NBSIR 77-1387

Evaluation of A Test Method for Measuring Microwave Oven Cooking Efficiency

Owen B. Laug

Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

September 1977

Prepared for
Federal Energy Administration
Washington, D.C. 20461

NBSIR 77-1387

EVALUATION OF A TEST METHOD FOR MEASURING MICROWAVE OVEN COOKING EFFICIENCY

Owen B. Laug

Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

September 1977

Prepared for
Federal Energy Administration
Washington, D.C. 20461

U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*

Dr. Sidney Harman, *Under Secretary*

Jordan J. Baruch, *Assistant Secretary for Science and Technology*

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

Table of Contents

List of Figures and Tables

FOREWORD

This work was performed as a part of NBS technical support to the Federal Energy Administration (FEA) Energy Conservation Program for Appliances as required by the Energy Policy and Conservation Act (Pub. L. 94-163) and the Energy Conservation and Production Act (Pub. L. 94-385).

Introduction

This report describes the results of laboratory tests made in support of a test method recommended to FEA for determining the energy efficiency and average annual energy consumption of microwave cooking appliances. The objective in the selection and development of a method has been one which is simple, repeatable, and correlates with actual consumer usage. In addition, the laboratory method should be able to be combined with consumer use pattern data to obtain estimated annual cost of operation. The work described herein does not relate to consumer use patterns.

By necessity a variety of microwave ovens had to be selected for use in evaluating a procedure. Since the purpose of the work has been to develop a standard test method, the results of data reported should not be used for purposes of rating the particular ovens tested, rather the data are intended to show the workability of the method. The limited sampling of models could result in ratings that are misleading. Therefore, the appliances selected for use are identified in this report by alphabetical letters A through E.

Background

In the search for a suitable test procedure, two basic methods were found to exist. The first was a procedure in the process of being adopted by the International Electrical Commission referred to as IEC-SC-59H Methods of measuring performance of microwave cooking appliances for household and similar purposes. The second procedure was proposed by Litton which claims to be applicable to all types of cooking appliances including microwave ovens. The Litton procedure was basically designed as a method for determining the annual energy consumption of ranges and microwave ovens by utilizing a standard menu from which water equivalents are derived. The main drawback to this method is that it appears time consuming and raises some fundamental questions when used for comparative purposes between electric ranges, conventional ovens, and microwave ovens. A more complete discussion of the Litton procedure is presented later.

The (IEC-SC-59H) procedure (hereafter referred to as the IEC procedure) consists of heating measured quantities of water to determine the power output and efficiency. The Association of Home Appliance Manufacturers (AHAM) is in favor of this procedure. On August 3, 1976, AHAM presented to NBS their proposed standard test method for ranges and ovens including microwave ovens. Their test method for microwave ovens was essentially the same as an earlier IEC version with some minor modifications, together with a method of determining annual energy consumption.

Approach

The evaluation of the test methods was performed on five different manufactured ovens of the counter top variety. The newer combination types (i.e. conventional and microwave in the same cavity) were not tested because at the time only one manufacturer had models available and the market penetration was limited. The microwave ovens choosen for test ranged in advertised power ratings from 450 to 675 watts. The following lists some of the pertinent specifications and features of the ovens tested:

Oven	Power-Watts	Cavity Volume-m^3	Features
A	625	0.037	Cook by time or temp. 3 level setting
B	675	0.029	Defrost & slow cook Digital clock
C	450	0.021	Defrost setting
D	650	0.031	Variable level heat control
E	600	0.025	Defrost setting Carousel turntable

Two approaches were taken in evaluating the IEC test procedure. First, the test procedure was performed exactly as specified a number of times on each oven to determine the repeatability and identify any problems. The second approach was to measure the heat input to various types of foods cooked in each of the microwave ovens. The heat input to the food divided by the energy input to the appliance gives the efficiency of cooking a given food. These efficiency measures are compared with the efficiencies obtained by the IEC standard test procedure. The value of this technique is to show how well the test procedure correlates with actual use.

IEC Test Procedure Evaluation

The IEC test procedure prescribes four test loads of water containing one-percent by weight of sodium chloride. The load sizes specified are: 275 ml, 500 ml, 1000 ml, and 2000 ml. Each load is heated in the microwave oven until a temperature rise of about 25 $\pm 5^{\circ}$C is achieved. The actual temperature rise is measured and the time is recorded. Initial efforts to follow this procedure met with some difficulty because as will be shown later there is no practical way of monitoring temperature while the microwave oven is operating. Therefore, it was necessary to make a few trials to obtain the desired temperature rise. The amount of time depends on the oven power and the load size. However, with some experience the testor soon is able to gauge the length of time required to obtain the specified temperature rise. The disadvantage of this method is that an inexperienced testor must make several trials before beginning an actual measurement.

The reason for fixing or standardizing on a temperature rise rather than time is that as the temperature of the water increases the measured efficiency begins to drop off. The coupling of microwave energy into the water apparently decreases with temperature and at higher temperatures there is a greater amount of heat lost to the surroundings as well as some evaporative cooling[4]. Therefore, if time were specified rather than temperature higher wattage ovens would produce a greater temperature rise resulting in a lower efficiency, hence, penalizing the more powerful ovens. The effect of temperature on efficiency was examined in each of the ovens by measuring the temperature rise and input energy of a 3000 ml water load. This load was divided equally into six 500 ml beakers placed contiguously in the center of the load carrying surface. Each run was started with the water load at room temperature and the time for each run increased from the last run by three minutes so that the sixth and final run was 18 minutes. Fig. 1 summarizes the effect of final temperature on measured efficiency. The curve represents the average normalized efficiency of the five ovens as a function of final temperature. At a 45°C final temperature (a 25°C rise above a 20°C initial) a plus or minus ±5°C change will produce about a ± 2.5% change in efficiency. If it is desired to tighten this spread it may be done of course by reducing the tolerances on the initial temperature and temperature rise specifications. The original IEC version specified a final test load temperature of 45 ± 5°C whereas the updated version specifies a 25 ± 5°C rise together with a 20 ± 5°C initial temperature. This allows the tolerance of the final temperature to be ±10°C and could result in as much as a ±5% spread in efficiency.

The measurement of temperature rise of the water load directly effects the accuracy and repeatability of the efficiency measure. It is not recommended to monitor the temperature of the water load while heating in the microwave oven for two reasons: First, if alcohol or mercury thermometers are used errors will occur due to the heating of alcohol and the mercury column can behave as an antenna. A shielded thermocouple wire can be used, however, caution should be taken to insure that the wire which passes between the door and seals does not re-radiate microwave energy outside the oven causing a possible health hazard. The second reason for not monitoring the temperature of a water load while heating is that the temperature distribution of the water in a vessel from top to bottom is not uniform. As much as a 5 to 7°C difference between top and bottom has been observed. Placing the thermocouple junction midway between the bottom and top surface of the water provides an average temperature which closely matches the temperature obtained by thorough stirring. However, in order to obtain the most accurate results, the water should be thoroughly stirred before recording the temperature. This is somewhat impractical to do while the oven is operating and more so when more than one container is used.

When the load is divided among more than one container a sequential measurement of the final water temperature of each container is necessary. It is important to make these temperature measurements rapidly before the load begins to cool. As little as a 1°C drop in final temperature before measurement can result in a 4% error of efficiency.

A technique was developed to measure the final temperature of the water with minimum delay and maximum stirring. Polystyrene foam lids were fabricated for each size breaker and thermocouple wires inserted through a small hole in the center of the lids. The thermocouple junction was positioned so that when the lid is put in place the junction protrudes about half way down into the water. A multi-channel thermocouple indicator and magnetic stirrer were used. The technique of measuring final temperature after a run is as follows: The beaker to be measured is withdrawn from the oven and placed on the top plate of the stirrer. A 2.5cm length magnetic stirring bar is dropped into the water, the polystyrene foam lid with the thermocouple is placed on the beaker and the stirrer is turned on. In less than 10 seconds of stirring the temperature has stabilized and a reading is made. This process is repeated for each beaker. With this technique a two beaker load can be measured in less than 20 seconds with minimal cooling.

The updated version of the IEC test method changed the distribution of the 1000 ml and 2000 ml loads. In the original version one 500 ml size glass beaker having a nominal inside diameter of 85 mm was specified to be used for all loads. The 1000 ml load was specified to be placed in equal portions of 500 ml each located continguously side by side in the center of the load carrying surface. The 2000 ml load was specified to be placed in equal portions of 500 ml in four containers located contiguously in a square array in the center of the load carrying surface. The updated IEC test specified a 1000 ml size glass beaker having a nominal 110mm inside diameter to be used for the 1000 ml and 2000 ml loads. The 1000 ml load is contained in one 1000 ml beaker and the 2000 ml load is contained in two 1000 ml beakers each located contiguously side by side. The effect of this change is simply to reduce the number of beakers in which the final temperature of the water must be measured and the distribution of the load. Tests were conducted with each version to examine what effect if any this change would have on the results of efficiency. Tables I thru V shows the test data and resultant efficiencies obtained for three complete replications of the latest IEC test procedure. A fourth run was made on the 1000 and 2000 ml load size using the original proposed distributions (i.e. two and four 500 ml beakers for the 1000 ml and 2000 ml load respectively). The rated efficiency was computed for each run by averaging the specific efficiencies of each load. For each oven the rated efficiency determined from each run did not deviate more than 0.5%. The good repeatability obtained from these runs is mainly attributed to the uniform technique of measuring the final temperature. The specific efficiencies obtained in run 4 on each oven do not differ significantly from the specific efficiencies of the 1000 and 2000 ml loads in runs 1 thru 3. Furthermore, if the specific efficiencies obtained from run four are substituted for the specific efficiencies of the 1000 and 2000 ml loads of runs 1, 2, or 3 and averaged, the rated efficiency is not significantly altered. Thus, there is little difference in the measured efficiency using the updated IEC version of load distribution.

Examination of tables I thru V shows that the specific efficiency can, depending on the oven vary up to 10 percentage points from the small load size (275 ml) to the large load size (2000 ml). Generally the efficiency continues to increase with load size up to 2000 ml. The IEC test procedure specifies that the rated efficiency of an oven is determined by averaging the specific efficiency of the four loads. This method of averaging assumes that the use factor of each simulated load is equal. If however, survey data showed that most foods cooked are at predominately lighter or heavier loads than the laboratory simulation, then perhaps a weighing factor might be introduced or the range and size of the loads adjusted. An alternate method of determining the rated efficiency is to sum the output energies and divide by the sum of the input energies for each of the four loads. This method will result in a slightly different answer for the rated efficiency. For the time being, however, the simple averaging of the specific efficiencies to obtain the rated efficiency seems to be as good a way as any.

The addition of salt to the water was not extensively investigated. Generally distilled water without any salts will yield a higher efficiency, perhaps as much as 5%. No significant difference was found between distilled water and tap water in this area. Although in the IEC procedure it is specified that the salt is to be added to distilled water, specified, the addition of 1% by weight of sodium chloride produces a salt solution which totally overwhelms the salts and mineral deposits of most drinking water so that drinking water seems perfectly adequate for this test. Use of distilled water is perhaps simply an added precaution, and generally is readily available in most laboratories.

Efficiency of Cooking Foods

A second approach investigated is the direct measurement of heat input to various types of foods cooked in a microwave oven. The heat input to the food divided by the energy input to the appliance provides a meaningful measure of the efficiency of the appliance under conditions of actual use. The purpose of this investigation was to show how well actual efficiencies of cooking foods correlated with efficiencies determined by the standard test procedure which uses water as the food substitute load.

A water calorimeter was used to measure the heat in a given sample of cooked food. The container used for the calorimeter was a Dewar wide mouth jar fitted with a polystyrene foam lid to minimize heat transfer to the ambient. The procedure developed is as follows: A given quantity of food is cooked in the microwave oven until it is done. The degree of doneness is not critical and determined primarily by following the recipes provided with the appliance. However, overdoneness generally will result in a lower efficiency. Often, it was found that for an unfamiliar dish several trial runs had to be made in order to determine the desired doneness. The food sample is weighed before cooking and immediately after. After cooking and weighing the food it is quickly transferred to a calorimeter containing a known initial temperature and quantity of water. The mixture is thoroughly stirred until the final equilibrium temperature is reached. If no heat is lost from the calorimeter during the test the heat given up by the food must equal the heat gained by the water in the calorimeter. The approximate total heat expressed in joules that went into the food and the heat required to drive off moisture in the food is expressed below. (See Appendix I)

$$Q \equiv h(M_{f1} - M_{f2}) + (M_w + M_{f1})(t_2 - t_1)(4.19) \qquad (1)$$

where h = heat of vaporization of water at $100^{\circ}C \equiv 2260$ J/g

M_{f1} = initial weight of food - grams

M_{f2} = final weight of food - grams

M_w = weight of water in calorimeter - grams

t_2 = final temperature of system $^{\circ}C$

t_1 = initial temperature of system $^{\circ}C$

The advantage of this technique is that the final temperature of the food does not need to be measured, the distribution of the temperature throughout the food does not affect the measurement, and the specific heat capacity of the food does not need to be accurately known. (See Appendix I)

Often foods are cooked in a microwave oven from the frozen state. When frozen foods are introduced into the oven, heat is required to raise the food to a temperature of $0^{\circ}C$, thaw it, and raise it to the final done temperature. This amount of heat can also be measured by employing the water calorimeter. Two identical samples of frozen food of the same weight must be selected or prepared before freezing. One sample is put in the oven from the freezer, cooked, reweighed, and put in the calorimeter. The second sample is removed from the freezer and directly transferred to the calorimeter. The water is thoroughly stirred and the new temperature is recorded. The approximate heat required to thaw the food and bring it to room temperature is (see appendix I)

$$Q \simeq (M_w + M_{f1})(t_1 - t_4)\ (4.19) \qquad (2)$$

where t_4 is the final temperature of the system ^{o}C.

For frozen foods which are cooked, the heat determined from equation 2 is added to the heat determined in equation 1.

Once the total heat into the food (Q_T) has been measured and the input energy (E) to the appliance recorded during the cooking interval, then the specific efficiency of cooking a given food may be obtained from the expression below.

$$\text{efficiency} = \frac{Q_T}{3600\ E_{in}} \qquad (3)$$

where

the factor 3600 is used to convert the customarily measured units of input energy (E_{in}) in watt-hours to joules.

The above technique was used to measure the efficiency of cooking a variety of foods either from the frozen state or from room temperature. A total of nine food items were cooked in each of the five ovens. The selection of the food items and portion size was not comprehensive nor chosen from a standard menu, but simply a variety of foods chosen to demonstrate a technique. Tables VI thru X show the resultant efficiencies of cooking nine foods some of which were frozen. An average efficiency for each oven based on the specific efficiency of each food item is also shown. The cooking of six bacon strips consistently produced a lower efficiency in each of the ovens. This is primarily due to the small size of the load and perhaps its low thin profile. However, heating a half loaf of bread of similar weight resulted in efficiencies over 30% in each of the ovens. No attempt was made to extensively analyze the apparent differences among foods. The technique shows, however, that there are real differences in efficiencies for various foods.

Table XI summarizes the rated efficiencies for each of the five ovens determined by the standard IEC test procedure and from cooking foods. This table shows that the efficiencies are quite similar. Moreover, the ranking of ovens by either method is very close. Oven E clearly stands out to be the most efficient by either method. Ovens A and B are next and C & D last. In fact, efficiency figures shown are so close that ranking is somewhat meaningless since they are all very similar with the exception of oven E.

One can conclude from the data shown in table XI that the efficiencies determined by the standard test method utilizing multiple loads of water are realistic values which correlate reasonably well with actual food cooking efficiency. Although the efficiency values obtained from cooking foods are consistantly lower than the values obtained from the test procedure, the important distinction is that the relative ranking of the ovens by efficiency correlate well by either method.

Annual Consumption

The proposed AHAM standard for determining the Annual Consumption of a microwave oven is outlined below.

1. Representative Consumption

From a Range Energy Field test conducted by AHAM it was found that for a family of four where a microwave oven was used along with conventional surface units and ovens, annual consumption was 88 kWh (3.17×10^8J).

2. Energy Factor

The energy factor (i.e. the average of the rated efficiencies) of microwave ovens monitored in the AHAM field test is 0.3885.

3. Energy into the food

From the data in 1 and 2 above, it can be determined that the energy actually used to cook food was:

$$0.3885 \times 88 \text{ kWh} = 34.188 \text{ kWh } (1.23 \times 10^8 \text{J})$$

4. Annual Microwave Oven Consumption

To determine annual consumption of any oven, divide the standard energy into the food (34.183 kWh) by the energy factor (rated efficiency) of the microwave oven being tested,

$$\text{Annual Energy Consumption, kWh} = \frac{34.188}{\text{energy}} \text{ factor}$$

The above determination seems to be a valid method of determining annual energy consumption. The representative consumption is based on survey information. A separate project is underway to survey 150 experienced users of microwave ovens to substantiate the AHAM figure. The energy factor was determined by taking the average of the rated efficiencies of the ovens used in the AHAM field test. It is interesting to note that the AHAM field tests average is 0.3885 and the average of ovens A thru E (tables I - V) produces a value of 0.3868.

A four place figure for energy factor is quite meaningless in view of the accuracy and repeatibility of the procedure. Rounding off the energy factor to two significant figures would produce a more meaningful value of 0.39.

The method of determining annual microwave oven consumption should have an additional term to account for the energy features such as clocks when the oven is in the normal off condition. In the proposed standard to FEA the power rating of a feature in watts times 8.76 was added to the annual microwave energy consumption. This term can become significant in relation to the energy consumed for actual cooking. In fact, one oven evaluated had a digital clock display which consumed an average of 7 watts amounting to over 40% of the annual cooking energy consumption!

Litton Procedure

The Litton method of measuring the energy consumption of electric ranges, combination ranges, and microwave oven proposes the use of water as the universal test load. A water test load is defined after a total standard menu has been cooked under a controlled test with consistent techniques, heat settings, and end doneness. Once the menu is properly utilized with rise in food temperature and cooking time recorded, a water conversion is made for each food item by heating a like volume of water according to the specific cooking time. The result is a group of specified rises in water temperatures which represent various food items of a menu. Once the specification is established other ovens are then tested by bringing the specified water volumes to the standard temperature represented by each food item. The input energy to attain the specified temperature rises is recorded. The total input energy for a 7-day menu is recorded and multiplied by 52 weeks to obtain the annual consumption.

Although the Litton procedure was not specifically performed in the lab it was judged to be rather cumbersome and time consuming to perform in relation to the IEC procedure. Furthermore, there is no question that water is a good test load for microwave ovens and the two methods would probably not result in a significantly different ranking of the ovens. However, total annual consumption figures by the two methods may be quite apart from each other. The Litton procedure bases the annual energy consumption on a standard menu which may not correlate well with actual use patterns for microwave ovens.

In order to perform the Litton procedure it is necessary to monitor the temperature of the water in the container while the oven is operating. Their recommendation is to use a thermocouple positioned in the water halfway from the bottom of the pan and top surface of the water, not touching any sides. The thermocouple cord is placed so that the door can be closed and the oven operated. As mentioned previously it is undesirable to do this both from an accuracy and safety standpoint.

There are also serious questions aside from procedure as to whether the use of a water test load in a conventional oven is meaningful. The coupling of energy to water in a container being heated in a conventional oven may be quite different than food. No known study of this has been made. Much more effort would be required to show that water can be used satisfactorily on a comparative basis for all types of cooking appliances.

Proposed Test Procedure for Microwave Cooking Appliances

The following test procedure based on the IEC-SC-59H procedure was submitted to FEA. The NBS studies were concerned primarily with establishing the connection between efficiencies in water heating and the cooking of real foods. The IEC procedure contains certain additional operational requirements (Sec 5.2.1) which are included for maintaining uniformity but were not investigated for optimality in the present tests.

SECTION 1 PURPOSE

1.1 This test procedure is proposed as a standard method of determining the power output, efficiency, and annual energy consumption of microwave cooking appliances.

SECTION 2 SCOPE

2.1 This procedure applies to microwave cooking appliances as defined in 3.2 using electro-magnetic energy in one or more of the Industrial, Scientific, and Medical Equipment bands above 300 MHz to heat food. These ovens are primarily intended for household use.

2.2 This procedure includes definitions, standard test conditions, test procedures, and performance evaluation for microwave cooking appliances.

SECTION 3 DEFINITIONS

3.1 Compartment

The space enclosed by inner walls and doors into which food is placed to be heated or cooked by microwave energy.

3.2 Microwave Oven

A "microwave oven" is an appliance designed to heat food in a compartment by means of microwave energy.

3.3 Nameplate

A plate permanently attached to the microwave cooking appliance on which the electrical ratings and other identification appear.

3.4 Rated voltage

The voltage assigned to the appliance by the manufacturer.

3.5 Shelf

A horizontal food supporting surface in the cavity of a microwave cooking appliance.

SECTION 4 GENERAL TEST CONDITIONS

4.1 Electrical Supply

4.1.1 Frequency

Conduct all tests at nameplate frequency ± 1% unless otherwise specified.

4.1.2 Voltage

Conduct all tests at nameplate voltage. The test voltage is to be maintained within ± 1% at the inlet to the power supply cord when the oven is operated under loaded conditions.

4.2 Ambient Temperature

The ambient temperature is to be maintained at $20^\circ \pm 5^\circ$C ($72 \pm 9^\circ$F).

SECTION 5 PERFORMANCE TEST PROCEDURE

5.1 Instrumentation

All instruments used during the Standard Measurement Tests are to be accurate within ± 2% unless otherwise stated.

5.2 Microwave Power Output Measurement

5.2.1 Test Loads

Microwave power output measurements are to be made with the microwave cooking appliance connected to its rated supply voltage and frequency and operating at its maximum microwave power setting with a load of a) 275 ml ± 1%, b) 500 ml ± 1%, c) 1,000 ml ± 1% d) 2,000 ml ± 1%, of distilled water at an initial temperature of $20 \pm 5^\circ$C and containing 1% by weight NaCl.

The 275 ml and 500 ml loads are to be placed in a thin wall glass vessel having an inside diameter of approximately 85 mm at the center of the load carrying surface provided by the manufacturer.

The 1000 ml load is to be placed in a thin wall glass vessel having an inside diameter of approximately 110 mm at the center of the load carrying surface provided by the manufacturer.

The 2000 ml load is to be placed in equal portions of 1000 ml in two 110 mm diameter glass vessels located side by side in the approximate center of the load carrying surface provided by the manufacturer.

The testing time is the elapsed time while the magnetron is operating at full power (heat up time is not counted) and the duration of the test is until the temperature rise of the water load is $25 \pm 5^{\circ}C$. The time to reach the final water temperature and the actual initial and final water temperature should be recorded. The final temperature of the water must be measured after stiring sufficiently to create a uniform temperature distribution.

The tests are to be conducted using the following sequence: 2000 ml, 1000 ml, 500 ml, and 275 ml. The oven is to be stabilized with the room ambient of $20 \pm 5^{\circ}C$ prior to the start of the test sequence and there should be a one minute rest period between loads for the purpose of changing the load.

5.2.2 Computations

Calculate the Microwave Power Output for each test load as follows:

$$\text{Microwave Power Output (watts)} = \frac{W\,(4.19)\,\Delta T}{t}$$

where:

W = size of the water load in milliliters (ml), cubic centimeters (cc), or grams (g) (275, 500, 1000, 2000)

ΔT = Temperature rise of the load in degrees celcius, i.e., final water temperature ($^{\circ}C$) minus initial water temperature ($^{\circ}C$)

t = elapsed time in seconds at full microwave power.

Calculate the Average Microwave Power Output (Po) by calculating the simple average of the Microwave Power Output for each test load.

5.3 Rated Efficiency

5.3.1 Calculate the Specific Microwave efficiency (e) for each load as follows:

$$e = \frac{Po}{E} \times \frac{t}{3600}$$

where: Po = the Average Microwave Power Output (watts) for a given load.

t = the elapsed time of the test (seconds)

E = the electrical input energy in watt-hours measured by an induction energy meter.

5.3.2 Calculate the rated efficiency of the microwave oven (e_{avg}) as the simple average of the specific efficiency for each test load.

$$e_{(avg)} = \frac{e_{(275)} + e_{(500)} + e_{(1000)} + e_{(2000)}}{4}$$

SECTION 6 OVERALL ANNUAL ENERGY CONSUMPTION

6.1 Representative Consumption

From the AHAM Range Energy Field Test it was found that for a family of four where a microwave oven was used along with conventional surface units and ovens, annual consumption averaged 88 kWh (3.17×10^8 J).

6.2 Energy factor

The energy factor (EF mwo) of the microwave ovens monitored in the AHAM field test is 0.388

6.3 Standard Energy into the Food

From the data in 6.1 and 6.2 the average annual energy used to cook food is:

$$0.388 \times 88 = 34.2 \text{ kWh } (1.23 \times 10^8 \text{J})$$

6.4 Annual Microwave Oven Consumption

The annual consumption of any oven is determined as follows:

$$\text{ANNUAL ENERGY CONSUMPTION (joules)} = \left[\frac{34.2 \text{ kWh}}{e_{(avg)}} + \text{PRF } (8.76)\right]\left[3.6 \times 10^6\right]$$

where: $e_{(avg)}$ = the rated efficiency of an oven as determined in 5.3.2

PRF = Power Rating of Feature, watts

8.76 = Number of thousand hours in a year

3.6×10^6 = Energy conversion factor to convert kilowatt-hours to joules

Conclusions

A standard test method based on the IEC-SC-59H procedure has been verified in the laboratory on five microwave ovens. It has been recommended to FEA for their use in the energy conservation program for appliances. The results of the verification show that the method is repeatable to within 0.5%, relatively easy to perform, and requires a minimum of special techniques or apparatus. The Litton procedure is not recommended because it requires considerably greater time to perform than that required for the IEC procedure. Furthermore, it is questionable whether the procedure as proposed can be meaningfully used for comparative purposes among the various types of cooking appliances, particularly the conventional oven. Among the five microwave ovens tested the rated efficiency determined from the IEC procedure ranged from 36.3% to 42.2%. In comparison the average efficiencies determined by cooking nine food items ranged from 32% to 38%. One can conclude that the efficeincies determined by the standard test method utilizing multiple loads of water are realistic values which correlate well with actual food cooking efficiency.

APPENDIX

This method of measuring the heat into the food is derived from the technique known as the method of mixtures for measuring the average specific heat capacity of a material. A water calorimeter is used as follows. The food is heated in the oven and when it has reached the desired doneness it is quickly transferred to the calorimeter, the water thoroughly stirred, and the new temperature recorded. If no heat is lost from the calorimeter during the test, the heat given up by the food during cooling must equal the heat gained by the water and calorimeter.

Let the subscripts f and w stand for food and water respectively. Then, assuming all specific heat capacities to be constant and neglecting losses in the calorimeter,

$$M_f C_f (t_3 - t_2) = M_w C_w (t_2 - t_1) \qquad (1)$$

where M_f is the mass of the cooked food

M_w is the mass of water in the calorimeter

C_f is the specific heat of the food

C_w is the specific heat of water

t_3 is the final temperature of the cooked food

t_2 is the final temperature of the calorimeter system

t_1 is the initial temperature of the water in the calorimeter

Equation 1 is the heat liberated by the food equal to the heat absorbed by the water. However, we must account for the heat in the food from an initial room temperature to the final system temperature t_2 in order to obtain the total heat in the food. If the initial temperature of the food is the same temperature as the initial temperature of the water in the calorimeter (room temperature) then the total heat in the food from temperature t_1 to t_3 becomes

$$Q = M_w C_w (t_2 - t_1) + M_f C_f (t_2 - t_1) \tag{2}$$

The only quantity in equation (2) which may be unknown is the specific heat capacity of the food, C_f. However, this quantity does not need to be known accurately. In practice the mass of the water in the calorimeter is chosen to be much greater than the mass of the food so that the major quantity of heat measured is in the first term of equation (2). Then, if we assume that $C_f = C_w$ even a fairly large error is that assumption will not greatly affect the total accuracy of the heat determination. With this assumption and the specific heat of water equal to 4.19 J/g.°C equation 2 becomes

$$Q = (M_w + M_f)(t_2 - t_1)\ (4.19) \tag{3}$$

The only practical measure that has to be observed is to keep the ratio of M_w to M_f in a range so that the resultant temperature difference $(t_2 - t_1)$ can be accurately measured. Of course if the specific heat capacity of the food under test is known, then equation 2 is used.

The above assumption (C_f=C_w) becomes even more realizable when the heat of vaporization is accounted for in the total. The loss of mass of the food during the cooking process is attributed to the water that is driven off in the vapor phase. If the additional heat of vaporization is added to equation 3 then the total heat that went into the food and heat required to drive off some of the water is

$$Q_T \cong h\,(M_{f1} - M_{f2}) + (M_w + M_{f1})(t_2 - t_1)(4.19) \qquad (4)$$

where h equals the heat of vaporization of water at $100^\circ C \cong 2260$ J/g

$(M_{f1} - M_{f2})$ is the weight loss of food from cooking

When foods are cooked from a frozen state additional energy is required to warm the food to $0^\circ C$, thaw it, and raise the temperature to room temperature. This additional amount of heat can also be measured by employing the water calorimeter. A sample of frozen food is removed from the freezer, weighed and quickly transferred to the calorimeter which contains water at room temperature. The mixture is thoroughly stirred and the final temperature recorded.

Let the subscripts f and w stand for food and water respectively. Then the heat required to thaw the food and raise it to the final equilibrium temperature recorded in the calorimeter is

$$Q = M_w C_w (t_1 - t_4) \qquad (5)$$

where t_4 is the final equilibrium temperature

The heat required to raise the food temperature from t_4 to t_1 is

$$Q = M_f C_f\,(t_1 - t_4) \qquad (6)$$

The total heat required to bring a sample of food up to room temperature is the sum of equations 5 & 6 which yields,

$$Q = M_w C_w (t_1 - t_4) + M_f C_f\,(t_1 - t_4) \qquad (7)$$

Applying the same assumptions as previously explained

(i.e. $C_f = C_w = 4.19$ J/g$^\circ$C then equation 7 becomes

$$Q = (M_w + M_f)(t_1 - t_4)\,(4.19) \qquad (8)$$

Bibliography

[1] Sears and Zemansky, University Physics, Third Edition, Addison-Wesley Publishing Co.

[2] Ringle, Charles E. and David, Beatrice D., "Measuring Electric Field Distribution in a Microwave Oven" *Food Technology* Dec. 1975

[3] Van Zante, Helen J., The Microwave Oven Houghton Mifflin Co. Boston

[4] N. K. Albrecht and M. E. Purchase, A Comparison of Methods for Determining the Wattage Output and Energy Distribution in Microwave Ovens

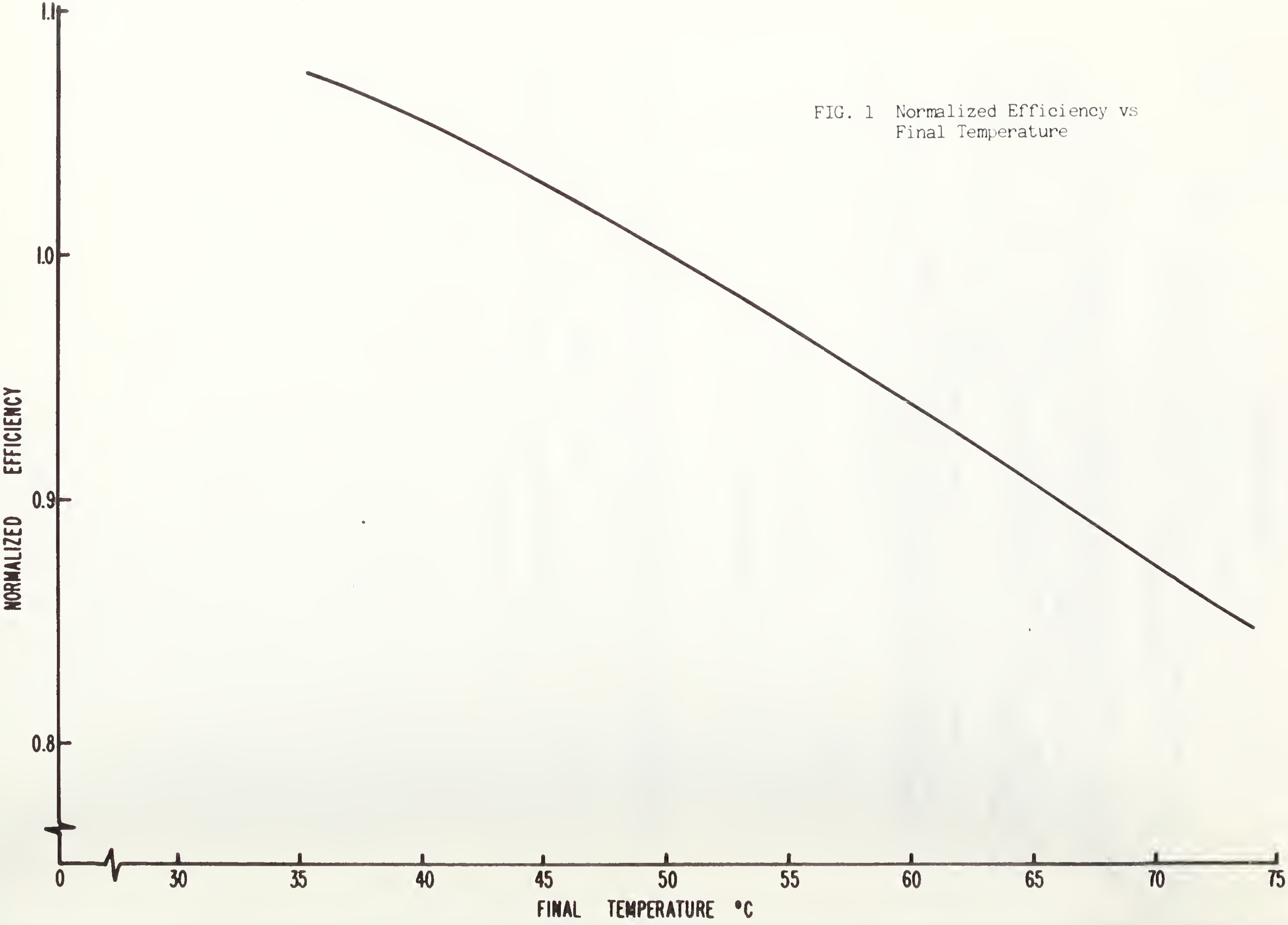

FIG. 1 Normalized Efficiency vs Final Temperature

on
Oven A

Run No.	Load Size	Size & (No. of Beakers)	Initial Temp.	Final Temp.	Temp. Rise	Time	Output Power	Input Energy	Specific Efficiency	Rated Efficiency
	ml	ml	°C	°C	°C	sec.	watts	joules	%	%
1	275	500(1)	22.6	47.9	25.3	70	416.5	83.9×10^3	34.8	
	500	500(1)	22.3	46.6	24.3	110	462.8	131	38.8	
	1000	1000(1)	22.0	45.6	23.6	195	507.1	238	41.5	
	2000	1000(2)	22.0 22.0	48.5 46.1	26.5 24.1	390	543.6	475	44.6	39.9
2	275	500(1)	21.8	47.9	26.1	70	429.6	82.4	36.5	
	500	500(1)	21.7	46.4	24.7	110	470.4	132	39.3	
	1000	1000(1)	21.6	44.6	23.0	195	494.2	236	40.8	
	2000	1000(2)	21.6 21.6	47.4 46.0	25.8 24.4	390	539.3	472	44.6	40.3
3	275	500(1)	22.3	48.6	26.3	70	432.9	83.5	36.3	
	500	500(1)	22.3	45.9	23.6	110	449.5	132	37.4	
	1000	1000(1)	22.2	45.7	23.5	195	504.9	238	41.4	
	2000	1000(2)	22.1 22.1	48.4 46.1	26.3 24.0	390	540.4	475	44.4	39.9
4	1000	500(2)	20.5 20.5	44.6 44.4	24.1 23.9	195	515.7	243	41.3	
	2000	500(4)	20.5 20.5 20.5 20.5	43.6 45.7 47.6 43.5	23.1 25.2 27.1 23.0	390	528.6	483	42.7	

TABLE II Standard Test Procedure Data
on
Oven B

Run No.	Load Size ml	Size & (No. of Beakers) ml	Initial Temp. °C	Final Temp. °C	Temp. Rise °C	Time sec.	Output Power watts	Input Energy joules	Specific Efficiency %	Rated Efficiency %
1	275	500(1)	22.3	47.4	25.1	60	482.0	82.8×10^3	34.9	
	500	500(1)	22.4	44.6	22.2	90	516.8	126	37.0	
	1000	1000(1)	22.1	46.9	24.7	180	574.6	255	40.5	
	2000	1000(2)	22.3	45.3	23.0	345	579.3	497	40.2	
			22.3	46.9	24.7					38.2
2	275	500(1)	21.0	46.6	25.6	60	491.6	82.2	35.6	
	500	500(1)	21.0	43.5	22.5	90	523.7	126	37.4	
	1000	1000(1)	21.0	46.0	25.0	180	581.9	256	40.9	
	2000	1000(2)	21.0	45.1	24.1	345	582.9	499	40.3	
			21.0	44.9	23.9					38.6
3	275	500(1)	21.3	46.6	25.3	60	485.9	82.2	35.2	
	500	500(1)	21.0	43.5	22.5	90	523.7	124	38.1	
	1000	1000(1)	21.1	45.5	24.4	180	568.0	252	40.5	
	2000	1000(2)	21.0	46.0	25.0	345	578.1	487	41.0	
			21.0	43.6	22.6					38.7
4	1000	500(2)	20.9	44.6	23.7	180	581.9	260	40.3	
			20.9	47.2	26.3					
	2000	500(2)	21.0	47.2	26.2	345	572.6	492	40.1	
			21.0	44.8	23.8					
			21.0	42.1	21.1					
			21.0	44.2	23.2					

TABLE III Standard Test Procedure Data on Oven C

Run No.	Load Size	Size & (No. of Beakers)	Initial Temp.	Final Temp.	Temp. Rise	Time	Output Power	Input Energy	Specific Efficiency	Rated Efficiency
	ml	ml	°C	°C	°C	sec.	watts	joules	%	%
1	275	500(1)	22.1	47.2	25.1	90	321.3	97.2×10^3	29.8	
	500	500(1)	21.7	47.9	26.2	135	406.6	148	37.2	
	1000	1000(1)	21.3	45.3	24.0	240	419.0	262	38.3	
	2000	1000(2)	21.1	45.0	23.9	450	454.4	496	41.2	
			21.1	46.0	24.9					36.6
2	275	500(1)	21.6	46.6	25.0	90	320.1	97.2	29.6	
	500	500(1)	21.5	45.2	23.7	135	367.8	146	33.9	
	1000	1000(1)	21.4	46.4	25.0	240	436.5	261	40.1	
	2000	1000(2)	21.3	43.3	22.0	450	451.6	491	41.4	
			21.3	47.8	26.5					36.2
3	275	500(1)	21.6	46.4	24.8	90	317.5	97.5	29.3	
	500	500(1)	21.6	45.7	24.1	135	374.0	147	34.3	
	1000	1000(1)	21.4	46.5	25.1	240	438.2	262	40.2	
	2000	1000(2)	21.3	45.3	24.0	450	442.3	495	40.2	
			21.3	44.8	23.5					36.0
4	1000	500(2)	21.0	41.5	20.5	240	412.0	257	38.5	
			21.0	48.7	26.7					
	2000	500(4)	20.9	43.9	23.0	450	437.6	500	39.4	
			20.9	48.2	27.3					
			20.9	40.0	19.1					
			20.9	45.5	24.6					

TABLE IV Standard Test Procedure Data
on
Oven D

Run No.	Load Size ml	Size & (No. of Beakers) ml	Initial Temp. °C	Final Temp. °C	Temp. Rise °C	Time sec.	Output Power watts	Input Energy joules	Specific Efficiency %	Rated Efficiency %
1	275	500(1)	21.6	49.1	27.5	75	422.5	102 x 10^3	31.1	
	500	500(1)	21.6	48.8	27.2	110	518.0	146	38.9	
	1000	1000(1)	21.0	47.2	26.2	210	522.7	283	38.8	
	2000	1000(2)	21.5 21.5	44.3 44.4	22.8 22.9	390	491.0	528	36.3	36.3
2	275	500(1)	22.1	43.8	21.7	60	416.7	79.2	31.6	
	500	500(1)	22.1	44.7	22.6	95	498.4	128	36.8	
	1000	1000(1)	21.6	46.2	24.6	195	528.6	266	38.7	
	2000	1000(2)	21.5 21.5	45.2 45.2	23.7 23.7	390	509.2	529	37.5	36.2
3	275	500(1)	21.3	43.0	21.7	60	416.7	78.8	31.7	
	500	500(1)	21.0	45.6	24.6	95	542.5	129	39.9	
	1000	1000(1)	21.1	46.0	24.9	195	535.0	265	39.4	
	2000	1000(2)	21.0 21.0	43.3 43.3	22.3 22.3	390	479.2	523	35.7	36.7
4	1000	500(2)	20.3 20.3	45.8 45.0	20.5 24.7	195	485.6	265	35.7	
	2000	500(4)	20.5 20.5 20.5 20.5	43.2 40.0 43.2 46.2	22.7 19.5 22.7 25.7	390	486.7	504	37.4	

TABLE V Standard Test Procedure Data
on
Oven E

Run No.	Load Size ml	Size & (No. of Beakers) ml	Initial Temp. °C	Final Temp. °C	Temp. Rise °C	Time sec.	Output Power watts	Input Energy joules	Specific Efficiency %	Rated Efficiency %
1	275	500(1)	22.5	47.2	24.7	75	379.5	85.3 x 10^3	33.4	
	500	500(1)	21.9	46.3	24.4	110	464.7	124	41.3	
	1000	1000(1)	21.7	47.5	25.8	195	554.4	236	45.8	
	2000	1000(2)	21.4 21.4	46.7 46.6	25.3 25.2	390	542.5	446	47.4	42.0
2	275	500(1)	20.3	46.7	26.4	75	405.6	83.5	36.4	
	500	500(1)	21.6	46.3	24.7	110	470.4	123	42.0	
	1000	1000(1)	21.4	47.0	25.6	195	550.1	237	45.3	
	2000	1000(2)	21.3 21.3	45.9 46.6	24.6 25.3	390	536.1	443	47.2	42.7
3	275	500(1)	21.0	47.7	26.7	75	410.2	82.8	37.2	
	500	500(1)	21.1	45.6	24.5	110	466.6	122	41.9	
	1000	1000(1)	21.0	44.3	23.3	195	500.6	236	41.3	
	2000	1000(2)	20.8 20.8	45.6 45.5	24.8 24.7	390	531.8	440	47.1	41.9
4	1000	500(2)	21.0 21.0	44.0 44.3	23.0 23.3	195	497.4	220	44.0	
	2000	500(4)	20.9 20.9 20.9 20.9	45.0 44.3 46.5 46.0	24.1 23.4 25.6 25.1	390	527.5	442	46.5	

TABLE VI Test Data on Various Foods Cooked in Oven A

Food Item	Initial Weight grams	Weight Loss grams	Cooking Time sec.	Energy Into Food joules	Input Energy joules	Efficiency %
4 Potatoes	755.0	144	1080	47.8×10^4	132×10^4	36
Corn 10 oz Frozen Pouch	316.5	23.5	390	18.4	47.6	39
Bread 1/2 Loaf	130.0	5	90	2.74	8.96	31
Salisbury Steak (Frozen)	156.5	12	210	9.86	25.5	39
4 Hot Dogs	181.0	7.5	110	4.61	13.4	34
6 Bacon Strips	115.7	31.2	270	8.53	32.8	26
Lima Beans 16 oz Can	491	40	420	18.9	51.2	37
Fresh Beans 1/2 lb	227	67.9	480	21.4	58.6	37
Lima Beans Frozen Pouch	305.5	38.0	540	22.9	65.9	35
						35 AVG

TABLE VII Test Data on Various Foods Cooked in Oven B

Food Item	Initial Weight grams	Weight Loss grams	Cooking Time sec.	Energy Into Food joules	Input Energy joules	Efficiency %
4 Potatoes	674.0	179.0	1020	$52.5\mathrm{x}10^4$	$146\mathrm{x}10^4$	36
Corn 10 oz Frozen Pouch	305.0	13.0	270	15.5	39.0	40
Bread 1/2 Loaf	138.0	15.5	90	4.86	13.1	37
Salisbury Steak (Frozen)	153.0	15.0	180	10.2	26.3	38
4 Hot Dogs	174.2	7.7	90	4.75	12.8	37
6 Bacon Strips	112.8	23.8	225	6.91	32.2	21
Lima Beans 16 oz Can	483.0	43.0	420	20.3	60.7	34
Fresh Beans 1/2 lb	227.0	27.0	240	11.2	35.0	32
Lima Beans Frozen Pouch	297.0	71.0	540	30.3	77.4	39
						35 AVG

TABLE VIII Test Data on Various Foods Cooked in Oven C

Food Item	Initial Weight	Weight Loss	Cooking Time	Energy Into Food	Input Energy	Efficiency
	grams	grams	sec.	joules	joules	%
4 Potatoes	819.0	126.0	1200	45.6×10^4	131×10^4	35
Corn 10 oz Frozen Pouch	300.0	26.0	420	18.5	47.0	39
Bread 1/2 Loaf	130.0	2.0	45	1.80	5.11	35
Salisbury Steak (Frozen)	154.5	15.0	240	10.3	26.3	39
4 Hot Dogs	178.5	9.2	135	4.90	14.6	34
6 Bacon Strips	112.0	33.4	450	9.04	12.6	19
Lima Beans 16 oz Can	491.3	23.3	420	15.0	45.7	33
Fresh Beans 1/2 lb	227.0	21.5	270	9.61	29.2	33
Lima Beans Frozen Pouch	290.0	28.0	480	19.8	52.2	38
						34 AVG

TABLE IX Test Data on Various Foods Cooked in Oven D

Food Item	Initial Weight grams	Weight Loss grams	Cooking Time sec.	Energy Into Food joules	Input Energy joules	Efficiency %
4 Potatoes	712.0	130.0	900	$43.3\text{x}10^4$	$123\text{x}10^4$	35
Corn 10 oz Frozen Pouch	306.5	6.5	300	14.2	39.8	36
Bread 1/2 Loaf	92.0	3.5	90	2.02	6.70	30
Salisbury Steak (Frozen)	155.5	12.5	210	10.1	28.0	36
4 Hot Dogs	178.5	5.0	95	4.14	12.9	32
6 Bacon Strips	117.3	35.2	360	9.47	48.2	20
Lima Beans 16 oz Can	497.5	41.0	420	20.2	56.2	36
Fresh Beans 1/2 lb	227.0	44.7	360	15.6	48.1	32
Lima Beans Frozen Pouch	300.5	45.0	540	25.3	73.0	35
						32 AVG

TABLE X Test Data on Various Foods Cooked in Oven E

Food Item	Initial Weight	Weight Loss	Cooking Time	Energy Into Food	Input Energy	Efficiency
	grams	grams	sec.	joules	joules	%
4 Potatoes	680.0	57.0	660	$29.4\text{x}10^4$	$75.1\text{x}10^4$	39
Corn 10 oz Frozen Pouch	310.0	18.0	360	16.3	40.3	40
Bread 1/2 Loaf	105.5	11.0	90	3.89	10.1	38
Salisbury Steak (Frozen)	178.0	12.5	210	10.0	23.8	42
4 Hot Dogs	177.3	6.9	110	4.64	12.2	38
6 Bacon Strips	103.0	32.0	270	8.60	30.2	28
Lima Beans 16 oz Can	490	38.0	420	18.7	47.1	40
Fresh Beans 1/2 lb	162.5	40.5	300	12.4	33.6	37
Lima Beans Frozen Pouch	315.9	27.9	420	20.0	47.2	42
						38 AVG

TABLE XI Summary of Oven Efficiencies
Measured With The Standard Test Procedure & Foods

Oven	Test Procedure Avg. Efficiency	Cooking Foods Avg. Efficiency
A	40.0	35
B	38.5	35
C	36.3	34
D	36.4	32
E	42.2	38

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM.
BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION OR REPORT NO. NBSIR 77-1387

2. Gov't Accession No.

3. Recipient's Accession No.

4. TITLE AND SUBTITLE

Evaluation of a Test Method for Measuring Microwave Oven Cooking Efficiency

5. Publication Date

6. Performing Organization Code

7. AUTHOR(S) Owen B. Laug

8. Performing Organ. Report No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)*

Federal Energy Administration
Washington, D. C. 20461

13. Type of Report & Period Covered

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A standard test procedure for measuring the energy efficiency of microwave ovens has been developed and tested on current representative products. The test method is based on the International Electrical Commission (IEC-SC-59H) procedure for measuring performance of microwave cooking appliances. The results of laboratory tests show that the method is repeatable, easy to perform, and requires a minimum of special techniques or apparatus. A technique was developed to measure the efficiency of cooking various foods in the ovens. The efficiencies determined by the standard test method are shown to be realistic and correlate well with the efficiencies determined by cooking a variety of foods.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Energy efficiency; Microwave oven

18. AVAILABILITY ☒ Unlimited

☐ For Official Distribution. Do Not Release to NTIS

☐ Order From Sup. of Doc., U.S. Government Printing Office
Washington, D.C. 20402, SD Cat. No. C13

☒ Order From National Technical Information Service (NTIS)
Springfield, Virginia 22151

19. SECURITY CLASS (THIS REPORT) UNCLASSIFIED

20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED

21. NO. OF PAGES 34

22. Price $4.50

USCOMM-DC 29042-P74