

DEVELOPMENT OF A STANDARD TEST TO DETERMINE
THE THERMAL EFFICIENCY OF PORTABLE CONVECTION OVENS

by

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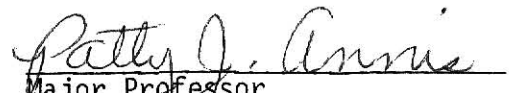
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INTRODUCTION

The increase in home energy costs and the hurried lifestyle of consumers demand that residential cooking appliances be faster and more energy-efficient than the conventional method of cooking foods. Some consumers want appliances that cook food quickly and produce nicely-browned, crisp foods. Appliance manufacturers developed and advertised the portable convection ovens as a fast and energy-efficient cooking appliance.

Department store retailers reported that in 1979 convection ovens were the most popular items sold in the electric housewares department [28, p. 53]. Manufacturers are expecting about 2 million convection ovens to be sold during 1981, an estimated sales figure equal to that of broiler and microwave ovens [26, p. 2]. Claims by manufacturers of the advantages of portable convection ovens over conventional ovens include: (1) foods cook 20-50% faster, (2) meats and poultry are juicier and tenderer, (3) foods cook evener, (4) consumers will save 25-30% on energy used for cooking, (5) oven temperature settings can be reduced 25-75 F, and (6) the kitchen will stay cooler. The author found no research studies published in referred journals to substantiate the energy-related claims. Information on the performance of portable convection ovens is most often provided by oven manufacturers, independent organizations such as Consumer's Union, and freelance appliance consultants.

The Energy Policy and Conservation Act of 1975 (EPCA) mandated an appliance energy conservation program [29, pp. 70 & 72]. It consisted of test procedures, energy efficiency targets, and energy labels. Though virtually all major appliances were covered by EPCA, an amendment to the act narrowed the scope to 13 appliance categories, with priority being given to 9 of them, one of which was kitchen ranges and ovens. The ruling mandating energy labels on kitchen ranges and ovens was rescinded later because the difference in energy cost between the least and most energy-efficient models of conventional cooking appliances is minimal and the substantial costs of a labeling requirement would not produce corresponding consumer benefits [14, p. 66469].

According to EPCA, standard test procedures were to be developed for determining the thermal efficiency of ranges and ovens. The test procedures were to be representative of consumers' usage of the appliance. Consequently, numerous studies were initiated to identify consumers' use of conventional ranges (ovens and surface units) and microwave ovens [12, p. 32]. The developed standard test would be used in determining compliance with the target thermal efficiency.

A replicable and valid test for determining the thermal efficiency of the conventional oven, which consists of calculating the energy used to heat an 8.5 lb aluminum block, was developed through efforts of representatives of manufacturers of gas and electric ranges and the American Gas Association (AGA) Laboratories [12, p. 32]. Although that test was accepted by the Department of Energy (DOE) as the "standard" test, Eisele [12, p. 39] suggested that perhaps it should be modified for the forced convection oven. DeWerth, Himmel, and Griffiths [10, p. 32] concurred

with Eisele, because when the test was used with the forced convection oven, the expected increase in thermal efficiency for the convection oven over that for the conventional oven was not observed. Convection ovens were not included in the study by Fechter and Porter [13, p. 6] that determined the degree of correlation between the energy efficiency of an oven in "real life" and laboratory settings. For these reasons, a standard test to determine the thermal efficiency of convection ovens is needed.

A standard test for the thermal efficiency of portable convection ovens will be useful to regulatory agencies, consumer product testing agencies, and appliance manufacturers in determining an appropriate method to calculate portable convection oven thermal efficiencies and to substantiate portable convection oven advertising claims. Consumers will benefit from such a standard test by having knowledge of the energy consumption of a portable convection oven at point of purchase and a relative comparison of the thermal efficiency of a portable convection oven to a conventional or microwave oven.

Objective

Lack of consumer usage information and a standard thermal efficiency test for portable convection ovens provided the impetus for this study. The objective of this research was to develop a realistic, repeatable standard test to determine the thermal efficiency of portable convection ovens. Following are the phases of this study:

- PHASE I. Determine by a field survey foods being prepared most often by consumers in portable convection ovens
- PHASE II. Determine the thermal efficiency of portable convection ovens using food loads
- PHASE III. Investigate simulated loads for use in a standard test to calculate the thermal efficiency of portable convection ovens
- PHASE IV. Report the annual energy consumption of portable convection test ovens based on results of a standard test for thermal efficiency and the present consumer usage level

REVIEW OF LITERATURE

Heat Transfer

In conventional ovens, heat is transferred to food by radiation, conduction, and convection [6, p. 22]. Radiation is the transfer of an electromagnetic wave motion through space [24, pp. 49 & 50]. The motion (radiant energy) travels in straight lines and will pass through media that are transparent to it. Radiant energy is absorbed by dark, rough surfaces and reflected by shiny, light-colored surfaces. When conventional ovens are heated, the oven walls become hot and radiate heat directly to the utensil and foods in the oven [25, p. 81].

Conduction is the transfer of heat from one particle to another through direct contact. Though not visible, the molecules of the heated bodies are in violent motion, passing energy from one molecule to another. In general, metals have a relatively high thermal conductivity; thus, they are conductors. Materials that transmit very little heat, or have a low thermal conductivity, such as fiberglass surrounding an oven cavity, are insulators [24, pp. 47 & 48].

In an oven, conduction heat transfer takes place by cooking utensils touching the food with the utensil's thickness and material type affecting the amount and speed of heat conducted. A utensil placed in a hot oven will acquire heat faster than one in a cold oven because the temperature difference where the conduction takes place also affects the amount of heat transferred [6, pp. 13 & 14].

Convection is heat transfer by the motion of a fluid, liquid, or gas. Heated molecules of the medium become separated by continual jostling, resulting in a less dense medium that tends to rise [6, p. 14].

The Association of Home Appliance Manufacturers (AHAM) [2, p. 3] defines cooking compartments of conventional and forced convection ovens as:

Conventional Oven. A cooking compartment in which heat is utilized through radiation, convection and conduction unassisted by any other means.

Forced Convection Oven. A conventional oven in which a fan or other means is used to circulate the heated air within the cooking compartment.

Air heated by the electric element(s) or gas burner in a conventional oven rises to the top of the oven allowing cool, heavy air to fill in the void and create a natural convection current [25, p. 79]. The convection current aids in cooking the food.

In a forced convection oven, a fan draws fresh air over the heating element(s) or gas burner [7, p. 47]. The forced air then penetrates the cool air band that surrounds the food and acts as an insulator [22, p. 1]. After passing over the food, the air goes through a mesh filter and back over the heating element(s) or gas burner where the air is reheated and recirculated into the oven cavity. Only 10% of the air is expelled through a vent [26, p. 3].

Portable Convection Ovens

Convection ovens were introduced for home use in 1973 in the form of a countertop portable model [7, p. 47]. Today, they are available in a free-standing or built-in range and in a portable appliance, with

either: (1) convection mode only, (2) combination convection, conventional, and slow cook modes, or (3) combination convection and microwave modes.

Portable convection ovens differ in style from very conservative to ultra sleek. Oven interior capacities are from 0.6 to 1.5 cu ft, with the oven interior walls frequently having a continuous cleaning finish. The exterior walls are made of either stainless steel, porcelain enamel, or tempered glass. Some models are insulated in the wall areas. Portable convection ovens vary in wattage from 1400 to 1650 W and operate on standard 120 v, 20 amp circuit. The fan-motor may be located in the top, back, side, or bottom of the oven cavity. Grease filters and vents are included in portable convection ovens with or without additional features, such as an automatically controlled temperature probe, kebob rack, rotisserie, and extra shelves.

Development of Standard Test for Conventional Ovens

Between 1972 and 1975, appliance manufacturers were voluntarily responding to energy reduction programs administered by the Department of Commerce (DOC) and the Federal Energy Administration (FEA). Progress by the industry towards achieving an increase in the thermal efficiency of major appliances included: (1) continued development of energy consumption test procedures and appliance labeling guidelines, (2) establishment of efficiency improvement targets for appliances, and (3) tentative agreement on methods of measuring and reporting manufacturer's progress towards the target efficiencies. Manufacturers

representing 94% of the production in the appliance industry had agreed to participate in the voluntary programs [29, p. 70].

In 1972, the American National Standards Institute, Inc. (ANSI) adopted test procedures (ANSI C71.1) for determining the thermal efficiency of surface units of an electric range. Aluminum blocks of a specified composition and weight were used as a heating medium in the standard tests. Work also began at this time on a proposed standard test for determining the thermal efficiency of ovens using an aluminum block [12, p. 33].

In 1974, AHAM's Range Engineering Committee approved the 8.5 lb aluminum block test method for determining oven efficiency. Though approved, AHAM was concerned that the test method did not relate to consumers' use of the appliance, so consumer usage information was sought [21, p. 2]. Data on consumers' energy consumption for ranges were reported by several investigators as early as 1950. Details such as sample size, equipment features, demographic data, and standard deviation usually were missing [8, p. I-9]; therefore, AHAM initiated 2 programs in 1974 to study consumers' use of range component parts and microwave ovens.

First, a field test program was started whereby ranges were monitored in 80 homes. Demographic information for the sites was gathered. The families were chosen to represent a wide variety of income levels and varied in size from 2 to 8 members [8, p. I-2].

Metered ranges and ovens were representative of sales patterns and included built-in and free-standing ranges. The cooking tops were either conventional or glass tops and the ovens either the conventional

or self cleaning type [12, p. 32]. Twenty four of the sites had microwave ovens [8, p. I-2]. Energy for the cooking tops, ovens, and microwave ovens were monitored separately. Data were collected quarterly and variations in usage as a function of time of the year were determined [12, p. 32]. An annual energy consumption figure of 376 kwh for conventional ovens was obtained from the field test program but 36 kwh were subtracted to compensate for energy consumed by clocks and self cleaning oven operations; thus, the annual energy consumption for an oven became 340 kwh [8, pp. I-2 & I-3]. The annual energy consumption figure and the average thermal efficiency of a conventional oven were used to calculate the annual useful cooking energy output.

The second program AHAM initiated to study consumers' use of range component parts and microwave ovens was to develop a weekly menu. The menu was designed by educators, nutritionists, USDA representatives, and food specialists, processors, and editors to represent the "typical" foods eaten by a family of 4 for 7 days. The purpose of the menu was to provide oven operation factors, such as oven temperature, length of cooking times, and cooking utensil, for a simulated load test [12, pp. 33 & 35].

DeWerth, Himmel, and Griffiths, [10, p. 10] used the AHAM menu and a similar weekly menu, developed by the Consumer Information Counselor of AGA, to determine the number of medium and small loads cooked per year, assuming there would be 2 equivalent weeks of time annually when the range would not be used. The annual number of medium and small food loads provided a basis for weighting the average thermal efficiency for ovens. Through consultation with various home economists and representatives

of industry and universities, it was decided that a representative light load would be a single layer cake and a representative medium load would be a meatloaf containing meat, milk, eggs, and bread. Foods representative of a large load such as an 18-lb turkey were not included because it was estimated that such a load was cooked in an oven only 3 times yearly. The effect of including data for a large load when calculating the "average" food load thermal efficiency would have been negligible [10, pp. 10 & 14].

The EPCA, passed in 1975, mandated improvement in appliance energy efficiencies, as determined by standard test procedures, and inclusion of energy labels on appliances. EPCA called for a 40% improvement in thermal efficiency for 1980 kitchen ranges and ovens over their counterpart 1972 models [29, p. 71]. Energy labels were to include the estimated annual energy cost of the appliance labeled and a range of estimated annual energy costs for comparable appliances [14, p. 66466]. Both the thermal efficiency and energy labeling programs required suitable energy consumption test methods that would reflect actual consumer usage. AHAM and the Gas Appliance Manufacturers Association (GAMA) worked on developing such test methods. The test procedure to determine the thermal efficiency of an oven developed by AHAM and GAMA, involving heating an 8.5 lb aluminum block, was presented to the National Bureau of Standards (NBS) in August of 1976 and is outlined in the AGA Laboratories Research Report No. 1510 [10, p. 1].

NBS undertook a study [13, p. vii] to determine the correlation between "real-life" and the laboratory test method (8.5 lb aluminum block test) for measuring oven thermal efficiencies. Ten ovens, whose thermal

efficiencies had been determined by the standard test, were used by 58 homemakers to prepare meals from the AHAM Weekly Menu. There was a high correlation between the thermal efficiencies by the standard test and those when homemakers prepared food in the ovens.

In December of 1977, DOE [11, p. 20108] proposed test procedures for determining the energy consumption of conventional ovens. Oral and/or written comments by interested persons concerning the proposed procedure were solicited. In May of 1978, a Final Energy Conservation Test procedure was published by DOE in the Federal Register. The effect of the ruling by DOE was to establish a standard method of testing when testing was required by EPCA or by regulations implementing other parts of the program. The effective date was June 15, 1978. The oven test procedure consisted of the amount of energy required to heat an 8.5 lb aluminum block 234 F above its initial room temperature. The test set forth by DOE applied only to kitchen ranges and ovens that were used as the major household cooking appliance. It did not include portable convection ovens.

Thermal Efficiency

The thermal efficiency of a cooking appliance, as described by DOE [11, p. 20119], is the ratio of the cooking energy output to the cooking energy input. A simpler definition is the amount of energy used in cooking food divided by the amount of energy used by the appliance during the cooking process. The higher the thermal efficiency, the smaller the percentage of energy used by the appliance for items other than cooking the food. Energy for other items includes energy

used to heat the oven walls and racks and the air surrounding the food. A variety of methods to determine the thermal efficiency of appliances has been used. Following is a discussion of these methods:

AGA Laboratories [10, pp. 9-10] determined the thermal efficiency of an oven, when using food loads, as the energy absorbed by the cake or meatloaf in proportion to the energy used by the oven for cooking those foods. The thermal efficiency of an oven was calculated by:

$$Eff_0 = \frac{(C_{pf})(W_f)(\Delta T_f) + (C_{pp})(W_p)(\Delta T_p) + (H_w)(\Delta W_w)}{S J} \times 100 \quad \text{Eq (1)}$$

where:

C_{pf} = Specific heat of food, Btu/lb/F

W_f = Weight of food, lb

ΔT_f = Temperature difference of food, F

C_{pp} = Specific heat of utensil, Btu/lb/F

W_p = Weight of utensil, lb

ΔT_p = Temperature difference of utensil, F

H_w = Latent heat of vaporization, 970 Btu/lb_m

ΔW_w = Evaporative loss, lb

S = Electrical energy to oven, Wh

J = Conversion factor, 3.412 Btu/Wh

From the typical weeks' menus developed by AHAM and AGA, it was estimated that 75 small and 200 medium loads would be cooked in a conventional oven in a year. A cake and meatloaves prepared in 2 pan sizes were chosen to be representative of small and medium loads, respectively. After the thermal efficiency of the ovens was determined by cooking the

cakes and meatloaves, the weighted average thermal efficiency was calculated by the following method [10, pp. 10 & 14]:

1. The average thermal efficiency of the test ovens for each food load size was multiplied times the approximate frequency that food load size would be prepared annually
2. The data for all food load sizes were added
3. The sum was divided by the total number of food loads prepared annually

After the weighted average thermal efficiency of an oven containing food was determined, a simulated load that provided a simple, repeatable, and representative procedure was sought. DeWerth, Himmel, and Griffiths [10, pp. 14-16] reported that an 8.5 lb aluminum block offered a reasonable test load for determining thermal efficiencies for conventional gas and electric ovens. The block was chosen over other possible loads that included water with cotton sateen, cotton toweling, cotton muslin, sand, asbestos, or an 18.55 lb shiny aluminum block, water only, or an 18.55 lb black aluminum block. Though critics of the 8.5 lb aluminum block test argued that no one cooks aluminum blocks, it is true that any food cooked is a heat absorbing medium [21, pp. 1-2]. Therefore, when the aluminum block is heated, it becomes the heat absorbing medium and represents the cooking of food. The advantage of the block is that it is standardized, whereas, there is considerable variability in foods.

The 8.5 lb aluminum block test for the thermal efficiency of ovens suggested by DeWerth, Himmel, and Griffiths [10, pp. 16 & 26] is to set the oven thermostate to provide an average internal temperature of 400 F.

The block shall be set in the center of the usable baking space and the oven shall be operated for 60 min. The energy consumed shall be recorded and the thermal efficiency of the oven calculated by:

$$\text{Eff}_0 = \frac{(W_b)(C_{pb})(\Delta T_b)}{S J} \times 100 \quad \text{Eq (2)}$$

where:

W_b = Weight of block, lb

C_{pb} = Specific heat of block, 0.23 Btu/lb/F

ΔT_b = Temperature difference of block, F

S = Electrical energy to oven, Wh

J = Conversion factor, 3.412 Btu/Wh

The test procedure using an 8.5 lb aluminum block for determining the thermal efficiency of ovens proposed by DOE [11, pp. 20122-20125] differs from that suggested by DeWerth, Himmel, and Griffiths [10, pp. 16 & 26] because the block is heated 234 F above its initial temperature rather than for 60 min. If an oven permits baking by either forced convection or without forced convection, DOE instructs the oven be tested in each mode and averaged. The formula used to calculate the cooking efficiency, in percentage, of an electric oven using the 8.5 lb aluminum block is the same as used by DeWerth, Himmel, and Griffiths [10, pp. 16 & 26], (Eq 2).

Davies et al. [8, p. I-4] estimated the average thermal efficiency of the ovens in the AHAM field test program to be 13.85%. That figure was determined using the 8.5 lb aluminum block test procedure suggested by DOE.

Annual Energy Consumption for Conventional Ovens

DeWerth, Himmel, and Griffiths [10, p. 38] used the percentage thermal efficiency, as determined by the 8.5 lb aluminum block test, to calculate the annual energy consumption of an oven. The amount of energy, in kwh, that an oven consumed annually, was:

$$E_{AO} = \frac{(E_{FO})(Eff_{TO})}{Eff_0} \quad \text{Eq (3)}$$

where:

E_{FO} = Avg annual energy consumption from AHAM field test program, kwh

Eff_{TO} = Thermal efficiency of test ovens in AGA Laboratories study, 12.1%

Eff_0 = Thermal efficiency of oven for which the annual energy consumption is sought, %

DeWerth, Himmel, and Griffiths [10, pp. 11 & 14] also suggested that the energy consumption for a single "average" food load could be related to the annual energy consumption of an oven. An oven's annual energy consumption, in kwh, was determined by:

$$E_{AO} = \left(\frac{E_f}{H_E} \right) (F) \quad \text{Eq (4)}$$

where:

E_f = Energy consumption for weighted avg food load, Btu

H_E = Conversion factor, 3.412 Btu/kwh

F = Avg food loads/yr, 275

In the Federal Register [11, p. 20124], DOE expresses the annual energy consumption for an electric oven, in kwh, using the 8.5 lb aluminum block test, as:

$$E_{AO} = \frac{(E_O)(H_E)(O_O)}{(W_b)(C_{pb})(\Delta T_b)} \quad \text{Eq (5)}$$

where:

E_O = Electrical energy to oven, Wh

H_E = Conversion factor, 3.412 Btu/Wh

O_O = Annual useful cooking energy output, 47.09 kwh as determined by (340 kwh, annual energy consumption of a conventional oven) (13.85%, avg thermal efficiency of a conventional oven)

W_b = Weight of block, lb

C_{pb} = Specific heat of block, 0.23 Btu/lb/F

ΔT_b = Temperature rise of block, 234 F

Upon determination of the annual energy consumption for an appliance, the estimated annual operating cost (EAOC) can be calculated. The EAOC is the figure that was felt would make the biggest impression on the consumer at point of purchase. DOE [11, p. 20119] suggested that the EAOC, in dollars, be determined as follows:

$$EAOC = (E_{AO})(C) \quad \text{Eq (6)}$$

where:

E_{AO} = Annual energy consumption of oven, kwh

C = Avg cost of electrical usage, dollars/kwh

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PHASE I - CONSUMER USAGE

In this study, a field survey was conducted to determine types of foods being prepared, length of cooking times, utensils used, and oven temperature settings chosen when consumers were using portable convection ovens. The information supplied by the field survey was used to select the food loads and oven operation factors for determining the thermal efficiencies of portable convection ovens.

Procedure

Volunteers owning portable convection ovens were solicited through publicity of the research project in: (1) Harvey, Sedgwick, and Johnson County Extension Home Economics Newsletters, (2) The Wichita Eagle-Beacon and The Kansan newspapers, and (3) KJRG/KOEZ radio program. Respondents received a follow-up letter giving detailed information about their responsibilities and a questionnaire concerning both the type of oven owned and demographic information (Appendix A).

A log sheet (Appendix B), developed for volunteers to complete and return on a weekly basis, requested the kind and quantity of food prepared, length of operational time (preheat and cooking time), type of utensil used, and oven temperature setting selected. The volunteers were asked to indicate by connecting food items with a bracket, the number prepared in the oven at one time. In order to pretest the log, Harvey County Extension Office employees completed log sheets as if they

were volunteers.

The Department of Family Economics at Kansas State University, a utility company, and a County Extension Office provided portable kilowatt-hour meters for use by some of the volunteers to measure energy consumption of their portable convection ovens. The ovens were connected to the meters and the meters into the wall outlets. Readings were taken at the beginning of the project and on a weekly basis, thereafter, by the volunteers to determine the kilowatt-hour usage of the ovens.

The meters were in the homes from October 1980 to April 1981, a time period reflecting the seasonal changes from fall to spring, to eliminate the possibility of differences in the amount of cooking done because of changing weather conditions. The metered time period also included Thanksgiving and Christmas, times when consumers may do abnormal amounts of baking (either above or below the average).

Results

For the consumer usage survey, 16 portable convection oven owners living in Harvey, Sedgwick, Cowley, Reno, Johnson, and Marion counties in Kansas volunteered to record the foods prepared in their ovens and the oven operation factors related to those foods. Demographic information was gathered on the volunteers. The average household consisted of 3.06 persons with 19% having children under 5 years of age and 31% having children 5-18 years of age. When the volunteers used their portable convection ovens, they were cooking for an average of 2.75 people. Fourteen of the 16 field survey sites were located in urban areas.

Among the 16 volunteers, 9 owned Farberware portable convection ovens, 2 owned Rival, Toastmaster, and Maxim ovens, and one owned a Montgomery Ward oven.

The field survey volunteers kept the logs from October 1980 to February 1981. Foods from the logs were grouped into 6 food categories: (1) meats (one-ingredient main dishes), (2) other main dishes (multiple-ingredient), (3) vegetables and other side dishes, (4) bread products, (5) desserts, and (6) miscellaneous. The frequency of items prepared in each of the categories is shown in Appendix C. Bread products accounted for 26.0% of the total foods prepared by volunteers. This was followed by meats which were prepared 23.0% of the time, and vegetables and other side dishes 21.0%. Desserts, other main dishes, and miscellaneous categories were prepared 14.8, 12.7, and 2.7% of the time, respectively.

Oven temperature settings and utensil materials used by volunteers for food preparation in their portable convection ovens are summarized in Tables 1 and 2. An oven temperature setting category 300-349 F was used 35% of the time and 350-399 F, 26%. In decreasing order of usage, utensil materials frequently selected by the volunteers were aluminum, glass-ceramic, metals (not specified), aluminum foil, and glass. The number of food items left uncovered vs. those covered were approximately 5 to 1. The number of food items cooked simultaneously by volunteers in their portable convection ovens is summarized in Table 3. The frequency decreased as the number of food items cooked simultaneously increased.

Seventy percent of the time the field survey volunteers did not

preheat their oven before cooking food in it, 20% of the time they did preheat, it was already hot from another food load 6% of the time, and 2% of the time the preheat factor was not specified by the volunteer.

PHASE I - CONSUMER USAGE of the research study was achieved by determining the foods commonly prepared by a limited number of consumers in a portable convection oven and oven operation factors for those food loads. That information was used to select the food and simulated loads for portable convection oven thermal efficiency tests.

Table 1. Portable convection oven temperatures and the frequency of use by volunteers.

Oven temperature setting, F	Frequency of use	
	No. times	%
50-99	20	2
100-149	3	0
150-199	10	1
200-249	20	2
250-299	35	4
300-349	326	35
350-399	246	26
400-449	153	16
450-500	116	12
Broil	6	1
All	935	100

Table 2. Utensils for food prepared in portable convection ovens and the frequency of use by volunteers.

Utensil material	Frequency of use	
	No. times	%
Metals		
Aluminum	192	26
Not specified	143	20
Aluminum foil	118	16
Stainless steel	15	2
Other	7	0
Glass-ceramic	179	25
Glass	64	9
Other	<u>7</u>	<u>1</u>
All	725	100

Table 3. Frequency of food loads prepared simultaneously by volunteers in portable convection ovens.

Food item(s)	Frequency of use	
	No. times	%
One	175	74
Two	40	17
Three	17	7
Four	<u>4</u>	<u>2</u>
All	236	100

PHASE II - FOOD LOADS

Food loads, selected as a result of the consumer usage field survey data collected in PHASE I - CONSUMER USAGE, were used in test procedures to determine the thermal efficiency of portable convection ovens.

PHASE II - FOOD LOADS was conducted on 4 portable convection test ovens in the household equipment laboratory, Justin 328, at Kansas State University. The temperature of the room ranged from 73 to 78 F throughout the testing period.

Test Ovens

Information was obtained on the wattage, voltage, fan position, insulation type, interior finish, special features, oven cavity size, and oven temperature settings of portable convection ovens available in the marketplace. After collecting the information, 4 portable convection oven models (Plates I-A, I-B, I-C, and II-A) were chosen to be tested. The models represented a variety in oven fan position, cavity size, and wall construction materials (Table 4).

Food Load Tests

As the weight of the food being cooked in a conventional oven increases, the thermal efficiency of the oven increases [27, p. 73]. Therefore, the foods prepared by the field survey volunteers in portable convection ovens were grouped by weight. For purposes of this study,

**THIS BOOK
CONTAINS
NUMEROUS
PICTURES THAT
ARE ATTACHED
TO DOCUMENTS
CROOKED.**

**THIS IS AS
RECEIVED FROM
CUSTOMER.**



Plate I-A. Cusinart portable convection test oven.



Plate I-B. Rival portable convection test oven.



Plate I-C. Montgomery Ward portable convection test oven.

**THIS BOOK
CONTAINS
NUMEROUS PAGES
WITH DIAGRAMS
THAT ARE CROOKED
COMPARED TO THE
REST OF THE
INFORMATION ON
THE PAGE.**

**THIS IS AS
RECEIVED FROM
CUSTOMER.**

Table 4. Portable convection test oven specifications.

Oven	Cavity size	Voltage, Volts	Wattage, Watts	Fan position	Interior and exterior wall construction materials	Insulation, Cavity and door
Farberware Model no. 460/5	18" W 12" D 9 $\frac{1}{4}$ " H 1.16 cu ft	120	1500	top-center	Int - Catalytic-coated stainless steel Ext - Vinyl wrap over stainless steel	Cavity - Triple chamber construction, Door - Tempered glass
Cusinart Model no. OAS-100	11 $\frac{1}{2}$ " W 9 $\frac{1}{2}$ " D 9 $\frac{1}{2}$ " H 0.60 cu ft	115	1650	back	Int & Ext - Heavy duty tempered safety glass	None
Rival Model no. 4021	16" W 14" D 8 3/4" H 1.13 cu ft	120	1500	top-back	Int - Catalytic-coated porcelain enamel Ext - Baked enamel	Cavity - Double wall construction, $\frac{1}{2}$ in. thick ceramic fiber-fill blanket Door - Double-paned glass
Montgomery Ward Model no. 8284	17" W 12" D 12 $\frac{1}{2}$ " H 1.45 cu ft	120	1500	bottom	Int - Porcelain enamel Ext - Baked enamel	Cavity - Approximately 1 $\frac{1}{2}$ in. thick fiberglass Door - int--tempered glass, ext--plate glass

heavy was defined as a load with an approximate weight of 1-3 lb. Heavy items were foods such as roasts, meatloaves, steaks, pizza, and casseroles. A medium load was one weighing about 1 lb. Examples of foods in a medium size load were vegetable dishes, convenience food dinners, cakes, pies, and quick breads. Light loads, those less than 1 lb, included rolls, muffins, doughnuts, and bread slices. The field survey logs revealed that consumers were using the portable convection oven 36% of the time for heavy food loads, 33% for medium food loads, and 32% for light food loads.

Surface area of the food being cooked is directly related to the thermal efficiency of a conventional oven [10, p. 11]. The specific heat of the food and cooking utensil affects the oven's thermal efficiency; the higher the specific heat, the higher the thermal efficiency. Food loads representative of various weights, surface areas, specific heats, and utensil materials were chosen to test the thermal efficiencies of portable convection ovens.

Heavy food load

A meatloaf was selected to represent the heavy food load for the following reasons: (1) field survey volunteers prepared meatloaf frequently (15 times), (2) the fat content of ground meat could be controlled, (3) the ingredients were relatively inexpensive compared to other possible food products, (4) the specific heat of meatloaf could be calculated, (5) the recipe ingredients could be standardized, and (6) the end point temperature could be established.

A special order for fresh ground round specified as 5% or less fat

content, was purchased from a grocery store to use in the basic meatloaf recipe (Appendix D). Beef fat varies in specific heat from 0.40 Btu/lb/F at 32 F to 0.45 Btu/lb/F above 122 F [4, p. 29.10]. Because the meat would be changing temperature during the thermal efficiency test, and because it was necessary to have the specific heat of the food load remain constant, meat with minimal fat content was selected. The specific heat of the meatloaf used for the medium food loads was 0.78 Btu/lb/F (Appendix D).

The homogeneity of the meat was determined by a moisture content test on duplicate samples from 3 sections (A, B, and C) of the meat order. A C.W. Brabender Semi-Automatic Rapid Moisture Tester, No. 271, Type SAS, was used to determine the moisture content. The 10-g samples were placed on teflon coated pans in the preheated tester and dried until all moisture was removed. Results of the tests showed the meat to be an average of 68.575% from section A, 70.075% from section B, and 70.700% from section C.

The meat was weighed and packaged in the amount needed for each meatloaf, 1.5 lb. All packages of meat for the heavy food load tests were frozen until the day before each thermal efficiency test when it was thawed in the refrigerator.

During each test, the temperature of the meatloaf went from 42 ± 2 to 150 ± 1 F, the average end point temperature for medium done meat [18, p. 148]. An oven temperature setting of 350 F was selected because this setting was used most often by field survey volunteers when cooking meatloaf. As specified by the oven manufacturers' instructions for cooking meatloaf, the ovens were not preheated.

Because meatloaf was frequently cooked by field survey volunteers in a loaf dish, it was selected for the utensil used in the heavy food load tests. A glass loaf dish was chosen because it fit within the utensil size requirements as outlined by oven manufacturers. The glass material helped add weight to the load, and the specific heat of glass was readily known, 0.18 Btu/lb/F [17, p. 314]. The dish was a 1½-qt, 8½ X 4½ X 2½ in. Pyrex brand of Corning Glass Works. It weighed 1.745 lb and the thickness of the sides and bottom were 0.115 in. and 0.174 in., respectively.

Medium food load

A single-layer white cake was chosen as the food representing the medium food load for a number of reasons. Cake is a sensitive indicator of heat transfer into food [23, p. A-2], AHAM used cake as a test of oven performance in the ER-1 Standard [2, p. 14], and field survey volunteers frequently (27 times) prepared cakes in their portable convection ovens. Other reasons for choosing cake were that the specific heat of cake could be calculated by knowing the recipe and cake ingredients were relatively standardized and inexpensive.

The cake recipe used for this research (Appendix E) was a slight modification of the one used in AHAM ER-1 [2, p. 14]. Lard was substituted for hydrogenated vegetable oil shortening because the specific heat could be identified for lard. As shown in Appendix E, the specific heat of the cake batter was 0.55 Btu/lb/F. Batter for 4 cakes or 4 thermal efficiency tests was prepared at one time and stood at room temperature until used. The initial temperature of the batter before

baking was 80 ± 2 F.

The researcher found a variation in the literature for the end point temperature of cake. Therefore, sample cakes were baked in one test oven to varying end point temperatures as determined by the average temperature of 3 thermocouples. Differences among the cakes baked to an average temperature of 196, 208, 205, and 209 F were established by means of a sensory panel. Garrison and Peart [15, p. 1] reported 196 F as the temperature of a "done" cake and 208 F appeared to be the stabilization temperature while heating the cake. The cake baked to 208 F remained at this temperature for 15 min before being removed from the test oven. The third and fourth sample cakes were representative of ones with a temperature nearly midway between the previously mentioned points and at the maximum temperature. A 10-member sensory panel from the College of Home Economics evaluated the sample cakes, considering external and internal appearance, flavor, and moistness. An example of the score card panel members completed for the 4 cakes is in Appendix F. Each member was given a sample from the same section of the cake. The cake baked to 209 F was scored in the "average good quality" range and chosen for the end point temperature of cakes used for the medium food load.

At this time, a decision needed to be made whether or not the oven should be preheated. Of the test ovens, 2 brands (Rival and Montgomery Ward) recommended preheating before baking cakes. The other brands did not. Kelly [20, p. 2] and Ojakangas [22, p. 1] reported that as a general rule, preheat was not necessary in a convection oven. When the field survey volunteers baked cakes in their portable convection ovens, 59% of

the time they did not preheat the oven. For the 2 previously mentioned reasons, and because it was desirable to keep the thermal efficiency test oven operation factors the same for all test ovens, the ovens were not preheated. An oven temperature of 300 F was selected because it was recommended by several test oven manufacturers and used most frequently by field survey volunteers when baking cakes.

Field survey volunteers used metal utensils most frequently for baking cakes. An 8-in. round aluminum pan was chosen for the medium food load thermal efficiency tests because of its weight, known specific heat, standardization, and adherence to oven manufacturers' utensil size requirements. Two Wear-Ever, No. 2713, cake pans, identified as pan A and B, weighing 0.318 lb each, were used for baking the layer cakes. The specific heat of the pans was 0.23 Btu/lb/F [17, p. 314] with the sides being 0.030 in. thick and the bottoms 0.037 in.

Light food load

Light food loads, such as rolls, bread slices, and small dishes of leftovers, were reheated frequently by field survey volunteers in their portable convection oven. Such foods were inappropriate to use for testing purposes because it would have been difficult to determine their internal temperature, the end point temperature varied greatly, and the ingredients were not standardized. Therefore, it was decided to continue using cake, baked in a small aluminum loaf pan, for the light food load.

The same cake recipe used for the medium load was used for the light food load, except 0.4 lb rather than 0.8 lb of batter was poured into each pan. Batter for 8 cakes was prepared at one time and remained at 80 ± 2 F until used.

Because the middle of the loaf cake was still doughy when baked to an average end point temperature of 209 F, used for the medium food load cakes, the loaf cake was not an acceptable product as determined by the researcher in consultation with 2 other consumers. Cake baked to an average temperature of 215 F was established, by consensus of the researcher and several consumers, as a good product for the loaf cakes, thus, was used for the light food load tests. An oven setting of 300 F was chosen for the loaf cakes and as in the medium food load tests, the oven was not preheated.

A small aluminum foil loaf pan was chosen for light food load tests, because it was lightweight and similar to the foil wrappings used frequently by field survey volunteers in preparing small food items. The area of the loaf pan was suitable for the volume of cake baked and the specific heat of the pan, 0.23 Btu/lb/F [17, p. 314], could be determined. The Aluminum Foil Baby Loaf Pans, made by the E-Z Por Corporation, were 5 11/16 X 3 1/4 X 2 in., had an average weight of 0.021 lb, and were 0.003 in. thick on the sides and bottoms.

Test Equipment

Following is a description of the instruments used for the food load tests. Plate II-A shows the manner in which the instruments were arranged for the testing procedure.

Energy measuring instruments

Adjustment of the voltage applied to the oven before each test was done by means of Powerstat Voltage Regulator, Type 126. A Western Voltmeter was used to measure the voltage, and a Duncan-Duncan, single station

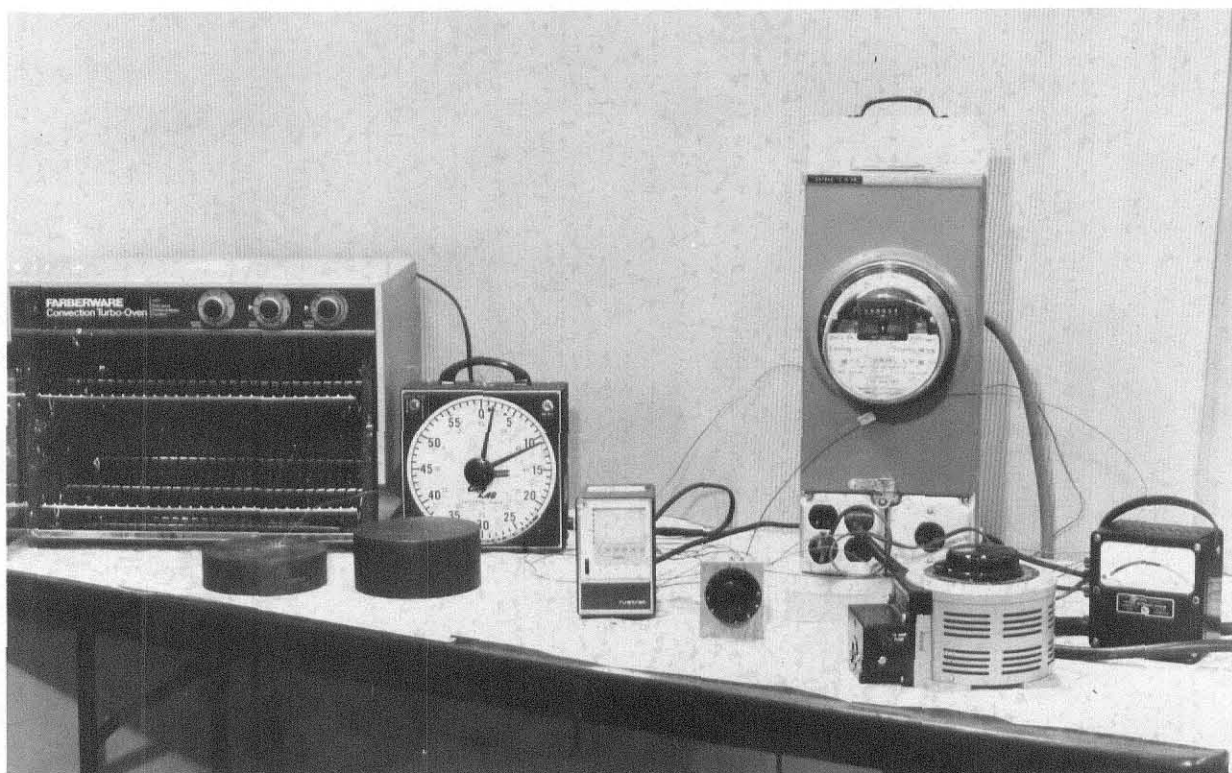


Plate II-A. Farberware portable convection test oven and arrangement of testing instruments.

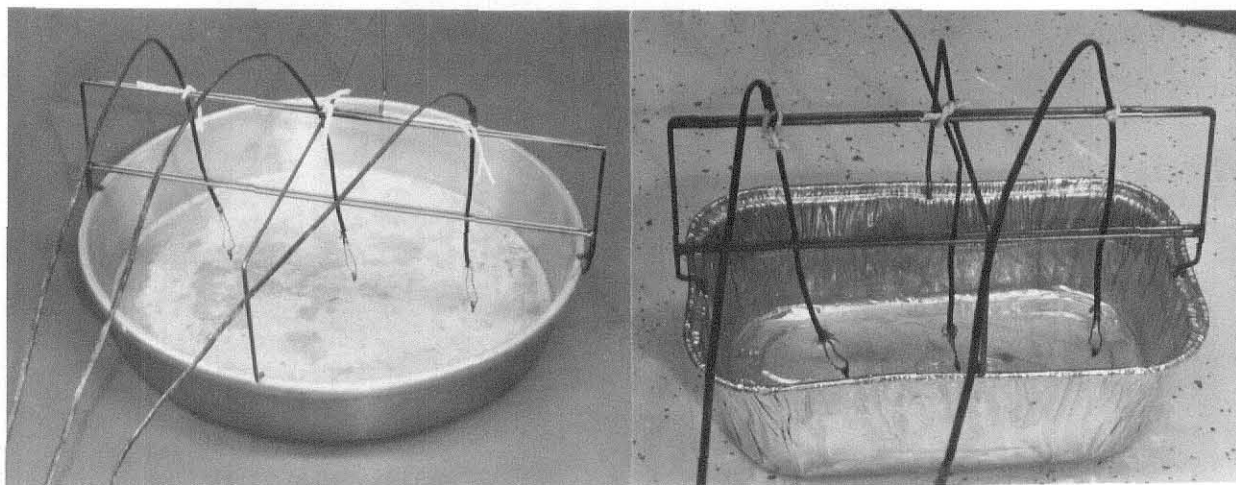


Plate II-B. Harness for round pan.

Plate II-C. Harness for loaf pan.

watthour meter, Serial #21 599 924, was chosen to determine the number of watthours used by each test oven.

Before testing began, each oven thermostat was calibrated at 300, 350, and 400 F. A chromel-alumel thermocouple, attached to a Rustrak Recording Potentiometer, Model 2155A, was shielded with foil and placed in the center of the usable oven baking space. The average internal temperature for 3 consecutive on/off cycles, excluding the preheat period, was recorded and the oven temperature dial was adjusted, if necessary, until the average temperature of the cycles was ± 5 F of the specified oven temperature setting.

To measure the temperature of the food load, 3 chromel-alumel thermocouples were connected to a switch and the recording potentiometer. The thermocouples were positioned equidistant from one another in the horizontal plane of the food load; soldered tips of the thermocouples were 1.2 in. below the top surface for the meatloaf, 0.3 in. for the layer cake, and 0.48 in. for the loaf cake.

The thermocouples were calibrated periodically throughout the testing period. Calibration was determined by recording the thermocouple temperature in boiling water.

Auxiliary equipment

During the meatloaf tests, the thermocouple lead wires were secured by pieces of aluminum foil to an oven rack positioned above the food load. Because the Montgomery Ward oven did not have a second rack, a piece of steel resting on the upper rack position guides was used to anchor the lead wires.

Harnesses, fitting over the cake pans, held the thermocouples in

position during the medium and light food load thermal efficiency tests (Plates II-B and II-C). The harnesses, made of stainless steel and soldered with silver solder, weighed 0.049 and 0.034 lb for the round and loaf pans, respectively. The specific heat of the harnesses was 0.12 Btu/lb/F [4, p. 29.11].

Test Procedure

A data sheet (Appendix G) was developed and used for each thermal efficiency test. Information recorded on the data sheet consisted of the date, test oven brand, voltage, load size type, food, utensil, room temperature, oven temperature setting, test number, time, load data (weight, specific heat, and initial and end temperatures), cooking utensil data (weight, specific heat, and initial and end temperatures), evaporative loss, watthours consumed, and thermal efficiency. A minimum of 3 replications for the 3 food loads was performed in each of the test ovens with the oven testing sequence being randomly selected.

A check list of steps was followed in each thermal efficiency test to enhance reproducibility (Appendix H). The line voltage to the portable convection test ovens was regulated to 122 v before each test began. No attempt was made to control input voltage to ovens.

Thermal Efficiency Calculations

The equation used for food load thermal efficiency tests of portable convection ovens follows:

$$\text{Eff}_{\text{PCO}} = \frac{(C_{pf})(W_f)(\Delta T_f) + (C_{pp})(W_p)(\Delta T_p) + (\Delta W_w)(H_w)}{S J} \times 100 \quad \text{Eq (6)}$$

where:

C_{pf} = Specific heat of food, Btu/lb/F

W_f = Weight of food, lb

ΔT_f = Temperature difference of food, F

C_{pp} = Specific heat of pan, Btu/lb/F

W_p = Weight of pan, lb

ΔT_p = Temperature difference of pan, F

ΔW_w = Evaporative loss, lb

H_w = Latent heat of vaporization, 970 Btu/lb_m

S = Electrical energy to oven, Wh

J = Conversion factor, 3.412 Btu/Wh

For thermal efficiency tests using food loads, the numerator of the equation included heat absorbed by the food, as calculated by multiplying the weight of the item by the temperature rise and specific heat of the food, and heat required to heat the pan, because the utensil was a necessary part of the cooking process. Heat absorbed by the utensil was calculated by multiplying the weight of the utensil by the specific heat of the utensil and the temperature rise which was assumed to be the difference between room temperature and the midpoint temperature of the end point food temperature and internal oven temperature. The weight of the utensil and food was recorded before and after cooking to determine the evaporative loss, assumed to be evaporated water, during the test [10, p. 9]. Energy required for the food load test was reflected in the denominator of the thermal efficiency equation as shown in the calculation example for a thermal efficiency food load test given in Appendix I.

When a harness was used for a food load, the thermal efficiency test equation of the portable convection oven was as follows:

$$Eff_{PCO} = \frac{(C_{pf})(W_f)(\Delta T_f) + (C_{pp})(W_p)(\Delta T_p) + (\Delta W_w)(H_w)}{SJ - (C_{ph})(W_h)(\Delta T_h)} \times 100 \text{ Eq (7)}$$

where:

C_{pf} = Specific heat of food, Btu/lb/F

W_f = Weight of food, lb

ΔT_f = Temperature difference of food, F

C_{pp} = Specific heat of pan, Btu/lb/F

W_p = Weight of pan, lb

ΔT_p = Temperature difference of pan, F

ΔW_w = Evaporative loss, lb

H_w = Latent heat of vaporization, 970 Btu/lb_m

S = Electrical energy to oven, Wh

J = Conversion factor, 3.412 Btu/Wh

C_{ph} = Specific heat of harness, Btu/lb/F

W_h = Weight of harness, lb

ΔT_h = Temperature difference of harness, F

The energy required to heat the harness was calculated by multiplying the weight of the harness by the specific heat of the harness and the temperature rise, the difference between the room temperature and the internal oven temperature. Because the harness was not considered part of the normal oven or cooking process, the energy required to heat the harness was subtracted from the total energy used by the oven during the test. Appendix J gives an example of the thermal efficiency test calculation when a harness was used.

Results

The average of the replications in each test oven for the heavy, medium, and light loads was calculated. Table 5 shows results of the food load thermal efficiency tests. Because of the wide range in thermal efficiencies of the initial 3, 4 replications of the heavy food load test were made in the Cusinart oven. The Montgomery Ward oven was the highest thermal efficiency for the heavy load, 15.35%, and the Rival, Farberware, and Cusinart ovens followed, in descending order, 13.41, 13.31, and 11.91%. The average thermal efficiency for all test ovens for the heavy food load was 13.50%.

The highest average thermal efficiency for the medium food load tests was 9.45% on the Montgomery Ward oven, the Farberware oven was the second highest thermal efficiency, 9.29%, and the Rival and Cusinart ovens followed with 8.74 and 8.53%, respectively. The average thermal efficiency for all test ovens on a medium food load was 9.00%.

The Montgomery Ward oven had the highest thermal efficiency, 4.22%, for the light food loads, the Farberware oven was the second highest thermal efficiency, 4.19%, and the Cusinart and Rival ovens followed with 3.99 and 3.96%, respectively. The average thermal efficiency for all test ovens on a light food load was 4.09%.

The averages of each food load size for the test ovens represented the average food load thermal efficiency for the ovens. In all test ovens, the thermal efficiency decreased when the food load weight decreased. The Montgomery Ward oven had the highest average food load thermal efficiency, 9.67%, the Farberware and Rival ovens followed with thermal efficiencies of 8.93 and 8.70%, respectively, and the lowest test

Table 5. Test oven thermal efficiencies for food loads.^a

Oven	Replication no.	Thermal efficiency, %			
		Heavy ^b	Medium ^c	Light ^d	All
Farberware	1	13.56	9.17	4.54	
	2	12.83	9.59	3.97	
	3	13.54	9.11	4.05	
	Avg	13.31	9.29	4.19	8.93
Cusinart	1	12.63	8.28	4.11	
	2	11.00	8.77	3.84	
	3	11.70	8.53	4.02	
	4	12.32			
	Avg	11.91	8.53	3.99	8.14
Rival	1	13.37	8.65	3.93	
	2	13.31	8.89	3.96	
	3	13.55	8.67	4.00	
	Avg	13.41	8.74	3.96	8.70
Montgomery Ward	1	14.87	9.51	4.20	
	2	15.75	9.62	4.32	
	3	15.43	9.21	4.14	
	Avg	15.35	9.45	4.22	9.67
All test ovens		13.50	9.00	4.09	8.86

^aBased on raw data presented in Appendices K, L, and M.^bMeatloaf cooked to medium doneness, 150 F internal temperature.^cLayer cake cooked to 209 F internal temperature.^dLoaf cake cooked to 215 F internal temperature.

oven thermal efficiency was for the Cusinart oven, 8.14%. The average thermal efficiency of all test ovens on all food loads was 8.86%.

The tests using the 3 size food loads established the thermal efficiencies of the test ovens according to consumer usage. Because of the variability in food products making reproducibility of the test procedure difficult, a simulated load standard test that would reflect food load test results was sought. Other reasons food loads are not practical for thermal efficiency tests include: (1) the food ingredients are somewhat expensive and difficult to obtain, (2) the procedure for mixing the food loads are somewhat complex, and (3) disposal, without waste, of the cooked products becomes a problem.

PHASE III - SIMULATED LOADS

Various simulated loads were explored for use in a standard test procedure that determined the thermal efficiency of portable convection ovens and reflected thermal efficiencies using food loads. Criteria for acceptability of the standard test using a simulated load was:

1. Representative - resultant thermal efficiency comparable to the thermal efficiency using food loads. Thermal efficiency shall not be more than $\pm 3\%$ of average food load thermal efficiency. Sequence of thermal efficiency for test ovens shall be comparable to that when using food loads
2. Reproducible - ability to run the same test on the identical oven and reproduce the same result. The range in thermal efficiency test replications shall not be greater than 1%
3. Simple - maintenance of a simple test procedure familiar to educators and manufacturers involved. It should be compatible with existing test facilities

8.5 lb Aluminum Block Test

The initial simulated load explored was an 8.5 lb black aluminum block (Appendix N). This load is accepted by DOE for thermal efficiency test procedures in the conventional standard-sized oven [11, p. 20121].

The block has the following specifications:

- No. 6061 aluminum alloy
- 0.23 Btu/lb/F specific heat
- 6.25 ± 0.05 in. diameter
- 2.8 in. high, adjusted according to weight
- 8.5 ± 0.1 lb weight
- Black finish with a minimum thickness of 0.001 in.

A chromel-alumel thermocouple was installed in the top of the block and connected to the recording potentiometer.

The same data sheet used for the food load tests (Appendix G) was used for the block tests and a check list of steps was followed in each block test to enhance reproducibility (Appendix O). The energy consumed by the test oven to heat the block 234 F above its initial temperature at an oven temperature setting of 400 F was recorded. Three replications were performed in each test oven in a randomly selected sequence. The following equation was used to determine the thermal efficiency of a portable convection oven using the 8.5 lb block:

$$\text{Eff}_{\text{PCO}} = \frac{(W_b)(C_{pb})(\Delta T_b)}{S \cdot J} \times 100 \quad \text{Eq (8)}$$

where:

W_b = Weight of block, lb

C_{pb} = Specific heat of block, 0.23 Btu/lb/F

ΔT_b = Temperature difference of the block, 234 F

S = Electrical energy to oven, Wh

J = Conversion factor, 3.412 Btu/Wh

Results of the oven thermal efficiency tests for the 8.5 lb block are presented in Table 6. The highest thermal efficiency was for the Montgomery Ward oven, 15.67%, the Rival and Farberware ovens followed with thermal efficiencies of 14.85 and 14.15%, respectively, and the Cusinart oven had the lowest thermal efficiency, 12.44%. The average thermal efficiency of all test ovens using the 8.5 lb block was 14.28%. If results of the 8.5 lb block thermal efficiency tests would have mirrored those using food loads, the study would have been terminated. There appeared to be justification for continued study because the overall test oven thermal efficiency was much higher, 5.42%, for the block

Table 6. Test oven thermal efficiencies using 8.5 lb aluminum block.^a

Oven	Replication no.	Thermal efficiency, %
Farberware	1	13.85
	2	14.64
	3	13.97
	Avg	14.15
Cusinart	1	12.10
	2	12.46
	3	12.77
	Avg	12.44
Rival	1	14.42
	2	14.77
	3	15.36
	Avg	14.85
Montgomery Ward	1	15.41
	2	16.02
	3	15.57
	Avg	15.67
All test ovens		14.28

^aBased on raw data presented in Appendix P. 8.5 lb black aluminum block heated 234 F above initial temperature.

than the food loads and the oven sequence of thermal efficiencies, from high to low, was not the same for the 8.5 lb block as for the food loads.

Other Simulated Load Tests

Applicable literature was reviewed and knowledgeable resource persons were interviewed concerning potential simulated load tests to determine the thermal efficiency of portable convection ovens. Factors considered for each simulated load possibility were: (1) specific heat, (2) water evaporation, (3) size, shape, and color, (4) availability, (5) standardization, (6) density, and (7) cost. The equipment, procedures (Appendices H and O), and thermal efficiency calculations (Eqs 6-8) specified for the food load and 8.5 lb aluminum block tests were used, where applicable, for potential simulated load tests. Initial testing of the possible simulated loads was done in the Cusinart and Farberware ovens, test ovens that represented a difference in thermal efficiencies on food loads, and in cavity size, wall construction materials, and fan position. They were 2 test ovens in which manufacturers did not recommend preheat. When warranted, the potential simulated loads were tried in the remaining test ovens, Rival and Montgomery Ward.

Table 7 outlines the simulated load tests investigated and rejected. The loads were sand (2 particle size distributions) and water, water alone, a shiny 8.5 lb aluminum block, cotton and water, and starch dough (2 utensils). Oven and test procedure factors are given in the table. Results obtained for the various simulated load tests were compared to the average test oven food load thermal efficiencies.

Those simulated load tests rejected because the test oven sequence

Table 7. Simulated load tests investigated and rejected.^a

Test no.	Materials		Utensil		Oven temp, F	Final load temp, F	Test oven	Thermal efficiency		Rejection Reason
	Type	Wt, lb	Specifications	Type	Wt, lb	Specifications	Specific heat, Btu/lb/F	Avg for load, %	Comparable food load Avg, %	
1	Sand	1.49	Quartz Sieve size- upper #30 lower #40	Aluminum pan	0.318	8" Rd	0.230	7.28 8.36	8.93 8.14	Wrong oven sequence
	Water	0.02	Distilled							
2	Water	1.59	Distilled	Aluminum pan	0.318	8" Rd	0.230	17.75	8.93	Efficiency too high
3	Aluminum block	8.50	Alloy no. 6061 2.8" high 6.25" dia No finish	-	-	-	-	12.40 10.75 13.37 12.42	8.93 8.14 8.70 9.67	Wrong oven sequence
4	Cotton	0.13	Print cloth Style #400 Test fabric	Aluminum pan	0.318	8" Rd	0.230	9.14 9.42	8.93 8.14	Wrong oven sequence
	Water	0.13	Distilled							
5	Sand	1.51	Quartz Sieve size- upper #8 lower #16	Aluminum pan	0.318	8" Rd	0.230	8.41 9.26 7.20	8.93 8.14 9.67	Wrong oven sequence
	Water	0.02	Distilled							
6	Starch dough	2.11	See Appendix Q	Loaf dish	1.745	1½ qt glass	0.180	9.54 8.46 9.08 11.00	8.93 8.14 8.70 9.67	Dish not standardized
7	Starch dough	1.00	See Appendix Q	Aluminum pan	0.318	8" Rd	0.230	10.90 10.49 9.14	8.93 8.14 9.67	Wrong oven sequence

^aBased on raw data presented in Appendix R.^bTest oven code: F = Farberware
C = CusinartR = Rival
M = Montgomery Ward

was not comparable to that when using food loads were the sand and water, shiny 8.5 lb aluminum block, cotton and water, and starch dough in a round aluminum cake pan (Test nos. 1, 3, 4, 5, and 7). The thermal efficiency of water (Test no. 2), as a simulated load for test procedures, was 8.82% higher than comparable food thermal efficiency; thus, was rejected. The starch dough (Test no. 6) appeared to be a good potential simulated load for testing the thermal efficiency. However, it was not certain that the cooking utensil, a glass loaf dish, would always be available. An equal weight of starch dough was pursued as a simulated load in other standardized utensils.

Evaluation of Two Simulated Loads

Simulated loads meeting the criteria of being representative, reproducible and simple were starch dough in a crystallization dish and a 5.24 lb aluminum block. These simulated load thermal efficiency test results were subjected to critical statistical analysis to determine the correlation between the simulated load test results and the food load test results.

Starch dough-crystallization dish

A starch dough was investigated as a possible simulated load for a standard test determining the thermal efficiency of a portable convection oven. The dough, as specified in Appendix P, was a combination of flour, salt, water, and oil and had a specific heat of 0.51 Btu/lb/F. These ingredients were readily available, inexpensive, and easily mixed. Color and density of the dough approximated the average of the test foods.

The consistency of the dough allowed good thermocouple placement and its moisture content allowed for evaporative loss during heating. The dough heated evenly, resulting in a narrow temperature range for the 3 thermocouples. The disadvantage of using starch dough as a simulated load was that it could not be reused. The weight of dough used during the initial simulated load testing, 2.11 lb, was chosen for the thermal efficiency test.

The investigator experimented with several baking utensils, restricting herself to those sufficiently common and standardized to permit future verification of results. A crystallization dish, Pyrex brand Corning #3140, Corning Catalog No. 08-741 H, 7.6 in. diameter X 4 in. high, proved to be appropriate (Plates III-A and III-B). The glass dish had straight sides and a flat bottom which were 0.0853 in. and 0.0910 in. thick, respectively, had a specific heat of 0.18 Btu/lb/F (Appendix Q) and weighed 0.89 lb. Such a crystallization dish was a standardized dish, readily available in chemistry supply catalogs. Though unlikely, if the dish was not available in the future, it could easily be manufactured because of its simple styling. The crystallization dish was similar in volume to the glass loaf dish used in the initial simulated load testing with 45.36 and 38.25 sq in., respectively. The crystallization dish was also chosen because it fit criteria for "utensil size" outlined by the portable convection test oven manufacturers.

Since 300 F was the most frequently used oven temperature setting by the field survey volunteers, it was selected as the one to be used for the standard test. As recommended by Kelly [20, p. 2] and Ojakangas

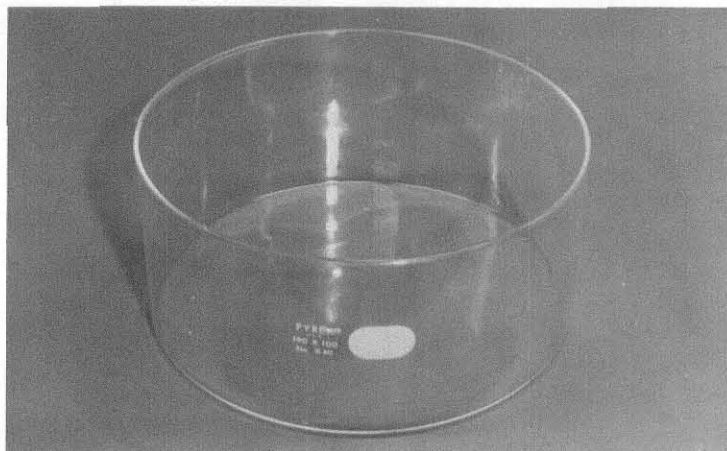


Plate III-A. Crystallization dish used in starch dough thermal efficiency test.

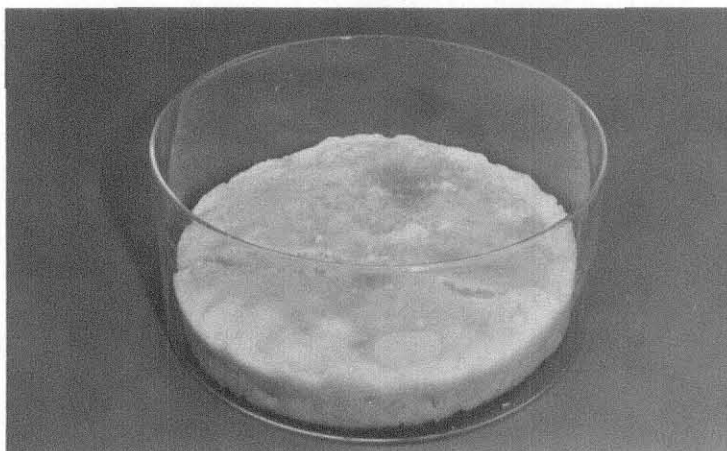


Plate III-B. Crystallization dish and simulated load used in starch dough thermal efficiency test.

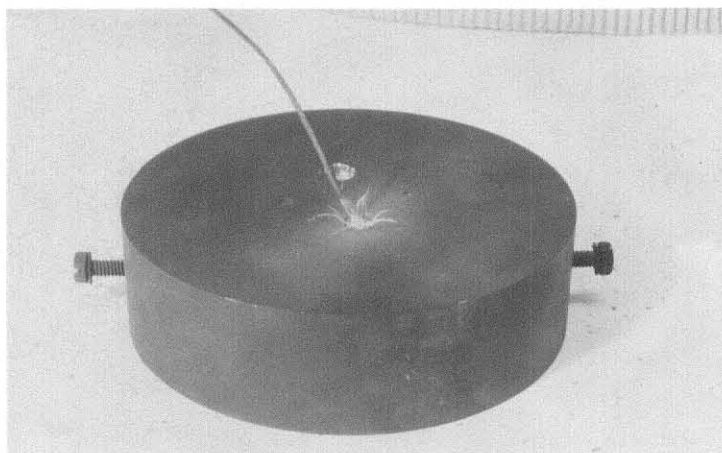


Plate III-C. 5.24 lb aluminum block used in thermal efficiency test.

[22, p. 1], and as reflected by field survey volunteers in their actual use of portable convection ovens, the ovens were not preheated for the starch dough-crystallization dish thermal efficiency tests. The crystallization dish containing starch dough was placed in each oven on a rack in the lowest position.

Three chromel-alumel thermocouples were positioned 0.5 in. below the top surface of the starch dough. Thermocouples 1 and 3, those on the outside, were 1.8 in. from the dish edge and thermocouple 2, the middle one, was in the center of the horizontal plane, 2 in. from either outside thermocouple. The thermocouple lead wires were secured by pieces of aluminum foil to an oven rack placed above the food load. Because the Montgomery Ward oven did not have a second rack, a piece of steel resting on the upper rack position guides was used to anchor the lead wires.

The starch dough, 81 ± 3 F before each thermal efficiency test, was heated to an average temperature of 200 ± 1 F. The number of watthours required to reach this temperature end point was recorded, and the evaporative loss, as calculated by the difference between the total weight of the load before and after the test, determined. The same equipment, procedure steps (Appendix H), and thermal efficiency calculations (Eqs 6 & 7), as described for food loads, was utilized for the thermal efficiency test using starch dough. The starch dough-crystallization dish thermal efficiency test was replicated 3 times in each test oven in a random sequence.

5.24 1b aluminum block

A further investigation of suitable simulated loads for a portable

convection oven thermal efficiency standard test was undertaken. An aluminum block seemed to be a good possible simulated load because it could be used repeatedly and the 8.5 lb aluminum block is accepted as the test media for conventional oven thermal efficiency tests.

A modified weight and shape of the 8.5 lb block was discussed and it was decided to cut the 8.5 lb block to approximately two-thirds the original height, leaving the diameter the same. The weight of the modified block also became approximately two-thirds the weight of the 8.5 lb block. Specifications for the modified block are as follows:

- No. 6061 aluminum alloy
- 0.23 Btu/lb/F, specific heat
- 5.24 lb weight
- 6.25 in. diameter
- 1.81 in. height
- Black finish with a minimum thickness of 0.001 in.

The oven temperature setting selected for this test was 400 F, the same as that in the 8.5 lb block test. A chromel-alumel thermocouple was attached to the top of the 5.24 lb block by a set screw (Plate III-C) and the thermocouple to the recording potentiometer. The 5.24 lb aluminum block was at 85 ± 5 F before each test.

The procedure (Appendix O), equipment, and thermal efficiency equation (Eq 8) used for the 8.5 lb aluminum block standard test were used during tests with the 5.24 lb aluminum block in the portable convection test ovens. The thermal efficiency on the 5.24 lb block tests was calculated after 40, 50, and 60 min and when the block had reached a temperature 234 F above its initial temperature. The test was replicated 3 times in each test oven in a randomly selected sequence.

Comparison of starch dough-crystallization dish and 5.24 lb aluminum block tests

As shown in Table 8, the average thermal efficiency when using the starch dough-crystallization dish test was 10.68% for the Montgomery Ward oven, 9.35% for the Rival oven, 9.33% for the Farberware oven, and 8.83% for the Cusinart oven. This sequence is a slight deviation from the test oven sequence when using food loads because the Rival oven is 0.02% higher than the Farberware oven. The average of the test ovens for the starch dough-crystallization dish thermal efficiency tests is 11.28%.

The 5.24 lb aluminum block test results wherein the block was heated 234 F above its initial temperature appeared to be more reflective of the food load thermal efficiency test results than when the block was heated for 40, 50, and 60 min. The thermal efficiencies of the test ovens for the 5.24 lb block when heated +234 F tests are 12.07% for the Montgomery Ward oven, 11.90% for the Farberware oven, 11.49% for the Rival oven, and 9.65% for the Cusinart (Table 8). The average of the 5.24 lb block +234 F thermal efficiency tests is 11.28%.

The following discussion is the researcher's interpretation of a statistical analysis of the simulated load thermal efficiency test results done by Annis [5].

Linear regression was performed to study the relationship between the thermal efficiency simulated load tests, where tests were performed on at least 3 of the test ovens, and the food load tests. The analysis shows to what extent variation in food load thermal efficiencies caused a variation in the thermal efficiency using a simulated load.

Table 8. Test oven thermal efficiencies for starch dough-crystallization dish and 5.24 lb aluminum block tests.^a

Oven	Replication no.	Thermal efficiency, %				
		Starch dough- crystallization dish ^b	5.24 lb aluminum block ^c +234 F	40 min	50 min	60 min
Farberware	1	9.52	11.71	10.86	9.64	8.58
	2	9.33	11.93	10.88	9.60	8.56
	3	9.15	12.07	11.10	9.77	8.68
	Avg	9.33	11.90	10.95	9.67	8.61
Cusinart	1	8.88	9.75	9.11	8.06	7.15
	2	8.80	9.72	9.14	8.13	7.19
	3	8.80	9.47	9.07	8.05	7.09
	Avg	8.83	9.65	9.11	8.08	7.14
Rival	1	9.38	11.40	11.01	10.32	9.31
	2	9.14	11.89	11.28	10.44	9.45
	3	9.52	11.18	10.91	10.03	9.22
	Avg	9.35	11.49	11.07	10.26	9.33
Montgomery Ward	1	10.82	12.34	11.88	11.20	10.47
	2	10.59	12.08	11.68	11.22	10.33
	3	10.64	11.79	11.81	11.30	10.19
	Avg	10.68	12.07	11.79	11.24	10.33
All test ovens		9.55	11.28	10.73	9.81	8.85

^aBased on raw data presented in Appendices S and T.

^bStarch dough heated to 200 F internal temperature.

^c5.24 lb black aluminum block heated 234 F above initial temperature, and 40, 50, and 60 min.

The degree of association between 2 variables is determined by a coefficient of correlation ($\hat{r}$) which is an outcome of the regression analysis. The value of $\hat{r}$ depends on the slope of the regression line and the deviation of the data points from the line. The coefficient of correlation is positive or negative, respectively, for a positive or negative slope. When $\hat{r} = 0$ there is no linear regression correlation between the 2 variables being compared in the analysis. When $\hat{r} = \pm 1$, all of the observations fall on the regression line. Therefore, $\hat{r}^2$ is the fraction of the total variance that is "accounted for" by the regression and a simulated load test where $\hat{r}$ approached 1 was sought in this study's analysis. A positive slope nearing 1 was sought since it was desirable that Y_1 tended to increase with X_1 . A negative slope would have indicated Y_1 decreased as X_1 increased.

As indicated in Table 9 and Figure 1, the starch dough in a glass loaf dish resulted in the highest $\hat{r}$ value, 0.969. However, this simulated load test was not acceptable because the utensil was not standardized. The starch dough simulated load test, when a standardized crystallization dish was used, came the next closest to 1, $\hat{r} = 0.949$. Results of the 5.24 lb aluminum block tests show the 50 min test as having the highest correlation coefficient, $\hat{r} = 0.919$, for that simulated load.

In order to obtain the desired regression line, the method of least squares was utilized. It follows:

$$Y = a + b X \quad \text{Eq (9)}$$

where:

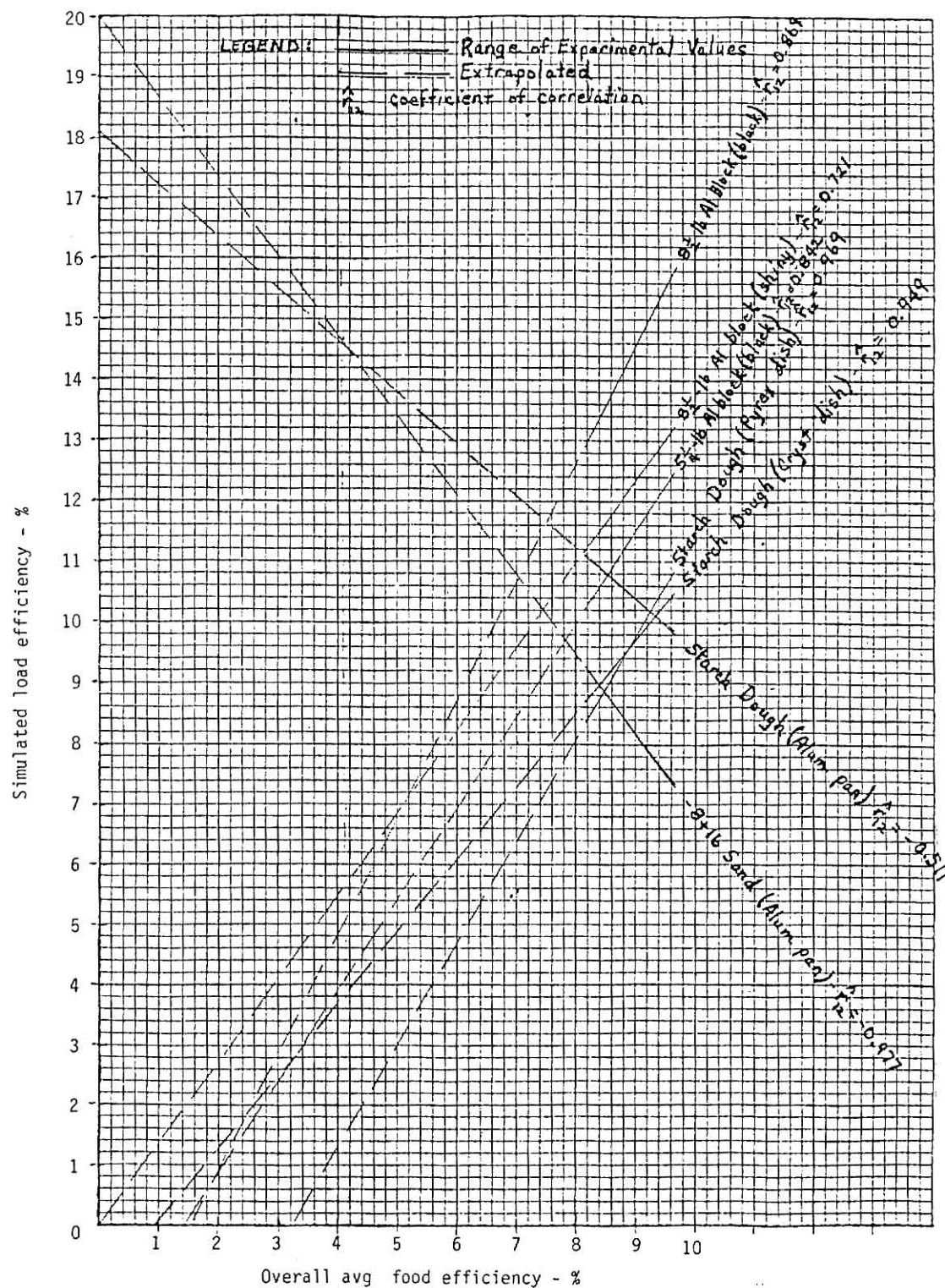
Y = vertical axis value

Table 9. Linear regression analysis of simulated load test thermal efficiencies (Y) on average food load thermal efficiencies (X).^a

Simulated Load	Utensil	Mean $\bar{Y}$, %	Mean $\bar{X}$, %	Y-intercept, a	Slope of line, b	Coefficient of correlation, $\hat{r}$
8.5 lb block, black	-	14.280	8.860	-2.968	1.947	0.869
8.5 lb block, No finish	-	11.900	8.700	0.023	1.366	0.721
Starch dough	Glass loaf dish	9.519	8.860	-5.441	1.688	0.969
Starch dough	Aluminum pan	10.468	8.920	18.085	-0.854	-0.511
Starch dough	Crystallization dish	9.548	8.860	-1.159	1.208	0.949
Sand & water	Aluminum pan	8.680	8.600	19.968	-1.312	-0.977
5.24 lb block +234 F	-	11.280	8.860	-2.148	1.515	0.842
40 min	-	10.730	8.860	-3.895	1.650	0.910
50 min	-	9.810	8.860	-7.256	1.927	0.919
60 min	-	8.850	8.860	-8.312	1.937	0.914

^aFrom Patty Annis. "Statistical Analysis of Data to Develop a Standard Test to Determine the Thermal Efficiency of Portable Convection Ovens." Household Equipment Report No-1-81.

Figure 1. Correlation of simulated and natural food load convection oven efficiencies.



X = horizontal axis value

a = point where line crosses the vertical axis

b = amount by which the line rises for each unit increase in X

It was desirable in this study's analysis for " a " to approach 0, resulting in a regression line intersecting near the point of origin. A simulated load test in which " b " approached 1 was sought since it was desirable for an increase of 1% thermal efficiency using food loads (X_1) to produce a 1% thermal efficiency increase using a simulated load (Y_1).

The simulated load test resulting in values for " a " and " b " most desirable ($a = 0$ and $b = 1$) was the 8.5 lb block--no finish load, as shown in Table 9 and Figure 1, $a = 0.023$ and $b = 1.366$. The starch dough in a crystallization dish came the second closest, $a = -1.159$ and $b = 1.208$. When considering the Y-intercept and slope of line, the 5.24 lb aluminum block test when heated +234 F was the most desirable of the 5.24 lb block tests, $a = -2.148$ and $b = 1.515$.

How nearly equal the means were of the 2 variables, the simulated load tests ($\bar{Y}$) and food load tests ($\bar{X}$), was a consideration in the statistical analysis. Though it was desirable for the means to be close (criteria for acceptance of a simulated load stated $\pm 3\%$), it was more important that the other criteria for a good correlation of variables ($\hat{r}$ and $b = 1$, and $a = 0$) be met.

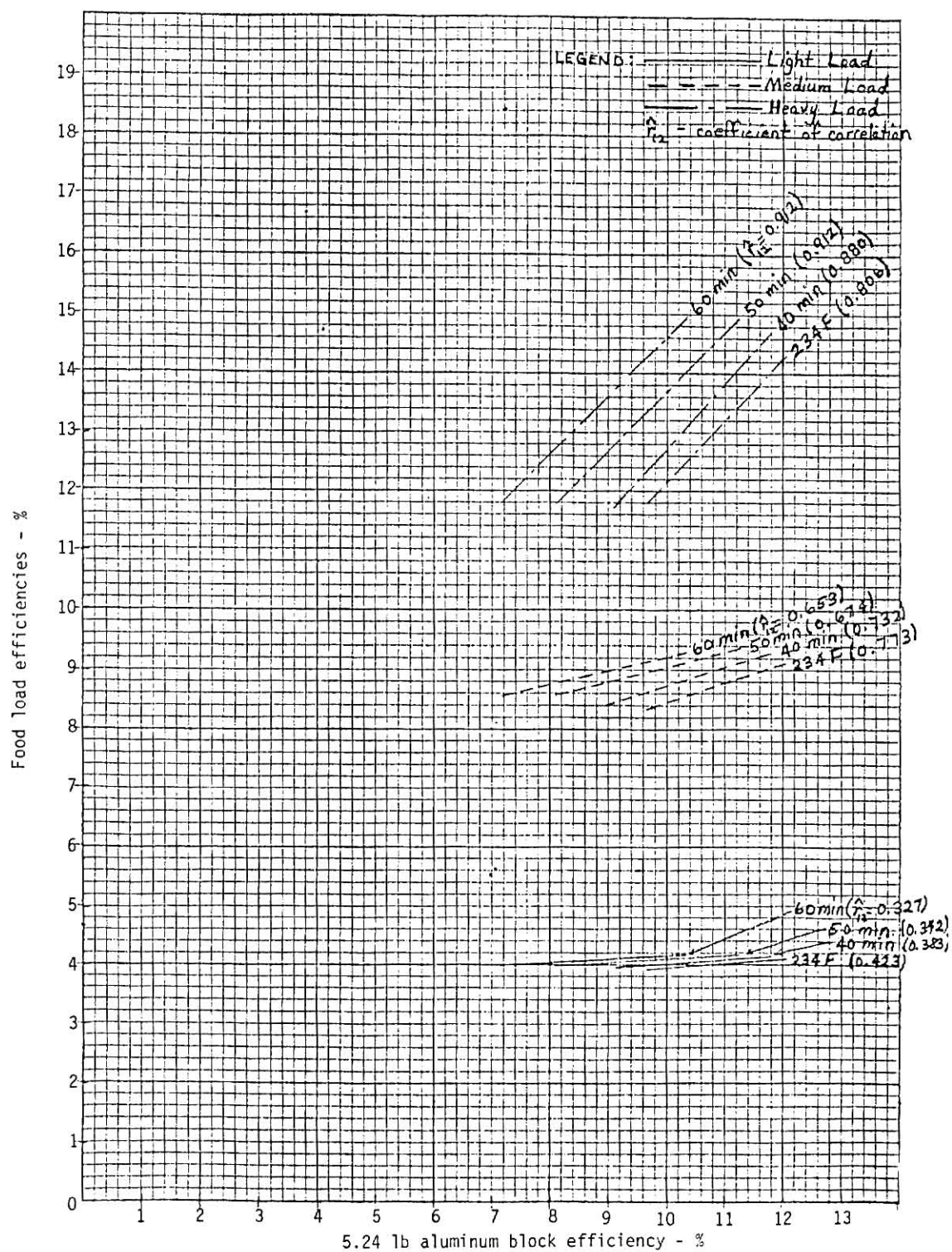
Results from the linear regression performed on the relationship between the thermal efficiency of each of the 3 food load tests and the 5.24 lb block heated to various end points are shown in Table 10 and Figure 2. Results sought for the tests were again that $\hat{r}$ and " b "

Table 10. Linear regression analysis of food load thermal efficiencies (Y) on average 5.24 lb block thermal efficiencies (X).^a

Food load size	Block test, End point	Mean Y, %	Mean X, %	Y-intercept, a	Slope of line, b	Coefficient of correlation, r
Heavy	+234 F	13.37	11.15	1.776	1.0400	0.806
	40 min	13.37	10.61	1.578	1.1120	0.880
	50 min	13.37	9.68	3.634	1.0060	0.912
	60 min	13.37	8.72	4.674	0.9980	0.912
Medium	+234 F	9.00	11.28	5.203	0.3370	0.773
	40 min	9.00	10.73	5.669	0.3100	0.732
	50 min	9.00	9.81	6.578	0.2470	0.674
	60 min	9.00	8.85	6.912	0.2360	0.653
Light	+234 F	4.09	11.28	3.181	0.0806	0.423
	40 min	4.09	10.73	3.327	0.0711	0.383
	50 min	4.09	9.81	3.552	0.0548	0.342
	60 min	4.09	8.85	3.632	0.0517	0.327

^aFrom Patty Annis. "Statistical Analysis of Data to Develop a Standard Test to Determine the Thermal Efficiency of Portable Convection Ovens." Household Equipment Report No-1-81.

Figure 2. Correlation of natural food and 5.24 lb aluminum block convection oven efficiencies.



approach 1 and "a" approach 0.

When comparing the efficiencies of the test ovens using the heavy food load and the 5.24 lb block, the best coefficients of correlation were the tests where the block was heated for 50 and 60 min, $\hat{r} = 0.912$. When considering the medium and light food loads, the block test where it was heated +234 F was highest, $\hat{r} = 0.773$ and $\hat{r} = 0.423$, respectively. The low thermal efficiency percentages involved in the light load food tests (3.84 to 4.54%) could partially account for the low $\hat{r}$ value.

Values for "a" and "b" on the heavy food load comparison were best when the block was heated 40 and 60 min, respectively. For the medium and light loads, the test when the 5.24 lb block was heated +234 F was the most desirable 5.24 lb block test choice considering the "a" and "b" values.

To determine if there was a significant difference among the thermal efficiencies of the portable convection test ovens using food loads and if so, if those differences were reflected in the standard tests using a simulated load, the thermal efficiency test data were analyzed statistically. First an F-value was calculated for pairs of test ovens to determine difference between the variances of their thermal efficiencies; one then could select the proper t-test. Table 11 shows where a significant difference in thermal efficiency existed at the 95% confidence level ($\alpha = .05$). It was more likely that a significant difference would not show up in the lighter loads because of the low thermal efficiencies involved.

The test oven pairs showing a significant difference on the heavy food loads match the ones on the starch dough in the crystallization

Table 11. Analysis of significant difference existing between thermal efficiencies of portable convection test ovens on various loads.^a

Test load	Oven Combinations ^b					
	F & C	F & R	F & M	C & R	C & M	R & M
5.24 lb block, +234 F	Yes	No	No	Yes	Yes	No
Starch dough-crystallization dish	Yes	No	Yes	Yes	Yes	Yes
Heavy food load	Yes	No	Yes	Yes	Yes	Yes
Medium food load	Yes	Yes	No	No	Yes	Yes
Light food load	No	No	No	No	No	Yes

^aFrom Patty Annis. "Statistical Analysis of Data to Develop a Standard Test to Determine the Thermal Efficiency of Portable Convection Ovens." Household Equipment Report No-1-81.

Based on values of F and t-test analysis presented in Appendix U. 2-tailed t-test, 95% confidence level, $\alpha = .05$, variance equal.

^bOven code: F = Farberware, C = Cusinart, R = Rival, and M = Montgomery Ward.

dish test. However, the 5.24 lb aluminum block +234 F test results did not match in 2 pairs, the Farberware oven vs Montgomery Ward oven and Rival oven vs Montgomery Ward oven.

Results of the linear regression and t-test statistical analysis show the starch dough-crystallization dish to be the most desirable simulated load test to determine the thermal efficiency of portable convection ovens. The 5.24 lb aluminum block heated +234 F is a second choice of simulated load thermal efficiency tests for portable convection ovens because it fit the criteria of being representative, reproducible and simple, but was not as desirable as the starch dough-crystallization dish test according to the statistical analysis.

PHASE IV - ANNUAL ENERGY CONSUMPTION OF PORTABLE CONVECTION TEST OVENS

Data from the field survey and most desirable simulated load thermal efficiency tests (starch dough-crystallization dish) were used to calculate the annual energy consumption of the portable convection test ovens. Annual energy consumption information is most meaningful to consumers when converted to dollars/yr to operate, so the estimated annual operating cost of the portable convection test ovens was calculated.

Field Survey Energy Consumption Data

Results of the energy consumed by a portable convection oven from the field survey are shown in Table 12. The number of days each volunteer metered their oven's energy consumption varied with the number of meters available at the time. Based on this limited data, the average energy consumption was 0.3674 kwh/day, thus 134.10 kwh/yr. The annual useful cooking energy output for a portable convection oven was determined by the average test oven thermal efficiency from the starch dough-crystallization dish test, 9.55%, times the annual energy consumption, 134.10 kwh, and equaled 12.81 kwh.

Test Procedure and Results

The DOE [11, p. 20124] recommended formula for determining the annual energy consumption of conventional ovens (Eq 4) was followed

Table 12. Energy consumption of portable convection ovens by field survey volunteers.

Volunteer no.	Length of time metered, No. of days	Energy consumed, kwh	Energy consumed/day, kwh
1	28	6.9	0.2464
2	217	67.0	0.3088
3	217	189.0	0.8710
4	182	48.2	0.2648
5	140	64.0	0.4571
6	203	91.3	0.4498
7	196	52.0	0.2653
8	161	28.8	0.1789
9	56	27.0	0.4821
10	133	19.9	<u>0.1496</u>
Avg all			0.3674

to calculate the annual energy consumption of the portable convection test ovens. Results of the field survey and starch dough-crystallization dish tests are included in the equation given below to determine the annual energy consumption, in kwh/yr, of the portable convection test ovens:

$$E_{PCO} = \frac{(E_0)(H_E)(O_0)}{(W_d)(C_{pd})(\Delta T_d)} \quad \text{Eq (10)}$$

where:

E_0 = Avg electrical energy to oven during starch dough-crystallization dish tests, Wh

H_E = Conversion factor, 3.412 Btu/Wh

O_0 = Annual useful cooking energy output, 12.81 kwh

W_d = Weight of starch dough, 2.11 lb

C_{pd} = Specific heat of starch dough, 0.51 Btu/lb/F

ΔT_d = Temperature rise of starch dough, F

The annual energy consumption of the test ovens used during this study is 147.28 kwh for the Montgomery Ward oven, 155.44 kwh for the Farberware oven, 161.52 kwh for the Rival oven, and 164.77 kwh for the Cusinart oven. The average of the test oven's annual energy consumption is 157.25 kwh. An example of the calculation is given in Appendix V.

As shown in Eq (6) DOE [11, p. 20119] determines the estimated annual operating cost of a conventional oven as the annual energy consumption times the average cost of electrical usage, \$0.0497 per kwh as of November 1979 [14, p. 66478]. Accordingly, the estimated annual operating cost of the portable convection test ovens, rounded to the nearest quarter dollar, are Montgomery Ward oven \$7.25, Farberware oven \$7.75,

Rival oven \$8.00, and Cusinart oven \$8.25 and averaged \$7.75. Appendix V shows an example of this calculation.

SUMMARY

This study was undertaken to develop a realistic, repeatable standard test determining the thermal efficiency of a portable convection oven. Following is a summary of the phases in this study.

The objective of PHASE I - CONSUMER USAGE was to determine the foods being prepared most often by consumers in portable convection ovens. Volunteers owning a portable convection oven participated in a field survey to establish the types of foods being prepared most often and the oven operation factors, such as oven temperature settings and utensil materials, being used frequently. Bread products were prepared 26.0% of the time, meats (one-ingredient main dishes) 23.0%, vegetables and other side dishes 21.0%, desserts 14.8%, other main dishes 12.7%, and miscellaneous foods 2.7%. The most frequently used oven temperature settings were in the 300-399 F category. Popular utensil materials were aluminum, glass-ceramic, metals (not specified), aluminum foil, and glass.

The objective of PHASE II - FOOD LOADS was to determine the thermal efficiency of portable convection ovens using food loads. In this study heavy, medium, and light food loads were used to test the thermal efficiency of 4 portable convection oven models. Meatloaf was used for the heavy load, a layer cake for the medium load, and a loaf cake for the light load. The thermal efficiencies of the test ovens ranged from 8.14 to 9.67%, and averaged 8.86%.

The objective of PHASE III - SIMULATED LOADS was to determine a

simulated load for use in a standard test procedure to calculate the thermal efficiency and annual energy consumption of a portable convection oven. Considering results of the linear regression of simulated load thermal efficiency tests on overall average food load thermal efficiency tests, a starch dough-crystallization dish and a 5.24 lb aluminum block appear to be reasonable substitutes for food.

The objective of PHASE IV - ANNUAL ENERGY CONSUMPTION OF PORTABLE CONVECTION TEST OVENS was to determine the average annual energy consumption of the portable convection test ovens. Results of the limited data collected from the field survey by having volunteers meter their ovens show portable convection ovens to consume 134.10 kwh annually. The annual energy consumption of the test ovens used in this study was calculated, based on the energy consumed during the starch dough-crystallization dish thermal efficiency tests. The energy consumption, in descending order, was 164.77 kwh/yr for the Cusinart oven, 161.52 kwh/yr for the Rival oven, 155.44 kwh/yr for the Farberware oven, and 147.28 kwh/yr for the Montgomery Ward oven. The average of the test oven's annual energy consumption, 157.25 kwh, times the average cost/kwh, \$0.0497, results in an average estimated annual operating cost of the portable convection test ovens of \$7.75.

CONCLUSIONS, RECOMMENDATIONS, AND IMPLICATIONS

It is concluded from the results of this study that a test using a starch dough-crystallization dish simulated load is a realistic, repeatable standard test for determining the thermal efficiency of portable convection ovens. An alternative simulated load test to determine the thermal efficiency of portable convection ovens uses a 5.24 lb aluminum block heated +234 F. Further study in modifying the 5.24 lb block in shape, weight, and finish are recommended by the researcher to identify a standard test using an aluminum block which is more desirable when attempting to replicate the thermal efficiency results using food loads.

The standard tests recommended in this study to determine the thermal efficiency of portable convection ovens follows:

TEST CONDITIONS AND INSTRUMENTATION

Voltage. Input voltage to portable convection oven shall be controlled at 120 v during the heat on portion of the cycle.

Energy measurement. Energy consumed by the portable convection oven shall be measured to the nearest whole watt-hour by use of a watt-hour meter.

Ambient room air temperature. The air temperature surrounding the portable convection oven shall be measured to the nearest 0.5 F on a thermometer and shall be 74 ± 4 F.

Simulated load and oven temperature. Chromel-alumel thermocouples connected to a recording potentiometer shall be used to measure the load and internal oven temperatures. When an average of 3 temperatures is required, the thermocouples shall be connected to a switch and the switch to the recording potentiometer. Thermocouples shall be calibrated by recording the thermocouple temperature in boiling water.

The simulated load and portable convection oven shall be at room temperature before each test.

Internal oven temperature. A thermocouple shall be placed in the center of the oven cavity. The internal oven temperature as determined by the average temperature of 3 consecutive on/off cycles, excluding the preheat period, shall be ± 5 F of the specified oven temperature setting.

Installation. The portable convection oven shall be connected to the voltage regulator and the voltage regulator to the watthour meter and the watthour meter into the wall outlet. The voltmeter shall also be connected to the voltage regulator.

Any baking racks shall be in place in accordance with the manufacturer's instructions; however, drip and/or broiler pans are to be removed from the oven cavity.

The thermocouple lead wires shall be secured when necessary by pieces of aluminum foil to an oven rack positioned above the load. When only one rack is provided for the oven, a piece of steel weighing 0.11 lb resting on the upper rack position guides shall be used as the auxilliary piece of equipment.

Ingredient and load weights. Ingredients for the simulated load and/or the total load weight shall be measured on a balance.

STARCH DOUGH-CRYSTALLIZATION DISH TEST

Simulated load. Prepare starch dough as directed in Appendix Q and press 2.11 lb of the dough in a glass crystallization dish having a 7.6 in. diameter, 4 in. high straight sides, and 0.89 lb weight. Weigh the simulated load (starch dough and dish).

Procedure. Perform a test following the applicable guidelines set forth in TEST CONDITIONS AND INSTRUMENTATION. Set the simulated load in the oven cavity in the center of a rack which is on the lowest position guide for the oven. Three thermocouples shall be positioned perpendicular to the oven floor, 0.5 in. below the top surface of the dough, and across the diameter of the dish in a straight line with one in the center and the others on 2 in. either side of the center. The internal oven temperature shall be 300 F.

Shut the oven door and start the oven. Monitor the starch dough temperature until the average temperature is 200 ± 1 F. Turn oven off, immediately weigh simulated load and record watthours used.

Calculation. Determine the thermal efficiency of the portable convection oven by:

$$\text{Eff}_{\text{PCO}} = \frac{(C_{\text{pd}})(W_{\text{d}})(\Delta T_{\text{d}}) + (C_{\text{pp}})(W_{\text{p}})(\Delta T_{\text{p}}) + (\Delta W_{\text{w}})(H_{\text{w}})}{S J} \times 100 \text{ Eq (11)}$$

where:

C_{pd} = Specific heat of dough, 0.51 Btu/lb/F

W_d = Weight of dough, 2.11 lb
 ΔT_d = Temperature difference of dough, F
 C_{pp} = Specific heat of pan (dish), 0.18 Btu/lb/F
 W_p = Weight of pan (dish), lb
 ΔT_p = Temperature difference of pan (dish), F^a
 ΔW_w = Evaporative loss, lb
 H_w = Latent heat of vaporization, 970 Btu/lb_m
 S = Electrical energy to oven, Wh
 J = Conversion factor, 3.412 Btu/Wh

When an auxiliary piece of equipment is used to secure the thermocouple lead wires, subtract from the denominator of the equation:

$$(C_{pa})(W_a)(\Delta T_a)$$

where:

C_{pa} = Specific heat of auxiliary equipment, 0.12 Btu/lb/F
 W_a = Weight of auxiliary equipment, 0.11 lb
 ΔT_a = Temperature difference of auxiliary equipment, F^b

^aEnd temperature is considered to be at a point half way between the end starch dough temperature and the internal oven temperature.

^bEnd temperature is considered to be the internal oven temperature.

5.24 LB BLOCK TEST

Simulated load. The test block is to be made of aluminum alloy No. 6061, with a specific heat of 0.23 Btu/lb/F, 5.24 lb weight, 6.25 in. diameter, and 1.81 in. height. It shall have a black finish with a minimum thickness of 0.001 in. A hole in the top center of the block, 0.08 in. diameter and 0.80 in. deep, shall be made in the block. A thermocouple shall be installed such that the junction is at the bottom of the hole and makes good thermal contact with the aluminum block.

Procedure. Perform a test following the applicable guidelines set forth in TEST CONDITIONS AND INSTRUMENTATION. Set 5.24 lb aluminum block in the oven cavity in the center of a rack which is on the lowest position guide for the oven. The internal oven temperature shall be 400 F.

Shut the oven door and start the oven. Monitor the 5.24 lb aluminum block temperature until it reaches 234 F above the initial temperature. Turn oven off and record watthours used.

Calculation. Determine the thermal efficiency of the portable convection oven by:

$$\text{Eff}_{\text{PCO}} = \frac{(W_b)(C_{pb})(\Delta T_b)}{S J} \times 100 \quad \text{Eq (12)}$$

where:

W_b = Weight of block, 5.24 lb

C_{pb} = Specific heat of block, 0.23 Btu/lb/F

ΔT_b = Temperature difference of block, 234 F

S = Electrical energy to oven, Wh

J = Conversion factor, 3.412 Btu/Wh

Problems with the reproducibility of these standard tests for the thermal efficiency of portable convection ovens may be encountered if there is a sudden fluctuation in line voltage during the test or if the oven's electrical power (wattage) varies greatly during the test procedure. These problems could be diminished by constantly monitoring the voltage during tests and regulating it so the voltage remained at 120 v.

The thermal efficiency of a portable convection oven using the starch dough-crystallization dish standard test, 9.55%, can be compared by consumers to that of a conventional oven 13.85%, and a microwave oven 38.85% [8, p. I-4]. The consumer should not interpret this data to

mean that it will take less energy to cook a food (i.e., a cake) in a conventional or microwave oven than in a portable convection oven since the appliance's wattage and the time required to cook the food in the appliance will affect the total energy consumption. Further research is needed comparing the energy consumption of various oven types using the same foods to help consumers choose the most energy efficient appliance when preparing foods.

The difference in the thermal efficiency figures for each of the test ovens used in this study could be used by consumers as a guide for choosing the most energy efficient portable convection oven model at point of purchase. According to the results of this study, using the standard starch dough-crystallization dish test, the most energy efficient model would be the Montgomery Ward oven 10.68%, next the Rival and Farberware ovens at 9.35 and 9.33%, respectively, lastly the Cusinart oven at 8.83%. Further research studying the effect of a portable convection oven features, such as fan position, wall material, insulation, and cavity size, on thermal efficiency would help the consumer know what features to look for when selecting among the various models available on the market.

Consumers can estimate, as a result of this study based on limited data of present usage level and a limited number of portable convection oven models used for testing, that a portable convection oven will consume approximately 157.25 kwh annually or cost approximately \$7.75/yr to operate. Though according to DOE, the conventional oven consumes approximately 340 kwh/yr and the microwave oven 88 kwh/yr, the consumer should not interpret this data to mean it would take more energy to cook

a particular food (i.e., a cake) in the conventional oven and less energy in the microwave oven than in a portable convection oven. The annual energy consumption figures are based on the average consumers' use of the appliance and the appliance's thermal efficiency, not on the energy consumption annually to cook the same number and types of foods in the appliance.

Results of this study show it to not be economically feasible to require the estimated annual operating cost on labels of portable convection ovens because: (1) the range in operating costs among the appliance test models was small, \$1.00, in contrast to their initial cost, \$100.00 to \$250.00, and (2) consumer benefits of labels including energy operating costs would not correspond to industry's costs of a labeling requirement.

Manufacturers and regulatory agencies could substantiate energy advertising claims on portable convection ovens by using the recommended test procedure for the thermal efficiency (starch dough-crystallization dish test) developed in this study, if adopted by DOE. The developed standard test could also be used by consumer product testing organizations when reporting a comparison of models available to the consumer on the market.

ACKNOWLEDGMENT

Sincere appreciation is expressed to Patty J. Annis, Assistant Professor, Department of Family Economics, and Dr. Jason C. Annis, engineering consultant, Manhattan, Kansas, for their guidance and assistance during the investigative study and manuscript preparation.

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APPENDICES

Appendix A. Letter and questionnaire to field survey volunteers.



Cooperative Extension Service

Harvey County Extension Office
P.O. Box 583, Courthouse
Newton, Kansas 67114
316 283-7232

September 24, 1980

Dear Research Participant,

Thank you for volunteering to help supply information concerning the actual use of a portable convection oven by consumers. The data collected from participants will be invaluable as a basis for comparison during experimentation with test methods in the laboratory at Kansas State University.

Your part of the research project will include filling out the enclosed forms entitled, "Log for Convection Oven Use." There are four provided, one for each week of the assignment. Please answer the questions on the enclosed page, then record on the log for week number 1 the foods you prepare those 7 days. I would suggest keeping the form and a pencil right on top of your oven or near it so you can easily fill in the information as you use the oven. Take special note of the direction given in number 1, which asks you to place a bracket connecting all food items you prepare together in your oven.

Send your logs in one of the enclosed, self-addressed envelopes, after each week's worth of recording.

If, at any time, you have questions, please feel free to call me. My office number is 316-283-7232 and home number is 316-283-5834.

The effort you put into this project is certainly appreciated.

Sincerely yours,

Carolyn Jackson

Carolyn Jackson
CEHE, Fds. & Nutr.

Appendix A. Letter and questionnaire to field survey volunteers.
(Concluded)

PORTABLE CONVECTION OVEN QUESTIONNAIRE

1. What brand of portable convection oven do you own? _____
2. What is the wattage of your portable convection oven? (This can be found on the name plate or in the specification sheet that came with your appliance.) _____ watts
3. Number of people in your household. _____
4. Number of people (on the average), you are preparing food for when using your portable convection oven (i.e. though there's 5 in your household, maybe you only use your oven for cooking lunch when there's 2 of you at home). _____
 - a. _____ Number of adults
 - b. _____ Number of children 0-5 yrs
 - c. _____ Number of children 5-18 yrs

Name _____

Please return with log for Week 1.

ILLEGIBLE DOCUMENT

**THE FOLLOWING
DOCUMENT(S) IS OF
POOR LEGIBILITY IN
THE ORIGINAL**

**THIS IS THE BEST
COPY AVAILABLE**

Appendix C. Foods prepared by volunteers in portable convection oven field survey.

Food category	Sub-category	Frequency prepared		
		No. times	Percentage	
			Sub-category	Food category
Meats (One-ingredient main dishes)	Meat mixture (Meat balls & loaf)	15	6.2	
	Ground meat (Sausage & hamburgers)	18	7.5	
	Weiners	15	6.2	
	Fish (Whole, fillets, sticks & steaks)	21	8.7	
	Poultry (Whole & pieces)	22	9.1	
	Pork (Bacon, chops, & ham)	36	14.9	
	Roast (Beef & pork)	20	8.3	
	Steaks (Beef, pork, & lamb)	37	15.4	
	Thawing meat	4	1.7	
	Reheating meat	39	16.2	
	Misc. (Ribs, kebobs, liver & brisket)	14	5.8	
	Sub total	241	100.0	23.0
Other main dishes (Multiple-ingredient)	Pizza	24	18.0	
	Casseroles	39	29.3	
	Convenience foods (TV dinners & pot pies)	19	14.3	
	Sandwiches	15	11.3	
	Quiches & Souffles	6	4.5	
	Soups	3	2.3	
	Thawing main dishes	4	3.0	
	Reheating main dishes	23	17.3	
	Sub total	133	100.0	12.7
Side dishes	Potatoes (Baked white, casserole-type, yams, fries & hash browns)	95	43.0	
	Cook other vegetables	50	22.7	
	Casserole-type other vegetables	11	5.0	
	Fruit	20	9.1	
	Reheating vegetables	44	20.0	
	Sub total	220	100.0	21.0

Appendix C. Foods prepared by volunteers in portable convection oven field survey. (Concluded)

Food category	Sub-category	No. times	Frequency prepared	
			Sub-category	Food category
Bread products	Bake: Bread	33	12.1	
	Rolls	48	17.6	
	Biscuits & muffins	25	9.2	
	Coffeecake, cornbread, & quick breads	17	6.2	
	Reheat: Bread & rolls	64	23.4	
	Doughnuts, biscuits & muffins	11	4.0	
	Coffeecakes	6	2.2	
	Taco shells, tortillas & pancakes	5	1.8	
	Thaw: Bread & buns	13	4.8	
	Doughnuts	6	2.2	
	Coffeecakes	1	.4	
	Toast: Bread	16	5.9	
	Muffins & buns	7	2.6	
	Proof yeast doughs	21	7.7	
	Sub total	273	100.0	26.0
Desserts	Cakes	26	16.8	
	Pies & pastries	50	32.3	
	Puddings	16	10.3	
	Crisps, cobblers & dumplings	12	7.7	
	Cookies	43	27.7	
	Misc.	8	5.2	
	Sub total	155	100.0	14.8
Misc.	Warm other items	22	78.6	
	Sun tea	4	14.3	
	Salad dressing	1	3.6	
	Drying foods	1	3.6	
	Sub total	28	100.0	2.7
Total foods		1050		100.0

Appendix D. Recipe and specific heat of meatloaf.

Ingredient	Amount	Weight, g	Specific heat, Btu/lb/F
Ground round, Less than 5% fat content	1.5 lbs	681	0.74 ^a
Milk, fluid skim	1 c	245	0.93 ^a
Egg, large	1	50	0.79 ^a
Bread, 24 slices per 1.5 lb loaf	3 slices	84	0.71 ^b
Salt, noniodized	1 t	5	0.22 ^c
TOTAL		1065	

Directions for mixing:

Tear bread slices into crumbs. Beat egg slightly. Weigh all ingredients and combine. Press into loaf dish.

Calculation for specific heat of meatloaf

$$C_{pm} = \frac{(681)(0.74) + (245)(0.93) + (50)(0.79) + (84)(0.71) + (5)(0.22)}{1065}$$

$$C_{pm} = 0.78 \text{ Btu/lb/F}$$

^aFrom ASHRAE, ASHRAE Handbook of Fundamentals (1977), pp. 29.4 & 29.5.

^bFrom AGA Laboratories (1960), p. 45.

^cFrom Harrel & Thelen, Conversion Factors and Technical Data for the Food Industry (1959), p. 468.

Appendix E. Recipe and specific heat of cake.

Ingredient	Amount	Weight, g	Specific heat, Btu/lb/F
Lard	1 c	205.0	0.54 ^a
Vanilla, imitation	2 t	9.9	-
Granulated sugar	2 c	400.0	0.30 ^a
Eggs, large	4	192.0	0.76 ^a
Milk, fluid skim	1½ c	367.5	0.94 ^a
Cake flour, sifted	4½ c	425.0	0.38 ^a
Baking powder	4½ t	16.0	-
Salt	1 t	5.0	0.22 ^b
TOTAL		1620.4	

Directions for mixing:

Ingredients shall be at room temperature. Ingredients shall be weighed before mixing. Baking powder and salt shall be added to flour, sifted together 3 times, and divided into 3 portions. Milk shall be divided into 2 parts. Bottom of pan shall be greased.

A mixer^c, equipped with an off-center flat beater shall be used. Mixing of ingredients shall be done in a mixing bowl with a 8.5 in. diameter and 4.5 in. depth.

Beat eggs at medium speed for 30 seconds. Put lard and vanilla into mixer bowl. With beater operating at high speed, add sugar gradually over a period of one minute. Stop mixer, and scrape sides of bowl. Beat one minute longer at high speed. Turn to medium speed, add eggs gradually over a period of one minute. Stop mixer, and scrape

^aFrom AGA Laboratories (1960), pp. 45 & 46.

^bFrom Harrel and Thelen, Conversion Factors and Technical Data for the Food Industry (1959), p. 468.

^cA Hamilton Beach Mixer, Model 8FM-127.

Appendix E. Recipe and specific heat of cake. (Concluded)

bowl and beat one minute longer at medium speed. Stop the mixer and scrape the bowl. Turn mixer to low speed, adding 1/3 of the dry ingredients over a period of one minute and 1/2 of the milk over a period of 30 seconds. Add another 1/3 of the dry ingredients over a period of one minute. Stop the mixer and quickly scrape down the sides of the bowl. Add 1/2 of the milk over a period of 30 seconds; add final 1/3 of dry ingredients over a period of one minute. At the end of the third addition of dry ingredients, stop the mixer, scrape down the sides of the bowl, turn to medium speed and beat 10 seconds longer. Pour the batter quickly into the pan, smoothing evenly, and rap pan sharply 3 times on the table to remove air bubbles.

Calculation for specific heat of cake

$$C_{pc} = (205)(0.54) + (400)(0.30) + (192)(0.76) + (376.5)(0.94) + (425)(0.38) + (5)(0.22) / 1620.4$$

$$C_{pc} = 0.55 \text{ Btu/lb/F}$$

Appendix F. Score card for layer cakes (medium food load) used by sensory panel members.

Judge no. _____

Score Card for Plain Cake

Factor	Qualities	Stand- ard	Sample No.				Comments
			A	B	C	D	
I. External Appearance	Shape, symmetrical, slightly rounded top, free from cracks or peaks	10					
	Crust, smooth uniform golden brown	10					
II. Internal Appearance	Texture, light & fluffy	10					
	Grain, fine, round, evenly distributed cells with thin cell walls, free from tunnels	10					
	Color, crumb even and rich looking	10					
III. Flavor	Delicate, well-blended flavor of ingredients. Free from unpleasant odors or taste	10					
IV. Moistness	Moist, velvety	10					

Directions for use of score card for plain cake:

Standard	10	No detectable fault, highest possible score
Excellent	8-9	Of unusual excellence but not perfect
Good	6-7	Average good quality
Fair	4-5	Below average, slightly objectionable
Poor	2-3	Objectionable, but edible
Bad	0-1	Highly objectionable, inedible

Source: Adaptation from Dawson, E.H., and Harris, B.L. Sensory Method for Measuring Differences in Food Quality. Review of Literature and Proceedings of Conference. U.S. Dep. Agr., Agr. Infor. Bull. cited by Griswold, R.M. 1963. The Experimental Study of Foods. Boston: Houghton Mifflin Company. p. 509.

**THIS BOOK IS OF
POOR LEGIBILITY
DUE TO LIGHT
PRINTING
THROUGH OUT IT'S
ENTIRETY.**

**THIS IS AS
RECEIVED FROM
THE CUSTOMER.**

Appendix G. Food load thermal efficiency test data sheet.

Cooking Load Test			Test number	Date
Oven	Load size type	Temp. Dry Bulb	Time, start	
Voltage	Food	Temp. Wet Bulb	Time, end	
	Utensil	Room humidity	Time lapsed	
		Oven setting		

LOAD INFORMATION

Sp. A of food	Wt. of food	Initial temp. of food	Sp. A of utensil	Wt. of utensil	Initial temp. of utensil	Total wt. of load
		#1				
		#2				
		#3				
Ave.						

End temp. of food #1	End temp. of utensil	End wt. of load
#2		
#3		

Ave.

Calculation:

BTU _____ Total Λ absorbed by load

ENERGY INFORMATION

Initial Wh meter reading	Sp. A of harness	Wt. of harness	Initial temp. of harness
-----------------------------	---------------------	-------------------	-----------------------------

[illegible]

Calculation:

BLU	Energy used by Oven
1	100
2	100
3	100
4	100
5	100
6	100
7	100
8	100
9	100
10	100
11	100
12	100
13	100
14	100
15	100
16	100
17	100
18	100
19	100
20	100
21	100
22	100
23	100
24	100
25	100
26	100
27	100
28	100
29	100
30	100
31	100
32	100
33	100
34	100
35	100
36	100
37	100
38	100
39	100
40	100
41	100
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80	100
81	100
82	100
83	100
84	100
85	100
86	100
87	100
88	100
89	100
90	100
91	100
92	100
93	100
94	100
95	100
96	100
97	100
98	100
99	100
100	100

EFFICIENCY INFORMATION

Calculation:

CONTENTS

Appendix H. Test procedure for thermal efficiency tests using food loads.

Following is a check list of steps followed in each thermal efficiency test using food loads:

1. Psychrometer - fill with distilled water, plug in, and warm up
2. Fill in information on top portion of data sheet
3. Regulate line voltage to 122 v
4. Turn watthour meter to 0
5. Select appropriate oven temperature setting
6. Weigh utensil
7. Weigh and combine food ingredients
8. Place food in utensil and weigh total load
9. Place load in center of bottom oven rack and insert thermocouples
10. Shut oven door and turn on
 - a. Start recording potentiometer
 - b. Start timer
 - c. Check and record room temperature
11. Monitor internal food temperature until average end temperature ± 1 F is reached
12. Turn oven off
 - a. Record average temperature of load
 - b. Check timer
 - c. Record watthour meter reading
13. Weigh total load
14. Remove food from utensil

Appendix I. Example of calculation for food load thermal efficiency tests.

Data: 0.78 Btu/lb/F, specific heat of food
 2.314 lb, weight of food
 108.4 F, temperature difference of food
 0.18 Btu/lb/F, specific heat of pan
 1.745 lb, weight of pan
 177.5 F, temperature difference of pan
 0.204 lb, evaporative loss
 971 Wh, electrical energy to oven

Calculation, following Eq (6):

$$\text{Eff}_{\text{PCO}} = \frac{(0.78)(2.314)(108.4) + (0.18)(1.745)(177.5) + (0.204)(970)}{(971)(3.412)} \times 100$$

$$\text{Eff}_{\text{PCO}} = 13.56\%$$

Appendix J. Example of calculation for food load thermal efficiency tests when harness was used.

Data: 0.55 Btu/lb/F, specific heat of food
 0.8 lb, weight of food
 127 F, temperature difference of food
 0.23 Btu/lb/F, specific heat of pan
 0.318 lb, weight of pan
 177.5 F, temperature difference of pan
 0.048 lb, evaporative loss
 357 Wh, electrical energy to oven
 0.12 Btu/lb/F, specific heat of harness
 0.049 lb, weight of harness
 223 F, temperature difference of harness

Calculation, following Eq (7):

$$\text{Eff}_{\text{PCO}} = \frac{(0.55)(0.8)(127) + (0.23)(0.318)(177.5) + (0.048)(970)}{(357)(3.412) - (0.12)(0.049)(223)} \times 100$$

$$\text{Eff}_{\text{PCO}} = 9.49\%$$

Appendix K. Thermal efficiency test data for heavy food load.^a

Replication no.	Food temperature difference, F	Utensil temperature difference, F	Harness ^b temperature difference, F	Evaporative loss, lb	Oven energy consumption, Wh
F-1	108.4	177.5	-	0.204	971
F-2	106.7	173.4	-	0.201	1012
F-3	107.0	172.5	-	0.222	1003
C-1	108.3	174.7	-	0.242	1128
C-2	105.3	171.7	-	0.235	1263
C-3	107.4	174.0	-	0.187	1080
C-4	107.0	174.5	-	0.230	1124
R-1	105.3	174.5	-	0.182	929
R-2	106.3	173.0	-	0.181	932
R-3	106.7	174.0	-	0.210	978
M-1	106.3	173.5	273.5	0.243	953
M-2	106.3	173.7	273.7	0.237	890
M-3	106.7	173.2	272.7	0.235	906

^aMeatloaf cooked to medium doneness, 150 F internal temperature.^bWhen value is given, indicates harness used during test.

Appendix L. Thermal efficiency test data for medium food load.^a

Replication no.	Food temperature difference, F	Utensil temperature difference, F	Harness temperature difference, F	Evaporative loss, lb	Oven energy consumption, Wh
F-1	127.0	177.5	223.0	0.048	369
F-2	127.6	178.5	223.5	0.045	345
F-3	129.0	177.0	222.5	0.050	380
C-1	129.0	177.5	223.0	0.056	439
C-2	128.3	177.0	222.5	0.044	375
C-3	127.7	178.0	223.0	0.044	385
R-1	126.7	178.5	224.0	0.045	381
R-2	128.7	178.0	223.0	0.047	380
R-3	127.3	177.5	223.0	0.043	374
M-1	127.0	177.5	223.0	0.051	365
M-2	130.3	177.0	223.0	0.058	386
M-3	127.3	176.5	222.0	0.048	368

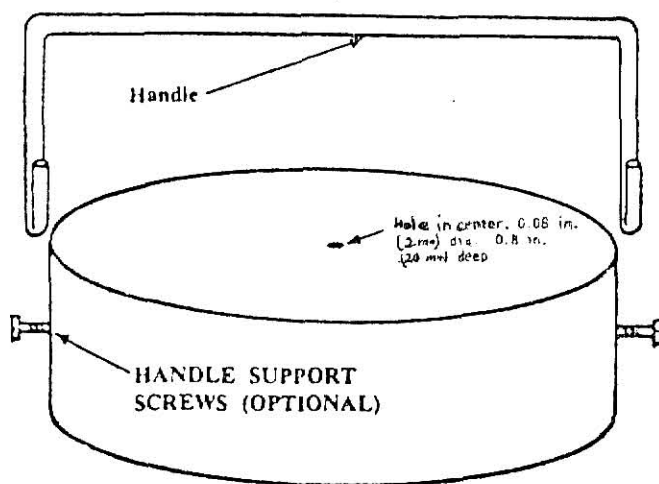
^aLayer cake cooked to 209 F internal temperature using harness on pan.

Appendix M. Thermal efficiency test data for light food load.^a

Replication no.	Food temperature difference, F	Utensil temperature difference, F	Harness temperature difference, F	Evaporative loss, lb	Oven energy consumption, Wh
F-1	133.7	181.0	223.0	0.022	333
F-2	133.0	181.5	224.0	0.022	381
F-3	133.0	179.5	222.0	0.025	393
C-1	133.0	180.0	222.5	0.022	367
C-2	134.0	180.0	222.0	0.020	380
C-3	133.0	180.5	223.0	0.026	404
R-1	133.0	180.0	222.5	0.022	383
R-2	133.0	182.0	224.5	0.022	381
R-3	136.0	180.5	223.0	0.026	410
M-1	133.0	180.5	223.0	0.026	387
M-2	133.0	182.0	224.5	0.023	356
M-3	133.0	180.0	224.5	0.026	392

^aLoaf cake cooked to 215 F internal temperature using harness on pan.

Appendix N. 8.5 lb aluminum block used for standard test determining the thermal efficiency of conventional standard-sized ovens.



Material:

Aluminum, 96% + pure (alloy #6061 or equivalent).

Aluminum, specific heat

$$\frac{0.23 \text{ Btu}}{\text{#OF}} \text{ or } \frac{962 \text{ J}}{\text{kg}^\circ\text{K}} \text{ at } 0 - 20^\circ\text{C}$$

Bottom shall be flat to within ± 0.002 in. (0.051 mm).

Handle is optional. Include screws in total weight.

Dimensions:

Small

Diameter 6.25 ± 0.05 in. (158.8 $\pm$ 1.3 mm)

*Height 2.8 in. (71 mm)

**Weight 8.5 ± 0.1 lb. (3.8556 $\pm$ 0.05 kg)

Large

Diameter 9 ± 0.05 in. (228.6 $\pm$ 1.3 mm)

*Height 3.0 in. (76 mm)

**Weight 19.0 ± 0.1 lb. (8.6184 $\pm$ 0.05 kg)

*Adjust height to match weight.

**Weight includes handle support screws.

Source: Appendix A of AHAM Standard Method for Measuring Performance of Household Electric Ranges, AHAM ER-1.

Appendix O. Test procedure for thermal efficiency tests using an 8.5 lb aluminum block.

Following is a check list of steps followed in each thermal efficiency test using the 8.5 lb aluminum block:

1. Fill in information on top portion of data sheet
2. Regulate line voltage to oven to 122 v
3. Turn watthour meter to 0
4. Turn oven temperature setting to 400 F
5. Set block in the center of the oven cavity. All baking racks shall be in place. Drip pans shall be removed
6. Shut oven door and turn oven on
 - a. Start recording potentiometer
 - b. Start timer
 - c. Record block temperature
7. Monitor block temperature until 234 F above initial temperature
8. Turn oven off
 - a. Record temperature
 - b. Check timer
 - c. Record watthour meter reading

Appendix P. Thermal efficiency test data for 8.5 lb aluminum block.^a

Replication no.	Oven energy consumption, Wh
F-1	968
F-2	916
F-3	960
C-1	1108
C-2	1076
C-3	1050
R-1	930
R-2	908
R-3	873
M-1	870
M-2	837
M-3	861

^a8.5 lb black aluminum block heated 234 F above initial temperature.

Appendix Q. Recipe and specific heat of starch dough.

Ingredient	Amount	Weight, g	Specific heat, Btu/lb/F
Flour, all-purpose, unsifted	3 c + 3 T	398	0.42 ^a
Salt, noniodized	1 c + 1 T	255	0.22 ^b
Water, distilled	1 c + 1 T	238	1.00 ^b
Oil, liquid soybean	½ c + 1½ t	116	0.48 ^c
Total		<u>1007</u>	

Directions for mixing:

Weigh all ingredients. Stir flour and salt together. Add water and oil. Stir until liquid ingredients are absorbed by the flour-salt mixture. Weigh 2.11 lb of dough. Press dough firmly into crystallization dish so that no apparent air bubbles are present.

Calculation for specific heat of starch dough

$$C_{pd} = \frac{(398)(0.42) + (255)(0.22) + (238)(1.00) + (116)(0.48)}{1007}$$

$$C_{pd} = 0.51 \text{ Btu/lb/F}$$

^aFrom ASHRAE, ASHRAE Guide and Data Book, Applications (1971), p. 412.

^bFrom Harrel and Thelen, Conversion Factors and Technical Data for the Food Industry (1959), p. 468.

^cFrom International Research Council and the National Academy of Sciences, Conversion Factors and Technical Data for the Food Industry (1927), p. 210.

Appendix R. Thermal efficiency test data for simulated loads investigated and rejected.

Test no.	Replication no.	Load temperature difference, F	Utensil temperature difference, F	Harness ^a temperature difference, F	Evaporative loss, lb	Oven energy consumption, Wh
1	F-1	80.0	154.5	224.0	0.009	178
1	C-1	77.0	154.0	224.0	0.008	147
1	C-2	78.0	153.0	222.0	0.009	139
1	C-3	75.0	155.0	225.0	0.004	147
2	F-1	73.0	152.5	223.0	0.048	287
2	F-2	71.0	154.0	224.0	0.074	323
2	F-3	81.0	151.0	221.0	0.081	365
3	F-1	234.0	-	-	-	1064
3	F-2	234.0	-	-	-	1077
3	F-3	234.0	-	-	-	1103
3	C-1	234.0	-	-	-	1242
3	C-2	234.0	-	-	-	1268
3	C-3	234.0	-	-	-	1234
3	R-1	234.0	-	-	-	1003
3	M-1	234.0	-	-	-	1080
4	F-1	75.0	151.0	221.0	0.020	158
4	F-2	75.0	154.0	223.0	0.039	184
4	F-3	78.0	153.0	222.5	0.034	178
4	C-1	80.0	154.5	224.5	0.032	175

^aWhen value is given, indicates harness used during test.

Appendix R. Thermal efficiency test data for simulated loads investigated and rejected. (Concluded)

Test no.	Replication no.	Load temperature difference, F	Utensil temperature difference, F	Harness ^a temperature difference, F	Evaporative loss, lb	Oven energy consumption, Wh
5	F-1	112.0	172.0	222.0	0.018	224
5	C-1	116.0	172.0	222.0	0.017	200
5	C-2	112.0	172.0	222.0	0.019	213
5	C-3	117.0	173.5	223.5	0.021	215
5	M-1	116.0	173.5	223.5	0.020	275
6	F-1	108.0	176.5	-	0.030	611
6	F-2	116.0	176.0	-	0.035	664
6	C-1	113.0	176.5	-	0.036	748
6	C-2	111.0	176.0	-	0.031	696
6	R-1	111.0	176.0	-	0.032	670
6	R-2	113.0	176.0	-	0.033	669
6	M-1	104.0	176.0	225.0	0.043	541
6	M-2	114.0	176.5	225.0	0.048	618
7	F-1	145.0	190.5	225.5	0.021	311
7	F-2	143.0	184.5	220.5	0.032	313
7	F-3	150.0	187.5	221.0	0.026	293
7	C-1	144.0	190.5	226.0	0.018	293
7	M-1	139.0	189.5	225.0	0.035	381

^aWhen value is given, indicates harness used during test.

Appendix S. Thermal efficiency test data for starch dough-crystallization dish test.^a

Replication no.	Dough temperature difference, F	Utensil temperature difference, F	Harness ^b temperature difference, F	Evaporative loss, lb	Oven energy consumption, Wh
F-1	117.0	180.0	-	0.017	527
F-2	122.0	180.0	-	0.022	570
F-3	118.0	180.0	-	0.025	577
C-1	115.0	179.5	-	0.019	564
C-2	120.0	179.5	-	0.023	600
C-3	118.0	180.0	-	0.023	593
R-1	119.0	180.0	-	0.031	584
R-2	119.0	180.0	-	0.033	606
R-3	120.0	180.0	-	0.022	552
M-1	118.0	180.0	230.0	0.030	502
M-2	118.0	176.0	226.0	0.033	519
M-3	121.0	180.0	230.0	0.046	562

^aStarch dough heated to 200 F internal temperature.

^bWhen value is given, indicates harness used during test.

Appendix T. Thermal efficiency test data for 5.24 lb aluminum block test.^a

Replication no.	Test							
	+234 F		40 min		50 min		60 min	
	Wh	$\Delta T, F$	Wh	$\Delta T, F$	Wh	$\Delta T, F$	Wh	$\Delta T, F$
F-1	706	234	833	256	1008	275	1173	285
F-2	693	234	831	256	1001	272	1168	283
F-3	685	234	827	260	998	276	1164	286
C-1	848	234	965	249	1179	269	1384	280
C-2	850	234	962	249	1165	268	1380	281
C-3	873	234	966	248	1180	269	1395	280
R-1	725	234	818	255	955	279	1100	290
R-2	695	234	814	260	954	282	1091	292
R-3	739	234	800	247	954	271	1084	283
M-1	670	234	746	251	877	278	975	289
M-2	684	234	753	249	853	271	971	284
M-3	701	234	751	251	853	273	988	285

^a5.24 lb black aluminum block heated 234 F above initial temperature.

Appendix U. F and t-test values to determine significance of difference among the thermal efficiencies of the portable convection test ovens using food and simulated loads.^a

Test load	Oven combinations ^b	Degrees of freedom, n_1 / n_2	Calculated F-value	F-table values ($\alpha = .05$)		$\sigma_1^2 = \sigma_2^2$	$\sigma_1^2 \neq \sigma_2^2$
				lower	upper		
5.24 lb block, + 234 F	F vs C	2 / 2	1.3935	0.0256	39.0	Assumed yes	No
	F vs R	2 / 2	0.2493	0.0256	39.0	Assumed yes	No
	F vs M	2 / 2	0.4351	0.0256	39.0	Assumed yes	No
	C vs R	2 / 2	0.1789	0.0256	39.0	Assumed yes	No
	C vs M	2 / 2	0.3122	0.0256	39.0	Assumed yes	No
	R vs M	2 / 2	1.7450	0.0256	39.0	Assumed yes	No
Starch dough-cryst dish	F vs C	2 / 2	16.0469	0.0256	39.0	Assumed yes	No
	F vs R	2 / 2	0.9269	0.0256	39.0	Assumed yes	No
	F vs M	2 / 2	2.3394	0.0256	39.0	Assumed yes	No
	C vs R	2 / 2	0.0578	0.0256	39.0	Assumed yes	No
	C vs M	2 / 2	0.1458	0.0256	39.0	Assumed yes	No
	R vs M	2 / 2	2.5239	0.0256	39.0	Assumed yes	No
Heavy food load	F vs C	2 / 3	0.3328	0.0625	16.0	Assumed yes	No
	F vs R	2 / 2	11.0833	0.0256	39.0	Assumed yes	No
	F vs M	2 / 2	0.8715	0.0256	39.0	Assumed yes	No
	C vs R	3 / 2	33.3050	0.0625	16.0	No	Yes
	C vs M	3 / 2	2.6187	0.0625	16.0	Assumed yes	No
	R vs M	2 / 2	0.0786	0.0256	39.0	Assumed yes	No

^aFrom Annis, "Statistical Analysis of Data to Develop a Standard Test to Determine the Thermal Efficiency of Portable Convection Ovens."

^bOven code: F=Farberware, C=Cusinart, R=Rival, M=Montgomery Ward.

Appendix U. F and t-test values to determine significance of difference among the thermal efficiencies of the portable convection test ovens using food and simulated loads. (Continued)

Test load	Oven combinations	Degrees of freedom, n_1 / n_2	Calculated F-value	F-table values ($\alpha = .05$)		$\sigma_1^2 = \sigma_2^2$	$\sigma_1^2 \neq \sigma_2^2$
				lower	upper		
Medium food load	F vs C	2 / 2	1.1394	0.0256	39.0	Assumed yes	No
	F vs R	2 / 2	3.8571	0.0256	39.0	Assumed yes	No
	F vs M	2 / 2	1.5189	0.0256	39.0	Assumed yes	No
	C vs R	2 / 2	3.3853	0.0256	39.0	Assumed yes	No
	C vs M	2 / 2	1.3331	0.0256	39.0	Assumed yes	No
	R vs M	2 / 2	0.3938	0.0256	39.0	Assumed yes	No
Light food load	F vs C	2 / 2	5.0388	0.0256	39.0	Assumed yes	No
	F vs R	2 / 2	77.2162	0.0256	39.0	No	Yes
	F vs M	2 / 2	11.3373	0.0256	39.0	Assumed yes	No
	C vs R	2 / 2	15.3243	0.0256	39.0	Assumed yes	No
	C vs M	2 / 2	2.2500	0.0256	39.0	Assumed yes	No
	R vs M	2 / 2	0.1468	0.0256	39.0	Assumed yes	No

Appendix U. F and t-test values to determine significance of difference among the thermal efficiencies of the portable convection test ovens using food and simulated loads. (Continued)

Test load	Oven combinations	Degrees of freedom, n	F-test conclusion $\sigma_1^2 = \sigma_2^2$	Calculated P(t)	Table P(t) ($\alpha = .05$)		Significant difference
					upper	lower	
5.24 lb block, + 234 F	F vs C	4	Yes	0.99996	0.975	0.025	Yes
	F vs R	4	Yes	0.92360	0.975	0.025	No
	F vs M	4	Yes	0.21528	0.975	0.025	No
	C vs M	4	Yes	0.00063	0.975	0.025	Yes
	C vs M	4	Yes	0.00009	0.975	0.025	Yes
	R vs M	4	Yes	0.04613	0.975	0.025	No
Starch dough-cryst dish	F vs C	4	Yes	0.99499	0.975	0.025	Yes
	F vs R	4	Yes	0.46759	0.975	0.025	No
	F vs M	4	Yes	0.00023	0.975	0.025	Yes
	C vs R	4	Yes	0.00518	0.975	0.025	Yes
	C vs M	4	yes	0.00001	0.975	0.025	Yes
	R vs M	4	Yes	0.00026	0.975	0.025	Yes
Heavy food load	F vs C	5	Yes	0.98433	0.975	0.025	Yes
	F vs R	4	Yes	0.35516	0.975	0.025	No
	F vs M	4	Yes	0.00220	0.975	0.025	Yes
	C vs R	5	No	0.00886	0.975	0.025	Yes
	C vs M	5	Yes	0.00040	0.975	0.025	Yes
	R vs M	4	Yes	0.00095	0.975	0.025	Yes

Appendix U. F and t-test values to determine significance of difference among the thermal efficiencies of the portable convection test ovens using food and simulated loads. (Concluded)

Test load	Oven combinations	Degrees of freedom, n	F-test conclusion $\sigma_1^2 = \sigma_2^2$	Calculated P(t)	Table P(t) ($\alpha = .05$)		Significant difference
					upper	lower	
Medium food load	F vs C	4	Yes	0.98948	0.975	0.025	Yes
	F vs R	4	Yes	0.98454	0.975	0.025	Yes
	F vs M	4	Yes	0.23280	0.975	0.025	No
	C vs R	4	Yes	0.13106	0.975	0.025	No
	C vs M	4	Yes	0.00398	0.975	0.025	Yes
	R vs M	4	Yes	0.00400	0.975	0.025	Yes
Light food load	F vs C	4	Yes	0.81482	0.975	0.025	No
	F vs R	4	No	0.85953	0.975	0.025	No
	F vs M	4	Yes	0.43319	0.975	0.025	No
	C vs R	4	Yes	0.61945	0.975	0.025	No
	C vs M	4	Yes	0.03674	0.975	0.025	No
	R vs M	4	Yes	0.00529	0.975	0.025	No

Appendix V. Example of calculation for determining the annual energy consumption and estimated annual operating cost of a portable convection oven.

Data, using Farberware oven:

588 Wh, avg standard starch dough-crystallization dish test energy consumption

12.81 kwh, annual useful cooking energy output of portable convection oven*

0.51 Btu/lb/F, specific heat of starch dough

2.11 lb, weight of starch dough

119.0 F, avg temperature rise of starch dough

0.89 lb, weight of utensil

0.18 Btu/lb/F, specific heat of utensil

180.0 F, avg temperature rise of utensil

0.0497 dollars/kwh, cost of electrical usage

*Product of 0.3674 kwh (avg energy usage/day from field survey) times 365 days/yr times 0.0955 (avg thermal efficiency of portable convection test ovens on starch dough-crystallization dish test).

Calculation, following Eqs (6) & (10):

$$E_{PCO} = \frac{(558)(3.412)(12.81)}{(0.51)(2.11)(119.0) + (0.89)(0.18)(180.0)}$$

$$E_{PCO} = 155.44 \text{ kwh}$$

$$EAOC_{PCO} = (155.44)(0.0497)$$

$$EAOC_{PCO} = \$7.73 \text{ or } \$7.75$$

DEVELOPMENT OF A STANDARD TEST TO DETERMINE
THE THERMAL EFFICIENCY OF PORTABLE CONVECTION OVENS

by

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B.S., Kansas State University, 1975

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This study was concerned with developing a standard test to determine the thermal efficiency of portable convection ovens that was realistic and reproducible. A field survey involving volunteers owning portable convection ovens was conducted to establish the types of foods being prepared in a portable convection oven and the oven operation factors for those foods.

Heavy, medium, and light food loads represented by a meatloaf, layer cake, and loaf cake, respectively, were used in testing the thermal efficiency of 4 portable convection oven models. The thermal efficiency was calculated by the ratio of the energy absorbed by the food and cooking utensil to the energy required by the oven for the test. The average thermal efficiency of the portable convection test ovens on all food load sizes was 8.86%.

Various simulated loads that could be used in a standard thermal efficiency test for portable convection ovens were investigated. A simulated load was sought because of the variability in foods causing tests to be less reproducible. Two simulated load tests for calculating the thermal efficiency of portable convection ovens were developed and determined as representative of consumers' usage and reproducible.

Starch dough, 2.11 lb, heated in a crystallization dish to 200 ± 1 F with the oven temperature setting at 300 F was chosen as the test to determine the thermal efficiency of portable convection ovens. The average thermal efficiency of the test ovens used in this study according to the starch dough-crystallization dish test was 9.55%.

A test using a 5.24 lb black aluminum block heated 234 F above its initial temperature with the oven temperature setting at 400 F, also was selected as a recommended standard test; though not as highly recommended as the starch dough-crystallization dish test. The average thermal efficiency of the test ovens using the 5.24 lb aluminum block test was 11.28%.

Based on kilowatt hour data collected from the field survey volunteers and results of the thermal efficiency starch dough-crystallization dish tests on the portable convection test ovens, the average annual energy consumption of the test ovens was determined to be 157.25 kwh. The estimated annual operating cost of the portable convection test ovens, using the average cost per kwh of \$0.0497, resulted in a yearly cost of \$7.75.

The starch dough-crystallization dish and 5.24 lb aluminum block tests developed in this study are recommended to be used by regulatory agencies as standard test procedures determining the thermal efficiency of portable convection ovens. Manufacturers are urged to use these tests as a basis for energy-related advertising claims and consumer product testing agencies should use the tests for comparing portable convection oven models.