Energy and Water Saving Potential of Dishwashers and Clothes Washers: An Update

Peter J. Biermayer, Lawrence Berkeley National Laboratory

This paper analyzes possible design options that could be used to save energy and water for residential dishwashers and clothes washers. Payback periods and life-cycle costs for these design options and how they vary with electric and gas water heating sources are provided. The range of current efficiencies of dishwashers and clothes washers are also shown. The effects of adaptive control features on test procedure results are discussed.

INTRODUCTION

Dishwashers use 1.4 percent of total residential energy. Clothes washers use 2.6 percent of total residential energy. In both cases most of the energy consumption is for hot water supplied by an external water heater (Turiel et al. 1995, 3). Although large gains in energy efficiency have been made in the past, further gains are still possible. Minimum energy efficiency requirements in the United States are mandated by the National Appliance Energy Conservation Act (NAECA 1987).

Background

This paper shows results of data collected on energy efficiency for various design options. Most of this data was collected from manufacturers who are members of the Association of Home Appliance Manufacturers (AHAM). Questionnaires were sent to AHAM, who in turn collected cost and energy use data from manufacturers. AHAM converted individual data into shipment weighted averages to protect the confidentiality of individual manufacturers. This data was then analyzed at Lawrence Berkeley National Laboratory (LBNL). In some cases the design options were combined and ranked by cumulative payback.

DISHWASHERS

Currently United States regulations require that dishwashers have an option for a non-heated dry cycle and that standard dishwashers have a minimum energy factor of 0.46 cycles per kWh (2.17 kWh/cycle), (U.S. 1991).

Federal Trade Commission (FTC) data. Figure 1 shows the current range of dishwasher energy factors (cycles/kWh). The percentage of models does not necessarily correspond to the number of sales. Data for this chart was taken from manufacturer submitted data to the FTC over the period from January 1995 to July 1995. Dishwashers with an adaptive control or auto-fill feature were not included in this chart because the existing DOE test procedure may not realistically portray savings for this design. Currently, the DOE and FTC have different definitions for compact dishwashers. The DOE defines compact dishwashers as having and exterior width of 22 inches or less, whereas the FTC defines compact dishwashers as having capacity for eight place settings or less. One European manufacturer has an FTC full size dishwasher that would be considered a compact by DOE standards. The DOE definition of compact and standard was used for this chart.

Test Procedure

The existing DOE test procedure allows dishwashers to be tested with 50° F, 120° F, and 140° F water. If tested at 140° F inlet water, the dishwasher is tested empty; at 50° F or 120° F, clean dishes are used as a dishwasher load. Data provided by AHAM is based on an assumed water inlet temperature of 120° F. Since manufacturers say 135° F to 140° F water is needed to dissolve fats on dishes, a booster heater is used in the baseline dishwasher. All dishwashers manufactured in the United States have a booster heater. This is an electric heater that further raises and maintains the water temperature above 120° F (usually based on a timer rather than a thermostat or temperature sensing device). The DOE test procedure has no requirement for the cleaning performance of dishwashers. The DOE also specifies that dishwashers are tested at the normal setting as opposed to ‘‘short wash’’, ‘‘pots & pans’’, or similarly labeled cycles. Each manufacturer defines what constitutes a normal cycle on their dishwasher.

Classes and Categories

DOE issued an Advance Notice of Proposed Rulemaking (ANOPR) in November 1994 to begin the process of updating the minimum efficiency standards for dishwashers, clothes washers, and clothes dryers (U.S. 1995). The two classes of dishwashers listed in the DOE's ANOPR are: (1) compact and (2) standard. Typically, classes are differentiated by fuel type, size, and differences in consumer utility. This report will only discuss the standard class, which is defined as a dishwasher with an exterior width equal to or greater than 22 inches. AHAM further subdivided the standard design class into four categories for ease in collecting data:

food disposing—no or coarse filter
food disposing—fine filter
non-food disposing—no or coarse filter
non-food disposing—fine filter

There are about 4.15 million dishwashers sold per year. Of these approximately half are fine filter models and half are no or coarse filter models (AHAM 1995a). The categories are defined below:

Food disposing. This means that the food washed off the dishes is macerated and disposed of down the drain with the rinse water. The food particles do not have to be manually removed from a strainer.

Non-food disposing. In a non-food disposing dishwasher how often this must be done varies widely. This will depend somewhat on the design and the manufacturer. Some strainers catch only large food items. This design is popular among European manufacturers.

No or Coarse Filter. In this design, food particles stay in suspension and can be redeposited onto the dishes. Typically a greater amount of rinse water is needed with this design.

Fine Filter. Dishwashers utilizing a fine filter have less food redeposited on dishes as it is filtered out before being recirculated by the pump through the spray arms. This feature is more typically available on high end machines. Typical designs have a self-cleaning feature that washes the filter and therefore avoids the necessity of manual filter cleaning. Although, less water is required for rinsing, the washing of the filter requires water use.

Data

AHAM supplied data on only the food disposing dishwashcome in both coarse and fine filter, with the fine filter usually the high end or more costly product. Questionnaires were sent out listing design options. Working with AHAM, the questionnaire was modified and design options were refined as the data gathering process took place. Data supplied by AHAM consists of shipment weighted averages. Data was reviewed for inconsistencies, some of which were a result of the following factors: (1) not all manufacturers responded to all questions, (2) since data was presented as shipment weighted averages, fine filter data will be skewed by the data of a predominately fine filter dishwasher manufacturer and likewise for coarse filter data.

Analysis

Some of the design options were combined and new costs and energy savings were derived from the original data submitted by AHAM. The combining of options was done in a manner to avoid double counting energy savings.

Design Options

The design options and how they can save energy are explained below:

Baseline. The baseline design option energy usage and costs, provided by manufacturers, represent the typical dishwashers being sold today. Note that the energy factors shown in Tables 1 & 2 are above the minimum current standard. This means that when the more efficient dishwashers currently sold are averaged in with those just meeting the current standard, the shipment weighted average has an efficiency above the minimum required by law.

Improved Food Filter. This could prevent the redepositing of food, necessitating perhaps one less fill. Note that there wasn't a large difference between coarse and fine filter baseline energy use (see Table 1). Possibly a very fine mesh filter could be developed that would enable less fill and reduce motor run time (AHAM 1995a).

Improved Spray Arm Geometry. Water energy savings would result from reduced flow rates which enable smaller fills to be used (AHAM 1995a).

Modified Sump Geometry. This design would optimize the sump to minimize the total amount of water needed per fill. The amount of water needed depends on the amount of head needed at the pump inlet. Also affected is how quickly water can flow back to the sump after being sprayed on the dishes.

Modified Pump Geometry. The pump design could be improved to make it more efficient. The pump could be redesigned in conjunction with an improved spray arm to reduce flow.

Efficient Motor. The split phase or shaded pole motor could be replaced by a more efficient permanent split capacitor (PSC). A PSC motor is approximately 10 percent more efficient than a split phase motor. This design option has even greater savings if a shaded pole motor is being replaced.

Improved Dry Cycle. Dishes are currently dried by using the heating element in the bottom of the dishwasher. Sometimes a heating element with an integral blower is also used. The drying cycle length is controlled by a timer. Dishwashers also have a feature that allows for air drying without using a heating element or a blower. Less variance in heating could be achieved by tighter tolerance on timers. Possibly sensors could be used to terminate the heated dry option when no longer needed.

Reduced Inlet Water Temperature. Originally this option was interpreted several different ways. As shown in Tables 1 & 2, this option was taken to mean cold or tempered water is used for some of the rinses. Because dishwashers in North America are connected to a hot water line only, this option would necessitate plumbing in a cold water line to the dishwasher in addition to the currently used hot water line. Another interpretation with different savings and costs would be to lower the temperature of the water heater and use more booster heat. Lowering the water heater temperature below 120° F may not satisfy other household hot water requirements. No satisfactory detergent is available to wash dishes soiled with animal fats at temperatures less than 135° F to 140° F.

Increased Insulation. By increasing insulation at the bottom of the dishwasher, less heat would be lost through conduction and less booster heat would be needed to maintain the water temperature. Adding insulation has been shown to have a minimal effect on efficiency (U.S. DOE 1990).

Improved Wash Cycle. This could involve improved controls such as accurate thermostats to reduce heating variance.

Adaptive Control. Two American manufacturers currently offer dishwashers with adaptive control. These sense the load or soil level in the dishwasher and use sensors, fuzzy logic and a micro controller to adjust the amount of water and/or water temperature used. This is somewhat analogous to manually selecting light, normal or heavy duty wash selection, except the dishwasher does this for you. One manufacturer states that its dishwasher has sensors that monitor the amount of food soil in the water and adjust water temperature and cycle time accordingly. It also tracks the amount of time lapsed between loads so it can adjust for dried-on food. It also takes into account the number of times the door has been opened to size up the load (Maytag 1996).

Table 1. *No or Coarse Filter Dishwasher*

Level	Design Options	Retail Cost 1994$	ENERGY AND WATER USAGE: Water Energy (kWh/cycle)	Machine Energy (kWh/cycle): Normal	Machine Energy (kWh/cycle): Truncated	Total Energy (kWh/cycle)	Energy Factor (cycles/kWh)	Water Use (gal/cycle)	PAYBACK: Electric Payback (years)	PAYBACK: Gas Payback (years)	LIFE-CYCLE COST: Electric W.H.	LIFE-CYCLE COST: Gas W.H.
0	Baseline	$332	1.42	0.83	0.61	2.14	0.47	8.44	Cumul.	Cumul.	$734	$587
1	Improved spray arm geometry	$333	1.38	0.83	0.60	2.10	0.48	8.21	1.0	1.8	$726	$583
2	Add improved food filter	$350	1.28	0.79	0.57	1.96	0.51	7.62	4.4	7.5	$717	$585
3	Add modified sump geometry & modified pump design	$356	1.28	0.80	0.54	1.95	0.51	7.62	5.8	9.6	$722	$590
4	Add increased motor efficiency by 10%	$361	1.27	0.77	0.52	1.92	0.52	7.56	5.9	9.3	$721	$589
5	Add improved dry cycle	$369	1.27	0.76	0.52	1.91	0.52	7.56	7.4	11.4	$728	$596
6	Add increased motor efficiency 20% above baseline	$396	1.27	0.73	0.49	1.88	0.53	7.56	11.5	16.9	$750	$619
7	Level 6 + reduced inlet water temp. w/plumbing	$475 (a)	0.97	0.88	0.63	1.73	0.58	7.56	16.9	46.5	$804	$704
8	Level 7 + increased insulation	$530	0.97	0.84	0.59	1.68	0.60	7.56	21.3	50.3	$851	$751
9	Improved wash cycle	$420	1.28	0.81	0.59	1.98	0.51	7.62	24.2	44.5	$790	$658
10	Adaptive control (b)	$422	1.35	0.85	0.63	2.09	0.48	8.04	73.5	211.3	$814	$674
11	Ultrasonic washing	$631	2.69	0.83	0.61	3.41	0.29	16.01	N/A	N/A	$1,287	$1,009

Notes: Mark up from manufacturers = 2
Cycles / year = 250
Mark up = 2.00
Cycles/yr = 250
Elect. (94) = $0.0838/kWh
Gas (94) = $6.030/MBTU
Water = $2.84/kGal.
Water Heater Efficiency: Gas = 75%, Electric = 100%
Dishwasher Life = 12.6 years
Discount Rate = 6%
Gas Fuel Price Multiplier = 1.01
Electricity Fuel Price Multiplier = 0.90
(a) $75 was added as a cost to add a cold water line to an existing installation
(b) AHAM values, not using DOE test procedure

Ultrasonic Washing. This option has not been shown to save energy. The dishes would have to be submerged while subjected to ultrasonic waves.

Not all manufacturers agree that all of the above design options would save energy. There is concern among manufacturers that for some design options there is a danger in reduced cleaning performance.

Energy Usage

Cycles per Year. The analysis shown in Tables 1 & 2 is based on the existing DOE test procedure with the exception of using 250 cycles per year. The existing DOE test procedure assumes a dishwasher is used on average 322 times (cycles) per year. Based on field data, 250 cycles per year has been shown to be more typical of actual dishwasher

Table 2. Fine Filter Dishwasher

Level	Design Options	Retail Cost 1994$	ENERGY AND WATER USAGE: Water Energy (kWh/cycle)	Machine Energy (kWh/cycle): Normal	Machine Energy (kWh/cycle): Truncated	Total Energy (kWh/cycle)	Energy Factor (cycles/kWh)	Water Use (gal/cycle)	PAYBACK: Electric Payback (years)	Gas Payback (years)	LIFE-CYCLE COST: Electric W.H.	Gas W.H.
0	Baseline	$407	1.39	0.80	0.61	2.09	0.48	8.24			$800	$657
1	Add improved food filter & spray arm geometry	$422	1.26	0.78	0.59	1.94	0.52	7.48	4.5	8.2	$785	$656
2	Add modified sump geometry & modified pump design	$431	1.24	0.77	0.59	1.92	0.52	7.40	6.3	11.4	$791	$662
3	Level 2 & Increase motor efficiency 10%	$432	1.24	0.74	0.55	1.89	0.53	7.40	5.5	8.8	$786	$657
4	Level 3 & Improved dry cycle	$435	1.24	0.73	0.54	1.88	0.53	7.40	6.1	9.7	$788	$659
5	Level 2 + 20% motor + improved dry cycle	$462	1.24	0.71	0.52	1.86	0.54	7.40	11.0	16.7	$812	$683
6	Level 5 + reduced inlet water temp. w/plumbing (a)	$540	0.85	0.91	0.71	1.66	0.60	7.40	15.1	55.9	$857	$769
7	Level 6 + increased insulation	$572	0.85	0.88	0.69	1.64	0.61	7.40	17.9	58.2	$884	$797
8	0 + Improved wash cycle	$508	1.19	0.81	0.62	1.90	0.53	7.06	22.5	47.8	$862	$739
9	0 + Adaptive AHAM (b)	$539	1.16	0.86	0.65	1.91	0.52	6.90	30.3	79.4	$894	$774
10	0 + Ultrasonic washing	$827	1.65	0.80	0.61	2.36	0.42	9.82	N/A	N/A	$1,273	$1,102

Notes: Mark up from manufacturers = 2
Cycles / year = 250
Mark up = 2.00
Cycles/yr = 250
Elect. (94) = $0.0838/kWh
Gas (94) = $6.030/MBTU
Water = $2.84/kGal.
Water Heater Efficiency: Gas = 75%, Electric = 100%
Dishwasher Life = 12.6 years
Discount Rate = 6%
Gas Fuel Price Multiplier = 1.01
Electricity Fuel Price Multiplier = 0.90
(a) $75 was added as a cost to add a cold water line to an existing installation
(b) AHAM values, not using DOE test procedure

usage. The test procedure is currently being revised and the cycles per year will be updated. The number of cycles per year does not affect the energy factor but it does affect the payback period and the life cycle cost.

Parameters. Tables 1 and 2, show the disaggregated energy use for dishwashers as well as the energy factor and water use. Water energy refers to only the energy value in the water supplied from an outside source. It does not include water heated or temperature maintained by the integral heating element at the bottom of the dishwasher. The machine energy includes the heating element energy used to heat and maintain water temperature, heating element energy used in the dry cycle, and motor energy used for all pumps and blowers. The truncated cycle refers to the normal dishwasher cycle without a power dry component. Total energy assumes that the truncated cycle is used 50 percent of the time. The water use column shows the total amount of water used.

Order of Design Options. Design options were combined and ordered by shortest cumulative payback.

Shipment Weighted Averages. A comparison between coarse and fine filter energy consumption shows differences in energy consumption for the same design option. Although the baseline models start with different designs (fine versus coarse filter), there is not a major difference in energy use between the baseline cases. Much of the difference can be attributed to the data being based on shipment weighted averages. Different manufacturers have different designs and different opinions on how much energy a particular design option saves and what it costs to implement. If one manufacturer produces more coarse filter dishwashers than fine filter dishwashers, then that manufacturer's data is predominately reflected in the numbers for coarse filters.

Adaptive Control. The adaptive control design option energy savings would be overstated if based on the existing DOE test procedure because it specifies clean dishes in its test procedure (U.S. 1994b). The dishwasher would sense that the dishes are clean and would tell the machine to run the cycle with the lowest energy use.

Discussions with manufacturers explain the wide difference in energy use between coarse and fine filter machines for the adaptive control options (see Tables 1 & 2). If a coarse filter adaptive control dishwashers were manufactured, its design would be different than that for a fine filter machine. In a coarse filter design, macerated food particles are kept in suspension rather than filtered out during a wash cycle and food particles are later diluted with succeeding rinse cycles. Therefore, according to discussions with manufacturers, sensors designed to detect the turbidity would not show a reduction in the amount of food soil in the water.

The future DOE test procedure will take this design option into account and will more accurately determine actual energy savings. The amount of savings for this design option will depend not only on the sophistication of the controls but also on the dishwashing habits of the consumer.

Economic Analysis

Assumptions. Incremental manufacturing costs were supplied by AHAM. Retail costs were determined by applying a markup of two. Gas and electricity costs are national averages in 1994 dollars using Energy Information Agency forecasts for the year 2000 (EIA 1995, Bureau of Labor Statistics). Fuel price multipliers are used to account for differences in average fuel prices depending on whether or not a gas or electric water heater is used. For example, electric water heaters are more likely to be used where electricity prices are lower.

Payback and Life Cycle Cost. Tables 1 & 2 show payback period and life-cycle cost assuming electric and gas water heaters. The national existing stock of residential water heaters is 55 percent gas and 45 percent electric (AHAM 1995b). Payback is equal to the change in purchase price divided by the yearly dollar savings. All payback calculations are shown referenced to the baseline. In both payback period and life cycle cost, the cost of water as well as energy was taken into account. Life-cycle cost is calculated based on (1) 250 cycles per year, (2) gas and electricity prices in 1994 dollars projected into the year 2000 based on Energy Information Agency projections, (3) a discount rate of 6 percent and (4) a dishwasher life of 12.6 years (U.S. 1990, 4-4). The costs shown are based on the premise that, as a minimum, all of a manufacturer's models would meet energy requirements based on this design option, therefore economies of scale are being reflected.

RESULTS

Payback periods less than the dishwasher life, and life-cycle costs less than the baseline can be achieved with higher energy factors. The coarse filter design can meet the above criteria and achieve energy factors of 0.52 cycles per kWh for both gas and electric water sources. This corresponds to an increase in energy efficiency of 13 percent over the existing requirement of 0.46 cycles per kWh. The fine filter design can meet the above criteria and achieve energy factors of 0.53 cycles per kWh for both gas and electric water sources. This corresponds to a 15 percent increase in efficiency over current standards.

FTC data in Figure 1 shows that a significant number of models are being sold that exceed the current energy efficiency requirements. In fact models are being sold in the energy factor level meeting payback and life-cycle cost criteria discussed above. This further corroborates that improvements in dishwasher efficiency can be achieved.

CLOTHES WASHERS

Currently, United States regulations require that top loading, standard capacity clothes washers have a minimum energy factor equal to or greater than 1.18 cubic feet per kWh. Current efficiency standards made effective in May 1994 classify top loading and front loading machines as separate product classes, with no efficiency requirement for front loading washers (U.S. 1991). The most current ANOPR classifies clothes washers into two classes: (1) compact and

standard (U.S. 1995) Test procedure changes include (1) using 392 cycles per year, (2) clarification of wash/rinse temperatures to avoid ambiguity, (3) specification of agitation and spin speed settings, and (4) new provisions to account for an automatic fill control feature. In addition, the following informational measures will be defined: total (both hot and cold) water consumption, remaining moisture content (RMC) in a test load after the final spin cycle, and a calculated modified energy factor (MEF). The MEF will include the energy needed to dry clothes in a dryer after a final washer spin cycle.

Proposed test procedure. The proposed test procedure will make some of the informational changes in the interim test procedure mandatory. Major changes in the test procedure will preclude making adjustments from the existing test procedure with only a correction factor. Among the changes in test procedure will be (1) new temperature use factors (TUF's), (2) lowering inlet hot water from 140° F to 135° F, and (3) provisions to account for adaptive control and auto-fill. (Temperature use factors are used to prorate energy consumption among cold, warm and hot wash, as well as to factor in a warm rinse if offered.) Clothes washer loads specified will depend on washer clothes container volume. Remaining moisture content after a final spin cycle will be accounted for and a modified energy factor (MEF) will replace the current energy factor (EF). The above changes should result in a more accurate prediction of actual energy.

Data and Analysis

AHAM submitted data based on the existing DOE test procedure as well as on a proposed AHAM test procedure that is similar to the proposed DOE test procedure. Adjustments have been made to the AHAM data to account for proposed changes in the test procedure. These include adjusting the hot water energy to reflect changes in inlet water temperature and adding provisions to account for remaining moisture content (i.e., to calculate the energy needed to dry the load after a final washer spin cycle). These adjustments not only affect the absolute value of energy use but also the order of design options. For example, a higher assumed inlet water temperature would make thermostatic mixing valves a more desirable design option. There is no simple conversion factor that can be used on existing energy factors to obtain the new modified energy factor.

Design Options

Decrease Remaining Moisture Content (50%, 40%, 35%, 30%). There are several ways to reduce the moisture content of the laundry load after the final spin cycle. An effective way is to increase the spin speed of the final spin. Others include changing direction of rotation, having a longer spin cycle, and increasing the size or number of drainage holes in the washer drum. Since mechanical drying is more efficient than using heat to dry, energy consumption for the combined wash and dry process is reduced.

Thermostatic Mixing Valve. This design option could achieve energy savings by more accurately controlling inlet water temperature for hot or warm fills. Hot and cold inlet water valves would temper water from the water heater to achieve the desired hot and warm water temperature.

Improved Fill Control. Water level is sometimes filled higher than required for a ''good'' wash. This design option would decrease the tolerance on fill. Data on this design option was highly dependent on how the manufacturer defined it.

Horizontal Axis Design. The horizontal axis machines rotate the drum and clothes about a horizontal axis. The clothes do not have to be fully submerged in this design, therefore energy is saved by reducing the amount of water used. Typically, washer is filled to a certain level. As clothes absorb the water, a water level sensor allows more water to enter to maintain this level. In this way the water level is inherently matched to the laundry load. Some machines incorporate an internal heater to maintain the water temperature. Since less water is used in this design, there is less thermal mass available and the water could cool off quicker than in a vertical axis design. This is the predominate European washer design.

Horizontal Axis with recirculation. This is similar to the horizontal axis design except even less water is required. Water is collected in a sump underneath the rotating drum and pumped through a spray nozzle into the interior of the rotating drum.

Auto-Fill Control. An auto-fill control would sense the amount and/or type of clothes and fill the water level accordingly. This would overcome the tendency of consumers to manually select a water level greater than that required. AHAM data is not yet publicly available for this option.

Adaptive Control. This design option would measure the soil load and adjust the wash time and the amount of rinse water to save energy. AHAM data is not yet publicly available for this option.

Not all manufacturers agree that all design options discussed above can be achieved and still provide acceptable performance to the public. Manufacturer comments to DOE's November 1994 ANOPR show special concern over whether lower values of remaining moisture content (35 and 30 percent) are achievable.

Table 3. *Standard Clothes Washer Energy Usage and Operating Cost*

		ENERGY & WATER USAGE				ANNUAL OPERATING COST					
						Hot Water Energy					
Design Level	Design Option	Retail Cost (a)	Total Energy kWh/ cycle	MEF cu. ft. per kWh/ cycle	Water Total Gallons	Electric $/yr	Gas $/yr	Machine Energy $/yr	Water Use $/yr	Elect. Dryer $/yr	Gas Dryer $/yr
0	Baseline (vert. axis)	$383	3.33	0.878	38.9	$47	$17	$7	$43	$46	$14
1	0 + RMC = 50%	$399	3.02	0.969	38.9	$47	$17	$7	$43	$36	$11
2	0 + RMC = 40%	$414	2.76	1.059	38.9	$47	$17	$7	$43	$28	$9
3	2 + Thermostatic mixing valve	$428	2.62	1.119	38.9	$42	$15	$7	$43	$28	$9
4	3 + Improved fill control	$456	2.47	1.184	36.1	$38	$14	$7	$40	$28	$9
5	4 + RMC = 35%	$494	2.35	1.246	36.1	$38	$14	$7	$40	$24	$7
6	4 + RMC = 30%	$501	2.25	1.303	36.1	$38	$14	$8	$40	$20	$6
0	Baseline (vert. axis)	$383	3.33	0.878	38.9	$47	$17	$7	$43	$46	$14
7	Horizontal axis design	$555	2.25	1.228	26.1	$14	$5	$7	$29	$46	$14
8	Horz. axis w/recirculation	$561	2.17	1.259	21.8	$11	$4	$8	$24	$46	$14
9	8 + RMC = 50%	$577	1.86	1.471	21.8	$11	$4	$8	$24	$36	$11
10	8 + RMC = 40%	$592	1.60	1.707	21.8	$11	$4	$8	$24	$28	$9
11	8 + RMC = 35%	$629	1.48	1.849	21.8	$11	$4	$8	$24	$24	$7
12	8 + RMC = 30%	$636	1.38	1.987	21.8	$11	$4	$9	$24	$20	$6
13	12 + Thermostatic mixing valve	$650	1.34	2.039	21.8	$10	$4	$9	$24	$20	$6

Notes: Elect. (94$/kWh) = 0.0838
Gas (94$/MBTU) = 6.03
Water Cost ($/1000 gal.) = 2.84
Water Heater Efficiency: Elect. = 1.00; Gas = 0.75
Fuel Price Multiplier: Elect. = 0.90; Gas = 1.01
Cycles per year = 392 (current standard uses 416 cycles/year)
(a) Manufacturer markup = 1.7

Energy Usage

The column labeled Total Energy is simply the sum of hot water energy, machine energy and dryer energy. Hot Water Energy is the energy content of external hot water supplied to the washer. Machine Energy represents the energy to move an agitator in a vertical axis design or to rotate the wash drum in a horizontal axis design. This value also includes the electrical energy to run pumps, timers, etc. Dryer Energy is the energy calculated for a typical electric clothes dryer to dry the clothes to a 4 percent remaining moisture content, after the final spin cycle in a washer. The Modified Energy Factor is the washer drum capacity (in cubic feet) divided by the Total Energy. Water use was supplied by AHAM and represents both hot and cold water usage. Vertical and horizontal design options are separated into two sections so that the maximum technologically feasible vertical axis washer design could be shown.

Economic Analysis

Annual Cost. Table 3 shows the relative costs of energy and water used. Note that the cost of water is often greater than the cost of heating it. This is especially true if the hot water source is gas-fired. The cost of drying clothes is also shown to be significant. The cost of water is a national, population weighted average and includes disposal or sewage costs (Dietemann 1995).

Payback. The payback periods were shortest where both clothes dryer and clothes washer were electric (see Table 4). In all cases the payback is well below the typical 14.1 year lifetime of a clothes washer (U.S. 1990). Detergent usage and cost is assumed to remain unchanged regardless of water use. In previous analyses detergent use was assumed to be lower for horizontal axis machines. This was based on one manufacturer's recommendation of decreased detergent use to avoid over sudsing. Over-sudsing is a problem only when the detergent is not specifically formulated for horizontal axis washer use. The amount of detergent required is more a function of the amount of dirt (laundry load) and not the amount of water. In Europe the amount of detergent used in horizontal axis machines is not less than vertical axis machines for the equivalent amount of clothes washed (Cahn 1994).

Life Cycle Cost. Table 4 shows the life cycle cost for combinations of gas and electric water heaters and clothes dryers. All combinations have lower life cycle costs than the baseline. Life cycle cost savings were greater with horizontal design options than for the vertical axis design option combinations.

RESULTS

Based on the expected proposed test procedure, modified energy factors for conventional vertical axis machines could be improved from a baseline of 3.33 kWh/cycle to 2.25 kWh/cycle, or by 32.4 percent. Maximum increases in efficiency based on a horizontal axis design are (from 3.33 kWh/cycle to 1.34 kWh/cycle) up to 60 percent. Increases in efficiency are possible with payback periods from 1.8 to 9.6 years, and with life-cycle costs lower than the baseline.

CONCLUSIONS

Opportunities for dishwasher energy efficiency improvements on the order of 10 to 11 percent exist, with payback

Table 4. *Standard Clothes Washer Payback and Life-Cycle Cost*

		PAYBACK YEARS				LIFE-CYCLE COST			
		Electric Dryer		Gas Dryer		Electric Dryer		Gas Dryer	
Design Level	Design Option	Electric W.H.	Gas W.H.	Electric W.H.	Gas W.H.	Electric W.H.	Gas W.H.	Electric W.H.	Gas W.H.
0	Baseline (vert. axis)					$1,708	$1,433	$1,411	$1,136
1	0 + RMC = 50%	1.8	1.8	6.1	6.1	$1,638	$1,363	$1,402	$1,128
2	0 + RMC = 40%	1.8	1.8	6.4	6.4	$1,581	$1,307	$1,397	$1,122
3	2 + Thermostatic mixing valve	2.1	2.4	4.9	7.0	$1,554	$1,305	$1,370	$1,121
4	3 + Improved fill control	2.6	3.2	4.4	6.6	$1,514	$1,290	$1,330	$1,106
5	4 + RMC = 35%	3.4	4.1	6.3	9.2	$1,518	$1,294	$1,359	$1,135
6	4 + RMC = 30%	3.3	4.0	6.7	9.6	$1,497	$1,273	$1,364	$1,140
0	Baseline (vert. axis)					$1,708	$1,433	$1,411	$1,136
7	Horizontal axis design	3.7	6.7	3.7	6.7	$1,448	$1,367	$1,151	$1,070
8	Horizontal axis w/recirculation	3.3	5.7	3.3	5.7	$1,387	$1,322	$1,090	$1,025
9	8 + RMC = 50%	3.1	4.8	3.5	5.8	$1,317	$1,252	$1,081	$1,016
10	8 + RMC = 40%	3.0	4.4	3.6	5.8	$1,260	$1,195	$1,076	$1,011
11	8 + RMC = 35%	3.3	4.8	4.2	6.7	$1,264	$1,199	$1,105	$1,040
12	8 + RMC = 30%	3.3	4.7	4.3	6.9	$1,243	$1,178	$1,110	$1,045
13	12 + Thermostatic mixing valve	3.4	4.9	4.4	7.2	$1,247	$1,188	$1,114	$1,055

Notes: Clothes Washer Life = 14.1 years
Discount Rate = 6%

periods from 6.1 to 11.4 years. There are dishwashers on the American market today that show substantial increases in energy efficiency. In order to account for possible new technologies using fuzzy logic, sensors and micro controllers, the DOE test procedure would have to be modified.

With regard to clothes washers, energy efficiency gains of 32 percent for vertical axis design and 60 percent for horizontal axis design may be possible with lower life cycle costs, and payback periods shorter than the appliance life span. In order to account for changes in clothes washer technology, including adaptive control and auto-fill, new test procedures would be needed.

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