



ENERGY STAR® Dishwasher Webinar: Cleanability Test Procedure Discussion

U.S. Department of Energy

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ENERGY STAR

Dishwasher (DW) History



- Energy and water consumption for DWs are determined using the DOE test procedure at 10 CFR 430, Subpart B, Appendix C
- ENERGY STAR qualification criteria for DWs have been in place since 2001:

Effective Date	Compact	Standard
January 2001	N/A	EF \geq 0.58
January 2007	EF \geq 0.88	EF \geq 0.65
August 2009 (current)	EAEU \leq 234 kWh/yr WC \leq 4.0 gal/cycle	EAEU \leq 324 kWh/yr WC \leq 5.8 gal/cycle

Note: EF is Energy Factor; EAEU is Estimated Annual Energy Use; WC is Water Consumption.

Drivers for Specification Revision



- Future qualification criteria:
 - Tier 2 qualification criteria will include a cleaning performance requirement
 - ENERGY STAR must specify a test method for evaluating cleaning performance

	Tier 1 Effective January 20, 2012		Tier 2 Effective January 1, 2014		
Product Type	Energy	Water	Energy	Water	Cleaning
Compact	222 kWh/yr	3.5 gal/cycle	TBD	TBD	TBD
Standard	295 kWh/yr	4.25 gal/cycle	TBD	TBD	TBD

ENERGY STAR MOU



EPA and DOE signed a memorandum of understanding (MOU) on 9/30/2009 designed to enhance and strengthen the ENERGY STAR program

EPA	DOE
Brand manager for ENERGY STAR	Leads the development of product testing procedures and metrics
Will establish the performance levels for the ENERGY STAR products programs, with technical support from DOE	Provides technical support, especially in the areas of product testing and verification

ENERGY STAR Roles for Dishwashers



- U.S. EPA
 - Lead revision of dishwasher specification
 - EPA Lead: Amanda Stevens, EPA
 - Support: D&R and ICF
- U.S. DOE
 - Investigate, review, revise, and validate dishwasher cleaning performance test method
 - DOE Lead: Ashley Armstrong, DOE
 - Support: Navigant

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Possible Test Methods for Evaluating Cleanability



- DOE test procedure (10 CFR 430 subpart B appendix C)
 - Requires soiled load to measure energy and water use of soil-sensing DWs
 - No provisions for evaluating cleanability
- AHAM DW-1-2009 “Household Electric Dishwashers”
 - Scores cleanability by means of a Cleaning Index
 - Typically used for U.S. dishwashers
- IEC Standard 60436 Ed. 3.1 “Electric dishwashers for household use – Methods for measuring the performance”
 - Scores cleanability by means of a Performance Index
 - Typically used in Europe and other countries

Test Goals



- Determine which test method provides repeatable results with cleaning differentiation at the lowest test burden
- Experiment with test method and scoring combinations and modifications to increase repeatability, increase differentiation, and reduce test burden
- Test results and stakeholder feedback will serve as the basis for a second investigative phase of testing

Test Procedure Comparison



	DOE	AHAM	IEC
Test load	8	At least 10; 12 used for this investigation	Rated capacity; 12 used for this investigation
Soiling	4 place settings, not including silverware and serving pieces; AHAM soils	All place settings, all serving dishes and all silverware	All place settings, serving dishes, and some silverware
Reference DW	No	No	Yes

Note: The above comparison is for standard DWs only. Compact DWs were not tested.

Test Procedure Comparison



	DOE	AHAM	IEC
Pre-conditioning cycles	1	At least 1, with detergent and rinse aid	At least 3, with detergent and no rinse aid; used rinse aid for this investigation
Number of test cycles	N/A for energy and water rating; 3 for this investigation	3	At least 5
Cleaning between cycles?	N/A for energy and water rating; cleaned filter for this investigation	Yes	No

Note: The above comparison is for standard DWs only. Compact DWs were not tested.

Test Procedure Comparison



Soiling materials used in the test procedures:

AHAM (also used for DOE)

- Egg yolk
- Creamed corn
- Oatmeal (with milk)
- Mashed potatoes
- Ground beef/tomato paste
- Raspberry preserves
- Peanut butter (AHAM only)
- Tomato juice
- Coffee/coffee grounds

IEC

- Milk
- Tea
- Raw ground beef with egg
- Egg
- Oat flakes
- Spinach
- Margarine

AHAM/DOE Soil Preparation



Dish/Utensil Type	Soiling
Dinner plates	Quarter sections of egg yolk, mashed potatoes, ground beef/tomato paste mix, and red raspberry preserves with coffee grounds
Bread and butter plates, dessert bowls	Half sections of oatmeal and creamed corn
Coffee cups and saucers	Coffee
Glasses	Tomato juice
Serving bowls and spoons (AHAM only)	1 with creamed corn, 1 with mashed potatoes, or half sections if only 1 bowl used
Knives and serving platter (AHAM only)	Peanut butter (applied to knives)
Spoons (AHAM only)	Half with creamed corn, half with oatmeal
Forks and serving fork (AHAM only)	Egg yolk

Note: Soils were dried for 2 hours after the application of oatmeal. After 2 hours, the dishes were stacked and loaded into the DW.

AHAM/DOE Soil Preparation



IEC Soil Preparation



Dish/Utensil Type	Soiling
Dinner plates	Half with ground beef/egg mixture, half with egg yolk
Bread and butter plates	Half with egg yolk, half with ground spinach
Coffee cups and saucers	Tea
Glasses	Milk (cooked dry in microwave)
Serving bowls	1 with ground beef/egg mixture, 1 with ground spinach, 1 dessert bowl with spinach
Serving platter	Margarine
Dinner forks	Egg yolk
Salad forks and dessert bowls	Oat flakes

Note: Soils were air-dried for 15 – 18 hours after application.

IEC Soil Preparation



Scoring and Cleaning Index



- Scoring
 - Assigned numerical value to each item in test load based on observed amount of soil remaining
 - Conducted as each item is removed from the unit under test (UUT)
- Cleaning index or performance index
 - Calculated single overall numerical rating for the cleaning performance of the UUT
 - Based on the scoring of individual items, and compared to a reference unit (if applicable)

AHAM Scoring



- Score of 0 (best) to 9 (worst) assigned to each piece of dishware, flatware, or glassware
- Glassware also scored for water spots or streaks, and rack contact marks

Particle size	Score
$\leq 1/8$ in (3 mm)	Score 1 per particle with a maximum score of 9
$> 1/8$ in (3 mm) and $\leq 1/4$ in (6 mm)	Score 3 per particle with a maximum score of 9
$> 1/4$ in (6 mm) and $\leq 3/8$ in (10 mm)	Score 7 per particle with a maximum score of 9
$> 3/8$ in (10 mm)	Score 9 per particle with a maximum score of 9
Spots or streaks on glassware	$< 3/8$ " score 1, $> 3/8$ " score 3 with a maximum score of 9
Rack contact marks on glassware	Light marks score 1, white marks score 3 with a maximum score of 9

IEC Scoring



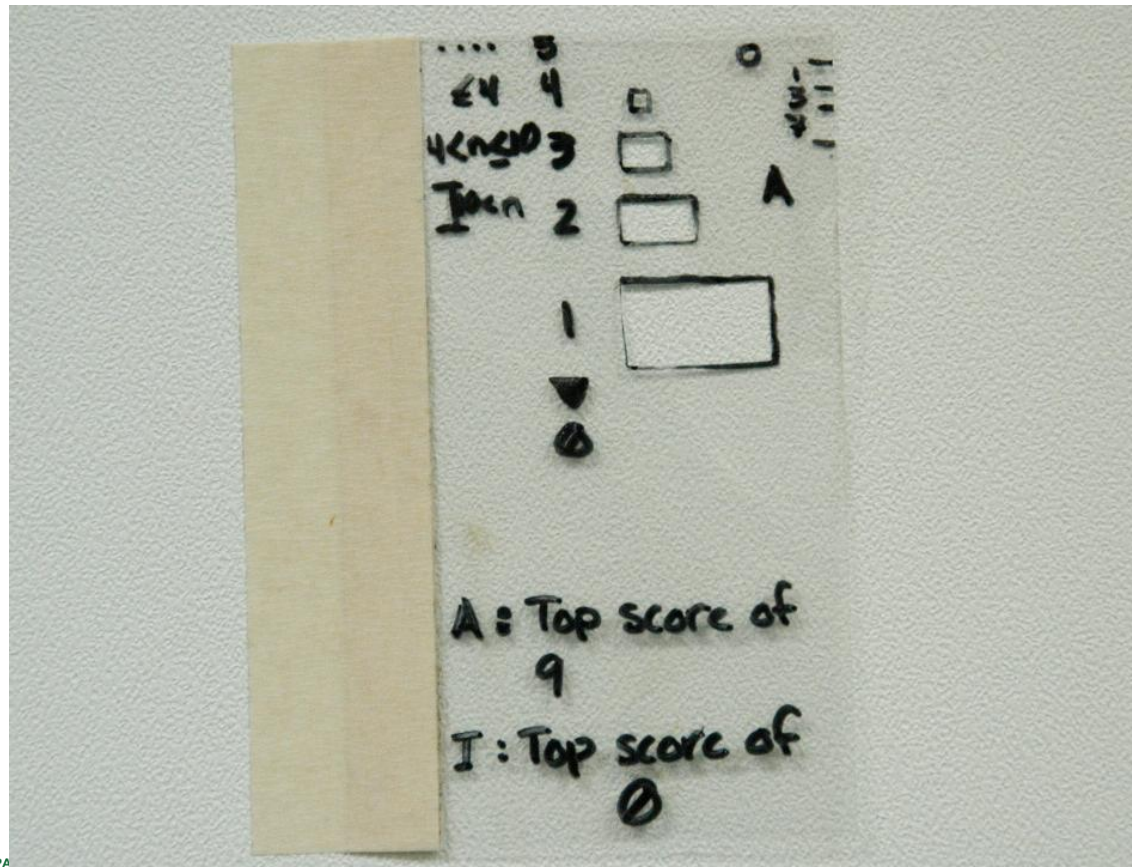
- Score of 5 (best) to 0 (worst) assigned to each item in the test load
- Lowest score based on number of particles or soiled area is assigned to each item

Number of soil particles	Total soiled area A (mm ²)	Score
N = 0	A = 0	5
$0 < n \leq 4$	$0 < A \leq 4$	4
$4 < n \leq 10$	$4 < A \leq 20$	3
$10 < n$	$20 < A \leq 50$	2
Not applicable	$50 < A \leq 200$	1
Not applicable	$200 < A$	0

AHAM and IEC Scoring Tool



Scoring template for AHAM and IEC test-methods



Hybrid Scoring



- AHAM and IEC scoring methods have limitations
 - AHAM scoring tends to penalize items that are generally clean but have multiple, very small particles
 - IEC scoring tends to be lenient for items with a large number of small particles because scores less than 2 depend only on soiled area
- DOE developed hybrid scoring system as a modification to IEC scoring

Number of soil particles	Total soiled area A (mm ²)	Score
$N = 0$	$A = 0$	5
$0 < n \leq 3$	$0 < A \leq 4$	4
$3 < n \leq 6$	$4 < A \leq 20$	3
$6 < n \leq 9$	$20 < A \leq 50$	2
$9 < n \leq 12$	$50 < A \leq 200$	1
$12 < n$	$200 < A$	0

AHAM Cleaning Index



- Each unit starts with a cleaning index of 100
- Points are subtracted for each item in the test load with a score greater than 0, using weightings for each grade:

$$S = 100 - (12.5 (N_1) + 25 (N_2 + N_3) + 50 (N_4 + N_5 + N_6) + 75 (N_7 + N_8) + 100 (N_9)) / N_{tot}$$

- N_1, N_2, \dots = number of items with grade 1, 2, ...
- N_{tot} = total number of items in the test load

- Results from 3 separate test runs are averaged to determine cleaning index of UUT

AHAM Totalized Scoring



Example of totalized score and cleaning index results:

AHAM Score	Test 1	Test 2	Test 3
0	46	49	38
1	22	32	23
2	12	8	16
3	6	17	10
4	8	7	6
5	3	5	8
6	1	0	5
7	6	6	0
8	0	0	2
9	34	14	30

Number of items that received a score of 0 in test 1

AHAM Score	Test 1	Test 2	Test 3
Total Cleaning Index	62.5	74.8	63.5
Average Machine Cleaning Index	66.9		

Cleaning index for test 1 using the equation from previous slide

IEC Performance Index

- A cleaning index is calculated for the UUT and the reference unit:

$$C = (N_1+2 \ N_2+3 \ N_3+4 \ N_4+5 \ N_5)/N_{tot}$$

- N_1, N_2, \dots = number of items with score 1, 2, ...
 - N_{tot} = total number of items in the test load
- The performance index, P_C , for each test is:
$$\ln(P_C) = \ln(C_T/C_R)$$
 - C_T, C_R = Cleaning index of the test and reference unit respectively
- Performance index of the UUT is calculated by averaging $\ln(P_C)$ for each test run, then determining overall P_C

IEC Performance Index



Example of results:

Number of items in the reference DW that received a score of 0 in test 1

IEC Score	Test 1		Test 2		Test 3		Test 4		Test 5	
	Ref. DW	UUT	Ref. DW	UUT	Ref. DW	UUT	Ref. DW	UUT	Ref. DW	UUT
0	13	33	30	9	30	28	25	16	47	25
1	13	3	8	35	3	18	20	4	4	19
2	34	19	21	30	7	42	28	45	19	11
3	46	21	33	33	14	20	47	17	21	32
4	9	34	23	6	51	18	9	32	27	17
5	24	29	24	25	34	13	10	25	21	35
Cz	375	385	361	343	433	299	303	398	318	380
CR,i	2.698		2.597		3.115		2.180		2.288	
CT,i	2.770		2.486		2.151		2.863		2.734	
ln (PC,i)	0.026		-0.044		-0.370		0.273		0.178	
ln (PC)	0.013									
PC	1.013									

Summary



- DOE, AHAM, and IEC test methods
- AHAM and IEC soil preparation
- AHAM, IEC, and hybrid scoring methods
- Cleaning index and performance index

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Units Tested



- Conducted performance testing on 8 residential DWs at DOE/NETL ATEC laboratory
 - Selected units that met current and future Tier 1 ENERGY STAR criteria
 - Included variety of features that may affect cleaning performance (i.e. soil sensors, spray configurations)
- Reference DW
 - The IEC test requires the use of a specific, custom-manufactured European DW as the reference unit
 - Phase 1 tests were conducted with a consistently-performing U.S. DW as the reference unit
 - The IEC-specified reference unit will be available for Phase 2 tests

Test Setup

Test setup at DOE/NETL ATEC:



DOE Tests



- 3 test cycles with the sensor heavy response cycle as defined in the DOE test procedure (even for non-soil-sensing units) with modifications:
 - Soil substitutions for unavailable items: suitable replacements were found for butter, creamed corn, and milk
 - Current AHAM DW-1-2009 soil load used instead of DW-1-1992 soil load specified in DOE test procedure
 - Cleaned filters between test cycles
- Additional tests used modified soiling method (discussed later in this section) to evaluate reducing the test burden

DOE Test Scoring and Cleaning Index



- Three approaches investigated:
 1. AHAM scoring and cleaning index used
 2. IEC scoring used to generate a cleaning index on a 0 to 100 scale similar to AHAM method
$$S = 100 - (12.5 N_4 + 25 N_3 + 50 N_2 + 75 N_1 + 100 N_0) / N_{tot}$$
 3. Hybrid scoring system used on 3 units to generate a cleaning index on a 0 to 100 scale using equation above

AHAM Tests



- 3 test cycles conducted with 12 place settings
- Same soil substitutions as for DOE test
- Additional tests conducted with same modified soiling method as in DOE tests
- Key differences from DOE test:
 - Heavier soil load
 - Rinse aid used for tests
 - Clean-up cycle between tests with filter cleaning
- Scoring and cleaning index same as DOE tests

IEC Tests



- 5 test cycles conducted with 12 place settings
- Substitutions:
 - U.S. residential DW for IEC reference DW
 - Test conditions as specified in DOE test procedure
 - AHAM-style load used for reference DW and UUT
 - AHAM detergent and rinse aid used for consistency
 - Suitable U.S. based soil substitutions made
- Key differences from DOE test:
 - Heavier soil load
 - Rinse agent used
 - No clean-up cycle between test cycles

IEC Tests Scoring and Performance Index



- Three approaches investigated:
 1. AHAM scoring and cleaning index (with 5 instead of 3 test cycles)
 2. IEC scoring and performance index that compares performance to the reference DW
 3. Hybrid scoring and performance index (used for 5 DWs)
- The performance index for IEC and hybrid scoring for the reference DW is 1

Additional Investigations



- Alternate AHAM soil application method
- Additional tests using variants of the DOE test procedure
- Tests to ensure scorer repeatability

Alternate AHAM Soil Application

- 3 DOE and 3 AHAM tests on 1 unit
- Single soil applied on each dinner plate instead of 1 soil on each quadrant
- Single soil applied on each bread-and-butter plate instead of 1 soil on each half



Additional DOE-Based Tests



- DOE sensor light response and sensor medium response tests
 - 1 sensor light response test and 1 sensor medium response test on 1 unit
 - Soiled according to DOE test procedure
- DOE sensor extra-heavy response tests
 - 3 tests each on 3 units with a clean-up cycle between tests
 - Soiled all 8 place settings without soiling serving pieces and silverware

Scorer Repeatability Tests



- Tests were conducted to determine variation in scoring between three technicians
- Performed tests where one technician scored the reference unit and UUT for each test run
- Initial results do not provide enough information to reach any conclusions on scorer variability
- Further testing may be required

Summary



- 8 units tested at ATEC
- DOE tests and cleaning index
- AHAM tests and cleaning index
- IEC tests, cleaning index, and performance index
- Additional investigations
 - Alternate AHAM soil application
 - Additional tests using variants of DOE test procedure
 - Tests to ensure scorer repeatability

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Test Observations



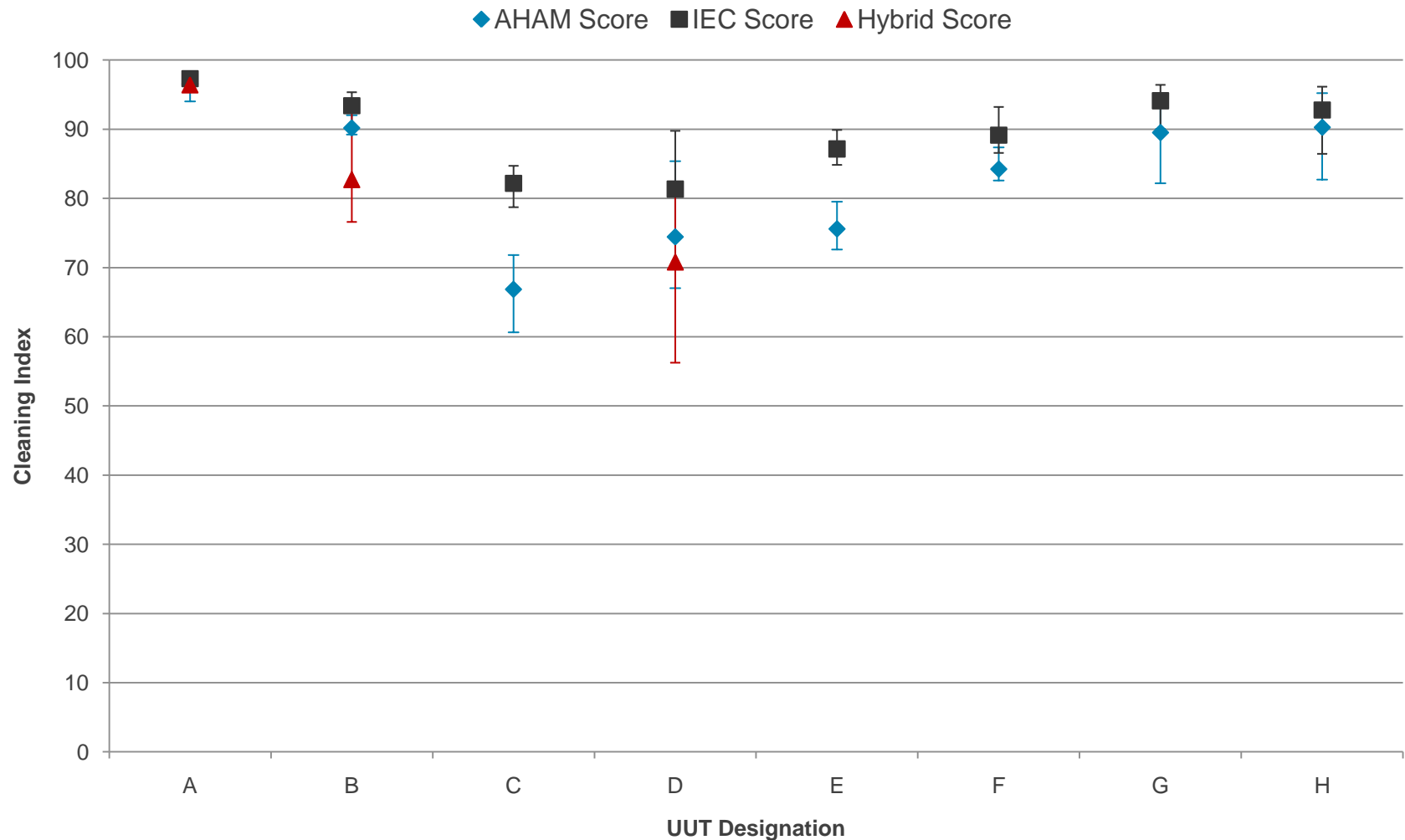
- AHAM soils
 - Coffee grounds float inside the unit, are re-deposited on most items, and accumulate on the filter
 - If oatmeal sticks to ware, it typically gets a score of 9
- IEC soils
 - Tea stains are hardest to clean
 - Spinach floats inside the unit, is re-deposited on most items, and accumulates on the filter
 - If oatmeal sticks to ware, it typically gets a score of 0
 - Serving bowls are not completely cleaned apparently due to the specified loading pattern

Comparison Between Test Methods

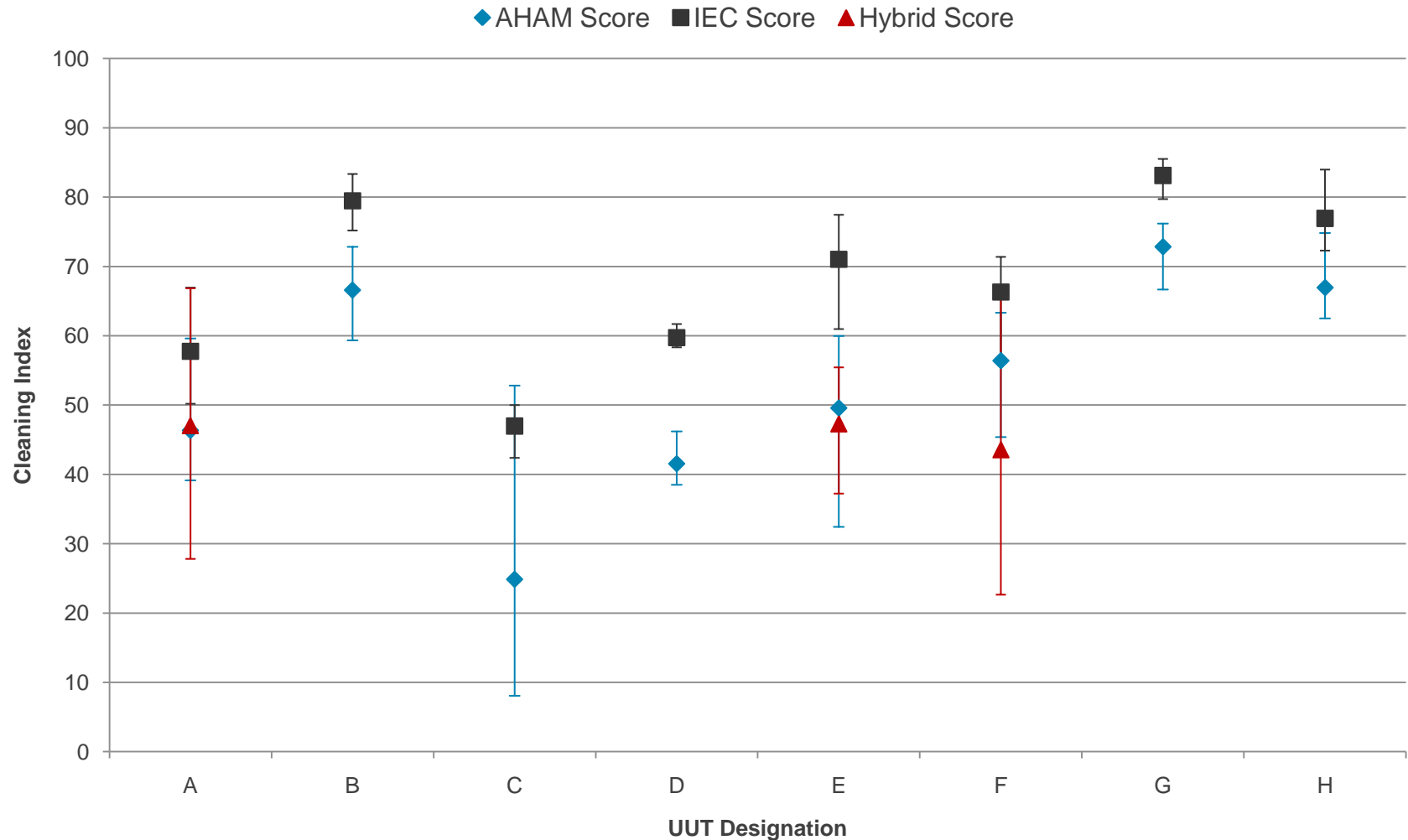


	DOE Test Method	AHAM Test Method	IEC Test Method
Typical scores	70 – 95 with all scoring methods	25 – 85 with all scoring methods	AHAM: 40 – 80 IEC/Hybrid: 0.75 – 1.75
Differentiation among test units	Low	High	Moderate for AHAM grading Low for IEC and Hybrid grading
Consistency and repeatability	High, especially for IEC grading	High for IEC grading Moderate for AHAM and Hybrid grading	Low
Test burden	Low	Moderate	High

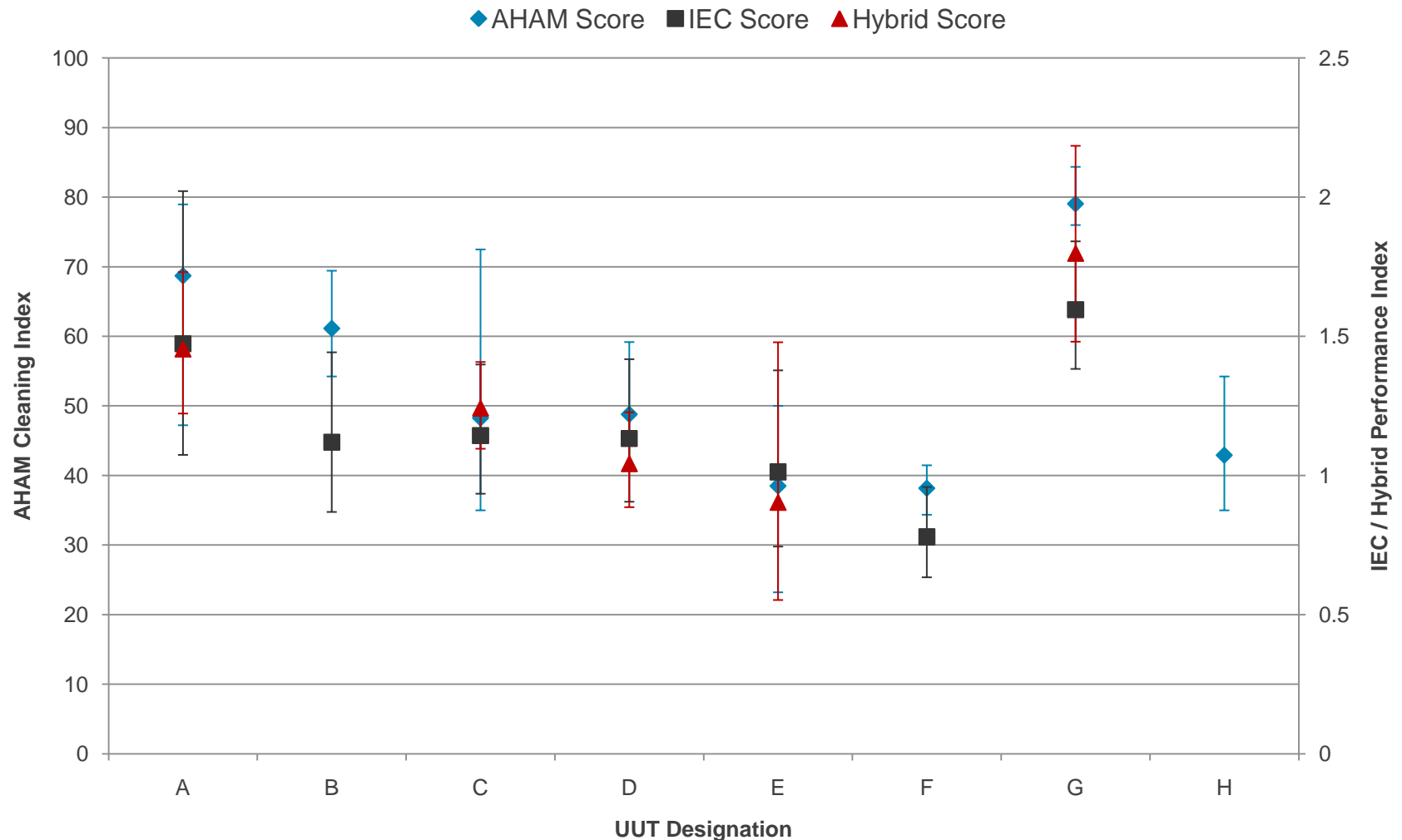
DOE Test Results



AHAM Test Results



IEC Test Results

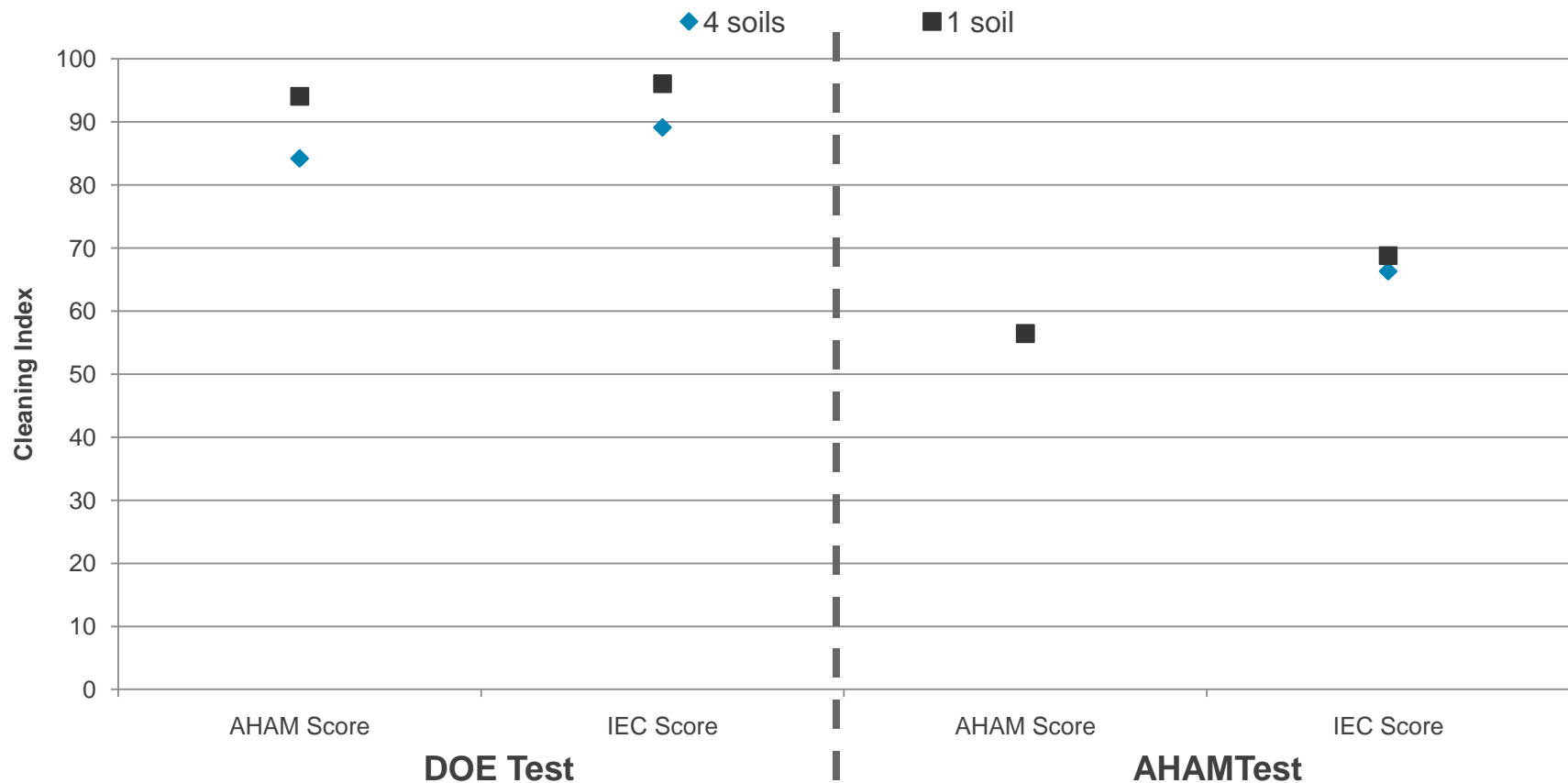


Note: Unit H includes only an AHAM score because it is the reference unit for the IEC and hybrid scoring.

Alternate AHAM Soil Application Results



Reduces test burden by shortening preparation time by ~60% without significant changes in results



DOE Sensor Light Response and Sensor Medium Response Results



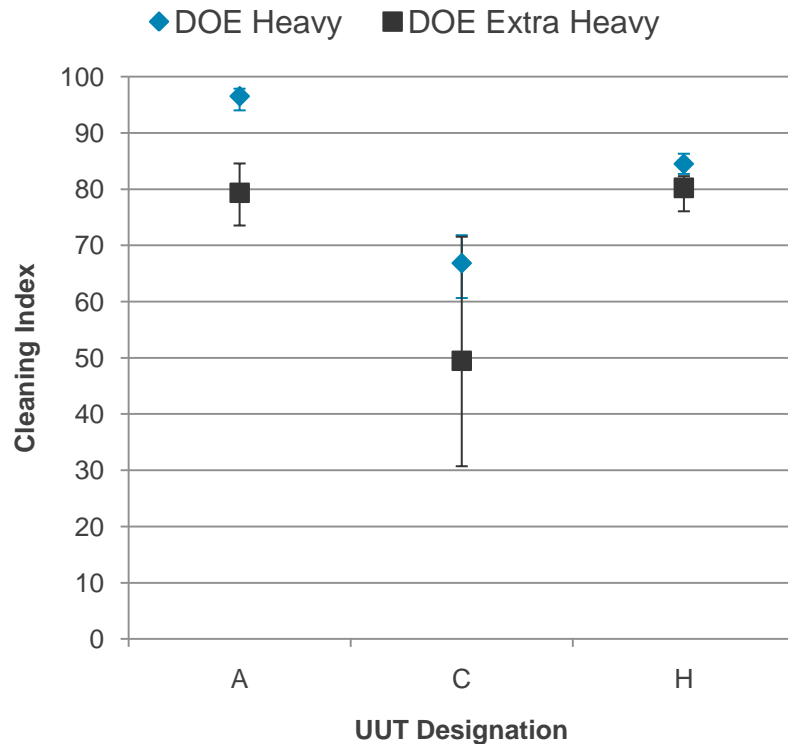
- Observations
 - AHAM and IEC cleaning index results between 95 – 98
 - No test-to-test differentiation
- Conclusions
 - Not a good indicator for cleaning performance
 - Should not use the lighter soil loads specified in the current DOE test procedure for performance testing

DOE Sensor Extra-Heavy Response Results

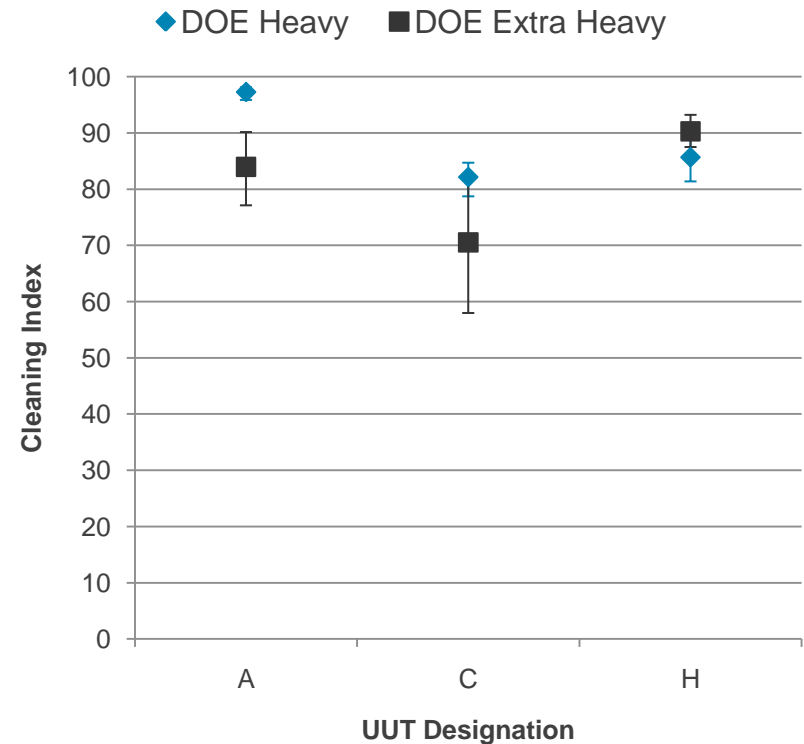


Moderate to high consistency in scoring and greater differentiation between units compared to DOE sensor heavy response

AHAM Score



IEC Score



Note: The DOE heavy soil load scores for unit H are based on two data points only.

Summary



- Test observations
- DOE, AHAM, and IEC test results
- Alternate AHAM soil application test results
- DOE sensor light response and sensor medium response test results
- DOE sensor extra-heavy response test results

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Initial Recommendations



- DOE sensor extra-heavy response tests with IEC scoring
 - Provides adequate differentiation among units
 - Least impact on test burden among methods showing differentiation: can be conducted as additional cycles after DOE testing to measure EAEU using same soil
 - Moderate to highly consistent; will require tests on more units to confirm
 - Provides best harmonization: cleanability would be measured according to similar soil as used for energy testing
- Alternatively, AHAM tests with IEC scoring
 - Provides high differentiation among units with highly consistent results
 - Somewhat more test burden compared to DOE extra-heavy soil load tests

IEC Test Method Not Recommended



- Significantly higher test burden
 - Uses completely different soils and preparation
 - Needs 2 – 3 technicians for one round of testing
 - Takes a long time to prepare, apply, and dry soils
 - Requires at least 5 cycles for both UUT and reference DW
- Our results indicate that the IEC test method does not provide consistent results or adequate differentiation among units tested

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Phase 2 Testing



- Perform validation tests (e.g. more units, single soil on each dish)
- Evaluate if there is an increased consistency in results with the IEC reference DW used for DOE and AHAM test methods
- Analyze changes in energy and water use with a heavier soil load and compare these with the rated energy and water consumption to determine representativeness of cleanability results.

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