ELECTRIC POWER RESEARCH INSTITUTE

# Residential Appliances: Energy Efficiency and Technology Trends

**1018980**

# Residential Appliances:
# Energy Efficiency and Technology Trends

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Technical Update, December 2009

EPRI Project Managers

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# PRODUCT DESCRIPTION

Although residential appliance efficiency has improved significantly over the past three decades, greater efficiency is feasible. A number of design options are in fact available to improve the efficiency of residential appliances, varying by equipment, but including power electronics and digital controls, advanced motors, improved materials and insulation, changes in refrigerants, and enhanced configuration and design integration. This technical update focuses on energy efficiency and electricity use of U.S. residential appliances as of 2009, with information on options for increasing the efficiency or reducing the use of this class of products.

## Results and Findings

The residential appliances addressed in this report—clothes washers and dryers, refrigerators and freezers, cooking equipment, and dishwashers (“white goods”)—account for about 20% of residential electricity use in the average U.S. household. With average U.S. household electricity consumption at ~12,400 kWh per year, 20% translates into ~2480 kWh per household per year. This usage is even higher when including electricity used to heat water that services clothes washers and dishwashers.

Considerable strides have been made in recent decades in the efficiency of appliances, but significant improvements are technically feasible through upgrading appliance components, controls, and materials. Energy-efficient residential technologies that might be considered advanced or emerging can also make a difference. In particular, the report notes that heat pump clothes dryers and induction cooktop technologies can decrease appliance electricity use. Heat pump clothes dryers are not yet commercially available in the United States, although they are widely used in Europe and Asia. Induction cooktops are offered in the United States, and the latest generation of this technology—albeit a small segment of the residential cooking equipment market—is a growing portion of the high-end cooking product sales.

Not only *can* appliance efficiency be increased, but also it most certainly will see increases, as the U.S. Department of Energy updates or develops new federal energy efficiency appliance standards for many products, including refrigerators and freezers, clothes washers and dryers, and dishwashers. Plans for updating these appliance standards are outlined in this report.

## Challenges and Objective(s)

The objective of this project is to provide a reference with information on basic appliance technology, energy use, and the status of efficiency improvement efforts in the United States. This technical update is intended as an overview of appliance electricity use and technologies for energy efficiency program managers and those involved in residential sector electricity use issues.

## Applications, Values, and Use

Peak load savings can be achieved with greater appliance energy efficiency. Savings will vary by utility, depending on utility load shapes and coincidence of end uses with peak demand. EPRI analysis shows that residential appliances account for about 15% of average U.S. summer residential sector peak demand.

## EPRI Perspective

Utilities are looking to energy efficiency to help meet the challenges of maintaining reliable and affordable electric service, wisely managing energy resources, and reducing carbon emissions. The residential sector will need to be a part of an energy efficiency strategy, and understanding prospective and impending changes in the efficiency of household appliances will help inform program planning for the mass market.

## Approach

This report is based on secondary research—compiling results of several government studies—as well as interviews with industry experts. This report was produced as part of EPRI Program 170—End Use Energy Efficiency and Demand Response.


## Keywords

Clothes Washers
Clothes Dryers
Dishwashers
Induction Cooking
Refrigerators
Freezers
Residential Appliances
Energy Efficiency

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# CONTENTS

# 1
# INTRODUCTION AND OVERVIEW

This Technical Update is a snapshot of the electricity use and energy efficiency trends of residential appliances in 2009. The appliances addressed in this update include those traditionally referred to as "white goods":

- Refrigerators and freezers
- Cooking equipment (with a focus on induction cooktops)
- Clothes washers and dryers
- Dishwashers

Information provided is based primarily on secondary research, including a literature review and interviews with industry experts and manufacturers. This document compiles results of several government and other studies and is intended as a review of energy consumption and an examination of technologies and approaches that can improve the energy efficiency (or reduce energy use) of residential appliances. It was produced as part of the EPRI Energy Efficiency and Demand Response Program's (Program 170).

## 1.1 A Significant Load with Potential for Greater Efficiency

Residential appliances covered in this report represent about 20% of household electricity use. With an average U.S. household's electricity consumption at about 12,400 kWh per year, 20% translates into 2480 kilowatt hours (kWh) per household (hh) per year (excluding indirect electric water heating energy for clothes washing and dishwashers).

Peak load savings can also be achieved with greater appliance energy efficiency. This will vary by utility, depending on the utility load shapes and coincidence of end uses with peak demand. EPRI analysis shows that residential appliances account for about 15% of average U.S. summer residential sector peak demand.

Although residential appliance efficiency has improved significantly over the past three decades, greater efficiency is feasible. A number of design options are available to improve the efficiency of residential appliances, varying by equipment, but including power electronics and adaptive controls, advanced motors, improved materials and insulation, changes in refrigerants, and enhanced configuration and design integration. For clothes washers and dishwashers, measures include those that reduce the amount of water needed.

Boosting efficiency is mostly a matter of combining or integrating more efficient components or materials rather than using alternative, new technologies. However, in the case of clothes dryers and cooktops, "new" technologies can make a difference. In particular, heat pump clothes dryers and induction cooktops are technologies that can affect appliance electricity use. Neither of these technologies are new in the sense that they have been recently developed. However, they are new in terms of potential to capture a portion of the U.S. appliance market.

Heat pump clothes dryers are not yet commercially available in the U.S., but are offered in Europe and Asia, and are poised to change the efficiency of U.S. clothes dryers if introduced by manufacturers serving the U.S. market. Induction cooktops are available in the U.S., and in recent years the latest generation of this technology, albeit a small segment of the residential cooktop market, is a growing portion of the high-end cooking product sales.

Not only *can* appliance efficiency be increased, it *will* increase, as the Department of Energy updates federal energy efficiency appliance standards for many products, including refrigerators and freezers, dishwashers, clothes washers, and clothes dryers. The following section summarizes federal standards for residential appliances.

## 1.2 U.S. Federal Energy Efficiency Standards

Energy efficiency standards for appliances are a pillar of national energy policy on residential energy use. U.S. federal energy efficiency standards for residential appliances came into being in 1987, when Congress passed the National Appliance Energy Conservation Act (NAECA). This legislation required minimum energy efficiency standards for 13 major residential appliances, and required the U.S. Department of Energy (DOE) to periodically review and update the standards, with the goal of maximum improvement that is both technically feasible and economically justified.

In subsequent years of 1992, 2005, and 2007 Congress enacted additional laws establishing standards. The Energy Independence and Security Act (EISA) of 2007 is the most recent. A summary of the standards affecting the residential appliances covered in this report is provided in **Table 1-1**.

## Table 1-1 U.S. Federal Standards Status and Schedule

| Product Category | Current Standard | Status of Updates or New Standards | Final Action Date | Effective Date | Comment |
|---|---|---|---|---|---|
| Refrigerators and Freezers | Standards in effect as of 2009 became effective in 2001, and are based on maximum allowable energy use in kWh/yr based on adjusted volume (AV) in cubic feet for each product type and configuration. For example, the standard for a refrigerator-freezer with a top-mounted freezer and automatic defrost is 9.80AV + 276.0 or 491.6 kWh/yr for a 22 cu ft unit. | EISA 2007 requires that DOE consider strengthened standards per the timetable to right. | Dec 2010 | 2014 | A preliminary DOE Technical Support Document was published by DOE in November 2009. See http://www1.eere.energy.gov/buildings/appliance_standards/residential/refrigerators_freezers_prelim_tsd_mtg.html/ |
| Cooking Appliances | Standard outlaws constant burning pilot lights in gas stoves and ovens. | DOE rulemaking for microwave oven standby power | March 2011 | 2014 | |
| Clothes Dryer | Current standard for electric vented dryers is minimum energy factor of 3.01 lb/kWh, and dryers are required to have sensors for termination control. (Pilot lights in gas dryers have been banned since 1987.) | DOE rulemaking for a new standard began in 2007. | June 2011 | 2014 | No technical analysis has yet been issued and test procedures have not been updated since the 1980s. Dryers require no Energy Guide label and none are ENERGY STAR labeled, since units use about the same amount of energy. |
| Residential Clothes Washers | Current standards require a modified energy factor[a] (MEF) of at least 1.26 | EISA 2007 requires water efficiency standards for the first time (a water factor[b] [WF] of 9.5 or less by 2011); energy efficiency standards were left the same. Rulemaking to assess stronger standards planned by 2011. | Dec 2011 | 2015 | |
| Dishwashers | The current standard, established in a 2003 rulemaking, is an energy factor (EF) of 0.46 cycles/kWh for standard size dishwasher for "normal" cycle. | EISA 2007 requires water efficiency standards for the first time. | Jan 2015 | | The ratings are being switched from an EF to a kWh/yr metric. |

Notes:

a Modified energy factor (MEF) = a combination of energy factor and remaining moisture content. This is a measurement of how many cubic feet of laundry can be washed and dried with one kilowatt hour. (The remaining moisture content affects the energy use of the dryer). The higher the number, the greater the efficiency.

b Water factor (WF)= Number of gallons of water needed for each cubic foot of laundry. The lower the number, the more efficient use of water.

With new and updated standards imminent, manufacturers will be investing considerable amounts of money in manufacturing capacity and revamped production lines for new designs. Appliance industry manufacturers interviewed for the Department of Energy's 2005 technical support analysis of standards for refrigerator-freezers reported that the level of investment for the 2001 change in refrigerator standards was close to a billion and a half dollars.[1]

As one manager at an appliance manufacturer noted in an EPRI interview, "Tooling is so expensive, we don't change unless it entails a significant performance improvement."[2] So in times of major change, like new federal standards, it is a good time for utilities to consider how their efficiency, incentive, and market transformation programs will influence, and operate in, the residential appliance market that manufacturers are planning for. As the average efficiency of residential appliances continues to increase through standards, utility programs need to respond so that they promote appliances that are considerably more efficient than standard efficiency products.

Programs can influence manufacturer production. For example, DOE interviewed refrigerator manufacturers about their production of ENERGY STAR units and found that:

> *Manufacturers noted that they often do not necessarily maintain their margins for higher-cost Energy Star units because they believe that consumers do not think that the additional costs can justify the relatively modest savings. To date, however, many have produced Energy Star units because they need them to have their product line marketed via major retail chains, to sell to government, and to have their products part of utility rebate programs. —DOE's Analysis of Amended Energy Conservation Standards for Residential Refrigerator-Freezers*[3]

## 1.3 Labeling: EnergyGuide and ENERGY STAR®

To enable consumers to make more informed choices when purchasing appliances, U.S. government agencies offer two labeling programs. One is mandatory for certain appliances, the U.S. Federal Trade Commission's (FTC) EnergyGuide. The other is voluntary, the U.S. Environmental Protection Agency and Department of Energy's ENERGY STAR label.

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[1] Technical Report: Analysis of Amended Energy Conservation Standards for Residential Refrigerator-Freezers. U.S. Department of Energy: Washington, DC. (October 2005) Downloaded from http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/refrigerator_report_1.pdf/
[2] D. Najewicz, GE Appliances, personal communication. October 2009
[3] Technical Report: Analysis of Amended Energy Conservation Standards for Residential Refrigerator-Freezers. U.S. Department of Energy: Washington, DC. (October 2005) Downloaded from http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/refrigerator_report_1.pdf/

### 1.3.1 U.S. EnergyGuide Label

The Federal Trade Commission issues rules for labeling energy use of residential clothes washers, dishwashers, refrigerators, freezers, and dishwashers (as well as water heaters, window air conditioners, central air conditioners, furnaces, boilers, heat pumps, and pool heaters). No labels are mandated for clothes dryers or cooking equipment.

The most prominent feature on EnergyGuide labels for most appliances is an estimate of what it costs to run that model for one year, along with the highest and lowest operating costs for competing models. (See **Figure 1-1** for an example label.) Prior to 2007 the label showed the annual kWh usage more prominently than cost. An estimate of actual energy use is still included in the label.

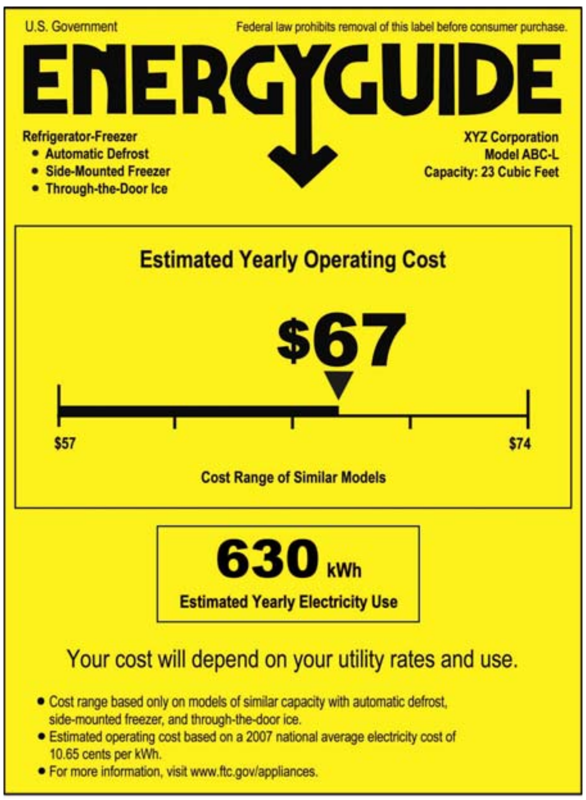


**Figure 1-1 Example U.S. EnergyGuide Label**

*Source: Federal Trade Commission (www.ftc.gov August 7, 2007 press release)*

### 1.3.2 ENERGY STAR®

A joint program of the EPA and DOE, ENERGY STAR was created in 1992 as a voluntary labeling program to help consumers identify energy-saving equipment. Initially focused on computers and monitors, residential dishwashers and refrigerators were added in 1996 and clothes washers in 1997. (No ENERGY STAR labels are provided for clothes dryers or residential cooking equipment.)

Performance levels to attain an ENERGY STAR label are tied to the federal energy efficiency standards, with ENERGY STAR models required to attain a certain "percent better" than the standard, such as ENERGY STAR refrigerators, which must be at least 20% better than the standards. For appliances like dishwashers and clothes washers that include water usage thresholds, criteria are presented in metrics that address both energy use and water use.

ENERGY STAR requirements have evolved along with the standards, and Congress also mandates when EPA and DOE should create new criteria levels. For example, the Energy Policy Act of 2005 mandated that ENERGY STAR clothes washer criteria be established.

In addition to significant energy savings, guidelines for creating an ENERGY STAR designation for a product include that there be no impact on product performance, that it be cost effective, that several technology options can achieve the criteria, that the label differentiates the product and that energy consumption can be quantified.[4]

Meeting ENERGY STAR criteria relies on a manufacturer self test, and testing of ENERGY STAR products has been an issue of concern in 2009. The DOE and EPA recently entered into a memorandum of understanding to address some shortcomings in testing procedures revealed in a DOE internal audit. According to an October 19, 2009 article in the *New York Times*, the DOE audit found that the department "does not properly track whether manufacturers that give their appliances an ENERGY STAR label have met the required specifications for energy efficiency."[5] At a 2009 ENERGY STAR Appliance Partner Meeting, DOE staff noted that the department is designing and will implement a third party independent testing program to be able to test off-the-floor appliances for ENERGY STAR compliance.

DOE reports[6] that in 2008, the national share of appliances sold that had an ENERGY STAR label were:

Clothes washers – 24%

Dishwashers – 67%

Refrigerators – 31%

ENERGY STAR offers a wealth of information and resources online for both consumers and organizations in the energy or appliance industry. The ENERGY STAR webpage "Partner Resources" provides materials tailored to different groups, including utilities, such as lists of qualified products, ENERGY STAR criteria, market assessments, brochures, and training materials for ENERGY STAR related programs, including how to promote ENERGY STAR to retailers and to consumers. See the URL www.energystar.gov, view Partner Resources, and ENERGY STAR Training Center.

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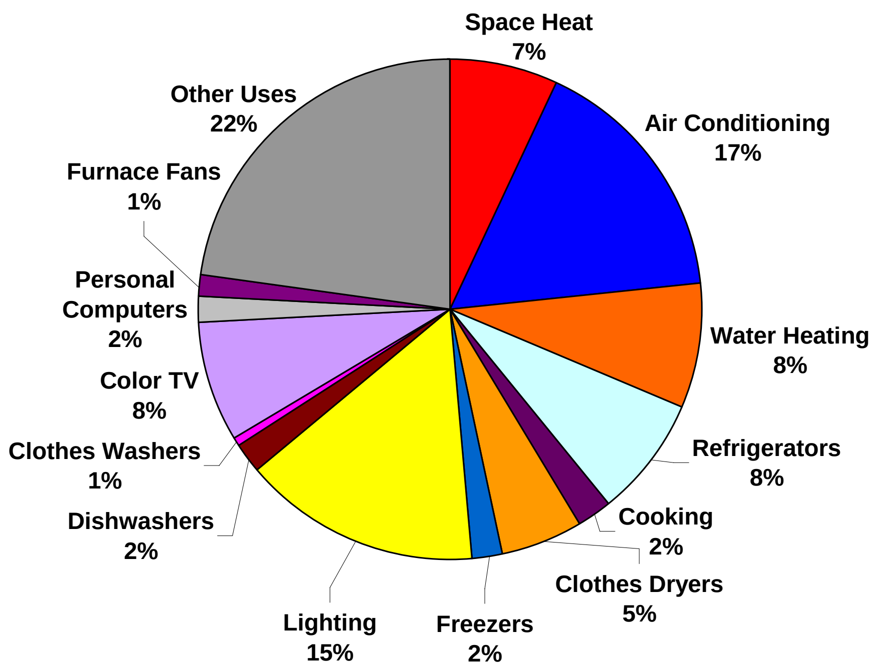
[4] Seize the ways! ENERGY STAR® 10th Annual Appliance Partner Meeting, Chicago IL. September 21-23, 2009.

[5] Matthew L. Wald, "Energy Star Appliances May Not All Be Efficient, Audit Finds," *New York Times*. October 19, 2009. Downloaded from www.nytimes.com/.

[6] Seize the ways! ENERGY STAR® 10th Annual Appliance Partner Meeting, Chicago IL. September 21-23, 2009.

## 1.4 Energy Use of Residential Appliances

Residential appliances account for about 20% of an average U.S. household's electricity use, excluding energy use by electric water heaters that serve the clothes washer and dishwasher (about 45% of water heaters in the U.S. are electric[7]). A breakdown of average electricity consumption by end use is provided in **Figure 1-2**.




Source: 2008 Annual Energy Outlook

**Figure 1-2 2008 U.S. Residential Electricity Use by End Use**

The average energy use of appliances in U.S. households is listed, by region and for the nation, in **Table 1-2**. This is the average across all households, not just those households that have a particular appliance. For example, nationally, electric clothes dryers are present in only 62% of U.S. households (an additional 20% have gas dryers),[8] so the average electricity use of dryers across all households is lower than the unit energy use (UEC) of an electric clothes dryer, which about 1067 kWh/yr.[9]

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[7] 31st Annual Portrait of the Appliance Industry, "The Saturation Picture," *Appliance Magazine*. September 2008
[8] Ibid.
[9] End-Use Consumption of Electricity 2001, available at http://www.eia.doe.gov/emeu/recs/contents.html . According to the EIA, sampling issues with updated data collected in 2005 have prevented release of 2005 data.

**Table 1-2 2008 U.S. Residential Electricity Use per Household by Region (kWh/household)**

| | Northeast | Midwest | South | West | U.S. |
|---|---|---|---|---|---|
| Space Heat | 538 | 784 | 1,163 | 616 | 845 |
| Air Conditioning | 753 | 1,425 | 3,617 | 1,184 | 2,064 |
| Furnace Fans | 251 | 316 | 84 | 97 | 170 |
| Water Heating | 476 | 743 | 1,631 | 574 | 988 |
| Refrigerators | 960 | 1,055 | 961 | 908 | 977 |
| Freezers | 138 | 279 | 221 | 181 | 211 |
| Dishwashers | 205 | 245 | 257 | 237 | 243 |
| Cooking | 180 | 260 | 365 | 209 | 274 |
| Clothes Washers | 79 | 95 | 92 | 81 | 88 |
| Clothes Dryers | 424 | 674 | 858 | 488 | 658 |
| Lighting | 1,708 | 1,936 | 1,980 | 1,802 | 1,895 |
| Personal Computers | 202 | 210 | 206 | 191 | 204 |
| Color TV | 932 | 1,003 | 990 | 888 | 966 |
| Other Uses | 1,947 | 2,902 | 3,677 | 1,997 | 2,823 |
| **Total** | **8,793** | **11,927** | **16,101** | **9,454** | **12,407** |

*Source: 2008 Annual Energy Outlook Reference Case*

## 1.5 Peak Demand of Residential Appliances

EPRI estimated in its study *Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S.*,[10] that U.S. summer peak demand of residential appliances (refrigerators, freezers, dishwashers, cooking equipment, clothes washer and clothes dryers) is 0.51 kW per average U.S. household, out of a total peak demand of 3.38 kW/hh (See **Table 1-3** and **Figure 1-3**.) This is about 15% of residential sector summer peak demand. In aggregate, this represents 58,018 MW of peak demand in 2008, and is projected to grow proportionally to 81,370 MW by 2030.

[10] *Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S. (2010 – 2030).* EPRI, Palo Alto, CA: 2009. 1016987.

**Table 1-3**
**2008 Residential Summer Peak Demand by Region and End Use (kW/household)**

| | Northeast | Midwest | South | West | U.S. |
|---|---|---|---|---|---|
| Space Heat | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Air Conditioning | 1.43 | 2.04 | 2.42 | 1.47 | 1.95 |
| Furnace Fans | 0.01 | 0.02 | 0.03 | 0.02 | 0.02 |
| Water Heating | 0.31 | 0.44 | 0.52 | 0.32 | 0.42 |
| Refrigerators | 0.24 | 0.35 | 0.41 | 0.25 | 0.33 |
| Freezers | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Dishwashers | 0.02 | 0.03 | 0.04 | 0.02 | 0.03 |
| Cooking | 0.03 | 0.04 | 0.04 | 0.03 | 0.03 |
| Clothes Washers | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 |
| Clothes Dryers | 0.07 | 0.10 | 0.12 | 0.07 | 0.10 |
| Lighting | 0.25 | 0.35 | 0.42 | 0.25 | 0.34 |
| Personal Computers | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Color TV | 0.02 | 0.03 | 0.04 | 0.02 | 0.03 |
| Other Uses | 0.07 | 0.11 | 0.13 | 0.08 | 0.10 |
| **Total** | **2.48** | **3.54** | **4.19** | **2.54** | **3.38** |

Although cooling is the end use that offers the greatest potential for peak demand savings in the residential sector, appliances, particularly refrigerators, offer potential as well**.**

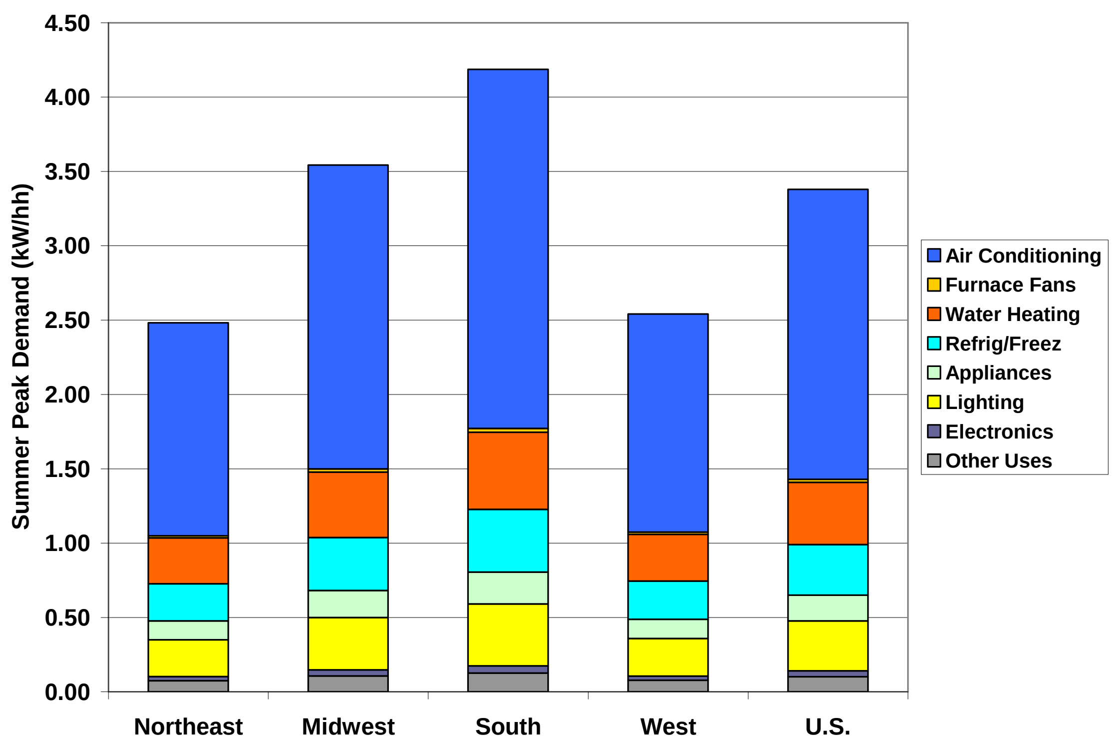


**Figure 1-3  2008 Residential Summer Peak Demand by Region (kW/household)**

### *1.5.1 Non-Coincident Summer Peak Demand Forecast*

EPRI's assessment of peak demand savings potential is based on forecasts of growth. The U.S. summer peak demand forecast grows at roughly the same rate across sectors (see **Table 1-4** and **Figure 1-4**). In absolute terms, the residential sector peak increases the most, by 154 GW. (The commercial sector summer peak increases by 101 GW. The 38% increase in the industrial sector summer peak is only 61 GW.)

**Table 1-4 U.S. Summer Peak Demand Forecast (GW)**

| | 2008 | 2010 | 2020 | 2030 | % Increase (2030/2008) | Average Growth Rate |
|---|---|---|---|---|---|---|
| Residential | 382 | 394 | 462 | 536 | 40% | 1.54% |
| Commercial | 258 | 266 | 310 | 359 | 39% | 1.50% |
| Industrial | 161 | 166 | 192 | 222 | 38% | 1.48% |
| **Total** | **801** | **826** | **964** | **1,117** | **39%** | **1.51%** |

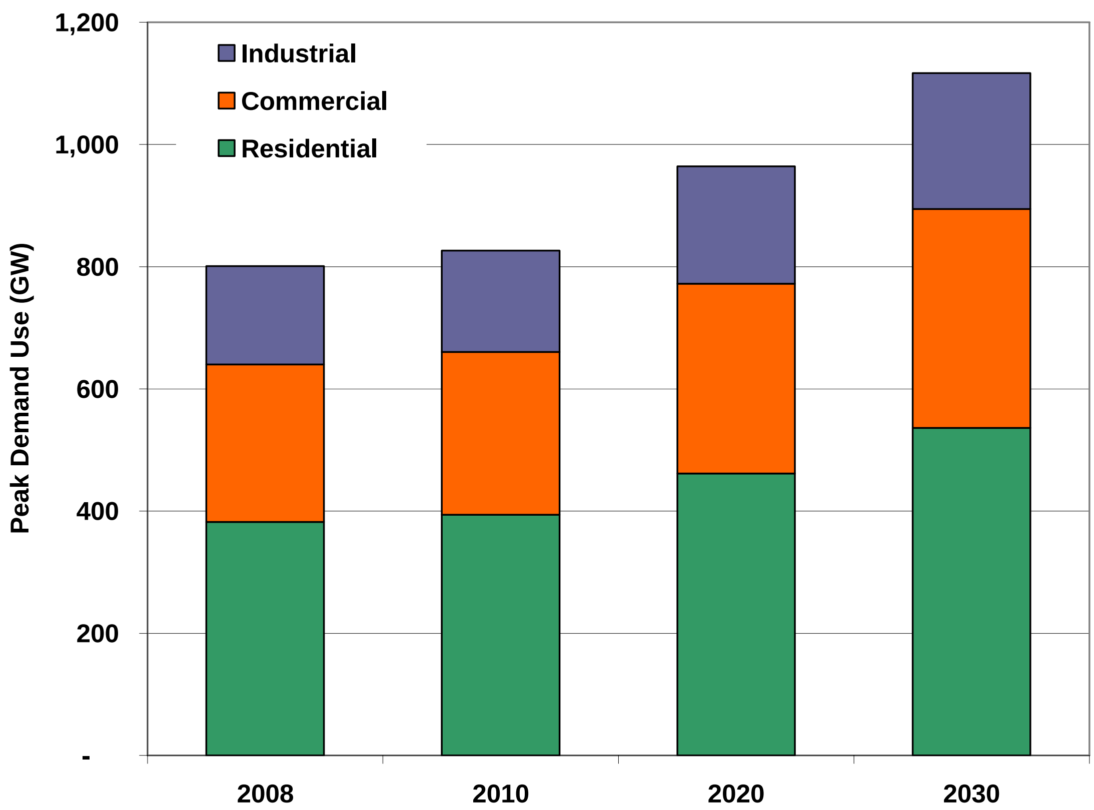


**Figure 1-4 Forecast of U.S. Summer Peak Demand by Sector (GW)**

### 1.5.1.1 Residential Sector Summer Peak Demand Forecast

The residential summer peak demand forecast grows by 40%, a 154 GW increase from 382 GW in 2008 to 536 GW in 2030. Air conditioning accounts for 89 GW of the increase, or almost 60%. All other end uses grow proportionately to the summer peak in 2008. **Figure 1-5** and **Table 1-5** show the residential summer peak forecast by end use.

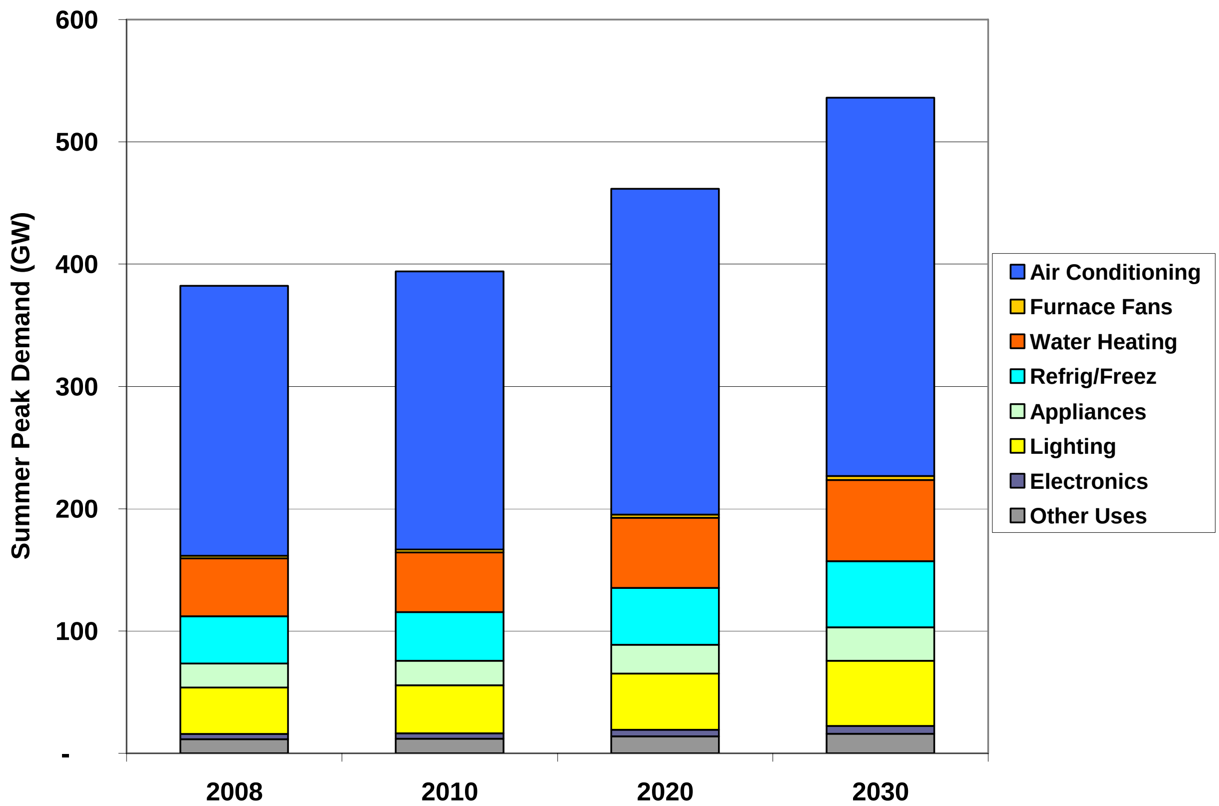


**Figure 1-5**
**Forecast of U.S. Residential Summer Peak Demand by End Use (GW)**

**Table 1-5**
**Forecast of U.S. Residential Summer Peak Demand by End Use (MW)**

| | **2008** | **2010** | **2020** | **2030** |
|---|---|---|---|---|
| Space Heat | 0 | 0 | 0 | 0 |
| Air Conditioning | 220,528 | 227,393 | 266,398 | 309,285 |
| Furnace Fans | 2,307 | 2,379 | 2,787 | 3,235 |
| Water Heating | 47,381 | 48,856 | 57,237 | 66,451 |
| Refrigerators | 37,437 | 38,602 | 45,224 | 52,505 |
| Freezers | 1,073 | 1,107 | 1,296 | 1,505 |
| Dishwashers | 3,363 | 3,468 | 4,062 | 4,717 |
| Cooking | 3,937 | 4,059 | 4,756 | 5,521 |
| Clothes Washers | 1,396 | 1,439 | 1,686 | 1,958 |
| Clothes Dryers | 10,812 | 11,149 | 13,061 | 15,164 |
| Lighting | 38,022 | 39,206 | 45,931 | 53,325 |
| Personal Computers | 866 | 893 | 1,046 | 1,214 |
| Color TV | 3,565 | 3,675 | 4,306 | 4,999 |
| Other Uses | 11,484 | 11,841 | 13,872 | 16,106 |
| **Total** | **382,170** | **394,067** | **461,662** | **535,985** |

### *1.5.2 Estimating Residential Appliance Peak Demand Savings*

The peak load savings that can be achieved by increasing the energy efficiency of appliances can be calculated using modeled and measured data, and is a function of the utility's load profile, the diversity and shape of end use loads, and the coincidence of the energy savings with peak demand.

The coincidence of peak demand and appliance energy use is illustrated in a residential load shape (**Figure 1-6**) featuring single family homes in the mountain region of the U.S. (The mountain region includes Arizona, Colorado, Idaho, New Mexico, Montana, Utah, Nevada, and Wyoming.)

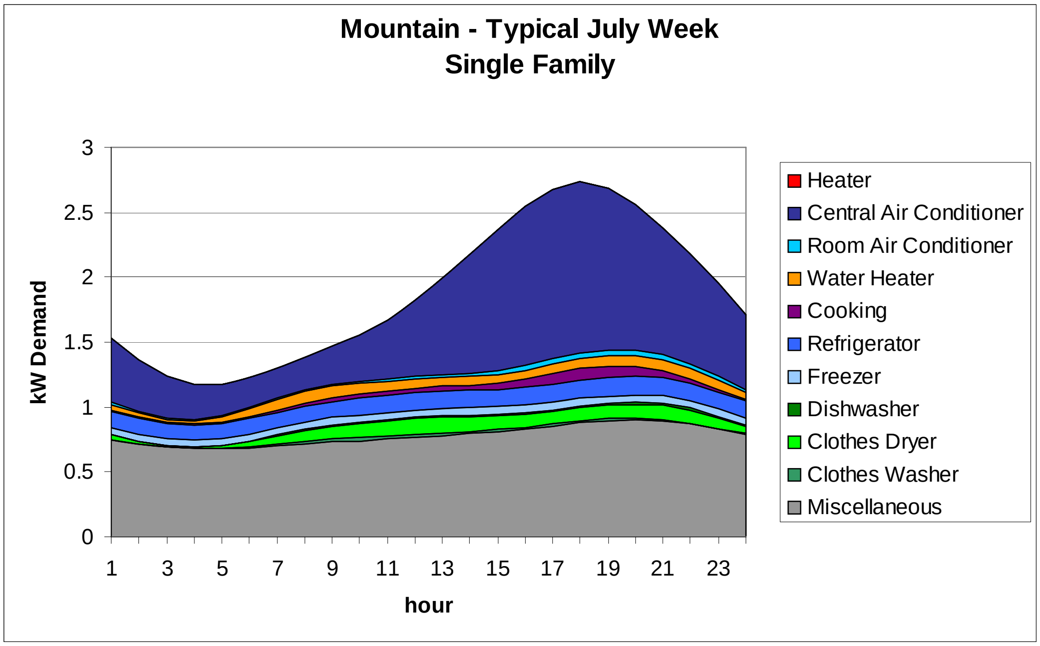


**Figure 1-6**
**Mountain July Weekday, Single Family**

Peak demand savings potential for specific utilities can be estimated using EPRI's model, the basis for the results presented in *Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S.*

The Lawrence Berkeley National Laboratory (LBNL) has also developed a spreadsheet method for calculating peak demand savings without use of a model, and has conducted studies related to the impact of various end use equipment on peak demand.[11]

Peak demand savings have already been achieved through increased residential appliance energy efficiency. For example, per an LBNL analysis for the Department of Energy of the program benefits of the ENERGY STAR program, annual peak demand savings achieved in 2007 from ENERGY STAR clothes washers, dishwashers, and refrigerators was 1.042 GW.[12] (See **Table 1-6**.)

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[11] See the Lawrence Berkeley National Laboratory's website for a list of publications and description of projects conducted. http://enduse.lbl.gov/Projects/peakdemand.html
[12] Maria Sanchez, Gregory Homan, and Richard Brown, Calendar Year 2007 Program Benefits for ENERGY STAR Labeled Products, Lawrence Berkeley National Laboratory. October 2008. LBNL-1217E

**Table 1-6 Achieved Annual Peak Savings in 2007**

| ENERGY STAR Residential Appliance | Peak Load Savings (GW) |
|---|---|
| Clothes Washer | 0.493 |
| Dishwasher | 0.306 |
| Refrigerator | 0.243 |
| TOTAL | 1.042 |

Estimated annual peak load savings in the U.S. in 2007 achieved by ENERGY STAR labeled appliances.

# 2
# REFRIGERATORS AND FREEZERS

If energy efficient appliances had a poster product, it would be the refrigerator. Today's average size unit uses less than a third of the electricity required by its counterpart of the 1970's. The 1970's model used about 1800 kWh/yr. In 1980 the average unit used 1276 kWh/yr, and today an average model, now somewhat larger, requires less than 500 kWh/yr. [13]

Trends affecting the electricity use and energy efficiency of refrigerators and freezers include the design of components such as compressors, which is covered in section 2.5, Design Options. In addition, the size of the unit, its configuration (such as location of the freezer compartment), as well as whether or not it has through-the- door ice dispensing will affect energy use. As illustrated by the requirements for standards shown in **Table 2-3**, a top mount refrigerator-freezer of the same size as a bottom mount unit will use less energy.

Another trend that affects energy use of refrigerators is the growing percentage of households that have more than one refrigerator. The refrigerator is a fixture in virtually every U.S. household, with a market saturation of close to 100%—and 26% of households have two or more refrigerators.[14] On average, a second unit uses 840 kWh/yr.[15]

## 2.1 Definition/Description

Per the Department of Energy, a refrigerator is a cabinet designed for storage of foods at temperatures above 32°F and below 39°F. It uses a single phase, alternating current input. The common refrigerator-freezer includes a freezer section in which foods can be stored at temperatures below 8°F. A stand alone freezer stores food at below 0°F.

The DOE categorizes refrigerators and freezers by a number of different characteristics:

- Type: whether it is a refrigerator only, refrigerator-freezer, or freezer only
- Geometry of configuration; i.e., position of the freezer compartment—top-, side-, or bottom-mount freezer
- Size: standard or compact (•7.75 cu. ft. volume and •36 inches in height)
- Defrost system; manual, partial, or automatic
- Presence of through-the-door (TTD) ice service

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[13] AHAM Energy Efficiency and Consumption Trends, Washington, DC. 2009. Available at www.aham.org/.
[14] Refrigerator Market Profile 2009. U.S. Department of Energy. Available at www.energystar.gov/.
[15] Ibid.

The most popular models in 2008 were refrigerator-freezers with top- or bottom-mounted freezers, and side-by-side models with through-the-door ice dispensing.[16]

## 2.2 Energy Use and Peak Demand

Refrigerators account for about 8% of residential energy use in the average U.S. household, and 977 kWh/yr according to estimates from the 2008 Annual Energy Outlook (AEO). Freezers, which are present as stand alone units in 32% percent of households,[17] average 211 kWh/yr electricity use across all residences. Stand alone freezers represent about 2% of U.S. residential electricity use.

The residential sector summer peak demand for refrigerators ranges from 0.24 kW to 0.41 kW depending on region, with an average residential U.S. summer peak demand of 0.33 kW (see Chapter 1, Table 1-3). Freezer residential summer peak demand is the same across regions, at 0.01 kW.

### *2.2.1 Reductions in Unit Energy Use*

The changes in energy use of new refrigerator models over nearly two decades is shown in **Table 2-1**, based in data from the Association of Home Appliance Manufacturers (AHAM).[18] Since 1990, energy consumption by unit has been reduced by almost half.

**Table 2-1 AHAM Refrigerator Energy Efficiency and Consumption Trends**

| | Adjusted Volume/Unit[a] | | Energy Consumption/Unit[a] | | Efficiency[a] | |
|---|---|---|---|---|---|---|
| **Year** | **Cu Ft** | **% change from 1990** | **kWh/yr** | **% change from 1990** | **Energy Factor[b]** | **% change from 1990** |
| **1990** | 20.45 | -- | 916 | -- | 8.15 | -- |
| **1995** | 19.95 | -2.4% | 649 | -29.1% | 11.22 | 37.7% |
| **2000** | 21.90 | 7.1% | 704 | -23.1% | 11.11 | 36.3% |
| **2003** | 22.28 | 8.9% | 514 | -43.9% | 15.30 | 87.7% |
| **2008** | 21.35 | 4.4% | 483 | -47.2% | 15.50 | 90.2% |

a = Shipment weighted averages
b = Energy factor is kWh/yr per adjusted volume.

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[16] Refrigerator Market Profile 2009, U.S. Department of Energy. Available at www.energystar.gov/
[17] Residential Energy Consumption Survey 2005 Energy Information Administration, as reported in Preliminary Technical Report Document: Energy Efficiency Program for Consumer Products: Refrigerators, Refrigerators-Freezers, and Freezers, U.S. Department of Energy, Washington, DC. Prepared by Navigant Consulting and Lawrence Berkeley National Laboratory (November 2009), p. 3-31.
[18] Appliance Energy Efficiency and Consumption Trends, AHAM, Washington, DC. Downloaded from www.aham.org in July 2009.

## 2.3 Standards and Labeling

U.S. energy efficiency standards have had a huge effect on the energy use of today's refrigerators. Consumers desiring units that are even more efficient have the benefit of government sponsored EnergyGuide labels and ENERGY STAR ratings. Moreover, the non-profit, private Consortium for Energy Efficiency (CEE) has The Super-Efficient Home Appliance Initiative (SEHA), which complements ENERGY STAR. In effect since 1997, the program defines "super-efficiency" by establishing performance tiers that utilities and others can voluntarily adopt for use in local programs. See www.cee1.org for more information. **Table 2-2** shows the qualifying criteria for ENERGY STAR and CEE efficiency ratings.

**Table 2-2 ENERGY STAR and CEE Ratings**

| Efficiency level | Percentage above Federal Standards | |
|---|---|---|
| | **Compact Refrigerators**[a] | **Standard Size Refrigerators** |
| ENERGY STAR® | 20% | 20% |
| CEE Tier 1 (same as ENERGY STAR) | 20% | 20% |
| CEE Tier 2 | 25% | 25% |
| CEE Tier 3 | 30% | 30% |

[a] Capacity smaller than 7.75 cu. ft

### *2.3.1 U.S. Federal Energy Efficiency Standards for Refrigerators and Freezers*

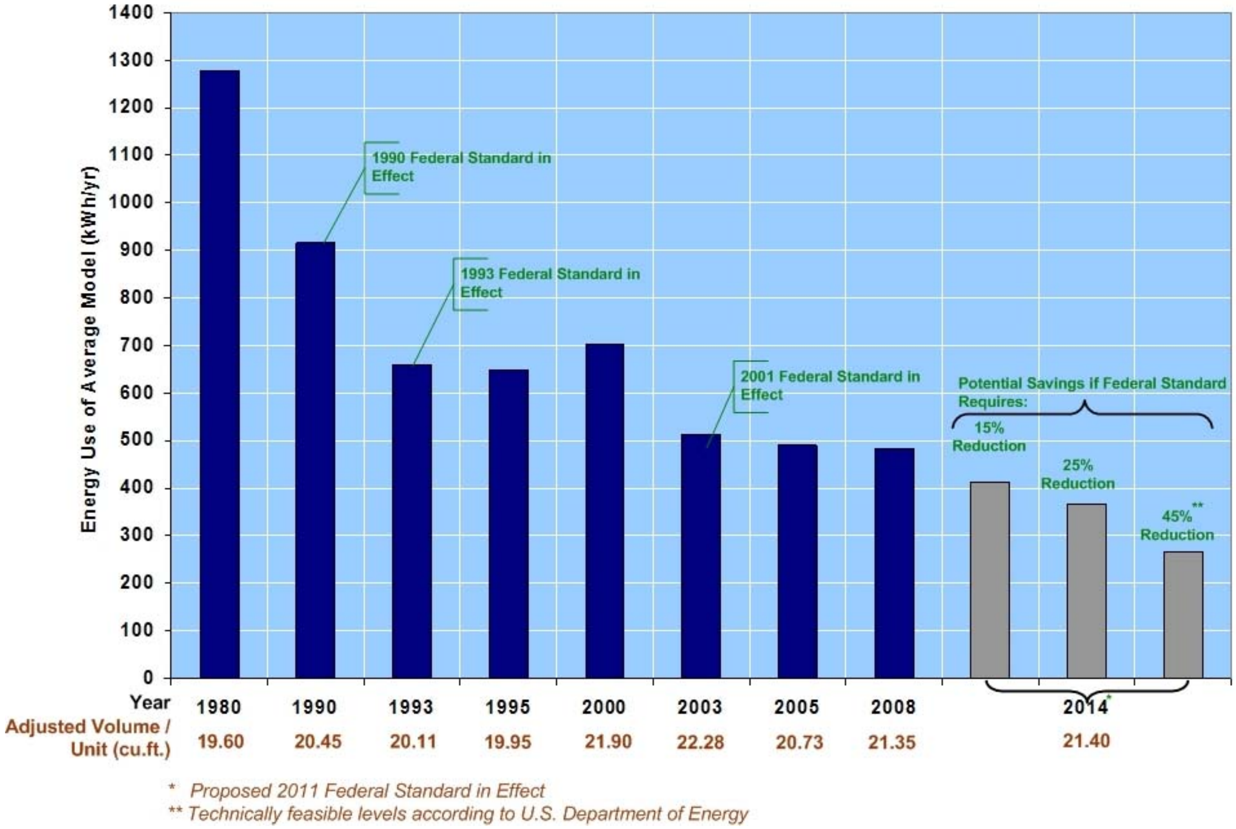
Federal standards for refrigerators and freezers in 2009 have been in effect since 2001, and are expressed in maximum allowable kilowatt hours per year, according to the unit's adjusted volume. Adjusted volume is a measure of internal volume in cubic feet. Adjustments account for the ratio of freezer to fresh food storage space. For example, for the category refrigerator-freezer, the fresh food internal volume is a direct measurement, but the freezer volume is multiplied by 1.63 and added to the fresh food volume to get the adjusted volume (AV). **Table 2-3** provides standards for a few common product classes.

**Table 2-3 U.S. Energy Efficiency Standards for Common Refrigerator/Freezer Types**

| Refrigerator or Freezer Type | Requirement (kWh/yr) | Examples | |
|---|---|---|---|
| | | **Adjusted volume** | **Maximum allowable energy use (kWh/yr)** |
| Refrigerator-freezer with automatic defrost with bottom-mounted freezer (without through-the-door ice service) | 4.60AV + 459.0 | 22 cu. ft. | 560.2 |
| Refrigerator-freezer with automatic defrost with top-mounted freezer (without through-the-door ice service) | 9.80AV + 276.0 | 22 cu. ft. | 491.6 |
| Refrigerator-freezer with automatic defrost with side-mounted freezer, with through-the-door ice service | 10.10AV + 406.0 | 22 cu. ft. | 628.2 |
| Upright freezers with automatic defrost | 12.43AV + 326.1 | 24 cu. ft. | 624.4 |
| Chest freezers and all other freezers except compact freezers | 9.88AV + 143.7 | 24 cu. ft. | 380.8 |
| Compact refrigerator and refrigerator-freezer with manual defrost | 10.70AV + 299.0 | 7 cu. ft. | 373.9 |
| Compact refrigerator-freezers – partial automatic defrost | 7.00AV +398.0 | 7 cu. ft. | 447 |

Notes: AV = adjusted volume

New federal standards for refrigerators, which will be determined by DOE by 2011 and go into effect in 2014, will reduce energy use in refrigerators from 2009 levels. The energy use reduction level that will be required for revised standards is yet to be determined, but **Figure 2-1** shows what energy use might be in 2014 for an average size model assuming the standard reduces electricity use by 15%, 25% or 45%.




Note: 2014 values are forecasts, based on various federal standards scenarios. *Source: AHAM shipment weighted averages*

**Figure 2-1 Energy Consumption of Refrigerator-Freezers**

The new standard will depend on both technical and economic feasibility. Preliminary engineering analyses of technical and economic feasibility are available in the DOE preliminary Technical Support Document on refrigerators and freezers published by DOE in November 2009.[19] For the economic analysis, including how changes would affect the manufacturer's selling price, DOE used the 45% figure as the upper boundary of technical feasibility, although for some product classes higher efficiency levels are possible.

Standards are not likely to specify reductions as great as the 45% technically feasible level because economic feasibility will also be an important factor in setting the rules. For example, a life cycle cost and payback period analysis was conducted for DOE in the 2009 preliminary Technical Support Document for different refrigerator-freezer product classes. This analysis found that the average payback period for the incremental cost of the energy efficiency standard would range from about 1 year to about 16 years depending on product class and the percentage

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[19] Preliminary Technical Report Document: Energy Efficiency Program for Consumer Products: Refrigerators, Refrigerators-Freezers, and Freezers. U.S. Department of Energy: Washington, DC. Prepared by Navigant Consulting and Lawrence Berkeley National Laboratory. (November 2009)

reduction compared to baseline energy use (base case is no revised efficiency standard). Example findings are shown in **Table 2-4, 2-5, and 2-6**.

**Table 2-4 Payback Period for Top Mount Refrigerator Freezer: TSD Analytic Results**

| **Efficiency level -<br>% less than baseline energy use** | **Life Cycle Cost (LCC) (2008$)** | | | **Average payback (years)** |
|---|---|---|---|---|
| | Average Product Costs ($) | Average Annual Operating Costs ($) | Average LCC ($) | |
| Baseline (current standards) | 591 | 77 | 1,505 | -- |
| 15% | 599 | 67 | 1,398 | 1.1 |
| 20% | 631 | 60 | 1,343 | 3.2 |
| 45% | 845 | 44 | 1,367 | 9.7 |

*Source: DOE Preliminary Technical Support Document, November 2009*

**Table 2-5 Payback Period for Bottom Mount Refrigerator Freezer: TSD Analytic Results**

| **Efficiency level -<br>% less than baseline energy use** | **Life Cycle Cost (LCC) (2008$)** | | | **Average payback (years)** |
|---|---|---|---|---|
| | Average Product Costs ($) | Average Annual Operating Costs ($) | Average LCC ($) | |
| Baseline (current standards) | 1,758 | 70 | 2,591 | -- |
| 15% | 1,759 | 69 | 2,576 | 0.8 |
| 25% | 1,782 | 64 | 2,542 | 6.0 |
| 45% | 2,953 | 47 | 2,610 | 16.6 |

*Source: DOE Preliminary Technical Support Document, November 2009*

**Table 2-6 Payback Period for Side-by-Side w/ Through the Door Ice Service Refrigerator Freezer: TSD Analytic Results**

| Efficiency level - % less than baseline energy use* | Life Cycle Cost (LCC) (2008$) | | | Average payback (years) |
|---|---|---|---|---|
| | Average Product Costs ($) | Average Annual Operating Costs ($) | Average LCC ($) | |
| Baseline (current standards) | 1,459 | 116 | 2,840 | |
| 15% | 1,469 | 108 | 2,759 | 1.6 |
| 25% | 1,563 | 97 | 2,724 | 7.6 |
| 40% | 1,815 | 78 | 2,744 | 11.2 |

*Source: DOE Preliminary Technical Support Document, November 2009*

### 2.3.2 ENERGY STAR Refrigerators

To qualify as an ENERGY STAR refrigerator, a unit must beat federal standards by 20%. ENERGY STAR models as of 2009 included units that are up to about 33% better than standards. Lists of qualifying products and materials for partners such as utilities are available at www.energystar.org/.

## 2.4 How It Works

Refrigerators rely on the vapor compression cycle to remove heat from the air in a food storage cabinet. A fluid called the refrigerant is circulated that absorbs heat as it vaporizes, and gives off heat as it condenses. As shown in **Figure 2-2**, the basic cycle operates like this:

An electric motor drives a compressor that draws refrigerant vapor from the evaporator (where the refrigerant absorbs heat) and pressurizes and pumps it to the condenser, where it is cooled and condensed to a liquid, and heat from this process is dissipated into ambient air. The liquid refrigerant is passed through a pressure reducing capillary tube back to the evaporator, where the low pressure liquid absorbs heat and vaporizes, to go back to the compressor.

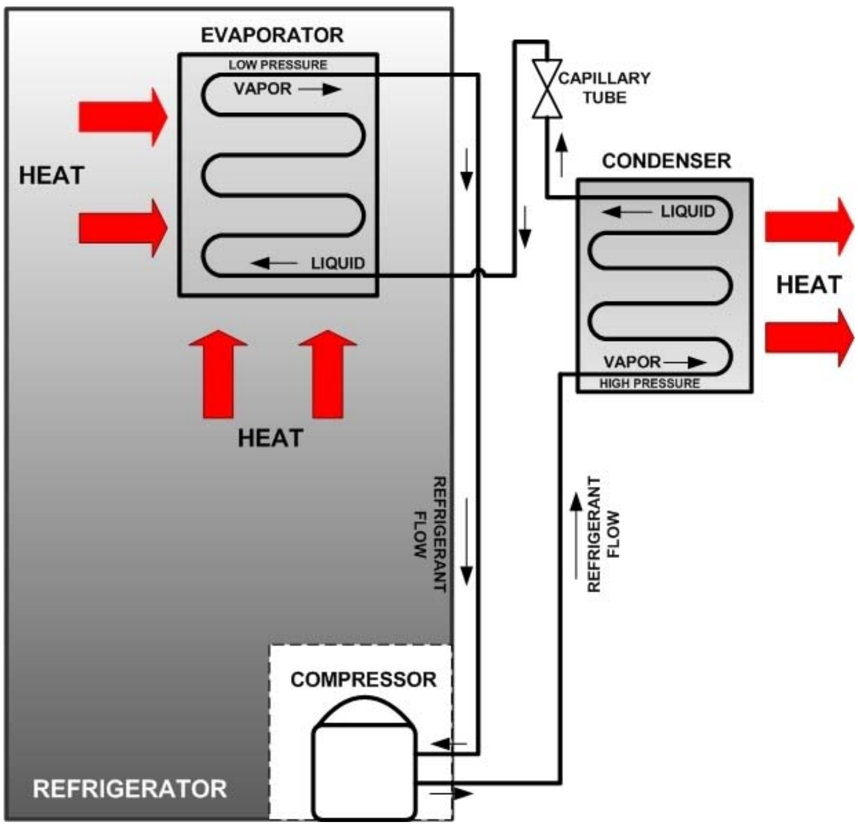


**Figure 2-2 The Vapor-Compression Cycle in a Refrigerator**

## 2.5 Design Options and Advanced Technologies

A number of design options are available for reducing the energy consumption of refrigerator and freezers. These all rely on vapor-compression technology. Although a few alternative refrigeration technologies have been in the lab, or used for niche products, none are on the horizon that will affect standard-size, mass market refrigerators any time soon.

The system efficiency achieved by combining and integrating different types of components and materials is the design challenge for product engineers. While striving for greater energy efficiency they must consider trade-offs between efficiency measures and desirable functions and features such as amount of space for food storage, ease of door opening, and, of course, cost.

### *2.5.1 Design Options*

A number of design options are available that can be used singly or in some combination to increase the energy efficiency of refrigerators and freezers. Several rely on a trend toward increased use of electronics for greater control. Some design options are:

1) Higher efficiency compressors and variable speed compressors

2) Higher efficiency fan motors on fans used to increase heat transfer at the evaporator and condenser

3) Adaptive defrost technologies

4) Improved (lower conductivity) insulation or vacuum panel insulation

5) Other components and materials such as better sealing doors and gaskets, alternate refrigerants, different refrigerator configurations, enhanced evaporator heat exchange performance and more.

#### 2.5.1.1 Higher Efficiency Compressors

The compressor is the heart of the refrigerator system. It is the major power-using component in refrigerators and freezers; therefore, increasing its efficiency increases the energy efficiency of the appliance.

The majority of compressors rely on induction motors and reciprocating compressors. The induction motors are typically resistance start/capacitor run.

Standard size refrigerator freezers generally use compressors with an EER of 5.0 to 5.5 Btu/h-W. DOE has identified commercially available compressors with an EER of 5.75 to 6.25 that can meet capacity needs of standard size refrigerator-freezers (typically 600 to 800 Btu/h, up to about 950 Btu/h). The EER of compressors drops off considerably at lower capacities, so the EER of compressors for compact refrigerator-freezers is much lower. This is attributed to manufacturer focus on efficiency for larger capacity applications, and to higher mechanical losses and other losses in smaller units because of their reduced volume.

#### *2.5.1.1.1 Variable Speed Compressors*

Most compressors operate at a single speed, but variable speed compressors can operate at multiple speeds rather than just in ON mode. See **Figure 2-3**. As a result, the compressor can better match the load, running at lower speeds for longer periods of time. The fan runs longer, which uses more energy, but losses during the OFF cycle are reduced, and heat exchangers operate more effectively as well.

Electronic controls enable variable speed, typically with inverter-driven induction motors or permanent magnet motors. The electronics used for control of variable speed compressors makes the units more expensive than single speed units.

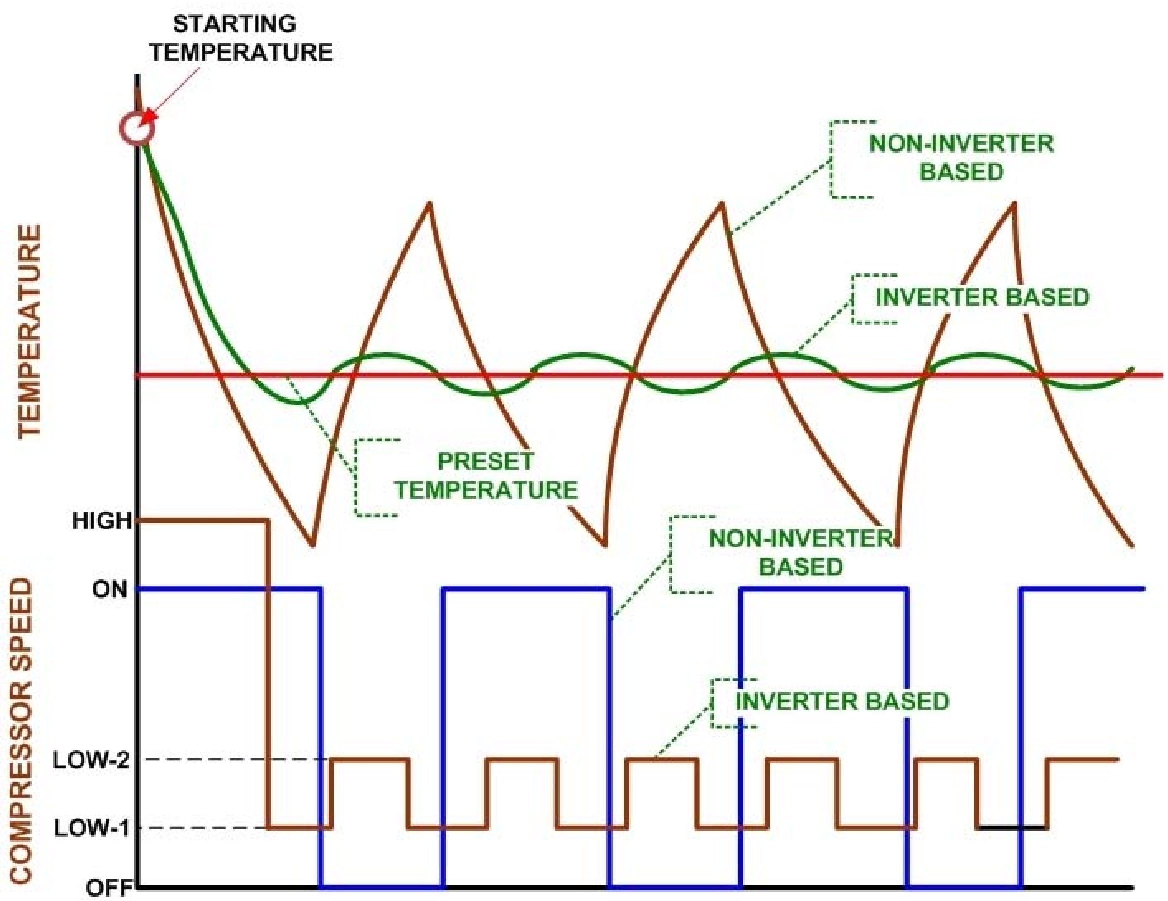


**Figure 2-3 Operation of Inverter-Driven Variable Speed Compressor vs. Single Speed Compressor**

The 2009 DOE preliminary TSD cites studies from the late 1990s that reported energy savings from use of variable speed vs. single speed compressors of 4% to 25%.[20] In terms of energy efficiency improvement, the Consortium for Energy Efficiency estimates that a variable speed compressor has potential for a 10% efficiency gain.[21]

Typically, U.S. refrigerators-freezers rely on single speed compressors, but there are some refrigerator-freezer models in the U.S. that include variable speed compressors. These generally have up to three speed settings.

Two refrigerator-freezers that use inverter-driven compressors , including one from Samsung and one for GE, are being tested as part the EPRI Energy Efficiency Demonstration, in which field measurements will be done on refrigerator-freezers as part of the residential appliances demonstration portion of the program. (For more information on the EPRI Energy Efficiency Demonstration, see the Research tab at www.epri.com/. As of 2009, the Energy Efficiency Demonstration is described on the Industry Technology Demonstrations page.)

#### *2.5.1.1.2 Linear Compressors*

Linear compressors use a linear rather than a rotary motor. As described by LG Electronics, which has developed a linear compressor for refrigerators, "While conventional reciprocating compressors turn the motor's rotational movement into the piston's linear movement to compress refrigerant, in LG's linear compressors, the motor directly connected to the piston moves along a linear track to compress refrigerant, minimizing energy loss during conversion and lowering energy use by up to 30 percent."[22]

LG claims its latest generation linear compressor, which debuted in 2009 in a large capacity side-by-side model, "will lower consumption by 20% compared to a conventional compressor."[23] The test was done using LG reference conditions, not ASHRAE rating conditions, so DOE conducted an analysis that is reported in the preliminary TSD. Researchers compared a very high efficiency rotating-shaft reciprocating compressor (Embraco EGX70HLC) to the LG linear compressor, showing that the Embraco would have an operating EER of about 6.9 Btu/hr-W and the LG linear compressor "may be 9% more efficient" than this unit.[24]

Linear compressors have been discussed for years as a means of improving efficiency. One of the first developed for the refrigerator market was produced by SunPower of Athens, Ohio (www.sunpower.com/), which developed a unit for the European refrigerator makers.

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[20] U.S. Department of Energy, Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors, Final Report, December 1, 1999. Prepared by Arthur D. Little, Inc., Washington DC, No. DE-AC01-90C01-90CE23821 and T.R. DuMolin and D.A. Colling, "Higher Efficiency by Means of Variable Speed Technology in Domestic Refrigeration Appliances," *ASHRAE Transactions*. 1998. Vol. 104, Pt. 2
[21] See Home Appliances at www.cee1.org/.
[22] LG Press Releases, LG Enhances Environmental Leadership with Third Generation Linear Compressor," (April 20, 2009) Downloaded from www.lge.com/
[23] Ibid.
[24] Preliminary Technical Support Document: Energy Efficiency Program for Consumer Products: Refrigerators, Refrigerators-Freezers, and Freezers. U.S. Department of Energy, Washington, DC. Prepared by Navigant Consulting and Lawrence Berkeley National Laboratory. November 2009, p. 3-60.

LG reports that it “plans to provide the compressor to other refrigerator makers around the world,”[25] but whether manufacturers would be willing to use them in their products is yet to be determined.

### 2.5.1.2 Fans and Fan Motors

Fans are used for heat transfer at the evaporator and condenser. Efficiency measures include variable speed evaporator fans, different fan blade designs, and more efficient fan motors including permanent split capacitor motors and brushless DC motors.

More efficient fan motors will mean less heat loss into the cabinet, reducing the load and therefore the power use of the compressor. And, of course, the power consumption of the motor itself will be reduced.

Fans are typically acquired by appliance manufacturers from outside vendors, so getting these suppliers to provide more efficient fans is the key to this design option.

### 2.5.1.3 Adaptive Defrost

In units with automatic defrost, heaters in the freezer are needed to melt frost build-up. Energy is used by the heater, and energy is consumed when removing the heat from the freezer compartment. Defrost heater efficiency is already very good in order to meet current refrigerator energy efficiency standards.

Adaptive defrost control is another option for efficiency improvement, although the extent to which it has been or can be applied has not yet been identified by DOE. Adaptive defrost entails use of controls to adapt the timing of the defrost function, so that it is done only when needed, rather than at pre-set intervals according to a mechanical timer. An adaptive defrost might change the defrost interval from once every day to once every few days.

According to a 2005 DOE assessment of refrigerator-freezers,[26] the adaptive system can adjust the timing so defrost occurs only when needed by assessing how quick the warm-up time is. If it is fast, it means a thin frost layer, so the adaptive controls can set defrost to a longer interval. The thickness of the frost layer is based primarily on factors such as door opening, moisture content of the freezer, and ambient conditions.

### 2.5.1.4 Improved Insulation

Like a building, the walls and doors of the refrigerator or freezer transfer heat, and must be insulated. The primary thermal load of the refrigerator and freezer is heat transfer through the cabinet. To minimize this heat transfer, insulation is used. As of 2009, most U.S. refrigerators and freezers use polyurethane foam for insulation.

Increasing the thickness of the polyurethane foam is one option for improving efficiency. However, this is an unpopular option among manufacturers for several reasons, including the

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[25] LG Press Releases, LG Enhances Environmental Leadership with Third Generation Linear Compressor,” (April 20, 2009) Downloaded from www.lge.com/

[26] Technical Report: Analysis of Amended Energy Conservation Standards for Residential Refrigerator-Freezers U.S. Department of Energy: Washington, DC. (October 2005)

need to decrease interior space, since the external dimensions of refrigerator cannot expand. Residential kitchens have a limited amount of space available for home refrigerators and freezers. The cost of changing product dimensions would be high as well, requiring changes in tooling and other expenses.

Changing blowing agents is another option that can affect the conductivity of the insulation. A variety of agents can be used; many manufacturers today rely on HFC 245fa, deemed among the best energy performing of allowable foaming agents. (See **Table 2-7** for more on blowing agent regulations.) HFCs are the primary group of blowing agents used by the U.S. appliance industry, which favors them over hydrocarbons. Cyclopentane is a hydrocarbon that is used in some cases in the U.S., and hydrocarbons are widely used in Europe. However, concerns about flammability and volatile organic compounds make hydrocarbons less favored for the American market.

**Table 2-7 Allowable Blowing Agents**

| Time Period or Date | Blowing Agent | Action |
|---|---|---|
| 1980s | CFC-11 | Used for all polyurethane foam insulation |
| 1990s | CFC-11<br><br>HCFC-141b | Banned from use by Montreal Protocol<br><br>Adopted as blowing agent since less ozone depleting |
| 2003 | HCFC-141b<br><br>HFC-245fa | Banned from production in the U.S.<br><br>Determined as most attractive substitute for HCFC-141b from energy standpoint by Oak Ridge National Laboratory |

### Vacuum Insulated Panels

Vacuum insulated panels (VIPs) are a means of insulating without making refrigerator and freezer walls thicker. Like thermos bottles, these panels reduce heat conduction with a low vacuum. VIPs are commercially available, albeit at much greater cost than polyurethane foam insulation.

VIPs are used in some refrigerator-freezers now. For example, Panasonic announced in early 2009 that it was introducing a European refrigerator-freezer model that uses the U-Vacua vacuum insulation panel.[27] The U-Vacua panel was developed by the Japanese company Matsushita, which claims its U-Vacua (Ver. IV) has "achieved the world's highest level of insulation efficiency."[28]

The Department of Energy preliminary TSD analysis indicates that vacuum-insulated panels could be a major design option for meeting any revised standards, and that "dramatic reductions in energy use are possible in many of the product classes." The DOE reports that VIPs can add up to $300 to the refrigerator manufacturer selling price, but preliminary analyses indicate the panels would be economically justified. DOE is soliciting comments and information on VIPs as it works on new refrigerator and freezer standards, so the department can do further analysis on whether high-volume deployment of VIPs is feasible.

The Consortium for Energy Efficiency estimates a potential 10-20% efficiency gain from use of vacuum insulated panels.[29]

### 2.5.1.5 Other Design Options

A number of additional options for increasing efficiency in refrigerator-freezers are listed below. Details on even more options are available in the DOE preliminary TSD, a 678-page document available at [http://www1.eere.energy.gov/buildings/appliance_standards/](http://www1.eere.energy.gov/buildings/appliance_standards/).

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[27] Panasonic Press Release, "Panasonic Introduce Fridge-Freezers and Washing Machines in Europe." February 24, 2009. Downloaded from www.panssonic.co.uk/

[28] Japan for Sustainability Press Release "Matsushita's Vacuum Panel Wins 2006 Energy Conservation Award." July 15, 2007. Downloaded from ww.japanfs.org/en/

[29] See Home Appliances, Refrigerators, at www.cee1.org

### Improved Heat Exchange

The evaporator is a major component of the refrigeration system, and improving its performance can increase energy efficiency. Increasing heat exchange surface area is one alternative, although use of more interior space is a hurdle for this design alternative. Integrating phase change materials into the heat exchanger may be another.

### Alternative Refrigerant Cycles

The basic refrigeration cycle described in section 2.4, How It Works, can be reconfigured to help improve system energy efficiency. For example, dual loop systems, which have a separate, independent cycle for the freezer and the fresh food compartment are available in some products. Dual compressor systems are also being incorporated into some models.

### Better Gaskets and Doors

Keeping heat from entering the refrigerator or freezer cabinet is a basic means of managing the load. Door construction and the gaskets should minimize infiltration. Old refrigerators used to rely on heavy latches and doors for the job, before magnetic strips were added to gaskets to keep air from leaking into the cabinet. The extent to which the gaskets can be changed to enhance air tightness is unclear, although this could potentially reduce heat load. Manufacturers have to ensure that doors open easily, so increasing the force of magnetic strips in the gaskets is constrained by this usability factor.

Low conductivity materials in doors, such as plastics, are an option already used by refrigerator makers, so the extent to which door material changes can improve efficiency is also unknown.

### Anti-Sweat Heaters

In standard size refrigerator-freezers the exposed surfaces near gaskets and where doors meet can "sweat" in humid environments from the condensation of ambient moisture. To prevent this sweating, heat is applied to these areas. This is done by placing refrigerant tubes near areas prone to sweating. Warm gas or liquid flowing through the tubes heats the surfaces. An anti-sweat electric resistance heater can also be used. Anti-sweat heaters add to the heat load of the refrigerator-freezer, so increasing the efficiency may enable reduced load and energy use reduction. "Energy saver switches" that allow the customer to turn off a heater if it is not needed can also reduce energy use.

### Alternative Refrigerants

Since the Montreal Protocol banned CFC-12, refrigerator manufacturers in the U.S. have been using HFC-134a as the refrigerant in refrigerators and freezers. HFC-134a is a few percentage points less efficient than CFC-12, although in the right operating conditions can be equivalent. However, HFC-134a does contribute to global warming, and alternatives such as hydrocarbons have been discussed as possible alternatives. Hydrocarbons are as energy efficient as CFC-12 so are attractive from an energy use standpoint. However, as noted in information on blowing agents for insulation in section 2.5.1.4 Improved Insulation, HFCs are preferred by U.S. manufacturers because of concerns about flammability of hydrocarbons and volatile organic compounds.

Some European and Asian refrigerator makers have used the hydrocarbon isobutene for more than a decade, and one U.S. manufacturer, GE, is testing a model using isobutene. GE intends to introduce a Monogram® brand refrigerator in 2010 that uses isobutene for a refrigerant.[30] Cyclopentane, another hydrocarbon, will be used as a blowing agent in the refrigerator. According to GE, the primary motivation for this action is the environmental benefits of the refrigerant, rather than energy use reductions.[31] However, a small energy efficiency improvement is expected.

### 2.5.2 Alternatives to the Vapor Compression Cycle

Barring some breakthrough, the vapor compression refrigeration cycle will be the basis of U.S. refrigerators and freezers for some time to come. Research has been done on alternatives, such as Stirling cycle systems, but technical problems have limited this technology to small test units. Acoustic cooling has also been explored. Researchers have shown that sound can vibrate and compress gas to drive the cooling process, but this technology is not practical for home refrigerators.

Thermoelectric cooling is one alternative technology that made it out of the lab and into the market, but it is not an energy efficient technology, nor appropriate for use for standard size refrigerators. Thermoelectric cooling has been employed for wine coolers and compact refrigerators. It is generally only applied in environments where the solid state nature (no moving parts, maintenance-free, absolutely quiet) provides significant benefits that balance the low efficiency. They can include:

- Small coolers/refrigerators (e.g., under 3.5 cu. ft.)
- Small wine coolers
- Cooling electronic components and small instruments
- Extracting water from the air in dehumidifiers
- Cooling photon detectors such as CCDs used in astronomical telescopes or expensive digital cameras
- Cooling computer components to keep temperatures within design limits without the noise of a fan, or to maintain stable functioning when over-clocking. A Peltier cooler with a heat sink or water block can cool a chip to well below ambient temperature.
- Providing precision temperature control in laboratory settings

Research and development to improve energy conversion efficiencies in thermoelectric modules is focused on materials science, but significant energy efficiency improvements of thermoelectric technology for standard size refrigerators or freezers is not expected any time soon.

[30] GE Press Release, "GE Opening a Door to a Future of Cleaner Home Refrigeration," (October 28, 2008). Downloaded from www.genewscenter.com/
[31] D. Najewicz, GE Appliances, personal communication. October 2009.

## 2.6 Market Data

The Department of Energy *Refrigerator Market Profile 2009* presents details on the refrigerator market, noting data from the Association of Home Appliance Manufacturers and the *Appliance Magazine's* 2008 31st Annual Portrait of the Appliance Industry. Some key facts include:

- From 8 million to 12 million refrigerators are sold each year in the U.S, although the recent economic downturn has depressed sales.
- 145 million refrigerators are installed in the U.S.
- Virtually all homes have a refrigerator, and 26% have more than one. The percentage of homes with more than one unit is expected to grow by 1% annually. 10% of households that buy a new refrigerator keep their old one; another 33% of the old units are sold or given away rather than retired.
- The size of refrigerators has increased in recent years, growing from an adjusted volume of 20.45 cu. ft. in 1990 to 21.35 cu. ft. in 2008, per the Association of Home Appliance Manufacturers.
- Customer preferences for refrigerator-freezers have changed in recent years, with more demand for models with bottom-mounted freezers and side-by-side units with through-the-door ice dispensers. Manufacturers have promoted such models, as they are more profitable than the top-mounted units.

## 2.7 Program Opportunities for Reducing Energy Use of Refrigerators and Freezers

Beyond simply improving the energy efficiency of products, and promoting the purchase of the most efficient models, there are many opportunities to reduce refrigerator-freezer energy use. These include several actions recommended to ENERGY STAR partners by the Department of Energy[32]:

- **Increase the market share of refrigerators with an ENERGY STAR rating.** Such units are at least 20% better than federal standards. Currently, 31% of refrigerators sold are ENERGY STAR models.

- **Keep older primary units that are replaced from being reintroduced to the grid**. Most second refrigerators are displaced primary units. About three-quarters of displaced units still work, and about half of these are kept, sold, or given away.

- **Reduce the number of second refrigerators.** In 2008, about 26% of U.S. households had a second refrigerator, and that number is growing at a rate of 1% per year. [33] On average, a second unit uses 840 kWh/yr. Many are pre-1993 models

[32] U.S. Department of Energy, New Opportunities for Multiple Savings, Refrigerator Market Profile 2009.

[33] U.S. Department of Energy, New Opportunities for Multiple Savings, Refrigerator Market Profile 2009, p.1.

(28%), built before the major energy use reductions mandated by the 1993 federal standards.

Many utilities work with other organizations and retailers to not only promote purchase of the higher efficiency refrigerator models, but also may support or co-sponsor efforts to pick-up and recycle old refrigerators. The DOE's *Refrigerator Market Profile 2009* points out that "full recycling of refrigerators can increase carbon savings per unit up to 40% by capturing the potent greenhouse gases trapped in the foam."[34]

[34] Ibid, p.1.

# 3
# COOKING EQUIPMENT: INDUCTION COOKTOPS

Cooking is a central function in the home, and often a design focus or expression of style. From a consumer's viewpoint, cooking appliances are not a major contributor to electricity bills, but cooking appliance energy use has an effect in aggregate on energy use and on residential peak demand.

Cooking appliances can use gas, electricity, or microwave energy to heat food. The fuel type does not have a significant impact on consumer energy bills, so fuel choice in the residential sector is usually based on the preferences of the cook, and fuel availability (some households do not have gas).

A wide variety of products are available. The basic types of residential cooking equipment include:

- Ranges: unit integrating cooktop and oven. This has been the conventional cooking technology used in residences, and "still rules when it comes to cooking appliances," according to *Consumer Reports*.[35]
- Cooktops: horizontal cooking top with either gas burners or electricity-based heating mechanism, such as electric elements, halogen lights, and induction systems. Cooktops offer greater flexibility of placement, as they are separate from the oven and can be placed in any countertop.
- Ovens: heating compartment that can be incorporated into a range or into a wall.
- Microwave ovens.

The focus of this chapter is on electric cooktops, more specifically on induction cooktops (**Figure 3-1**). Although not a new technology per se, the latest generation induction cooktops are the first version of the technology to be accepted by U.S. consumers. In 2007 The Partnership for Advancing Technology in Housing (PATH) deemed induction cooking one of the top ten residential building innovations of the year.[36]

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[35] Cooktops and Wall Oven Buying Guide, ConsumerReports.org. Downloaded December 2009.
[36] 2007 PATH Top Ten Technologies. February 2007. Downloaded from www.toolbase.org/

*Source: Photo courtesy of Diva de Provence*

**Figure 3-1 Residential Induction Cooktop – Built-in**

Induction cooking offers significant improvements in energy efficiency compared to other electric cooktops. They achieve efficiencies in the range of 80-95%, compared to efficiency of conventional smooth top electric cooktops of 50-65%. Also, since heat is generated in the food container, rather than at the burner, this form of cooking can also reduce the amount of heat being released into the kitchen. It also is an attractive option for customers with all-electric service—not only because it is energy efficient, but because it compares favorably with gas cooktops in terms of features valued by cooks, such as responsiveness, precise temperature control, and safety.

One market barrier to induction cooktops is that they are expensive, and can cost more than double the price of some electric cooktops. As such, the target for this cooking technology is the higher-end kitchen appliance market. Another market barrier is that this technology only works with ferromagnetic cookware—so cooks are limited to using cast iron or stainless steel. However, according to manufacturers, the rate of sales growth for induction cooktops exceeds that of conventional electric and gas cooktops in the U.S., at least based on the sales data up until the economic downturn.

## 3.1 A Brief History of U.S. Induction Cooktops

Induction heating technology is well understood, and has been used for decades in industrial applications such as heat treating of metals. The concept of induction cooking was displayed as early as 1933 at the Chicago World's Fair.[37]

Induction cooktops were introduced in the 1970's in Europe in response to demand for more energy efficient cooking systems. During this same time period, induction cooktops were introduced in the United States by Westinghouse. Westinghouse offered a four element induction range called the Cool Top 2 (CT2).[38] In addition to Westinghouse, General Electric and Kenmore brands[39] also entered the U.S. market with induction cooking systems.

While induction cooking did catch on in Europe, and subsequently in Asia, the technology did not fare well in the United States. Early generation induction cooktops tended to have relatively low power, and in the U.S. the premium priced induction technology was not well received. In

[37] Colin Young, Induction Cooking, online posting, http://inductioncooking.wikispaces.com/AboutInduction
[38] Induction Cooker, Wikipedia, http://en.wikipedia.org/wiki/Induction_cooker .
[39] A. Girgis, Diva de Provence, personal communication.

addition to low power and high cost, some early generation induction cooktops were reported to have reliability and performance (e.g., noise) drawbacks that limited consumer interest. Westinghouse stopped production in 1975, and later GE and Kenmore also stopped offering induction cooktops in the United States (although they reentered the market in the 2000s). Outside of the United States, however, induction cooktops continued to succeed, especially in Europe and Asia.

Induction cooking systems have always been, and continue to be, more expensive than alternative cooking technologies (see Section 3.7.2, Prices). However, around 2000, European manufacturers developed a less expensive design that allowed better integration of the electronics and induction generator coils—key induction cooktop components. These cost engineering improvements reduced the first cost premium of induction cooktops compared to conventional systems, and sales began to climb overseas.

In 2002, Diva de Provence re-introduced induction cooking in North America, and several other manufacturers soon followed.[40] The technology still had a higher first cost compared to conventional electric and gas cooktops, but the performance deficits of the early generation systems had been corrected.

## 3.2 Cooktop Definition/Description

Electric cooktops can be divided into five types:

- Electric Coil
- Solid Disk
- Halogen
- Radiant
- Induction

Electric coil cooktops have the familiar coiled elements that are heated by electric resistance. Solid disk designs are similar to exposed electric coil units, except the coiled electric elements are configured in a solid design for easier cleaning.

Halogen and radiant cooktops are frequently referred to as "smooth top" designs. In both halogen and radiant technologies, the heating elements are placed beneath a smooth ceramic glass surface, which facilitates easy cleaning. Halogen systems use a quartz halogen lamp, and radiant designs use an electric coil. In both halogen and radiant units, the heating elements radiate energy through the ceramic glass to the cookware.

Induction systems, which are typically designed as smooth tops, transfer energy to cookware through a magnetic field.

The relative ranking of efficiency for these technologies is as follows (from lowest to highest): solid disk (lowest), electric coil, radiant smooth top, halogen smooth top, and induction (highest).

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[40] A. Girgis, Diva de Provence, personal communication.

## 3.3 Energy Use and Peak Demand

Cooking is about 2% of the average U.S. household electricity per the Energy Information Administration's 2008 Annual Energy Outlook. Average energy use for U.S. households is 274 kWh/yr, and this amount varies by region from 180 kWh/yr/hh in the Northeast to 365 kWh/yr/hh in the South (see Chapter 1, Table 1-2).

The average residential summer peak demand for cooking is 0.03 kW per household (see Chapter 1, Table 1-3). About two-thirds of households cook a hot meal at least once a day, and a third cook at least 2 meals a day.[41] Dinner preparations mean that cooking load can be coincident with periods of peak demand. This is illustrated in **Figure 3-2**, the load shape for a July weekday in a single-family residence in the East South Central U.S. (Alabama, Kentucky, Mississippi, and Tennessee).

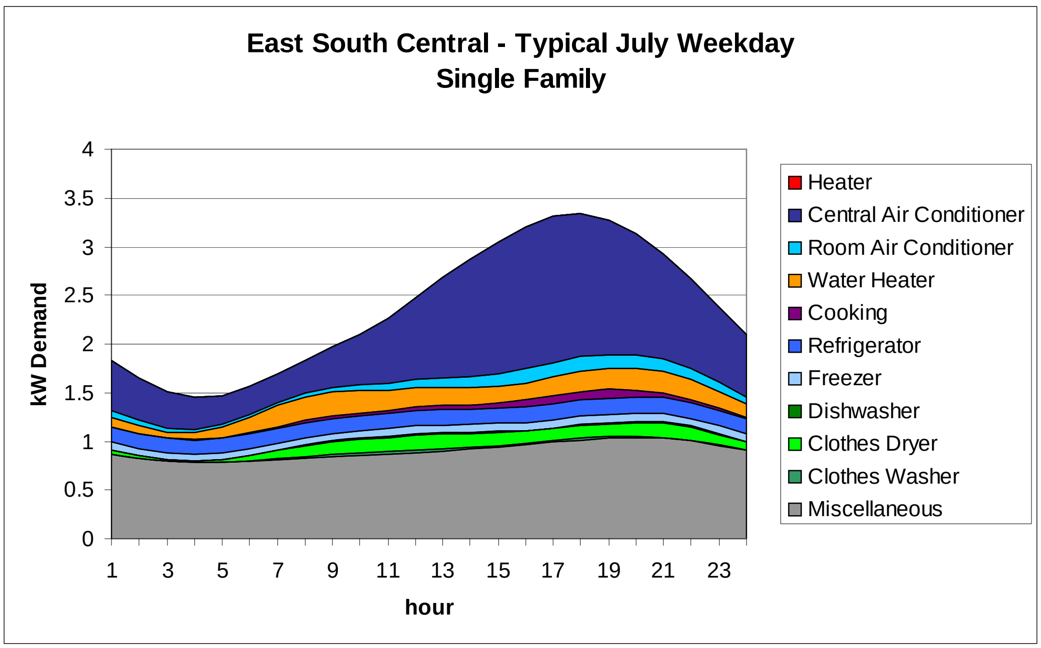


**Figure 3-2. Cooking peak demand can be coincident with residential summer peak demand.**

**Table 3-1** shows the expected energy reductions that might be achieved with induction cooktops based on efficiency values developed by DOE. As indicated, an induction cooktop can be expected to use approximately half the energy of a gas system, and over 10% less energy compared to conventional electric cooktops (the table shows two types of conventional electric – coil and smooth top).

**Table 3-1 Energy Comparison Based on DOE Efficiency Values**

[41] Energy Information Administration, 2005 Residential Energy Consumption Survey: Preliminary Housing Characteristics Tables, Table HC2.10. Downloaded from http://www.eia.doe.gov/emeu/recs/recs2005/hc2005_tables/detailed_tables2005.html

| Type of Cooktop | Output Energy (1) | Efficiency | Input Energy (1) | Energy Reduction if Induction Used |
|---|---|---|---|---|
| Gas | 1.0 | 39.9% | 2.51 | 53% |
| Electric Coil | | 73.7% | 1.36 | 13% |
| Electric Smooth Top (2) | | 74.2% | 1.35 | 12% |
| Induction | | 84.0% | 1.19 | --- |

**Note:**
1) Output energy and input energy are expressed without dimensions in this table.

2) Smooth top is presumed to have a halogen element

If industry efficiency estimates are used, rather than DOE efficiency numbers, the savings are even larger. Using 40% for gas, 55% for electric coil, 60% for electric smooth top, and 90% for induction, the energy savings for induction become 56% compared to gas, 39% compared to electric coil, and 33% compared to electric smooth top (see **Table 3-2**) .

**Table 3-2 Energy Comparison Based on Industry Efficiency Values**

| Type of Cooktop | Output Energy (1) | Efficiency | | Energy Consumption Based on DOE Efficiency Values | |
|---|---|---|---|---|---|
| | | Range | Used for Calculations | Input Energy (1) | Energy Reduction if Induction Used |
| Gas | 1.0 | 30-45% | 40% | 2.50 | 56% |
| Electric Coil | | 45-60% | 55% | 1.82 | 39% |
| Electric Smooth Top (2) | | 50-65% | 60% | 1.67 | 33% |
| Induction | | 80-95% | 90% | 1.11 | --- |

**Notes:**
1) Output energy and input energy are expressed without dimensions in this table.

2) Smooth top is presumed to have a halogen element

## 3.4 Standards and Labeling

Efficiency test standards have been developed for cooktops, but no energy efficiency standards for induction cooktops are mandated by the U.S. Federal government.[42] Even though there is no mandated requirement to test and report efficiency levels, there is consensus that induction cooking is the most efficient cooktop technology available. One recent journal article[43] reported induction cooktops to be more than 90% efficient, followed by conventional electric at 65%, and gas at 30%. An older, but rather extensive study completed by the U.S. Department of Energy in

[42] A test covers efficiency is ASTM F1521-03, Standard Test Methods for Performance of Range Tops.
[43] Oliver Hellmund, Reinhard Metz, and Peter Stipan, Cooking: Improved Induction, *Appliance Design*. January 31, 2008.

1996 reported induction units to be 84% efficient, followed by conventional electric systems near 74%, and gas units at approximately 40%.[44]

The standards for other cooking equipment were updated by the DOE in 2009, when the department published a final rule amending the energy conservation standards for gas and electric kitchen ranges and ovens. DOE outlaws standing pilot lights for gas kitchen ranges and ovens and determined that standards for electric household ranges and ovens did not warrant standards—a "no-standard" standard.[45]

No EnergyGuide labels or ENERGY STAR ratings are available for cooking equipment.

## 3.5 How it Works

A diagram of an induction cooktop is shown in **Figure 3-3**. Induction cooking systems use a solid-state power supply to convert 50/60 Hz 120/240 volt alternating current into a high frequency (typically 22 kHz to 35 kHz) alternating current. [46] This high-frequency current is supplied to an inductor, which is typically a flat spiral coil located below a smooth ceramic top. The inductor coil produces an alternating magnetic field, and this magnetic field creates heating in ferromagnetic cookware that is placed above the inductor coil.

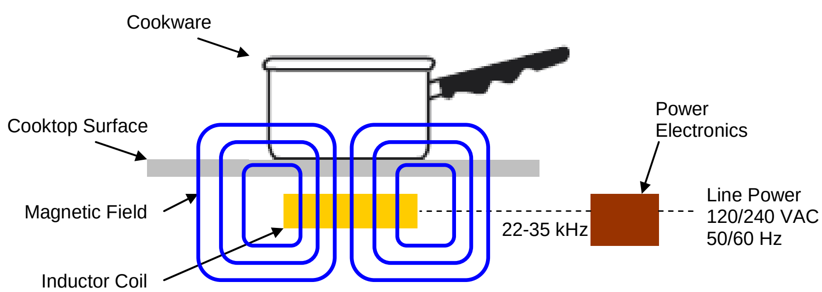


**Figure 3-3 Diagram of Induction Cooktop**

In an induction cooktop, the magnetic cookware is heated as a result of both "eddy" currents and "hysteresis heating." The magnetic field induces currents, referred to as eddy currents, in the metal material, and these eddy currents create heat (similar to heat produced from a resistance heating element). "Hysteresis" heating also occurs. Magnetic materials resist changes in a magnetic field, and the rapidly alternating magnetic field generated by the induction coil creates friction within the material. This friction creates heat, which is referred to as hysteresis heating. A metal that offers high resistance is said to have high magnetic "permeability." For perspective, magnetic materials typically have a non-dimensional permeability in the range of 100 to 500 (as

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[44] U.S. Department of Energy, Technology and Market Assessment Group, Potential Impact of Alternative Efficiency Levels for Residential Cooking Products, Prepared by Lawrence Berkeley National Laboratory (LBNL), 1996. Available online at http://www.eere.energy.gov/buildings/appliance_standards/residential/pdfs/cookgtsd.pdf .

[45] From http://www1.eere.energy.gov/buildings/appliance_standards/residential/cooking_products.html

[46] R. Metz, CookTek, personal communication.

permeability increases, hysteresis heating increases). Non-magnetic materials have a permeability value of one.[47]

For induction cooking, cookware must be magnetic for proper operation. Cast iron and steel work well, but non-magnetic pots and pans made of aluminum, copper, Pyrex, and some stainless steels will not be heated by induction.

## 3.6 Design Options

One research and development (R&D) area is to identify new product niches and develop suitable induction products. In addition to cooktops, induction technology has been successfully incorporated into portable household equipment such as woks or outdoor grills for apartment balconies, and other small portable cooking applications.

In the commercial sector, induction cooking is used in food service sector because of its precision and control, and it is well suited to portable units that offer flexibility in organizing the kitchen. Specialty applications such as heating pizza delivery bags and induction technologies for table side cooking, particularly for meat products (e.g., fajitas at Mexican restaurants and entrees at steakhouses) are also being developed for the commercial sector. For pizza bags and table side cooking, induction technologies offer substantial time savings compared to conventional approaches that rely on heating metal plates or stones in a convection oven. Other innovative induction cooking products can be expected to enter the commercial-sector market, particularly where time savings can be achieved.

### *3.6.1 "All Material" Induction Cooking*

One R&D topic that has received attention is the development of "all material" induction cooktops. Cooktops currently work with magnetic materials, and manufacturers have attempted to produce induction units that function with other cookware materials. There are reports of all material induction cooking units being introduced in the 1990s in Japan, but these products apparently did not succeed.[48]

Recent approaches for developing all materials induction cooktops appear to be directed at changing the properties of the cookware. For example, it might be feasible to manufacture a thin film material with inducible properties that could be temporarily applied to the bottom surface of glass or aluminum cookware when this cookware needs to be heated with an induction cooktop.

### *3.6.2 Smart Induction Cooking*

One active area of R&D is related to the development of smart induction appliances and cookware.[49] For example, radio frequency identification (RFID) is being investigated as a means of automating the cooking process. One cookware company, Vita Craft, sells cookware that has an RFID chip in the cookware handle that can communicate with recipe cards to regulate a cooktop's temperature to avoid over or under cooking. In concept, RFID cookware could work with any type of cooktop that had the necessary sensors and controls. However, fast response

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[47] Ameritherm, Induction Heating Fundamentals, www.ameritherm.com/aboutinduction.php .
[48] R. Metz, CookTek, personal communication.
[49] P. Stipan, Infineon, personal communication.

induction cooktops, which typically already have temperature sensors, are a good match for this type of smart technology. Smarter induction cooktops are also being developed that can balance the power between elements. For example, control schemes are being investigated to automatically control the power of individual elements based on the cooking demand at each element.

There are also reports of "zoneless" induction cooktops being developed. A zoneless unit would presumably not require the cookware be placed directly over an induction coil. Rather, the cookware could be placed anywhere on the smooth top cooking surface.

## 3.7 Market Data

### *3.7.1 Manufacturers*

Most major cooking appliance manufacturers have an induction cooktop product offering. In some cases, manufacturers have had induction product offerings for several years. In other cases, manufacturers have recently added induction product lines. **Table 3-3** lists over makers of residential induction cooking products offered in North America.

**Table 3-3 Induction Cooktop Brands in North America (Residential)**

| | |
|---|---|
| Athena | LG |
| Bosch | Miele |
| Diva de Provence (Canada) | RambleWood |
| Electrolux | Samsung |
| Gaggenau | Siemens |
| GE | Sunpentown |
| Iwatani | Viking |
| Kenmore (Sears) | Wolf |
| Kuppersbusch | Tatung USA |

### *3.7.2 Prices*

Induction cooktop prices are higher than conventional electric and gas units. To put prices in comparison, similar residential electric and gas cooktops were compared.

To begin the comparison, **Table 3-4** shows prices for three brands of induction cooktops. These prices represent major brands, and show a range of slightly below $200/kW to slightly over $300/kW.

**Table 3-4 Price Comparison for Residential Induction Cooktops (5 element models)**[50]

| **Brand** | **Model** | **Total Power** (kW) | **Price** | |
|---|---|---|---|---|
| | | | ($) | ($/kW) |
| GE | PHP960 | 11.6 | $1,869 | $191 |
| Bosch | NIT8653UC | 10.8 | $2,395 | $222 |
| Diva de Provence | DDP-5 | 10.8 | $3,295 | $305 |

**Table 3-5 Comparison of GE Profile Cooktop Prices**[51]

| **Type** | **Model** | **No. of Elements or Burners** | **Total Power** | **Price** ($) |
|---|---|---|---|---|
| Induction | PHP960 | 5 | 11.6 kW | $2,549 |
| Electric Smooth Top | PP980 | 5 | 8.6 kW | $1,749 |
| | JP960 | 5 | 9.6 kW | $1,099 |
| Gas | JGP963 | 5 | 45.5 MBtu/hr | $1,299 |

[50] Prices obtained online from the Induction Site, www.theinductionsite.com/.
[51] Prices obtained online from GE Appliances, all prices for stainless steel trim, www.geappliances.com .

Price variations for the same exact products will occur between sellers, and price variations will occur for similar products offered by different manufacturers. While price differences do exist, the results in the table provide a reasonable perspective of how prices compare for induction, electric smooth top, and gas cooktops. As the numbers suggest, induction systems are about double the price of competing gas cooktops. Smooth top electric technologies come in several variations, at least for the GE Profile line, and the price premium for induction ranges from slightly over double ($1,099 versus $2,549) to about 50% ($1,749 versus $2,549).

### *3.7.3 Market Barriers*

In addition to the high first cost, there are other considerations that can limit market penetration of induction cooking technologies. These include:

- Magnetic cookware is required. Cast iron and steel are fine, but non magnetic pots and pans made of aluminum, copper, Pyrex, and some stainless steels will not work with induction systems.
- Perception of problems based on previous generation products and information:
  - Noise. Early generation induction cooking systems generated electrical noise. However, this problem has been corrected in induction cooking units produced today by leading manufacturers.
  - Radiation hazards. Studies have been conducted to determine if induction elements present human health hazards (e.g., interference with implantable cardiac devices such as pace makers and defibrillators). The studies suggest that the risk is low. [52, 53, 54]

### *3.7.4 Benefits*

While high initial cost and the need to use magnetic cookware can be drawbacks for induction cooking, this technology does offer several benefits, including:

- Efficiency. Induction cooking is the most efficient cooking method available, with efficiencies in the range of 80-95%. For comparison, data supplied by manufacturers suggests that the efficiency of conventional smooth top electric cooktops is 50-65%, and the efficiency of gas cooktops is 30-45%.
- Safety. Induction cooktops heat cookware directly, and do not rely on hot surface elements or burners. Risks associated with accidental burns, for both adults and children, are reduced with induction systems. Induction units typically incorporate sensors that prevent the elements from being energized unless a metal pan is placed over the induction coil. Induction elements will not turn on in the presence of small metal objects, such as jewelry or utensils.

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[52] Minoru Hirose, et al., Electromagnetic Interference of Implantable Unipolar Cardiac Pacemakers by an Induction Oven, Pacing and Clinical Electrophysiology, June 2005.
[53] Werner Irnich and Alan D. Bernstein, “Do Induction Cooktops Interfere with Cardiac Pacemakers?,” Europace, March 2006.
[54] Other references regarding health risks are cited on the Induction Site, www.inductionsite.com .

- Responsiveness. Cookware temperatures can be controlled over a wide temperature range and adjusted quickly by varying the strength of the magnetic field. This responsiveness is ideal for handling delicate cooking needs (e.g., simmering sauces and melting chocolate) as well as saving time with common chores (e.g., rapidly boiling water).

## 3.8 Program Opportunities

The focus of incentive and rebate programs for cooking technologies has been on commercial-sector cooking equipment rather than on residential cooking appliances because such emphasis meets the cost/benefit requirements of efficiency programs.

For residential cooking, the focus has been primarily on providing information such as buying tips. This has included marketing residential induction cooking as an alternative to gas cooktops, since they are not only energy efficient, but enable fast, safe and responsive cooking.

Tips on cooking behavior to reduce energy use are also a focus. Use advice includes using smaller appliances instead of ovens, using a microwave oven when it can meet quality needs for items to be cooked, or using cookware that matches the size of the heating element (e.g., ACEEE's online consumer guide to appliance notes that a 6" pan on an 8" burner will waste over 40% of the heat produced by the burner[55]).

Likewise, federal programs focus on energy saving tips and buying tips rather than providing EnergyGuide labels or ENERGY STAR ratings.

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[55] From http://www.aceee.org/Consumerguide/cooking.htm#cookware/

# 4
# CLOTHES WASHERS

Clothes washers are powered by electricity, but only about 10% of the energy used by these appliances is for directly operating the machine. Ninety percent of energy use is for water heating, so cleaning clothes is less water is a significant component of reducing residential energy use. Moreover, the spin speed of the washers is also an important consideration for energy efficiency, since the remaining moisture content of the laundry load has a significant affect on the amount of energy and time needed for evaporative drying.

Reducing water use was the impetus for development of residential front loading or horizontal axis washing machines. The introduction of the Maytag Neptune horizontal axis machine in 1997, which EPRI helped develop and test, helped spur major manufacturers to introduce more energy efficient models, and as of 2005, horizontal axis machines constituted about 8% of the installed clothes washers in the U.S.

## 4.1 Definition/Description

Washers are typically categorized according to whether they are vertical axis (top loading) or horizontal axis (typically front loading). Capacity is also a characterizing feature, and clothes washers are classified as compact or standard size. Compact washers are defined by DOE as having a capacity of less than 1.6 cubic feet. Some compact units are combination units, integrating the washing and drying functions in one appliance.

## 4.2 Energy Use and Peak Demand

Since energy use for clothes washing is mostly for heating water, reducing water volume is one the key energy-saving features of modern washing machines. The amount of electricity that can be saved by efficient clothes washers will depend on the type of energy used for water heating and for drying, since clothes washer water use and spin speed affects each. For example, DOE estimates that ENERGY STAR washers that use 31% less energy and 55% less water than new standard clothes washers –and are installed in homes with both an electric water heater and electric dryer—will save 242 kWh/yr in water heater and dryer electricity use.[56] Another 16 kWh/yr is saved from use of ENERGY STAR vs. standard new clothes washers, for a total electricity savings of 258 kWh/yr. If the ENERGY STAR washer is compared to the existing, older washer that it replaces, electricity savings are greater.

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[56] U.S. Department of Energy, Clothes Washer Product Snapshot. Prepared by D&R International. May 2008, p. 9.

Average U.S. residential electricity use of clothes washers (excluding electric water heating consumption for water that fills the washer) is about 1%. That is an average 88 kWh/hh nationally. Since not all households have clothes washers, the average unit electricity use is higher; i.e., the electricity used for washers in households that have washers is 120 kWh/yr.[57]

Washer efficiency has improved in the last two decades, as the capacity of washers has increased. This is shown in data from the Association of Home Appliance Manufacturers in **Table 4-1**.

**Table 4-1 AHAM Clothes Washer Energy Efficiency and Consumption Trends**

| | Tub Volume/Unit | | Energy Consumption/Unit[a] | | Efficiency | |
|---|---|---|---|---|---|---|
| **Year** | **Cu Ft** | **% change from 1990** | **kWh/cycle** | **% change from 1990** | **Energy Factor[b]** | **% change from 1990** |
| 1990 | 2.63 | -- | 2.67 | -- | 0.99 | -- |
| 1995 | 2.72 | 3.4% | 2.22 | -16.9% | 1.23 | 24.2% |
| 2000 | 2.92 | 11.0% | 2.20 | -17.6% | 1.47 | 48.5% |
| 2005 | 3.08 | 17.2% | 1.13 | -57.5% | 1.37 | 37.9% |
| 2008 | 3.22 | 22.4% | .80 | -70.1% | 1.67 | 68.4% |

a = Shipment weighted averages

b = Energy factor is cu.ft./kWh/cycle. The higher the EF the more efficient the washer, as greater capacity is handled per unit of energy.

## 4.3 Standards and Labeling

Federal energy efficiency standards were set in 2001, requiring a modified energy factor (MEF) of 1.26. The MEF is a combination of energy factor and remaining moisture content. This is a measurement of how many cubic feet of laundry can be washed and dried with one kilowatt hour. The higher the number, the greater the efficiency.

EISA 2007 requires changes in clothes washer standards, but the MEF will remain the same, requiring a minimum MEF of 1.36. What will change is that water use efficiency will be added to the standard in 2011, requiring that the maximum water factor (WF) be 9.5 or less. The water factor is the number of gallons of water needed for each cubic foot of laundry. The lower the number, the more efficient use of water.

Clothes washers require an EnergyGuide label. They are also rated by ENERGY STAR, and to qualify for an ENERGY STAR, clothes washers must be at least 37% better than standards (the MEF). ENERGY STAR also sets a threshold for water use (water factor). The Consortium for

[57] U.S. Energy Information Administration, End-use Consumption of Electricity 2001. Downloaded from www.eia.doe.gov/.

Energy Efficiency also has developed efficiency tiers for residential clothes washers, as shown in **Table 4-2**.

**Table 4-2 ENERGY STAR and CEE Ratings**[58]

| Efficiency level | Percentage above Federal Standards | |
|---|---|---|
| | **Modified Energy Factor (MEF)a** | **Water Factor (WF)** |
| Federal standard | 1.26 | No requirement, but will be 9.5 in 2011 |
| ENERGY STAR® | 1.80 | 7.5 (will become 6.0 in 2011) |
| CEE Tier 1 (same as ENERGY STAR) | 1.80 | 7.5 |
| CEE Tier 2 | 2.00 | 6.0 |
| CEE Tier 3 | 2.20 | 4.5 |

[a] MEF = how many cubic feet of laundry can be washed and dried with 1 kWh. The higher the number the higher the efficiency.

[b] WF = water factor, the number of gallons of water needed for each cubic feet of laundry.

## 4.4 How it Works

Three kinds of energy are used to clean laundry: thermal, mechanical, and chemical. The chemical energy is the detergent, the thermal energy is the warm or hot water. The mechanical energy is agitation or tumbling of the clothes in the tub, driven by the clothes washer motor. The thermal energy needed for washing requires the most energy (90%) .

Soil is removed as it is dislodged by motion of the clothes and carried away by water. Heat activated detergents emulsify oils that bind the dirt, or provide enzymes that break down proteins. Dirt, grease, proteins and other materials are rinsed away, and the wet laundry is spun in the tub to remove moisture and reduce the energy needed to dry the load.

In typical top loading units, clothes are immersed in a tub of water and a vertical agitator that moves back and forth creates the motion needed to help dislodge dirt. In horizontal axis models, there is no agitator against which to rub the clothes; the mechanical energy is the rotation of the tub, which tosses the clothes and plunges them in a shallow pool of water.

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[58] Copyrighted information from the Consortium for Energy Efficiency used with permission. www.cee1.org/.

## 4.5 Design Options

A number of options are available for increasing the efficiency of clothes washers:

- Front loaders and advanced top loader designs that reduce water requirements and thus reduce energy use. The most radical change in clothes washer design is the emergence of models that use significantly less water than clothes washers of yesteryear. These are typically horizontal-axis, front-loading designs, although advanced top-loader models also increase efficiency using altered agitator designs and cycling of clothes through a reduced stream of water. Use of high pressure sprays for rinsing rather full tubs of water also decrease water use.

- The efficiency of motors, which move the agitator or spin the drum, also affect energy efficiency. To reduce energy requirements many appliance manufacturers use washer designs that rely on permanent magnet synchronous motors instead of the split-phase, ac induction motors.[59] Eliminating the belt transmission system and connecting the motor directly to the drum can also reduce energy use.

- High spin speeds reduce overall laundry energy use. Efficient motors spin the washer drum two or three times faster, ideally at about 1,500 to 2,000 rpm, to extract water. It is considerably more efficient to extract water in the spin cycle than to remove it in an evaporative dryer. The effect of moisture retention in laundry loads is the reason that federal regulations use a "modified energy factor" (MEF) as a metric to measure washer efficiency. It incorporates not only the energy factor (kWh/cu ft) but also the moisture retention factor.

- New technologies. One change in technology is to alter the chemistry of the water used in the washer. For example, the SilverCare washer from Samsung creates silver ions that are released in the water to help sterilize the clothes; the Haier Wash20 washer (available only in Europe, not in the U.S.) splits water molecules. The Samsung silver ion technology is supposed to clean clothes well in cold water, with no need for heat for sanitizing clothing. However, the U.S. Environmental Protection Agency is concerned that silver ions in wastewater could harm aquatic life. *Consumer Reports* online reports that the EPA anticipates that Samsung will submit data to the agency regarding the safety of SilverCare.[60] Haier claims that the main feature of the Wash20 washer is that it requires no detergent. It also claims effective cleaning in cold water. Environmental affects of this technology were not researched by EPRI.

- Advanced software, sensors and controls permit greater automation of washing machine operation. Water levels, motor operation, wash time, and spin speed can be more precisely controlled as more sophisticated controls are built into the system.

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[59] Patrick Heath, "Using Field-Weakening Motor Control in Washing Machines," *Appliance Magazine*. October 2009. Downloaded from www.appliancemagazine.com/

[60] Washers and Dryers: Performance for Less, *Consumer Reports*. Downloaded from www.consumer reports.org in December 2009.

## 4.6 Market Data

Clothes washer saturation and use characteristics reported in the EIA 2005 Residential Energy Consumption Survey[61] include:

- About 82% of households, representing almost 92 million homes, use a clothes washer. (Note that appliance industry statistics based on producer data shows a higher saturation, at 95%.[62])
- About 92% of installed clothes washers are top loading models, although the share of front-loading units is inching up.
- For the wash cycle, most (55%) of households with washers use warm water, about 7% use hot water, and 38% use cold water.
- For the rinse cycle, cold water prevails, with 78% selecting cold water, 20% using warm water, and 2% opting for hot water.

The ENERGY STAR Clothes Washer Product Snapshot,[63] provides additional insight on the clothes washer market:

- Very efficient clothes washers typically are costlier to produce by manufacturers, so most are premium, high priced products that incorporate a number of extra features such as steam, more cycle options, touch-pad controls, and greater capacity.
- Prices of clothes washers range from about $240 to about $1,500. The most efficient washers, such as ENERGY STAR models, tend to be higher cost, ranging from about $550 to $1,500.
- The average household does 392 loads of laundry annually, consuming about 13,500 gallons of water.
- The average life of a clothes washer is 11 years.
- Top loaders are favored by consumers because they tend to be lower cost and familiar.
- Operation of front loading washers requires some adjustments in behavior, including switching to low sudsing detergents formulated specifically for front loaders. (High sudsing detergents may not completely rinse out.) Also, front loaders also require periodic rinses with bleach or with manufacturer-branded special cleaners to avoid mold build up in the clothes washer.

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[61] Energy Information Administration, 2005 Residential Energy Consumption Survey: Preliminary Housing Characteristics Tables, Table HC2.10 Downloaded from http://www.eia.doe.gov/emeu/recs/recs2005/hc2005_tables/detailed_tables2005.html

[62] "The Saturation Picture," 31st Annual Portrait of the U.S. Appliance Industry, *Appliance Magazine*. September 2008.

[63] U.S. Department of Energy, Clothes Washer Product Snapshot. Prepared by D&R International. May 2008.

## 4.7 Program Opportunities

Utility rebates and incentives for energy and water efficient clothes have helped move the market toward greater efficiency and promoted adoption of front loading technology.

Continuing promotion of ENERGY STAR and CEE-rated clothes washers can continue the growth in market share of efficient washers, which accounted for about 24% of the market in 2008.[64] About 40% of all washing machine models are ENERGY STAR qualified.[65]

The amount of electricity that can be saved by promoting purchase of more energy efficient clothes washer will depend on the type of energy used for water heating and for drying, since clothes washer efficiency affects both. As noted in section 4.2, Energy Use and Peak Demand, an ENERGY STAR clothes washer can save an estimated 258 kWh/yr if savings from an electric water heater and electric dryer are taken into account.

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[64] Seize the ways! ENERGY STAR® 10th Annual Appliance Partner Meeting, Chicago IL. September 21-23, 2009.

[65] U.S. Department of Energy, Clothes Washer Product Snapshot. Prepared by D&R International. May 2008.

# 5
# CLOTHES DRYERS

Clothes dryers can use either gas or electricity; this report focused on electric clothes dryers. Clothes dryers offer opportunities for energy efficiency improvements in the U.S. In particular, introduction of heat pump dryers, which can use about half of the electricity used by conventional electric evaporative dryers, could begin to alter the energy efficiency of U.S. dryers. Heat pump dryers are not yet available in the U.S. as of 2009, but may be introduced in the future by U.S. manufacturers or imported from Asia or Europe, where they are commercially available.

## 5.1 Definition/Description

Dryers are typically classified by their fuel source (gas or electricity) and capacity. Standard size is 4.4 cubic feet or larger, and compact size is less than 4.4 cubic feet. Vented dryers are the norm in the U.S., but ventless condensing dryers are also available. These are typically compact units, and can be standalone or integrated into compact combination washers- dryers. Since these units do not require a vent duct, they are an option for those who do not have the ability to vent a dryer; for example, apartment dwellers. They are typically not any more energy efficient than evaporative dryers.

## 5.2 Energy Use and Peak Demand

Average electricity use of clothes dryers in U.S. households is 658 kWh/yr, which is more than 5% of residential electricity consumption. Nationally, electric clothes dryers are present in only 62% of U.S. households (an additional 20% have gas dryers),[66] so the average electricity use of dryers across all households is lower than the unit energy use (UEC) of an electric clothes dryer, which is about 1067 kWh/yr.[67]

Peak demand of clothes dryers averages 0.10 kW/hh in the U.S. (See Chapter 1, Table 1-3.)

Water extraction in the washer spin cycle has been the primary means of reducing dryer energy use in the U.S. market since U.S. dryer energy use does not vary much.

## 5.3 Standards and Labeling

The first federal energy efficiency standard for clothes dryers affected gas dryers only, prohibiting gas pilot lights. An update in 1991 required that a temperature or moisture sensor be incorporated in all types of dryers to enable termination control when clothes are dry. The next

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[66] 31st Annual Portrait of the Appliance Industry, “The Saturation Picture,” *Appliance Magazine*. September 2008.
[67] End-Use Consumption of Electricity 2001 and available at http://www.eia.doe.gov/emeu/recs/contents.html . According to the EIA, sampling issues with updated data collected in 2005 have prevented release of 2005 data.

standards took effect in 1994 and required minimum efficiency levels shown in **Table 5-1**. The rulemaking process for a new standard began at DOE in 2007, and is slated for completion in 2011. Implementation of a new standard will take effect in 2014.

**Table 5-1 U.S. Clothes Dryer Federal Standards**

| Vented Dryers | Energy Factor (EF) (lb/kWh) |
|---|---|
| Electric, standard | 3.01 |
| Electric, compact* (120 volts) | 3.13 |
| Electric, compact (240 volts) | 2.90 |
| Gas | 2.67 |

| Vented Dryers | |
|---|---|
| Electric, compact | Not applicable** |
| Electric, combination washer-dryer | Not applicable** |

*Compact = less than 4.4 cubic feet capacity

**DOE has not established a baseline energy efficiency for this product class because efficiency cannot be measured by the current test procedure

The maximum efficiency available in a U.S. standard vented dryer is 3.39 EF. For compact 120 volt units the most efficient unit has an EF of 3.79.[68]

There are no ENERGY STAR clothes dryers, and as noted on the ENERGY STAR website (www.energystar.com/):

> *"The Department of Energy's Appliance Standards program conducted a detailed study which found that the clothes dryers on the U.S. market do not vary significantly from each other in terms of energy consumption. This is also the reason why the Federal Trade Commission (FTC) does not require clothes dryers to have a yellow EnergyGuide label."*

## 5.4 How it Works

Most dryers on the U.S. market are evaporative dryers. In the case of an electric dryer, an electric heating coil or element, also called a calrod, is used to heat air drawn from the home into the dryer. (Gas burners supply heat in a gas dryer.)

By tumbling clothes in a turning drum the moisture in the wet fabric is evaporated. To enhance heat transfer the motor rotates the drum slowly to maintain space between the articles in the load. The resulting moist air is vented, typically to the outdoors through a exhaust pipe. Heat levels are regulated by a thermostat. Temperature sensors in the exhaust can be used to signal termination control to prevent overdrying and wasted energy, or a moisture sensor can be used for this. The moisture sensor is the more effective of the two so is a preferred energy saving feature.

[68] U. S. Department of Energy, Framework Document Public Meeting on Energy Conservation Standards for Residential Clothes Dryers and Room Air Conditioners. Washington, DC. October 24, 2007

### 5.4.1 Ventless Condensing Dryers

Condensing dryers differ from evaporative dryers in that instead of venting moist air out of the dryer, the moisture in the air is cooled and condensed at a heat exchanger in the unit, and channeled into a drain line. Air-to-air or water-to-air heat exchangers can be used. In combination washer-dryers water-to-air heat exchangers are typically used (with cool water rather than cool air used for condensing moisture). The efficiency of condensing dryers is typically about the same as evaporative dryers.

## 5.5 Design Options

The greatest strides in electric evaporative dryer efficiency have been from better termination controls and added insulation of the dryer. No major technology breakthroughs or major leap in efficiency has been achieved as yet in the U.S. market.

Design options for increasing efficiency were identified in 1994 in an advanced notice of public rulemaking, but the Department of Energy has yet to issue a technical analysis of clothes dryers for the rulemaking begun in 2007.

Among the design options that may be included in the analysis include :

- Advanced software, sensors and controls. Incorporation of moisture sensors into dryers enables shut off when the clothes are dry, reducing operating time and saving energy. The sensitivity of sensors, and the software used in clothes dryers can enable more precise automated operation. For instance, Whirlpool claims a dryer model it brought to market in 2009 has advanced software that enables better termination control that can reduce dryer energy use by up to 40% for small and medium size laundry loads.[69] This dryer is being tested in the EPRI Energy Efficiency Demonstration as part of the residential appliances portion of the program. (For more information on the EPRI Energy Efficiency Demonstration, see the Research tab at www.epri.com/. As of 2009, the Energy Efficiency Demonstration is described on the Industry Technology Demonstrations page.)
- Drum upgrades such as drum design and reverse tumble options.
- For vented models, recycling of exhaust hear and preheating of inlet air.
- Enhance motor efficiency.

### 5.5.1 Alternative Heat Generation Technologies

Major changes in dryers, and in their energy efficiency, will likely involve alternative technologies for producing the heat needed to dry clothes. The main options for alternative heat generation in electric dryers are heat pump and microwave technologies.

[69] A. Sinclair, Whirlpool Corp., personal communication. July 2009.

### 5.5.1.1 Heat Pump Dryers

Heat pump dryers rely on the vapor compression cycle for extracting heat; similar to a window air conditioner operating in reverse. Hot moist air is channeled through the heat pump, where moisture is condensed and sent to a drain, and then the air is reheated by the heat pump, and the dehumidified warm air is recirculated through the drum. Warm air is not exhausted, it is conserved within the machine, one of the reasons these dryers can use up to half of the electricity consumed by conventional dryers.

Heat pump dryers are available in Europe and Asia. (**Figure 5-1** below shows a combination washer and heat pump dryer from Panasonic.) A heat pump unit offers the greatest opportunity for energy savings in dryers since they can halve the amount of energy used. DOE assessment done by TIAX in 2005 of estimated energy savings achieved by commercially available heat pumps dryers in 2005 was 30-50%.[70]


*Source: Photo courtesy of Panasonic.*

**Figure 5-1 Panasonic Combo Washer-Dryer with Heat Pump, Consumer Electronics 2009 Show**

## *5.5.2 Microwave Dryers*

Microwaves can dry clothing as they penetrate easily to the moisture in the interior of fabrics and vaporize it. Use of microwaves for clothes dryers have been investigated by appliance manufacturers, as well as by electric utilities. A microwave clothes dryer combining a

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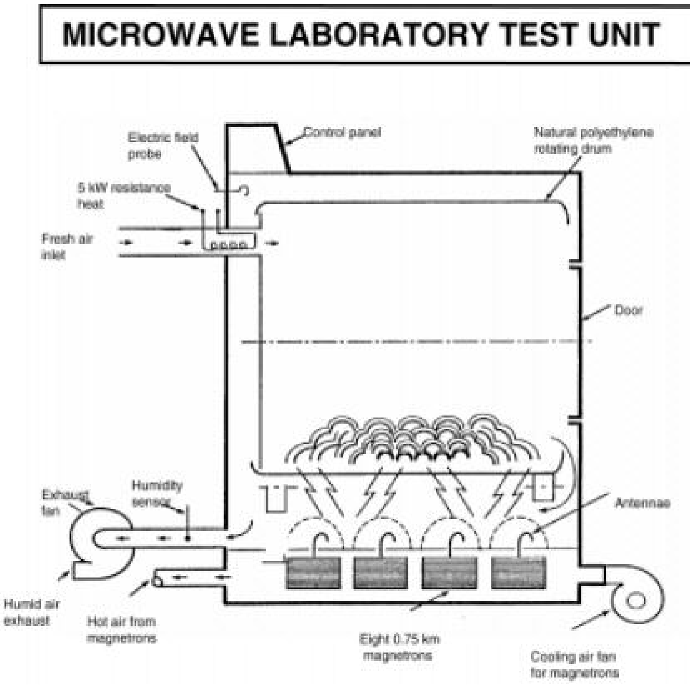
[70] U.S. Department of Energy, *High Efficiency, High Performance Clothes Dryer*. Prepared by TIAX LLC. 2005.

conventional electric resistance heating element with microwave generating magnetrons was tested  by EPRI in the early 1990s as a tailored collaborative research effort.




Note: This schematic is a copy of a figure from the EPRI  report *Development of a Microwave Clothes Dryer*. July 1993. TR-102114.

**Figure 5-2  A Schematic of a Microwave Dryer**

EPRI's microwave dryer test unit combined a conventional electric resistance heating element with magnetrons for drying. The unit could operate in three modes: cool drying (microwave power and ambient air), fast drying (microwave power and resistance element heating), and high-efficiency drying (microwave power and waste heat recovery). Which mode of operation was used had a impact on efficiency, with the efficiency of the test units ranging from slightly worse than conventional dryers to 13%-25% better. A residential clothes dryer prototype was developed but was never commercialized, primarily because the improved efficiency attained would have had a cost that resulted in a simple payback period exceeding the likely lifetime of the dryer.

## 5.6 Market Data

2008 appliance industry market statistics on electric dryers include[71]:

- More than 6 million electric dryers were shipped in 2007, compared to one and a half million gas dryers.
- Electric dryer saturation in U.S. households is about 62% (an additional 20% have gas dryers). Of this group, according to the 2005 EIA Residential Energy Consumption Survey, more than 72% use the dryer for every load washed. Another 12% use the dryer for some, but not all loads, and close to 3% use their dryer infrequently.
- The average lifetime of both electric and gas dryers is 12 years.
- More than 4 million dryers are due to be replaced in 2009.

## 5.7 Program Opportunities

Since all U.S. dryers use about the same amount of energy, no rebates or rating programs are used for dryers. The reductions in dryer energy use are focused on providing incentives for washers that have a high spin speed and remove a considerable amount of the moisture in laundry loads in the washer spin cycle. This moisture retention is integrated into the metric for measuring washing machine efficiency, the modified energy factor (MEF).

Going forward, working with manufacturers to encourage greater efficiency or development and testing of heat pump dryers could make a difference in the energy efficiency of available dryers. In addition, ENERGY STAR is examining possible ratings for dryers, linked to upcoming standards, which will be developed by DOE in 2011 and implemented in 2014.

[71] 31st Annual Portrait of the U.S. Appliance Industry. *Appliance Magazine*. September 2008. Available www.appliancemagazine.com/.

# 6
# DISHWASHERS

Dishwashers are among the residential appliances with greatly improved energy efficiency in recent years, as shown in **Table 6-1** which displays data from the Association of Home Appliance Manufacturers. Moreover, use of dishwasher can be much more efficient than washing dishes by hand. ENERGY STAR reports that its qualified units use half as much energy as hand washing.

**Table 6-1 AHAM Dishwasher Energy Efficiency and Consumption Trends**

| | Energy Consumption/Unit[a] | | Efficiency | |
|---|---|---|---|---|
| **Year** | **kWh/cycle** | **% change from 1990** | **Energy Factor[b]** | **% change from 1990** |
| 1990 | 2.67 | -- | 0.37 | -- |
| 1995 | 2.07 | -22.5% | 0.48 | 29.7% |
| 2000 | 2.00 | -25.1% | 0.51 | 36.6% |
| 2005 | 1.67 | -37.4% | 0.60 | 62.3% |
| 2008 | 1.52 | -43.2% | 0.67 | 79.9% |

[a] = Shipment weighted averages
[b] = Energy factor is cycles/kWh. The higher the EF the more efficient the dishwasher

## 6.1 Definition/Description

Dishwashers are a cabinet-like appliance that automates the process of cleaning dishes. Dishwashers are categorized by size, either compact or standard. Standard-size dishwashers can hold eight or more place settings; compact products less than eight place settings. Most dishwashers in the U.S. automatically dispose of food remnants left from the wash via the rinse drain. Non-food dispensing units require manual removal of food particles.

## 6.2 Energy Use and Peak Demand

The average U.S. household energy use of dishwashers is 243 kWh/yr. The unit energy use; i.e., the amount of energy used in homes that have a dishwasher, is higher. The EIA's End-Use Consumption of Electricity 2001 data shows unit energy use as 512 kWh/yr/hh.

Dishwasher average peak demand ranges from 0.02 to 0.04 kW/hh depending on region, with an average U.S. peak demand per household of 0.03 kW/hh.

## 6.3 Standards and Labeling

The Energy Independence and Security Act of 2007 (EISA) establishes new federal standards for dishwashers. This standard will establish a water efficiency requirement for the first time. The current standard, established in a 2003 rulemaking, is an energy factor (EF) of 0.46 cycles/kWh for standard size dishwasher for "normal" cycle.

The federal government is shifting from measuring energy efficiency as an energy factor (EF) to kWh/year so that it can account for standby power. For example, 355 kWh/yr is the equivalent of an EF of 0.62 (347 kWh/yr) plus the 8kWh/yr that a 1 watt dishwasher will use in standby mode.[72]

Dishwashers are among the appliances that have EnergyGuide labels. ENERGY STAR criteria for dishwashers require that the appliances be at least 41% more efficient than the minimum federal energy efficiency standard. The Consortium for Energy Efficiency (CEE) has also developed super efficient thresholds for dishwashers, per **Table 6-2**.

**Table 6-2 Dishwasher Energy Efficiency Specifications[73] (As of August 11, 2009)**

| Efficiency level | Minimum Energy Factor | Maximum kWh/yr | Maximum gallons/cycle |
|---|---|---|---|
| | **Standard -size dishwashers[a]** | | |
| Federal standard | 0.46 | No requirement | No requirement |
| ENERGY STAR® | No requirement | 324 | 5.8 |
| CEE Tier 1 | 0.75 | 307 | 5.00 |
| CEE Tier 2 | 0.75 | 295 | 4.25 |
| | **Compact dishwashers[b]** | | |
| Federal Standard | 0.46 | No requirement | No requirement |
| ENERGY STAR® | No requirement | 234 | 4.00 |
| CEE Tier 1 | 1.00 | 222 | 3.50 |

[a] Dishwasher that hold eight or more place settings
[b] Dishwashers that hold fewer than eight place settings

[72] Market Impact Analysis on the Potential Revision of the ENERGY STAR Criteria for Dishwashers. August 15, 2008. Downloaded from www.energystar.gov
[73] Copyrighted information from the Consortium for Energy Efficiency used with permission. www.cee1.org/.

## 6.4 How it Works

Dishwashers use thermal, chemical and mechanical energy to clean and rinse and dry dishes. Water from the home's water heater is piped to the dishwasher, where a booster heater brings it to a preset temperature. Booster heaters are normally activated if inlet water temperature is below 140°F.

A water pump that uses a fractional horsepower motor circulates water through spray arms above and below the dish racks. (The pump also can be reversed so it flushes a food filter and discharges waste water into the drain.)

The water motion and chemical action of the water-detergent solution dislodge food and emulsify grease on dishes. Wash and rinse cycles alternate to remove particles. After the final rinse, the dishes are dried with an electric element heater or users can select a natural air drying option.

Soil sensors and controls in some models adjust cycles according to how dirty the dishes are, and optimize energy and water use. For small loads or lightly soiled loads this can reduce energy use.

## 6.5 Design Options

Like most appliances, no major changes in basic dishwashing technology are emerging. Efficiency improvements can be achieved by combining and integrating a number of design options. These include:

- Smart controls. For example, optical soil sensors and adaptive controls can adjust functions to get dishes clean with minimal energy and water use. Smart controls enable greater precision for operations such as timing cycles, water temperature, and water fill levels.
- Designing jets for efficiency so that less energy is used to spray water and detergent.
- Designing filters so that food does not redeposit on dishes.
- Whether booster heater efficiency improvements can sufficiently increase energy efficiency to be cost effective is uncertain. But based on field measurements of three dishwashers, the Florida Solar Energy Center (FSEC)[74] recommends that in addition to any technology changes in the dishwasher itself, methods be used to reduce the frequency and duration of booster heater activation. This includes 1) setting water heater temperature to the minimum acceptable level of 120°F, and 2) minimizing the length of plumbing from the water heater to the dishwasher and insulating pipes. In FSEC tests, measured water temperatures showed that in a 30 ft. plumbing run, only a portion of the water drawn from the storage tank actually reaches the dishwasher. Water from the tank cools in the piping, to be reheated in the dishwasher. The situation is even more inefficient for longer plumbing runs, particularly in a cooling dominated climate, where the residual heat in the pipes is lost to the interior, increasing cooling load.

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[74] David E. Hoak, Danny S. Parker and Andreas H. Hermelink, *How Energy Efficient are Modern Dishwashers?*, Florida Solar Energy Center: Cocoa, FL. 2008. FSEC-CR-1772-08.

## 6.6 Market Data

Per ENERGY STAR[75], the dishwasher market has responded to consumer demand for energy efficient models:

- The existing market includes 21 different manufacturers that produce a total of 948 dishwasher models under a total of 58 brands. Of these 948 models, 655 or 69% of the available models are ENERGY STAR qualified. Seven manufacturers' entire dishwasher product lines are ENERGY STAR qualified.
- About 67% of units sold are ENERGY STAR models. This is the largest percentage of the market for any residential appliance.

According to appliance industry statistics: [76]

- Dishwashers are present in at least 61% of U.S. households.
- In 2007, 6.9 million dishwashers were shipped in the U.S.
- The average lifetime of a dishwasher is 12 years.
- The number of units ready to be replaced in 2009 is 5.7 million.

Customer behavior that can influence energy use includes:

- Washing dishes only when there is a full load, which *Consumer Reports* says is the practice of 83% of households.[77]
- Foregoing rinsing of dishes before placing them in the dishwasher. Many people continue to do this although it is not needed to get dishes clean. According to a survey on energy-saving habits conducted by the Consumer Reports National Research Center, only 10% of respondents forego rinsing dishes before loading in the dishwasher. As advised by most appliance makers, just scraping is needed. Rinsing can use 20 gallons of water before the cleaning process begins.

## 6.7 Program Opportunities

More energy efficient dishwashers are on the horizon and utilities can continue to promote purchase of the most efficient ENERGY STAR and tier-based CEE-qualified models to ensure that consumers are provided the incentives and information needed to purchase the highest efficiency models.

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[75] Sieze the ways! ENERGY STAR® 10th Annual Appliance Partner Meeting, Chicago IL. September 21-23, 2009.

[76] 31st Annual Portrait of the U.S. Appliance Industry. *Appliance Magazine*. September 2008. Available www.appliancemagazine.com/.

[77] "By the numbers: U.S. consumers adopting some greener behavior," *Consumer Reports*. October 3, 2009. Downloaded from www.consumereports.com/.

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