# CHAPTER 5. ENGINEERING ANALYSIS

## TABLE OF CONTENTS



## LIST OF TABLES

## LIST OF FIGURES

# 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 energy and water consumption and costs of products at various levels of increased efficiency. This section provides an overview of the engineering analysis (section 5.1), considers technologies that are unable to analyzed for this rulemaking (section 5.2), discusses proposed product classes (section 5.3), establishes baseline unit specifications (section 5.4.1), discusses incremental efficiency levels (section 5.4.2), explains the methodology used during data gathering (5.5) and discusses the analysis and results (section 5.6) DOE completed a separate engineering analysis for residential cooking products and commercial clothes washers (CCWs).

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 cost and energy efficiency data, which DOE received from the Association of Home Appliance Manufacturers (AHAM) and qualified and supplemented through teardown analysis and manufacturer interviews. The primary output of the engineering analysis is a set of cost-efficiency curves. In the subsequent markups analysis (chapter 7), 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 6) 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; (2) the efficiency-level approach, which calculates the relative costs of achieving increases in energy efficiency levels, 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 TECHNOLOGIES UNABLE TO BE INCLUDED IN THE ANOPR ANALYSIS

In performing the engineering analysis, DOE did not consider for analysis certain technologies that met the screening criteria but were unable to be evaluated for one or more of the following reasons: (1) data are not available to evaluate consumer usage of a product incorporating the technology and, therefore, the test procedure conditions and methods may not be applicable; (2) data are not available to evaluate the energy efficiency characteristics of the technology; and (3) available data suggest that the efficiency benefits of the technology are negligible. In the first two cases, DOE is unable to adequately assess how these technologies impact annual energy consumption.

For technologies that lack consumer usage details, including operating conditions, duration, and frequency, DOE believes that the existing test procedures may specify conditions and methods that are not representative of actual usage. DOE further believes that even if data were available to amend the test procedures, such changes could be extensive enough to require total revision, which in turn could warrant the creation of a separate product class for that technology in the event that the test procedure changes indicated unique utility.

Furthermore, certain technologies cannot be measured according to the conditions and methods specified in the existing test procedure.

In other cases, available data suggest that some of the design options would result in such small energy savings as to be negligible. Because DOE intends to focus on the technologies with measurable impact on efficiency, design options with negligible energy savings have been eliminated from further consideration.

***Cooking Products***

Several technologies are available for cooktops that allow the burners or heating elements to automatically adjust in response to cooking-state setpoints, such as cooking vessel temperature. These include thermostatically controlled gas cooktop burners as well as electronic controls for electric cooktops. However, DOE is unaware of any data to quantify the energy efficiency effects of such technologies. Further, efficiency benefits of these design options can only be realized under variable burner or element conditions. Because the cooktop test procedure does not account for consumer usage patterns, the energy savings of these technologies cannot be adequately measured. Therefore, DOE will not consider these design options for further analysis for the NOPR.

Similarly, DOE is unaware of any data that indicates a measurable energy efficiency impact of insulation in gas and electric coil cooktops, so DOE will not analyze this design option in the NOPR for these product classes.

Induction cooktops require ferromagnetic cookware in order to transfer energy to the food contents. While the test block specified in the DOE test procedure is aluminum and thus is unable to measure the efficiency of induction cooktops, the National Bureau of Standards (NBS), now called National Institute of Standards and Technology (NIST), proposed an alternate method of measuring the energy consumption of such cooktops by simply attaching a ferromagnetic material to the bottom of the test block. Data obtained by this method suggested an efficiency improvement over baseline electric smooth cooktops. However, this test method has not been rigorously validated for incorporation into the DOE test procedure and therefore, due to the unresolved nature of the NIST data, DOE will eliminate induction elements for electric smooth cooktops from further consideration in the NOPR.

Some electric cooktops and microwave ovens with electronic controls consume standby power, but the efficiency metrics do not incorporate such power in their calculation. Even though DOE considers the consumer usage of these products to be well-defined, the current test procedure does not measure standby power. Thus DOE is unable to quantify the impact on energy savings of low-standby-loss electronic controls for these products and will not consider these design options during the NOPR analysis.

The only currently available gas ovens that DOE is aware of that incorporate radiant burners do so for broiling, which is a secondary cooking function that is not the focus of the DOE efficiency measurement; energy efficiency is instead measured during the primary bake function. Thus the energy benefits are not captured by the test procedure under these conditions. Accordingly, DOE will eliminate radiant burners in gas ovens from further analysis for the NOPR.

While there are several residential steam ovens currently on the market, DOE believes that the existing test procedure may specify conditions and methods that are not representative of actual usage. DOE further believes that even if data were available to amend the test procedure, such changes could be extensive enough to require total revision, which in turn could warrant the creation of a separate product class in the event that the test procedure changes indicated unique utility. Thus, DOE will not consider steam cooking in the NOPR analysis.

For added insulation in microwave ovens, this technology will not improve the energy factor (EF), since during the short duration of the DOE test procedure as well as during typical usage, the microwave oven cavity walls do not measurably heat up. Thus, the energy savings of this design option would be so small as to not be measurable.

Cooking sensors, which terminate the operation of a microwave oven based upon inferred cooking state, appear to promote shorter cook times and thus lower energy consumption. Due to the lack of consumer usage details, including operating conditions, duration, and frequency of use, DOE believes that the existing test procedure may specify conditions and methods that are not representative of actual usage. Thus, DOE will not consider this design option for further analysis for the NOPR.

According to AHAM, dual magnetrons in microwave ovens do not improve energy efficiency due to the added losses associated with two magnetron heaters. In addition, AHAM stated that the additional cost of dual magnetrons could not be economically justified. DOE does not have any efficiency data on dual magnetrons by which to evaluate this design option. Therefore, it will not consider dual magnetrons for further analysis in the NOPR.

AHAM stated that virtually no residential solo-function microwave oven still uses a ceramic stirrer. Almost all microwave ovens use polypropylene or mica film stirrers, which have lower losses than ceramic stirrers. According to AHAM, this design option has already been optimized so there is no opportunity for efficiency improvements. The stirrer cover, however, may be made of ceramic when there are browning elements that generate too much heat for a plastic cover. These covers absorb some microwave energy but are needed to prevent food splatter inside the wave guide. Eliminating the ceramic cover would adversely affect consumer utility by requiring cleaning of the stirrer or by reducing the life of the stirrer. Therefore, DOE's NOPR analysis will not consider eliminating or improving the ceramic stirrer cover.

According to AHAM, losses associated with the wave guide are typically less than 0.5 percent of the overall energy consumption. DOE is not aware of any data demonstrating efficiency improvements associated with wave guide improvement, so DOE will not analyze this design option for the NOPR.

***Commercial Clothes Washers***

Although several manufacturers have made claims regarding improved wash performance and greater utility of improved drum designs for front-loading clothes washers, DOE is unaware of any publicly available data to corroborate a decrease in cycle time or water consumption or an increase in modified energy factor (MEF) as a result of implementing this design option. Therefore, DOE will not analyze this design option for the NOPR.

Even though DOE considers consumer usage of CCWs to be well-defined, the current tests procedures do not measure standby power. Also, DOE is unaware of any data demonstrating energy savings associated with low-standby power supplies for CCWs. Thus, in the context of the present rulemaking, DOE eliminated the low-standby-power design option from the NOPR analysis.

## 5.3 PRODUCT CLASSES ANALYZED

DOE separated residential cooking products and CCWs into product classes. Because DOE formulated a separate energy conservation standard 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) and 6316(a))

For **cooking products**, DOE analyzed product classes based on the energy source (*i.e.*, gas or electric) and the cooking method (*i.e.* cooktops, ovens, and microwave ovens.) These distinctions yielded five cooking product classes: (1) gas cooktops; (2) electric cooktops; (3) gas ovens; (4) electric ovens; and (5) microwave ovens. DOE's product classes are based on the list of product classes defined by DOE in its 1996 *Technical Support Document for Residential Cooking Products* (1996 TSD), which was released as part of the previous standards rulemaking.[1] Gas and electric ranges[a] are not listed below as product classes. Because ranges consist of both a cooktop and oven, any potential cooktop and oven standards will apply to the individual components of the range. As a result, product classes for ranges are not necessary.

For **gas cooktops**, DOE's analyzed product class is:

- Conventional burners.

For **electric cooktops**, DOE's 1996 TSD determined that the ease of cleaning smooth elements provides enhanced consumer utility over coil elements. Because smooth elements typically use more energy than coil elements, DOE analyzed the following product classes for electric cooktops:

- Low or high wattage open (coil) elements; and
- Smooth elements.

For **electric ovens**, the 1996 TSD determined that the type of oven-cleaning system is a utility feature that affects performance. DOE found that standard ovens and ovens using a catalytic continuous-cleaning process use roughly the same amount of energy. Self-cleaning ovens use a pyrolytic process that provides enhanced consumer utility with lower overall energy consumption as compared to either standard or catalytically lined ovens. Thus, DOE analyzed the following product classes for electric ovens:

- Standard oven with or without a catalytic line; and
- Self-cleaning oven.

For **gas ovens**, DOE analyzed the following product classes based upon the same reasoning as electric ovens:

- Standard oven with or without a catalytic line; and
- Self-cleaning oven.

For **microwave ovens**, DOE analyzed no further class breakdown. This product class can encompass microwave ovens with and without browning elements, but does not include microwave ovens that incorporate convection systems (combination ovens). DOE will not conduct an analysis at this time of combination microwave ovens due to the inability of the test procedure to measure the performance of the convection component and thus a lack of data evaluating the energy efficiency or energy efficiency characteristics of microwave ovens incoporating convection systems.

For **commercial clothes washers**, DOE is proposing the following product classes based on the method of access:

---

[a] DOE defines a "conventional range" under EPCA as "a class of kitchen ranges and ovens which is a household cooking appliance consisting of a conventional cooking top and one or more conventional ovens." (10 CFR 430.2)

- Top-loading; and
- Front-loading.

## 5.4 EFFICIENCY LEVELS

### 5.4.1 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 or lower energy efficiency design option with the baseline unit.

The identification of baseline units required establishing the baseline efficiency level. For cooking products, no minimum standards exist, so DOE selected baseline levels from the 1996 TSD. The Energy Policy Act of 2005 (EPACT 2005) (Pub. L. 109-58) established standards for CCWs that became effective October 1, 2007. DOE used these baseline levels to evaluate new standards for water factor (WF) in addition to energy conservation standards. For residential **cooking products** (except for the prescriptive standard for gas products), there are no existing minimum energy conservation standards, as previous analyses failed to determine economic justification for them. The DOE test procedure uses EF to rate the efficiency of cooking products. The EF for these products is the ratio of the annual useful cooking energy output of the residential cooking appliance (*i.e.* the energy conveyed to the item being heated) to its total annual energy consumption. In accordance with the 1996 TSD on residential cooking products, DOE has selected the baseline EFs for the product classes DOE is using in this rulemaking listed in Table 5.4.1.

**Table 5.4.1 1996 TSD Baseline Energy Factors for Cooking Products**

| Product Class | Baseline from 1996 TSD EF |
|---|---|
| Gas Conventional Burner Cooktop | 0.156 |
| Electric Open (Coil) Element Cooktop | 0.737 |
| Electric Smooth Element Cooktop | 0.742 |
| Gas Standard Oven | 0.030 |
| Gas Self-Clean Oven | 0.054 |
| Electric Standard Oven | 0.107 |
| Electric Self-Clean Oven | 0.096 |
| Microwave Oven | 0.557 |

For **microwave oven** standby power, energy conservation standard levels are expressed as a maximum average standby power consumption, in watts (W). Based on product testing (see section 5.6.1.3), DOE selected a baseline standby level which was the highest typical standby power for a microwave oven to provide full consumer utility. 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 a cooking sensor). DOE selected a baseline standby level of 4.0 W for the single microwave oven product class.

For **commercial clothes washers**, energy conservation standard levels are defined by two factors normalized by wash basket volume –MEF and WF. The MEF is the quotient of the cubic foot capacity of the clothes container divided by the total clothes washer energy consumption per cycle. The MEF takes into consideration not only the energy consumption of the washer but also the amount of energy required to dry clothes based on the remaining moisture content (RMC) of the clothes. The WF is the quotient of the total weighted per-cycle water consumption divided by the cubic foot capacity of the clothes washer. These two variables are only directly related to each other via the average hot water usage by a clothes washer as measured by the test procedure. Other measured variables affect only one variable or the other. For example, cold water consumption only affects the WF, while RMC only affects the MEF.

The Energy Policy and Conservation Act (EPCA) of 1975 (42 U.S.C. 6291–6309) establishes the following energy and water conservation standards for all CCWs: a minimum MEF of 1.26 cubic feet ($ft^3$) per kilowatt-hour (kWh) and a maximum WF of 9.5 gallons per $ft^3$. (42 U.S.C. 6313(e); see also 70 FR 60416 (Oct. 18, 2005), adding 10 CFR 431.156) Based on comments and the determination at that time to consider a single product class for CCWs, DOE selected baseline levels for the advance notice of proposed rulemaking (ANOPR), published on November 15, 2007 (November 2007 ANOPR), that were based on current Federal energy conservation standards. Because, as discussed in detail in chapter 3, the determination of two product classes for CCWs was subsequently made, DOE revised the baseline levels presented in the November 2007 ANOPR to characterize top-loading and front-loading CCWs separately. DOE has selected the baseline MEFs and WFs for the two product classes as listed in Table 5.4.2.

**Table 5.4.2 Baseline Modified Energy Factor and Water Factor for Commercial Clothes Washers**

| **Product Class** | **MEF,** ***$ft^3$/kWh*** | **WF,** ***gallons/$ft^3$*** |
|---|---|---|
| Top Loading | 1.26 | 9.5 |
| Front Loading | 1.72 | 8.0 |

### 5.4.2 Incremental Efficiency Levels

For the majority of the product classes presented in section 5.3, DOE analyzed several efficiency levels and obtained incremental cost data at each of these levels. Table 5.4.3 through Table 5.4.10 provide efficiency levels and the reference source of each level for each of the products under consideration. For cooking products, the maximum levels identified Table 5.4.3 through Table 5.4.7 are based on data developed from the design option analysis in the previous rulemaking. For microwave oven standby power and CCWs, the highest efficiency levels were identified based on a review of available product literature for models commercially available.

Table 5.4.3 presents the efficiency levels analyzed for residential **gas cooktops**. The baseline and higher efficiency levels are based on the analysis performed in 1996 for the previous rulemaking. Since the 1996 TSD took a design-option approach to the analysis, each efficiency level is associated with a particular design option or combination of design options. Two higher efficiency levels for gas cooktops were included in the 1996 TSD that are not considered here due to the elimination of design options. In the current analysis, reflective surfaces are screened out due to impacts on consumer utility, and thermostatically controlled burners were not analyzed for the NOPR due to the inability of the DOE test procedure to adequately represent usage patterns and therefore energy efficiency characteristics. The combination of design options that produces the maximum technologically feasible EF is designated as max-tech.

DOE has structured the analysis for standing pilot igntion systems as a design option associated with the baseline configuration because DOE has determined that cooktops incorporating such ignition systems do not provide unique utility for reasons stated in section 5.3. The first standards efficiency level corresponds to the elimination of standing pilot lights.

**Table 5.4.3 Efficiency Levels for Residential Gas Cooktops**

| Level | Efficiency Level Source | Conventional Burners | |
|---|---|---|---|
| | | Cooking Efficiency | EF |
| Baseline | 1996 TSD Baseline (with standing pilots) | 0.399 | 0.156 |
| 1 | 1996 TSD (without standing pilots) | 0.399 | 0.399 |
| 2 | Max-Tech (1996 TSD) | 0.420 | 0.420 |

The 1996 TSD analyzed two efficiency levels for **electric coil cooktops** and three levels for **electric smooth cooktops**. Since the 1996 TSD took a design-option approach to the analysis, each efficiency level is associated with a particular design option or combination of design options. In the current analysis, however, reflective surfaces are screened out as a design option for electric coil cooktops due to impacts on consumer utility, and induction elements are not analyzed for electric smooth cooktops because the available efficiency data, while suggestive of energy savings, cannot be validated by the existing DOE test procedure. In addition, radiant elements for smooth electric cooktops, which were included in the 1996 TSD, were not considered as a design option for this rulemaking because manufacturer data provided to DOE for the 1996 TSD indicated that this technology does not offer an efficiency improvement over the baseline according to the DOE test procedure. Therefore, only a single efficiency level beyond the baseline is being analyzed for both electric coil and smooth cooktops, and by default this level becomes the max-tech, as shown in Table 5.4.4.

**Table 5.4.4 Efficiency Levels for Residential Electric Cooktops**

| Level | Efficiency Level Source | Open (Coil) Elements | | Smooth Elements | |
|---|---|---|---|---|---|
| | | Cooking Efficiency | EF | Cooking Efficiency | EF |
| Baseline | 1996 TSD Baseline | 0.737 | 0.737 | 0.742 | 0.742 |
| 1 | 1996 TSD | 0.769 (Max-Tech) | 0.769 | 0.753 (Max-Tech) | 0.753 |

Efficiency levels for **gas ovens**, as shown in Table 5.4.5, are based on the 1996 TSD. Since the 1996 TSD took a design-option approach to the analysis, each efficiency level is associated with a particular design option or combination of design options. The oven separator design option from the 1996 TSD was screened out in the current analysis due to consumer safety and utility issues, as well as a lack of practicability to design and manufacture. Low-standby-loss electronic controls were added as design options for both standard and self-cleaning gas ovens, but were not included as efficiency levels because DOE does not have efficiency or cost increment information on them.

The baseline efficiency level for gas standard ovens assumes that the product is equipped with standing pilot lights, and the first standards efficiency level corresponds to the elimination of standing pilot lights based on the same reason as for gas cooktops. However, because the cleaning cycle of gas self-cleaning ovens requires electrical energy use, EPCA in effect requires that such ovens currently be equipped with a non-standing pilot ignition system because such an ignition system is disallowed if there is an electrical cord provided on the product. Therefore, the baseline efficiency level for gas self-cleaning ovens assumes they lack a standing pilot light. Further, the first standards efficiency level is not based on elimination of a standing pilot, but rather on the addition of the forced convection design option.

Electronic spark ignition lowers the standby power consumption as well as the cooking efficiency of standard gas ovens, and since the standard gas oven EF rating includes standby power, results in an overall reduction in energy consumption. Electric spark ignition has the same functionality as hot surface ignition sources and is therefore listed as an alternate efficiency level to the hot surface (glo-bar) design option.

**Table 5.4.5 Efficiency Levels for Residential Gas Ovens**

| Level | Efficiency Level Source | Standard Oven | | Self-Cleaning Oven | |
|---|---|---|---|---|---|
| | | Cooking Efficiency | EF | Cooking Efficiency | EF |
| Baseline | 1996 TSD Baseline (with standing pilot light) | 0.059 | 0.0298 | 0.071 | 0.0540 |
| 1 | 1996 TSD | 0.058 (Glo-bar ignition) | 0.0536 | 0.088 | 0.0625 |
| 2 | 1996 TSD | 0.061 | 0.0566 | 0.088 | 0.0627 |
| 3 | 1996 TSD | 0.062 | 0.0572 | 0.089 (Max-Tech) | 0.0632 |
| 4 | 1996 TSD | 0.065 | 0.0593 | - | - |
| 5 | 1996 TSD | 0.065 | 0.0596 | - | - |
| 6 | 1996 TSD/Current Analysis | 0.066 (Max-Tech) | 0.0600 | - | - |
| 1a(1) | 1996 TSD (with electronic spark ignition) | 0.058 | 0.0583 | - | - |

**(1) Note: Standard levels 1 and 1a correspond to designs that are utilized for the same purpose--eliminate the need for a standing pilot--but the technologies for each design are different. Standard level 1 is a hot surface ignition device while standard level 1a is a spark ignition device**

Efficiency levels for **electric ovens**, shown in Table 5.4.6, are primarily based on the 1996 TSD. The oven separator design option from the 1996 TSD was screened out in the current analysis due to consumer safety and utility issues, as well as a lack of practicability to design and manufacture. The bi-radiant oven was screened out due to a lack of technological feasibility and practicability to manufacture, as well as impacts on consumer utility. Low-standby-loss electronic controls were added as design options for both standard and self-cleaning electric ovens in this analysis, but were not included as efficiency levels because, even though the test procedure accounts for the energy consumption of electronic controls, DOE does not have incremental efficiency or cost information on them.

**Table 5.4.6 Efficiency Levels for Residential Electric Ovens**

| Level | Efficiency Level Source | Standard Oven | | Self-Cleaning Oven | |
|---|---|---|---|---|---|
| | | Cooking Efficiency | EF | Cooking Efficiency | EF |
| Baseline | 1996 TSD Baseline | 0.122 | 0.1066 | 0.138 | 0.1099 |
| 1 | 1996 TSD/Current Analysis | 0.128 | 0.1113 | 0.138 | 0.1102 |
| 2 | 1996 TSD/Current Analysis | 0.134 | 0.1163 | 0.142 (Max-Tech) | 0.1123 |
| 3 | 1996 TSD/Current Analysis | 0.137 | 0.1181 | - | - |
| 4 | 1996 TSD/Current Analysis | 0.140 | 0.1206 | - | - |
| 5 | 1996 TSD/Current Analysis | 0.141 (Max-Tech) | 0.1209 | - | - |

For **microwave oven** energy factor, Table 5.4.7 lists the efficiency levels that were retained from the 1996 TSD, even though recent AHAM-supplied data suggests slightly different baseline and maximum-available efficiencies of a representative sample of current models. For example, the minimum efficiency among the microwave ovens recently tested by AHAM was 54.8 percent, while the maximum efficiency was 61.8 percent, compared to 55.7 percent and 60.2 percent, respectively, from the 1996 TSD. However, it was noted that the standard deviation in efficiency measurements for any given microwave oven ranged from 0.2 to 1.2 absolute percentage points. To attempt to identify microwave oven design options associated with efficiency levels, DOE performed a reverse-engineering analysis on a representative sample of microwave ovens. DOE did not find any additional design options beyond those that were identified in the ANOPR. DOE also performed efficiency testing on the sample of microwave ovens, which validated data submitted by AHAM. Results from both AHAM and DOE efficiency testing showed no identifiable correlation between cooking efficiency and either cavity volume or rated output power. As part of the reverse-engineering analysis, DOE also evaluated microwave oven magnetrons, magnetron power supplies, and fan motors (identified as design options in chapter 3 of this TSD), and determined that efficiencies for these design options have changed little since the 1996 analysis. For these reasons, it was determined by DOE that the efficiency levels from the 1996 TSD were still representative of the state of current microwave oven technology to the extent that the DOE test procedure can capture performance. Further discussion of the AHAM test data and DOE testing and analysis is provided in section 5.6.1.1.

**Table 5.4.7 Efficiency Levels for Residential Microwave Ovens**

| Level | Efficiency Level Source | Efficiency Level (EF) |
|---|---|---|
| Baseline | 1996 TSD Baseline | 0.557 |
| 1 | 1996 TSD | 0.586 |
| 2 | 1996 TSD | 0.588 |
| 3 | 1996 TSD | 0.597 |
| 4 | 1996 TSD Max-Tech | 0.602 |

DOE conducted the engineering analysis for microwave oven standby power for the single product class DOE identified for microwave ovens. To analyze the cost-efficiency relationship for microwave oven standby power, DOE defined standby power levels expressed as a maximum average standby power, in W. These 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. DOE also added a standby power level as a gap-fill between the FEMP Procurement Efficiency Recommendation and IEA One-Watt Program levels. Table 5.4.8 provides the microwave oven standby levels and the reference source for each level that DOE has analyzed.

**Table 5.4.8 Standby Power Levels for Microwave Ovens**

| Standby Level | Standby 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 |

EPCA mandates that DOE determine both a minimum MEF and a maximum WF for CCWs. The two variables are related to a limited extent, but it was not clear initially to DOE which factor is more important in setting the energy conservation standards. DOE determined, based on comments from stakeholders, that a high MEF and low WF are not necessarily correlated, and, thus, a max-tech level based on the highest MEF and lowest WF is not realistic. That is, a CCW with the highest possible MEF may not achieve the lowest possible WF. Similarly, a CCW with the lowest WF may not achieve the highest MEF. Therefore, DOE selected CCWs currently available on the market that exhibit a balance of high MEF and low WF to represent the max-tech levels.

For top-loading CCWs, DOE analyzed 3 efficiency levels beyond the baseline, as listed in Table 5.4.9**.** These levels were based on the CEE Commercial Clothes Washer Initiative, and maximum levels that are currently commercially available. Based on market surveys of currently available models, DOE selected a max-tech level of (1.76 MEF/8.3 WF) for top-loading CCWs. For front-loading CCWs, DOE analyzed 4 efficiency levels beyond the baseline for CCWs, as listed in Table 5.4.10. These levels were based on ENERGY STAR, the CEE Commercial Clothes Washer Initiative, and maximum levels that are currently commercially available. Two gap-fill levels were added based on stakeholder input between the CEE Tier 3A and the maximum available level. For front-loading CCWs, DOE has determined a max-tech level for front-loading CCWs of (2.35 MEF/4.4 WF), based on a currently available CCW. These units were selected after an extensive market survey, and DOE's research suggests that their combination of high MEF and low WF represent the best-in-class balance between MEF and WF for the two product classes of CCWs. AHAM provided incremental cost data only at 2 of these levels (1.42 MEF/9.5 WF and 2.00 MEF/5.5 WF).

**Table 5.4.9 Efficiency Levels for Top-Loading Commercial Clothes Washers**

| Level | Efficiency Level Source | Efficiency Level | |
|---|---|---|---|
| | | MEF, $ft^3/kWh$ | WF, $gallons/ft^3$ |
| baseline | DOE Standard (effective 2007) | 1.26 | 9.5 |
| 1 | CEE Tier 1 (January 1, 2004) | 1.42 | 9.5 |
| 2 | CEE Tier 2 (January 1, 2004) | 1.60 | 8.5 |
| 3 | ENERGY STAR (effective 2007)Max-Tech | 1.762 | 8.30 |

**Table 5.4.10 Efficiency Levels for Front-Loading Commercial Clothes Washers**

| Level | Efficiency Level Source | Efficiency Level | |
|---|---|---|---|
| | | MEF, $ft^3/kWh$ | WF, $gallons/ft^3$ |
| baseline | ENERGY STAR (effective 2007) | 1.72 | 8.0 |
| 1 | CEE Tier 3A (January 1, 2004) | 1.80 | 7.5 |
| 2 | Gap Fill 1 | 2.00 | 5.5 |
| 3 | Gap Fill 2 | 2.20 | 5.1 |
| 4 | Max-Tech | 2.35 | 4.4 |

## 5.5 METHODOLOGY OVERVIEW

DOE used data submitted by AHAM as the primary source of cost information for the engineering analysis. AHAM provided DOE with aggregated incremental manufacturing cost data from it member companies. DOE conducted an independent review of the AHAM data using several methods and data sources. To gain a better understanding of the data submitted by member companies and to be able to relate the costs of improving efficiency to discrete (or system) technologies, DOE conducted interviews with manufacturers of residential cooking products and CCWs. For cooking products, DOE reviewed the previous TSDs and compared cost and performance information to the AHAM data and other published data. For microwave ovens, DOE performed detailed product teardowns on a sample of product models spanning a range of efficiencies, product features, and standby power to generate similar cost-efficiency curves for validation of the AHAM data. Finally, DOE conducted detailed efficiency and standby power testing of microwave ovens to gain insight into the adequacy of the existing DOE test procedure, potential test procedure updates to incorporate the measurement of standby power, and the development and validation of cost-efficiency curves based on energy factor and standby power. Table 5.5.1 below shows which methods DOE used for each product.

**Table 5.5.1 Engineering Analysis Methods**

| Method | Products | |
|---|---|---|
| | **Cooking Products** | **Commercial Clothes Washers** |
| AHAM Data | √ | √ |
| Review of Past TSD | √ | √ |
| Product Teardown | √[1] | √[2] |
| Product Testing | √[1] | |
| Manufacturer Interviews | √ | √ |

[1]Microwave ovens only
[2] Limited reverse-engineering

### 5.5.1 AHAM Data Request

In support of this rulemaking effort, DOE requested incremental cost data from AHAM for each of the product categories. The data represent the average incremental production cost to improve a baseline unit to a specified efficiency level. This methodology constitutes an efficiency-level approach to the engineering analysis because DOE examined aggregated incremental increases in manufacturer selling price at specified levels of energy efficiency. In addition, DOE requested shipments, shipment-weighted average efficiency, and market share efficiency data. Tables of aggregated data provided to DOE by AHAM are contained in appendix 5A.

### 5.5.2 Manufacturer Interviews

AHAM provided to DOE shipment-weighted manufacturer costs. These costs included the shipment-weighted average cost as well as the lowest and highest single-manufacturer cost to achieve efficiency levels above the baseline level. Presenting the data in this manner enables stakeholders to appreciate the variability in baseline units, design strategies, and cost structures that exist among manufacturers. To better understand and explain the causes of these cost variances, DOE supplemented these cost data with information obtained through follow-up manufacturer interviews. These confidential interviews provided a deeper understanding of the various combinations of technologies used to increase product efficiency, 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 13B.

During the interviews, DOE also gathered information about the capital expenditures required to increase the efficiency of the baseline units to various efficiency levels (*i.e.*, conversion capital expenditures by efficiency or energy-use 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.

### 5.5.3 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 only performed physical teardown analysis on microwave ovens. The teardown methodology is described in detail in section 5.5.3.1 through section 5.5.3.3.

#### 5.5.3.1 Selection of Units

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

- What efficiency and/or standby power levels should be captured in the teardown analysis?
- Are there units on the market that capture all potential efficiency and/or 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 efficiency and/or 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-efficiency and/or 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 efficiency level and/or standby power level.

#### 5.5.3.2 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.[2] 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 2002–2006, these price increases are normalized, which better represents long-term material prices.

#### 5.5.3.3 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 5.5.1 shows the three major steps in generating the manufacturing cost.

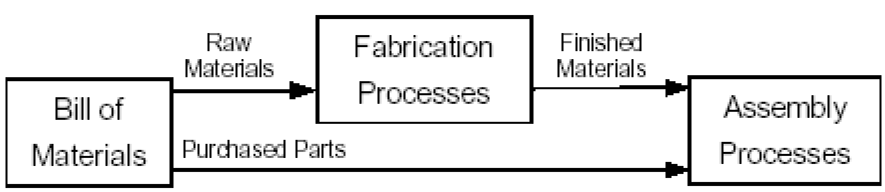


**Figure 5.5.1 Manufacturing Cost Assessment Stages**

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 5.5.2.

**Table 5.5.2 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.

### 5.5.4 Review of Previous Technical Support Documents

DOE reviewed previous rulemaking TSDs to assess their applicability to the current standard setting process for cooking products and CCWs. These previous rulemaking technical support documents served as a source for design options, baseline efficiency levels, and energy consumption analysis, in addition to other sources. DOE utilized the 1996 cooking products TSD as a source for baseline unit efficiency as well as design options and incremental cost and efficiency data. This approach for cooking products was endorsed by stakeholders. DOE also reviewed the 2000 residential clothes washer TSD since residential and CCWs share the same design options, are frequently built on the same chassis, and are therefore subject to similar economic impacts.

### 5.5.5 Product Testing

DOE conducted product testing on microwave ovens to develop a better understanding of the potential efficiency and standby power improvements associated with various design options.

## 5.6 ANALYSIS AND RESULTS

### 5.6.1 Cooking Products

#### 5.6.1.1 AHAM Data

***Conventional Cooking Products***

AHAM did not provide DOE with cost-efficiency data for conventional cooking products (*i.e.*, cooking products other than microwave ovens), in part because it stated that its members indicated that there have been no technology breakthroughs since the last rulemaking and that its members were not able to adequately assess many of the design options. In concurrence with stakeholders, DOE believes that the efficiency characteristics of gas and electric cooktops and ovens from the 1996 TSD are still valid. Therefore, the efficiency data provided in the 1996 TSD are also presumed to still be valid. Furthermore, DOE believes that the cost of the design options investigated in the 1996 TSD are also valid once adjusted to reflect changes in the producer price index (PPI). The data from the 1996 TSD are detailed in section 5.6.1.2.

***Microwave Ovens***

In contrast to conventional cooking products, microwave ovens were presumed to have incorporated improved technology since 1996. Therefore, AHAM provided data on microwave oven efficiency and microwave standby power for a sample of microwave ovens currently available in the U.S. market.[3] Microwave oven efficiency was tested according to DOE's test procedure, which utilizes the International Electrotechnical Commission (IEC) Standard 705-1988 and Amendment 2-1993, *Methods for measuring the performance of microwave ovens for household and similar purposes*. Standby power was tested in accordance with IEC Standard 62301-2005, *Household electrical appliances – Measurement of standby power*.

The microwave oven test procedure specified in IEC Standard 705-1998 and Amendment 2-1993 calls for heating a glass container containing one liter of water at full power until the water temperature is raised by a specified amount. The starting temperature of the water $T_1$ in degrees Celsius (°C) is given as:

$T_1 = T_0 - (10 \pm 1\ °C)$ where,

$T_0$ = the ambient temperature, specified as $20 \pm 2\ °C$

The water is heated by the operation of the microwave oven until the final water temperature $T_2$ in °C is:

$T_2 = T_0 \pm 1\ °C$

The microwave power output P in W is then calculated from:

$P = (4.187\ m_w (T_2 - T_1) + 0.88\ m_c (T_2 - T_0))/t$ where,

$m_w$ = the mass of the water in grams (g)
$m_c$ = the mass of the container in g
$t$ = the heating time in seconds (s)

The time to heat the water load, power input $P_{IN}$ in W, and the total energy consumption $E_M$ in watt-hours (Wh) of the microwave oven during the test period are also recorded. This test is repeated three times, unless the power output value resulting from the second test is within 1.5 percent of the value obtained from the first test. The two or three values of P are averaged for further calculations.

Cooking efficiency $Eff_{MO}$ is then obtained using:

$$Eff_{MO} = P/P_{IN}$$

For the remainder of the calculations, the test procedure specified in 10 CFR 430 subpart B appendix I is utilized. Note that in the following calculations, all temperatures are expressed in degrees Fahrenheit. The microwave oven test energy output $E_T$ in Wh (kilo-joules (kJ))[b] is calculated as:

$$E_T = C_P M_W (T_2 - T_1) + C_C M_C (T_2 - T_0))/K_e \text{ where,}$$

$M_W$ = the measured mass of the test water load in pounds (lb), (g)
$M_C$ = the measured mass of the test container before filling with test water load in lb (g)
$T_1$ = the initial test water load temperature in °F (°C)
$T_2$ = the final test water load temperature in °F (°C)
$T_0$ = the measured ambient room temperature in °F (°C)
$C_C$ = 0.210 British thermal units (BTU)/lb-°F (0.88 kJ/kilogram (kg)-°C), specific heat of the test container
$C_P$ = 1.0 BTU/lb-°F (4.187 kJ/kg-°C), specific heat of water
$K_e$ = 3,412 BTU/kWh (3,600 kJ/kWh), conversion factor of kWh to BTU.

The two or three values for test energy output are averaged and the microwave oven annual energy consumption $E_{MO}$ is calculated in kWh per year from:

$$E_{MO} = (E_M \times O_M)/E_T \text{ where,}$$

$E_M$ = the test energy consumption in Wh (kJ)

[b] Note that in order to correctly utilize the equation as specified in the test procedure to produce either watt-hours for standard units or kJ for metric units, additional factors must be applied. For standard units, $E_T$ must be multiplied by 1000. For metric units, $E_T$ must be divided by 3600.

$O_M$ = 79.8 kWh (287,280 kJ) per year, the microwave oven annual useful cooking-energy output

Finally, the microwave oven energy factor $R_{MO}$ (equivalent to EF) is calculated from:

$R_{MO} = O_M/E_{MO}$

EF is the metric for microwave ovens on which the DOE efficiency standard is based, while AHAM provided test data in terms of cooking efficiency in their data submittal for this rulemaking. From the above equations, it can be observed that there are several contributing factors that can lead to significant test-to-test variations in measured EF and efficiency. First, the tolerances on the temperature specifications are substantial relative to the absolute values. The range of allowable temperatures for ambient, starting, and final temperatures can lead to acceptable test load temperature rises ranging from 4–16 °C. Since the heating time is on the order of only a few tens of seconds, power and energy output calculations are difficult to measure consistently test-to-test. In addition, the efficiency calculation assumes that input power is constant for the duration of the test, which may not be the case. These factors make the existing test procedure difficult to conduct with accuracy and repeatability.

In the recent testing for this analysis, although AHAM only tested 21 units from 9 manufacturers, the units were selected to represent a broad spectrum of models available in the marketplace with varying capacities and features. Figure 5.6.1 through Figure 5.6.3 display the AHAM microwave oven efficiency and standby power data.

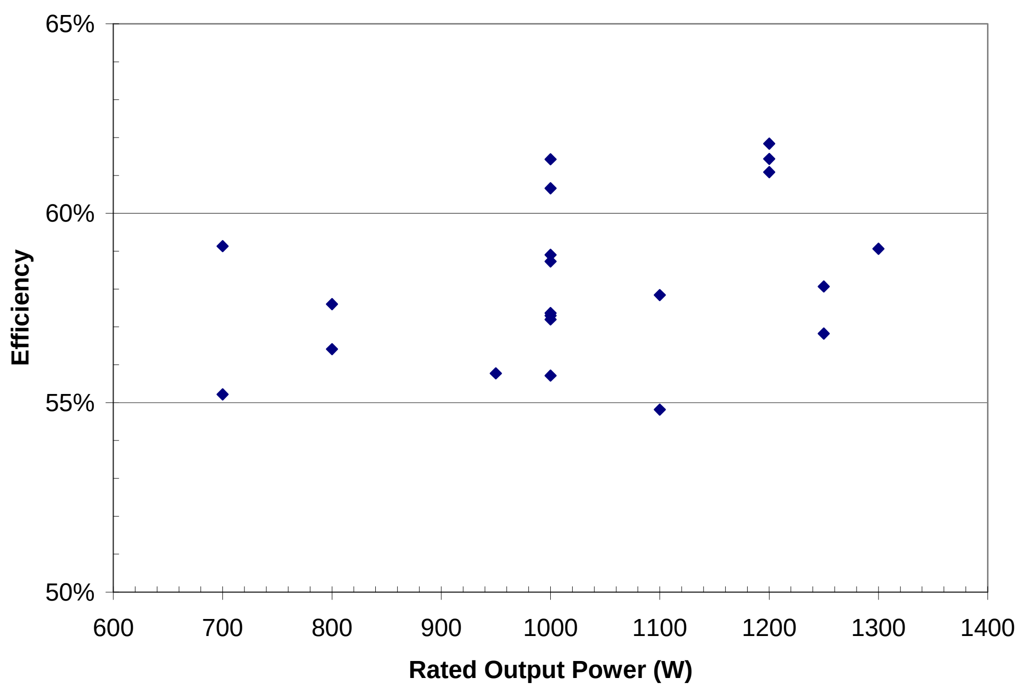


**Figure 5.6.1 AHAM Microwave Oven Efficiency versus Rated Output Power[4]**

Figure 5.6.1 illustrates a small variation in efficiency across all rated output powers, approximately ±3.5 absolute percentage points from the average efficiency. There is a lack of a correlation between microwave oven rated output power and microwave oven efficiency. Figure 5.6.2 illustrates the relationship between microwave oven efficiency and microwave oven volume. Similarly, there is no correlation between microwave oven efficiency and volume. Figure 5.6.1 and Figure 5.6.2 confirm DOE's approach of creating a single product class for microwave ovens irrespective of rated output power or cavity volume, and demonstrate that there is no basis to specify an efficiency standard that is a function of either rated output power or cavity volume.

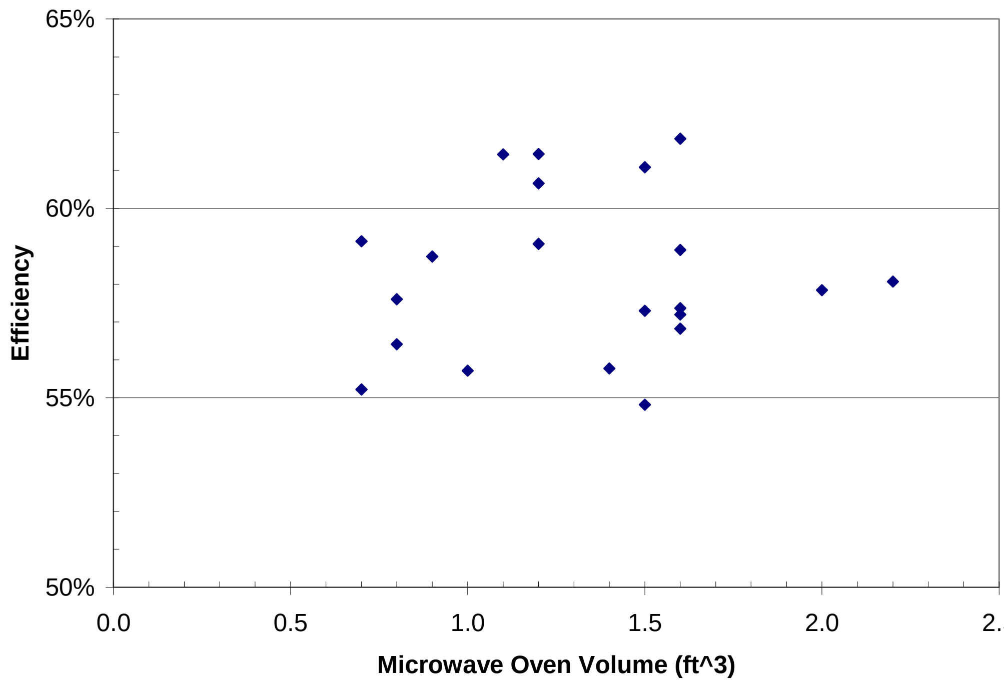


**Figure 5.6.2 AHAM Microwave Oven Efficiency versus Oven Cavity Volume[5]**

Figure 5.6.3 displays AHAM-measured microwave oven standby power data as a function of rated output power. Unlike efficiency, these data show a wide range of standby power, but there is no correlation between standby power and 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.

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) light emitting diode (LED) displays, (2) vacuum fluorescent displays (VFDs), and (3) liquid crystal displays (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.[6] Standby power consumption may also be affected by the electronic controls required for features such as cooking sensors, along with associated power supplies.

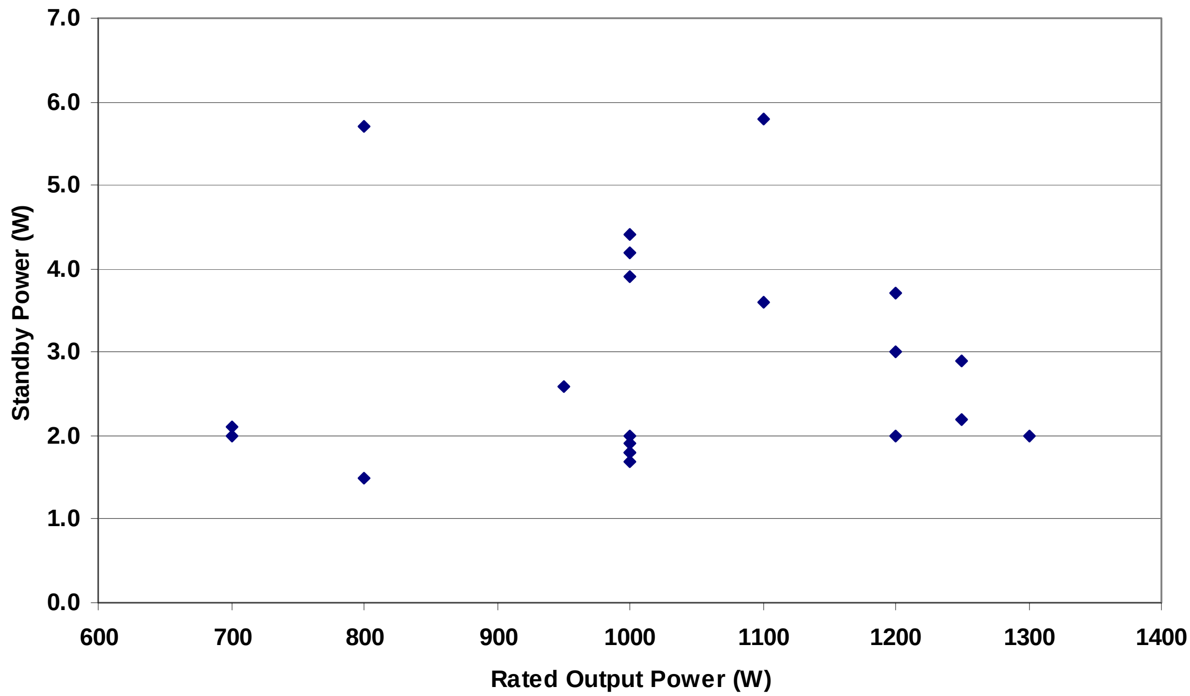


**Figure 5.6.3 AHAM Microwave Oven Standby Power[7]**

Table 5.6.1 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 5.6.1 Microwave Oven Standby Power Comparison**

| Source | Microwave Oven Standby Power | | | | |
|---|---|---|---|---|---|
| | Min *(W)* | Average *(W)* | Max *(W)* | Std Dev *(W)* | # Samples |
| AHAM 2006[8] | 1.5 | 2.9 | 5.8 | 0.8 | 21 |
| CBEEDAC 2006[9] | 0.4 | 1.9 | 3.3 | 0.8 | 19 |
| CREEDAC 2001 (New Stock)[10] | 0.8 | 3.8 | 12.6 | - | 4 |
| CREEDAC 2001 (Existing Stock)[11] | 0.0 | 2.1 | 7.3 | - | 64 |
| LBNL 1999[12] | 0.0 | 2.9 | 6.0 | - | 42 |
| Florida Solar Energy Center 1998[13] | - | 3.0 | - | - | 25 |
| LBNL 1997[14] | - | 3.1 | - | - | - |

Although the DOE test procedure currently does not measure standby power, it is recognized 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 kWh in annual energy consumption. The microwave oven test procedure assumes an annual useful cooking energy output ($O_M$) of 79.8 kWh. For a baseline microwave oven that operates at 55.7 percent efficiency ($E_T/E_M$), annual energy consumption ($E_{MO}$) not including standby power would be:

$$E_{MO} = O_M/(E_T/E_M) = 143.3 \text{ kWh}$$

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. Since the annual energy consumption of a more efficient unit will be lower, the standby power will have an even greater relative contribution for high efficiency microwave ovens.

#### 5.6.1.2 Review of Past TSDs

After consulting with AHAM and various stakeholders and suppliers, DOE determined that the design options for cooking products other than microwaves have not changed significantly since the 1996 TSD analysis. Also, no industry-aggregated manufacturing cost data were supplied to DOE in the ANOPR phase of this rulemaking. Therefore, DOE decided to update the 1996 TSD analysis using the PPI to scale incremental manufacturing cost data for gas and electric cooktops, and gas and electric standard and self-cleaning ovens. For gas cooktops and ovens, the PPI for gas household cooking equipment was utilized. Similarly, the PPI for electric household cooking equipment was used for electric cooktops and ovens.

Comparison of current microwave oven efficiency data with analogous data from the 1996 TSD shows that the range of efficiency levels based on EF analyzed in the 1996 TSD are still valid, although AHAM indicated in comments provided along with its data submittal for this rulemaking that certain design options used to achieve those levels have already been optimized.[15] But as noted in section 5.4.2, the range of efficiency levels from the 1996 TSD is still representative of the performance of current microwave oven models. Therefore, for the purposes of this analysis, the same efficiency levels are used. As with the conventional cooking products, the incremental manufacturing cost data from the 1996 TSD was scaled by the PPI for electric household cooking equipment, which includes microwave ovens, to obtain the cost-efficiency relationship. Microwave oven standby power was not analyzed in the 1996 TSD.

***Cooktop Test Procedure***

DOE's cooktop test procedure is based on measuring the amount of energy required to raise an aluminum block test load from room temperature to a specified temperature above room temperature at full input heating rate, then operating the burner or element a fixed time longer at a reduced input heating rate. The size of the test block depends on the burner or element size, and the test is repeated for each burner or element. Annual energy consumption is calculated from the average cooking efficiency of the burners or elements. Cooktops are rated using EF, which is the ratio of the annual useful cooking-energy output of the cooktop to its total annual energy consumption. The annual energy consumption includes the energy input during the time the load is being heated, plus the energy consumed by any standing pilot during standby hours for a gas cooktop. Therefore, design options that raise the cooking efficiency of a gas or electric cooktop and/or reduce the energy consumption of a pilot on a gas cooktop can decrease the total annual energy consumption and therefore improve EF.

***Gas Cooktops***

Table 5.6.2 describes the design options and design option combinations that result in increased EF of gas cooktops. The design options and efficiency levels analyzed are those presented in the 1996 engineering analysis, with several design options (reflective surfaces and thermostatically controlled burners) eliminated in this analysis as described in section 5.4.2.

**Table 5.6.2 Gas Cooktop Manufacturing Cost and Efficiency Increments**

| **Level** | **Efficiency Level Description** | **Cooking Efficiency** | **EF** | **Delta Manufacturer Cost from Baseline *(2006$)*** |
|---|---|---|---|---|
| Baseline | Baseline | 39.9% | 0.156 | - |
| 1 | Baseline + Electronic Ignition | 39.9% | 0.399 | $12.06 |
| 2 | 1 + Sealed Burners | 41.8% | 0.420 | $32.06 |

Notes:
Baseline: Cooktop cooking efficiency = 39.9%, four conventional 9,000 BTU/hr burners, two 117 BTU/hr standing pilot lights
(1) Electronic Ignition: Standing pilot lights eliminated, cooking efficiency increase = 0.0%
(2) Sealed Burners: Cooking efficiency increase = 4.8% (relative percent)

***Electric Coil Cooktops***

Table 5.6.3 describes the design option that results in increased cooking efficiency of electric open (coil) cooktops. The design option and efficiency levels analyzed are those presented in the 1996 engineering analysis, with one design option (reflective surfaces) eliminated in this analysis as described in section 5.4.2.

**Table 5.6.3 Electric Coil Cooktop Manufacturing Cost and Efficiency Increments**

| Level | Efficiency Level Description | Cooking Efficiency | EF | Delta Manufacturer Cost from Baseline *(2006$)* |
|---|---|---|---|---|
| Baseline | Baseline | 73.7% | 0.737 | - |
| 1 | Baseline + Improved Contact Conductance | 76.9% | 0.769 | $2.28 |

Notes:
Baseline: Cooktop cooking efficiency = 73.7%, two 6-inch 1,250 W and two 8-inch 2,100 W elements
(1) Improved Contact Conductance: Cooking efficiency increase = 4.3% (relative percent)

***Electric Smooth Cooktops***

Table 5.6.4 describes the design options that result in increased cooking efficiency of electric smooth cooktops. The design options and efficiency levels analyzed are those presented in the 1996 engineering analysis, with one design option (induction element) eliminated in this analysis as described in section 5.4.2. Another design option (radiant element) discussed in the 1996 engineering analysis was not included in this analysis because it exhibited a lower efficiency than the baseline cooktop.

**Table 5.6.4 Electric Smooth Cooktop Manufacturing Cost and Efficiency Increments**

| Level | Efficiency Level Description | Cooking Efficiency | EF | Delta Manufacturer Cost from Baseline *(2006$)* |
|---|---|---|---|---|
| Baseline | Baseline | 74.2% | 0.742 | - |
| 1 | Baseline + Halogen Lamp Element | 75.3% | 0.753 | $89.09 |

Notes:
Baseline: Cooktop cooking efficiency = 74.2%, two 6-inch 1,500 W and two 8-inch 2,000 W solid disk elements
(1) Halogen Element: Cooking efficiency increase = 1.5% (relative percent), two small 1,200 W and two large 1,800 W circular lamps

***Conventional Oven Test Procedure***

DOE's oven test procedure is based on measuring the amount of energy required to raise an aluminum block test load from room temperature to a specified temperature above room temperature. Ovens are rated using EF, which is the ratio of the annual useful cooking-energy output of the oven (energy conveyed to the item being heated) to its total annual energy consumption. The annual energy consumption includes the energy input during the time the load is being heated plus the energy consumed by other features such as a clock, standing pilot, electronic ignition system, and/or self-cleaning cycles. Therefore, design options that raise the cooking efficiency of the oven and/or reduce the energy consumption of features not related to heating food can decrease the total annual energy consumption and therefore improve EF.

***Gas Ovens***

Table 5.6.5 describes the design options and design option combinations that result in increased EF of gas standard ovens. The design options and efficiency levels analyzed are those presented in the 1996 engineering analysis, with one design option (oven separator) eliminated in this analysis as described in section 5.4.2.

**Table 5.6.5 Gas Standard Oven Manufacturing Cost and Efficiency Increments**

| **Level** | **Efficiency Level Description** | **Cooking Efficiency** | **EF** | **Delta Manufacturer Cost from Baseline *(2006$)*** |
|---|---|---|---|---|
| Baseline | Baseline | 5.9% | 0.0298 | - |
| 1 | Baseline + Electric Glo-bar Ignition | 5.8% | 0.0536 | $12.06 |
| 2 | 1 + Improved Insulation | 6.1% | 0.0566 | $15.64 |
| 3 | 2 + Improved Door Seals | 6.2% | 0.0572 | $16.72 |
| 4 | 3 + Forced Convection | 6.5% | 0.0593 | $38.86 |
| 5 | 4 + Reduced Vent Rate | 6.5% | 0.0596 | $40.48 |
| 6 | 5+ Reduced Conduction Losses | 6.6% | 0.0600 | $44.11 |
| 1a | Baseline + Electronic Spark Ignition | 5.8% | 0.0583 | $15.00 |

Notes:
Baseline: Cooking efficiency = 5.92%, 2 inches of 1.09 lb/cubic foot insulation, standing pilot light ignition = 175 BTU/hr
(1) Baseline + Electric Glo-Bar Ignition: Cooking efficiency decrease = 0.152 (absolute percentage points), added electricity consumption = 176 Wh
(2) 1 + Improved Insulation: Cooking efficiency increase = 4.9% (relative percent)
(3) 2 + Improved Door Seals: Cooking efficiency increase = 1.0% (relative percent)
(4) 3 + Forced Convection: Cooking efficiency increase = 4.8% (relative percent), added electricity consumption = 15 Wh
(5) 4 + Reduced Vent Rate: Cooking efficiency increase = 0.5% (relative percent)
(6) 5 + Reduced Conduction Losses: Cooking efficiency increase = 0.05 (absolute percentage points)
(1a) Baseline + Electronic Spark Ignition: Cooking efficiency decrease = 0.09 (absolute percentage points), added electricity consumption = 0.0 Wh. Standard levels 1 and 1a correspond to designs that are utilized for the same purpose--eliminate the need for a standing pilot--but the technologies for each design are different. Standard level 1 is a hot surface ignition device while standard level 1a is a spark ignition device

Table 5.6.6 describes the design options and design option combinations that result in increased EF of gas self-cleaning ovens. The design options and efficiency levels analyzed are those presented in the 1996 engineering analysis, with one design option (oven separator) eliminated in this analysis as described in section 5.4.2.

**Table 5.6.6 Gas Self-Cleaning Oven Manufacturing Cost and Efficiency Increments**

| Level | Efficiency Level Description | Cooking Efficiency | EF | Delta Manufacturer Cost from Baseline *(2006$)* |
|---|---|---|---|---|
| Baseline | Baseline | 7.1% | 0.0540 | - |
| 1 | Baseline + Forced Convection | 8.8% | 0.0625 | $11.01 |
| 2 | 1 + Reduced Conduction Losses | 8.8% | 0.0627 | $15.38 |
| 3 | 2 + Improved Door Seals | 8.9% | 0.0632 | $16.60 |

Notes:
Baseline: Cooking efficiency = 7.13%, clock power = 3.6 W, 2 inches of 1.90lb/cubic foot insulation, electronic ignition = 176 Wh, self-cleaning energy consumption = 43,158 BTU
(1) Baseline + Forced Convection: Cooking efficiency increase = 23% (relative percent), added electricity consumption (during cooking and cleaning cycles) = 15 Wh
(2) 1 + Reduced Conduction Losses: Cooking efficiency increase = 0.05 (absolute percentage points)
(3) 2 + Improved Door Seals: Cooking efficiency increase = 1.0% (relative percent)

***Electric Ovens***

Table 5.6.7 describes the design options and design option combinations that result in increased EF of electric standard ovens. The design options and efficiency levels analyzed are those presented in the 1996 engineering analysis, with several design options (bi-radiant oven and oven separator) eliminated in this analysis as described in section 5.4.2.

**Table 5.6.7 Electric Standard Oven Manufacturing Cost and Efficiency Increments**

| Level | Efficiency Level Description | Cooking Efficiency | EF | Delta Manufacturer Cost from Baseline, *(2006$)* |
|---|---|---|---|---|
| Baseline | Baseline | 12.2% | 0.1066 | - |
| 1 | Baseline + Reduced Vent Rate | 12.8% | 0.1113 | $1.63 |
| 2 | 1 + Improved Insulation | 13.4% | 0.1163 | $4.84 |
| 3 | 2 + Improved Door Seals | 13.7% | 0.1181 | $8.53 |
| 4 | 3 + Forced Convection | 14.0% | 0.1206 | $48.14 |
| 5 | 4 + Reduced Conduction Losses | 14.1% | 0.1209 | $51.69 |

Notes:
Baseline: Cooking efficiency = 12.15%, clock power = 3.9 W, 2 inches of 1.09 lb/cubic foot insulation
(1) Baseline + Reduced Vent Rate: Cooking efficiency increase = 0.62% (absolute percentage points)
(2) 1 + Improved Insulation: Cooking efficiency increase = 0.52% (relative percent)
(3) 2 + Improved Door Seals: Cooking efficiency increase = 0.24 (absolute percentage points)
(4) 3 + Forced Convection: Cooking efficiency increase = 0.33 (absolute percentage points), added electricity consumption = 15 Wh
(5) 4 + Reduced Conduction Losses: Cooking efficiency increase = 0.05 (absolute percentage points)

Table 5.6.8 describes the design options and design option combinations that result in increased EF of electric self-cleaning ovens. The design options and efficiency levels analyzed are those presented in the 1996 engineering analysis, with several design options (bi-radiant oven and oven separator) eliminated in this analysis as described in section 5.4.2.

**Table 5.6.8 Electric Self-Cleaning Oven Manufacturing Cost and Efficiency Increments**

| **Level** | **Efficiency Level Description** | **Cooking Efficiency** | **EF** | **Delta Manufacturer Cost from Baseline, *(2006$)*** |
|---|---|---|---|---|
| Baseline | Baseline | 13.8% | 0.1099 | - |
| 1 | Baseline + Reduced Conduction Losses | 13.8% | 0.1102 | $4.37 |
| 2 | 1 + Forced Convection | 14.2% | 0.1123 | $43.98 |

Notes:
Baseline: Cooking efficiency = 13.79%, clock power = 3.8 W, 2 inches of 1.09 lb/cubic foot insulation, self-cleaning energy consumption = 5,286 Wh
(1) Baseline + Reduced Conduction Losses: Cooking efficiency increase = 0.05 (absolute percentage points)
(2) 1 + Forced Convection: Cooking efficiency increase = 0.33 (absolute percentage points), added electricity consumption = 15 Wh

***Conventional Oven Energy Use versus Volume***

The oven cost-efficiency relationships detailed above are predicated upon baseline ovens with a cavity volume of 3.9 $ft^3$. It is well documented, however, that efficiency scales with oven cavity volume. This variation between efficiency, and thus EF, and oven volume results from the fact that larger ovens have higher thermal masses and larger vent rates than smaller ovens. Since the test procedure for establishing EF is a transient test with a fixed test load, the increased energy consumption due to the increased mass of larger units yields a lower EF. The 1980 DOE engineering analysis for residential appliances[16] established a relationship between oven volume and EF from data compiled by the National Bureau of Standards (which was renamed to the National Institute of Standards and Technology (NIST)). Using these data, linear equations were derived for both electric and gas ovens. No distinction was found to exist between standard and self-cleaning ovens for either gas or electric ovens. Intercepts for a particular baseline model or oven design were chosen so that the equations pass through the desired EF corresponding to a particular volume. Values from the 1996 TSD for the slopes and intercepts for gas and electric ovens are listed in Table 5.6.9. The 1996 TSD did not analyze data at every efficiency level, and higher efficiency levels are not included in because certain design options have been eliminated in the current analysis. DOE believes the slopes and intercepts of these equations from the 1996 TSD to still be valid.

**Table 5.6.9 Slopes and Intercepts for Oven Energy Factor versus Cavity Volume Relationship**

| Energy Efficiency Level | Electric | | Gas | |
|---|---|---|---|---|
| | Slope = -0.0157 | | Slope = -0.0073 | |
| | Standard | Self-Clean | Standard | Self-Clean |
| Baseline | - | 0.1632 | 0.0865 | 0.0865 |
| 1 | 0.1752 | - | 0.0895 | - |
| 2 | 0.1802 | - | - | - |
| 3 | 0.1822 | - | 0.0935 | - |

Note: EF = (Slope x Volume) + Intercept where Volume is expressed in cubic feet.

***Conventional Oven Standby Power***

In the ANOPR, DOE stated it would consider additional design options that would result in a lowering of the energy consumption of non-cooking features (*e.g.* standby power) for conventional ovens during the NOPR phase. However, no data were received on standby power for any of these products, so no additional analysis was performed.

***Microwave Ovens***

Table 5.6.10 describes the design options and design option combinations that result in increased EF of microwave ovens. The design options and efficiency levels analyzed are those presented in the 1996 engineering analysis, with incremental manufacturing costs scaled by the PPI for electric household cooking equipment. For the NOPR, DOE sought input from stakeholders on the approach of analyzing additional design options that would result in a lowering of the energy consumption of non-cooking features (*e.g.* standby power), even though the test procedure currently does not account for such usage in EF. DOE is separately considering an updated test procedure to incorporate a measurement of standby and off mode power, and section 5.6.1.3 discusses the testing and analysis that DOE conducted to characterize the design options associated with reductions in standby power.

**Table 5.6.10 Microwave Oven Manufacturing Cost and Efficiency Increments**

| Level | Efficiency Level Description | Cooking Efficiency | EF | Delta Manufacturer Cost from Baseline *(2006$)* |
|---|---|---|---|---|
| Baseline | Baseline | 55.7% | 0.557 | - |
| 1 | Baseline + More Efficient Power Supply | 58.6% | 0.586 | $8.68 |
| 2 | 1 + More Efficient Fan | 58.8% | 0.588 | $17.95 |
| 3 | 2 + More Efficient Magnetron | 59.7% | 0.597 | $32.53 |
| 4 | 3 + Reflective Surfaces | 60.2% | 0.602 | $51.11 |

Notes:
Baseline: Cooking efficiency = 55.7%
(1) Efficient Power Supply: Cooking efficiency increase = 2.9 (absolute percentage points)
(2) Efficient Fan: Cooking efficiency increase = 0.23 (absolute percentage points)
(3) Efficient Magnetron: Cooking efficiency increase = 0.90 (absolute percentage points)
(4) Reflective Surfaces: Cooking efficiency increase = 0.50 (absolute percentage points)

#### 5.6.1.3 Product Testing and Teardowns

***Microwave Oven Efficiency***

DOE conducted product testing and teardown analysis for microwave ovens to supplement AHAM-supplied data, to validate the approach of updating the 1996 TSD analysis, and to examine the microwave oven test procedure for potential updates. In order to identify design options, circuit designs, and display options, DOE disassembled a representative sample of 32 units to gain an in-depth understanding of common microwave oven design elements, components, and manufacturing practices. DOE also evaluated the IEC microwave oven test standard which is referenced by the current DOE test procedure (IEC Standard 705) in comparison to the current IEC test standard (IEC Standard 60705-2006, *Household microwave ovens – Methods for measuring performance* (IEC Standard 60705).)

*Test Units*

DOE conducted a market survey of microwave oven models and their associated features to identify the primary differentiators among commercially-available units, and to then select a representative range of test units which incorporate these features. DOE selected 32 microwave ovens based on parameters that could be identified from product literature. These included: 1) rated output power in W; 2) rated cavity volume in $ft^3$; 3) display type; 4) the presence or absence of a cooking sensor; and 5) magnetron power supply technology. For the latter, certain models were advertised as incorporating "inverter technology" that allows variable power output for different user-selectable cooking-level settings. The key parameters for each of the test units are presented in Table 5.6.11 through Table 5.6.14. In some cases, several units were selected from a single manufacturer that appeared to have similar construction, rated power, and volume, but differed in ancillary features such as the type of display or the presence of a cooking sensor. Such similarities are noted in the tables. Nomenclature for the display entries are described in the following paragraphs.

**Table 5.6.11 Microwave 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 |
| 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" |
| Unit is Similar to | | - | - | - | - | - | DOE5 | - | - |

**Table 5.6.12 Microwave 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 5.6.13 Microwave 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 5.6.14 Microwave 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 |
| | 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 |
| | # of LEDs for backlighting | 5 | 10 | 4 | 6 | 4 | 4 | 10 | 10 |
| | 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 |

The range of rated output powers and cavity volumes were determined on the basis of manufacturer specifications. Rated output power, which is a measure of the power transferred to the food load at the full-scale cooking setting, ranged from 700 to 1,300 W. Cavity volumes, which typically roughly scale with output power, ranged from rated values of 0.7 to 2.2 ft$^3$.

Three different display technologies were observed to be incorporated in the sample units: 1) LED; 2) LCD; and 3) VFD. (Details of each technology are discussed later in this section in the context of standby power.) 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.

All 32 microwave ovens in the DOE sample were subjected to efficiency testing via the current DOE test procedure, which is based by reference on IEC Standard 705, which has been superseded by IEC Standard 60705.[c] DOE subsequently subjected 12 of the 32 microwave ovens to additional cooking efficiency testing per IEC Standard 60705 to investigate the differences between the two test standards. DOE conducted additional testing of an inverter-based microwave oven to assess the impact of operating such a system at various power levels. Lastly, DOE considered possible improvement opportunities for the current cooking test procedure.

*General Construction*

All microwave 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

[c] Current IEC standards may be obtained from www.iec.ch. However, IEC does not make obsolete standards available.

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 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, baseline microwave ovens contain a magnetron power supply featuring a microwave oven transformer, a high voltage diode, and a high-voltage aluminum electrolytic capacitor. The user interface for these microwave baseline ovens is a simple LCD or LED display. 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. Cooking sensors and displays will be discussed in more detail below in sections regarding standby power.

Because the microwave field is not uniform inside microwave oven cavities (creating "hot" spots), manufacturers have developed various methods to improve cooking uniformity. Within the DOE sample, mode stirrers and turntables for the food were the only methods observed, although DOE is aware of other approaches that could be taken, such as utilizing dual magnetrons and associated wave guides. Mode stirrers temporally change the distribution of the microwave energy delivered to the cavity and thus cause the "hot" spots to move around the cavity. However, only one unit in the DOE sample (designated "DOE16") contains a mode stirrer. Most manufacturers have shifted away from this approach in favor of turntables. Turntable motors were observed in all microwave ovens sampled by DOE. By rotating the food through the "hot" spots, turntables help improve cooking uniformity. Both a turntable and mode stirrer require a motor, as does the blower, which provides cooling air to remove the significant heat dissipated by the magnetron and its power supply.

*Efficiency Testing Using the Current DOE Test Procedure*

DOE conducted efficiency tests on all sampled units using the current DOE test procedure, which references IEC Standard 705. As can be seen in Table 5.6.15 through Table 5.6.18, the DOE test results noted similar cooking efficiencies and input and output powers as the results submitted by AHAM, which were presented in section 5.6.1.1.

**Table 5.6.15 Microwave Oven Input, Output, and Cooking Efficiency (1 of 4)**

| DOE Unit Number | DOE1 | DOE2 | DOE3 | DOE4 | DOE5 | DOE6 | DOE7 | DOE8 |
|---|---|---|---|---|---|---|---|---|
| Stated Volume ($ft^3$) | 0.7 | 0.7 | 0.7 | 0.7 | 1.0 | 1.0 | 0.8 | 0.8 |
| Measured Input Power (W) | 1,192.8 | 1,129.8 | 1,121.9 | 996.8 | 1,374.6 | 1,314.9 | 1,356.7 | 1,374.0 |
| Rated Output Power (W) | 700.0 | 700.0 | 700.0 | 700.0 | 800.0 | 800.0 | 800.0 | 800.0 |
| Measured Output Power (W) | 686.1 | 654.8 | 627.0 | 593.8 | 818.5 | 767.6 | 781.7 | 786.7 |
| Energy Factor | 57.5% | 58.0% | 55.9% | 59.6% | 59.5% | 58.4% | 57.6% | 57.3% |

**Table 5.6.16 Microwave Oven Input, Output, and Cooking Efficiency (2 of 4)**

| DOE Unit Number | DOE9 | DOE10 | DOE11 | DOE12 | DOE13 | DOE14 | DOE15 | DOE16 |
|---|---|---|---|---|---|---|---|---|
| Stated Volume ($ft^3$) | 0.9 | 1.1 | 1.1 | 1.0 | 0.0 | 1.1 | 1.1 | 1.8 |
| Measured Input Power (W) | 1,602.4 | 1,769.9 | 1,701.8 | 1,713.0 | 1,736.4 | 1,886.2 | 1,876.3 | 1,566.7 |
| 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 |
| Measured Output Power (W) | 964.6 | 1,007.8 | 1,010.3 | 1,013.6 | 1,024.5 | 1,145.9 | 1,105.3 | 949.7 |
| Energy Factor | 60.2% | 56.9% | 59.4% | 59.2% | 59.0% | 60.8% | 58.9% | 60.6% |

**Table 5.6.17 Microwave Oven Input, Output, and Cooking Efficiency (3 of 4)**

| DOE Unit Number | DOE17 | DOE18 | DOE19 | DOE20 | DOE21 | DOE22 | DOE23 | DOE24 |
|---|---|---|---|---|---|---|---|---|
| Stated Volume ($ft^3$) | 1.0 | 1.4 | 1.0 | 1.3 | 1.1 | 1.0 | 1.4 | 2.2 |
| Measured Input Power (W) | 1,829.8 | 1,882.2 | 1,815.7 | 1,774.3 | 1,851.8 | 1,823.1 | 1,626.8 | 1,926.2 |
| 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 |
| Measured Output Power (W) | 1,046.7 | 1,114.0 | 1,057.3 | 1,072.5 | 1,134.0 | 1,038.2 | 966.7 | 1,130.8 |
| Energy Factor | 57.2% | 59.2% | 58.2% | 60.4% | 61.2% | 56.9% | 59.4% | 58.7% |

**Table 5.6.18 Microwave Oven Input, Output, and Cooking Efficiency (4 of 4)**

| DOE Unit Number | DOE25 | DOE26 | DOE27 | DOE28 | DOE29 | DOE30 | DOE31 | DOE32 |
|---|---|---|---|---|---|---|---|---|
| Stated Volume ($ft^3$) | 1.2 | 2.2 | 1.2 | 2.0 | 2.0 | 2.2 | 1.2 | 1.2 |
| Measured Input Power (W) | 1,871.2 | 1,925.1 | 1,812.7 | 1,904.5 | 1,904.5 | 1,919.8 | 1,917.1 | 1,928.2 |
| 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 |
| Measured Output Power (W) | 1,147.7 | 1,116.6 | 1,114.4 | 1,149.4 | 1,137.9 | 1,105.4 | 1,121.9 | 1,119.0 |
| Energy Factor | 61.3% | 58.0% | 61.5% | 60.4% | 59.7% | 57.6% | 58.5% | 58.0% |

Both DOE's and AHAM's microwave oven samples contained units with manufacturer-rated output powers ranging from 700 to 1,300 W. DOE-tested efficiencies varied from 56 to 61 percent. These measured efficiencies were similar to the results submitted by AHAM to DOE (see section 5.6.1.1), which noted cooking efficiencies of 55 to 62 percent.

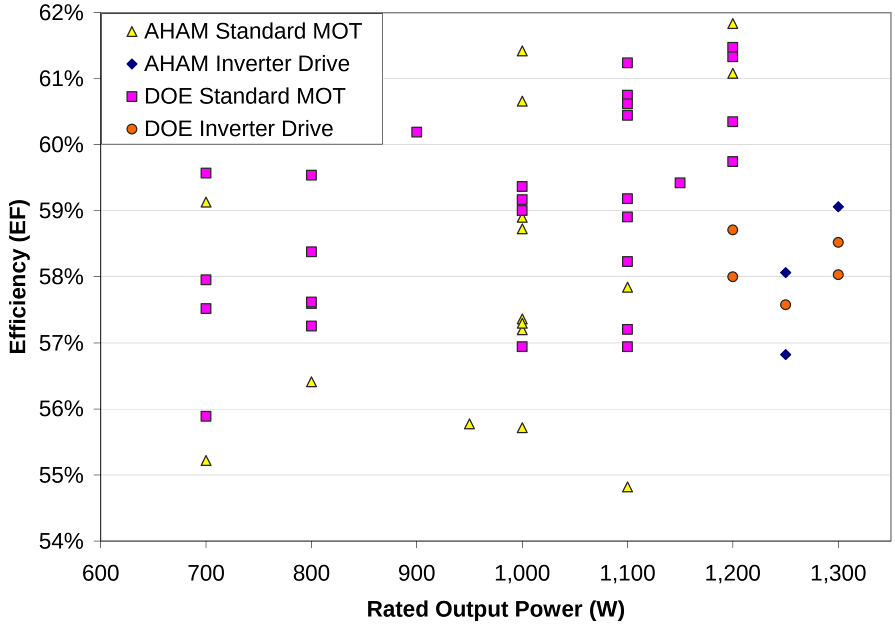


**Figure 5.6.4 DOE and AHAM Microwave Oven Efficiency versus Rated Output Power**

DOE is unaware of the specific microwave ovens that AHAM tested. However, it is possible to infer some model features on the basis of identified characteristics, such as rated output power. The models identified in Figure 5.6.4 as "AHAM Inverter" units were inferred as such because all of the microwave ovens that DOE is aware of on the market that have a rated output power at or in excess of 1,250 W feature an inverter driving the magnetron. DOE was unable to ascertain if any additional inverter units at lower output powers are contained within the AHAM data submittal. DOE noted that none of its microwave ovens with inverter-based magnetron power supplies achieved as high an efficiency as comparable microwave ovens with standard magnetron power supplies and high output powers. AHAM commented in its data submittal that inverter-based power supplies are 2 percent more efficient than standard power supplies (82 versus 84 percent, respectively).[17] Yet, collectively, the DOE and the inferred AHAM inverter units have lower cooking efficiencies than the highest-efficiency non-inverter units. Thus, while it is possible that inverter systems are more efficient than the simple microwave oven transformers they can replace, the overall efficiencies of inverter-based microwave ovens on the market do not presently demonstrate a corresponding efficiency improvement.

In considering the issue of inverter versus non-inverter power supply efficiencies, DOE observed that besides being much more complex, the inverter power supplies examined by DOE also feature large aluminum heat sinks and plastic tunnels to direct air flow over key components. The data sheets for the rectifiers and insulated-gate bipolar transistors used in the inverter power supplies note maximum heat dissipation requirements in excess of 400 W. During its teardown analysis, DOE also noted that inverter power supplies in its test sample use 50 percent heavier fan motors, indicating a greater need for heat removal from such systems and thus implying lower efficiencies, since energy is lost through heat dissipation from the power supply. However, regardless of the type of magnetron power supply used, almost all units in the AHAM and DOE samples meet the baseline efficiency of 55.7 percent for microwave ovens proposed in section 5.4.1.

DOE then investigated whether there was a correlation between microwave oven efficiency and measured output power. Typically, rated output powers in the test samples were observed to be within 50 W of measured output power, as shown in Table 5.6.19.

**Table 5.6.19 Microwave Oven Rated versus Measured Output for AHAM and DOE Tests**

| Unit # | Rated Output (W) | Measured Output (W) | Deviation from Rated Output |
|---|---|---|---|
| DOE4 | 700 | 594 | -15.2% |
| DOE3 | 700 | 627 | -10.4% |
| DOE2 | 700 | 655 | -6.5% |
| AHAM10 | 700 | 671 | -4.2% |
| DOE1 | 700 | 686 | -2.0% |
| AHAM11 | 700 | 699 | -0.1% |
| AHAM1 | 800 | 743 | -7.1% |
| DOE6 | 800 | 768 | -4.1% |
| DOE7 | 800 | 782 | -2.3% |
| DOE8 | 800 | 787 | -1.7% |
| AHAM16 | 800 | 795 | -0.7% |
| DOE5 | 800 | 818 | 2.3% |
| DOE9 | 900 | 965 | 7.2% |
| AHAM22 | 950 | 907 | -4.5% |
| AHAM20 | 1,000 | 930 | -7.0% |
| AHAM12 | 1,000 | 967 | -3.3% |
| AHAM4 | 1,000 | 971 | -2.9% |
| AHAM5 | 1,000 | 973 | -2.7% |
| AHAM14 | 1,000 | 986 | -1.4% |
| AHAM19 | 1,000 | 999 | -0.1% |
| DOE10 | 1,000 | 1,008 | 0.8% |
| DOE11 | 1,000 | 1,010 | 1.0% |
| DOE12 | 1,000 | 1,014 | 1.4% |
| AHAM3 | 1,000 | 1,015 | 1.5% |
| DOE13 | 1,000 | 1,025 | 2.5% |
| AHAM15 | 1,000 | 1,028 | 2.8% |

| Unit # | Inverter | Rated Output (W) | Measured Output (W) | Deviation from Rated Output |
|---|---|---|---|---|
| DOE16 | | 1,100 | 950 | -13.7% |
| DOE22 | | 1,100 | 1,038 | -5.6% |
| DOE17 | | 1,100 | 1,047 | -4.8% |
| DOE19 | | 1,100 | 1,057 | -3.9% |
| AHAM21 | | 1,100 | 1,060 | -3.7% |
| DOE20 | | 1,100 | 1,073 | -2.5% |
| DOE15 | | 1,100 | 1,105 | 0.5% |
| DOE18 | | 1,100 | 1,114 | 1.3% |
| AHAM13 | | 1,100 | 1,119 | 1.7% |
| DOE21 | | 1,100 | 1,134 | 3.1% |
| DOE14 | | 1,100 | 1,146 | 4.2% |
| DOE23 | | 1,150 | 967 | -15.9% |
| DOE27 | | 1,200 | 1,114 | -7.1% |
| DOE26 | Y | 1,200 | 1,117 | -7.0% |
| DOE24 | Y | 1,200 | 1,131 | -5.8% |
| DOE29 | | 1,200 | 1,138 | -5.2% |
| AHAM2 | | 1,200 | 1,145 | -4.6% |
| DOE25 | | 1,200 | 1,148 | -4.4% |
| DOE28 | | 1,200 | 1,149 | -4.2% |
| AHAM17 | | 1,200 | 1,152 | -4.0% |
| AHAM6 | | 1,200 | 1,205 | 0.4% |
| DOE30 | Y | 1,250 | 1,105 | -11.6% |
| AHAM8 | Y | 1,250 | 1,142 | -8.6% |
| AHAM9 | Y | 1,250 | 1,166 | -6.7% |
| DOE32 | Y | 1,300 | 1,119 | -13.9% |
| DOE31 | Y | 1,300 | 1,122 | -13.7% |
| AHAM7 | Y | 1,300 | 1,173 | -9.8% |

The measured output for the AHAM data averaged 2.8 percent less than rated output power, with a range in deviation from rated output of +3.1 percent to -9.8 percent). Most units had a measured output lower than their rated output. As mentioned previously, the AHAM data sample did not identify whether an microwave oven had an inverter power supply for the magnetron. Thus, the presence of an inverter in the AHAM data set is solely inferred by the DOE market survey.

Output power measurements within the DOE sample followed a similar pattern to the data submitted by AHAM, though with a greater proportion of units having measured output power below rated output power. The divergence ranged from a high of about 7 percent above rated output power to a low of about 16 percent below rated output power, with the average divergence being about -5 percent. As with the results for rated output power shown in Figure 5.6.4, Figure 5.6.5 shows that the DOE efficiency data as a function of measured output power exhibits largely similar characteristics as the AHAM data submittal, and neither shows an identifiable correlation.

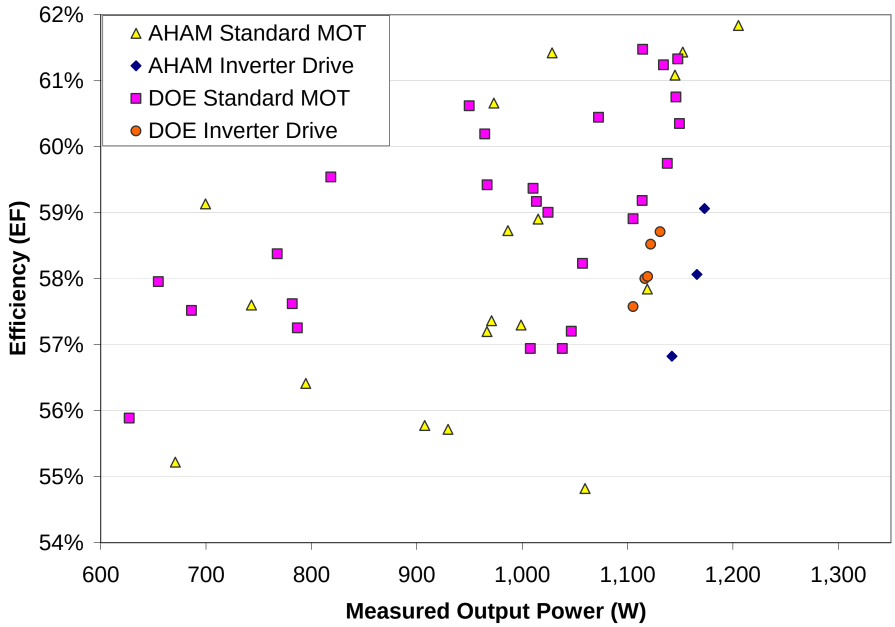


**Figure 5.6.5 DOE and AHAM Microwave Oven Efficiency versus Measured Output Power**

The maximum measured output power of approximately 1,200 W represents the practical limit of residential microwave ovens currently on the market, since at even the highest measured efficiency, input power is approaching the amperage limits of residential electrical circuits. For example, the maximum input power measured by DOE in its test sample was approximately 1,925 W, while two microwave ovens in the AHAM data submittal exceeded 2,000 W of input power during cooking efficiency tests. For a standard 120 volts AC (VAC) circuit, these input powers would correspond to 16.0 and 16.7 amperes (A), respectively. Higher output powers may thus only be achievable with microwave ovens that have even higher efficiencies or by a transition to 240 VAC circuits for microwave ovens. Higher input and output powers are common for commercial microwave ovens, but these products require higher line voltages.

*Impacts of Design Options on Cooking Efficiency*

DOE identified the following design options present in its sample of microwave ovens and observed the following impacts associated with each design option on cooking efficiency:

- Cooking sensors. There was no identifiable relationship between the absence or presence of a cooking sensor and the measured efficiency. The only clear impact of some cooking sensors was on the standby power consumption.

- Improved fan efficiency. The units subjected to reverse-engineering all appeared to incorporate fans of similar type and construction, *i.e*. single-speed shaded-pole-motors (SPMs) with plastic blades and presumably similar efficiency characteristics. Therefore, no impacts could be quantified for the effect of improved fan efficiency on microwave oven efficiency.

- Improved magnetron efficiency. Despite the range of magnetron manufacturers and models, there was notable consistency of rated magnetron efficiency among the data sheets that DOE was able to obtain. All data sheets indicated a conversion efficiency range of 71 to 72 percent. Therefore, no relationship between microwave oven efficiency and magnetron efficiency could be evaluated, nor did DOE have a means of evaluating the efficiency of those magnetrons for which data sheets were unavailable, since the magnetrons could not be tested by DOE in isolation.

- Improved microwave oven transformer power supply efficiency. Among the units torn down, only the inverter-type microwave ovens had an identifiably different efficiency performance characteristic than the microwave ovens with standard power supplies, and the data indicate that overall efficiency is not improved by inverter power supplies. All standard microwave oven transformers appear to be similar in construction and, hence, no data was available to evaluate the effect of incremental improvements in conventional microwave oven transformers. Furthermore, DOE did not have the means of evaluating the efficiency of the microwave oven power supplies alone, since they could not be tested by DOE in isolation.

- Low-standby-loss electronic controls. By definition, these technologies impact only standby power consumption rather than cooking efficiency.

- Modified wave guide. This design option described in the market and technology assessment (chapter 3 of the TSD), wherein special coatings are applied to the wave guide interior surfaces, was not observed in the DOE test units. However, two different orientations of the wave guide were noted, and an attempt was made to identify any impact that wave guide orientation would have on measured efficiency. No such relationship was found.

For more detailed descriptions of each of these design options, see chapter 3 of the TSD. Based on this analysis, DOE believes that the efficiency improvements associated with these design options has changed little since the 1996 TSD analysis.

*Comparison of IEC Test Procedures for Measuring Efficiency*

The existing DOE microwave oven test procedure references IEC Standard 705, but this IEC test procedure has been declared obsolete by the IEC. The current IEC test procedure is IEC Standard 60705. Because there are key differences between these two IEC procedures, the impact of which on efficiency measurements were not known to DOE, and because manufacturers which do conduct efficiency testing are likely to be using the current version, a test series was conducted on a sub-sample of the microwave ovens to compare efficiency measurements made using both IEC test procedures.

The general methodology for each test procedure is largely the same, and consists of heating 1 kg of water in a borosilicate container from about 10 °C below room temperature to room temperature, using the maximum power setting on the microwave oven. The input power over the duration of the test, and thus energy consumed during the test, are compared to the energy absorbed by the test load to obtain the efficiency measurement.

DOE conducted tests per IEC Standard 60705 on 12 selected microwave ovens from its original 32 unit sample with a representative range of output power, efficiency, and test-to-test variation observed in the DOE testing, which utilizes IEC Standard 705. The table below summarizes key differences noted between the test procedures that can potentially impact the final energy efficiency calculation.

**Table 5.6.20 Key Differences Between IEC Standard 705 and IEC Standard 60705**

| IEC Standard 705-1988 and Amendment 2-1993 | IEC Standard 60705-2006 |
|---|---|
| Ambient Temp., $T_0$ = 20 ± 2 °C<br>Starting Water Temp., $T_1 = T_0 - (10 \pm 1$ °C)<br>Final Water Temp., $T_2 = T_0 \pm 1$ °C | Ambient Temp., $T_0$ = 20 ± 5 °C<br>Starting Water Temp., $T_1$ = 10 ± 1 °C<br>Final Water Temp., $T_2$ = 20 ± 2 °C |
| Electrical Input Energy neglects the magnetron filament heat-up time, the measurement starting when the input current reaches 90 percent of its final value. | Measurement of Electrical Input Energy includes the energy consumed during the magnetron filament heat-up time. |
| No mention of rounding off efficiency or output power calculations | Efficiency is rounded off to the nearest whole number, while output power is rounded off to the nearest 50 W |
| Temperature measurement accurate within 0.25 °C and linearity better than 1 percent. Time measurement accurate within 0.25 seconds. | No specifications for accuracy of temperature and time measurements. |

It can be noted that, for the efficiency measurement, IEC Standard 60705 includes the energy consumed during the magnetron filament heat-up time, while IEC Standard 705 excludes filament heat-up time. Thus, the IEC Standard 60705 efficiency measurement can be considered more accurately as an overall microwave oven efficiency measurement, while the IEC Standard

705 efficiency measurement can be considered strictly a cooking efficiency measurement. Table 5.6.21 shows the results for the test procedure comparison. Per the IEC Standard 60705 test procedure, DOE rounded the measured output of each test to the closest 50 W and then averaged the rounded values.

**Table 5.6.21 IEC Standard 705 versus IEC Standard 60705 Test Results**

| | | IEC Standard 705-1998 and Amendment 2-1993 | | | IEC Standard 60705-2006 (rounded) | | |
|---|---|---|---|---|---|---|---|
| Test Unit # | Rated Power Output (W) | Measured Power Output (W) | Efficiency (%) | Test-to-Test Efficiency Range (%) | Measured Power Output (W) | Efficiency (%) | Test-to-Test Efficiency Range (%) |
| DOE1 | 700 | 686 | 57.5 | 1.46 | 650 | 55.3 | 3.57 |
| DOE6 | 800 | 743 | 58.4 | 0.06 | 733 | 57.0 | 3.45 |
| DOE5 | 800 | 795 | 59.5 | 0.4 | 733 | 58.7 | 3.33 |
| DOE9 | 900 | 965 | 60.2 | 0.48 | 917 | 58.3 | 5.00 |
| DOE22 | 1,100 | 1,038 | 56.9 | 0.71 | 1,000 | 55.0 | 3.57 |
| DOE19 | 1,100 | 1,057 | 58.2 | 0.47 | 1,017 | 56.7 | 3.45 |
| DOE15 | 1,100 | 1,073 | 58.9 | 0.77 | 1,083 | 58.0 | 3.39 |
| DOE21 | 1,100 | 1,105 | 61.2 | 0.21 | 1,083 | 59.3 | 1.67 |
| DOE27 | 1,200 | 1,114 | 61.5 | 1.07 | 1,067 | 59.3 | 1.67 |
| DOE29 | 1,200 | 1,131 | 59.7 | 0.92 | 1,100 | 58.0 | 0.00 |
| DOE30 | 1,250 | 1,142 | 57.6 | 0.67 | 1,050 | 55.3 | 1.79 |
| DOE32 | 1,300 | 1,119 | 58.0 | 1.24 | 1,083 | 57.0 | 5.17 |

There is a consistent decrease in efficiency of about 1 to 2 percent from IEC Standard 705 to IEC Standard 60705 for all of the microwave ovens. This largely-consistent decrease in the calculated efficiency for IEC Standard 60705 was due in significant part to the requirement that the measured input energy include the energy consumed during the magnetron filament heat-up time, whereas IEC Standard 705 specifies that the measurement of energy input begins when the current reaches 90 percent of its maximum value. Therefore, IEC Standard 60705 factors in a higher energy consumption to the efficiency calculation than IEC Standard 705 does.

Another significant difference between test procedures is the specifications for accuracy of the test instrumentation. IEC Standard 705 specifies that temperature measurements be accurate within 0.25 °C, with linearity better than 1 percent, as well as that time measurements be accurate within 0.25 seconds. In contrast, IEC Standard 60705 does not provide any accuracy requirements for these measurements. Using a standard thermocouple, which typically has an accuracy no better than 0.5 °C, or a less accurate time measurement equipment could create significant test-to-test variation in efficiency results.

The variation of test-to-test efficiency results per IEC Standard 60705 for an individual microwave oven ranged from 0 to 5 percent of the average value, which was much greater than the comparable variation for IEC Standard 705, whose test-to-test variation in efficiency results ranged from 0 to 1.5 percent for the same sub-sample of microwave ovens. This larger range associated with IEC Standard 60705 is believed to be attributable to the effects of the procedure's requirement to round the power output to the nearest 50 W and the efficiency to the nearest whole number after each individual test, prior to averaging.

The prescribed rounding under IEC Standard 60705 would make it more difficult to achieve an overall efficiency increase via improvements in minor components such as fan/turntable motors and oven light bulbs, which each consume less than 20 W. For any component efficiency improvements to have a measurable effect after rounding the power output and efficiency calculations, power consumption would have to be reduced by at least 25 W.

To demonstrate the effect of rounding more clearly, the raw data from the IEC Standard 60705 testing were used to calculate efficiency in the same manner as for IEC Standard 705; *i.e.*, no rounding was performed on output power or efficiency from the individual tests prior to averaging. As shown in Figure 5.6.6, the test-to-test variation in efficiency for the rounded data is on average four times higher than that of the non-rounded data. The effect of rounding output power and efficiency also causes a significant change in the calculated efficiency, as seen in Figure 5.6.7. The rounded efficiencies varied from the non-rounded values by as much as 0.75 percentage points.

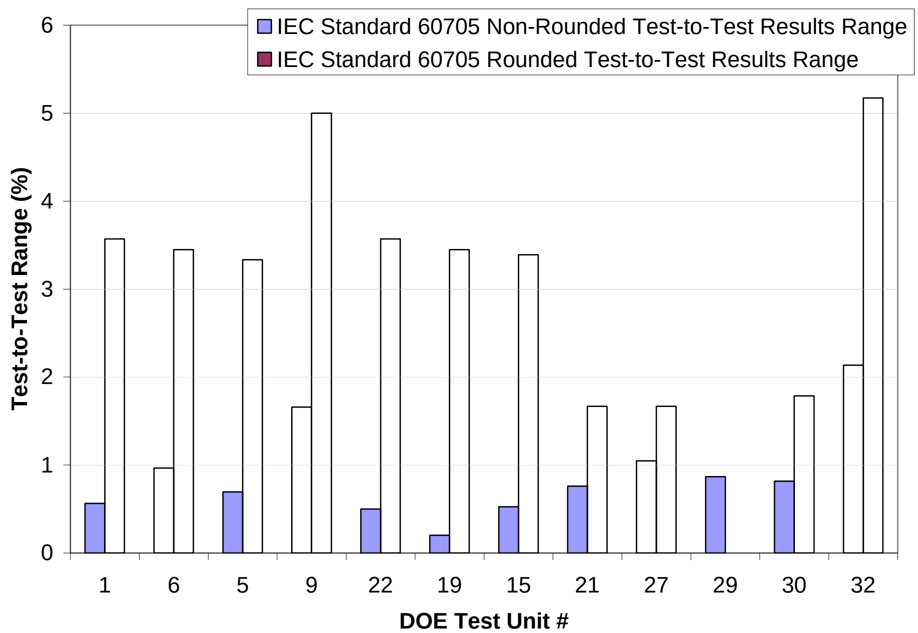


**Figure 5.6.6 DOE Non-Rounded versus Rounded Test-to-Test Efficiency Variation Measured Using IEC Standard 60705**

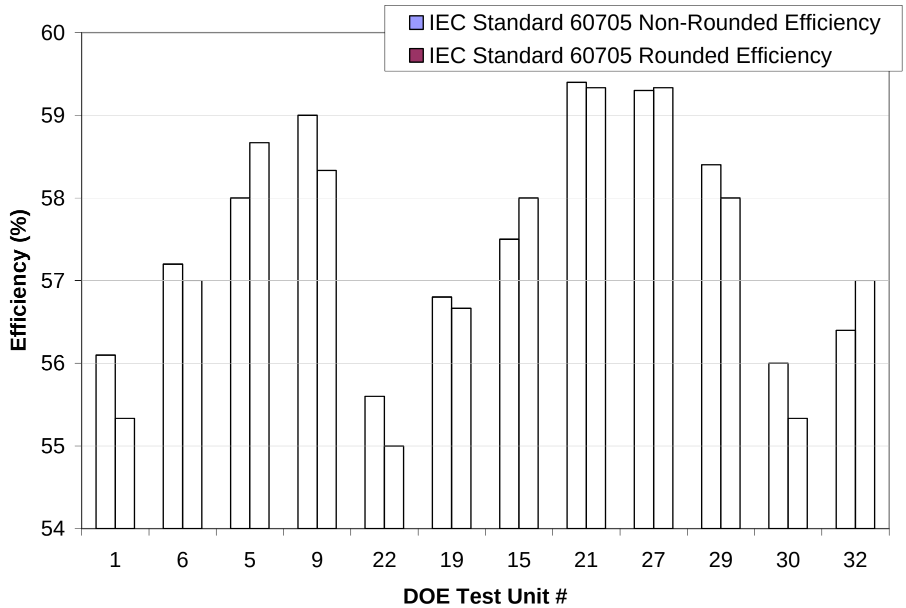


**Figure 5.6.7 DOE Non-Rounded versus Rounded Efficiency Measured Using IEC Standard 60705**

The non-rounded data obtained via IEC Standard 60705 still show a consistent 1 to 2 percentage point decrease in efficiency for all of the units tested as compared to the IEC Standard 705 tests, which DOE believes to be attributable to the differences in the energy input measurement. As with the rounded IEC Standard 60705 results, the non-rounded data for IEC Standard 60705 also show more test-to-test variation for a given unit (0 to 2.1 percentage points) than the variations test-to-test during the IEC Standard 705 testing (0 to 1.5 percentage points). This remaining increment in test-to-test variation was likely due to the more lenient tolerances on the prescribed ambient and final test load temperatures. The IEC Standard 60705 test procedure specifies ambient temperature as 20 ± 5 °C, as compared to 20 ± 2 °C for the IEC Standard 705 test procedure. For the final test load temperature, IEC Standard 60705 specifies 20 ± 2 °C, while IEC Standard 705 specifies it as ambient temperature ± 1 °C.

**Table 5.6.22 IEC Standard 705 versus IEC Standard 60705-2006 Test Results, Without Rounding**

| | | IEC Standard 705-1998 and Amendment 2-1993 | | | IEC Standard 60705-2006 (no rounding) | | |
|---|---|---|---|---|---|---|---|
| Test Unit # | Rated Power Output (W) | Measured Power Output (W) | Efficiency (%) | Test-to-Test Efficiency Range (%) | Measured Power Output (W) | Efficiency (%) | Test-to-Test Efficiency Range (%) |
| DOE1 | 700 | 686 | 57.5 | 1.46 | 659 | 56.1 | 0.56 |
| DOE6 | 800 | 743 | 58.4 | 0.06 | 740 | 57.2 | 0.96 |
| DOE5 | 800 | 795 | 59.5 | 0.4 | 722 | 58.0 | 0.70 |
| DOE9 | 900 | 965 | 60.2 | 0.48 | 925 | 59.0 | 1.66 |
| DOE22 | 1,100 | 1,038 | 56.9 | 0.71 | 1,012 | 55.6 | 0.50 |
| DOE19 | 1,100 | 1,057 | 58.2 | 0.47 | 1,023 | 56.8 | 0.20 |
| DOE15 | 1,100 | 1,073 | 58.9 | 0.77 | 1,075 | 57.5 | 0.53 |
| DOE21 | 1,100 | 1,105 | 61.2 | 0.21 | 1,087 | 59.4 | 0.76 |
| DOE27 | 1,200 | 1,114 | 61.5 | 1.07 | 1,061 | 59.3 | 1.05 |
| DOE29 | 1,200 | 1,131 | 59.7 | 0.92 | 1,112 | 58.4 | 0.87 |
| DOE30 | 1,250 | 1,142 | 57.6 | 0.67 | 1,074 | 56.0 | 0.82 |
| DOE32 | 1,300 | 1,119 | 58.0 | 1.24 | 1,087 | 56.4 | 2.14 |

Based on observations and analysis of test results, DOE believes that IEC Standard 705 is more likely to produce consistent test results than IEC Standard 60705 because the measurement requirements in IEC Standard 705 are more stringent. Therefore, DOE believes that IEC Standard 705 should be retained as the basis for the DOE cooking efficiency tests.

***Microwave Oven Standby Power***

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)) Even though the final rule for this rulemaking is scheduled for March 2009, DOE has decided, for reasons discussed in the NOPR, to accelerate the schedule for microwave ovens to include standby and off mode power in the proposed energy conservation standards. Therefore, DOE conducted microwave oven standby power testing to supplement the AHAM-supplied data, investigate design options, and develop a relationship between incremental manufacturing cost and standby power levels.

In the NOPR, DOE proposes to use the definitions of modes as specified in EPCA. EPCA defines "standby mode" as "the condition in which an energy-using product –

(I) is connected to a main power source; and

(II) offers 1 or more of the following user-oriented or protective functions:

(aa) To facilitate the activation or deactivation of other functions (including active mode) by remote switch (including remote control), internal sensor, or timer.

(bb) Continuous functions, including information or status displays (including clocks) or sensor-based functions."

(42 U.S.C. 6295(gg)(1)(A)(iii))

EPCA defines "off mode" as "the condition in which an energy-using product –

(I) is connected to a main power source; and

(II) is not providing any standby mode or active mode function."

(42 U.S.C. 6295(gg)(1)(A)(ii))

EPCA defines "active mode," which is referenced in the definition of "off mode," as "the condition in which an energy-using product –

(I) is connected to a main power source;

(II) has been activated; and

(III) provides 1 or more main functions."

(42 U.S.C. 6295(gg)(1)(A)(i))

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 the EPCA 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.

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.

DOE conducted product teardowns and testing in support of its standby power investigation. DOE also analyzed IEC Standard 62301 to determine its suitability for measuring standby power in microwave ovens. DOE found the results produced by IEC Standard 62301 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 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 5.6.23 through Table 5.6.26 summarize these results.

**Table 5.6.23 DOE Microwave 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 5.6.24 DOE Microwave 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 5.6.25 DOE Microwave 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 5.6.26 DOE Microwave 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 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 5.6.8, exhibits a relatively wide range of values. These measured data correlate well with the standby power measurements that AHAM submitted to DOE (see Figure 5.6.9). 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).

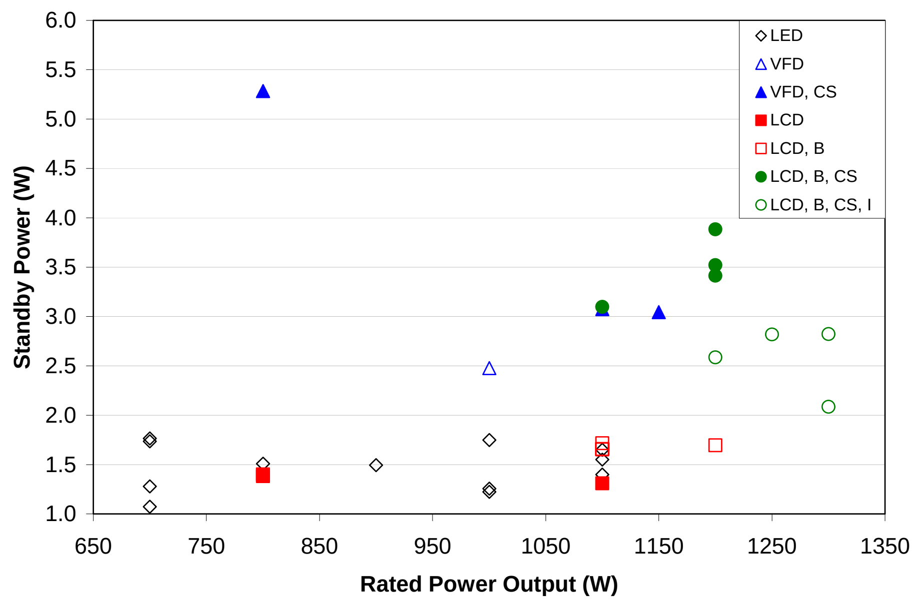


**Figure 5.6.8 DOE Microwave Oven Standby Power Consumption as a Function of Rated Output Power**

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

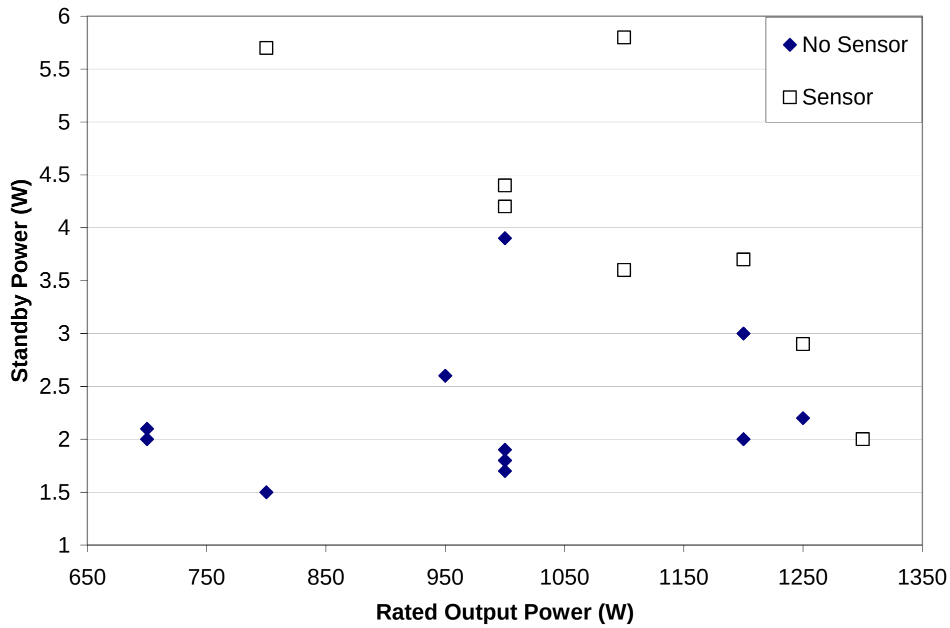


**Figure 5.6.9 AHAM Microwave Oven Standby Power Consumption and a Function of Rated Output Power**[18]

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 5.6.10 illustrates measured standby power consumption as a function of display size.

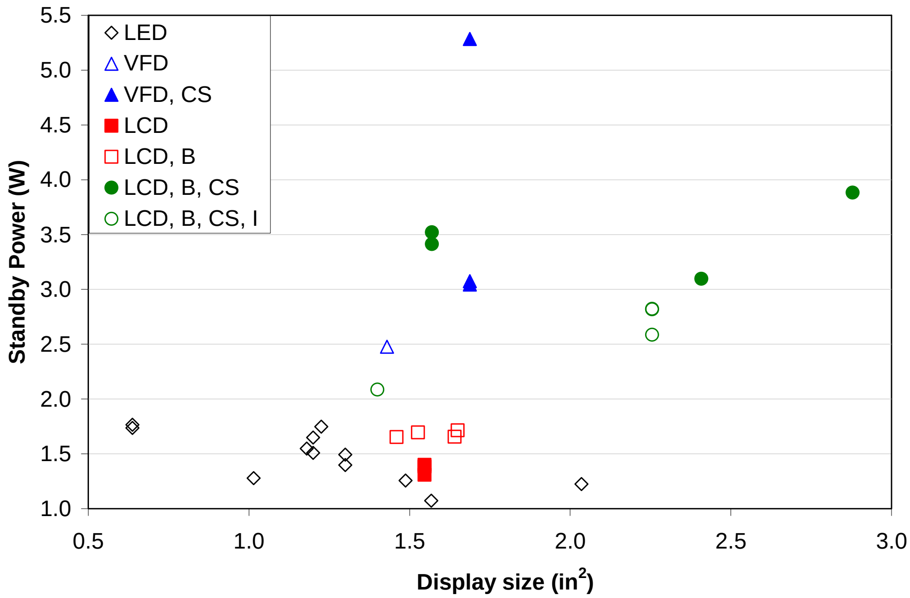


**Figure 5.6.10 DOE Microwave Oven Standby Power Consumption as a Function of Display Size**

Figure 5.6.11 through Figure 5.6.13 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 5.6.11 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 could not ascertain any information.

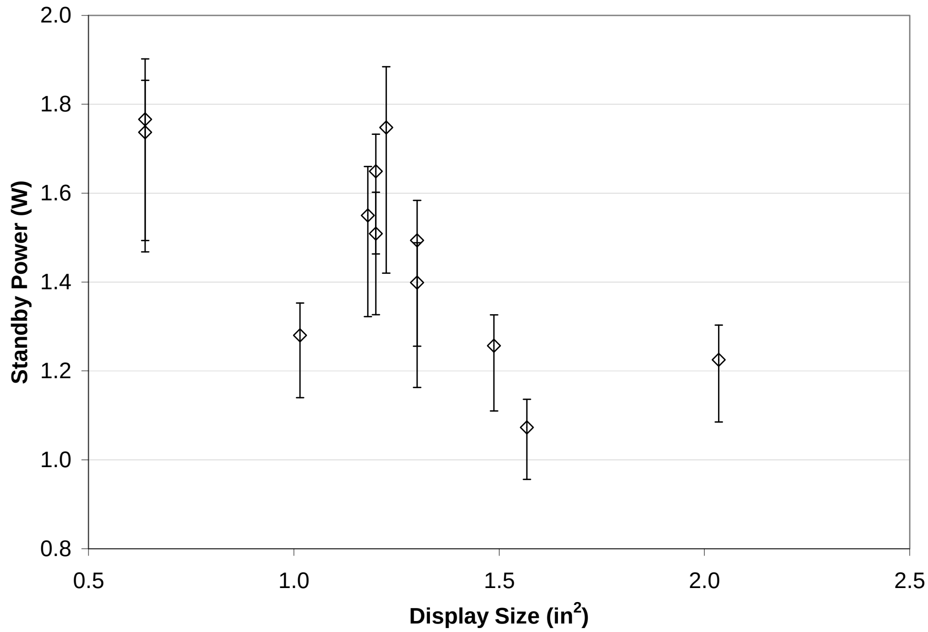


**Figure 5.6.11  DOE Standby Power Consumption as a Function of Display Size for Microwave Ovens with LED Displays**

- 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 5.5.1 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.

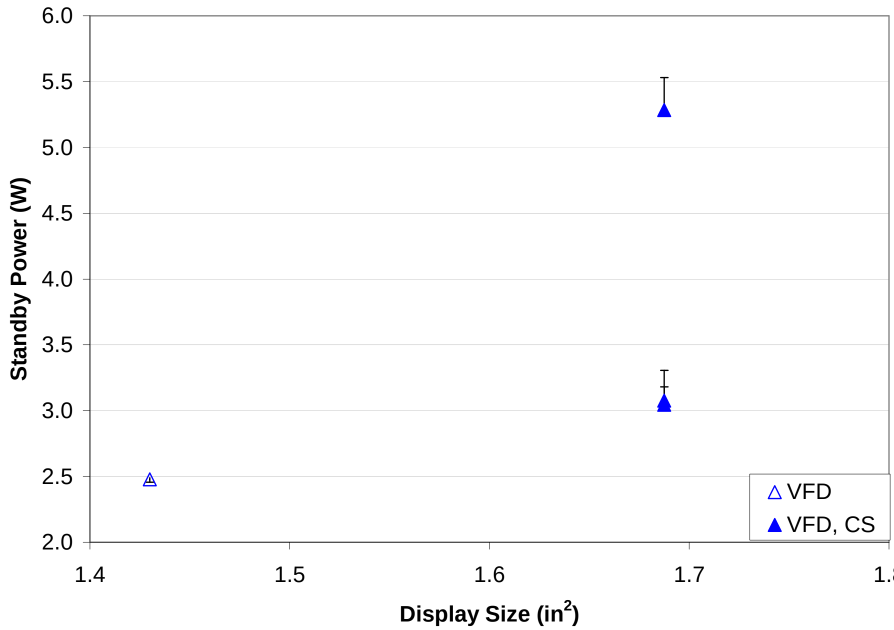


**Figure 5.6.12 DOE Standby Power Consumption as a Function of Display Size for Microwave Ovens with VFD Displays**

- 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 5.6.13, 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 5.6.13 also shows that the addition of a cooking sensor raises standby power consumption, on average, to over 2 W.

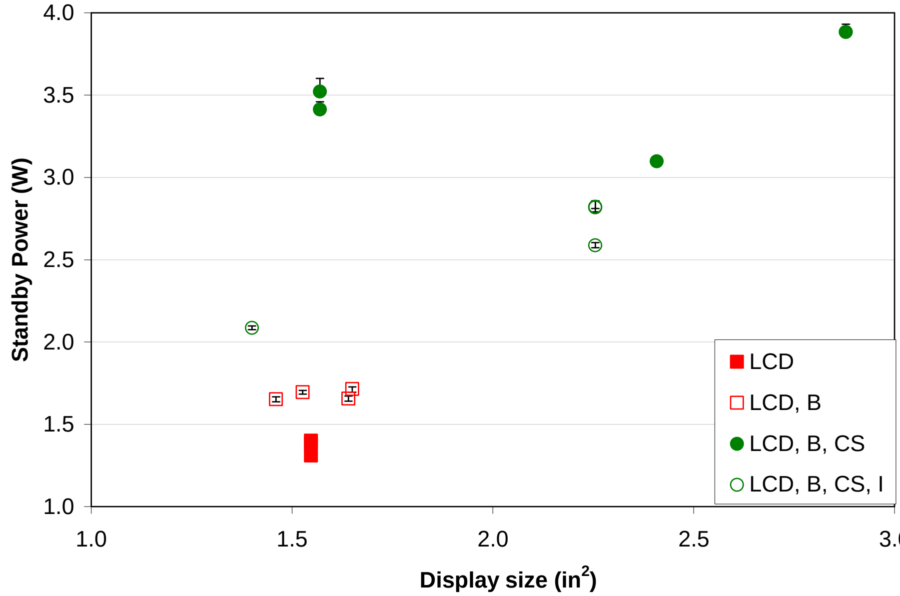


**Figure 5.6.13 DOE Standby Power Consumption as a Function of Display Size for Microwave Ovens with LCD Displays**

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 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 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 5.6.27 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 5.6.27 DOE Standby Power Requirements among Similar Microwave 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 5.6.14 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.

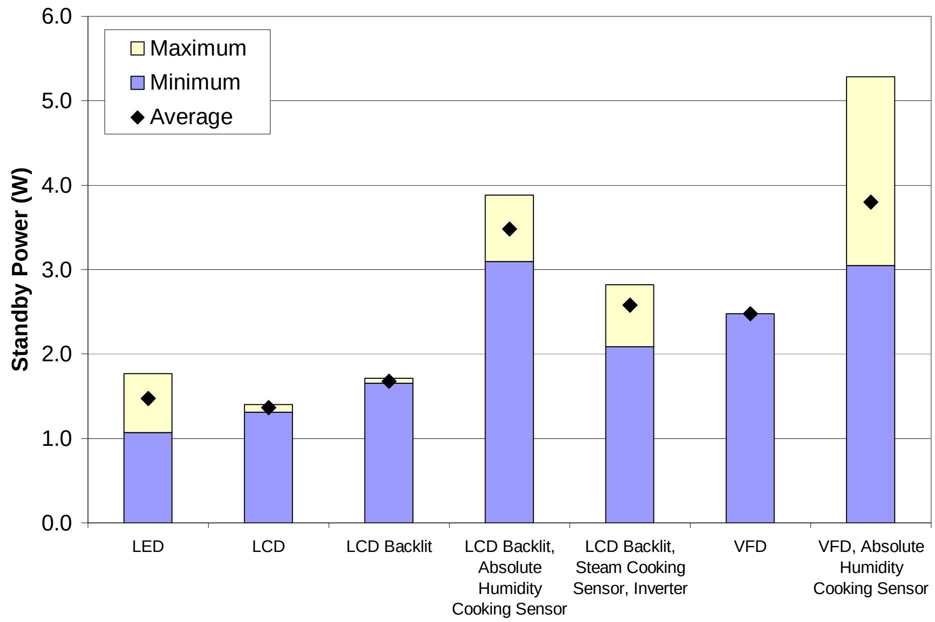


**Figure 5.6.14 DOE Standby Power Consumption Associated with Different Design Options**

*Incremental Cost Data for Standby Power Levels*

From the standby power testing and reverse-engineering, DOE observed correlations between specific components and technologies, or combinations thereof, and 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 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.

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 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 level above the baseline. DOE believes that, in order to meet standby 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 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 level 2 to standby 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 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 level 4, and would be the approach for microwave ovens with the other display technologies to meet standby level 4 as well. Table 5.6.28 presents the incremental manufacturing costs for each standby power level for microwave ovens.

Based on conversations with manufacturers and OEM suppliers, and the reverse-engineering analysis, DOE believes that all manufacturers can implement zero-standby cooking sensors by the expected effective date of the proposed standards. Thus, DOE believes that consumer utility would not be impacted by a standard at standby levels 1 or 2, since all display types could continue to be utilized. At standby level 3 for VFDs and standby 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 impact the consumer utility of having a clock display only if the consumer could not opt out of auto power-down.

**Table 5.6.28 Incremental Manufacturing Costs for Microwave Oven Standby Power**

| Standby Level | Standby Power *(W)* | Incremental Cost *(2007$)* |
|---|---|---|
| Baseline | 4.0 | $ 0 |
| 1 | 2.0 | $ 0.30 |
| 2 | 1.5 | $ 0.67 |
| 3 | 1.0 | $ 1.47 |
| 4 | 0.02 | $ 5.13 |

*Standby Power Test Procedure Issues*

During testing, DOE identified several issues that are not addressed in IEC Standard 62301 that can affect the stability and repeatability of the standby power measurements. For the 32 microwave ovens sampled by DOE, the variability of standby power appeared to be influenced primarily by changes in clock time over the duration of the test, the effect of which depended on the type of display technology used, and fluctuations in line voltage. The effect of each of these issues is discussed below.

- Clock Time

The IEC Standard 62301 test procedure specifies a 5-minute recording period for initially measuring standby power consumption. If the measured power fluctuations are less than 5 percent during this period, the power is simply averaged over the 5 minutes to obtain the standby power consumption. Conversely, if the fluctuations are greater than 5 percent, the standby power draw must be measured over a longer time period, which in the test procedure is only defined as "representative" and which for microwave ovens with a 12-hour clock would be reasonably interpreted as a full 12 hours. The test procedure, however, does not specify the starting clock time for the initial 5-minute measurement period, so it would be possible to selectively choose a starting time that shows a minimum of actively-lit elements and whose subsequent variability of lit elements is low. For example, programming 1:12 AM into the clock at the beginning of the test offers the combination of a minimal number of active elements as well as minimal active element variability, since during the 5 minute test the only change would be the last digit cycling from a value of 2 to a value of 7. Thus, a manufacturer could report lower standby power consumption than would be realized in actual operating conditions.

To illustrate this effect more clearly, Figure 5.6.15 shows that the number of active elements in the LED display of a representative unit among the DOE test samples ranged from 6 to 18, depending on the time being displayed. For this microwave oven, a 20-percent variation in standby power was observed as a function of the clock time being displayed. By choosing a starting clock time of 1:12, the number of active elements ranges from 7 to 10 for the 5 minute duration of the initial measurement. In fact, the average 8.6 active elements under these test conditions result in an average standby power consumption of approximately 1.25 W, instead of the approximately 1.4 W which would be obtained over the 12-hour period. Therefore, an apparent 11-percent improvement in standby power consumption could be obtained for this microwave oven by simply choosing this initial clock time. It should be noted that since display type, size, and luminosity affect standby power variability, this apparent improvement could be different for other microwave ovens.

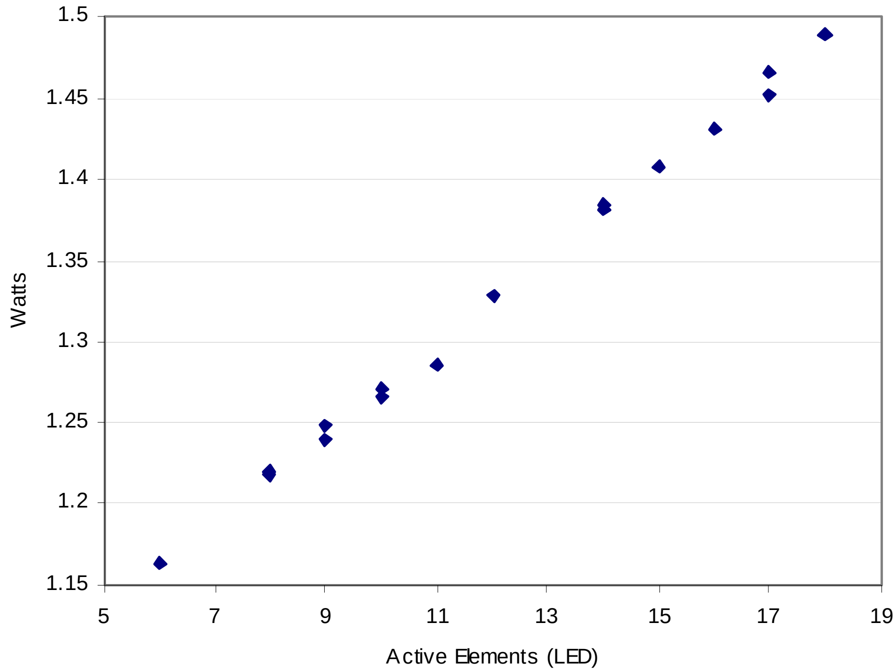


**Figure 5.6.15 Representative Variation in Standby Power Consumption as a Function of the Number of Active Elements in the Display**

- Line Voltage

DOE observed that line voltage fluctuations within the ± 1 percent tolerance allowed by IEC Standard 62301 resulted in greater than ± 1 percent variations in standby power measurements. A series of tests across multiple microwave ovens showed that a change of 2 VAC on a nominal 120 VAC line voltage, which is less than 2 percent, resulted in standby power measurements that varied by as much as 5 percent.

*Alternate Standby Power Test Methods*

DOE considered alternate testing methods to determine whether a representative standby power could be measured over a shorter period than 12 hours so that the test burden on manufacturers could be reduced. Thus, DOE developed an algorithm by which the power consumption and line voltage are measured as the clock is cycled through multiple digit combinations (in terms of active elements), followed by a regression analysis that quantifies the impact of the number of lit elements (by digit) and line voltage on power consumption. The results are then integrated across the number of minutes that each active element combination is "on" through the course of the 12 hours. This methodology, discussed in greater detail in appendix 5B, produced standby power measurements in less than 10 minutes of test time that agree to within 1 to 2 percent with the measurements made over 12 hours.

DOE recognizes, however, that this approach for accelerated standby testing offers the possibility that the rather unique combination of clock times could be detected. A microwave oven could be programmed to alter it behavior when such a test is detected in order to minimize measured standby power consumption. For example, a microwave oven could be programmed to turn off its cooking sensors and/or dim its display only during such a test. Thus, DOE is proposing in the NOPR the use of the longer 12-hour standby test.

*Standby Power Test Method Conclusions*

DOE has determined that the test conditions specified by IEC Standard 62301 were suitable for microwave oven tests. As discussed in chapter 3 of this TSD, DOE has initiated a test procedure change to incorporate standby power in parallel with this rulemaking. The proposed test procedure would incorporate by reference provisions from IEC Standard 62301 as well as language to clarify the application of these provisions for measuring standby mode where IEC Standard 62301 is non-specific. Specifically, DOE is proposing to specify a 12-hour duration for the measurement period as a qualification to IEC Standard 62301 in order to provide more consistent and repeatable results.

### 5.6.2 Commercial Clothes Washers

#### 5.6.2.1 AHAM Data

To support the DOE rulemaking, AHAM collected incremental CCW manufacturing cost data from its member companies in October 2006. Table 5.6.29 compiles unit shipment and energy efficiency data for CCWs from 2002–2005.

**Table 5.6.29 AHAM Commercial Clothes Washer Shipments and Shipment-Weighted MEF and WF Data Submittal**

| Year | Total Shipments | MEF ($ft^3/kWh$) | WF ($gallons / ft^3$) |
|---|---|---|---|
| **2002** | 175,187 | 1.30 | 11.77 |
| **2003** | 190,720 | 1.33 | 11.42 |
| **2004** | 178,382 | 1.33 | 11.33 |
| **2005** | 177,394 | 1.41 | 10.91 |

Table 5.6.30 reproduces AHAM's 2006 data submittal for the average water and power consumption agitator top-loading CCWs that meet the baseline 1.26 MEF energy efficiency level. Since January 2007, however, clothes washers manufactured at this baseline 1.26 MEF must meet a lower WF (9.5) than the one listed in the AHAM data submittal.

**Table 5.6.30 AHAM Baseline MEF Commercial Clothes Washer Average Energy and Water Use Data Submittal**

| Attributes of Average 1.26 MEF Washer | | | | | Power Consumption per Wash Cycle *(kWh)* | | |
|---|---|---|---|---|---|---|---|
| **MEF** *($ft^3$/kWh)* | **WF** *(gallons / $ft^3$)* | **Washer Capacity** *($ft^3$)* | **Water Use** *(gallons/cycle)* | **Standby Power Consumption** *(W)* | **Hot Water** | **Machine Power** | **Dryer Power** |
| 1.26 | 11.1 | 3.1 | 34.3 | * | 0.87 | 0.18 | 1.38 |

DOE initially requested incremental cost data for efficiency levels presented in the framework document for the single product class including both top-loading and front-loading CCWs. Data submitted by AHAM for the November 2007 ANOPR, shown in Table 5.6.31, represents aggregated input from the producers of CCWs sold in the United States The shipment-weighted incremental cost at each level is the cost to upgrade the baseline efficiency machine (1.26 MEF/9.5 WF) to that efficiency level for the single product class. The CCW industry currently has only three manufacturers with more than 1 percent market share, and there are a limited number of CCWs that operate at different efficiency points, restricting the amount of data that AHAM could submit[d]. Four efficiency levels contain no cost data since AHAM requires a minimum of three data points per efficiency level before submitting shipment-weighted results. Therefore, AHAM submitted two manufacturing cost estimates: (1) $74.63 at efficiency level 1; and (2) $316.35 at efficiency level 5, as noted in Table 5.6.31.

**Table 5.6.31 AHAM Commercial Clothes Washer Incremental Cost Data Submittal**

| **Efficiency Level** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|
| Exploratory MEF Levels – Commercial Clothes Washers | 1.42 | 1.6 | 1.72 | 1.8 | 2 | 2.2 |
| Exploratory WF Levels – Commercial Clothes Washers | 9.5 | 8.5 | 8.0 | 7.5 | 5.5 | 5.1 |
| Incremental Costs ($ Per Unit) – Shipment-Weighted | $ 74.73 | * | * | * | $ 316.35 | * |
| * Insufficient data reported | | | | | | |

Figure 5.6.16 plots the efficiency levels for the single CCW product class established in the November 2007 ANOPR for which AHAM submitted incremental manufacturing cost data, *i.e.* the baseline efficiency level, efficiency level 1, and efficiency level 5.

[d] AHAM is limited to publishing data to efficiency levels where at least three AHAM members can submit cost efficiency data, which AHAM then weights according to unit shipments by manufacturer.

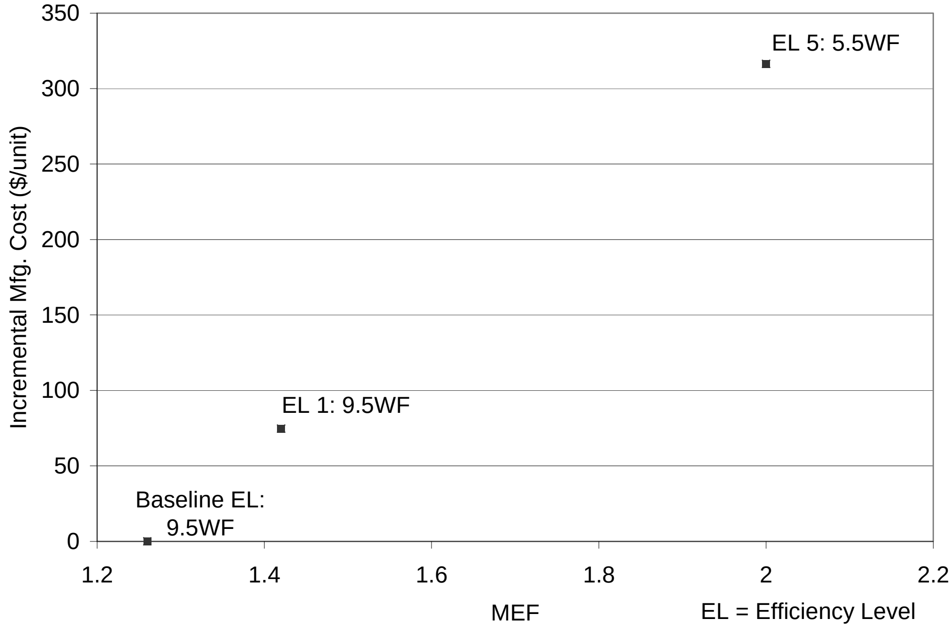


**Figure 5.6.16 AHAM Commercial Clothes Washer Incremental Cost Data Submittal**

Manufacturers stated that the baseline efficiency level (1.26 MEF/9.5 WF) and the efficiency level 1 (1.42 MEF/9.5WF) are attainable with agitator top-loading clothes washers. Manufacturers also stated that efficiency level 5 (2.00 MEF/5.5 WF) would require the use of front-loading clothes washers. Therefore, DOE believes the data in Table 5.6.31 is subject to a platform change from agitator top-loading to front-loading clothes washers between efficiency level 1 and efficiency level 5. Given the persistent manufacturing cost difference between these platforms, an incremental cost "curve" with more intermediate data points would thus likely exhibit a steep step change wherever that platform change occurs.

### 5.6.2.2 Review of the Most Recent TSD for Residential Clothes Washers

In 2001, DOE concluded a rulemaking for residential clothes washers. The intent of this section is to review some of the conclusions drawn in the 2000 TSD that supported that rulemaking, to update the data presented in it, and to assess in which ways the residential clothes washer TSD can be used in the context of this CCW rulemaking. In particular, this review will focus on the manufacturing costs published in the 2000 TSD. First, the 1996 AHAM residential clothes washer cost data submittal provided for the 2000 TSD will be examined, followed by the 2000 reverse-engineering analysis and an update on the low-volume manufacturer case.

***1996 AHAM Cost and Energy Use Data Submittal Review***

In 1996, manufacturers submitted manufacturing cost and energy use estimates by efficiency level for residential clothes washers to AHAM. This data was then aggregated by market share and efficiency level to prevent the disclosure of confidential information, and the results were used in the analysis reported in the 2000 TSD. While this process yielded viable results in the residential clothes washer rulemaking, the results are not directly applicable to the current CCW rulemaking due to differences in the following key parameters: (1) intended use and cycle life, (2) production scale, (3) technical advancements, (4) market share, (5) platform mixing, and (6) incompatibility of the MEF and WF pairings in the data submittal.

*Intended Use and Cycle Life*

Clothes washer manufacturers have traditionally designed their commercial units to share many parts with their residential platforms. Shared components typically consist of parts that do not affect unit life, such as cabinet stampings, that may or may not be selectively upgraded. For example, entry-level residential clothes washer cabinets typically feature a powder-coated plastic finish whereas commercial models may feature a more durable enameled finish. Purchased components such as motors, timers, and switches may also be customized to reflect the different and more rigorous usage patterns expected in commercial applications. For example, one manufacturer stated that their CCWs are expected to last 12,000 wash cycles whereas residential models are expected to last 6,000 or fewer wash cycles.

*Production Scale*

In 1996, a twenty-fold scale difference existed between residential and CCW market unit shipments. Since then, residential clothes washer shipments have grown while CCW sales have stagnated or declined. As a result, the current scale difference is more than forty-fold.

The scale difference helps explain why CCWs have traditionally been a product extension of existing residential clothes washer platforms for most manufacturers. By sharing many components with residential models, research and development, tooling and equipment, and other costs can be spread over the largest number of clothes washers. Consequently, any additional investment required for CCWs alone is depreciated over a much smaller production volume.

As efficiency standards are raised, manufacturers may be required to make investments in the form of capital expenditures, research and development, and implementation to meet such standards. Investments such as new tooling and research, in particular, are “step” functions, requiring a minimum investment regardless of production volume. A standard that affects CCWs first may thus require a substantial investment that can only be depreciated over a much smaller production volume.

As a result of the much lower production volumes, the per-unit conversion costs to accommodate higher efficiencies are greater per efficiency increment for CCWs than they are for residential models. Therefore, DOE believes Table 4.2 published in the 2000 TSD (duplicated below as Table 5.6.32) is not valid for CCWs, because the fixed costs are assumed to be depreciated over a much larger product volume and because the higher-volume production processes manufacturers envisioned minimize variable cost increases. Most manufacturers of residential clothes washers in 1996 had production levels in excess of 300,000 units per year, with the leading manufacturer producing about 3.5 million top-loading washers per year. In contrast, the two leading CCW manufacturers in 2007 have total CCW production levels of about 100,000 units per year.

Currently, as in 1996, there is a low-volume manufacturer (LVM) that operates in both the residential and CCW markets. While its volumes in the residential market are very small on a percentage basis, this manufacturer is very prominent in the CCW market. Unlike its diversified competitors, this company exclusively manufactures laundry equipment. A review of the Securities and Exchange Commission (SEC) 10-K documents revealed that, as of 2005, this company derived 22 percent of its total revenue from the sale of front- and top-loading clothes washers and 87 percent of that income was from the commercial market. As a result, this company will be affected disproportionately by the CCW rulemaking compared to its competitors, for whom CCWs represent about 2 percent of total clothes washer sales. For more information on the LVM, see appendix 13A of this TSD.

**Table 5.6.32 1996 AHAM Residential Clothes Washer Cost Data Submittal**

| **Product Characteristics** | | | **Incremental Variable Costs (*$ per Unit*)** | | | | **Total Fixed Costs (*$ per unit*)** | **Incre-mental Mfg. Cost (*$ per unit*)** | **No. of Res-pon-dents** |
|---|---|---|---|---|---|---|---|---|---|
| **Percent Improve-ment** | **MEF** | **WF** | **Ma-terials** | **Labor** | **Over-head** | **Total** | | | |
| **Baseline** | 0.817 | 13.779 | | | | | | | |
| **5** | 0.860 | 13.732 | $0.01 | $0.01 | $0.00 | $0.02 | $0.07 | $0.09 | 5 |
| **10** | 0.908 | 13.710 | $0.25 | $0.04 | $0.01 | $0.30 | $0.61 | $0.91 | 5 |
| **15** | 0.961 | 13.670 | $3.18 | $0.10 | $0.04 | $3.32 | $1.01 | $4.33 | 5 |
| **20** | 1.021 | 13.342 | $10.71 | -$0.02 | $1.80 | $8.89 | $6.21 | $15.10 | 5 |
| **25** | 1.089 | 9.220 | $36.14 | $8.61 | $0.09 | $44.84 | $19.29 | $64.13 | 5 |
| **30*** | | | | | | | | | |
| **35** | 1.257 | 7.601 | $86.73 | $10.94 | $7.78 | $105.45 | $22.72 | $128.17 | 5 |
| **40** | 1.362 | 7.610 | $87.15 | $10.94 | $7.78 | $105.87 | $22.72 | $128.59 | 5 |
| **45** | 1.485 | 8.570 | $125.58 | $15.52 | $14.51 | $155.61 | $24.67 | $180.28 | 4 |
| **50** | 1.634 | 8.570 | $132.40 | $15.68 | $14.51 | $162.59 | $24.67 | $187.26 | 4 |

***** No data were submitted at this efficiency level

*Technical Advancements*

While the general function of clothes washers has not changed since the 2000 TSD, many different technologies have been implemented. As with dishwashers and other residential appliances, clothes washers are built on platforms whose baseline performance can be improved with design options. Some platforms are inherently more energy and water efficient than others, allowing a manufacturer to use fewer design options to reach a particular efficiency level, but there are efficiency limits inherent to every platform regardless of how many design options are employed. These limits affect the MEF as well as the WF.

Clothes washers currently often use electronic controllers instead of electromechanical controllers, which were more prevalent at the time of the 2000 TSD. Electronic controllers usually carry a cost premium over electromechanical timers, driving up manufacturing cost. However, such controllers are appealing to customers and are required for some design options. Besides enabling certain design options, electronic controllers allow owners to more easily monitor washer utilization, functional status, and other parameters. There are potential reliability benefits as well. For example, one reason that variable-water-height selectors are atypical in commercial top-loading clothes washers is that owners prefer not to give users the ability to select water levels. If they did, users could attempt to wash a full load on a "low water" setting, potentially damaging the washer and/or the clothes being washed. Electronic controllers may be able to detect such overload conditions and stop the wash cycle before the clothes washer is harmed. Alternatively, controllers can be programmed to "reset" to default settings after each wash cycle. This forces the end-user select the appropriate cycle for each use, potentially reducing the incidence of accidental overloads.

Some manufacturers have also phased out mechanical transmission and clutch systems, replacing them with variable-speed electronic drive systems. Benefits include a reduction in mechanical complexity, increased cabinet space to accommodate potential expansion of the basket/tub, and greater wash program flexibility. The substitution of electronics for mechanical systems can increase overall unit cost, particularly if fixed in-house assets that had been used to manufacture mechanical transmission and clutch systems become stranded assets.

Many design options available in residential clothes washer have yet to find application in CCWs. The reliability and longevity requirements of CCWs combined with the production scale issues are such that manufacturers avoid adding design options unless necessary. As the part count increases, so does the probability that the clothes washer will break down, and purchased parts sourced just for CCWs are likely to carry a cost premium. Thus, DOE expects manufacturers will continue to introduce new features first in the residential markets before transitioning them to the commercial field.

Since the 2000 residential clothes washer TSD was written, there have been numerous technological advances incorporated into clothes washers, and the manufacturing costs submitted to AHAM were based on residential clothes washer models that are no longer in production. Thus, even if DOE could ascertain the manufacturing cost differential between commercial and residential clothes washers in 1996, that differential would no longer be valid for current models.

Most importantly, manufacturers have been able to improve the MEF and WF of agitator clothes washers at a much lower cost than they projected in 1996. Instead of using front-loading or non-agitator top-loading clothes washers as projected to meet a 1.26 MEF, current baseline 1.26 MEF CCWs consist of agitator models with reduced water consumption, lower wash temperatures, and improved control systems. Thus, manufacturers were able to reach the current efficiency requirements at much lower cost than projected in 1996. One manufacturer noted that the costs of improved control systems are substantially higher than those of the electromechanical controls they replaced and that the wash performance and hence end-user utility of top-loading clothes washers are affected by lower WF and higher MEF requirements.

*Market Share*

The market shares that AHAM used to aggregate manufacturer-submitted data were valid for the residential clothes washer market in 1996. However, since then there has been significant consolidation by domestic producers, and multiple foreign brands have started selling their clothes washers in the United States. More importantly, the market shares of producers in the residential clothes washer market are not equivalent to the market shares of manufacturers in the CCW industry.

Four to five residential clothes washer manufacturers submitted manufacturing cost data estimates for each efficiency level for the 1996 AHAM data request. However, there are currently essentially only three U.S. CCW manufacturers: Alliance Laundry Systems LLC (Alliance), General Electric GE Consumer & Industrial (GE), and Whirlpool (via its acquisition of Maytag Corporation (Maytag)). The low number of manufacturers limits current AHAM data submittals to DOE since AHAM requires a minimum of three data points per efficiency level before it publishes any results.

Since AHAM adjusts incremental manufacturing cost data submittals by efficiency level on a market-share basis, the manufacturing costs submitted by the largest manufacturers have the greatest weight. As noted above, the distributions of market share by manufacturer for commercial and residential clothes washers are quite different. Since DOE does not have access to the disaggregated data, there is no opportunity to compensate for market share differences between markets, even if the costs of manufacturing residential and CCWs were the same.

*Platform Mixing*

DOE's efforts to update the 1996 AHAM data submittal are hindered by the submittal's aggregation of top- and front-loading clothes washers. Based on the AHAM-supplied energy and water use data, reproduced in Table 5.6.33, DOE assumes that the cost and energy use tables contained only agitator top-loading data for efficiency improvement levels of up to, and including, 20 percent. This assumption is driven by the consistent water usage up to that point and the low incremental costs to reach that efficiency level. Similarly, DOE assumes that the two highest efficiency levels, 45 and 50 percent improvement, exclusively incorporated front-loading clothes washers. The 25 to 40 percent improvement categories appear to have aggregated high-efficiency top- as well as front-loading clothes washers.

**Table 5.6.33 1996 AHAM Residential Clothes Washer Energy and Water Use Data Submittal**

| Product Characteristics | | | | Energy Use (*kWh/cycle*) | | | Water Use | |
|---|---|---|---|---|---|---|---|---|
| **Percent Improve-ment** | **MEF** | **Total Energy w/Dryer (*kWh /cycle*)** | **Clothes Container ($ft^3$)** | **Hot Water** | **Machine Energy** | **Dryer Energy** | **(*gal/ cycle*)** | **(*gal/ $ft^3$*)** |
| **Baseline** | 0.817 | 3.227 | 2.847 | 1.587 | 0.209 | 1.430 | 39.181 | 13.779 |
| **5** | 0.860 | 3.165 | 2.817 | 1.543 | 0.209 | 1.413 | 38.613 | 13.732 |
| **10** | 0.908 | 3.017 | 2.822 | 1.408 | 0.209 | 1.400 | 38.613 | 13.710 |
| **15** | 0.961 | 2.833 | 2.832 | 1.216 | 0.209 | 1.407 | 38.621 | 13.670 |
| **20** | 1.021 | 2.739 | 2.893 | 1.113 | 0.218 | 1.408 | 38.446 | 13.342 |
| **25** | 1.089 | 2.292 | 2.866 | 0.715 | 0.304 | 1.273 | 26.600 | 9.220 |
| **30*** | | | | | | | | |
| **35** | 1.257 | 1.866 | 2.749 | 0.462 | 0.133 | 1.270 | 21.030 | 7.601 |
| **40** | 1.362 | 1.859 | 2.749 | 0.462 | 0.133 | 1.263 | 21.030 | 7.610 |
| **45** | 1.485 | 1.651 | 2.736 | 0.429 | 0.114 | 1.107 | 23.405 | 8.570 |
| **50** | 1.634 | 1.574 | 2.736 | 0.413 | 0.114 | 1.047 | 23.405 | 8.570 |

* No data were submitted at this efficiency level.

Since DOE does not have access to the disaggregated data and the clothes washer platforms that underlie the AHAM data submittals, there is no method by which DOE can assess how relevant the data submittal is to the current rulemaking. It is not clear to DOE which models were submitted at each efficiency level, whether these models use the same platforms as current CCWs, nor what efficiency improvements manufacturers have been able to achieve with these models since 1996.

*Incompatibility of the MEF and WF Pairings*

Table 5.6.33 shows the lowest shipment-weighted WF at 1.26 MEF. No top-loading clothes washers could reach 1.634 MEF in 1996, suggesting that the clothes washers at the two highest efficiency levels consisted of front-loading clothes washers, whereas baseline units consisted of agitator top-loading clothes washers. The WF is lowest at 1.26 MEF, indicating that the shipment-weighted WF for that efficiency level included clothes washers that had a lower WF than residential front-loading clothes washers did at that time.

DOE is aware of an agitator top-loading CCW platform from a major manufacturer that had achieved a 7.3 WF via spray rinse. However, this unit was withdrawn from the market a number of years ago due to end-user complaints regarding rinse performance. The CEC database of current CCWs lists no top-loading clothes washers with a similar WF. The closest model is an agitator top-loading washer platform with an 8.3 WF. The top-loading clothes washer platforms currently listed in the CEC residential clothes washer database that meets the 7.6 WF does not exist in a commercial version and consists of a non-agitator design.

Thus, the results at 1.26 MEF in Table 5.6.33 suggest multiple platforms, likely consisting of agitator top-loading with spray rinse, non-agitator top-loading, and front-loading residential clothes washers. Neither spray-rinse agitator nor non-agitator clothes washers are currently in production for commercial purposes. The incompatibility between the WF of machine properties submitted to AHAM for the 1996 data submittal and machines currently on the market is yet another indication of how the projections of manufacturers diverged from the agitator top-loading clothes washers they developed to meet the 1.26 MEF/9.5 WF requirements.

*Conclusion*

There are sufficient changes in market conditions due to intended use and cycle life, production scale, technical advancements, and market share to preclude the use of the 1996 AHAM data submittal as a basis for the current CCW analysis. Furthermore, the 1996 AHAM data submittal cannot be factored into the analysis due to platform mixing and the resulting inability to disaggregate the data into top- and front-loading machines.

***2000 TSD Reverse-Engineering Review***

Further manufacturing cost data by efficiency level was developed for the 2000 residential clothes washer rulemaking by DOE. Since DOE has access to this data, DOE has decided to review and publish data that remains relevant to the current CCW rulemaking.

*Reviewed Models*

For the 2000 residential clothes washer TSD, DOE reverse-engineered 8 residential clothes washers in 1999 from manufacturers with substantial market shares. DOE subsequently developed cost models to estimate the manufacturing costs of these washers at varying production levels.

The market share covered by the residential clothes washer platforms reverse-engineered in 1999 was about 80 percent. Three of the washers shared a chassis with CCWs in 1999. DOE could make estimates regarding the costs to update these platforms for commercial use, but the market share covered by these platforms is currently less than 20 percent of the commercial market, limiting the usefulness of the results.

All three of the major manufacturers currently serving the CCW industry have introduced new models or significantly revised existing models since the 2000 residential clothes washer TSD. Some manufacturers have updated the drive systems and other major system components to differentiate their products or improve energy efficiency. As a result, there have been significant changes in the baseline cost of clothes washers that the 2000 TSD could not have analyzed, even if it had reviewed CCW models.

*Market Share and Scale*

The U.S. CCW market is very small compared to the residential clothes washer market. Whereas shipments of residential clothes washers have been increasing, with more than 9.2

million units in 2005, CCW sales have stagnated or declined to about 200,000 units per year. The residential clothes washer market is dominated by the merged Whirlpool-Maytag entity, which has an approximate combined market share of 70 percent. The residential clothes washer sales of this entity exceed 6 million units per year, approximately 30 times the entire CCW market.

This scale difference is important in this analysis because agitator top-loading residential and CCWs typically share many parts to minimize tooling and equipment investments. Thus, a manufacturer that benefits from high manufacturing volumes on the residential side has a much larger potential base of units over which to depreciate investments. Commercial assembly lines can be repurposed towards residential clothes washer production if the commercial top-loading washer platform is no longer cost effective to produce.

While the largest competitor in the U.S. clothes washer manufacturing business may not realize much cost benefit due to manufacturing scale in moving to 6 million units per year versus the 1.5 million units per year modeled during the 2001 residential clothes washer rulemaking, there are other advantages to scale. For example, research and development and other overhead functions can be leaner as a percentage of sales revenue, yet still have far more available resources than comparable departments at lower-volume competitors.

High-volume competitors have a long history of improving the performance of agitator top-loading clothes washers via add-on design options such as spray rinse, nutating plates, and other means. For a lower-volume manufacturer, it is inherently more difficult to assemble and defend an intellectual-property portfolio. Similarly, a low-volume manufacturer may have to wait for innovations to trickle down from common suppliers since high-volume manufacturers typically get first (and sometimes exclusive) access to new technologies.

Manufacturers whose production comprises a high percentage of CCWs are thus impacted disproportionately by any regulatory burden regarding CCWs. One low-volume U.S. clothes washer manufacturer was contractually barred from manufacturing residential clothes washers from 1999 until 2004. While its subsequent SEC 10-K reports show significant growth in the residential market segment, commercial sales are still substantially higher. As a result, this LVM is not only concentrated in the CCW market, but its lack of diversification makes it particularly sensitive to any impacts on its CCW business as well.

*The Low-Volume Manufacturer Case*

The LVM has been successfully competing with much larger competitors in the commercial laundry market for several years. Based on the LVM's public SEC 10-K filings, DOE has estimated that the LVM derives about a third of its total revenues from the sales of clothes washers and dryers, which are usually bundled. Clothes washer sales by themselves account for more than 20 percent of total revenue. Laundry equipment for institutional use largely makes up the balance. For a detailed breakdown of LVM revenues by product line and market segment, see appendix 13A of the TSD, which details DOE's methodology and results for the LVM analysis.

As of 2005, agitator top-loading clothes washers sold by the LVM into the commercial market segment represented about 70 percent of unit shipments and about 60 percent of total CCW revenues.  Thus, any legislation that eliminates the use of such clothes washers from the commercial market would affect the LVM disproportionably due to the relative importance of the business and its effect on manufacturing scale.  Such a transition also poses a business risk since a platform change will reduce the value of accumulated spare-parts inventories, technician training, etc. to route operators.  Thus, any switching cost to other brands could be substantially reduced.

The LVM released a front-loading clothes washer for sale in 1999 and does not presently manufacture any non-agitator top-loading clothes washers.  As of 2005, its sales of front-loading clothes washers represent approximately 20 percent of total washer unit shipments and approximately 35 percent of total washer revenues.  Given the scale of the manufacturer at the time, the design was likely optimized for very low production volume.   Should the entire CCW industry be forced to migrate to front-loading clothes washers, the LVM would thus have to make substantial investments to make its design more cost competitive.  While the LVM is already at work to reduce front-loading unit costs, a market transition to front-loading washers accelerated by federal standards would most likely result in the LVM moving its front-loading manufacturing offshore.

However, unlike its larger rivals, the LVM does not benefit from very large scale in its residential operations to help amortize the investments in research, development, plant expenditures, and implementation expenses.  The size of the CCW market by itself is simply too small to justify large lump-sum investments.  The agitator top-loading units that the LVM manufactures have benefited from years of investments and refinements, whereas the front-loading model received its first update in 2003.

Besides benefiting from ongoing development and investments, agitator top-loading clothes washers at the LVM also benefit from well-depreciated equipment and tooling and a long-term knowledge base.  In the past, the LVM had residential sales well in excess of its CCW sales before a non-compete contract cut off the LVM from the residential market from 1999 until 2004.  Thus, while the LVM has gained the experience of producing hundreds of thousands of top-loading clothes washers per year, it has yet to gain the same experience with its front-loading clothes washer line.

The loss of the commercial market for agitator top-loading clothes washers is likely to make residential models of those clothes washers too expensive to manufacture due to the much smaller scale.  Whether the LVM could remain in the front-loading clothes washer business despite the loss of the agitator top-loading clothes washer business is also uncertain.  To date, the LVM has been able to grow its business despite adverse market conditions and much larger competitors.

*Implications of Scale for the Low-Volume Manufacturer*

As discussed previously, most of the clothes washers under review in the 2001 residential clothes washer rulemaking did not share a chassis with a commercial model. Thus, the results of the engineering analysis in the 2000 TSD do not apply to present day CCWs except for a very narrow set of observations.

A universal factor in manufacturing is scale, which describes how many units over which a fixed investment can be amortized. As part of the 2000 reverse-engineering analysis for residential clothes washers, DOE tried to understand the implications of low-volume manufacturing. Figure 5.6.17, originally published as Figure 5.10 in the 2000 residential clothes washer TSD, averages the cost differences among multiple baseline top-loading vertical-axis residential clothes washers at production levels of 1.5 million and 0.3 million units per year. It also averages front-loading horizontal-axis results for the residential front-loading horizontal-axis clothes washers that DOE reverse-engineered.

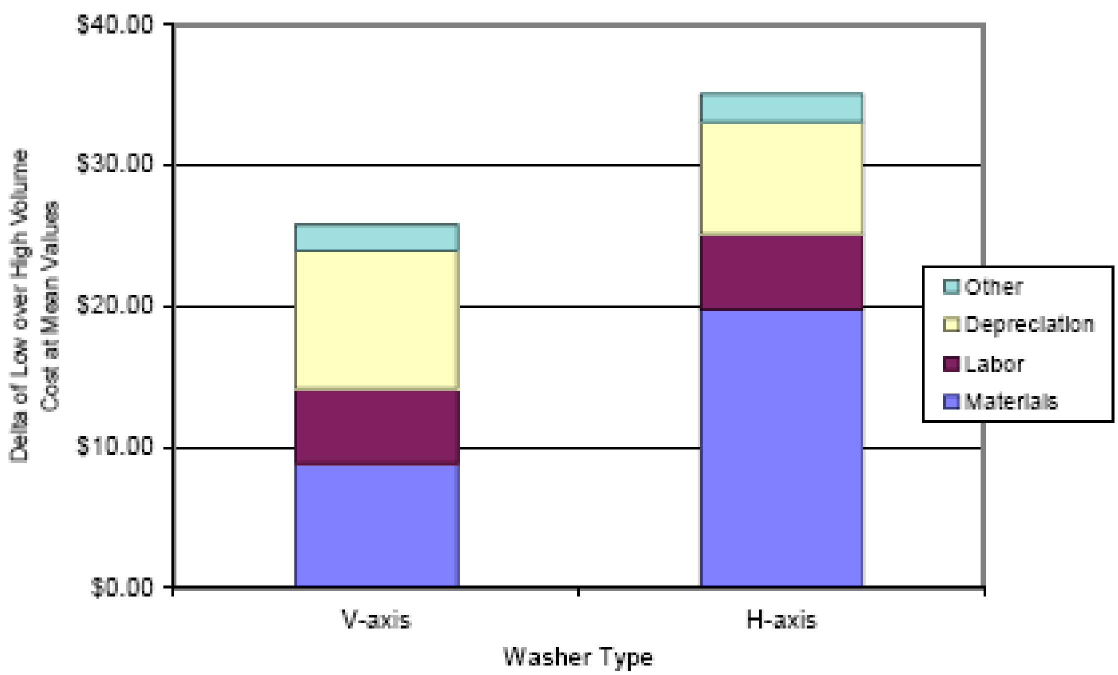


**Figure 5.6.17 2000 Low-Volume versus High-Volume Clothes Washer Cost Disadvantage**

While the units under review in the 2000 residential clothes washer TSD are not applicable to the current CCW analysis, the impact of manufacturing scale is still relevant to the CCW market. As manufacturing volumes shrink, labor costs rise due to growing inefficiencies within the fabrication and assembly lines. The effect of manufacturing scale on depreciation is even more pronounced, as there are minimum tooling and equipment investments required to start operations, regardless of what the actual manufacturing volume turns out to be. Careful design will minimize the amount of additional tooling required to bring a new product to market.

Results from the 2000 TSD analysis for the effects of manufacturing scale are presented as follows, recognizing that similar results will likely apply to CCWs. Figure 5.6.18 examines the case of very low-production volumes (100,000 units per year) versus producing at high volumes (1,500,000 units per year). Driven mainly by increases in depreciation costs, the very low-volume manufacturing cost increment over high-volume manufacturing increases to about $80 for both top-loading vertical-axis and front-loading horizontal-axis clothes washers.

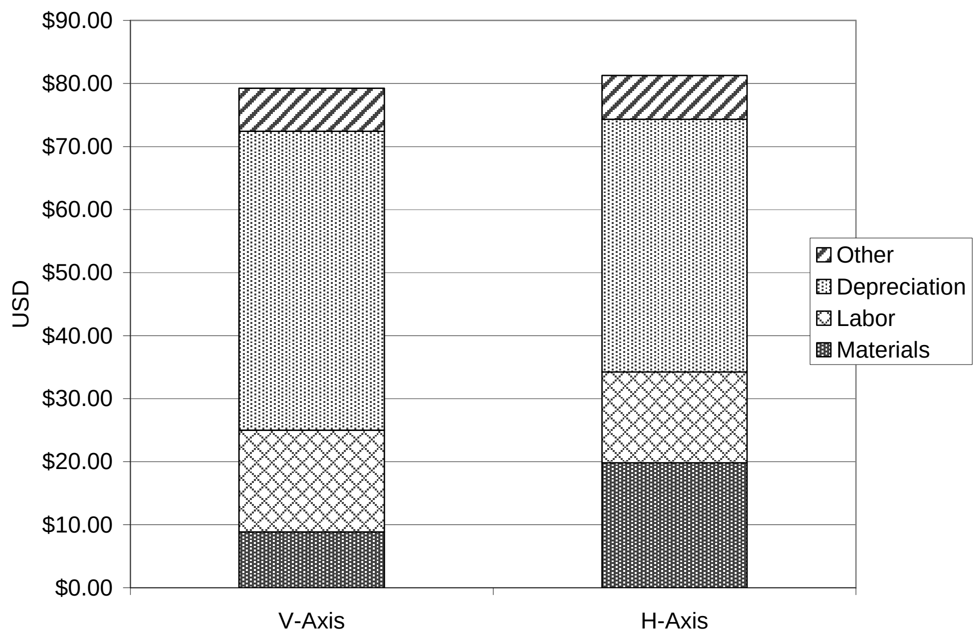


**Figure 5.6.18 2000 Cost Disadvantage of Producing 100,000 versus 1.5MM Clothes Washers per Year with Green Field Facility**

The agitator top-loading clothes washer market is largely commoditized, resulting in fierce price competition. A $156 price difference for the end user ($80 manufacturing cost multiplied by a 1.93 total markup (see chapter 7 of this TSD)) is not likely to be sustainable. However, the LVM is aided in this product segment by the extant tooling and equipment, years of research and development, etc. which represent a sunk cost.

In contrast, the front-loading clothes washer manufacturing line would have to increase its output by multiples to meet the unit demand that the top-loading line currently sustains. Since the two platforms do not share many components, the top-loading line would be likely to be written off, while substantial investments would be required to expand the output of the front-loading line. Such investments may not be justified by the potential market for them, and the larger rivals have a great advantage in terms of leveraging their residential clothes washer shipments to minimize depreciation on a per-unit basis.

Thus, while the LVM may be able to compete with its bigger rivals on the agitator top-loading platform due to depreciated plant and equipment, prior high-volume experience, and a long learning curve, it would be competing at a great disadvantage with its larger rivals should front-loading CCWs become the only platform that can meet future energy efficiency standards.

Manufacturers operating at very low volumes are likely to face margin pressure for both top- and front-loading clothes washers. To counter pressure from high-volume manufacturers, low-volume producers have to compete on the basis of service, reliability, bundling, and product differentiation. Its long legacy in the agitator top-loading market also aids the LVM in competing successfully with larger rivals.

*Conclusion*

In conclusion, the LVM faces larger rivals in all of the clothes washer markets it competes in, yet the LVM has been able to grow its revenue despite being heavily concentrated in the stagnant CCW market. As a result, the elimination of the agitator top-loading clothes washer platform from the CCW market would impact this manufacturer disproportionately and could therefore represent a material risk to the company.

***Other Observations Regarding the 2000 Residential Clothes Washer TSD***

*Historic Background*

When DOE began the 2001 residential clothes washer rulemaking, the U.S. residential clothes washer market consisted almost exclusively of top-loading vertical-axis platforms. Table 3.9 in the 2000 TSD noted that top-loading vertical-axis clothes washers comprised a 99.9 percent market share as of 1995. Available front-loading horizontal-axis clothes washers were limited to imported goods and two domestic platforms. While the majority of overall clothes washer shipments in the United States still consist of top-loading clothes washers, the shipment levels and market share of front-loading clothes washers have grown significantly.

Unlike in 1995, all remaining U.S. manufacturers now sell front-loading clothes washers that are either produced in their own factories or outsourced. The majority of residential front-loading clothes washers sold in the United States today are manufactured abroad. While a greater proportion of CCWs are made domestically, significant market scale differences remain. Thus, as markets for top-loading clothes washers decline, domestic clothes washer production will likely decline also.

In the 1996 AHAM data submittal, the maximum potential improvement was capped at an MEF of 1.634, whereas front-loading clothes washers from multiple vendors currently reach MEFs in excess of 2.00. Manufacturers have also increased the basket capacity of top- and front-loading clothes washers, reaching up to 4.7 $ft^3$ in some residential models. The WFs are also significantly lower on several current front-loading clothes washers found in either residential or CCW markets than they were for models in the 2000 TSD.

As a result of the residential clothes washer rulemaking, the standards for residential clothes washers were increased in two steps, reaching an MEF of 1.26 as of January 1, 2007. When that standard was issued, no front-loading clothes washer MEFs were below 1.26. Thus, only top-loading clothes washers were affected by the rulemaking. In the interim, manufacturers worked to find the most cost-effective way to modify their top-loading platforms to meet the current minimum MEF.

At the time of the 2000 TSD, a correlation was noted and assumed between MEF and WF (see Table 5.6.33). However, no WF was imposed in the final rulemaking. As a result, manufacturers could largely focus on reducing the energy content of the wash and rinse water rather than having to jointly focus on the MEF and the WF. None of the agitator top-loading clothes washers that currently meet the 1.26 MEF minimum efficiency standard also reach the WF predicted for that efficiency level by the 2000 TSD. Typically, such current top-loading clothes washers use two more gallons of water per $ft^3$ of capacity than the WF associated with the 1.26 MEF standard in the 2000 TSD.

*Impact of Product Test Procedures*

EPACT 2005 amended EPCA to require DOE to rate CCWs with the same test procedure established for residential clothes washers. (42 U.S.C. 6314(a)(8)) DOE adopted test procedures for CCWs in a final rule published on October 18, 2005. 70 FR 60407, 60416. The testing procedure for residential clothes washers is codified in 10 CFR part 430, subpart B, appendix J1.

When calculating MEF, the DOE test procedure factors in end-user-selectable variables including the wash and rinse water temperatures, and fill level. Thus, adaptive water levels (either user-set or automatic) and temperature choices are accounted for in the calculation. Some design options, such as reducing the amount of rinse water, have an efficiency benefit regardless of the user-set program. These and other design options have allowed the three highest-volume CCW manufacturers to reach the 1.26 MEF standard level at relatively low cost by making evolutionary changes to their top-loading platforms.

For example, the calculated MEF is a function of the cycle water temperatures. By requiring a cold rinse and offering more warm or cold wash programs while reducing the number of hot wash cycle options, the MEF of a washer can be raised without affecting the WF. The incremental cost of offering more wash temperatures or lowering the temperatures overall is relatively minor. Similarly, the added cost and complexity of offering a water level selector switch is relatively minor but it allows manufacturers to take advantage of the credits that the DOE test procedure gives to washers that have this design option.

At the time of the AHAM data submittal for the 2000 TSD, clothes washer manufacturers had little experience with the updated clothes washer test procedure, which was not published in the *Federal Register* until August 27, 2000. The only top-loading clothes washers on the market at the time that could reach an MEF of 1.26 were proprietary in design. Furthermore, the clothes washer manufacturing cost estimates for the 1.26 MEF levels were an amalgam of the high-cost proprietary top-loading design and several front-loading washers.

In conclusion, the cost of upgrading top-loading washers to reach an MEF of 1.26 was lower than manufacturers estimated according to the AHAM-supplied data. No expensive design options had to be employed to push the top-loading platform to that MEF level. Therefore, DOE believes that the current manufacturing cost of an agitator top-loading clothes washer that meets the 1.26 MEF/9.5 WF efficiency level is within 10 percent of the cost of a baseline washer in Table 5.6.33 once these costs are adjusted for inflation.

*Persistence of Baseline Top-loading versus Front-loading Clothes Washer Cost Differential*

Since the publication of the 2000 TSD, the clothes washer market has been transformed by the entrance of more foreign competitors, significant market consolidation, and the appearance of residential clothes washers that have higher load capacities than the basket-capacity limits defined by EPACT 2005. For example, front-loading residential clothes washers from BSH Home Appliances Corporation (Bosch-Siemens), GE, LG Electronics, Inc. (LG), and Whirlpool have a stated basket capacity in excess of the 3.5 $ft^3$ capacity product class definition limit set by EPACT 2005 for residential clothes washers.

Despite the entrance of multiple front-loading clothes washers into the commercial and residential markets, a significant retail price difference between agitator top- and front-loading clothes washer platforms persists. This suggests that manufacturers have yet to overcome the inherently higher costs associated with manufacturing front-loading clothes washer platforms.

These cost differences are due in part to the suspensions, seals, drive systems, and stainless-steel wash baskets that front-loading clothes washers employ and which can be simpler, unnecessary, and/or less expensive in baseline top-loading models. The higher strength, stiffness, and vibration-resistance requirements for front-loading clothes washers add further cost and complexity. Electronic drive systems are found in all front-loading clothes washers, whereas simpler and less expensive induction motors are typically found on baseline top-loading clothes washers.

High-volume manufacturers of top-loading clothes washers also benefit from a plant and equipment stock that have been largely depreciated, yet remain functional. The growth in front-loading clothes washer sales continues to demand factory expansion and the resultant investments.

As noted above, the reverse-engineering analysis of the 2000 residential clothes washer TSD is largely not a valid basis upon which to compare costs in the commercial market. However, it is interesting to note how manufacturers were able to meet the current 1.26 MEF residential clothes washer standard with little to no additional manufacturing cost. Thus, the cost of a baseline top-loading washer has not changed much in the interim, other than to reflect changes in raw materials costs. Front-loading clothes washer costs are similarly affected, so that the manufacturing cost differential between the two residential clothes washer platforms has remained largely the same.

The retail pricing survey for this current TSD underscores this persistent differential, as noted in Figure 3.11.1 in chapter 3 of this TSD. This figure demonstrates that the average retail price difference between commercial top-loading and front-loading washers varies between $531 for washers with coin boxes and $625 for washers without coin boxes. As noted in chapter 7 of this TSD, the total markup from manufacturer to end user is 1.93 for CCWs. Therefore there is a manufacturing cost difference of $275 to $327 between top-loading and front-loading CCW platforms.

This difference is about $100 higher than the average difference calculated in the 2000 residential clothes washer TSD between a baseline top-loading and two front-loading clothes washers that were subjected to reverse-engineering analysis. However, the residential designs were produced at much a higher manufacturing scale, suggesting higher cost optimization, better purchasing power, and lower raw material costs. Higher-volume manufacturing allows a manufacturer to consider more platform and design options that could not be economically justified at a very low manufacturing scale.

Thus, the $316 cost difference in the AHAM-submitted data for top-loading and front-loading CCWs is plausible. A cost difference higher than that found in the residential market is reasonable since CCWs are designed to be more rugged, are required to be more reliable, and are produced at a much lower scale. As a consequence, manufacturers cannot readily cost-optimize front-loading designs to the extent that they have been able to refine their extant top-loading units. In addition, even an optimized front-loading CCW will remain inherently more expensive to produce than a high-volume residential model built on the same platform due to the volume over which customized items like controllers have to be depreciated.

## REFERENCES


[1] U.S. Department of Energy (DOE). 1996. *Technical Support Document for Residential Cooking Products.* Washington, DC. Available online at http://www.eere.energy.gov/buildings/appliance_standards/residential/cooking_products_0998_r.html

[2] American Metals Market. Available online at http://www.amm.com/.

[3] Association of Home Appliance Manufacturers (AHAM). 2006. *AHAM Test Data on Microwave Ovens*. October 23, 2006. Docket No. EE-2006-STD-0127, Comment Number 17.

[4] *Ibid*.

[5] *Ibid*.

[6] *Ibid.*

[7] *Ibid*.

[8] *Ibid*.

[9] Fish, N. *et al*. 2006. *Standby Power Energy Use of Common Household Appliances*. Canadian Building Energy End-Use Data and Analysis Centre, CBEEDAC 2006-RP-04-DRAFT, July 2006.

[10] Aulenback, A. *et al*. 2001. *Stand-By Power Requirements for Household Appliances*. Canadian Residential Energy End-Use Data and Analysis Centre, CREEDAC-2001-05-04, May 2001.

[11] *Ibid*.

[12] Lawrence Berkeley National Laboratory (LBNL). 1999. *Standby Power Summary Table*. Available online at http://standby.lbl.gov/Data/SummaryTable.html.

[13] Floyd, D. and Webber, C. 1998. "Leaking Electricity: Individual Field Measurement of Consumer Electronics." *Proceedings of American Council for an Energy-Efficient Economy*, Florida Solar Energy Center, August 1998.

[14] Meier, A. and Huber, W. 1997. *Results from the Investigations on Leaking Electricity in the USA*. Lawrence Berkeley National Laboratory, Berkeley, CA, LBNL-40909, 1997.

[15] AHAM. 2006. *Op. cit*.

[16] U.S. Department of Energy (DOE). 1980. *Engineering Analysis*. Washington, DC, DOE/CS-1066, June 1980.

[17] AHAM. 2006. *Op. cit*.