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Energy and Water Consumption Testing of a Conventional Dishwasher and an Adaptive Control Dishwasher

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ABSTRACT and ACKNOWLEDGMENT

In an effort to determine whether the Department of Energy (DOE) test method for dishwashers, contained in 10 CFR Part 430 [1], can effectively measure the energy and water consumption of models using new technologies as well as conventional models, tests were conducted on a conventional and an adaptive control dishwasher. The adaptive control dishwasher represents a class of innovative models which measure certain quantities (e.g., turbidity, water temperature) and adapt to the information by shortening or extending the wash cycle. The results showed that the adaptive control model had an energy factor of 2.41 cycles/MJ (0.67 cycles/kWh) compared to 1.58 cycles/MJ (0.44 cycles/kWh) for the conventional model. However, the high energy factor of the adaptive control model, caused by the control action to shorten the cycle due to the lack of soils in the test method, is not representative of a typical cycle in actual field applications. This points out the need for revisions in the DOE dishwasher test procedure to obtain efficiency factors which consumers can rely on for making purchase decisions.

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1. INTRODUCTION

In recent years, residential dishwashers with adaptive controls have been introduced to the US appliance market. The current trend in innovative dishwasher controls is to use sensors to gather information on the soil load (e.g., heating, wash duration) and fuzzy logic controls to adjust the wash cycle to meet the demand. Additionally, fault detection features are incorporated into the control system to report selected malfunctions. In tests of an innovative dishwasher, substantial reductions in water and energy consumption were recorded. It was also determined that the DOE test procedure, does not provide an adequate evaluation technique for comparing the performance of innovative models to conventional models. This report presents dishwasher results for tests conducted in the normal cycle as required by the DOE test procedure, as well as the heavy an light cycles, and tests using a high temperature wash option. The deficiencies in the DOE test procedure are discussed and recommendations are made on test procedure revisions to cover these new products.

2. THE DOE TEST PROCEDURE

The Energy Conservation Program for Consumer Products, DOE 10 CFR Part 430 [1], requires the evaluation of the 'basic model' for each covered product, as defined in the standard. The test procedure for dishwashers, Subpart B to Part 430, requires the calculation of the estimated annual operating cost (EAOC) and the energy factor (EF). EAOC is a cost estimate based on energy consumption, while the EF is a direct measure of energy consumption, including machine electrical energy and water energy, and will be the basis of rating energy consumption in this report.

Tests are conducted in accordance with the DOE test conditions presented in Table 1. Test water is supplied at 10 °C (50 °F) or 48.9 °C (120 °F) for a water-heating dishwasher, or 60 °C (140 °F) for a non-water heating dishwasher. A water heating dishwasher is designed to heat 10 °C (50 °F) inlet water or operate with a nominal inlet water temperature of 48.9 °C (120 °F), heating the internal water to above 48.9 °C (120 °F) in at least one phase of the wash cycle. The DOE test procedure requires an eight place-setting load, as specified in section 6.1.1 of AHAM Standard DW-1[2], for water heating dishwashers, while tests of non water-heating dishwashers are conducted without a test load.

TABLE 1: DOE Test Procedure Test Conditions

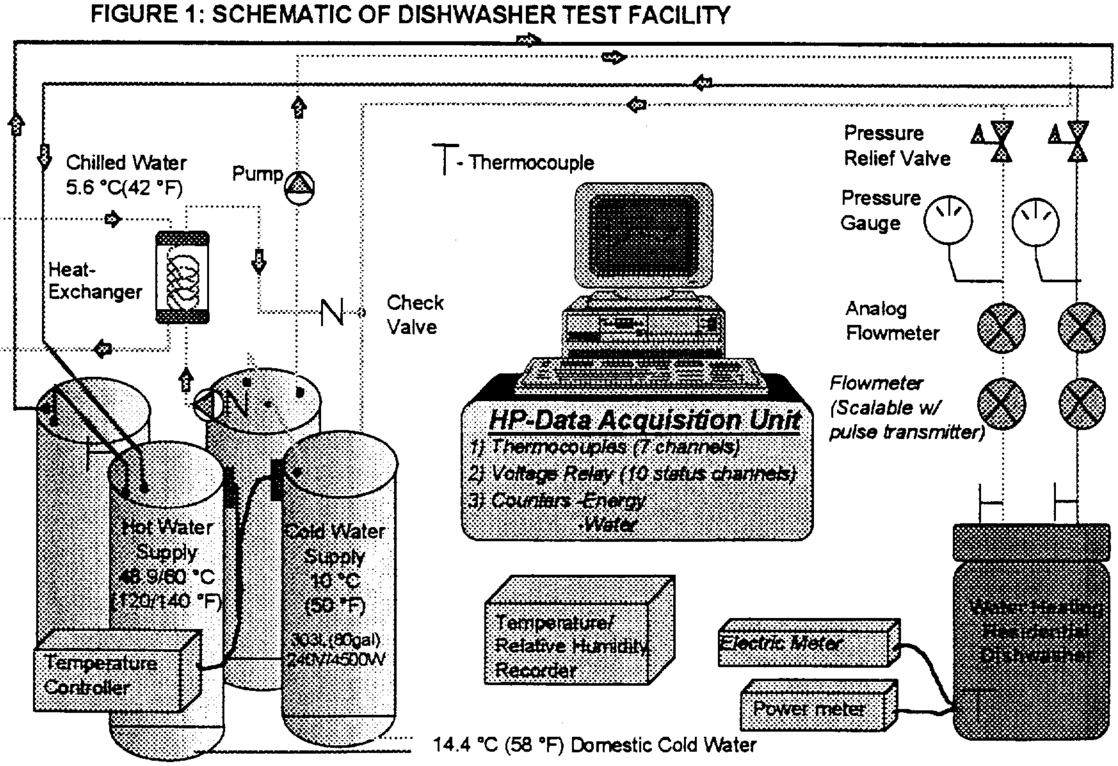
	Water Heating Dishwashers		Non Water-heating
Test WaterTemperature	10±1.1 °C (50±2 °F)	48.9±1.1 °C (120±2 °F)	60±2.8 °C (140±5 °F)
Ambient & Machine Temperature	23.9 °C to 29.4 °C (75 °F to 85 °F)	23.9 °C to 29.4 °C (75 °F to 85 °F)	23.9 °C to 29.4 °C (75 °F to 85 °F)
Water Pressure	241±17kPa (35±2.5 psi)	241±17kPa (35±2.5 psi)	241±17kPa (35±2.5 psi)
Test Load	8 place setting	8 place setting	No Load

The dishwasher's electrical energy consumption and the water consumption are used to calculate the per-cycle water energy consumption and the EF. Water energy consumption is the product of the water usage and the electrical energy needed to raise the water used in the cycle from 10 °C (50 °F) to the supply temperature. The machine energy is the total per cycle electrical energy for the appliance. The EF of a water-heating or non water-heating appliance is the reciprocal of the total per cycle energy for the normal cycle, calculated as the sum of the water and machine energy. However, if the unit has a truncating option, defined as a feature to de-activate the heating element in the drying stage of a cycle, the total per-cycle energy consumption for a water heating unit is an average of the total per-cycle energy for the normal and truncated normal cycle. Dishwashers manufactured between January 1, 1988 and May 14, 1994 were required by DOE 10 CFR Part 430 to be equipped with a truncating option. Since then, the sole requirement is compliance with the Minimum Energy Standard, an EF of at least 1.65 cycles/MJ (0.46 cycles/kWh). This factor is the basis of comparison for all models.

3. THE NIST TEST FACILITY

Tests were conducted in the Domestic Appliances Test Facility at the National Institute of Standards and Technology consisting of two water conditioning loops and a dedicated transformer for electrical energy supply. Temperature sensors, energy and water meters relayed information to a Data Acquisition System (DAS) which recorded the data (See Figure 1). Instruments were calibrated to meet the DOE test procedure specifications. The combined standard uncertainty for the test measurements was 2.8%.

FIGURE 1: SCHEMATIC OF DISHWASHER TEST FACILITY



3.1 The Conditioning Loop

The conditioning loop provides temperature and pressure regulation of water supplied to the test appliances. Two 303 liter (80 gal) capacity water heating tanks were used in each of the cold and hot water conditioning loops. Domestic cold water (14.4 °C (58 °F)) was supplied to the tanks and the desired water temperatures were maintained in each loop using an automatic temperature controller with a type T thermocouple. Cold supply water 10 °C (50 °F) was obtained using a heat exchanger with a working fluid of chilled brine at 5.6 °C (42 °F). Hot supply water was generated by two 4.5 kW heating elements in each of the tanks. Circulation pumps delivered test water from the storage tanks through insulated pipes to the test appliances. Pressure regulating valves in the supply line, controlled the test water pressure and pressure gauges located one meter above the water inlet were used to monitor in line pressure during testing.

3.2 Instrumentation and the Data Acquisition System (DAS)

Instrumentation was installed throughout the system for fully automated data collection and to establish the required DOE test conditions. Two nutating disc positive displacement water meters were installed in series; one with an analog readout and the second with an electronic transmitter to deliver signals to the DAS. Type T premium grade thermocouples were used to collect temperature data on the supply water, dishwasher tub, and ambient: two placed at the storage tanks, two at the end of the piping, one at the base of the sump area of each dishwasher tubs and one in the ambient air. A watt-hour meter was used to measure the energy consumption for the test appliance. In addition, a relative humidity recorder and a power meter monitored electrical use characteristics of selected cycles (e.g., wattage).

The DAS consisted of a desk-top computer and a data acquisition unit with a thermocouple card, voltage card, and a counter/totalizer card. Individual data acquisition software programs were designed for the adaptive control and conventional dishwashers with data recorded every three seconds. A graphical display allowed the operator to monitor the data during the tests. The counter/ totalizer card was used to tally the machine electrical energy usage and the water usage measured by the hot and cold line water meters. Voltage relays were connected to the fill valve, wash/drain motor, heating element, and blower. The relay sent a 1.5 volt signal to the DAS whenever a component was powered. The DAS recorded the voltages, thereby tracking each component at every sampling interval. All temperature sensors were connected to a single thermocouple card. Three data files were created for each test 1) Counts, 2) Volts, and 3) Temps and analyzed using a spreadsheet program.

4. DISHWASHERS TESTED

Two domestically manufactured, standard size residential water-heating dishwashers were tested, a conventional model and an adaptive control model. Both units offer several cycle selections that represent variations in the number of repetitions of the fill-rinse-drain pattern. The conventional model has a manual selection of the wash sequence while the adaptive control machine uses fuzzy logic controls to reduce energy consumption.

4.1 The Conventional Dishwasher

The conventional model was manufactured in January 1995. It has five cycle settings (rinse, short, light, normal, heavy). Three special options are available for each cycle: 1) high temperature rinsing- to activate the heating element in all rinses, 2) high temperature wash- to extend the main wash time with the heating element activated until a thermistor reaches a temperature defined by the manufacturer, and 3) truncated cycle de-activating the heating element in the drying stage. A cycle is selected by the user and has a preset sequence of events (e.g. drain, fill, wash). Water consumption for each fill is regulated by a timer and a float control device.

4.2 The Adaptive Control Dishwasher

The adaptive control model, manufactured in June 1995, has a single button activation for the normal cycle and the controls determine the events of the wash cycle as information is collected on the cycle (e.g., water temp., turbidity). The fuzzy logic controls process the data and adapt the cycle as needed or the user can override sensor regulation of the cycle by selecting a standard light cycle or heavy cycle. The water fill valve is regulated by a timer and a float control and a truncated option deactivates the heating element for drying.

5. TEST RESULTS AND DISCUSSION

Both dishwashers were tested with test water temperatures of 10 °C, 48.9 °C, and 60 °C (50 °F, 120 °F, and 140 °F) using water heating in the main portion of the wash cycle. However, the 10 °C (50 °F) tests, marked with an asterisk in Tables 2a and 3a, could only reach the required minimum water temperature of 48.9 °C (120 °F) using a special feature (high temperature wash). This is not a DOE test condition and therefore not a valid DOE test. The DOE test procedure is based solely on the average energy consumption in the normal and truncated normal cycle. Tests which follow the DOE test procedure are shaded in Tables 2a-3b.

TABLE 2a: Conventional Dishwasher Water and Energy Data					
CYCLE TYPE/ Load (# of place-settings)	*Test Water Temp ℃ (℉)*	*Water Usage Liters (Gallons)*	*Water Energy MJ (kWh)*	*Machine Energy MJ (kWh)*	*Energy Factor cycles/MJ (cycle/kWh)*
1 Normal /8	48.9 (120)	35.0 (9.25)	6.19 (1.72)	2.01 (0.58)	
Trunc-Normal /8	48.9 (120)	36.0 (9.50)	6.37 (1.77)	1.69 (0.47)	1.58 (0.44)
2 Normal	48.9 (120)	33.4 (8.83)	5.90 (1.64)	2.05 (0.57)	
Trunc-Normal	48.9 (120)	36.5 (9.64)	6.44 (1.79)	1.73 (0.48)	1.62 (0.45)
3 Heavy /8	48.9 (120)	43.0 (11.36)	7.60 (2.11)	2.23 (0.62)	
Trunc-Heavy /8	48.9 (120)	43.0 (11.35)	7.60 (2.11)	1.87 (0.52)	1.33 (0.37)
4 Heavy	48.9 (120)	42.4 (11.21)	7.49 (2.08)	2.23 (0.62)	
Trunc-Heavy	48.9 (120)	42.3 (11.18)	7.49 (2.08)	1.87 (0.52)	1.37 (0.38)
5 Light /8	48.9 (120)	27.4 (7.25)	4.86 (1.35)	1.76 (0.49)	
Trunc-Light /8	48.9 (120)	27.6 (7.28)	4.86 (1.35)	1.51 (0.42)	1.98 (0.55)
6 Normal	60 (140)	35.1 (9.28)	8.00 (2.22)	1.94 (0.54)	
Trunc-Normal	60 (140)	36.1 (9.55)	8.21 (2.28)	1.69 (0.47)	1.29 (0.36)
7 *Normal /8	10 (50)	30.7 (8.10)	0 (0)	2.16 (1.60)	
*Trunc-Normal/8	10 (50)	30.7 (8.10)	0 (0)	2.12 (1.59)	2.27 (0.63)

Special Feature -high temperature wash

TABLE 2b: Adaptive-Control Dishwasher Water and Energy Data					
CYCLE TYPE/ Load (# of place-settings)	*Test Water Temp ℃ (℉)*	*Water Usage Liters (Gallons)*	*Water Energy MJ (kWh)*	*Machine Energy MJ (kWh)*	*Energy Factor cycles/MJ (cycle/kWh)*
1 Normal /8	48.9 (120)	17.79 (4.70)	3.13 (0.87)	2.23 (0.62)	
Trunc-Normal /8	48.9 (120)	19.46 (5.14)	3.46 (0.96)	1.98 (0.55)	2.41 (0.67)
2 Normal	48.9 (120)	17.79 (4.70)	3.17 (0.88)	1.94 (0.54)	
Trunc-Normal	48.9 (120)	21.08 (5.57)	3.71 (1.03)	1.69 (0.47)	2.45 (0.68)
3 Heavy /8	48.9 (120)	36.38 (9.61)	6.44 (1.79)	3.89 (1.08)	
Trunc-Heavy /8	48.9 (120)	36.45 (9.63)	6.44 (1.79)	3.60 (1.00)	1.26 (0.35)
4 Heavy	48.9 (120)	43.72 (11.55)	7.74 (2.15)	3.74 (1.04)	
Trunc-Heavy	48.9 (120)	49.13 (12.98)	8.03 (2.23)	3.53 (0.98)	1.12 (0.31)
5 Light /8	48.9 (120)	18.74 (4.95)	3.31 (0.92)	0.83 (0.23)	
Trunc-Light /8	48.9 (120)	18.09 (4.78)	3.20 (0.89)	0.47 (0.13)	3.31 (0.92)
6 Normal	60 (140)	20.18 (5.33)	4.57 (1.27)	1.40 (0.39)	
Trunc-Normal	60 (140)	17.64 (4.66)	4.00 (1.11)	1.15 (0.32)	2.34 (0.65)
7 *Normal /8	10 (50)	22.11 (5.84)	0 (0)	3.67 (1.02)	
*Trunc-Normal/8	10 (50)	29.82 (7.88)	0 (0)	3.20 (0.89)	3.78 (1.05)

5.1 Water Consumption

Water consumption is evaluated with respect to the cycle, independent of the test water temperature. The conventional dishwasher values are listed in Table 2a and include tests with and without a DOE test load. The average per-cycle water consumption for normal and truncated normal cycles of the conventional model, based on ten tests, is 35.43 L with a standard deviation (std-dev) of 0.95 L (9.36 gal, std-dev 0.25) The average per-cycle water usage was 27.52 L with a standard deviation of 0.08 L (7.27 gal, std-dev 0.02) for all light cycles and 42.66 L with a standard deviation of 0.38 L (11.27 gal, std-dev 0.10) for all heavy cycles. Table 2b shows the adaptive control dishwasher per-cycle water usage data for the heavy, normal, and light cycles. The normal cycle and truncated normal cycle average per-cycle water consumption is 20.67 L with a standard deviation of 4.05 L (5.46 gal, std-dev 1.07). This is based on ten test runs with and without a standard test load. The heavy cycle had an average per-cycle water usage of 40.50 L with a standard deviation of 4.73 L (10.70 gal, std-dev 1.25), based on four test runs with and without a standard test load. The average per-cycle water usage of the light cycle with and without a test load was 18.43 L with a standard deviation of 0.12 L (4.87 gal, std-dev 0.45).

Individual fills for the wash cycle are regulated by timer control, and by float control which is a safety cut off for the valve. The float control has a cap that rises and triggers valve closure when the water level in the machine exceeds the operating level. It is expected that small fluctuations exist in the fill data due to water remaining in the sump area of the dishwasher, however large deviations were recorded on the total per-cycle water consumption for all cycles of both models tested. To determine the cause of the variations, the individual fills were analyzed.

TABLE 3a: Fill Data for Conventional Dishwasher w/ No Soil Load in Liters (Gallons)

CYCLE TYPE	TOTAL	1st FILL	2nd FILL	3rd FILL	4th FILL	5th FILL	6th FILL
1 Normal	35.0(9.25)	7.50(1.98)	7.58(2.00)	6.50(1.72)	6.73(1.78)	6.69(1.77)	
Trunc-Normal	36.0(9.50)	7.73(2.04)	7.85(2.07)	6.84(1.81)	6.81(1.80)	6.73(1.78)	
2 Normal	33.4(8.83)	7.54(1.99)	5.76(1.52)	6.54(1.73)	6.81(1.80)	6.77(1.79)	
Trunc-Normal	36.5(9.64)	7.97(2.10)	7.81(2.06)	6.77(1.79)	7.00(1.85)	6.96(1.84)	
3 Heavy	43.0(11.36)	7.89(2.08)	7.62(2.01)	7.62(2.01)	6.57(1.74)	6.65(1.76)	6.65(1.76)
Trunc-Heavy	43.0(11.35)	7.70(2.03)	7.58(2.00)	7.70(2.03)	6.57(1.74)	6.73(1.78)	6.69(1.77)
4 Heavy	42.4(11.21)	7.54(1.99)	7.70(2.03)	7.62(2.01)	6.46(1.71)	6.69(1.77)	6.42(1.70)
Trunc-Heavy	42.3(11.18)	7.70(2.03)	7.50(1.98)	7.54(1.99)	6.57(1.74)	6.46(1.71)	6.54(1.73)
5 Light	27.5(7.25)	7.77(2.05)	6.50(1.72)	6.57(1.74)	6.61(1.75)		
Trunc-Light	27.6(7.28)	7.70(2.03)	6.61(1.75)	6.73(1.78)	6.54(1.73)		
6 Normal	35.1(9.28)	7.70(2.03)	7.65(2.02)	6.59(1.74)	6.51(1.72)	6.67(1.76)	
Trunc-Normal	36.1(9.55)	8.09(2.14)	7.81(2.06)	6.71(1.77)	6.79(1.79)	6.75(1.78)	
7 *Normal	34.7(9.16)	6.86(1.81)	5.71(1.51)	6.86(1.81)	7.62(2.01)	7.62(2.01)	
*Trunc-Normal	36.2(9.56)	6.47(1.71)	6.86(1.81)	7.62(2.01)	7.62(2.01)	7.62(2.01)	

* Special Feature- high temperature wash

The normal cycle for the conventional model (Table 3a) has an average fill of 7.08 L with a standard deviation of 0.57 L (1.87 gal, std-dev 0.15), based on eight tests of the normal cycle. The light cycle fill average is 6.89 L with a standard deviation of 0.53 L (1.82 gal, std-dev 0.14). The heavy cycle has an average fill of 7.12 L with a standard deviation of 0.57 L (1.88 gal, std-dev 0.15). The adaptive control model, Table 3b, has variations in the average fill data similar to the conventional model. The normal cycle has an average fill of 6.62 L, based on eight tests with a standard deviation of 0.91 L (1.75 gal, std-dev 0.24). The reason the controls added a fourth fill in the 10°C (50°F) test of the truncated normal cycle is not fully understood, however it is known that turbidity has the greatest effect on the control sequence. These conditions were re-tested and the same four fill wash pattern was recorded. In tests of the heavy cycle, the average fill was 6.85 gallons, based on four tests with a standard deviation of 0.95 gallons (1.81 gal, std-dev 0.25). The light cycle average fill was 6.13 L with a standard deviation of 1.32 L (1.62 gal, std--dev 0.35), based on two tests.

TABLE 3b: Fill Data for Adaptive Control Dishwasher w/ No Soil Load in Liters (Gallons)

CYCLE TYPE	TOTAL	1st FILL	2nd FILL	3rd FILL	4th FILL	5th FILL	6th FILL
1 Normal	17.8(4.70)	7.04(1.86)	5.38(1.42)	5.38(1.42)			
Trunc-Normal	19.5(5.14)	7.08(1.87)	5.30(1.40)	7.08(1.87)			
2 Normal	17.8(4.70)	7.00(1.85)	5.41(1.43)	5.38(1.42)			
Trunc-Normal	21.1(5.57)	6.92(1.83)	7.00(1.85)	7.15(1.89)			
3 Heavy	36.4(9.61)	7.97(2.10)	6.07(1.60)	6.07(1.60)	7.77(1.60)	7.19(1.46)	7.35(1.43)
Trunc-Heavy	36.4(9.63)	7.70(2.03)	6.03(1.59)	6.19(1.63)	7.85(1.63)	7.27(1.45)	7.27(1.48)
4 Heavy	43.7(11.55)	8.04(2.12)	6.23(1.64)	7.77(2.05)	6.07(2.05)	5.53(1.90)	5.41(1.94)
Trunc-Heavy	45.4(11.98)	7.89(2.08)	7.89(2.08)	7.85(2.07)	6.19(2.07)	5.49(1.92)	5.61(1.92)
5 Light	18.8(4.95)	8.01(2.11)	5.45(1.44)	5.30(1.40)			
Trunc-Light	18.1(4.78)	7.66(2.02)	5.22(1.38)	5.22(1.38)			
6 Normal	19.9(5.25)	7.50(1.98)	6.96(1.84)	5.41(1.43)			
Trunc-Normal	17.4(4.59)	6.77(1.79)	5.30(1.40)	5.30(1.40)			
7 *Normal	22.1(5.84)	7.39(1.95)	7.27(1.92)	7.38(1.97)			
*Trunc-Normal	37.0(7.88)	7.35(1.83)	7.42(1.95)	7.38(1.95)	7.57(2.00)		

Large fill variations were observed. The open period of the fill valve was studied to find the cause of this irregularity, as seen in the third and fourth tests in Table 3a where the second fill for the normal and truncated normal cycle were 5.75 liters (1.52 gal) and 7.80 liters (2.06 gal) respectively. It was determined that the timer control was not closing the valve but rather the float control was the limiting factor on the fill. Although the timer control allots approximately 100 seconds for the fill, on several fills the float control closed the valve after only 60 seconds. The source of this variation in fills was traced to the float cap design of the float control. Small air holes, located at the top of the float cap, are susceptible to being sealed with water droplets. Water is circulated throughout the tub after the first fill and droplets of water wash over the air holes, some of which seal the hole thereby trapping air under the float cap. As the water level rises, the air under the float cap is pressed upwards causing the float cap to rise and close the fill valve prematurely. Data collected shows no evidence of fill interruption for the first fill of each cycle. This is attributed to the fact that the air holes in the float cap remain dry until the first fill is completed.

Nine tests were conducted on the adaptive control dishwasher with a standard soiled test load. The load was soiled following the ANSI/AHAM DW-1 1992 standard and tested using the normal cycle. A sample of the fill data collected from these tests is listed in Table 3c. Results for the adaptive control dishwasher without and with a standard test load are given in Table 4. The results indicate a 64% increase in the average total water usage and an 8% increase in the average water use per individual fill, along with a significant decrease in the standard deviation for these measurements. This suggests the necessity of soiled dishes and detergent to measure per-cycle water consumption that is representative of consumer usage. The 8% increase per fill is attributed to the effect of soils keeping the air holes in the float open. Most of the 64% increase in total water usage is due to additional fills in the cycle with soiled dishes.

TABLE 3c: Fill Data for Adaptive Control Dishwasher w/ Soil Load in Liters (Gallons)

CYCLE	TOTAL	1st FILL	2nd FILL	3rd FILL	4th FILL	5th FILL	6th FILL
1a) Normal	34.22(9.04)	6.93(1.83)	6.81(1.80)	6.86(1.81)	6.81(1.80)	6.77(1.79)	0 (0)
2a) Normal	34.30(9.06)	6.86(1.81)	6.81(1.80)	6.77(1.79)	7.08(1.87)	6.73(1.78)	0 (0)
3a) Normal	35.28(9.32)	7.04(1.86)	7.00(1.85)	7.08(1.87)	7.12(1.88)	7.12(1.88)	0 (0)
4a) Normal	35.62(9.41)	7.15(1.89)	7.23(1.91)	7.04(1.86)	7.12(1.88)	7.12(1.88)	0 (0)
5a) Normal	37.10(9.80)	7.23(1.91)	7.54(1.99)	7.31(1.93)	7.50(1.98)	7.54(1.99)	0 (0)

TABLE 4: Adaptive Control Dishwasher Average Fill Water Data

Cycle Type	*Average Total Fill (std-dev)*	*Average Individual Fill (std-dev)*
Normal w/o Soiled Load	20.7L (4.05L) | 5.46gal (1.07gal)	6.78L (0.87L) | 1.79gal (0.23gal)
Normal w/ Soiled Load	35.7L (2.12L) | 9.42gal (0.56gal)	7.31L (0.42L) | 1.93gal (0.11gal)

FIGURE 2: DISHWASHER WATER CONSUMPTION (*non-soiled load)

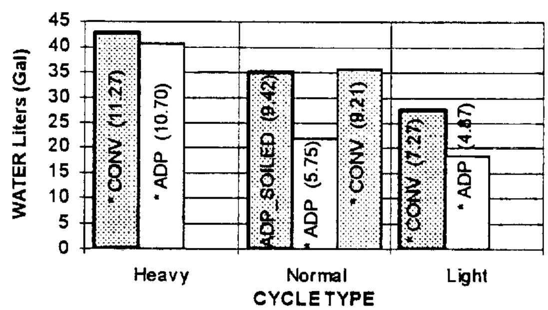
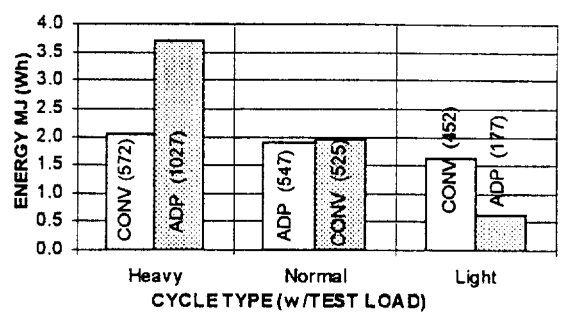


FIGURE 3: DISHWASHER MACHINE ENERGY CONSUMPTION



The normal cycle of the adaptive control dishwasher, tested without a soil load, will default to the light cycle which consists of a rinse, a wash, and a single short rinse, unless there are soils detected. Therefore, the unsoiled water consumption values for the adaptive control model, as determined using the DOE test procedure with unsoiled dishes, are misleading to consumers when evaluated in comparison with conventional models.

5.2 Energy Consumption Tests

All tests involved heating supply water temperatures, however, tests conducted with 10 °C (50 °F) inlet water have a water energy component equal to zero since all water heating is performed by electric heating element and adds to the machine energy component.

In Figure 3, the average machine energy consumption of the two dishwashers is listed for the light, normal, and heavy cycles and includes truncated and non-truncated cycles. The average machine energy for conventional dishwasher using 48.9 °C (120 °F) water was 1.63 MJ (452 Wh) for the light cycle, 1.89 MJ (525 Wh) for the normal cycle, and 2.06 MJ (572 Wh) for the heavy cycle. The adaptive control dishwasher jumps from 0.64 MJ (177 Wh) for the light cycle to 1.97 MJ (547 Wh) for the normal cycle and as much as 3.70 MJ (1027 Wh) for the heavy cycle. In the heavy cycle the adaptive control model consumes significantly more energy than the conventional model. This additional 1.64 MJ (455 Wh) is used primarily in the heated wash portion of the cycle which has the greatest energy load with both the motor and heating element activated. The main wash of the adaptive control machine is extended to heat the water to approximately 65.5 °C (150 °F), 11.1 °C (20 °F) above the maximum temperature reached by the conventional dishwasher. In the normal cycle, the conventional and adaptive control models appear to draw the same amount of energy, however, the adaptive control normal cycle consists of only a 3-fill cycle, an abridged version of the typical wash sequence when run with a soiled load. Similarly, in comparing the light cycles, the adaptive control sequence consists of 3-fills, one less fill than that of the conventional dishwasher, and reaches temperatures of only 49.4 °C (121 °F). The total energy consumption of the adaptive control dishwasher under actual soiled conditions is expected to be much higher for the normal cycle due to increases in the number of fills contributing to both the water energy and machine energy usage.

For tests without soil loads, the energy consumption values (Table 5a and 5b) are extracted from Tables 2a and 2b for the conventional and adaptive control dishwasher. The water energy data for the conventional dishwasher reflects additional fills and the average machine energy consumption is lower than that of the adaptive control dishwasher. Data from the adaptive control dishwasher clearly shows the water energy consumption contributes over 50% of the total energy consumption. Water usage fluctuated between cycles, the variations in water energy usage, seen in Figures 5a and 5b, are attributed to fluctuations in water usage between cycles with water energy usage directly proportional to water energy consumption. In Tables 5a and 5b, the average hot water energy for the conventional dishwasher in the normal cycle is roughly 35% higher than that of the adaptive control dishwasher, having a large effect on the total energy consumption of the cycle. In data of the adaptive control truncated normal cycle, without a test load, the total energy is higher than that of the normal cycle despite the fact that the truncated normal cycle deactivates the heating element in the drying portion of the cycle. As one might expect, the machine energy for the truncated normal cycle is lower than the normal cycle. However the water energy component for the truncated normal cycle was notably higher due to the increased water consumption, thereby raising the energy total to 6% over the normal cycle. This anomaly is directly attributable to fill variations.

TABLE 5: ENERGY CONSUMPTION for TESTS WITHOUT A SOIL LOAD			
5a: Conventional Dishwasher			
CYCLE TYPE w/ 120 °F INLET WATER	*WATER ENERGY MJ/cycle (kWh/cycle)*	*MACHINE ENERGY MJ/cycle (kWh/cycle)*	*TOTAL ENERGY MJ/cycle (kWh/cycle)*
Normal w/ Load % of total energy	6.19 (1.72) 75%	2.09 (0.58) 25%	8.28 (2.30)
Normal w/o Load % of total energy	5.90 (1.64) 74%	2.05 (0.57) 26%	7.95 (2.21)
Truncated Normal w/ Load % of total energy	6.37 (1.77) 79%	1.69 (0.47) 21%	8.06 (2.24)
Truncated Normal w/o Load % of total energy	6.44 (1.79) 79%	1.73 (0.48) 21%	8.17 (2.27)
5b: Adaptive Control Dishwasher			
Normal w/ Load % of total energy	3.17 (0.88) 59%	2.23 (0.62) 41%	5.40 (1.50)
Normal w/o Load % of total energy	3.13 (0.87) 62%	1.94 (0.54) 38%	5.07 (1.41)
Truncated Normal w/ Load % of total energy	3.46 (0.96) 64%	1.98 (0.55) 36%	5.44 (1.51)
Truncated Normal w/o Load % of total energy	3.71 (1.03) 69%	1.69 (0.47) 31%	5.40 (1.50)

5.3 Energy Factor Calculation

The energy factor represents the number of cycles the appliance can complete per kilowatt-hour of energy consumed. Using water and machine energy consumption data, the energy factors for the conventional dishwasher were determined to be 1.58,1.62, 1.33, 1.37, 1.98, 1.29, and 2.27 cycles/MJ (0.44, 0.45, 0.37, 0.38, 0.55, 0.36, and 0.63 cycles/kWh) as shown in Table 2a. Energy factors were computed for the normal and truncated normal cycles as required in Appendix C of Subpart B to Part 430 [1] for various test conditions. These tests were conducted with inlet water temperatures of 10°C, 48.9 °C, and 60 °C (50 °F, 120 °F, and 140 °F), both with and without a DOE test load. Of these calculated energy factors, only two test cases are acceptable for rating a water heating dishwasher. The first, conducted with 48.9 °C (120 °F) inlet water and a DOE test load, had an energy factor of 1.58 cycles/MJ (0.44 cycles/kWh) and the second, conducted with 60 °C (140 °F) inlet water and no DOE test load, had an energy factor of 1.29 cycles/MJ (0.36 cycles/kWh). The difference in the energy factor for the 60 °C (140 °F) test can be explained by the additional water energy required to raise the supply water temperature from 10 °C to 60 °C (50 °F to 140 °F), 11.1 °C (20 °F) higher than the 48.9 °C (120 °F) test. When running the cycle, the machine heats the water to over 48.9 °C (120 °F), however, this generally occurs in only one fill of the wash cycle involving roughly two gallons, whereas water energy calculations involve the total water supplied to the dishwasher. Using energy to heating only one fill results in higher energy factors for most dishwashers when tested with lower supply temperatures which explains the trend by manufacturers to conduct tests for water-heating units with 48.9 °C (120 °F) supply water.

The energy factors for data collected on the adaptive control dishwasher with 48.9 °C (120 °F) test water are 2.41, 2.45, 1.26, 1.12, and 3.31 cycles/MJ (0.67, 0.68, 0.35, 0.31, and 0.92 cycles/kWh) for the normal cycle with and without load, the heavy cycle with and without load, and the light cycle with load. Further testing of the adaptive control dishwasher using the 60 °C (140 °F) and 10 °C (50 °F) supply water yielded energy factors of 2.34, 3.78 cycles/MJ (0.65 and 1.01 cycles/kWh), see Table 2b. The adaptive control dishwasher's highest energy factors involve tests conducted with the lowest supply water temperature 10 °C (50 °F), however, in this test a special feature was used which eliminates it as a valid DOE test. The two DOE tests established the energy factor of the conventional machine at 1.58 cycles/MJ (0.44 cycles/kWh) for the normal cycle test with load using 48.9 °C (120 °F) supply water and 2.34 cycles/MJ (0.65 cycles/kWh) for the adaptive control dishwasher test of the normal cycle without a test load and using the 60 °C (140 °F) supply water. Thus, the conventional dishwasher did not meet the required minimum energy standard of 1.67 cycles/MJ (0.46 cycles/kWh) [1]. The adaptive control dishwasher rates far better than the conventional model under these test without soil loads. However, as explained earlier, when the dishwasher has a soil load, the energy consumption for the adaptive control unit is significantly higher than the conventional unit. This means that under real world conditions the adaptive control dishwasher is likely to have an EF that is lower than the value obtained using the current DOE test procedure.

6. SUMMARY AND CONCLUSIONS

Laboratory tests were conducted on two residential dishwashers, a conventional and an adaptive control model in the light, normal, and heavy wash cycle following the DOE, "Uniform Test Method for Measuring the Energy Consumption of Dishwashers". Measurements were used to calculate the water energy consumption, the energy used for water electrically heated by the dishwasher, and the EF for each test unit. The test results in this paper have a combined standard uncertainty of 2.8%.

The energy consumption tests showed that the water energy had the greatest effect on the energy load, with water energy for the normal cycle of the adaptive control dishwasher representing an average of over 60% of the total energy for four test runs. However, the water energy was discovered to be the greatest source of variation between tests of the adaptive control dishwasher, conducted under similar testing conditions. The results show that the total water usage, for a given cycle using either the conventional or adaptive control dishwasher, had low repeatability. This directly effects the overall energy factor for the dishwasher and can effect whether a model meets the minimum energy standard. For example, the conventional dishwasher had water usage of 36.5 L and 30.7 L (9.64 gal and 8.1 gal) for two tests in the normal cycle. If the water usage for the 48.9 °C (120 °F) test of the truncated normal cycle 30.7 L (9.64 gal) is replaced by the water usage recorded for the 10 °C (50 °F) test of the truncated normal cycle 30.7 L (8.1 gal), the energy factor increases from 1.62 to 1.85 cycles/MJ (0.45 to 0.49 cycles/kWh).

The source of the fill variation seen in the data was traced to float control which prematurely closes the fill valve as water droplets form a seal over the air holes of the float cap. The effect did not exist in tests of the adaptive control dishwasher with a soiled test load because of reductions in the surface tension of water droplets. Thus the problem of comparing tests without a soil load not only exists between the adaptive control and conventional dishwashers but also may exist in tests of two different models within a given class of dishwashers. This is due to the effect of the float cap on fill data for the adaptive control model with and without soils.

The DOE test procedure does not effectively test the normal cycle under real world conditions involving soiled dishes. Thus the energy factor determined for the adaptive control dishwasher using the current DOE test procedure should not be compared with the EF obtained for the conventional dishwasher. The adaptive control dishwasher shortens the normal cycle whenever the test procedure is run without soils. This gives the machine a high energy factor that is not representative of the models performance in the field with normally soiled loads. Therefore, the DOE test procedure requires revisions to provide a proper basis for evaluation of innovative and conventional dishwashers.

7. REFERENCES

1. DOE 10 CFR Part 430, Appendix C to Subpart B "Uniform Test Method for Measuring the Energy Consumption of Dishwashers", 1987

2. ANSI/AHAM DW-1-1992, "Household Electric Dishwashers", 1992