CHAPTER 5. ENGINEERING ANALYSIS

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CHAPTER 5. ENGINEERING ANALYSIS

5.1 INTRODUCTION

After conducting the screening analysis, the U.S. Department of Energy (DOE) performed an engineering analysis based on the remaining design options. The engineering analysis consists of estimating the standby energy consumption and costs of products at various levels of increased efficiency. This section provides an overview of the engineering analysis (section 5.1), discusses proposed product classes (section 5.2), establishes baseline unit specifications (section 5.3.1), discusses incremental efficiency levels (section 5.3.2), explains the methodology used during data gathering (5.4) and discusses the analysis and results (section 5.5)

The primary inputs to the engineering analysis are baseline information from the market and technology assessment (chapter 3 of the technical support document (TSD)) and technology options from the screening analysis (chapter 4.) Additional inputs include laboratory testing and reverse-engineering of representative microwave ovens. The primary output of the engineering analysis is a set of cost-efficiency curves. In the subsequent markups analysis (chapter 6), DOE determined customer (*i.e.,* product purchaser) prices by applying distribution markups, sales tax and contractor markups. After applying these markups, they serve as the input to the building energy-use and end-use load characterization (chapter 7) and the life-cycle cost (LCC) and payback period (PBP) analyses (chapter 8).

DOE typically structures its engineering analysis around one of three methodologies. These are: (1) the design-option approach, which calculates the incremental costs of adding specific design options to a baseline model that will improve its efficiency (*i.e.*, lower its energy use in standby mode and off mode); (2) the efficiency-level approach, which calculates the relative costs of achieving increases in energy efficiency levels (in this case, levels of reduced standby power), without regard to the particular design options used to achieve such increases; and/or (3) the reverse engineering or cost-assessment approach, which involves a "bottom-up" manufacturing cost assessment based on a detailed bill of materials (BOM) derived from teardowns of the product being analyzed. Deciding which methodology to use for the engineering analysis depends on the product, the design options under study, and any historical data that DOE can draw on.

5.2 PRODUCT CLASSES ANALYZED

DOE separated residential microwave ovens into product classes. Because DOE formulated a separate energy conservation standard for standby power consumption for each product class, the criteria for separation into different classes are (1) type of energy used (natural gas or electricity), and (2) capacity or other performance-related features such as those that provide utility to the consumer, or others deemed appropriate by the Secretary that would justify the establishment of a separate energy conservation standard. (42 U.S.C. 6295 (q))

For the reasons discussed in chapter 3 of this TSD, DOE has analyzed for the purposes of this supplemental notice of proposed rulemaking (SNOPR) the following two product classes for microwave ovens:

- Microwave-only ovens and countertop combination microwave ovens
- Built-in and over-the-range combination microwave ovens

5.3 EFFICIENCY LEVELS

5.3.1 Baseline Units

DOE selected baseline units as reference points for each product class, against which DOE measured changes resulting from energy conservation standards. The baseline unit in each product class represents the basic characteristics of equipment in that class. Typically, a baseline unit is a unit that just meets current required energy conservation standards and provides basic consumer utility.

DOE used the baseline units in the engineering analysis and the life-cycle-cost and payback-period analysis. To determine energy savings and changes in price, DOE compared each higher energy efficiency design option with the baseline unit.

The identification of baseline units required establishing the baseline standby power level. For microwave oven standby power, energy conservation standard levels are expressed as a maximum standby power consumption, in watts (W). As discussed in chapter 3 of this TSD, DOE is not aware of any current microwave ovens that are capable of operation in off mode. As a result, the standards do not include off mode power. Based on product testing (see section 5.6.1.3), DOE selected a baseline standby power level which was the highest typical standby power for a microwave oven to provide full consumer utility for each product class. For the purpose of this rulemaking, DOE determined consumer utility to be the ability to display complex characters, brightness, and viewing angle of the display as well as the ability to automatically control the cooking operation (*i.e.,* through the use of an absolute humidity cooking sensor). For the built-in and over-the-range combination microwave ovens product class, consumer utility also included a sufficiently sized power supply capable of operating additional features required to handle the thermal loads associated with their installation and to provide consumer utility, such as additional exhaust fan motors, convection fan motors and heaters, and additional lights. For both product classes, the baseline power supply used a conventional linear power supply with an efficiency of approximately 55 percent. DOE selected a baseline standby power level of 4.0 W for the microwave-only ovens and countertop combination microwave ovens product class. For the built-in and over-the-range combination microwave ovens product class, DOE selected a baseline standby power level of 4.5 W. As discussed in section 5.5.1.2, DOE noted that the built-in combination microwave ovens in its test sample consumed more standby power than the over-the-range combination microwave ovens.

However, DOE notes that built-in and over-the-range combination microwave ovens have essentially the same features (*i.e.*, exhaust fans and convection heaters). DOE also noted that the two built-in combination microwave ovens in its test sample were high-end units with large displays and a larger number of cooking settings and options. As a result, DOE believes that the standby power level of 4.5 W for the built-in and over-the-range combination microwave ovens product class provides full consumer utility and that the higher levels observed in DOE's test sample for built-in combination microwave ovens are not appropriate for establishing the baseline standby power levels.

5.3.2 Incremental Standby Power Levels

For the product classes presented in section 5.2, DOE analyzed several standby power levels and obtained incremental cost data at each of these levels. Table 5.3.1 and Table 5.3.2 provide standby power levels and the reference source of each level. DOE conducted the engineering analysis for microwave oven standby power for the two product classes DOE identified for microwave ovens. To analyze the cost-energy use relationship for microwave oven standby power, DOE defined standby power levels expressed as a maximum average standby power, in W. For the reasons noted above in section 5.3.1, the standard levels do not include off mode power.

For the microwave-only ovens and countertop combination microwave ovens product class, the standby power levels were derived from review of the Federal Energy Management Program (FEMP) procurement efficiency recommendation, the International Energy Agency's (IEA) One-Watt program to lower standby power consumption below 1 W for various electrical appliances, and the current maximum microwave oven standby technology (*i.e.* lowest standby power) that DOE believes is or could be commercially available at the time the energy conservation standards become effective. The max-tech microwave-only oven and countertop combination microwave oven standby power level of 0.02 W corresponds to a unit equipped with a default automatic power-down function that shuts off certain power-consuming components after a specified period of user inactivity. The standby power at max-tech was obtained from a microwave oven currently on the market in Korea which incorporates such a feature. DOE also added a standby power level as a gap-fill between the FEMP Procurement Efficiency Recommendation and IEA One-Watt Program levels. Table 5.3.1 provides the microwave-only ovens and countertop combination microwave ovens product class standby power levels and the reference source for each level that DOE has analyzed.

Table 5.3.1 Standby Power Levels for Microwave-Only Ovens and Countertop Combination Microwave Ovens

Standby Power Level	Standby Power Level Source	Standby Power *(W)*
Baseline	Baseline	4.0
1	FEMP Procurement Efficiency Recommendation	2.0
2	Gap Fill	1.5
3	IEA 1-Watt Program	1.0
4	Max-Tech	0.02

For the built-in and over-the-range combination microwave oven product class, the standby power levels were determined based on reverse-engineering analyses on a representative sample of built-in and over-the-range combination microwave ovens to analyze the various components that contribute to the standby power consumption of the unit. DOE also measured the standby power consumed by these components individually.

In its analysis, DOE observed that the absolute humidity cooking sensor used in these combination microwave ovens on average consume 0.9 W of standby power. For standby power level 1, DOE believes that standby power can be reduced by incorporating a zero-standby cooking sensor. For standby power level 2, DOE analyzed potential improvements to the power supply design. DOE noted that microwave ovens at the baseline standby energy use incorporate a linear power supply. DOE measured the standby power consumption of the power supply and found that the transformer used to step down the line input voltage contributes most significantly to the standby power consumption. DOE then performed a power budget analysis to determine the size of the transformer needed to operate a microwave at full load, and the results suggest that replacing the conventional linear power supply with a more efficient switch mode power supply will eliminate the need for a large transformer and effectively reduce the standby power associated with the power supply. DOE thus estimated the standby power for standby power level 2 based on the improvement associated with changing from a conventional linear power supply with an efficiency of 55 percent to a switch mode power supply with an efficiency of 75 percent. DOE developed this estimate for the efficiency of a switch mode power supply based on research of such power supply designs for appliance applications.[a] For standby power level 3, DOE analyzed the impact relays have in determining the size of a power supply. DOE compared the power budget of a control board with electromechanical relays to that with solid state relays, and observed that the power requirement of a control board, with similar input and load, is lower with solid state relays than with electromechanical relays. Therefore, DOE estimated the standby power at standby power level 3 based on design improvements associated with using more efficient components in a switch mode power supply that incorporates solid state relays. For standby power level 4, DOE analyzed an automatic function that turns off power to standby power consuming components after a certain period of inactivity and that uses a transformerless power supply to maintain the microcontroller chip while the microwave oven is not powered on.

[a] Information on the design and efficiency of switch mode power supplies can be found at http://www.powerint.com/en/applications/major-appliances.

DOE estimated the standby power at standby power level 4 based on the standby power requirements of the controller microcontroller chip.

Table 5.3.2 presents the proposed standby power levels for built-in and over-the-range combination microwave ovens.

Table 5.3.2 Standby Power Levels for Built-In and Over-the-Range Combination Microwave Ovens

Standby Level	**Standby Power Level Source**	**Standby Power *(W)***
Baseline	Baseline	4.5
1	Zero W Cooking Sensor	3.7
2	Switch Mode Power Supply	2.7
3	Improved Relay Power Supply Design	2.2
4	Max-Tech (Automatic Power Down)	0.04

5.4 METHODOLOGY OVERVIEW

In order to develop the cost-efficiency relationships for microwave ovens, DOE performed detailed product teardowns and reverse-engineering analyses on a sample of product models spanning a range of standby power levels and product features. DOE also conducted detailed standby power testing to gain insights into energy performance in standby mode and to evaluate individual components contributing to standby power consumption. AHAM also submitted data to DOE on standby power testing that it conducted. DOE supplemented this information by conducting interviews with manufacturers of microwave ovens. Table 5.4.1 below shows which methods DOE used for each product class.

Table 5.4.1 Engineering Analysis Methods

Method	Microwave-Only Ovens and Countertop Combination Microwave Ovens	Built-In and Over-the-Range Combination Microwave Ovens
AHAM Data	√	
Product Teardown	√	√
Product Testing	√	√
Manufacturer Interviews	√	

5.4.1 AHAM Data Submittal

In support of this rulemaking effort, AHAM submitted data regarding standby power in microwave ovens. The AHAM submittal contained general descriptions of components related to standby power as well as data from standby power testing. The data provided to DOE by AHAM are contained in appendix 5A.

5.4.2 Manufacturer Interviews

DOE conducted confidential interviews with microwave ovens manufacturers to develop a deeper understanding of the various combinations of technologies used to reduce standby power consumption, and their associated manufacturing costs. Sample questions asked during the follow-up interviews, which were also conducted in support of the manufacturer impact analysis, are contained in appendix 12B.

During the interviews, DOE also gathered information about the capital expenditures required to reduce the standby power consumption of the baseline units to various standby power levels (*i.e.*, conversion capital expenditures by standby power level). The interviews provided information about the size and the nature of the capital investments. DOE also requested information about the depreciation method used to expense the conversion capital.

5.4.3 Product Teardowns

Other than obtaining detailed manufacturing costs directly from a manufacturer, the most accurate method for determining the production cost of a piece of equipment is to disassemble the equipment piece-by-piece and estimate the material and labor cost of each component using a process commonly called a physical teardown. A supplementary method, called a catalog teardown, uses published manufacturer catalogs and supplementary component data to estimate the major physical differences between a piece of equipment that has been physically disassembled and another piece of similar equipment. DOE performed physical teardown analysis on microwave ovens for this rulemaking. The teardown methodology is described in detail in section 5.5.3.1 through section 5.5.3.3.

5.4.3.1 Selection of Units

During the process of selecting units for teardown, DOE considers three main questions:

- What standby power levels should be captured in the teardown analysis?
- Are there units on the market that capture all potential standby power levels and design options?
- Which of the available units are most representative?

In responding to the preceding questions, DOE adopts the following criteria for selecting units for the teardown analysis:

- The selected products should span the full range of standby power levels for each product class under consideration;
- Within each product class, if possible, the selected products should come from the same manufacturer and be within the same product series;
- The selected products should primarily come from manufacturers with large market share in that product class, although the highest efficiency products were chosen irrespective of manufacturer; and
- The selected products should have non-standby power-related features that are the same as, or similar to, features of other products in the same class and at the same standby power level.

5.4.3.2 Generation of Bill of Materials

The end result of each teardown is typically a structured bill of materials (BOM). The process is discussed here in the context of the general methodology used for teardown analysis, although it should be noted a more limited approach was used for microwave ovens due to the substantial uniformity in design and construction among the sample units. Structured BOMs describe each equipment part and its relationship to the other parts, in the estimated order of assembly. The BOMs describe each fabrication and assembly operation in detail, including the type of equipment needed (*e.g.*, stamping presses, injection molding machines, spot-welders, etc.) and the process cycle times. The result is a thorough and explicit model of the production process.

The BOMs incorporate all materials, components, and fasteners, classified as either raw materials or purchased parts and assemblies. The classification into raw materials or purchased parts is based on DOE's previous industry experience, recent information in trade publications, and discussions with high- and low-volume original equipment manufacturers (OEMs).

For purchased parts, the purchase price is an estimate based on volume-variable price quotations and detailed discussions with suppliers. For fabricated parts, the price of intermediate materials (*e.g.*, tube, sheet metal) and the cost of transforming them into finished parts are an estimate based on current industry pricing.

The cost of raw materials is determined using prices for copper, steel and aluminum from the American Metals Market.[1] The price of steel drastically increased in 2005, and the price of copper has increased steadily since 2004. Because DOE is using a 5-year average in material prices from 2005–2009, these price increases are normalized, which better represents long-term material prices.

5.4.3.3 Cost Structure of the Spreadsheet Models

The manufacturing cost assessment methodology used is a detailed, component-focused technique for rigorously calculating the manufacturing cost of a product (direct materials, direct labor and some overhead costs.) Figure 5.4.1 shows the three major steps in generating the manufacturing cost.

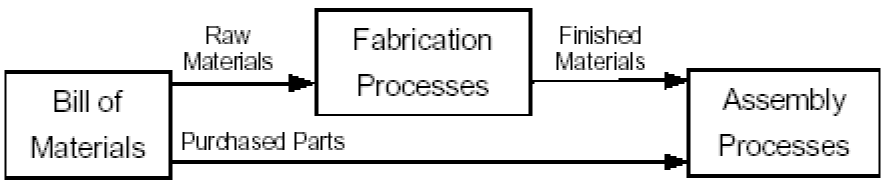

Figure 5.4.1 Manufacturing Cost Assessment Stages

The first step in the manufacturing cost assessment is the creation of a complete and structured BOM from the disassembly of the units selected for teardown. The units are dismantled, and each part is characterized according to weight, manufacturing processes used, dimensions, material, and quantity. The BOM incorporates all materials, components, and fasteners with estimates of raw material costs and purchased part costs. Assumptions on the sourcing of parts and in-house fabrication are based on industry experience, information in trade publications, and discussions with manufacturers. Interviews and plant visits are also conducted with manufacturers to ensure accuracy on methodology and pricing.

Following the development of a detailed BOM, the major manufacturing processes are identified and developed for the spreadsheet model. These processes are listed in Table 5.4.2.

Table 5.4.2 Major Manufacturing Processes

Fabrication	Finishing	Assembly/Joining	Quality Control
Fixturing	Washing	Adhesive Bonding	Inspecting & Testing
Stamping/Pressing	Powder Coating	Spot Welding	
Brake Forming	De-burring	Seam Welding	
Cutting and Shearing	Polishing		
Insulating			

Fabrication process cycle times are estimated and entered into the BOM. For this analysis, $24.00 per hour was used as the average fully-burdened labor rate based on typical annual wages and benefits of industry employees. In the final step of the cost assessment, assembly times and associated direct labor costs are estimated. Once the cost estimate for each teardown unit is finalized, a detailed summary is prepared for relevant components, subassemblies and processes. The BOM thus details all aspects of unit costs.

Design options used in units subject to teardown are noted in the summary sheet of each cost model and are cost-estimated individually. Thus, various implementations of design options can be accommodated, ranging from assemblies that are entirely purchased to units that are made entirely from raw materials. Hybrid assemblies, consisting of purchased parts and parts made on site are thus also accommodated.

5.4.4 Product Testing

DOE conducted product testing on microwave ovens to develop a better understanding of the potential standby power improvements associated with various design options. As part of this testing, DOE measured the power consumption of components contributing to standby power individually to further evaluate the strategies manufacturers may take to reduce standby power.

5.5 ANALYSIS AND RESULTS

5.5.1.1 AHAM Data

AHAM provided data on microwave oven standby power for a sample of microwave ovens currently available in the U.S. market.[2] Standby power was tested in accordance with the International Electrotechnical Commission (IEC) Standard 62301-2005, *Household electrical appliances – Measurement of standby power* (IEC Standard 62301 (First Edition)). Figure 5.5.1 displays AHAM-measured microwave oven standby power data as a function of rated cooking output power. Unlike efficiency, these data show a wide range of standby power, but there is no correlation between standby power and cooking output power. Standby power ranged from 1.5 to 5.8 W, with 9 of the 21 microwave ovens meeting the FEMP recommendation of 2.0 W or less. The average standby power measured was 2.9 W. AHAM did not provide any information with which DOE could correlate standby power with other features such as cooking sensors or displays. The data did not indicate the product type (*i.e.*, microwave only, combination) or the installation configuration (*i.e.*, countertop, over-the-range, built-in).

DOE notes that microwave oven standby power consumption is impacted significantly by the digital clock display, with more complex graphical displays drawing more power. According to AHAM, the three major types of displays used in microwave ovens are (1) LED displays, (2) VFDs, and (3) LCDs. Typically, LCDs without back-lighting use the least amount of energy while VFDs use the most. Energy consumed by LCDs would depend on whether back-lighting is present or not, and if present, the number of LEDs used for back-lighting. For LED displays, the number of segments, color, and operating temperature affect energy consumption. The size of the display (number of digits and icons) also affects the energy consumed by the display. For VFDs, the size of the display is a major factor in energy consumption.[3] Standby power consumption may also be affected by the electronic controls required for features such as cooking sensors, along with associated power supplies.

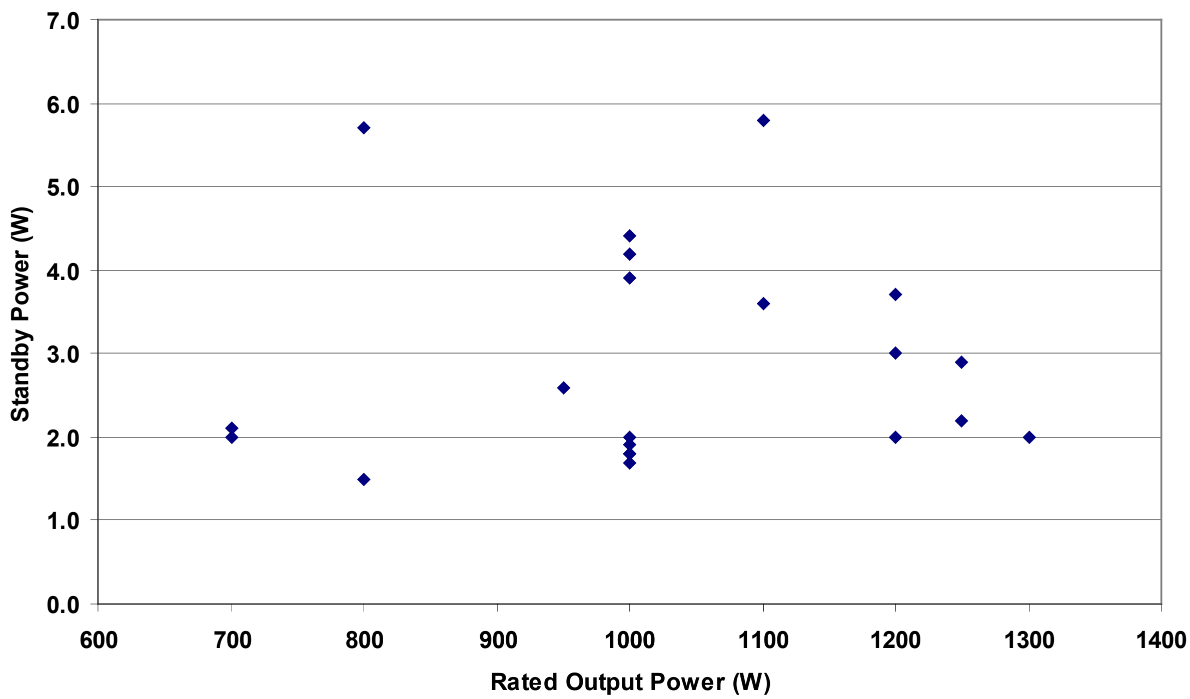

Figure 5.5.1 AHAM Microwave Oven Standby Power[4]

Table 5.5.1 compares the AHAM-measured microwave oven standby power data with data from other studies that have examined standby power in the United States and Canada. It can be seen that average standby power has remained relatively constant since 1997 even though minimum and maximum levels have varied by a greater amount.

Table 5.5.1 Microwave Oven Standby Power Comparison

Source	Microwave Oven Standby Power				
	Min *(W)*	Average *(W)*	Max *(W)*	Std Dev *(W)*	# Samples
AHAM 2006[5]	1.5	2.9	5.8	0.8	21
CBEEDAC 2006[6]	0.4	1.9	3.3	0.8	19
CREEDAC 2001 (New Stock)[7]	0.8	3.8	12.6	-	4
CREEDAC 2001 (Existing Stock)[8]	0.0	2.1	7.3	-	64
LBNL 2008[9]	1.4	3.1	4.9	-	18
Florida Solar Energy Center 1998[10]	-	3.0	-	-	25
LBNL 1997[11]	-	3.1	-	-	-

DOE recognizes that annual energy consumption can be significantly affected by standby power in real-world usage. For example, a 1-W increase in standby power corresponds to an increase of 8.76 kilowatt-hours (kWh) in annual energy consumption. Prior to it being repealed in a final rule published on July 22, 2010 (75 FR 42579), the microwave oven test procedure assumed an annual useful cooking energy output of 79.8 kWh. For a baseline microwave oven that operates at 55.7 percent efficiency, annual energy consumption not including standby power would be 143.3 kWh. Therefore each W of standby power included in the annual energy consumption metric would increase it by 6 percent for a baseline microwave oven. Since the highest measured standby power was 5.8 W, the increment of 3.8 W over the FEMP-recommended level of 2.0 W would represent a 23-percent increase in annual energy consumption for a baseline microwave oven.

5.5.1.2 Product Testing and Teardowns

Microwave-Only Ovens and Countertop Combination Microwave Ovens

Section 310 of the Energy Independence and Security Act of 2007 (EISA 2007) (Pub. L. No. 110-140) amends Section 325 of the EPCA to require DOE to incorporate standby mode and off mode energy use into a single amended or new standard, if feasible, for covered products, including microwave ovens, for any final rule establishing or revising a standard adopted after July 1, 2010. If such a single standard is not feasible, DOE shall prescribe a separate standard for standby mode and off mode energy consumption, if justified. (42 U.S.C. 6295(gg)(3)) As discussed in chapter 3 of this TSD, DOE published a final rule on July 22, 2010 repealing the provisions in the existing microwave oven test procedure relating to the measurement of cooking efficiency and energy factor (EF). 75 FR 42579. DOE notes that the absence of active mode testing provisions in the microwave oven test procedure results in a *de facto* separate energy use descriptor for microwave oven standby mode and off mode energy use. Therefore, DOE conducted microwave oven standby power testing to supplement the AHAM-supplied data, investigated design options, and developed a relationship between incremental manufacturing cost and standby power levels.

As discussed in chapter 3 of this TSD, in the March 2011 TP Interim Final Rule, DOE adopted definitions of standby, off, and active mode based on the provisions in IEC Standard 62301 Second Edition, Final Draft International Standard (IEC Standard 62301 FDIS). 76 FR 12825, 12834–37 (Mar. 9, 2011). DOE defines "standby mode" as the condition in which an energy-using product is connected to a mains power source and offers one or more of the following user oriented or protective functions which may persist for an indefinite time –

(I) a remote switch (including a remote control), internal sensor, or timer to facilitate the activation of other modes (including activation or deactivation of active mode); and
(II) continuous functions, including information or status displays (including clocks) or sensor-based functions. 76 FR 12825, 12836 (Mar. 9, 2011).

DOE defines "off mode" as the condition in which an energy-using product is connected to a mains power source, is not providing any active or standby mode function, and may persist for an indefinite time. Off mode would also include an indicator that shows the user only that the product is in the off position. *Id*.

DOE defines "active mode," as the condition in which an energy-using product is connected to a main power source, has been activated, and provides 1 or more main functions. Delay start mode is a one off user initiated short duration function that is associated with an active mode. *Id*.

DOE considers "main functions" for a microwave oven to be those operations in which the magnetron and/or thermal element is energized for at least a portion of the time for purposes of heating, cooking, and/or defrosting the load. According to these definitions, standby mode would thus comprise the conditions in which the microwave oven is plugged in and consuming power for features including displays, cooking sensors, and sensors to reactivate the microwave oven from a low-power state after a period of user inactivity. For reasons discussed later in this section, DOE does not believe that any microwave ovens currently for sale in the United States are capable of operation in off mode.

General Microwave Oven Construction

All microwave-only ovens examined by DOE contain a metal cavity that is mechanically attached to the front and rear chassis frames. Each of these pieces had been formed by stamping, joined, and then the assembly is painted. To this frame, a bottom panel is attached. This bottom panel covers the turntable motor and also acts as an electrical ground for the magnetron power supply and the magnetron. The inner cavity occupies, on average, about 70 percent of the width and height of the microwave oven. The remaining space is used for cooling channels, the magnetron, the magnetron power supply, the cooling fan, the microwave oven controller, and other miscellaneous components.

All of the microwave-only ovens examined have a door that is hinged on the left side of the unit. Beneath the right edge of the door, a latch mechanism with three switches ensures that the microwave oven cannot operate its magnetron without the door being closed. To the right of the door, the user interface frame typically features a foil-based button array under a flexible plastic cover, along with the display. The display may be either attached directly to the user interface frame or integrated into the main control board for the microwave oven. The main control board typically consists of a single-sided printed circuit board (PCB) which features a small alternating current to direct current (AC-DC) power supply, several relays, and control logic. All power coming into the microwave oven is filtered through a separate power filtration board to which the power cord is attached.

In addition to the aforementioned components, microwave-only ovens contain a magnetron power supply featuring a microwave oven transformer, a high voltage diode, and a high-voltage aluminum electrolytic capacitor. A single-speed fan keeps the magnetron and microwave oven transformer cool during operation, while a turntable may rotate the food load inside the cavity while the microwave oven is operating. A single incandescent light bulb (20 W and higher) typically provides cavity illumination during operation and when the door is open. More sophisticated microwave ovens may contain cooking sensors, larger and multi-colored displays with more complex graphics, and/or inverter-based magnetron power supplies.

Test Units

DOE conducted standby power testing and reverse engineering analyses on a representative sample of 32 microwave-only ovens. DOE noted key parameters for each test unit, presented in Table 5.5.2 through Table 5.5.5. Since manufacturers are not required to report standby power for microwave ovens, DOE could not select its sample test units on the basis of standby power consumption. Instead, DOE selected its sample microwave ovens to cover a wide range of cavity sizes and output power, as well as other features such as display type, power supply type, and presence of cooking sensors. DOE was unable to identify any microwave oven models with an automatic powerdown feature. Within the test sample, DOE observed significant standby power differences which it believes are attributable to specific design options or design option combinations.

Table 5.5.2 Microwave-Only Oven Features (Table 1 of 4)

DOE Unit Number		DOE1	DOE2	DOE3	DOE4	DOE5	DOE6	DOE7	DOE8
Rated Output Power (W)		700	700	700	700	800	800	800	800
Stated Volume (ft^3)		0.7	0.7	0.7	0.7	1	1	0.8	0.8
Cooking Sensor		-	-	-	-	Y	-	-	-
Inverter Power Supply		-	-	-	-	-	-	-	-
Display	Type	LED	LED	LED	LED	VFD	LED	LCD	LCD
	Characters	#, 1 x 4	#, 1 x 4	#, 1 x 4	#, 1 x 4	A, 1 x 7	#, 1 x 4	#, 1 x 4	#, 1 x 4
	# of LEDs for backlighting	N/A	N/A	N/A	N/A	N/A	N/A	None	None
	Size	1.50" x 0.43"	1.50" x 0.43"	1.45" x 0.70"	1.90" x 0.83"	2.25" x 0.75"	1.50" x 0.80"	1.87" x 0.83"	1.87" x 0.83"
Unit is Similar to		-	-	-	-	-	DOE5	-	-

Table 5.5.3 Microwave-Only Oven Features (Table 2 of 4)

	DOE Unit Number	DOE9	DOE10	DOE11	DOE12	DOE13	DOE14	DOE15	DOE16
	Rated Output Power (W)	900	1000	1000	1000	1000	1100	1100	1100
	Stated Volume (ft^3)	0.9	1.1	1.1	1	0	1.1	1.1	1.8
	Cooking Sensor	-	-	-	-	-	-	Y	Y
	Inverter Power Supply	-	-	-	-	-	-	-	-
Display	Type	LED	LED	LED	LED	VFD	LED	LCD	VFD
Display	Characters	#, 1 x 4	#, 1 x 4	#, 1 x 4	#, 1 x 4	#, 1 x 4	#, 1 x 4	A, 1 x 6	A, 1 x 7
Display	# of LEDs for backlighting	N/A	N/A	N/A	N/A	N/A	N/A	5	N/A
Display	Size	2.00" x 0.65"	1.85" x 1.10"	1.75" x 0.85"	1.75" x 0.70"	2.20" x 0.65"	2.00" x 0.65"	2.53" x 0.95"	2.25" x 0.75"
	Unit is Similar to	-	-	-	-	-	-	DOE14	-

Table 5.5.4 Microwave-Only Oven Features (Table 3 of 4)

	DOE Unit Number	DOE17	DOE18	DOE19	DOE20	DOE21	DOE22	DOE23	DOE24
	Rated Output Power (W)	1100	1100	1100	1100	1100	1100	1150	1200
	Stated Volume (ft^3)	1	1.4	1	1.3	1.1	1	1.4	2.2
	Cooking Sensor	-	-	-	-	-	-	Y	Y
	Inverter Power Supply	-	-	-	-	-	-	-	Y
Display	Type	LCD	LCD	LCD	LED	LED	LCD	VFD	LCD
Display	Characters	#, 1 x 4	A, 1 x 5	#, 1 x 4	#, 1 x 4	#, 1 x 4	#, 1 x 4	A, 1 x 7	A, 1 x 6
Display	# of LEDs for backlighting	3	4	None	N/A	N/A	3	N/A	10
Display	Size	1.83" x 0.80"	2.03" x 0.81"	1.87" x 0.83"	1.50" x 0.80"	1.47" x 0.80"	2.00" x 0.83"	2.25" x 0.75"	2.05" x 1.10"
	Unit is Similar to	-	-	DOE17	-	-	DOE17	DOE16	DOE30

Table 5.5.5 Microwave-Only Oven Features (Table 4 of 4)

	DOE Unit Number	DOE25	DOE26	DOE27	DOE28	DOE29	DOE30	DOE31	DOE32
	Rated Output Power (W)	1200	1200	1200	1200	1200	1250	1300	1300
	Stated Volume (ft^3)	1.2	2.2	1.2	2	2	2.2	1.2	1.2
	Cooking Sensor	-	Y	Y	Y	Y	Y	Y	Y
	Inverter Power Supply	-	Y	-	-	-	Y	Y	Y
Display	Type	LCD	LCD	LCD	LCD	LCD	LCD	LCD	LCD
Display	Characters	#, 1 x 4	A, 1 x 6	A, 1 x 7	D, 2 x 8	A, 1 x 7	A, 1 x 6	#, 1 x 4	A, 1 x 6
Display	# of LEDs for backlighting	5	10	4	6	4	4	10	10
Display	Size	1.85" x 0.83"	2.05" x 1.10"	2.03" x 0.78"	2.45" x 1.17"	2.03" x 0.78"	2.05" x 1.10"	1.75" x 0.80"	2.05" x 1.10"
	Unit is Similar to	DOE17	DOE30	DOE25	-	-	DOE31	-	DOE31

Three different display technologies were observed to be incorporated in the sample units: 1) LED; 2) LCD; and 3) VFD. The display format for each microwave oven was characterized as either numeric (#), alphanumeric (A), or dot matrix (D). Whereas numeric displays can only show time, alphanumeric displays can also display letters (though usually in simplified format). Dot matrix displays can show various fonts, letters, and symbols via matrices of pixels, making them the most flexible display technology. Since display power consumption is a function of not only the type of technology used but the overall size and number of digits in the display as well, the dimensions of each display were measured and the number of rows and columns of digits were recorded. Finally, some LCDs use LEDs for backlighting, allowing a microwave oven user to read the display both at night and in daylight.

Microwave-Only Ovens Product Teardowns and Testing

DOE conducted product teardowns and testing in support of its standby power investigation for microwave-only ovens. DOE also analyzed IEC Standard 62301 (First Edition) to determine its suitability for measuring standby power in microwave ovens. DOE found the results produced by IEC Standard 62301 (First Edition) to be fairly consistent for many microwave ovens. However, for a few microwave ovens in the test sample, the standby power consumption varied by more than 5 percent over the course of 5 minutes, a threshold above which IEC Standard 62301 (First Edition) requires a longer 12-hour standby test duration. Investigating the source of these variations in power consumption, DOE determined that standby power can vary significantly with clock time, depending on the display type.

DOE tested a sub-sample of microwave ovens over 12-hour periods and subsequently developed an alternate 10-minute standby power test that achieved results for average power consumption that were within 1 to 2 percent of the 12-hour test results (see appendix 5B). Using the most consistent data from: (1) the IEC Standard 62301 5-minute test, (2) the regression analysis as described in appendix 5B, and/or (3) 12-hour tests, standby power for each microwave oven in the sub-sample was characterized, the minimum, maximum, and average input powers were recorded, and from the average standby power, an annual energy consumption in kWh was calculated. Table 5.5.6 through Table 5.5.9 summarize these results.

Table 5.5.6 DOE Microwave-Only Oven Standby Power (Table 1 of 4)

DOE Unit Number		DOE1	DOE2	DOE3	DOE4	DOE5	DOE6	DOE7	DOE8
Rated Output Power (W)		700.0	700.0	700.0	700.0	800.0	800.0	800.0	800.0
Stated Volume (ft^3)		0.7	0.7	0.7	0.7	1.0	1.0	0.8	0.8
Cooking Sensor		-	-	-	-	Y	-	-	-
Display	Type	LED	LED	LED	LED	VFD	LED	LCD	LCD
Display	Characters	#, 1 x 4	#, 1 x 4	#, 1 x 4	#, 1 x 4	A, 1 x 7	#, 1 x 4	#, 1 x 4	#, 1 x 4
Display	# of LEDs for backlighting	N/A	N/A	N/A	N/A	N/A	N/A	None	None
Display	Size	1.50" x 0.43"	1.50" x 0.43"	1.45" x 0.70"	1.90" x 0.83"	2.25" x 0.75"	1.50" x 0.80"	1.87" x 0.83"	1.87" x 0.83"
Standby	Min (W)	1.47	1.49	1.14	0.96	5.28	1.33	1.37	1.38
Standby	Average (W)	1.74	1.77	1.28	1.07	5.28	1.51	1.38	1.40
Standby	Max (W)	1.85	1.90	1.35	1.14	5.53	1.60	1.41	1.41
Standby	Annual (kWh)	15.22	15.47	11.21	9.40	46.28	13.22	12.12	12.28
Unit is Similar to		-	-	-	-	-	DOE5	-	-

Table 5.5.7 DOE Microwave-Only Oven Standby Power (Table 2 of 4)

	DOE Unit Number	DOE9	DOE10	DOE11	DOE12	DOE13	DOE14	DOE15	DOE16
	Rated Output Power (W)	900.0	1,000.0	1,000.0	1,000.0	1,000.0	1,100.0	1,100.0	1,100.0
	Stated Volume (ft^3)	0.9	1.1	1.1	1.0	0.0	1.1	1.1	1.8
	Cooking Sensor	-	-	-	-	-	-	Y	Y
Display	Type	LED	LED	LED	LED	VFD	LED	LCD	VFD
Display	Characters	#, 1 x 4	#, 1 x 4	#, 1 x 4	#, 1 x 4	#, 1 x 4	#, 1 x 4	A, 1 x 6	A, 1 x 7
Display	# of LEDs for backlighting	N/A	N/A	N/A	N/A	N/A	N/A	5	N/A
Display	Size	2.00" x 0.65"	1.85" x 1.10"	1.75" x 0.85"	1.75" x 0.70"	2.20" x 0.65"	2.00" x 0.65"	2.53" x 0.95"	2.25" x 0.75"
Standby	Min (W)	1.26	1.09	1.11	1.42	2.46	1.16	3.08	3.08
Standby	Average (W)	1.49	1.23	1.26	1.75	2.48	1.40	3.10	3.08
Standby	Max (W)	1.58	1.30	1.33	1.88	2.49	1.49	3.12	3.31
Standby	Annual (kWh)	13.09	10.73	11.01	15.32	21.71	12.26	27.14	26.95
	Unit is Similar to	-	-	-	-	-	-	DOE14	-

Table 5.5.8 DOE Microwave-Only Oven Standby Power (Table 3 of 4)

	DOE Unit Number	DOE17	DOE18	DOE19	DOE20	DOE21	DOE22	DOE23	DOE24
	Rated Output Power (W)	1,100.0	1,100.0	1,100.0	1,100.0	1,100.0	1,100.0	1,150.0	1,200.0
	Stated Volume (ft^3)	1.0	1.4	1.0	1.3	1.1	1.0	1.4	2.2
	Cooking Sensor	-	-	-	-	-	-	Y	Y
Display	Type	LCD	LCD	LCD	LED	LED	LCD	VFD	LCD
Display	Characters	#, 1 x 4	A, 1 x 5	#, 1 x 4	#, 1 x 4	#, 1 x 4	#, 1 x 4	A, 1 x 7	A, 1 x 6
Display	# of LEDs for backlighting	3	4	None	N/A	N/A	3	N/A	10
Display	Size	1.83" x 0.80"	2.03" x 0.81"	1.87" x 0.83"	1.50" x 0.80"	1.47" x 0.80"	2.00" x 0.83"	2.25" x 0.75"	2.05" x 1.10"
Standby	Min (W)	1.64	1.64	1.30	1.46	1.32	1.70	3.05	2.57
Standby	Average (W)	1.65	1.66	1.31	1.65	1.55	1.72	3.05	2.59
Standby	Max (W)	1.67	1.67	1.34	1.73	1.66	1.73	3.18	2.60
Standby	Annual (kWh)	14.48	14.51	11.48	14.44	13.57	15.02	26.68	22.66
	Unit is Similar to	-	-	DOE17	-	-	DOE17	DOE16	DOE30

Table 5.5.9 DOE Microwave-Only Oven Standby Power (Table 4 of 4)

	DOE Unit Number	DOE25	DOE26	DOE27	DOE28	DOE29	DOE30	DOE31	DOE32
	Rated Output Power (W)	1,200.0	1,200.0	1,200.0	1,200.0	1,200.0	1,250.0	1,300.0	1,300.0
	Stated Volume (ft^3)	1.2	2.2	1.2	2.0	2.0	2.2	1.2	1.2
	Cooking Sensor	-	Y	Y	Y	Y	Y	Y	Y
Display	Type	LCD	LCD	LCD	LCD	LCD	LCD	LCD	LCD
Display	Characters	#, 1 x 4	A, 1 x 6	A, 1 x 7	D, 2 x 8	A, 1 x 7	A, 1 x 6	#, 1 x 4	A, 1 x 6
Display	# of LEDs for backlighting	5	10	4	6	4	4	10	10
Display	Size	1.85" x 0.83"	2.05" x 1.10"	2.03" x 0.78"	2.45" x 1.17"	2.03" x 0.78"	2.05" x 1.10"	1.75" x 0.80"	2.05" x 1.10"
Standby	Min (W)	1.68	2.57	3.50	3.86	3.38	2.79	2.08	2.81
Standby	Average (W)	1.70	2.59	3.52	3.88	3.41	2.82	2.09	2.82
Standby	Max (W)	1.71	2.60	3.60	3.93	3.46	2.86	2.10	2.86
Standby	Annual (kWh)	14.86	22.66	30.84	34.02	29.90	24.69	18.28	24.72
	Unit is Similar to	DOE17	DOE30	DOE25	-	-	DOE31	-	DOE31

In the course of examining the 32 microwave-only ovens in the test sample, DOE noted that all power supplies for the logic boards contain similar components. Incoming AC line voltage is reduced via a small (2 to 7 VA) transformer, input to a bridge rectifier, and subsequently smoothed with capacitors to produce unregulated DC voltage (VDC). Multiple voltages for logic integrated circuits (ICs) (usually 5 VDC or less) and relay control (12 to 24 VDC) are established either via multiple taps on the transformer or through the use of voltage regulators. None of the microwave ovens analyzed by DOE feature an on/off switch or electromechanical controls. DOE is unaware of any microwave ovens still on the market with electromechanical controls and no displays; DOE believes that the U.S. microwave oven market has completely transitioned to electronic controls with displays. Thus, all sampled microwaves consume standby power while waiting for user input. DOE does not believe that any domestic microwave ovens are capable of operating in off mode, as defined by EPCA. (42 U.S.C. 6295(gg)(1)(A)(ii))

The average standby power, disaggregated by display type and the presence of a cooking sensor as shown in Figure 5.5.2, exhibits a relatively wide range of values. These measured data correlate well with the standby power measurements that AHAM submitted to DOE (see Figure 5.5.3). In the DOE test sample, none of the microwave ovens with LED displays include a cooking sensor, and these models all consume less than 2 W in standby mode. Similar low standby power requirements were observed for microwave ovens with LCD displays and no cooking sensors. For those microwave ovens with LCD displays and cooking sensors, the standby power ranged from 2 to 4 W. VFD-equipped microwave ovens demonstrate fairly consistent power draw, and the microwave oven with the highest standby power uses a cooking sensor and a VFD.

In the following figures, the legend key includes designations for the presence of a cooking sensor (CS), backlighting (B), and inverter drive for the magnetron (I).

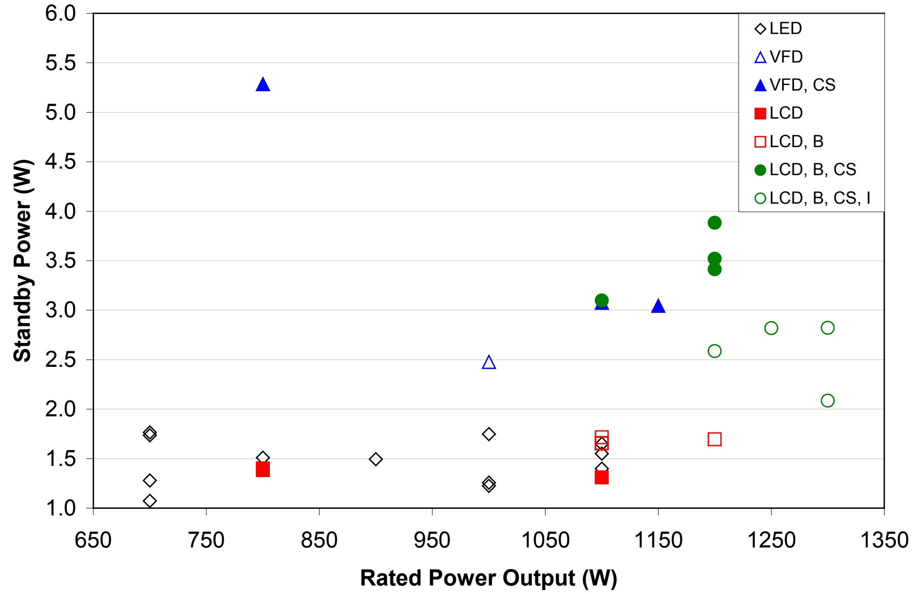

Figure 5.5.2 DOE Microwave-Only Oven Standby Power Consumption as a Function of Rated Output Power

While AHAM did not identify specific models in its data submittal, and thus DOE could not derive information on display type, the data does note which microwave ovens contain cooking sensors. Like the microwave ovens in the DOE test sample, the microwave ovens with cooking sensors in the AHAM sample, have on average, higher standby power consumption than microwave ovens without cooking sensors.

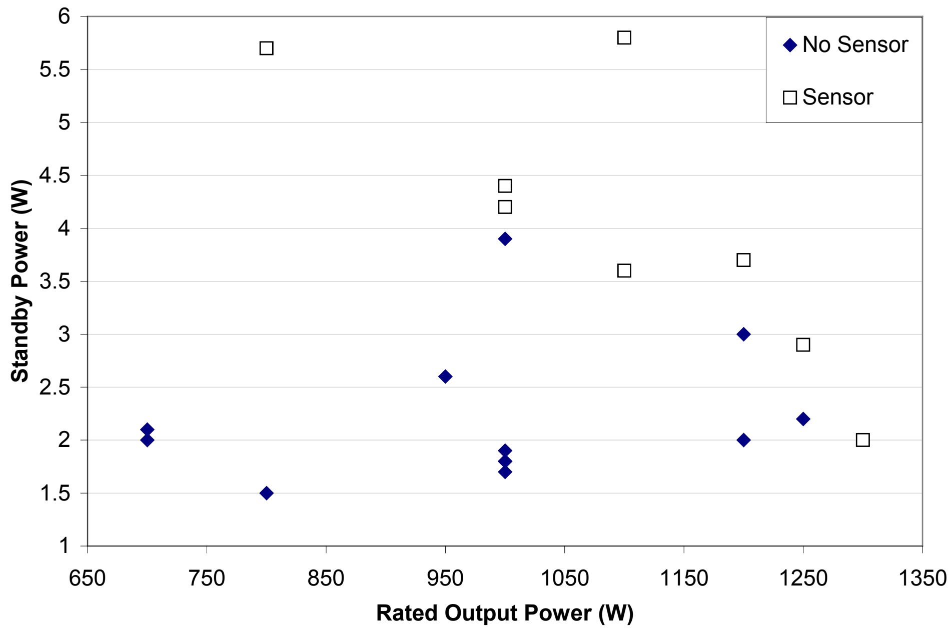

Figure 5.5.3 AHAM Microwave Oven Standby Power Consumption as a Function of Rated Output Power[12]

Based on these standby power observations, DOE concludes that standby power is a function of features including the display, the presence of a cooking sensor, and controller power requirements. The following sections discuss the impact of each of these features on overall standby power consumption.

Impact of Display Type on Standby Power

DOE noted three different types of displays among the 32 microwave ovens in its sample. The sampled display capabilities ranged from only being able to display numbers, to displaying alphanumeric characters, to incorporating dot-matrix-based displays which allow the display of multiple fonts, symbols, and, in some cases, graphics.

Display power requirements depend on the fundamental technology as well as the size of the display, the brightness, and the number and range of characters it can display. Figure 5.5.4 illustrates measured standby power consumption as a function of display size.

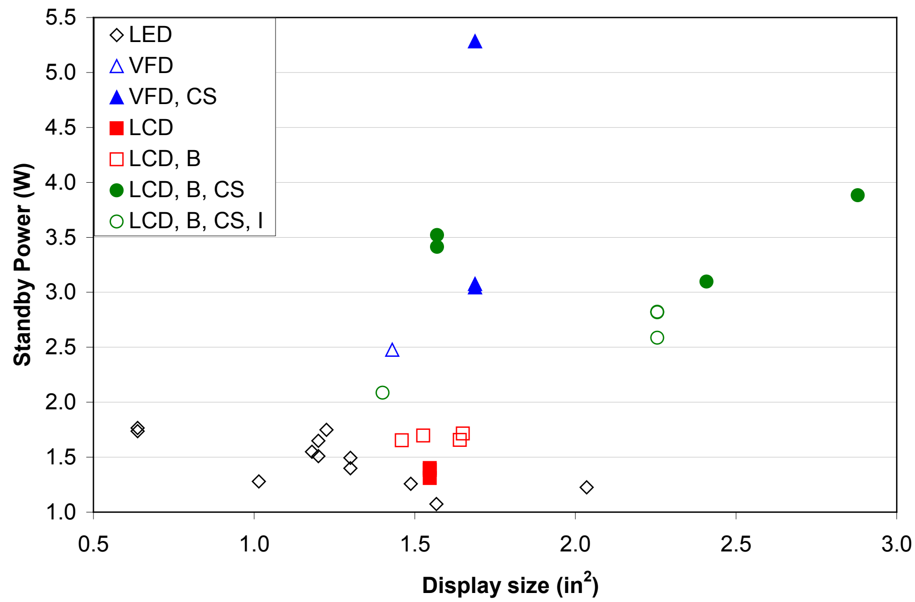

Figure 5.5.4 DOE Microwave-Only Oven Standby Power Consumption as a Function of Display Size

Figure 5.5.5 through Figure 5.5.7 show the average measured standby power with minimum and maximum values for each type of display. See appendix 5C for a further discussion of display technologies.

- Light Emitting Diode (LED)

LED displays operate by individually lighting up each element in the display to create a character or number or to illuminate a symbol. DOE confirmed that the power consumption of such displays varies depending on how many elements (and hence diodes) are active at any given time. Thus, LED-display-equipped microwave ovens demonstrate the greatest variation in standby power consumption over the course of a day as the clock cycles.

The span between the maximum and minimum standby power consumption, based on the number of elements illuminated, ranges from 0.2 to 0.4 W in the DOE test sample. Figure 5.5.5 shows the average standby power consumption (with maximum and minimum values) for microwave ovens with LED displays as a function of the measured size of the display in square inches. DOE found no apparent correlation between display size and standby power consumption. DOE recognizes that diode energy efficiency characteristics may be an important variable, but one for which DOE was not able to ascertain any information.

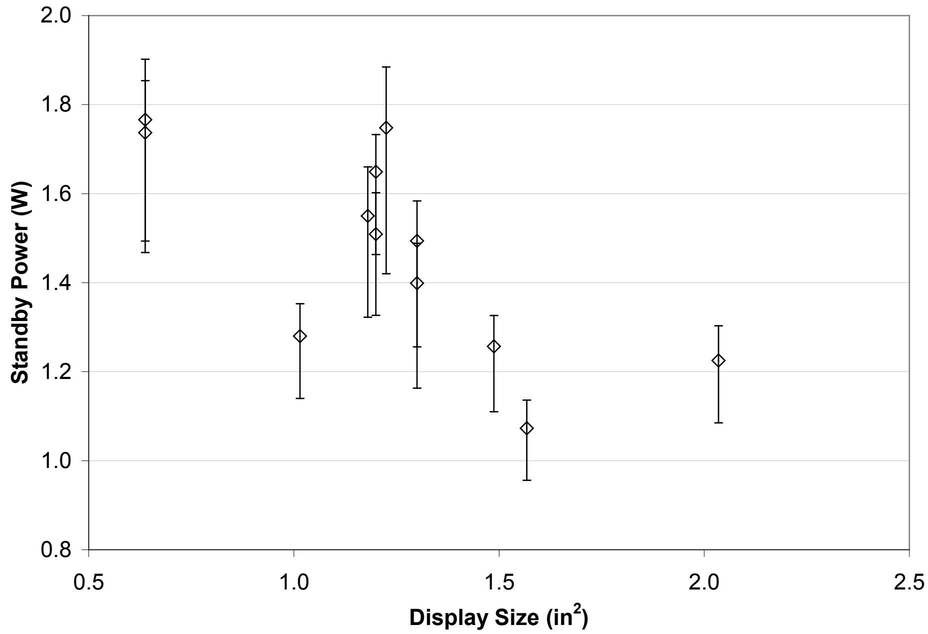

Figure 5.5.5 DOE Standby Power Consumption as a Function of Display Size for Microwave-Only Ovens with LED Displays

- Vacuum-Fluorescent Display (VFD)

VFDs typically require more power than LCD- or LED-based displays, but offer high brightness levels and wide viewing angles. Note that the three VFD models with cooking sensors have a feature that allows the display to be switched off, but selecting this option decreases standby power consumption by only 0.1 to 0.25 W. According to the IEC Standard 62301 test procedure, standby power would be measured with the displays powered off, resulting in a constant average value over the 12-hour period. These data are denoted in Figure 5.5.6 by the symbols. DOE also measured the variations in standby power with the displays on during the 12-hour cycle for these units, and these variations, which are all additive from the minimum standby power levels measured with the displays turned off, are indicated on the chart by bars on each symbol.

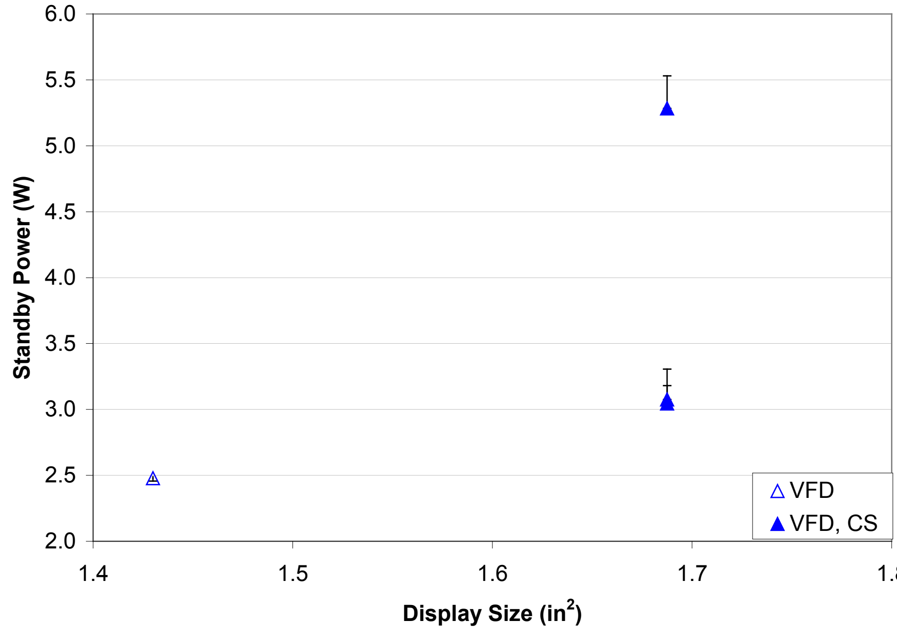

Figure 5.5.6 DOE Standby Power Consumption as a Function of Display Size for Microwave-Only Ovens with VFD Displays

- Liquid Crystal Display (LCD), with or without backlighting

An LCD without backlighting requires some ambient light to allow a user to read it because it relies on reflected light to create a visible contrast. LCDs without backlighting are frequently found on entry-level microwave ovens, whereas more expensive units tend to have backlit displays. LCDs with backlighting can be read regardless of ambient lighting conditions. The backlighting typically consists of multiple LEDs mounted behind the LCD display on the same circuit board. LCDs with backlighting were found on 12 of the microwave ovens in the DOE sample. As shown in Figure 5.5.7, the standby power consumption for microwave ovens with LCDs in the DOE sample remains nearly constant over time (since the bars showing variation during 12-hour tests are virtually indistinguishable from the symbols denoting the average values.) Figure 5.5.7 also shows that the addition of a cooking sensor raises standby power consumption, on average, to over 2 W.

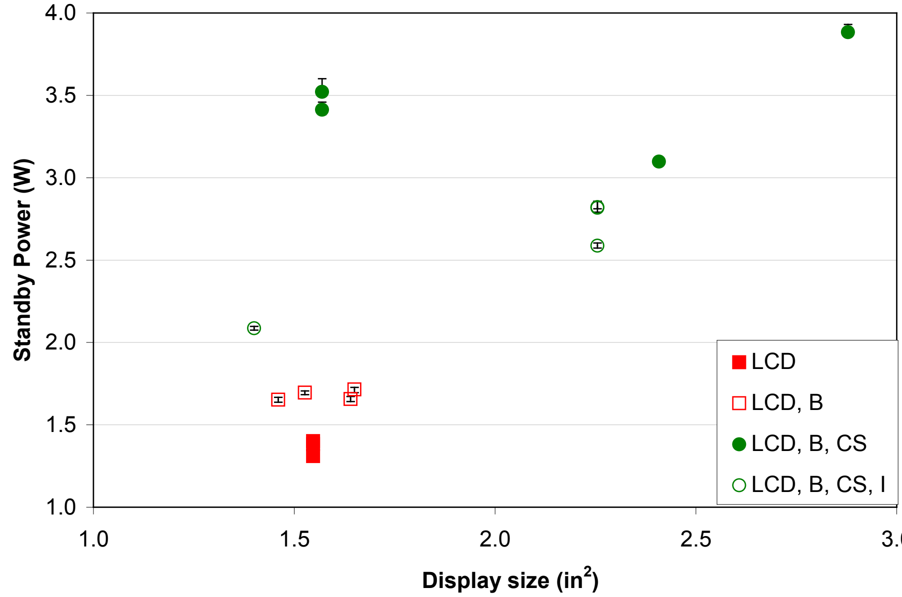

Figure 5.5.7 DOE Standby Power Consumption as a Function of Display Size for Microwave-Only Ovens with LCD Displays

Based on its research, DOE concludes that certain display technologies such as VFDs inherently consume more power, on average, than comparably-sized displays using other illumination technologies. Standby power is also a function of the size and the complexity of the display; more complex and larger displays typically consume more power than smaller, simpler displays.

Impact of a Cooking Sensor on Standby Power

DOE noted from its testing that microwave ovens with cooking sensors typically consume more power than comparable models that do not feature a cooking sensor. From its reverse-engineering activities, DOE identified two different types of cooking sensors generally used in microwave ovens: (1) absolute humidity sensors; and (2) piezo-electric steam sensors. A literature review of identifiable absolute humidity cooking sensors indicates that such sensors typically supply power to a resistive heating element whose conductivity changes in response to the presence of water vapor or other gases associated with food cooking processes. Based on its standby power observations between otherwise identical microwave ovens and information provided by sensor manufacturers, DOE concludes that the resistive elements in the cooking sensors are typically maintained at operating temperature during standby mode because warmup times (which can be several minutes) are longer than many microwave oven cooking times.

The specification sheet for one representative absolute humidity cooking sensor notes that the sensor requires approximately 0.9 W to remain warm and ready for use. Based on a typical power supply efficiency of about 65 percent, the required microwave oven input power associated with the absolute humidity cooking sensor is thus approximately 1.6 W. Other microwave-only ovens in the DOE sample use absolute humidity sensors whose power requirements appear comparable to those for the absolute humidity sensor referenced above. Testing performed on the steam sensors used in a number of microwave-only ovens in the DOE sample revealed that these sensors do not consume power in standby mode. For further discussion of steam cooking sensors, refer to chapter 3 of this TSD.

Table 5.5.10 shows a comparison of standby power for three pairs of microwave ovens in the DOE sample containing the same basic parts (power conditioner, transformer, magnetron, and cavity) with and without an absolute humidity cooking sensor. In all three cases, the microwave ovens with a cooking sensor consume at least 1.6 W more than comparable microwave ovens without a sensor. In the case of DOE test units #5 and #6, assuming the absolute humidity cooking sensor consumes about 1.6 W implies that the remaining differential between the two units of approximately 2.2 W of standby power consumption is attributable to the use of a VFD instead of an LED. The standby power consumption of other absolute humidity sensors, which can be inferred from units #25 and 27 with similar displays, is approximately 1.8 W.

Table 5.5.10 DOE Standby Power Requirements among Similar Microwave-Only Ovens with Different Options

Test Unit #	Display Type	# of LEDs used to backlight display	Display Size	Cooking Sensor Type	Avg. Standby Power Consumption (W)
DOE21	LED	N/A	1.47" x 0.80"	None	1.55
DOE15	LCD	5	2.53" x 0.95"	Absolute Humidity	3.10
DOE6	LED	N/A	1.50" x 0.80"	None	1.51
DOE5	VFD	N/A	2.25" x 0.75"	Absolute Humidity	5.28
DOE25	LCD	5	1.85" x 0.83"	None	1.70
DOE27	LCD	4	2.03" x 0.78"	Absolute Humidity	3.52

Figure 5.5.8 shows the cumulative impact of each design option on overall standby power. The figure shows the average standby power consumption for all microwave oven models in the DOE sample which have the designated design options, as well as the minimum and maximum values for each group.

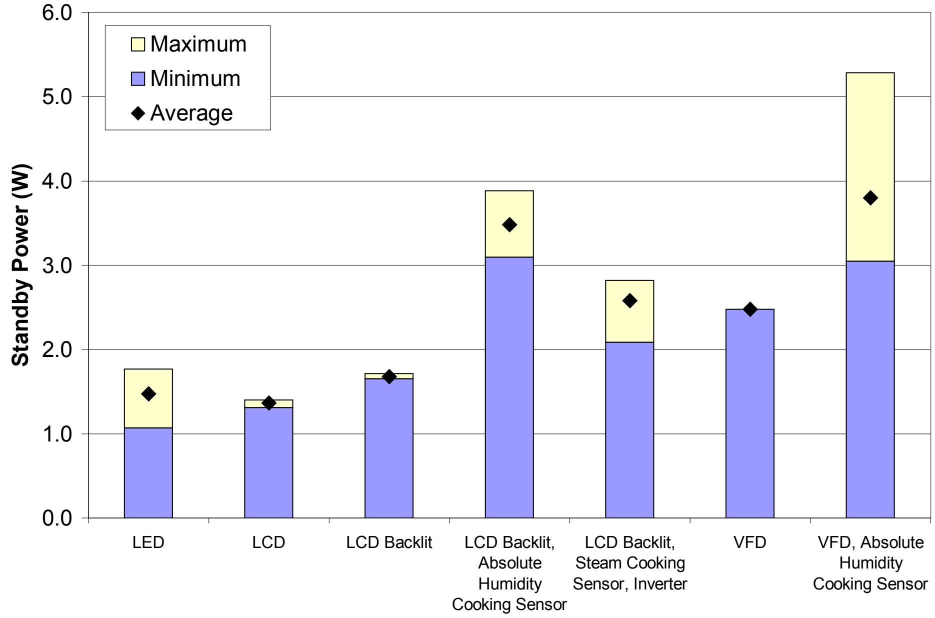

Figure 5.5.8 DOE Standby Power Consumption Associated with Different Design Options

Incremental Cost Data for Standby Power Levels for Microwave-Only Ovens and Countertop Combination Microwave Ovens

From the standby power testing and reverse-engineering, DOE observed correlations between (1) specific components and technologies, or combinations thereof, and (2) measured standby power. Costs for each of the components and technologies were estimated by DOE using quotes obtained from suppliers, interviews with manufacturers, interviews with subject matter experts, research and literature review, and numerical modeling. Preliminary incremental manufacturing costs associated with the standby power levels were then obtained by considering combinations of these components as well as other technology options identified to reduce standby power. Manufacturer interviews were also conducted to obtain greater insight into the design strategies to improve efficiency and the associated costs. As discussed above in section 5.2, DOE believes the standby power levels and characteristics of power supply designs (*i.e.*, size of the power supply) associated with microwave-only countertop and over-the-range units as well as countertop combination microwave ovens are similar. As a result, DOE proposed to analyze microwave-only ovens and countertop combination microwave ovens as a single product class. Therefore, DOE developed a single cost-energy use relationship for this product class.

The design options DOE considered in the engineering analysis include various display technologies, cooking sensors with no standby power requirement, higher-efficiency controller power supplies and relays, and improved control strategies. For details on the microwave oven standby design options, refer to chapter 3 of this TSD. DOE selected the design option(s) it believed manufactures would most likely implement to achieve a given standby power level for a given display technology. The incremental cost, then, for each display technology was weighted by the estimated percentage of shipments currently using that type of display in order to obtain a weighted-average incremental cost at each standby power level above the baseline. DOE believes that, in order to meet standby power level 1, manufacturers would likely have to utilize a cooking sensor with no standby power requirements. Additionally, for microwave ovens with VFDs and backlit LCDs, the conventional power supplies would need to be upgraded to higher efficiency conventional power supplies. Standby power level 2 would likely also require LED-equipped microwave ovens to upgrade the efficiency of the existing power supply, and DOE believes that manufacturers would have to change to sensitive-coil relays in order to continue using VFDs. To move from standby power level 2 to standby power level 3, DOE believes that manufacturers would have to additionally incorporate the sensitive-coil relays for LED and backlit LCD-based microwave ovens. Optionally, manufacturers of LED-equipped microwave ovens could choose to change to a switching power supply without upgrading the relays. Each of these two LED options was assumed to be equally likely since the cost of each path was similar. At standby power level 3, backlit LCD-equipped microwave ovens would likely also need to be changed to a switching power supply along with implementing the sensitive-coil relays. DOE believes the only way for manufacturers of VFD-equipped microwave ovens to meet a 1 W standby threshold would be to implement an automatic powerdown feature, in which a controller turns off power to standby-power-consuming components after a certain period of inactivity. This feature would also allow VFD-equipped microwave ovens to meet standby power level 4, and would be the approach for microwave ovens with the other display technologies to meet standby power level 4 as well. Table 5.5.11 presents the incremental manufacturing costs for each standby power level for microwave ovens. DOE originally developed and presented these costs the October 2008 NOPR, and therefore costs were presented in $2007. DOE updated these costs to $2010 to reflect changes in the producer price index (PPI) for electronic components and accessories.

Based on conversations with manufacturers and OEM suppliers, and the reverse-engineering analysis, DOE believes that all manufacturers can and likely will implement zero-standby cooking sensors by the effective date of standby mode and off mode energy conservation standards. Thus, DOE believes that consumer utility would not be impacted by a standard at standby power levels 1 or 2, since all display types could continue to be used. At standby power level 3 for VFDs and standby power level 4 for all display technologies, DOE analysis suggests the need for a separate controller (auto power-down) that automatically turns off all other power-consuming components during standby mode. Such a feature would affect the consumer utility of having a clock display only if the consumer could not opt out of auto power-down.

Table 5.5.11 Incremental Manufacturing Costs for Microwave-Only Oven and Countertop Combination Microwave Oven Standby Power

Standby Power Level	Standby Power, *W*	Incremental Cost, *2007$*	Incremental Cost, *2010$*
Baseline	4.0	$ 0	$ 0
1	2.0	$ 0.30	$ 0.27
2	1.5	$ 0.67	$ 0.60
3	1.0	$ 1.47	$ 1.31
4	0.02	$ 5.13	$ 4.58

Countertop Combination Microwave Oven Testing and Product Teardown

DOE also conducted standby power testing on 5 countertop combination microwave ovens, presented below in Table 5.5.12. Testing showed standby power levels ranging from 1.2 W to 4.7 W, with an average of 3.0 W. As discussed above in section 5.2, these standby power levels are similar to the standby power levels for microwave-only ovens. DOE also noted that the countertop combination microwave ovens used similar display types as microwave-only ovens (*i.e.*, LED displays, LCDs, and VFDs).

Table 5.5.12 DOE Countertop Combination Microwave Oven Standby Power

DOE Countertop Combo MWO Test Unit	Rated Microwave Cooking Output Power, *W*	Display Type	Display Size, *in.²*	Cooking Sensor	# of Heaters	Average Standby Power, *W*
DOE CTC1	1,000	LED	2.25	-	2	1.20
DOE CTC2	900	LCD w/ LED Backlight	3.75	-	2	2.36
DOE CTC3	900	VFD	3.00	Yes	1	3.23
DOE CTC4	1,100	LCD w/ LED Backlight	2.66	Yes	1	3.55
DOE CTC5	1,000	VFD	10.86	Yes	1	4.68

Figure 5.5.9 illustrates the measured standby power consumption as a function of display size for countertop combination microwave ovens. Similar to microwave-only ovens, DOE observed that standby power tends to increase as display size increases.

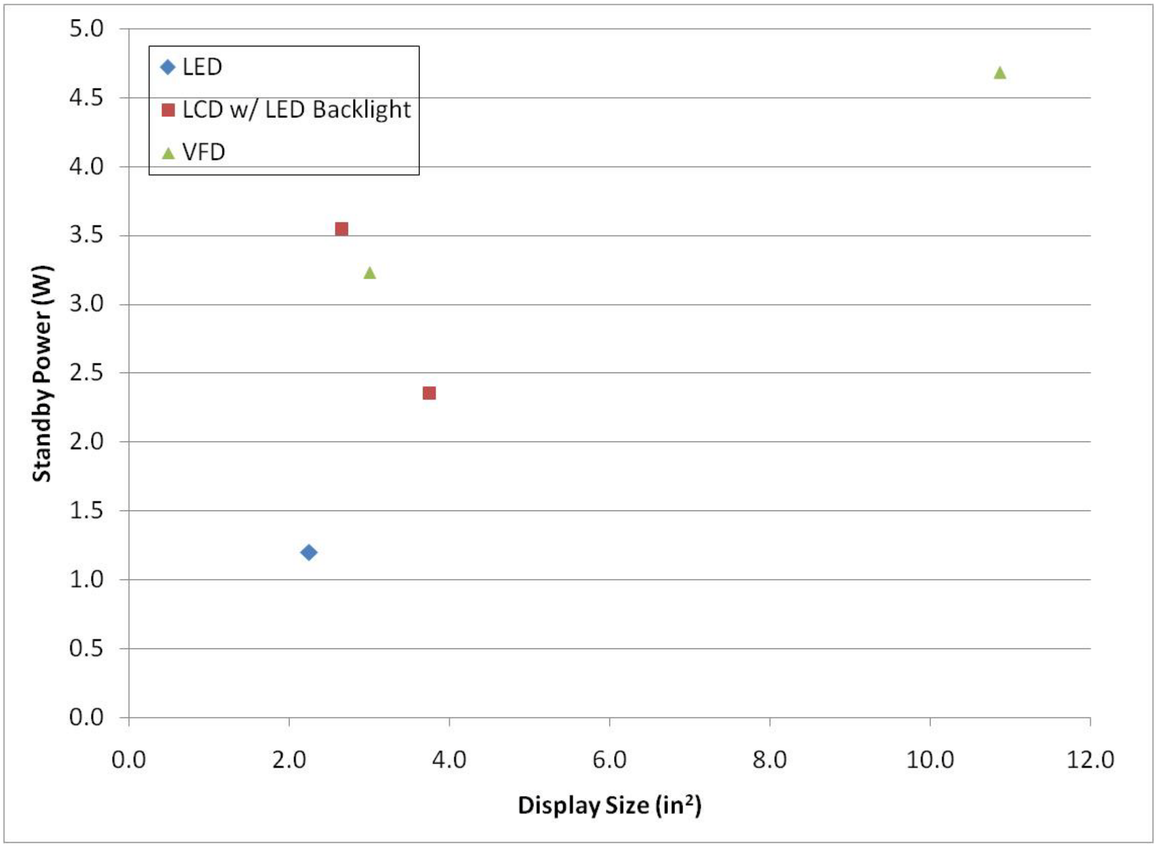

Figure 5.5.9 DOE Standby Power Consumption as a Function of Display Size for Countertop Combination Microwave Ovens

DOE also conducted product teardowns and standby power testing of individual components contributing to the total standby power consumption. DOE noted that the cooking sensors used in these models were similar to those used in microwave-only ovens. DOE also investigated the requirements for the size of the controls power supply for countertop combination microwave ovens. DOE noted that the size of a conventional linear power supply depends largely on the transformer used to step down the line input voltage to operate the controls. DOE isolated the power supply transformers in the controls these countertop combination microwave ovens and measured the standby power consumption. DOE similarly measured the power supply transformer standby power consumption for a limited number of the microwave-only ovens in its test sample. The results from this testing, presented below in Table 5.5.13, showed that the size of the controls power supplies (*i.e.*, the standby losses associated with the power supply transformers) were similar for both countertop combination microwave ovens and microwave-only ovens. In addition, as presented above in Table 5.5.12, the total standby power consumption for countertop combination microwave ovens is similar to that for microwave-only ovens. For these reasons, DOE believes that the sizes of the power supplies for countertop microwave ovens are similar to those for microwave-only ovens. As a result, DOE did not establish a separate product class for countertop combination microwave ovens. Therefore, the incremental manufacturing costs listed above in Table 5.5.11 would also apply for countertop combination microwave ovens.

Table 5.5.13 Control Power Supply Transformer Standby Power Test Results

DOE Countertop Combo MWO Test Unit	Transformer Standby Power, *W*	DOE Microwave-Only Test Unit	Transformer Standby Power, *W*
DOE CTC1	0.57	DOE28	1.44
DOE CTC2	0.95	DOE29	0.89
DOE CTC3	0.93	DOE30	1.11
DOE CTC4	1.81		
DOE CTC5	1.08		

***Built-In and Over-the-Range Combination Microwave Ovens*.**

Built-In and Over-the-Range Combination Microwave Oven Testing and Product Teardown

As discussed above in section 5.2, DOE proposed to analyze a separate product class for built-in and over-the-range combination microwave ovens. DOE conducted standby power testing on a sample of six over-the-range combination microwave ovens and two built-in combination microwave ovens. The results from this testing are shown below in Table 5.5.14. Testing showed standby power levels ranging from 4.1 W to 8.8 W. DOE noted that all of the units in its test sample had a cooking sensor and either a LCD touch screen with backlighting or a VFD. DOE noted that the built-in combination microwave ovens in its test sample consumed more standby power than the over-the-range combination microwave ovens. However, DOE also noted that these two units were higher-end units with larger displays and a larger number of cooking settings and options.

Table 5.5.14 DOE Built-In and Over-the-Range Combination Microwave Oven Standby Power

DOE Built-In/Over-the-Range Combo MWO Test Unit	Installation	Rated Microwave Cooking Output Power, *W*	Display Type	Display Size, *in.*^{2}	Cooking Sensor	# of Heaters	Average Standby Power, *W*
DOE OTRC1	Over-the-Range	1,200	LCD Touch w/ Backlight	13.66	Y	4	4.19
DOE OTRC2	Over-the-Range	1,200	LCD Touch w/ Backlight	13.66	Y	4	4.37
DOE OTRC3	Over-the-Range	1,100	VFD	3.91	Y	4	4.50
DOE OTRC4	Over-the-Range	1,100	VFD	3.91	Y	1	4.59
DOE OTRC5	Over-the-Range	1,000	VFD	7.75	Y	1	4.14
DOE OTRC6	Over-the-Range	900	VFD	4.00	Y	4	6.65
DOE BC1	Built-In	975	VFD	7.39	Y	4	8.16
DOE BC2	Built-In	950	VFD	7.39	Y	4	8.76

As discussed above for microwave-only ovens, display power requirements depend on the fundamental technology as well as the size of the display, the brightness, and the number and range of characters it can display. Figure 5.5.10 illustrates the measured standby power consumption as a function of display size for built-in and over-the-range combination microwave ovens.

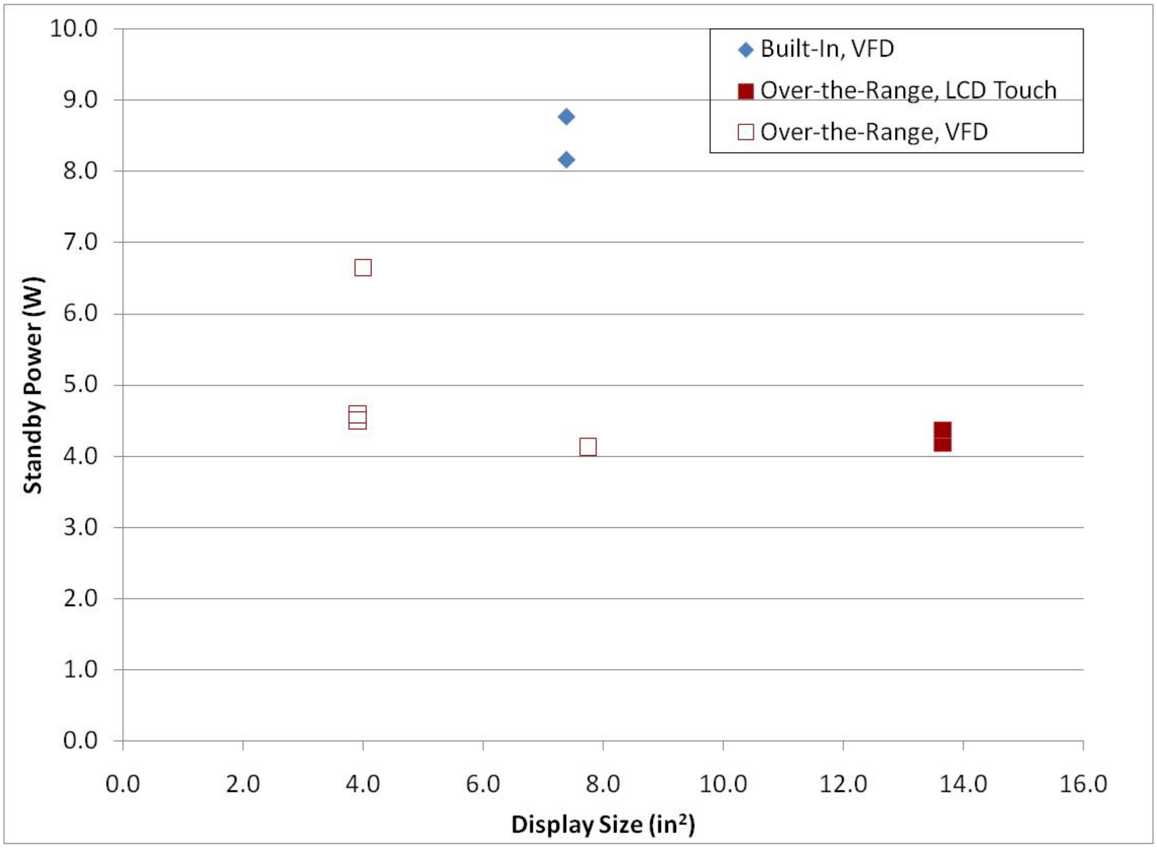

Figure 5.5.10 DOE Standby Power Consumption as a Function of Display Size for Built-In and Over-the-Range Combination Microwave Ovens

For each sample test unit, DOE also conducted standby power testing on individual components contributing to the total standby power consumption of each unit. DOE isolated and measured the standby power consumption of power filtration printed circuit boards, cooking sensors, and displays/user interface control boards. Results of this testing are shown below in Table 5.5.15. DOE noted that the power filtration boards consumed on average approximately 0.03 W. Similarly, cooking sensors consumed on average 0.86 W in standby mode. DOE also noted that display and user interface control board standby power consumption ranged from 0.75 W to 4.24 W, with an average of 2.03 W. Note that DOE was not able to isolate every component consuming power in standby mode, therefore the power consumption of the individual components listed in the Table 5.5.15 will not add up to the total standby power consumption of the unit.

Table 5.5.15 DOE Built-In and Over-the-Range Combination Microwave Oven Disaggregated Components Standby Power Consumption

DOE Built-In/Over-the-Range Combo MWO Test Unit	Standby Power Consumption, *W*			
	Power Filtration Board	Cooking Sensor	Display/User Interface	Total Unit
DOE OTRC1	0.06	0.82	1.88	4.19
DOE OTRC2	0.06	0.84	1.96	4.37
DOE OTRC3	0.03	0.82	0.75	4.50
DOE OTRC4	0.03	0.82	0.75	4.59
DOE OTRC5	0.01	0.92	1.38	4.14
DOE OTRC6	0.01	0.68	1.1	6.65
DOE BC1	0.01	1.05	4.15	8.16
DOE BC2	0.01	0.96	4.24	8.76

Incremental Cost Data for Standby Power Levels for Built-In and Over-the-Range Combination Microwave Ovens

DOE conducted standby power testing and reverse engineering analyses on the 8 built-in and over-the-range combination microwave ovens in its test sample in order to develop the cost-efficiency relationships. DOE used a design-option approach to determine the incremental manufacturing costs of combination microwave ovens for each standby power level. As discussed above for the microwave-only oven and countertop combination microwave oven product class, DOE observed correlations between specific components and technologies, or combinations thereof, and measured standby power. Costs for each of the components and technologies used at each standby power level were estimated by DOE using quotes obtained from various component suppliers as well as interviews with manufacturers.

For standby power level 1, DOE believes that, similar to the microwave-only oven and countertop combination microwave oven product class, manufacturers would likely have to utilize a cooking sensor with no standby power requirements. DOE estimated that the manufacturing cost of a zero-standby cooking sensor would be the same as that of the cooking sensor with high standby power.

DOE believes that, in order to achieve standby power level 2, manufacturers would likely change the conventional linear power supply to a switch mode power supply. DOE used reverse engineering to determine the cost of the components used in a design of a switch mode power supply capable of delivering the same output power as the baseline conventional linear power supply.

To move from standby power level 2 to standby power level 3, DOE estimated the cost of implementing a control board design with a switch mode power supply and replacing the electromechanical relays (used to drive components such as heaters, motors, lights, etc.) with solid state relays capable of driving the same loads as the electromechanical relays. Because implementing solid state relays would decrease the total power requirements of the control board, DOE also estimated the cost of changing power supply components based on the smaller power supply size.

For standby power level 4, DOE estimated the manufacturing cost based on the cost of the components needed to design an automatic power-down function that uses a transformerless power supply for the microprocessor chip along with a conventional linear power supply that is activated when the unit goes into active mode. DOE also estimated the costs associated with a door limit switch and Triac to control power through the transformer.

The results of this analysis for built-in and over-the-range combination microwave ovens are summarized in Table 5.5.16.

Table 5.5.16 Built-In and Over-the-Range Combination Microwave Oven Incremental Manufacturing Costs

Standby Power Level	Maximum Average Standby Power Consumption, *W*	Incremental Cost, *2010$*
Baseline	4.5	$ 0
1	3.7	$ 0
2	2.7	$ 2.29
3	2.2	$ 9.44
4	0.04	$ 5.18

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