic properties of water at saturation,
= 970 Btu/lb,
T_2 = final temperature of the whole chickens,
T_1 = initial temperature of the whole chickens, and
$E_{appliance}$ = energy into the appliance, Btu.

The conversion factor for electric energy is 3 413 Btu/kWh.

11.8.2 Calculate the cooking energy rate for heavy and light-load cooking tests based on the following:

$$q_{cook} = \frac{E \times 60}{t} \quad (6)$$

where:

q_{cook} = cooking energy rate, Btu/h (kJ/h) or kW,
E = energy consumed during cooking test, Btu (kJ) or kWh, and
t = cooking test period, min.

For gas appliances, report separately a gas cooking energy rate and an electric cooking energy rate.

11.8.3 Calculate production capacity (lb/h (kg/h)) based on the following:

$$PC = W \times \frac{60}{t} \quad (7)$$

where:

PC = production capacity of the combination oven, lb/h (kg/h),
W = total weight of whole chickens cooked during heavy-load cooking test, lb (kg), and
t = total time of heavy-load cooking test, min.

11.8.4 Calculate product shrinkage (%) based on the following:

$$S = \frac{W_{raw} - W_{net}}{W_{raw}} \times 100 \quad (8)$$

where:

S = product shrinkage, %,
W_{raw} = total weight of the uncooked chickens (lb (kg)), and
W_{net} = final net weight of the cooked chickens (lb (kg)).

11.8.5 Calculate the average water consumption rate during the test based on the following:

$$gal/h = gal \times \frac{60}{t} \quad (9)$$

where:

gal/h = average water consumption rate during the test,
gal = water consumed by the combination oven during the test, and
t = cooking test period, min.

11.8.6 Calculate the maximum temperature and the average temperature of the cooking condensate during the test, °F (°C).

11.8.7 Report the three-run average value of cooking-energy efficiency, cooking energy rate, production capacity, product shrinkage, water consumption, and condensate temperature.

11.8.8 Report the oven temperature and humidity settings used to cook the whole chickens in 10.7.

12. Precision and Bias

12.1 *Precision*:

12.1.1 *Repeatability (within laboratory, same operator and equipment)*:

12.1.1.1 For the cooking energy efficiency, cooking energy rate, and production capacity results, the percent uncertainty in each result has been specified to be no greater than ± 10 % based on at least three test runs.

12.1.1.2 The repeatability of each remaining parameter is being determined.

12.1.2 *Reproducibility (multiple laboratories)*—The inter-laboratory precision of the procedure in this test method for measuring each reported parameter is being determined.

12.2 *Bias*—No statement can be made concerning the bias of the procedures in this test method because there are no accepted reference values for the parameters reported.

13. Keywords

13.1 combination oven; combination oven/steamer; cooking-energy efficiency; efficiency; energy; performance; production capacity; steamer condensate temperature; throughput; water consumption; water usage

ANNEX

(Mandatory Information)

A1. PROCEDURE FOR DETERMINING THE UNCERTAINTY IN REPORTED TEST RESULTS

NOTE A1.1—The procedure described as follows is based on the method for determining the confidence interval for the average of several test results discussed in section 6.4.3, ASHRAE Guideline 2-1986(RA90). It should only be applied to test results that have been obtained within the tolerances prescribed in this method (for example, thermocouples calibrated, range was operating within 5 % of rated input during the test run).

A1.1 For the Cooking Energy Efficiency and Production Capacity procedures, results are reported for the cooking energy efficiency (η_{cook}) and the production capacity (*PC*). Each reported result is the average of results from at least three test runs. In addition, the uncertainty in these averages is reported. For each cooking energy efficiency test (light and heavy), the uncertainty of η_{cook} must be no greater than ±10 % before η_{cook} for that test can be reported. For the heavy-load test, the uncertainty of *PC* must also be no greater than ±10 % before *PC* for that test can be reported.

A1.2 The uncertainty in a reported result is a measure of its precision. If, for example, the η_{cook} is 40 %, the uncertainty must not be larger than ±4 %. This means that the true η_{cook} is within the interval between 36 and 44 %. This interval is determined at the 95 % confidence level, which means that there is only a 1 in 20 chance that the true η_{cook} could be outside of this interval.

A1.3 Calculating the uncertainty not only guarantees the maximum uncertainty in the reported results, but also is used to determine how many test runs are needed to satisfy this requirement. The uncertainty is calculated from the standard deviation of three or more test results and a factor from Table A1.1 which depends on the number of test results used to calculate the average. The percent uncertainty is the ratio of the uncertainty to the average expressed as a percent.

A1.4 *Procedure:*

NOTE A1.2—See A1.5 for an example of applying this procedure.

A1.4.1 *Step 1*—Calculate the average and the standard deviation for the η_{cook} and *PC* using the results of the first three test runs:

NOTE A1.3—The following formulas may be used to calculate the average and sample standard deviation. However, it is recommended that a calculator with statistical function be used. If one is used, be sure to use the sample standard deviation function. Using the population standard deviation function will result in an error in the uncertainty.

The formula for the average (three-test runs) is as follows:

$$Xa_3 = (1/3) \times (X_1 + X_2 + X_3) \quad \text{(A1.1)}$$

where:
Xa_3 = average of results for η_{cook}, *PC*, and
X_1, X_2, X_3 = results for η_{cook}, *PC*.

The formula for the sample standard deviation (three test runs) is as follows:

$$S_3 = (1/\sqrt{2}) \times \sqrt{(A_3 - B_3)} \quad \text{(A1.2)}$$

where:
S_3 = standard deviation of results for η_{cook}, *PC*,
A_3 = $(X_1)^2 + (X_3)^2$, and
B_3 = $(1/3) \times (X_1 + X_2 + X_3)^2$.

NOTE A1.4—The *A* quantity is the sum of the squares of each test result, while the *B* quantity is the square of the sum of all test results multiplied by a constant (1⁄3 in this case).

A1.4.2 *Step 2*—Calculate the absolute uncertainty in the average for each parameter listed in Step 1. Multiply the standard deviation calculated in Step 1 by the Uncertainty Factor corresponding to three test results from Table A1.1.

The formula for the absolute uncertainty (three test runs) is as follows:

$$U_3 = C_3 \times S_3 \quad \text{(A1.3)}$$

$$U_3 = 2.48 \times S_3 \quad \text{(A1.4)}$$

where:
U_3 = absolute uncertainty in average for η_{cook}, *PC*, and
C_3 = uncertainty factor for three test runs (Table A1.1).

A1.4.3 *Step 3*—Calculate the percent uncertainty in each parameter average using the averages from Step 1 and the absolute uncertainties from Step 2.

TABLE A1.1 Uncertainty Factor

Test Results, *n*	Uncertainty Factor, *Cn*
3	2.48
4	1.59
5	1.24
6	1.05
7	0.92
8	0.84
9	0.77
10	0.72

The formula for the percent uncertainty (three test runs) is as follows:

$$\% U_3 = (U_3/Xa_3) \times 100 \% \quad \text{(A1.5)}$$

where:
$\% U_3$ = percent uncertainty in average for η_{cook}, *PC*,
U_3 = absolute uncertainty in average for η_{cook}, *PC*, and
Xa_3 = average η_{cook}, *PC*.

A1.4.4 *Step 4*—If the percent uncertainty, $\% U_3$, is not greater than ±10 % for η_{cook} then report the average for η_{cook} and *PC* along with their corresponding absolute uncertainty, U_3 in the following format:

$$Xa_3 \pm U_3 \quad \text{(A1.6)}$$

If the percent uncertainty is greater than ±10 % for η_{cook} then proceed to Step 5.

A1.4.5 *Step 5*—Run a fourth test for each η_{cook} that resulted in the percent uncertainty being greater than ±10 %.

A1.4.6 *Step 6*—When a fourth test is run for a given η_{cook}, calculate the average and standard deviation for η_{cook} and *PC* using a calculator or the following formulas:

The formula for the average (four test runs) is as follows:

$$Xa_4 = \left(\frac{1}{4}\right) \times (X_1 + X_2 + X_3 + X_4) \quad \text{(A1.7)}$$

where:
Xa_4 = average of results for η_{cook}, *PC*, and
X_1, X_2, X_3, X_4 = results for η_{cook}, *PC*.

The formula for the standard deviation (four test runs) is as follows:

$$S_4 = (1/\sqrt{3}) \times \sqrt{(A_4 - B_4)} \quad \text{(A1.8)}$$

where:
S_4 = standard deviation of results for η_{cook}, *PC* (four test runs):
A_4 = $(X_1)^2 + (X_2)^2 + (X_3)^2 + (X_4)^2$, and
B_4 = $(1/4) \times (X_1 + X_2 + X_3 + X_4)^2$.

A1.4.7 *Step 7*—Calculate the absolute uncertainty in the average for each parameter listed in Step 1. Multiply the standard deviation calculated in Step 6 by the uncertainty factor for four test results from Table A1.1.

The formula for the absolute uncertainty (four test runs) is as follows:

$$U_4 = C_4 \times S_4 \quad \text{(A1.9)}$$

$$U_4 = 1.59 \times S_4 \quad \text{(A1.10)}$$

where:
U_4 = absolute uncertainty in average for η_{cook}, *PC*, and
C_4 = uncertainty factor for four test runs (Table A1.1).

A1.4.8 *Step 8*—Calculate the percent uncertainty in the parameter averages using the averages from Step 6 and the absolute uncertainties from Step 7.

The formula for the percent uncertainty (four test runs) is as follows:

$$\% U_4 = (U_4/Xa_4) \times 100 \% \quad \text{(A1.11)}$$

where:
$\% U_4$ = percent uncertainty in average for η_{cook}, *PC*,
U_4 = absolute uncertainty in average for η_{cook}, *PC*, and

Xa_4 = average η_{cook}, *PC*.

A1.4.9 *Step 9*—If the percent uncertainty, % U_4, is no greater than ±10 % for η_{cook} then report the average for η_{cook} and *PC* along with their corresponding absolute uncertainty, U_4, in the following format:

$$Xa_4 \pm U_4 \tag{A1.12}$$

If the percent uncertainty is greater than ±10 % for η_{cook}, proceed to Step 10.

A1.4.10 *Step 10*—The step required for five or more test runs are the same as those described above. More general formulas are listed as follows for calculating the average, standard deviation, absolute uncertainty, and percent uncertainty.

The formula for the average (*n* test runs) is:

$$Xa_n = (1/n) \times (X_1 + X_2 + X_3 + X_4 + \ldots + X_n) \tag{A1.13}$$

where:
n = number of test runs,
Xa_n = average of results for η_{cook}, *PC*, and
$X_1, X_2, X_3, X_4, \ldots X_n$ = results for η_{cook}, *PC*.

The formula for the standard deviation (*n* test runs) is:

$$S_n = (1/\sqrt{(n-1)}) \times (\sqrt{(A_n - B_n)}) \tag{A1.14}$$

where:
S_n = standard deviation of results for η_{cook}, *PC* (*n* test runs),
A_n = $(X_1)^2 + (X_2)^2 + (X_3)^2 + (X_4)^2 + \ldots + (X_n)^2$,
B_n = $(1/n) \times (X_1 + X_2 + X_3 + X_4 + \ldots X_n)^2$

The formula for the absolute uncertainty (*n* test runs) is:

$$U_n = C_n \times S_n \tag{A1.15}$$

where:
U_n = absolute uncertainty in average for η_{cook}, *PC*, and
C_n = uncertainty factor for n test runs (Table A1.1).

The formula for the percent uncertainty (*n* test runs) is:

$$\% U_n = (U_n/Xa_n) \times 100 \% \tag{A1.16}$$

where:
% U_n = percent uncertainty in average for η_{cook}, *PC*.

When the specified uncertainty, % U_n, is less than or equal to ± 10 %; report the average for η_{cook} and *PC* along with their corresponding absolute uncertainty, U_n, in the following format:

$$Xa_n \pm U_n \tag{A1.17}$$

NOTE A1.5—In the course of running these tests, the tester may compute a test result that deviates significantly from the other test results. It may be tempting to discard such a result in an attempt to meet the ±10 % uncertainty requirement. This should be done only if there is some physical evidence that the test run from which that particular result was obtained was not performed according to the conditions specified in this method. For example, a thermocouple was out of calibration, the oven's input rate was not within 5 % of the rated input, or a thermocouple slipped out of a chicken. To be sure all results were obtained under approximately the same conditions, it is good practice to monitor those test conditions specified in this method.

A1.5 *Example of Determining Uncertainty in Average Test Result:*

A1.5.1 Three test runs for the full-energy input rate cooking efficiency test yielded the following η_{cook} results:

Test	η_{cook}
Run No. 1	33.8 %
Run No. 2	31.3 %
Run No. 3	30.5 %

A1.5.2 *Step 1*—Calculate the average and standard deviation of the three test results for the η_{cook}.

The average of the three test results:

$$Xa_3 + (1/3) \times (X_1 + X_2 + X_3), \tag{A1.18}$$

$$Xa_3 = (1/3) \times (33.8 + 31.3 + 30.5),$$

$$Xa_3 = 31.9 \%.$$

The standard deviation of the three test results:
First calculate A_3 and B_3:

$$A_3 = (X_1)^2 + (X_2)^2 + (X_3)^2, \tag{A1.19}$$

$$A_3 + 33.8)^2 + (31.3)^2 + (30.5)^2,$$

$$A_3 = 3052,$$

$$B_3 = (1/3) \times [(X_1 + X_x + X_3)^2],$$

$$B_3 = (1/3) \times [(33.8 + 31.3 + 30.5)^2], \text{ and}$$

$$B_3 = 3046$$

The new standard deviation for the η_{cook} is:

$$S_3 = (1/\sqrt{2}) \times \sqrt{(3052} - 3046, \tag{A1.20}$$

$$S_3 = 1.73 \%.$$

A1.5.3 *Step 2*—Calculate the uncertainty in average.

$$U_3 = 2.48 \times S_3, \tag{A1.21}$$

$$U_3 = 2.48 \times 1.73,$$

$$U_3 = 4.29 \%.$$

A1.5.4 *Step 3*—Calculate percent uncertainty.

$$\% U_3 = (U_3/Xa_3) \times 100 \%, \tag{A1.22}$$

$$\% U_3 = (4.29/31.9) \times 100 \%, \text{ and}$$

$$\% U_3 = 13.5 \%.$$

A1.5.5 *Step 4*— Run a fourth test. Since the percent uncertainty for the η_{cook} is greater than ±10 %, the precision requirement has not been satisfied. An additional test is run in an attempt to reduce the uncertainty. The η_{cook} from the fourth test run was 31.8 %.

A1.5.6 *Step 5*—Recalculate the average and standard deviation for the η_{cook} using the fourth test result:

The new average η_{cook} is:

$$Xa_4 = \left(\frac{1}{4}\right) \times (X_1 + X_2 + X_3 + X_4), \tag{A1.23}$$

$$Xa_4 = \left(\frac{1}{4}\right) \times (33.8 + 31.3 + 30.5 + 31.8, \text{ and}$$

$$Xa_4 = 31.9\%$$

The new standard deviation:
First calculate A_4 and B_4:

$$A_4 = (X_1)^2 + (X_2)^2 + (X_3)^2 + (X_4)^2, \tag{A1.24}$$

$$A_4 = (33.8)^2 + (31.3)^2 + (30.5)^2 + (31.8)^2,$$

$$A_4 = 4064,$$

$$B_4 = \left(\frac{1}{4}\right) \times [(X_1 + X_2 + X_3 + X_4)^2],$$

$$B_4 = \left(\frac{1}{4}\right) \times [(33.8 + 31.3 + 30.5 + 31.8)^2], \text{ and}$$

$$B_4 = 4058.$$

The new standard deviation for the η_{cook} is as follows:

$$S_4 = (1/\sqrt{3}) \times \sqrt{(4064 - 4058)}, \quad (A1.25)$$

$$S_4 = 1.41 \%.$$

A1.5.7 *Step 6*—Recalculate the absolute uncertainty using the new average and standard deviation:

$$U_4 = 1.59 \times S_4, \quad (A1.26)$$

$$U_4 = 1.59 \times 1.41, \text{ and}$$

$$U_4 = 2.24 \%.$$

A1.5.8 *Step 7*—Recalculate the percent uncertainty:

$$\% U_4 = (U_4/Xa_4) \times 100 \%, \quad (A1.27)$$

$$\% U_4 = (2.24/31.9) \times 100 \%, \text{ and}$$

$$\% U_4 = 7 \%.$$

A1.5.9 *Step 8*—Since the percent uncertainty, % U_4, is less than ±10 %; the average for the η_{cook} is reported along with its corresponding absolute uncertainty, U_4, as follows:

$$\eta_{cook}: 31.9 \pm 2.24 \% \quad (A1.28)$$

The *PC* and its absolute uncertainty can be calculated and reported following the same steps, assuming the ±10 % precision requirement has been met for the corresponding η_{cook}.

APPENDIXES

(Nonmandatory Information)

X1. RESULTS REPORTING SHEETS

Manufacturer________________
Model ____________________
Serial # ____________________
Date ______________________
Test Reference Number (optional)_______________

Test Oven Description

Description of operational characteristics:
____
____
____
____

Physical Dimensions
Size of oven: ______Hx ______ Wx ______ D in.
Number of racks :______
Space between racks: ______in.

Apparatus

_____Check if testing apparatus conformed to specifications in Section 5.

Deviations
____
____
____

Energy Input Rate

Test Voltage (V) _____
Gas Heating Value (Btu/ft^3) ______
Rated (Btu/h or kW) ______
Measured (Btu/h or kW) ______
Percent Difference between Measured and Rated (%) ______
Fan/Control Energy Rate (kW, gas ovens only) ______

Preheat Energy and Time

Test Voltage (V) ______
Gas Heating Value (Btu/ft^3) ______
Energy Consumption (Btu or kWh) ______
Time from ______ °F to 350°F (min) ______

Idle Energy Rate

Test Voltage (V) ______
Gas Heating Value (Btu/ft^3) ______
Humidity Setting ______
Idle Energy Rate (Btu/h or kW) ______
Water Consumption Rate (gal/h) ______

Pilot Energy Rate

Gas Heating Value (Btu/ft^3) ______
Pilot Energy Rate (Btu/h) ______

Cooking-Energy Efficiency and Cooking Energy Rate

_____Check if oven was set at 350°F and full combination mode (maximum humidity) for the duration of the tests.

Alternate Cooking Program:
____
____
____

Light Load:

Test Voltage (V) ______
Gas Heating Value (Btu/ft^3) ______
Cooking-Energy Efficiency (%) ______
Cooking Energy Rate (Btu/h or kW) ______
Electric Energy Rate (kW, gas ovens only) ______
Cooking Time (min) ______
Shrinkage (%) ______
Water Consumption (gal/h) ______
Condensate Temperature Max. (°F) ______
Condensate Temperature Average (°F) ______

Heavy Load:

Test Voltage (V) ______
Gas Heating Value (Btu/ft^3) ______
Cooking-Energy Efficiency (%) ______
Cooking Energy Rate (Btu/h or kW) ______
Electric Energy Rate (kW, gas ovens only) ______
Cooking Time (min) ______
Shrinkage (%) ______
Water Consumption (gal/h) ______

Condensate Temperature Max. (°F) ______
Condensate Temperature Average (°F) ______

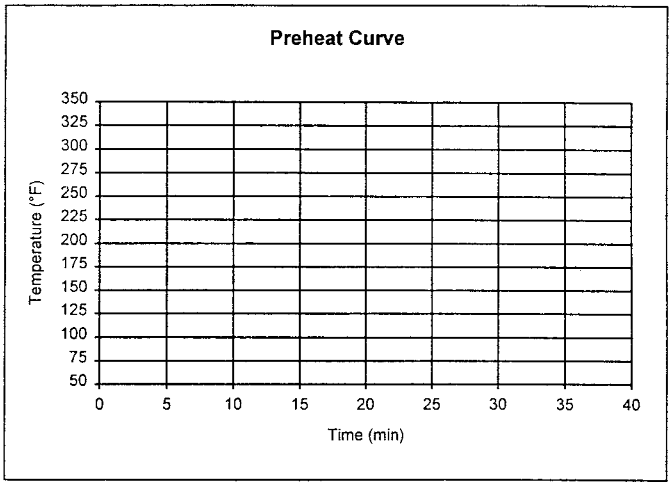

FIG. X1.1 Preheat Curve

X2. PROCEDURE FOR CALCULATING THE ENERGY CONSUMPTION OF A COMBINATION OVEN BASED ON REPORTED TEST RESULTS

X2.1 Appliance test results are useful not only for benchmarking appliance performance, but also for estimating appliance energy consumption. The following procedure is a guideline for estimating combination oven energy consumption based on data obtained from applying the appropriate test method.

X2.2 The intent of this Appendix is to present a standard method for estimating oven energy consumption based on ASTM performance test results. The examples contained herein are for information only and should not be considered an absolute. To obtain an accurate estimate of energy consumption for a particular operation, parameters specific to that operation should be used (for example, operating time, and amount of food cooked under heavy- and light-load conditions)

X2.3 The appropriate combination oven performance parameters are obtained from Section 11 in the test method.

X2.4 *Procedure*:

NOTE X2.1—Sections X2.5 and X2.6 show how to apply this procedure.

X2.4.1 The calculation will proceed as follows: First, determine the appliance operating time and total number of preheats. Then estimate the quantity of food cooked and establish the breakdown among heavy- (fully-loaded oven) and light- (single-rack) loads. For example, an oven operating for 12 h a day with two preheats cooked 200 lbs of food: 80 % of the food was cooked under heavy-load conditions and 20 % was cooked under light-load conditions. Calculate the energy due to cooking at heavy and light-load cooking rates, and then calculate the idle energy consumption. The total daily energy is the sum of these components plus the preheat energy. For simplicity, it is assumed that subsequent preheats require the same time and energy as the first preheat of the day.

X2.4.2 *Step 1*—Determine the oven operating time, number of preheats, and amount of food cooked under heavy- and light-load conditions.

X2.4.3 *Step 2*—Calculate the time and energy involved in cooking heavy- (full) loads. Heavy-loads are the equivalent of filling oven with food to be cooked.

X2.4.3.1 The total time cooking heavy-loads is determined as follows:

$$t_h = \frac{\%_h \times W}{PC} \qquad \text{(X2.1)}$$

where:

t_h = total time cooking heavy-loads, h,
$\%_h$ = the percentage of food cooked under heavy-load conditions during the day,
W = total weight of food cooked per day, lb, and
PC = the oven's production capacity as determined in 11.8.3, lb/h.

X2.4.3.2 The heavy-load energy consumption is calculated using the following set of equations. For gas ovens, any electric energy shall be determined separately using the electric equations.

$$E_{gas,h} = q_{gas,h} \times t_h \qquad \text{(X2.2)}$$
$$E_{elec,h} = q_{elec,h} \times t_h$$

where:

$E_{gas,h}$ = total gas heavy-load energy consumption, Btu,
$q_{gas,h}$ = gas heavy-load cooking energy rate as determined in 11.8.2, Btu/h,
$E_{elec,h}$ = total electric heavy-load energy consumption, kWh, and
$q_{elec,h}$ = electric heavy-load cooking energy rate as determined in 11.8.2, kW.

X2.4.4 *Step 3*—Calculate the time and energy involved in cooking light- (single-rack) loads.

X2.4.4.1 The total time cooking light-loads is determined as follows:

$$t_l = \frac{\%_l \times W}{PR_l} \quad \text{(X2.3)}$$

where:
t_l = total time cooking light-loads, h,
$\%_l$ = the percentage of food cooked under light-load conditions during the day,
W = total weight of food cooked per day, lb, and
PR_l = the oven's light-load production rate as determined in 11.8.6, lb/h.

X2.4.4.2 The light-load energy consumption is calculated using the following set of equations. For gas ovens, any electric energy shall be determined separately using the electric equations.

$$E_{gas,l} = q_{gas,l} \times t_l \quad \text{(X2.4)}$$
$$E_{elec,l} = q_{elec,l} \times t_l$$

where:
$E_{gas,l}$ = total gas light-load energy consumption, Btu,
$q_{gas,l}$ = gas light-load cooking energy rate as determined in 11.8.2, Btu/h,
$E_{elec,l}$ = total electric light -load energy consumption, kWh, and
$q_{elec,l}$ = electric light-load cooking energy rate as determined in 11.8.2, kW.

X2.4.5 *Step 4*—Calculate the total idle time and energy consumption.

X2.4.5.1 The total idle time is determined as follows:

$$t_i = t_{on} - t_h - t_l - \frac{n_p \times t_p}{60} \quad \text{(X2.5)}$$

where:
t_i = the total idle time, h,
t_{on} = the total daily on-time, h,
n_p = the number of preheats, and
t_p = preheat time, as determined in 11.5, min.

X2.4.5.2 The idle energy consumption is calculated using the following set of equations. For gas ovens, any electric energy shall be determined separately using the electric equations.

$$E_{gas,i} = q_{gas,i} \times t_i \quad \text{(X2.6)}$$
$$E_{elec,i} = q_{elec,i} \times t_i$$

where:
$E_{gas,i}$ = total gas idle energy consumption, Btu,
$q_{gas,i}$ = gas idle energy rate as determined in 11.6, Btu/h,
$E_{elec,i}$ = total electric idle energy consumption, kWh, and
$q_{elec,i}$ = electric idle energy rate as determined in 11.6, kW.

X2.4.6 *Step 5*—The total daily energy consumption is calculated as follows:

$$E_{gas,daily} = E_{gas,h} + E_{gas,l} + E_{gas,i} + n_p \times E_{gas,p} \quad \text{(X2.7)}$$
$$E_{elec,daily} = E_{elec,h} + E_{elec,l} + E_{elec,i} + n_p \times E_{elec,p}$$

where:
$E_{gas,daily}$ = the total daily gas energy consumption, Btu/d,
n_p = the total number of preheats per day,
$E_{gas,p}$ = gas preheat energy consumption as determined in 11.5, Btu,
$E_{elec,daily}$ = the total daily electric energy consumption, kWh/d, and
$E_{elec,p}$ = electric preheat energy consumption as determined in 11.5, kWh.

X2.4.6.1 The complete formulae for calculating daily energy consumption are as follows:

$$E_{gas,daily} = \frac{\%_h \times W}{PC} \times q_{gas,h} + \frac{\%_l \times W}{PR_l} \times q_{gas,l} + \left(t_{on} - \frac{\%_h \times W}{PC} - \frac{\%_l \times W}{PR_l} - \frac{n_p \times t_p}{60}\right) \times q_{gas,i} + n_p \times E_{gas,p} \quad \text{(X2.8)}$$
$$E_{elec,daily} = \frac{\%_h \times W}{PC} \times q_{elec,h} + \frac{\%_l \times W}{PR_l} \times q_{elec,l} + \left(t_{on} - \frac{\%_h \times W}{PC} - \frac{\%_l \times W}{PR_l} - \frac{n_p \times t_p}{60}\right) \times q_{elec,i} + n_p \times E_{elec,p}$$

X2.4.7 *Step 6*—The average electric demand for ovens may be calculated according to the following equation:

$$q_{avg} = \frac{E_{elec,daily}}{t_{on}} \quad \text{(X2.9)}$$

where:
q_{avg} = the average demand for the oven, kW,
$E_{elec,daily}$ = the total daily electric energy consumption, kWh/d, and
t_{on} = the total daily on-time, h.

NOTE X2.2—It has been assumed that the appliance's probable contribution to the building's peak demand is the average demand for the appliance. This is useful because the probability of an appliance drawing its average rate during the period that the building peak is set is significantly higher than for any other input rate for that appliance. If data exists otherwise for a given operation, the probable contribution to demand can be other than the average demand.

X2.4.8 *Step 7*—The estimated monthly appliance energy cost may be determined as follows:

$$C_{gas,monthly} = r_{gas} \times \frac{E_{gas,daily}}{100\,000\,\frac{Btu}{therm}} \times d_{op} \quad \text{(X2.10)}$$

$$C_{elec,monthly} = r_{elec} \times E_{elec,daily} \times d_{op} + r_{demand} \times q_{avg} \quad \text{(X2.11)}$$

where:
$C_{gas,monthly}$ = the monthly appliance gas cost, \$/mo,
r_{gas} = the appropriate utility gas rate, \$/therm,
$E_{gas,daily}$ = the total daily gas energy consumption, Btu/d,
d_{op} = the average number of operating days per month,

$C_{elec,monthly}$ = the monthly appliance electric cost, \$/mo,
r_{elec} = the appropriate utility electric rate, \$/kWh,
$E_{elec,daily}$ = the total daily electric energy consumption, kWh/d,
r_{demand} = the appropriate utility demand charge, \$/kW, and
q_{avg} = the average demand for the griddle, kW.

X2.5 *Example of Calculating the Daily Energy Consumption for an Electric Combination Oven*:

X2.5.1 Application of the test method to an electric oven yielded the following results:

TABLE X2.1 Electric Oven Test Results—Example

Test	Result
Preheat Time	11.0 min
Preheat Energy	1.5 kWh
Idle Energy Rate	2.1 kW
Heavy-Load Cooking Energy Rate	9.2 kW
Light-Load Cooking Energy Rate	3.7 kW
Production Capacity	73 lb/h
Light-Load Production Rate	15 lb/h

X2.5.2 *Step 1*—The following appliance operation is assumed:

TABLE X2.2 Oven Operation Assumptions

Operating Time	12 h
Number of Preheats	2 preheats
Total Amount of Food Cooked	200 lb
Percentage of Food Cooked under Heavy-Load Conditions	80 % (× 200 lb = 160 lb)
Percentage of Food Cooked under Light-Load Conditions	20 % (× 200 lb = 40 lb)

X2.5.3 *Step 2*—Calculate the total heavy-load energy.

X2.5.3.1 The total time cooking heavy-loads is as follows:

$$t_h = \frac{\%_h \times W}{PC} \tag{X2.12}$$

$$t_h = \frac{80\ \% \times 200\ lb}{73\ lb/h}$$

$$t_h = 2.19\ h$$

X2.5.3.2 The total heavy-load energy consumption is then calculated as follows:

$$E_{elec,h} = q_{elec,h} \times t_h \tag{X2.13}$$

$$E_{elec,h} = 9.2\ kW \times 2.19\ h$$

$$E_{elec,h} = 20.15\ kWh$$

X2.5.4 *Step 3*—Calculate the total light-load energy.

X2.5.4.1 The total time cooking light-loads is as follows:

$$t_l = \frac{\%_l \times W}{PR_l} \tag{X2.14}$$

$$t_l = \frac{20\ \% \times 200\ lb}{15\ lb/h}$$

$$t_l = 2.67\ h$$

X2.5.4.2 The total light-load energy consumption is then calculated as follows:

$$E_{elec,l} = q_{elec,l} \times t_l \tag{X2.15}$$

$$E_{elec,l} = 3.7\ kW \times 2.67\ h$$

$$E_{elec,l} = 9.88\ kWh$$

X2.5.5 *Step 4*—Calculate the total idle time and energy consumption.

X2.5.5.1 The total idle time is determined as follows:

$$t_i = t_{on} - t_h - t_l - \frac{n_p \times t_p}{60} \tag{X2.16}$$

$$t_i = 12.0\ h - 2.19\ h - 2.67 - \frac{2\ preheats \times 11.0\ min}{60\ min/h}$$

$$t_i = 6.77\ h$$

X2.5.5.2 The idle energy consumption is then calculated as follows:

$$E_{elec,i} = q_{elec,i} \times t_i \tag{X2.17}$$

$$E_{elec,i} = 2.1\ kW \times 6.77\ h$$

$$E_{elec,i} = 14.22\ kWh$$

X2.5.6 *Step 5*—The total daily energy consumption is calculated as follows:

$$E_{elec,daily} = E_{elec,h} + E_{elec,l} + E_{elec,i} + n_p \times E_{elec,p} \tag{X2.18}$$

$$E_{elec,daily} = 20.15\ kWh + 9.88\ kWh + 14.22\ kWh + 2 \times 1.5\ kWh$$

$$E_{elec,daily} = 47.25\ kWh/day$$

X2.5.7 *Step 6*—Calculate the average demand as follows:

$$q_{avg} = \frac{E_{elec,daily}}{t_{on}} \tag{X2.19}$$

$$q_{avg} = \frac{47.25\ kWh}{12.0\ h}$$

$$q_{avg} = 3.94\ kW$$

X2.6 *Example of Calculating the Daily Energy Consumption for a Gas Combination Oven*:

X2.6.1 Application of the test method to a gas oven yielded the following results:

TABLE X2.3 Gas Oven Test Results—Example

Test	Result
Preheat Time	15.0 min
Preheat Energy[A]	20 000 Btu + 110 Wh
Idle Energy Rate[A]	18 000 Btu/h + 450 W
Heavy-Load Cooking Energy Rate[A]	62 000 Btu/h + 450 W
Light-Load Cooking Energy Rate[A]	28 000 Btu/h + 450 W
Production Capacity	72 lb/h
Light-Load Production Rate	17 lb/h

[A] Includes electric energy consumed by the fan and controls.

X2.6.2 *Step 1*—The following appliance operation is assumed:

X2.6.3 *Step 2*—Calculate the total heavy-load energy.

X2.6.3.1 The total time cooking heavy-loads is as follows:

$$t_h = \frac{\%_h \times W}{PC} \tag{X2.20}$$

$$t_h = \frac{80\ \% \times 200\ lb}{72\ lb/h}$$

TABLE X2.4 Oven Operation Assumptions

Operating Time	12 h
Number of Preheats	2 preheats
Total Amount of Food Cooked	200 lb
Percentage of Food Cooked under Heavy-Load Conditions	80 % (× 200 lb = 160 lb)
Percentage of Food Cooked under Light-Load Conditions	20 % (× 200 lb = 40 lb)

$$t_h = 2.22\ h$$

X2.6.3.2 The total heavy-load energy consumption is then calculated as follows:

$$E_{gas,h} = q_{gas,h} \times t_h \quad (X2.21)$$

$$E_{gas,h} = 62\,000\ Btu/h \times 2.22\ h$$

$$E_{gas,h} = 137\,640\ Btu$$

$$E_{elec,h} = q_{elec,h} \times t_h$$

$$E_{elec,h} = 450\ W \times 2.22\ h$$

$$E_{elec,h} = 999\ Wh$$

X2.6.4 *Step 3*—Calculate the total light-load energy.

X2.6.4.1 The total time cooking light-loads is as follows:

$$t_l = \frac{\%_l \times W}{PR_l} \quad (X2.22)$$

$$t_l = \frac{20\ \% \times 200\ lb}{17\ lb/h}$$

$$t_l = 2.35\ h$$

X2.6.4.2 The total light-load energy consumption is then calculated as follows:

$$E_{gas,l} = q_{gas,l} \times t_l \quad (X2.23)$$

$$E_{gas,l} = 28\,000\ Btu/h \times 2.35\ h$$

$$E_{gas,l} = 65\,800\ Btu$$

$$E_{elec,l} = q_{elec,l} \times t_l$$

$$E_{elec,l} = 450\ W \times 2.35\ h$$

$$E_{elec,h} = 1058\ Wh$$

X2.6.5 *Step 4*—Calculate the total idle time and energy consumption.

X2.6.5.1 The total idle time is determined as follows:

$$t_i = t_{on} - t_h - t_l - \frac{n_p \times t_p}{60} \quad (X2.24)$$

$$t_i = 12.0\ h - 2.22\ h - 2.35\ h - \frac{2\ preheats \times 15.0\ min}{60\ min/h}$$

$$t_i = 6.93\ h$$

X2.6.5.2 The idle energy consumption is then calculated as follows:

$$E_{gas,i} = q_{gas,i} \times t_i \quad (X2.25)$$

$$E_{gas,i} = 18\,000\ Btu/h \times 6.93\ h$$

$$E_{gas,i} = 124\,740\ Btu$$

$$E_{elec,i} = q_{elec,i} \times t_i$$

$$E_{elec,i} = 450\ W \times 6.93\ h$$

$$E_{elec,i} = 3118\ Wh$$

X2.6.6 *Step 5*—The total daily energy consumption is calculated as follows:

$$E_{gas,daily} = E_{gas,h} + E_{gas,l} + E_{gas,i} + n_p + E_{gas,p} \quad (X2.26)$$

$$E_{gas,daily} = 137\,640\ Btu + 65\,800\ Btu + 124.\,740\ Btu + 2 \times 20\,000\ Btu$$

$$E_{gas,daily} = 368\,180\ Btu/day = 3.68\ therms/day$$

$$E_{elec,daily} = E + E_{elec,l} + E_{elec,i} + n_p \times E_{elec,p}$$

$$E_{elec,daily} = 999\ Wh + 1058\ Wh + 3118\ Wh + 2 \times 110\ Wh$$

$$E_{elec,daily} = 5395\ Wh/day$$

X2.6.7 *Step 6*—Calculate the average demand as follows:

$$q_{avg} = \frac{E_{elec,daily}}{t_{on}} \quad (X2.27)$$

$$q_{avg} = \frac{5395\ Wh}{12.0\ h}$$

$$q_{avg} = 450\ W$$