Designation: F2861 – 15

An American National Standard

Standard Test Method for Enhanced Performance of Combination Oven in Various Modes[1]

This standard is issued under the fixed designation F2861; 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 and water consumption and the cooking performance of combination ovens that can be operated in hot air convection, steam, and the combination of both hot air convection and steam modes. The test method is also applicable to convection ovens with moisture injection. The results of this test method can be used to evaluate a combination oven and understand its energy consumption.

1.2 This test method is applicable to gas and electric combination ovens that can be operated in convection, steam and combination modes.

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 in convection, steam and combination modes (10.4).

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

1.3.5 Cooking-energy efficiency, cooking energy rate, production capacity, water consumption and condensate temperature in steam mode (10.6).

1.3.6 Cooking-energy efficiency, cooking energy rate, and production capacity in convection mode (10.7).

1.3.7 Cooking uniformity in combination mode (10.8).

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]

D3588 Practice for Calculating Heat Value, Compressibility Factor, and Relative Density of Gaseous Fuels

F1217 Specification for Cooker, Steam

F1484 Test Methods for Performance of Steam Cookers

F1495 Specification for Combination Oven Electric or Gas Fired

F1496 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 mode, n*—for the purposes of this test method, combination mode is defined as moist heat at 350°F (177°C) with the humidity and fan set to operate at their maximum settings, hereafter referred to as combi mode.

3.1.2 *combination oven, n*—device that combines the function of hot air convection (oven mode), steam heating (steam mode), and a combination of both to perform steaming, which includes low or high temperature 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.

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

3.1.4 *convection mode, n*—for the purposes of this test method, convection mode is defined as dry heat only at 350°F (177°C) with the fan set to operate at the maximum setting.

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[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 Nov. 1, 2015. Published December 2015. Originally approved in 2010. Last previous edition approved in 2014 as F2861 – 14. DOI: 10.1520/F2861-15.

[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.

3.1.5 *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.

3.1.6 *cooking energy rate, n*—average rate of energy consumption (Btu/h (kJ/h) or kW) during the cooking-energy efficiency tests.

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

3.1.8 *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.

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

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

3.1.11 *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.

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

3.1.13 *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. May also be referred to as throughput.

3.1.14 *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.

3.1.15 *rack trolley, n*—as used in this test method, refers to a cart with integrated frame for holding pans that is designed for ease of loading and unloading product in a floor model (Specification F1495 Type 3) combination oven.

3.1.16 *steam generator, n*—as used in this test method, refers to one of three distinct methods which all conform to Grade A classification in F1217, 0 to 2.9 psig maximum compartment pressure:

3.1.16.1 *Discussion*—Injection refers to direct placement of water onto a hot surface in the cavity for moisture production (Specification F1495 Classification Style Injection).

3.1.16.2 *Discussion*—Boiler refers to a compartment outside the oven cavity through which water is heated for moisture production (Specification F1495 Classification Style Boiler).

3.1.16.3 *Discussion*—Water bath refers to a compartment inside the oven cavity through which water is heated for moisture production (Specification F1495 Classification Style Water Bath).

3.1.17 *steam mode, n*—for the purposes of this test method, steam mode is defined as the maximum humidity setting at a nominal 212°F (100°C).

3.1.18 *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)), maximum humidity, if adjustable) is determined.

4.4 Idle energy rate is determined with the combination oven set to maintain a ready-to-cook state without cooking in three operating modes—combi mode (350 ± 5°F (177 ± 2.8°C), maximum humidity, if adjustable), convection mode (350 ± 5°F (177 ± 2.8°C)), and steam mode (nominal 212°F (100°C), maximum humidity, if adjustable).

4.5 Cooking-energy efficiency, cooking energy rate and production rate are determined in steam mode and convection mode while cooking potatoes.

4.6 Water consumption (gal/h (L/h)) is monitored during idle conditions in steam mode, combi mode and convection mode and while cooking potatoes in steam mode and convection mode to characterize the rate of water usage.

4.7 Condensate temperature is monitored to characterize the combination oven's average and maximum drain temperature.

4.8 The uniformity of heating within the combination oven's compartment is determined and reported based on the average temperature on each pan during ice load cooking tests (pans of ice simulating pans of frozen food).

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 operating 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.

5.8 Cooking uniformity provides information regarding the combination oven's ability to cook food at the same rate throughout the oven compartment.

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 *Calibrated Exposed Junction Thermocouple Probes,* with a range from –20 to 400°F (–30 to 200°C), with a resolution of 0.2°F (0.1°C), and an uncertainty of ±1.0°F (±0.6°C), for measuring oven cavity and food product temperatures. Calibrated Type K thermocouples (24 GA wire) are a good choice.

6.10 *Thermocouple Probes,* with a range from 0 to 250°F (–18 to 121°C), with a resolution of 0.2°F (0.1°C), and an uncertainty of ±1.0°F (±0.6°C), for measuring temperature of the water entering the combination oven and condensate water entering the drain.

6.11 *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 %.

6.12 *Hotel Pans,* for ice loads, solid 12 by 20 by 2½-in. (300 by 500 by 65-mm) stainless steel, weighing 2.8 ± 0.2 lb (1.3 ± 0.1 kg), with a temperature sensor located in the center of each pan ⅝ in. (16 mm) from the bottom. A convenient method is to have Type T thermocouple probes with a stainless-steel protective sheath fabricated in the shape shown in Fig. 1. The sensing point is exposed and isolated thermally from the stainless-steel sheath. The probe is strapped to the pan using steel shim stock welded to the pan using a strain gage welder. The thermocouple lead TFE-fluorocarbon sheath is minimum thickness (TFE-fluorocarbon wrap rather than extruded TFE-fluorocarbon) to minimize the escape of steam where the thermocouple exits the cooking compartment. The lead is long enough to allow connection to the monitoring device while the ice loads are in the freezer, while they are being weighed, and while they are in the oven.

6.13 *2/3 Hotel Pans,* for ice loads, 13.875 by 12.750 by 2.5 in. (352 by 323 by 64 mm) stainless steel, weighing 1.8 ± 0.2 lb (0.8 ± 0.1 kg), with a temperature sensor located in the center of each pan ⅝ in. (16 mm) from the bottom (Fig. 1).

7. Reagents and Materials

7.1 *Water,* incoming water to the appliance shall have a maximum hardness of three grains per gallon and shall be within 70 ± 5°F (21 ± 3°C). If the tester's water supply does not meet the specification, a water softener or tempering kit or both may be required.

7.2 *Red Potatoes,* for the steam mode efficiency tests shall be fresh, whole, US No. 1, Size B, red potatoes. The average weight of the potatoes shall be 0.16 ± 0.02 lb (73 ± 9 g).

NOTE 1—Red potatoes are sold in three sizes: A, B, and C. This test uses Size B.

7.3 *Russet Potatoes,* for the convection mode efficiency tests shall be fresh, whole, prewashed, U.S. No. 1 Russets. Size shall be 100 count. The average weight of the potatoes shall be 0.48 ± 0.02 lb (218 ± 91 g).

7.4 *Steam Pans,* for the steam performance tests on half and full size combination ovens (Specification F1495, Classification Capacity A and B), shall be perforated 12 by 20 by 2½ in. (323 by 508 by 64 mm) stainless steel weighing 2.5 ± 0.5 lb (1.1 ± 0.2 kg).

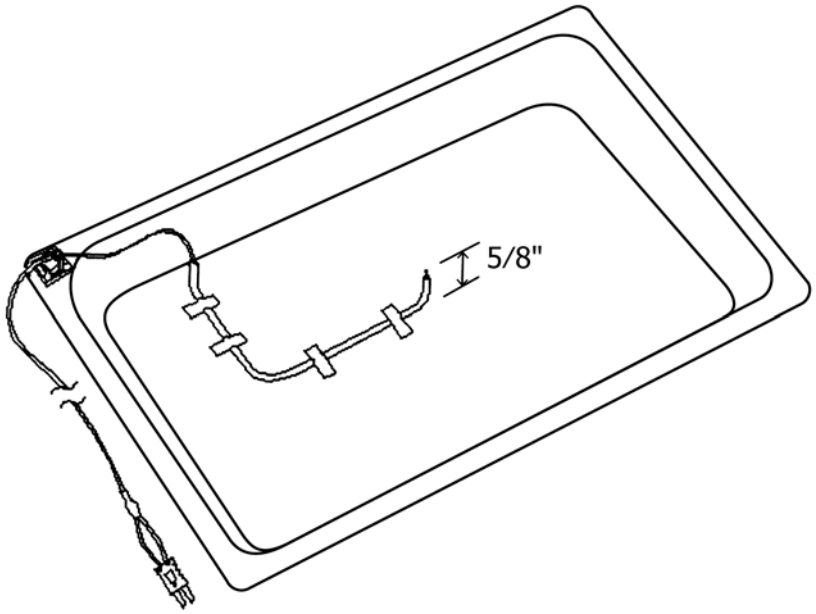

FIG. 1 Hotel Pan with Thermocouple Probe for Ice Loads

7.5 *Shallow Steam Pans,* for the convection performance tests on half and full size combination ovens (Specification F1495, Classification Capacity A and B), shall be perforated 12 by 20 by 1¼ in. (323 by 508 by 32 mm) stainless steel weighing 2.1 ± 0.5 lb (0.95 ± 0.2 kg).

7.6 *Two-Thirds Size Pans,* for testing 2/3-size combination ovens (Specification F1495, Classification Capacity C), shall be 13.875 by 12.750 by 2½ in. (352 by 323 by 64 mm) stainless steel weighing 1.6 ± 0.5 lb (0.7 ± 0.2 kg).

8. Sampling and 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 2—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.

9.7 Tape a temperature sensor firmly to the surface of a section of the metal tubing through which city water enters the combination oven.

9.8 Install a water regulator on incoming water lines. Adjust the dynamic water pressure to 45 psi (3.1 bar).

9.9 Determine the test capacity of the combination oven. For half-size (Capacity A) and full-size (Capacity B) combination ovens, the test capacity is equivalent to the manufacturer's stated capacity of standard 12 by 20 by 2½ in. (323 by 508 by 64 mm) hotel pans. For two-third size combination ovens

(Capacity C), the test capacity is the manufacturer' stated capacity of 13.875 by 12.750 by 2½ in. (352 by 323 by 64 mm) hotel pans. This will be the test capacity for all cooking tests (10.6, 10.7, 10.8).

9.10 For countertop (Specification F1495 Type 1) and stand mounted (Specification F1495 Type 2) combination ovens, the pan rack shall remain inside the oven for all tests. For floor model (Specification F1495 Type 3) combination ovens designed for operation with a removable rack trolley, the manufacturer may a provide removable bridge or a second rack trolley to close any remaining gap in the door when the rack is outside the oven during the stabilization period prior to conducting the cooking tests (10.6, 10.7, and 10.8).

10. Procedure

NOTE 3—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 day's testing).

NOTE 4—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.

10.1.5 For all tests, measure and record the ambient temperature, oven cavity temperature, incoming water temperature and condensate drain temperature.

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. For floor mounted (Type 3) combination ovens with a removable rack trolley, place the rack trolley inside the oven.

10.2.2 Set the temperature control to 350°F (177°C); set the controls to operate in the combi mode at maximum humidity; 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 operator 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 The preheat test shall be run as the first test of the day after allowing the oven to cool down for a minimum of 12 h.

NOTE 5—It is the intent of the preheat test to determine the amount of time for the combination oven to reach a ready-to-cook state in each mode after it has been off for an extended period (for example, overnight). The preheat tests for each mode should be conducted as the first appliance operation on the day of tests for each operating mode (for example, combi, convection, steam).

10.3.2 For floor mounted (Type 3) combination ovens with a removable rack trolley, place the rack trolley inside the oven.

10.3.3 Fill the boiler or reservoir (boiler or water-bath style combination ovens). Record the time required to fill it. Monitor the average temperature of the water as it enters the boiler or reservoir. If the average temperature was not 70 ± 5°F (21 ± 3°C), then allow the filled boiler or reservoir to sit until the temperature is within that range. Temperature of the water in the boiler can be estimated by measuring the boiler surface temperature using a surface temperature probe.

NOTE 6—In some units the filling and heating phases cannot be individually controlled. Heating may start as soon as the water level reaches the minimum while still filling the entire unit.

10.3.4 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 combi mode at maximum humidity and the fan set to operate in the maximum speed; and turn the combination oven on.

10.3.5 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).

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

10.3.7 After allowing the oven to cool for a minimum of 12 h, determine the preheat energy consumption and time for the oven operating in convection mode. Repeat 10.3.1 through 10.3.6 with the oven set to operate in convection (dry heat) mode, with the fan set to operate at its maximum speed and the oven cavity vent in the closed position.

10.3.8 After allowing the oven to cool for a minimum of 12 h, determine the preheat energy consumption and time for the oven operating in steam mode. Set the oven to steam mode (maximum humidity, maximum fan speed) at a nominal temperature setting of 212°F (100°C), based on the manufacturer controls.

10.3.9 Start the preheat and monitor energy consumption and time as soon as the unit is turned on. For a gas combination oven, the recorded preheat time shall include any delay between the time the unit is turned on and when the burners actually ignite. Preheat is judged complete when the primary burners, elements, or steam coil cycles off or when the steamer compartment reaches 205°F. Record preheat energy consumption, duration, and final temperature.

10.3.10 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:*

NOTE 7—It is the intent of the idle test to determine the average energy and water use under each operating mode (combination, convection and steam), while not cooking food.

10.4.1 For floor mounted (Type 3) combination ovens with a removable rack trolley, place the rack trolley inside the oven.

10.4.2 Determine the idle energy rate in combi mode. Set the temperature controls to maintain the average cavity air temperature at 350 ± 5°F (177 ± 2.8°C) and the oven set to operate in full combi mode (maximum humidity, maximum fan speed), then turn the combination oven on.

10.4.3 Allow the combination oven to stabilize at these settings for 60 min after the burners or elements commence cycling in that mode.

10.4.4 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.

10.4.5 At the end of the 3-h test, stop saving data, turn off the oven and open the door to cool and vent the cavity. Leave the door open for a minimum of 10 min to allow the cavity to fully vent before running additional idle tests.

10.4.6 Determine the idle energy rate in convection mode. Set the oven to operate in convection (dry heat) mode, with the fan set to operate at its maximum speed and the oven cavity vent in the closed position. Turn the oven on and repeat 10.4.3 through 10.4.5.

10.4.7 Determine the idle energy rate in steam mode. Set the oven to operate in steam mode (maximum humidity, maximum fan speed) at a nominal 212°F (100°C). Turn the oven on and repeat 10.4.3 through 10.4.5.

10.4.8 In accordance with 11.6, calculate and report the combination oven's idle energy rate and water consumption rate in each operating mode.

10.5 *Pilot Energy Rate (if applicable, for standing pilots):*

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 *Steam Mode Cooking Energy Efficiency:*

10.6.1 The steam mode cooking energy efficiency test 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, production capacity, cooking energy rate, condensate temperature, and water consumption shall be the average of the replications (runs).

10.6.2 For half-size (Capacity A) and full-size (Capacity B) combination ovens, the steam pans as specified in 7.4 shall be used for the steam mode cooking-energy efficiency tests. For two-thirds size (Capacity C) combination ovens the steam pans specified in 7.6 shall be used for the steam mode cooking-energy efficiency tests.

10.6.3 Number each steam pan and record the weight of each (empty) steam pan.

10.6.4 Prepare a minimum number of loads for three test runs. For half-size (Capacity A) and full-size (Capacity B) combination ovens, load each steam pan with 8.0 ± 0.2 lb (3.6 ± 0.1 kg) of red potatoes (7.2). Each pan shall contain between 48 and 52 red potatoes (see Fig. 2). For two-thirds size (Capacity C) combination ovens, load each steam pan with 5.3 ± 0.2 lb (2.4 ± 0.1 kg) of red potatoes (7.2). Each pan shall contain between 32 and 36 red potatoes. Record the actual weight and count of the potato load in each pan.

NOTE 8—If the weight of the potatoes on a pan is outside the 8.0 ± 0.2 lb (3.6 ± 0.1 kg) weight range specified above, substitute smaller or larger potatoes, as necessary, until the weight of the potatoes on each pan is within the required weight range while maintaining a count of 50 ± 2 potatoes per pan.

10.6.5 If the combination oven has a removable rack trolley, the rack trolley shall remain outside the oven until loading takes place (10.6.10). A manufacturer-supplied bridge or supplemental rack trolley may be required. Refer to the oven operator's manual.

10.6.6 For half-size (Capacity A) and full-size (Capacity B) combi ovens, randomly select 20 potatoes from the potato load for temperature monitoring, such that the monitored potatoes are located on each level of the combination oven, from top to bottom. For ⅔-size (Capacity C) combi ovens, select 10 potatoes from the potato load for temperature monitoring.

NOTE 9—For a given pan, monitor potatoes at different combinations of locations for each test run. For example, if for Run No. 1, potatoes on Pan No. 5 are monitored at Location Nos. 5, 17, and 29, potatoes on this pan

FIG. 2 Red Potato Load

are not to be monitored at this same combination of locations during subsequent test runs.

10.6.7 Shortly before each test run, place a thermocouple into the center of the randomly-selected potatoes. The thermocouple shall be inserted from the long end of oblong-shaped potatoes, into the potato's center. Secure each thermocouple lead wire in such a manner that its junction will remain at the center of the potato throughout the cooking period. The temperature of the potatoes at the start of each test shall be 75 ± 5°F (24 ± 3°C). If the Type 3 combination oven has a removable rack, load the pans of potatoes onto the rack. The temperature of the rack, pan and potatoes at the start of each test shall be 75 ± 5°F (24 ± 3°C).

10.6.8 Allow the combination oven to stabilize in a ready-to-cook (212°F (100°C)), maximum humidity, maximum fan speed) state for a minimum of 1 h.

NOTE 10—The combination oven shall be stabilized in the same operating mode that will be used for the cooking test. If the combination oven is to be tested in a reduced-input mode, then the oven shall be stabilized in the same mode for at least 1 h prior to loading with food product.

10.6.9 After the stabilization period, wait for the burners, or elements to cycle on and then off again. This assures a consistent starting point for replicate test runs.

10.6.10 When the oven ready light or heat on light goes off, begin recording the oven energy consumption. Open the oven door immediately, and allow it to remain open for the entire loading period, as indicated in 10.6.11. Do not close the door, even if the pan loading is completed in less than the allotted time. At the end of the load period, close the oven door and record the initial average potato temperature to the nearest 0.1°F (0.06°C). Record the time as the beginning of the cooking period.

10.6.11 The total loading time (the time from opening the first compartment to closing and starting the last compartment) shall be the total of 5 s per pan for each load used (for example, the total loading time for a test of a six-pan capacity, full-size combination oven would be: 5 s/pan × 12 pans = 60 s). For Type 3 combination ovens with a removable rack trolley, the maximum load time shall be 60 s.

10.6.12 Monitor the average potato temperature during cooking. When the average potato temperature reaches 195 ± 2°F (91 ± 1°C) shut the oven off immediately, and record the amount of water and energy consumed and the elapsed cook time to the nearest 0.1 min. (Cook time is the time from when the oven door is closed until the oven is shut off.)

NOTE 11—For gas combination ovens, the "electric energy rate" during the heavy load test will be reported separately from the gas "cooking energy rate." The two values are reported separately so that the respective fuel prices may be applied to estimate energy costs.

10.6.13 Confirm the cooked potato temperature by measuring and recording the temperature of five randomly selected potatoes for each pan. Ensure that each quadrant in each pan is represented. Temperature shall be measured immediately after cooking is terminated. The last temperature taken shall be no more than 3 min after cooking is terminated. The average temperature (including monitored and spot-checked potatoes) must be 195 ± 2°F (91 ± 1°C). If the temperature does not fall in this range, the test must be repeated with an adjusted cook time.

10.6.14 Remove the thermocouples from the potatoes, and quickly remove all of the pans from the oven prior to weighing them. Record the final weight of each pan of potatoes within the maximum allowed time as measured from the time at which the oven was shut off. Calculate and record the final weight of the potatoes in each pan. Record all weights to the nearest 0.01 lb (0.005 kg). Once the pans have been removed from the oven, close the door and restart the oven.

10.6.15 Remove the potato loads, and unless this was the final run (Run No. 3), return to step 10.6.7.

10.6.16 In accordance with 11.8, calculate and report cooking energy efficiency, cooking energy rate, production rate, water consumption, and average condensate temperature. After performing the necessary test replicates, report results as the average of the replications.

10.7 *Convection Mode Cooking Energy Efficiency and Production Capacity:*

10.7.1 The convection mode cooking energy efficiency test 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, production capacity, and cooking energy rate shall be the average of the replications (runs).

10.7.2 For half-size (Capacity A) and full-size (Capacity B) combination ovens, shallow steam pans as specified in 7.5 shall be used for the convection mode cooking-energy efficiency tests. For two-thirds size (Capacity C) combination ovens, the steam pans specified in 7.6 shall be used for the convection mode cooking-energy efficiency tests.

10.7.3 Number each shallow steam pan and record the weight of each (empty) shallow steam pan.

10.7.4 Prepare a minimum number of loads for three test runs. For half-size (Capacity A) and full-size (Capacity B) combination ovens, place 15 russet potatoes (7.3) (three rows of five potatoes per row) on each pan (Fig. 3). The weight of the potatoes on these pans shall be 7.25 ± 0.30 lb (3.3 ± 0.14 kg). For two-thirds size (Capacity C) combination ovens, load each steam pan with 10 russet potatoes. The weight of these potatoes shall be 4.8 ± 0.2 lb (2.2 ± 0.1 kg). Record the weight of the potatoes on each pan. For each test run, record the total weight of all of the potatoes as the initial potato weight. Record all weights to the nearest 0.01 lb (0.005 kg).

NOTE 12—If the weight of the potatoes on a pan is outside the 7.25 ± 0.30-lb (3.3 ± 0.14-kg) weight range specified above, substitute smaller or larger potatoes, as necessary, until the weight of the potatoes on each pan is within one of the appropriate required weight ranges.

10.7.5 Once the pans of potatoes have been prepared, mark selected potatoes to be monitored for temperature. Randomly select 20 potatoes from the potato load for temperature monitoring, such that the monitored potatoes are located on each level of the combination oven, from top to bottom.

NOTE 13—For a given pan, monitor potatoes at different combinations of locations for each test run. For example, if for Run No. 1, potatoes on Pan No. 5 are monitored at Location Nos. 5, 17, and 29, potatoes on this pan are not to be monitored at this same combination of locations during subsequent test runs.

10.7.6 If the Type 3 combination oven has a removable rack trolley, the rack trolley shall remain outside the oven until

FIG. 3 Russet Potato Load

loading takes place (10.7.10). A manufacturer-supplied bridge or supplemental rack trolley may be required. Refer to the combination oven operator's manual.

10.7.7 Shortly before each test run, place the bead of a bare junction thermocouple into the center of the marked potatoes being cooked. The thermocouple shall be inserted from the long end of the oblong-shaped potato, into the potato's center. Secure each thermocouple lead wire in such a manner that its junction will remain at the center of the potato throughout the cooking period. Ensure that the temperature readout device displays the average temperature of all of the monitored potatoes. The temperature of the potatoes at the start of each test shall be 75 ± 5°F (21 ± 2.8°C).

10.7.8 Set the oven to operate in convection mode at 350°F (177°C) (dry heat only, fan at maximum speed) and preheat the oven to 350°F (177°C). Allow the oven to idle at 350°F (177°C) for 1 h prior to the start of the first test run. Once this time period has elapsed, wait for the oven elements or burners to cycle one additional time before starting the test run to ensure that the oven cavity air temperature is at 350°F (177°C).

10.7.9 When the oven ready light or heat on light goes off, begin recording the oven energy consumption. Open the oven door immediately, and allow it to remain open for the entire loading period, as indicated in 10.7.10. Do not close the door, even if the pan loading is completed in less than the allotted time. At the end of the load period, close the oven door and record the initial average potato temperature to the nearest 0.1°F (0.06°C). Commence monitoring oven energy and water consumption, elapsed time and potato temperature. Record the time as the beginning of the cooking period.

10.7.10 The total loading time (the time from opening the first compartment to closing and starting the last compartment) shall be the total of 5 s per pan for each load used (for example, the total loading time for a heavy load test of a six-pan capacity, full-size combination oven would be: 5 s/pan × 12 pans = 60 s). For Type 3 combination ovens with a removable rack trolley, the maximum load time shall be 60 s.

10.7.11 Monitor the average potato temperature during cooking. When it reaches 205°F (96°C), shut the oven off immediately, and record the amount of energy consumed and elapsed cook time to the nearest 0.1 min. (Cook time is the time from when the oven door is closed until the oven is shut off.) Remove the thermocouples from the potatoes, and quickly remove all of the pans from the oven prior to weighing them. Record the final weight of each pan of potatoes within the maximum allowed time (5 min) as measured from the time at which the oven was shut off. Calculate and record the final weight of the potatoes in each pan. Record the sum of these five weights as the final potato weight. Record all weights to the nearest 0.01 lb (0.005 kg). Calculate the oven's cooking energy efficiency, production rate, and cooking energy rate (see 11.9). Once the pans have been removed from the oven, close the door and restart the oven.

10.7.12 Perform Run Nos. 2 and 3 by repeating the steps given in 10.7.4 – 10.7.11. Follow the procedure in Annex A1 to determine whether more than three test runs are required. Report the results for the cooking energy efficiency, production rate, cooking energy rate, and cook time as described in Annex A1.

10.8 *Combi Mode Cooking Uniformity:*

NOTE 14—The intent of this procedure is to demonstrate potential pan-to-pan temperature variability in the cooking compartment using ice as a simulated food product. Ice loads are representative of food loads, while allowing for more consistent temperature measurement.

10.8.1 The cooking uniformity test must be repeated three times. The reported final pan temperatures shall be the average of the replications (runs).

10.8.2 Prepare enough ice loads for three runs.

10.8.3 For half-size (Capacity A) and full-size (Capacity B) combination ovens, the solid hotel pans shall be as specified in 6.12. For two-thirds size (Capacity C) combination ovens, the solid hotel pans shall be as specified in 6.13.

10.8.4 Number each pan and record the weight of each of the (dry) pans.

10.8.5 For half-size (Capacity A) and full-size (Capacity B) combination ovens, fill the pans with 8.0 ± 0.2 lb (3.6 ± 0.1 kg) of water. For two-thirds size (Capacity C) combination ovens, fill the pans with 5.3 ± 0.2 lb (2.4 ± 0.1 kg) of water. Note that there may be some water loss after freezing.

10.8.6 Freeze the loads to 0 ± 5°F (–18 ± 2°C).

10.8.7 Record the initial average ice load temperature. Confirm that they are at 0 ± 5°F (–18 ± 3°C).

10.8.8 Allow the combination oven to stabilize in combi mode (350°F (177°C), maximum humidity, maximum fan speed) for a minimum of 1 h.

10.8.9 Near the end of the stabilization period, remove each pan from the freezer, remove the lid, and weigh. Record the starting weight of each ice load (including the pan itself) for that run. Record the dry pan weights as determined in 10.8.4. After the stabilization period, wait for the burners or elements to cycle on and then off again.

10.8.10 When the oven ready light or heat on light goes off, begin recording the oven energy consumption. Open the oven door immediately, and allow it to remain open for the entire loading period, as indicated in 10.8.11. Do not close the door, even if the pan loading is completed in less than the allotted time. At the end of the load period, close the oven door and record the initial average ice temperature to the nearest 0.1°F (0.06°C). Record the time as the beginning of the cooking period.

10.8.11 The total loading time (the time from opening the first compartment to closing and starting the last compartment) shall be the total of 5 s per pan for each load used (for example, the total loading time for a test of a six-pan capacity, full-size combination oven would be: 5 s/pan × 12 pans = 60 s). For Type 3 combination ovens with a removable rack trolley, the maximum load time shall be 60 s.

NOTE 15—Care shall be taken to minimize heat gain by the ice loads on the way from the freezer to the combination oven. During that time, they shall be isolated from any warmer surface by R10 or better insulation. PG&E found 2-in. (50-mm) thick square-edged polystyrene boards to be convenient as an insulating surface.

NOTE 16—Care shall be taken to minimize heat loss out of the cooking compartment where the sensor leads pass under the door gasket. PG&E found that heat loss was not significant as long as the sensor leads were not

bunched or paired as they passed under the door gasket.

10.8.12 When the first pan reaches 170°F (77°C), record the time and continue the test. Continue to monitor the ice load temperatures, recording the elapsed time as the next pan reaches 170°F (77°C).

10.8.13 When the last pan reaches 170°F (77°C), record the total elapsed time and turn off the combination oven.

10.8.14 Remove the ice loads, and unless this was the final run (Run No. 3), start timing the 10-min stabilization period before the next run. Return to 10.8.5.

10.8.15 In accordance with 11.10, calculate and report the average cook time and cooking uniformity. After performing this test at least three times, report the results as the average of the replications.

11. Calculation and Report

11.1 *Test Combination Oven*—Using Specification F1495 classifications, 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:

$$E_{gas} = V \times HV \tag{1}$$

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 (m^3),
T_{cf} = temperature correction factor,

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

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

P_{cf} = pressure correction factor,

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

NOTE 17—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 D3588 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 combi mode preheat energy consumption (Btu or kWh) and preheat time (min).

11.5.2 Report the preheat time and energy consumption for the convection and steam modes.

11.5.3 Generate a graph showing the combination oven cavity temperature versus time for the preheat period for each operating mode (combi, convection, steam).

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 Report the idle energy rate in convection and steam modes using the equation in 11.6.1.

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 *Steam Mode Cooking-Energy Efficiency, Cooking Energy Rate, Production Capacity, Water Consumption, and Condensate Temperature:*

11.8.1 Report a minimum of three run average value of steam mode cooking-energy efficiency, production capacity cooking energy rate and water consumption.

11.8.2 Calculate steam mode cooking-energy efficiency according to the following relationship:

$$\eta_{steam} = \frac{E_{potato,\ s} + E_{pan,\ s}}{E_{oven,\ s}} \quad (5)$$

where:

η_{steam} = steam mode cooking-energy efficiency, %,
$E_{potato,\ s}$ = heat gained by the red potatoes,
= $W_{p,s} \times Cp_{p,s} \times (Tf_{p,s} - Ti_{p,s})$

where:

$W_{p,s}$ = initial weight of red potatoes, lb,
$Cp_{p,s}$ = specific heat of red potatoes, Btu/lb°F,
= 0.87 Btu/lb°F,
$Tf_{p,s}$ = average temperature of all of the red potatoes at the end of the steam mode cooking test, °F,
$Ti_{p,s}$ = average temperature of all of the red potatoes at the beginning of the steam mode cooking test, °F, and
$E_{pan,s}$ = heat gained by the steam pan(s).

NOTE 18—For this analysis, the specific heat (C_p) of a load of red potatoes is considered to be the weighted average of the specific heat of its components (for example, water and nonfat protein). Research conducted by PG&E determined that the weighted average of the specific heat for potatoes cooked in accordance with this test method was approximately 0.87 Btu/lb* °F.

$$E_{pan,s} = W_{pan,s} \times Cp_{pan} \times \Delta T_{pan,s} \quad (6)$$

where:

$W_{pan,s}$ = weight of steam pan(s) used in steam mode test, lb,
Cp_{pan} = specific heat of stainless-steel, Btu/lb°F,
= 0.11 Btu/lb°F (see 2.4), and
$\Delta T_{pan,s}$ = useful temperature rise in steam pan(s), °F,
= $Tf_{p,s} - Ti_{p,s}$
$E_{oven,s}$ = total energy consumed by the combination oven during the steam mode cooking test, Btu (kJ). Includes sum of all fuel types used (for example, gas energy for heating plus electric energy used by steam circulating fans and/or controls).

11.8.3 Calculate the steam mode cooking energy rate as follows:

$$q_{steam} = \frac{E_{oven,s}}{t_s} \times 60 \quad (7)$$

where:

q_{steam} = steam mode cooking energy rate, Btu/h (kJ/h) or kWh,
t_s = steam mode cooking test period, min, and
$E_{oven,s}$ = total energy consumed by the combination oven during the steam mode cooking test, Btu (kJ).

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

11.8.4 Calculate steam mode production capacity (lb(kg)) using the following equation:

$$PC_{steam} = \frac{W_{potato,s}}{t_s} \times 60 \quad (8)$$

where:

PC_{steam} = production capacity, lb/h (kg/h),
$W_{potato,s}$ = weight of red potatoes, lb (kg), and
t_s = steam mode cooking test period, min.

11.8.5 Report the average cook time for the steam mode cooking test.

11.8.6 Report the average water consumption rate during the steam mode cooking test, gal/h (L/h).

11.8.7 Report the average and maximum temperatures of the condensate drain during the steam mode cooking test, °F (°C).

11.8.8 Report the average weight change of the red potatoes during the steam mode cooking test.

11.9 *Convection Mode Cooking Energy Efficiency, Cooking Energy Rate and Production Capacity:*

11.9.1 Report a minimum of three run average value of convection mode cooking-energy efficiency, production capacity cooking energy rate and water consumption.

11.9.2 Calculate and report the convection mode cooking-energy efficiency based on the following:

$$\eta_{conv} = \frac{E_{potato,c} + E_{pan,c}}{E_{oven,c}} \quad (9)$$

where:

η_{conv} = cooking energy efficiency, %,
$E_{potato,c}$ = energy into the potatoes, Btu (kJ), and
= $E_{sens,p} + E_{vap,p}$

where:

$E_{sens,p}$ = quantity of heat added to the russet potatoes, which causes their temperature to increase from the starting temperature to the final temperature (205°F), Btu (kJ)
= $Wi_{p,c} \times Cp_{p,c} \times (Tf_{p,c} - Ti_{p,c})$

where:

$Wi_{p,c}$ = initial weight of russet potatoes, lb (kg),
$Cp_{p,c}$ = specific heat of russet potatoes, Btu/lb, °F (kJ/kg, °C),
= 0.84.
$Tf_{p,c}$ = average temperature of all of the russet potatoes at the end of the convection mode cooking test, °F,
$Ti_{p,c}$ = average temperature of all of the russet potatoes at the beginning of the convection mode cooking test, °F,

NOTE 19—For this analysis, the specific heat (C_p) of a load of russet potatoes is considered to be the weighted average of the specific heat of its components (for example, water and nonfat protein). Research conducted by PG&E determined that the weighted average of the specific heat

for potatoes cooked in accordance with this test method was approximately 0.84 Btu/lb* °F.

$E_{evap,potato}$ = latent heat (of vaporization) added to the potatoes, which causes some of the moisture contained in the potatoes to evaporate. The heat of vaporization cannot be perceived by a change in temperature and must be calculated after determining how much moisture was lost during baking.
= $(Wf_{p,c} - Wi_{p,c}) \times H_v$

where:

$Wf_{p,c}$ = final weight of the baked russet potatoes, lb (kg),
$Wi_{p,c}$ = initial weight of the raw russet potatoes, lb (kg),
H_v = heat of vaporization, Btu/lb (kJ/kg),
= 970 Btu/lb (2256 kJ/kg), and

$$E_{pan,c} = W_{pan,c} \times Cp_{pan} \times \Delta T_{pan,c} \quad (10)$$

where:

$W_{pan,c}$ = weight of shallow steam pan(s) used in convection mode test, lb,
Cp_{pan} = specific heat of stainless-steel, Btu/lb°F,
= 0.11 Btu/lb°F (see 2.4), and
$\Delta T_{pan,c}$ = useful temperature rise in shallow steam pan(s), °F,
= $Tf_{p,c} - Ti_{p,c}$
$E_{oven,c}$ = total energy consumed by the combination oven during the convection mode cooking test, Btu (kJ). Includes sum of all fuel types used (for example, gas energy for heating plus electric energy used by steam circulating fans and/or controls).

11.9.3 Calculate and report the cooking energy rate for the convection mode cooking tests based on the following:

$$q_{conv} = \frac{E_{oven,c}}{t_c} \times 60 \quad (11)$$

where:

q_{conv} = convection mode cooking energy rate, Btu/h (kJ/h) or kW,
$E_{oven,c}$ = energy consumed during the convection mode cooking test, Btu (kJ) or kWh, and
t_c = convection mode cooking test period, min.

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

11.9.4 Calculate and report the convection mode production capacity (lb/h) for the oven as follows:

$$PC_{conv} = \frac{W_{potato,c}}{t_c} \times 60 \quad (12)$$

where:

PC_{conv} = convection mode production capacity, lb/h (kg/h),

$W_{potato,c}$ = initial weight of russet potatoes, lb (kg), and
t_c = convection mode cooking test period, min.

11.9.5 Report the cook time for the convection mode cooking tests.

11.9.6 Report the average water consumption rate during the convection mode cooking test, gal/h (L/h). If no water was consumed during the convection mode cooking test, then report the rate as zero.

11.10 *Combi Mode Cooking Uniformity:*

11.10.1 For each pan, report the average initial temperature of the water in the pans.

11.10.2 For each pan, report the final temperature of the water in the pans at the end of the test using the corresponding average temperatures for the three test runs.

11.10.3 Calculate and report the maximum temperature difference between the hottest pan and the coolest pan at the end of the test.

11.10.4 Report the average test time for the three test runs.

11.10.5 Report the time difference between the first pan to reach 170°F (77°C) and the last pan to reach 170°F (77°C).

11.10.6 Generate a graph showing pan temperature versus time for each pan during the cooking uniformity test.

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 interlaboratory precision of the procedure in this test method for measuring each reported parameter is being determined.

12.2 *Bias*—The interlaboratory precision of the procedure in this test method for measuring each reported parameter is being determined.

13. Keywords

13.1 combi condensate temperature; combination oven; combination oven/combi; cooking-energy efficiency; efficiency; energy; performance; production capacity; 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.

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 average (three-test runs) is as follows:

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

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:

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

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 (⅓ 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.

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:

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

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:

$$Xa_4 \pm U_4 \quad \text{(A1.12)}$$

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:

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

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:

$$S_n = \left(1/\sqrt{(n-1)}\right) \times \left(\sqrt{(A_n - B_n)}\right) \quad \text{(A1.14)}$$

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:

$$U_n = C_n \times S_n \quad \text{(A1.15)}$$

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:

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

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:

$$Xa_n \pm U_n \quad \text{(A1.17)}$$

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:

$$Xa_3 + \left(\frac{1}{3}\right) \times (X_1 + X_2 + X_3) \quad \text{(A1.18)}$$

$$Xa_3 + \left(\frac{1}{3}\right) \times (33.8 + 31.3 + 30.5)$$

$$Xa_3 = 31.9\ \%$$

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

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

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

$$A_3 = 3052$$

$$B_3 = \left(\frac{1}{3}\right) \times [(X_1 + X_2 + X_3)^2]$$

$$B_3 = \left(\frac{1}{3}\right) \times [(33.8 + 31.3 + 30.5)^2]$$

$$B_3 = 3046$$

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

$$S_3 = \left(1/\sqrt{2}\right) \times \sqrt{(3052)} - 3046 \quad \text{(A1.20)}$$

$$S_3 = 1.73\ \%$$

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

$$U_3 = 2.48 \times S_3 \quad \text{(A1.21)}$$

$$U_3 = 2.48 \times 1.73$$

$$U_3 = 4.29\ \%$$

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

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

$$\%\ U_3 = (4.29/31.9) \times 100\ \%$$

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

A1.5.5 *Step 4*—Run a fourth test. Since the percent uncertainty for the η_{cook} is greater than $\pm 10\ \%$, 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:

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

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

$$Xa_4 = 31.9\ \%$$

The new standard deviation:
First calculate A_4 and B_4:

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

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

$$A_4 = 4064$$

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

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

$$B_4 = 4058$$

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

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

$$S_4 = 1.41\ \%$$

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

$$U_4 = 1.59 \times S_4 \quad \text{(A1.26)}$$

$$U_4 = 1.59 \times 1.41$$

$$U_4 = 2.24\ \%$$

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

$$\%\ U_4 = (U_4/Xa_4) \times 100\ \% \quad \text{(A1.27)}$$

$$\%\ U_4 = (2.24/31.9) \times 100\ \%$$

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

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

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

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

APPENDIX

(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: _____ H× _____ W× _____ 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) _____

Steam Mode Cooking-Energy Efficiency and Cooking Energy Rate

Test Voltage (V) _____

Gas Heating Value (Btu/ft^3) _____

Cooking-Energy Efficiency (%) _____

Gas Energy Consumption (Btu or kWh) _____

Electric Energy Consumption (kWh, gas ovens only) _____

Cooking Energy Rate (Btu/h or kW) _____

Electric Energy Rate (kW, gas ovens only) _____

Cooking Time (min) _____

Energy-to-Food (Btu/lb) _____

Energy-to-Appliance (Btu/lb) _____

Water Consumption (gal/h) _____

Condensate Temperature Max. (°F) _____

Condensate Temperature Average (°F) _____

Convection Mode Cooking-Energy Efficiency and Cooking Energy Rate

Test Voltage (V) _____

Gas Heating Value (Btu/ft^3) _____

Cooking-Energy Efficiency (%) _____

Gas Energy Consumption (Btu or kWh) _____

Electric Energy Consumption (kWh, gas ovens only) _____

Cooking Energy Rate (Btu/h or kW) _____

Electric Energy Rate (kW, gas ovens only) _____

Cooking Time (min) _____

Energy-to-Food (Btu/lb) _____

Energy-to-Appliance (Btu/lb) _____

Water Consumption (gal/h) _____

Condensate Temperature Max. (°F) _____

Condensate Temperature Average (°F) _____

Combi Mode Cooking Uniformity (20-pan Example)

Number of Pans _____

Initial Pan Temperature (°F (°C)) _____

Final Pan Temperatures:

Pan	Pan Temperature (°F (°C))
(top)	_____
2	_____
3	_____
4	_____
5	_____
6	_____
7	_____
8	_____
9	_____
10	_____
11	_____
12	_____
13	_____
14	_____
15	_____
16	_____
17	_____
18	_____
19	_____
20 (bottom)	_____
Maximum Temperature Difference (°F (°C))	_____
Cooking Time (min)	_____
Maximum Time Delay (min)	_____

See Fig. X1.1.

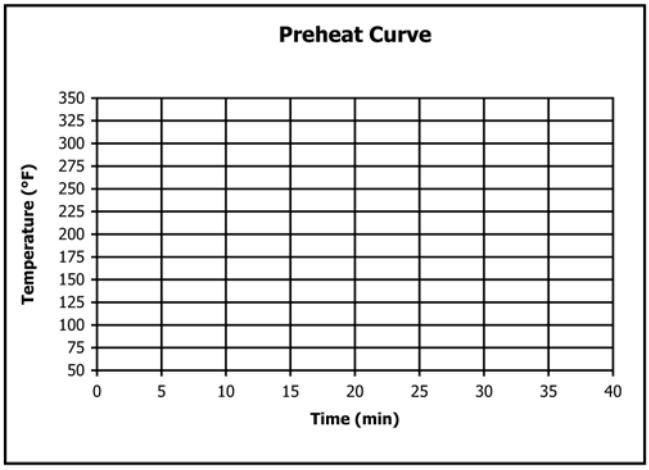

FIG. X1.1 Preheat Curve