

Procedures for Verification of RESNET Accredited HERS Software Tools

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1. Purpose

This publication provides procedures for the verification and accreditation of software tools used for calculating home energy ratings.

2. Scope

This procedure applies to the certification of residential Home Energy Rating Systems (HERS) software tools for all new and existing single family dwelling units and all new and existing multifamily dwelling units. This procedure employs a set of standard operating conditions representative of typical residences. As such, it may not accurately reflect the energy use of residences that depart from these standard operating conditions.

3. Procedures for Accreditation of Computerized HERS Rating Tools

Because Home Energy Rating Systems (HERS) are based on comparative performance analysis (Rated Home as compared with the HERS Reference Home), computer software modeling is required. In order to ensure the accuracy and comparability of HERS tools, software vendors seeking RESNET accreditation shall comply with the procedures prescribed by this document.

3.1 National Standard

ANSI/RESNET/ICC Standard 301-2019, including Addendum A, with applicable addenda as required for the software version being accredited, hereinafter referred to as “the Standard,” shall be the national standard for the development and use of HERS software tools. The Standard provides the technical basis for the development of HERS software tools that comply with the Standard. This document describes the verification tests that are required for RESNET accreditation of HERS software tools.

3.2 Software Verification Test Suite

The RESNET Software Verification Committee has defined a suite of software tests for use in verifying HERS software tool accuracy and comparability. The RESNET Board of Directors has adopted this test suite as the verification tests that shall be used by RESNET to accredit computerized HERS rating tools. The RESNET software verification test suite includes the following tests:

3.2.1 ANSI/ASHRAE Standard 140-2017, Class II, Tier 1 tests

The ANSI/ASHRAE Standard 140-2017, Class II, Tier 1 test procedure has been adopted by RESNET and is a requirement for all software programs to be accredited (See Section 4.1).

3.2.2 HERS Reference Home auto-generation tests

These tests verify the ability of the software tool to automatically generate the HERS Reference Home (See Section 4.2).

3.2.3 HERS method tests

These tests verifies that software tools can accurately calculate the HERS Index that is used as the numerical indicator of relative performance for a home (See Section 4.3).

3.2.4 HVAC tests

These tests verify the accuracy and consistency with which software tools predict the performance of HVAC equipment, including furnaces, air conditioners, and air source heat pumps (See Section 4.4).

3.2.5 Duct distribution system efficiency tests

These tests verify the accuracy with which software tools calculate air distribution system losses. ASHRAE Standard 152 results are used as the basis for the test suite acceptance criteria (See Section 4.5).

3.2.6 Hot water system performance tests

These tests determines the ability of the software to accurately predict hot water system energy use (See Section 4.6).

3.3 Process for Accrediting Software Programs

The RESNET accreditation process provides a suite of verification tests to certify that rating software tools conform to the verification criteria for each test. The software developer shall be required to submit the test results, test runs, and the software program with which the tests were conducted to RESNET. This information may be released by RESNET for review by any party, including competing software developers. This process is expected to result in compliance without a costly bureaucratic review and approval process.

3.4 Process for Exceptions and Appeals

RESNET has established an appeals process that software developers may use if their software is so unique that they cannot be accurately tested through the RESNET software testing procedures. The elements of this appeal process are:

- The software provider's documentation of how the software or qualification program meets or exceeds the criteria established in the RESNET software verification procedures.

- The software developer’s justification and documentation as to why the software is so unique that it cannot comply with the RESNET software tool testing protocols.
- Independent evaluation of the software tool by RESNET in collaboration with independent experts. Based upon the results of the evaluation, RESNET may certify that the software tool meets or exceeds the performance criteria of RESNET’s software tool verification procedures. RESNET will render a determination regarding certification within 90 days of receipt of appeal and supporting materials.

4. Test Suite Specifications and Acceptance Criteria

All test homes below are based on ASHRAE Standard 140 test cases. Unless otherwise specified, all assumptions should solely reflect the ASHRAE Standard 140 test specification.

4.1 ANSI/ASHRAE Standard 140-2017, Class II, Tier 1 Tests

Standard 140, Class II Tests were developed from the HERS BESTEST¹ for testing the accuracy of simulation software for predicting building loads. The ANSI/ASHRAE Standard 140-2017, Class II, Tier 1 test procedure has been adopted by RESNET and is a requirement for all software programs to be accredited. Acceptance criteria for this suite of tests shall be as follows:

Annual Heating Loads Colorado Springs, CO			Annual Heating Load Deltas Colorado Springs, CO		
Case	range max	range min	Case	range max	range min
L100AC	79.48	45.28	L110AC-L100AC	28.12	18.66
L110AC	103.99	71.51	L120AC-L100AC	-7.67	-18.57
L120AC	64.30	33.76	L130AC-L100AC	-5.68	-27.50
L130AC	53.98	37.75	L140AC-L100AC	1.86	-24.42
L140AC	56.48	43.24	L150AC-L100AC	-3.02	-12.53
L150AC	71.33	35.50	L155AC-L150AC	6.88	-1.54
L155AC	74.18	39.17	L160AC-L100AC	5.10	-3.72
L160AC	81.00	45.63	L170AC-L100AC	17.64	7.12
L170AC	92.40	54.16	L200AC-L100AC	107.66	56.39
L200AC	185.87	106.41	L202AC-L200AC	11.10	-0.51
L202AC	190.05	111.32	L302XC-L100AC	14.50	-31.96
L302XC	90.52	14.52	L302XC-L304XC	17.75	-4.60
L304XC	75.32	18.84	L322XC-L100AC	39.29	-31.30
L322XC	118.20	16.79	L322XC-L324XC	38.27	-14.25
L324XC	80.04	30.50			

¹ R. Judkoff and J. Neymark, 1995, “Home Energy Rating System Building Energy Simulation Test (HERS BESTEST), Volume 1, Report No. NREL/TP-472-7332a, National Renewable Energy Laboratory, Golden, Colorado. (online at: <http://www.nrel.gov/docs/legosti/fy96/7332a.pdf>)

Annual Cooling Loads Las Vegas, NV			Annual Cooling Load Deltas Las Vegas, NV		
Case	range max	range min	Case	range max	range min
L100AL	64.88	39.53	L110AL-L100AL	7.84	-0.98
L110AL	68.50	43.86	L120AL-L100AL	0.68	-8.67
L120AL	60.14	38.08	L130AL-L100AL	-9.53	-24.40
L130AL	45.26	29.19	L140AL-L100AL	-19.76	-38.68
L140AL	30.54	19.44	L150AL-L100AL	20.55	8.72
L150AL	82.33	48.53	L155AL-L150AL	-9.64	-22.29
L155AL	63.06	33.19	L160AL-L100AL	12.58	3.88
L160AL	72.99	49.62	L170AL-L100AL	-4.83	-15.74
L170AL	53.31	32.00	L200AL-L100AL	21.39	6.63
L200AL	83.43	52.49	L200AL-L202AL	14.86	2.03
L202AL	75.96	44.99			

4.2 HERS Reference Home Auto-Generation Tests

This section contains the Reference Home auto-generation test suite for HERS rating tools. The test cases in this proposed test suite are designed to verify that software tools automatically generate accurate Reference Homes given only the building information from the Rated home.

4.2.1 Minimum Reporting Requirements

Software tools applying for verification shall provide evidence that their software meets the requirements of this test suite. The software tool provider or software vendor is responsible for producing the documentation needed to show that the software has been verified through this test suite. In some cases, the data needed to verify accuracy is of no interest or value to the end-user of the software, but in any case, the software tool must generate it. At a minimum, software tools applying for accreditation must report the following values for the Reference Home:

1. Areas and overall U-factors (or R-values in the case of slab-on-grade construction) for all building components, including ceilings, walls, floors, windows (by orientation) and doors.
2. Overall solar-heat gain coefficient (SHGC_o)² of the windows during heating.
3. Overall solar-heat gain coefficient (SHGC_o) of the windows during cooling.
4. Wall solar absorptance and infrared emittance
5. Roof solar absorptance and infrared emittance
6. Sensible internal gains to the home (Btu/day)
7. Latent internal gains to the home (Btu/day)

² The overall solar heat gain coefficient (SHGC_o) of a fenestration is defined as the solar heat gain coefficient (SHGC) of the fenestration product taken in combination with the interior shade fraction for the fenestration.

8. Specific leakage area (SLA) for the building, by zone or as SLA_{o3}, as appropriate
9. Attic net free ventilation area (ft²)
10. Crawlspace net free ventilation area (ft²), if appropriate
11. Exposed masonry floor area and carpet and pad R-value, if appropriate
12. Heating system labeled ratings, including AFUE, COP, or HSPF, as appropriate.
13. Cooling system labeled ratings, including SEER or EER, as appropriate.
14. Thermostat schedule for heating and cooling
15. Air Distribution System Efficiency (DSE)
16. Mechanical ventilation kWh/y, if appropriate
17. DHW pipe length refPipeL (ft)
18. DHW loop length refLoopL (ft)

Software tools must have the ability to recreate or store the test case Reference Homes as if they were Rated Homes such that they also can be simulated and evaluated as Rated Homes.

4.2.2 Auto-generation Test Descriptions

Only the geometry of the ASHRAE Standard 140 test cases shall be used in these tests. Internal gains, and other assumptions not explicitly described below shall reflect the Energy Rating Reference Home configuration in ANSI/RESNET 301-2019, including Addendum A.

- 4.2.2.1 Test Case 1. ASHRAE Standard 140 case L100 building geometry configured as specified in the Standard 140 procedures except that the envelope leakage shall be 3.0 ach₅₀, located in Baltimore, MD (TMY3 site 724060, BALTIMORE BLT-WASHINGTON INT'L), including a total of 3 bedrooms and the following mechanical equipment: gas furnace with AFUE = 82% and central air conditioning with SEER = 11.0; no whole-dwelling mechanical ventilation system; a gas range/oven and clothes dryer; all other appliances are electric.
- 4.2.2.2 Test Case 2. ASHRAE Standard 140 case L100 building geometry except that the envelope leakage shall be 3.0 ach₅₀, configured on an un-vented crawlspace with R-7 crawlspace wall insulation, located in Dallas, TX (TMY3 site 722590, DALLAS-FORT WORTH INTL AP), including a total of 3 bedrooms and the following mechanical equipment: electric heat pump with HSPF = 7.5 and SEER = 12.0; exhaust-only whole-dwelling mechanical ventilation system; all appliances are electric.
- 4.2.2.3 Test Case 3. ASHRAE Standard 140 case L304 building geometry in Miami, configured as specified in the Standard 140 procedures except that the envelope leakage shall be 5.0 ach₅₀, located in Miami, FL (TMY3 site 722020, MIAMI INTL AP), including a total of 2 bedrooms and the following mechanical

³ SLA_o is the floor-area weighted specific leakage area of a home where the different building zones (e.g. basement and living zones) have different specific leakage areas.

equipment: electric strip heating with COP = 1.0 and central air conditioner with SEER = 15.0; balanced whole-dwelling mechanical ventilation without energy recovery system; all appliances are electric.

4.2.2.4 Test Case 4. ASHRAE Standard 140 case L324 building geometry configured as specified as in the Standard 140 procedures except that the envelope leakage shall be 3.0 ach50, located in Colorado Springs, CO (TMY3 site 724660, COLORADO SPRINGS MUNI AP), including a total of 4 bedrooms and the following mechanical equipment: gas furnace with AFUE = 95% and no air conditioning; balanced whole-dwelling mechanical ventilation system with a 60% energy recovery system; a gas range/oven and clothes dryer; all other appliances are electric.

4.2.2.5 Test Case 5. Recreate or store the Reference Homes created in Tests 1 through 4 as Rated Homes and simulate and evaluate them.

4.2.3 Acceptance Criteria

4.2.3.1 Test Cases 1 – 4

For test cases 1 through 4 the values contained in Table 4-1 shall be used as the acceptance criteria for software tool accreditation. For Reference Home building components marked by an asterisk (*), the acceptance criteria may include a range equal to $\pm 0.05\%$ of the listed value. For all other Reference Home components the listed value is exact. Note: Internal gain acceptance criteria are based on changes proposed in ANSI/RESNET 301-2019 Addendum B.

Table 4-1: Acceptance Criteria for Test Cases 1 – 4

Reference Home Building Component	Test 1	Test 2	Test 3	Test 4
Above-grade walls (U_o)	0.082	0.082	0.082	0.060
Above-grade wall solar absorptance (α)	0.75	0.75	0.75	0.75
Above-grade wall infrared emittance (ϵ)	0.90	0.90	0.90	0.90
Basement walls (U_o)	n/a	n/a	n/a	0.059
Above-grade floors (U_o)	0.047	0.047	n/a	n/a
Slab insulation R-Value	n/a	n/a	0	0
Ceilings (U_o)	0.030	0.035	0.035	0.030
Roof solar absorptance (α)	0.75	0.75	0.75	0.75
Roof infrared emittance (ϵ)	0.90	0.90	0.90	0.90
Attic vent area* (ft ²)	5.13	5.13	5.13	5.13
Crawlspace vent area* (ft ²)	n/a	10.26	n/a	n/a
Exposed masonry floor area * (ft ²)	n/a	n/a	307.8	307.8
Carpet & pad R-Value	n/a	n/a	2.0	2.0
Door Area (ft ²)	40	40	40	40
Door U-Factor	0.40	0.65	1.20	0.35
North window area* (ft ²)	69.26	69.26	69.26	102.63
South window area* (ft ²)	69.26	69.26	69.26	102.63
East window area* (ft ²)	69.26	69.26	69.26	102.63
West window area* (ft ²)	69.26	69.26	69.26	102.63

Reference Home Building Component	Test 1	Test 2	Test 3	Test 4
Window U-Factor	0.40	0.65	1.20	0.35
Window SHGC _o (heating)	0.34	0.34	0.34	0.34
Window SHGC _o (cooling)	0.28	0.28	0.28	0.28
SLA _o (ft ² /ft ²)	0.00036	0.00036	0.00036	0.00036
Sensible Internal gains* (Btu/day)	55,115	52,470	47,839	82,691
Latent Internal gains* (Btu/day)	13,666	12,568	9,152	17,769
Labeled heating system rating and efficiency	AFUE = 78%	HSPF = 7.7	HSPF = 7.7	AFUE = 78%
Labeled cooling system rating and efficiency	SEER = 13.0	SEER = 13.0	SEER = 13.0	SEER = 13.0
Air Distribution System Efficiency	0.80	0.80	0.80	0.80
Thermostat Type	Manual	Manual	Manual	Manual
Heating thermostat settings	68 F (all hours)	68 F (all hours)	68 F (all hours)	68 F (all hours)
Cooling thermostat settings	78 F (all hours)	78 F (all hours)	78 F (all hours)	78 F (all hours)
Mechanical ventilation (kWh/y) (±0.1%)	0.0	222.1	287.8	762.8
DHW pipe length refPipeL (±0.1 ft)	88.5	88.5	88.5	98.5
DHW loop length refLoopL (±0.1 ft)	156.9	156.9	156.9	176.9

4.2.3.2 Test Case 5

Test case 5 requires that each of the Reference Homes for test cases 1-4 be stored or recreated in the software tool as a Rated Home and simulated as any other rated home would be simulated. If the resulting Rated Home is correctly configured to be identical to its appropriate Reference Home, rating calculations arising from normal operation of the software tool should produce virtually identical scoring criteria for both the Reference Home and the Rated Home for this round of tests. For test case 5, the modified loads e-Ratio shall be calculated separately from the simulation results, as follows:

$$\text{e-Ratio} = (\text{Total normalized Modified Loads}) / (\text{Total Reference Loads})$$

Acceptance criteria for these calculations shall be $\pm 0.5\%$ of 1.00. Thus, for each of the preceding test cases (1-4), the e-Ratio resulting from these software tool simulations and the subsequent e-Ratio calculations shall be greater than or equal to 0.995 **and** less than or equal to 1.005.

4.3 HERS Method Tests

The HERS Method tests are intended to determine the ability of HERS tools to accurately calculate the HERS Index given a set of Reference Home End Use Loads (REUL), Reference Home End Use Energy Consumptions (EC_r), Rated Home End Use Energy Consumptions (EC_x), the applicable manufacturers equipment performance ratings (MEPR), and the Index Adjustment Design savings (IAD_{SAVE}). All hot water values shall be calculated according to the procedures in ANSI/RESNET 301-2019, including Addendum A.

4.3.1 Minimum Reporting Requirements

At a minimum, all software tools must report the following values:

4.3.1.1 Reference Home End Use Loads (REUL) to the nearest 0.1 MBtu

- i. Heating (MBtu)
- ii. Cooling (MBtu)
- iii. Hot water (MBtu)

4.3.1.2 Reference Home End Use Energy Consumption (EC_r) to the nearest 0.1 MBtu

- i. Heating (MBtu)
- ii. Cooling (MBtu)
- iii. Hot Water (MBtu)

4.3.1.3 Rated Home End Use Energy Consumption (EC_x) to the nearest 0.1 MBtu

- i. Heating (MBtu)
- ii. Cooling (MBtu)
- iii. Hot Water (MBtu)

4.3.1.4 Manufacturer's Equipment Performance Ratings (MEPR)

- i. Heating system (HSPF, COP, AFUE)
- ii. Cooling system (SEER, EER or COP)
- iii. Hot Water system (EF)

4.3.1.5 Index Adjustment Design savings (IAD_{SAVE})

4.3.2 Test Description

Only the geometry of the ASHRAE Standard 140 test cases shall be used in these tests. Internal gains, air exchange, and other assumptions not explicitly described below shall reflect the Energy Rating Reference Home configuration in ANSI/RESNET 301-2019, including Addendum A.

Home Energy Ratings for the following cases, located in Colorado Springs, CO, shall be computed, reporting the values listed above.

4.3.2.1 Case L100A-01: Using the ASHRAE Standard 140 L100 case, create a 3-bedroom Rated Home containing the following equipment:

- i. Heating system – electric HP with HSPF = 6.8
- ii. Cooling system – electric A/C with SEER = 10.0
- iii. Hot Water – 40 gal electric with EF = 0.88
- iv. All the equipment are to be located inside the conditioned space and heating and air conditioning ductwork are to be located in the conditioned space and have zero (0) air leakage.
- v. All appliances are standard electric

4.3.2.2 Case L100A-02: Identical to Case L100A-01 except for the following:

- i. Hot water heater is changed to a tankless natural gas with EF = 0.82
- ii. Range/oven and clothes dryer are changed to standard natural gas.

4.3.2.3 Case L100A-03: Identical to Case L100A-01 except for the following:

- i. Space heating system is changed to a natural gas furnace with AFUE = 78%
- ii. Number of bedrooms is changed from 3 to 2
- iii. Range/oven and clothes dryer are changed to standard natural gas.

4.3.2.4 Case L100A-04: Identical to Case L100A-01 except for the following:

- i. Space heating system is changed to a high efficiency HP with HSPF = 9.85
- ii. Number of bedrooms is changed from 3 to 4.

4.3.2.5 Case L100A-05: Identical to Case L100A-01 except for the following:

- i. Space heating system is changed to a natural gas furnace with AFUE = 96%
- ii. Range/oven and clothes dryer are changed to standard natural gas.

4.3.3 Acceptance Criteria

Using the calculation spreadsheet provided by RESNET on its Accredited HERS Software Tools webpage, software tools shall demonstrate the following:

4.3.3.1 That the difference between the HERS Indices calculated by the software tool and those calculated by the calculation spreadsheet provided with this Test Standard is less than 0.5% of the index reported by the software tool for all cases.

4.4 HVAC Tests

4.4.1 Required Capabilities

Tools must be capable of generating HVAC results using system type and efficiency as inputs. Additional efficiency information is allowable, but must not be required to operate the tool. Tools must also account for duct leakage, duct insulation levels and the presence of a programmable thermostat.

4.4.2 System Types

The following system types that must be supported by all tools:

1. Compressor based air conditioning system
2. Oil, propane or natural gas forced air furnaces
3. Electric resistance forced air furnaces
4. Air source heat pump

Optional system types that may be supported include:

1. Evaporative cooling, direct, indirect or IDEC
2. Ground or water source heat pumps
3. “Dual fuel” systems that utilize an electric air or ground source heat pump for primary heating and fuel for backup heating. An example of this would be an electric air source heat pump with a gas furnace as a supplement or backup.
4. Radiant heating systems including but not limited to hot water radiant floor systems, baseboard systems and ceiling cable systems.
5. Hydronic systems.
6. Combo systems in which the system supplies both domestic hot water and space heating.
7. Active solar space heating systems

Capability tests do not currently exist for the above optional system types. The following table lists the efficiency metrics that are reported by manufacturers, which shall be used for each system type.

Table 4-2: HVAC Equipment Efficiency Metrics

HVAC Equipment Type	Heating Efficiency Metric	Cooling Efficiency Metric	Comments:
Gas or Fuel Furnaces	AFUE		Includes wall furnaces, floor furnaces and central forced air furnaces.
Electric Resistance Furnace	COP		Use COP of 1.0, an HSPF of 3.413 may be equivalent and acceptable for some tools.
Air Source Heat Pump <65 kBtu/h	HSPF	SEER	
Air Cooled Central Air Conditioner <65 kBtu/h		SEER	
Air Cooled Window Air Conditioner		EER	PTAC units are included in this category

4.4.3 Detailed Default Inputs

Where tools use detailed modeling capabilities for HVAC simulation like DOE-2, the following values should be used as default values in the simulation tool to achieve the best results.

Table 4-3: Default Values for use with Detailed HVAC Simulation Tools

DOE-2 Keyword:	Description (units)	Value
HEATING-EIR	Heat Pump Energy Input Ratio compressor only, (1/cop)	0.582*(1/(HSPF/3.413))
COOLING-EIR	Air Conditioner Energy Input Ratio compressor only, (1/cop)	0.941*(1/(SEER/3.413))
DEFROST-TYPE	Defrost method for outdoor unit, (Reverse cycle)	REVERSE-CYCLE
DEFROST-CTRL	Defrost control method, (Timed)	TIMED
DEFROST-T (F)	Temperature below which defrost controls are activated, (°F)	40°
CRANKCASE-HEAT	Refrigerant crankcase heater power, (kW)	0.05
CRANK-MAX-T	Temperature above which crankcase heat is deactivated, (°F)	50°
MIN-HP-T (F)	Minimum temperature at which compressor operates, (°F)	0°
MAX-HP-SUPP-T	Temperature above which auxiliary strip heat is not available, (°F)	50°
MAX-SUPPLY-T (heating, heat pump)	Maximum heat pump leaving air temperature from heating coil, (°F)	105°
MAX-SUPPLY-T (heating, natural gas furnace)	Maximum gas furnace leaving air temperature from heating coil, (°F)	120°
FURNACE-AUX	Natural gas furnace pilot light energy consumption, (Btu/h)	100
MIN-SUPPLY-T (cooling)	Minimum cooling leaving air temperature from cooling coil, (°F)	55°
SUPPLY-KW	Indoor unit standard blower fan power, (kW/cfm)	0.0005
SUPPLY-DELTA-T	Air temperature rise due to fan heat, standard fan, (°F)	1.580
SUPPLY-KW	Indoor unit standard blower fan power, high efficiency fan, (kW/cfm)	0.000375

DOE-2 Keyword:	Description (units)	Value
SUPPLY-DELTA-T	Air temperature rise associated due to fan heat, high efficiency fan, (°F)	1.185
COIL-BF	Coil bypass factor, (dimensionless)	0.241
Other parameters:		
Part load performance curves	Compressor part load performance curves	Henderson, et.al. ⁴
Heating system size	Installed heat pump size, (kBtu/h)	Determined by Manual J (specified)
Coil airflow	Indoor unit air flow, (cfm)	30 cfm/(kBtu/h)
Cooling system size	Installed air conditioner size, (kBtu/h)	Determined by Manual J (specified)

4.4.4 Test Description and Acceptance Criteria

The following test suites represent tests that tools must pass to be accredited. All tests are to be performed using the L100 building case described by the ASHRAE Standard 140 procedures.

For each test case, acceptance criteria are provided. These criteria are based on reference results from 6 tools, which are capable of detailed hourly building simulation and HVAC modeling computations.⁵ The criteria are established as the greater of the 90% confidence interval using the student t-test criteria or 10% of the mean results for the 6 sets of reference results. In order to pass a specific test, tools must predict percentage energy use changes for the specified heating and/or cooling system tests that falls between the upper and lower acceptance criteria for that test.

Tools that do not model the performance of HVAC equipment in detail must provide for climate adjusted equipment performance factors in order to fall within the acceptance criteria for these tests. Methods of adjusting the manufacturer's nameplate ratings to account for climate dependent performance have been reported.⁶

4.4.4.1 Test Suite 1 – Air conditioning systems:

Test to ensure that there is the proper differential electrical cooling energy consumption by cooling systems when the efficiency is varied between SEER 10 and

⁴ Henderson, H.I., D.S. Parker and Y.J. Huang, 2000. "Improving DOE-2's RESYS Routine: User Defined Functions to Provide More Accurate Part Load Energy Use and Humidity Predictions," Proceedings of 2000 Summer Study on Energy Efficiency in Buildings, Vol. 1, p. 113, American Council for an Energy-Efficient Economy, 1001 Connecticut Avenue, Washington, DC.

⁵ Two DOE-2.1E tools, two DOE-2.2 tools, Micropas version 6.5 and TRNSYS version 15.

⁶ Fairey, P., D.S. Parker, B. Wilcox and M. Lombardi, "Climate Impacts on Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER) for Air Source Heat Pumps." ASHRAE Transactions, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA, June 2004. (Also available online at <http://www.fsec.ucf.edu/bldg/pubs/hspf/>)

a higher efficiency unit, taken to be SEER 13. For the purposes of this test assume zero duct leakage and all ducts and air handlers are in conditioned space.

Table 4-4: Air Conditioning System Test Specifications

Test #	System Type	Capacity	Location	Efficiency
HVAC1a	Air cooled air conditioner	38.3 kBtu/h	Las Vegas, NV	SEER = 10
HVAC1b	Air cooled air conditioner	38.3 kBtu/h	Las Vegas, NV	SEER = 13

Table 4-5: Air Conditioning System Acceptance Criteria

Test #	Average Change From Base Case	Low Acceptance Criteria	High Acceptance Criteria
HVAC1a	Base case	---	---
HVAC1b	-19.3	-21.2%	-17.4%

4.4.4.2 Test Suite 2 – Heating Systems:

Test to ensure that there is differential heating energy consumed by heating systems when the efficiency is varied between a code minimum heating and a higher efficiency unit. The tests will be carried out for both electric and non-electric heating systems. For the purposes of this test assume zero duct leakage and all ducts and air handlers in conditioned space.

Table 4-6: Gas Heating System Test Specifications

Test #	System Type	Capacity	Location	Efficiency
HVAC2a	Gas Furnace	56.1 kBtu/h	Colorado Springs, CO	AFUE = 78%
HVAC2b	Gas Furnace	56.1 kBtu/h	Colorado Springs, CO	AFUE = 90%

Table 4-7: Gas Heating System Acceptance Criteria

Test #	Average Change From Base Case	Low Acceptance Criteria	High Acceptance Criteria
HVAC2a	Base case	---	---
HVAC2b	-12.9%	-13.3%	-11.6%

Table 4-8: Electric Heating System Test Specifications

Test #	System Type	Capacity	Location	Efficiency
HVAC2c	Air Source Heat Pump	56.1 kBtu/h	Colorado Springs, CO	HSPF = 6.8
HVAC2d	Air Source Heat Pump	56.1 kBtu/h	Colorado Springs, CO	HSPF = 9.85
HVAC2e	Electric Furnace	56.1 kBtu/h	Colorado Springs, CO	COP = 1.0

Table 4-9: Electric Heating System Acceptance Criteria

Test #	Average Change From Base Case	Low Acceptance Criteria	High Acceptance Criteria
HVAC2c	Base case	---	---
HVAC2d	-22.9%	-29.0%	-16.7%
HVAC2e	61.3%	41.8%	80.8%

4.5 Duct Distribution System Efficiency (DSE) Tests (Suite 3)

Distribution System Efficiency (DSE) tests are designed to ensure that the impact of duct insulation, duct air leakage and duct location are properly accounted for in software. Table 4-10, Table 4-11, Table 4-12 and Table 4-13 below describe the test specifications and the bounds criteria for these tests.

4.5.1 Test Description

For all tests, assume that the air-handling unit is in conditioned space. If the software tool being tested has the ability to modify inputs for duct area, assume that the supply duct area is equal to 20% of the conditioned floor area and the return duct area is equal to 5% of the conditioned floor area. The duct leakage shall be 250 cfm₂₅ for cases 3d and 3h with the return and supply leakage fractions each set at 50%. All tests assume a natural gas forced air furnace and forced air cooling system with efficiencies of 78% AFUE = 78% for the heating system and SEER = 10 for the cooling system.

Furnace and air conditioner heating and cooling capacities shall be modified for each of the duct system efficiency test cases according to the values provided in Table 4-10 and Table 4-12. Similarly, the specified heating and cooling coil airflow (cfm) shall be altered by case using a value of 360 cfm/ton (30 cfm/kBtu) of capacity. Also, the exterior air film resistance of the duct system should be added to the specified duct R-values given in Table 4-10 and Table 4-12 to obtain agreement for duct conductance. For non-insulated sheet metal ducts (R=0) the air film has a resistance of approximately R=1.5 ft²-oF-hr/Btu and for insulated ducts (R=6) the air film has a resistance of R=1.0 as shown by test results obtained by Lauvray (1978) at a typical residential duct airflow rate of 530 fpm.⁷ These values are currently established for the purposes of duct design calculations by ASHRAE within the Handbook of Fundamentals (2001, p. 34.15). Thus, unless the software undergoing test accounts for these film resistances, the uninsulated sheet metal duct (R=0 in Table 4-10 and Table 4-12) shall be entered as R=1.5 while the insulated ducts (R=6 in tables) shall be entered as R=7.

For the heating comparison test cases (Table 4-10), which assume a basement, begin with the ASHRAE Standard 140 Case L322 home and make the following modifications. The basement shall be unconditioned, and therefore the infiltration rate

⁷ T.L. Lauvray, 1978. "Experimental heat transmission coefficients for operating air duct systems," ASHRAE Journal, June, 1978.

and Infiltration Volume shall match that of the ASHRAE Standard 140 Case L100 home, not the L322 home. The basement floor area shall be equal to the main floor area (1539 ft²) and have R-11 insulation in the floor joists of the main floor with a framing fraction of 13%. The basement case has no basement wall insulation. For the cooling comparison test cases (Table 4-12), use the ASHRAE Standard 140 case L100 home.

4.5.2 Acceptance Criteria

The acceptance criteria for these tests were established using ASHRAE Standard 152-04, using the spreadsheet tool constructed for the U.S. DOE *Building America* program by Lawrence Berkeley National Laboratory (LBNL).⁸ In all cases, the input values for the Standard 152 calculations assumed the following:

- Single story building
- Single speed air conditioner/heating system
- System capacities as specified in Table 4-10 and Table 4-12
- Coil air flow = 360 cfm per 12,000 Btu/h
- Ducts located as specified in Table 4-10 and Table 4-12
- Supply duct area = 308 ft²
- Return duct area = 77 ft²
- Supply and return duct insulation of R=1.5 and R=7 for uninsulated (R=0) and insulated (R=6) ducts, respectively
- Supply and return duct leakage = 125 cfm each, where so specified in Table 4-10 and Table 4-12.

Following the ASHRAE Standard 152 analysis, the resulting DSE values were converted to a percentage change in heating and cooling energy use (“Target Delta” in Table 4-11 and Table 4-13) using the following calculation:

$$\% \text{ Change} = 1.0 - (1.0 / \text{DSE})$$

Acceptance criteria were then established as this target delta plus and minus 5% to yield the values given in Table 4-11 and Table 4-13 for heating and cooling test minimum and maximum acceptance criteria, respectively.

4.5.3 Heating Energy Tests

Table 4-10: Heating Energy DSE Comparison Test Specifications

Test #	Location	System Type	System Capacity (kBtu/h)	Duct Location	Duct Leakage	Duct R-val*
HVAC3a (base case)	Colorado Springs, CO	Gas Furnace	46.6	100% conditioned	None	R=0

⁸ See http://www.eere.energy.gov/buildings/building_america/benchmark_def.html

HVAC3b	Colorado Springs, CO	Gas Furnace	56.0	100% in basement	None	R=0
HVAC3c	Colorado Springs, CO	Gas Furnace	49.0	100% in basement	None	R=6
HVAC3d	Colorado Springs, CO	Gas Furnace	61.0	100% in basement	250 cfm ₂₅	R=6
* Duct R-value does not include air film resistances. For uninsulated ducts, this film resistance is approximately R=1.5 and for insulated ducts it is approximately R=1.0. If software does not consider this air film resistance in detail, then these air film resistances should be added.						

Table 4-11: Heating Energy DSE Comparison Test Acceptance Criteria

Test #	Target Delta* Heating Energy Relative to HVAC3a	Minimum Delta* Heating Energy	Maximum Delta* Heating Energy
HVAC3a	Base case	---	---
HVAC3b	26.4%	21.4%	31.4%
HVAC3c	7.5%	2.5%	12.5%
HVAC3d	20%	15%	25%
* Delta = % Change in energy use = ((alternative – base case) / (base case)) * 100			

4.5.4 Cooling Energy Tests

Table 4-12: Cooling Energy DSE Comparison Test Specifications

Test #	Location	System Type	System Capacity (kBtu/h)	Duct Location	Duct Leakage	Duct R-val*
HVAC3e (base case)	Las Vegas, NV	Air Conditioner	-38.4	100% conditioned	None	R=0
HVAC3f	Las Vegas, NV	Air Conditioner	-49.9	100% in attic	None	R=0
HVAC3g	Las Vegas, NV	Air Conditioner	-42.2	100% in attic	None	R=6
HVAC3h	Las Vegas, NV	Air Conditioner	-55.0	100% in attic	250 cfm ₂₅	R=6
* Duct R-value does not include air film resistance. For uninsulated ducts, this film resistance is approximately R=1.5 and for insulated ducts it is approximately R=1.0. If software does not consider this air film resistance in detail, then these air film resistances should be added.						

Table 4-13: Cooling Energy DSE Comparison Test Acceptance Criteria

Test #	Target Delta* Cooling Energy Relative to HVAC3e	Minimum Delta* Cooling Energy	Maximum Delta* Cooling Energy
HVAC3e	Base case	---	---
HVAC3f	31.2%	26.2%	36.2%
HVAC3g	11.5%	6.5%	16.5%
HVAC3h	26.1%	21.1%	31.1%
* Delta = % Change in energy use = ((alternative – base case) / (base case)) * 100			

4.6 Hot Water System Performance Tests

Hot water system tests are designed to determine if HERS software tools accurately account for both the hot water usage rate (gallons per day) and the climate impacts (inlet

water temperatures) of hot water systems. Distribution losses and other features associated with hot water distribution systems are now covered in the hot water gallons per day, per ANSI/RESNET 301-2019, including Addendum A.

4.6.1 Test Description

The test homes are all based on the ASHRAE Standard 140 Case L100A building, as modified below.

Case L100AD-HW-01 (base case)

Climate location: Duluth, MN (TMY3 site 727450, DULUTH INTERNATIONAL ARPT)

Bedrooms: 2

Type: 40 gallon storage

Fuel: gas

Efficiency: $EF = 0.56$

Recovery Efficiency: $RE = 0.78$

DHW Heater Location: conditioned space

Plumbing fixtures: Standard flow

Pipe insulation: None

Piping length = Reference Home piping length

Recirculation: None (Standard system)

DWHR: None

Case L100AD-HW-02 (distribution base case)

Same as Case L100AD-HW-01 except with 4 bedrooms

Case L100AD-HW-03

Same as Case L100AD-HW-01 except gas water heater has $EF=0.62$

Case L100AD-HW-04

Same as Case L100AD-HW-02 except with all low-flow fixtures (all bath faucets and showers $\leq 2\text{gpm}$)

Case L100AD-HW-05

Same as Case L100AD-HW-02 except with recirculation

- Control = none
- 50 W pump
- Loop length is same as reference loop length
- Branch length is 10 ft
- All hot water pipes insulated to R-3

Case L100AD-HW-06

Same as Case L100AD-HW-05 except with Control = Manual Demand

Case L100AD-HW-07

Same as Case L100AD-HW-02 except with Drain Water Heat Recovery

- DWHR efficiency = 54%
- All showers connected to DWHR unit
- DWHR preheats both hot and cold supplies for showers

Cases L100AM-HW-01 through L100AM-HW-07

Same as Cases L100AD-HW except climate location = Miami, FL (TMY3 site 722020, MIAMI INTL AP)

The preceding list of Cases specifies the 14 required hot water tests. The first 3 tests for each climate location are the water heating tests. The other 4 tests for each climate location exercise the distribution system features. Overall the hot water tests are organized as one set of cold climate tests (Duluth, MN) and one set of hot climate tests (Miami, FL).

Additional specifications used in the creation of the reference results that establish the hot water system test acceptance criteria are as follows:

4.6.1.1 Hot Water Draw Profile

The hot water draw profile is as specified by Table 3, ASHRAE Standard 90.2, as given in Table 4-14 below:

Table 4-14: Hourly Hot Water Draw Fraction for Hot Water Tests

Hour of Day	Daily Fraction	Hour of Day	Daily Fraction	Hour of Day	Daily Fraction
1	0.0085	9	0.0650	17	0.0370
2	0.0085	10	0.0650	18	0.0630
3	0.0085	11	0.0650	19	0.0630
4	0.0085	12	0.0460	20	0.0630
5	0.0085	13	0.0460	21	0.0630
6	0.0100	14	0.0370	22	0.0510
7	0.0750	15	0.0370	23	0.0510
8	0.0750	16	0.0370	24	0.0085

4.6.1.2 Inlet Mains Temperature

The cold-water inlet mains temperatures to the hot water system are calculated in accordance with the following formula:⁹

$$T_{\text{mains}} = (T_{\text{amb,avg}} + \text{offset}) + \text{ratio} * (\Delta T_{\text{amb,max}} / 2) * \sin(0.986 * (\text{day\#} - 15 - \text{lag}) - 90)$$

⁹ NREL, "Building America Research Benchmark Definition." National Renewable Energy Laboratory, Golden, CO, December 29, 2004. May be found online at: http://www.eere.energy.gov/buildings/building_america/pa_resources.html. For software tools seeking RESNET accreditation, T_{mains} shall not drop below 32°F.

where:

T_{mains} = mains (supply) temperature to domestic hot water tank (°F)

$T_{\text{amb,avg}}$ = annual average ambient air temperature (°F)

$\Delta T_{\text{amb,max}}$ = maximum difference between monthly average ambient temperatures (e.g., $T_{\text{amb,avg,july}} - T_{\text{amb,avg,january}}$) (°F)

0.986 = degrees/day (360/365)

day# = Julian day of the year (1-365)

offset = 6°F

ratio = $0.4 + 0.01 (T_{\text{amb,avg}} - 44)$

lag = $35 - 1.0 (T_{\text{amb,avg}} - 44)$

4.6.2 Hot Water Acceptance Criteria

There are two metrics used for acceptance criteria: a difference metric (delta) and an absolute metric (MBtu/y). The delta metric is the % change in energy use for the alternative cases with respect to the base case, which is determined as follows:

$$\% \text{ Change} = (\text{base} - \text{alternative}) / (\text{base}) * 100$$

The absolute metric is the projected hot water energy use given in millions of Btu (MBtu/y). The acceptance criteria given in Table 4-15 below are determined from reference results from three different software tools – EnergyGauge USA version 6.2, Ekotrope v4.0, and OpenStudio-ERI v0.10.0 Beta. Minimum and maximum acceptance criteria for each result are determined by the range of results from the reference tools, expanded by $\pm 1\%$ of the reference results mean value.

4.6.2.1 Water Heating Tests

In the water heating tests, the first test listed (L100Ax- HW-01) is the base case and the next two cases are the alternative cases.

4.6.2.2 Hot Water Distribution Tests

For the hot water distribution system tests, the base case is always L100Ax-HW-02. Cases -04 through -07 test various aspects of the hot water distribution system.

Table 4-15: Acceptance Criteria for Hot Water Tests

Test Cases	Minimum	Maximum	Range
(Duluth MN)	(MBtu)	(MBtu)	(MBtu)
L100AD-HW-01	19.34	19.88	0.53
L100AD-HW-02	25.76	26.55	0.79
L100AD-HW-03	17.27	17.65	0.39
L100AD-HW-04	24.94	25.71	0.78
L100AD-HW-05	55.93	57.58	1.65
L100AD-HW-06	22.61	23.28	0.67
L100AD-HW-07	20.51	21.09	0.58
(Miami FL)	(MBtu)	(MBtu)	(MBtu)
L100AM-HW-01	10.87	11.12	0.25
L100AM-HW-02	13.47	13.79	0.32
L100AM-HW-03	8.94	9.20	0.26
L100AM-HW-04	13.15	13.46	0.31
L100AM-HW-05	30.84	31.55	0.71
L100AM-HW-06	12.19	12.48	0.29
L100AM-HW-07	11.95	12.23	0.28
(Duluth deltas)	(% Δ)	(% Δ)	(% Δ)
MN (1-2 delta)	-33.92%	-32.59%	1.33%
MN (1-3 delta)	10.60%	11.49%	0.89%
MN (2-4 delta)	3.13%	3.22%	0.10%
MN (2-5 delta)	-118.39%	-115.70%	2.69%
MN (2-6 delta)	12.08%	12.46%	0.38%
MN (2-7 delta)	20.14%	20.78%	0.64%
(Miami deltas)	(% Δ)	(% Δ)	(% Δ)
FL (1-2 delta)	-24.44%	-23.47%	0.98%
FL (1-3 delta)	16.99%	18.01%	1.02%
FL (2-4 delta)	2.30%	2.37%	0.07%
FL (2-5 delta)	-130.29%	-127.53%	2.76%
FL (2-6 delta)	9.30%	9.57%	0.26%
FL (2-7 delta)	11.12%	11.39%	0.27%
(MN-FL deltas)	(% Δ)	(% Δ)	(% Δ)
MN-FL (01)	43.21%	44.60%	1.38%
MN-FL (02)	47.18%	48.56%	1.38%
MN-FL (03)	47.28%	48.70%	1.42%
MN-FL (04)	46.73%	48.12%	1.39%
MN-FL (05)	44.35%	45.67%	1.32%
MN-FL (06)	45.51%	46.85%	1.34%
MN-FL (07)	41.23%	42.42%	1.19%

5. General Requirements

Accredited software tools shall be required to fulfill the requirements defined in this section.

5.1 Calculation Timestep Frequency

Accredited software tools shall perform energy calculations at a minimum frequency of once per hour. The software shall simulate the dynamic response of thermal mass associated with the dwelling unit based on the thermal history established in calculations from prior timesteps.

5.2 Minimum Output

The software shall provide users with the capability of generating the following outputs for every HERS analysis.

5.2.1 RESNET National Building Registry XML

The software shall demonstrate the capability of generating an XML file consistent with the RESNET national building registry schema (<https://github.com/natresnet/buildingregistry-schema-v2>), including the following components of the HERS Index calculation:

- HERS Index
- Reference Home End Use Loads (REUL)
- Reference Home End Use Energy Consumptions (EC_r)
- Rated Home End Use Energy Consumptions (EC_x)
- Purchased Energy Fraction
- IAD_{SAVE}

5.2.2 Hourly Output

The software shall provide the capability to output each of the following results from both the reference home and rated home simulations at an hourly resolution (output at other resolutions is permitted but not required):

- Average space temperatures (in °F) for each space modeled (including Unconditioned Space Volumes such as attics, garages, basements, and crawlspaces).

Whole-building site energy use for each fuel type (in kBtu for fossil fuels and kWh for electricity).

5.3 User Input Verification

Accredited software tools shall be required to verify the reasonableness and internal consistency of certain user inputs as specified by this section. Accredited software tools shall generate user warnings, software errors that prohibit further calculation and National Building Registry flags as specified by this section.

5.3.1 Building Attribute Verification

The software inputs for building attributes specified in Table 5-1 shall be verified by accredited software tools. Where the Action listed in Table 5-1 is ‘Error’ accredited software tools shall not complete the rating calculations until the input error is remediated. Where the Action is ‘Warning’ the accredited software tools shall store a warning flag in the building input file that is specific to the attribute and that can be transmitted to the RESNET National Building Registry when the building file is submitted for registration.

Table 5-1: Building attribute verification limits and required actions

Building Attribute	Limits	Action
Number of bedrooms	$\leq (CFA-120) / 70$	Error
Stories above grade	$1 \leq SAG \leq 4$	Warning
Average ceiling height	$7 \leq (Volume / CFA) \leq 15$	Warning
Below grade slab floors	$\Rightarrow 1$ below grade wall	Warning
Below grade walls	$\Rightarrow 1$ below grade slab floor	Warning
Crawlspace perimeter (ft)	$1 \leq \text{perimeter} \leq (EFA_{0.5} * 7)$	Warning
Basement perimeter (ft)	$1 \leq \text{perimeter} \leq (EFA_{0.5} * 7)$	Warning
Slab on grade perimeter (ft)	$1 \leq \text{perimeter} \leq (EFA_{0.5} * 7)$	Warning
Foundation wall height (ft)	$0 < \text{height} \leq 20$	Warning
Basement wall depth (ft)	$2 \leq \text{depth} \leq (\text{wall height} - 0.5)$	Warning
Uncond. foundation space	$\Rightarrow 1$ floor above foundation space	Error
Enclosure floor area	\leq enclosure ceiling area	Warning
Enclosure floor area	\leq conditioned floor area	Error
Enclosure gross wall area	$27 \leq (EGWA / (CFA * NCS)^{0.5}) \leq 105$	Warning
Above grade gross wall area	\geq door area + window area	Error
Rating date	\leq current date	Error

Acronyms:

CFA = Conditioned Floor Area (total)

SAG = Stories Above Grade

EFA = Enclosure Floor Area of the specific building attribute

EGWA = Enclosure Gross Wall Area (total)

NCS = Number of conditioned stories including conditioned basements

Where **Enclosure** shall mean the relevant building components comprising the bounding elements of the Rated Home’s Conditioned Space.

5.3.2 Mechanical Ventilation System Verification

5.3.2.1 Accredited software tools shall verify that mechanical ventilation fan energy use values are within the bounds specified in Table 5-2. Where the limits provided by Table 5-2 are exceeded, accredited software tools shall store a warning flag in the building input file that is specific to the system type and that can be transmitted to

the RESNET National Building Registry when the building file is submitted for registration.

Table 5-2: Mechanical ventilation system fan energy consumption limits

System Type	Exhaust fan	Supply fan	System total
Exhaust	=> 0.12 W/cfm	n/a	=> 0.12 W/cfm
Supply	n/a	=> 0.12 W/cfm	=> 0.12 W/cfm
Balanced	=> 0.12 W/cfm	=> 0.12 W/cfm	=> 0.24 W/cfm
ERV	n/a	n/a	=> 0.48 W/cfm
Central Fan Integrated Supply (CFIS - fan cyclor or similar):			
PSC motor (SEER <= 13; AFUE <= 90%)			=> 0.48 W/cfm
ECM motor (SEER => 15; AFUE => 92%)			=> 0.36 W/cfm

5.3.2.2 For the purposes of calculating the impacts of whole-house ventilation systems in the Rated Home, accredited software tools shall ensure that the time-averaged ventilation rate is equal to or greater than the minimum allowed by Section 4.2, ANSI/RESNET 301-2019, including Addendum A, regardless of the user's entry.¹⁰

5.3.3 Appliance Verification

5.3.3.1 Clothes washers and clothes dryers

Accredited software tools shall verify that user inputs for clothes washers and clothes dryers do not exceed the limits specified by Table 5-3. Accredited software tools shall provide user warnings where these limits are exceeded. In all cases, where the limits provided by Table 5-3 are exceeded, accredited software tools shall store a warning flag in the building input file that is specific to the attribute and that can be transmitted to the RESNET National Building Registry when the building file is submitted for registration.

Table 5-3: Clothes washer and clothes dryer input limits

Attribute	Limits	Action
Clothes washers (kWh/y)	$(21 * \text{Nbr} + 73) > \text{CWkWh} > (1.92 * \text{Nbr} + 6.77)$	Warning
Electric dryers (kWh/y)	$(163 * \text{Nbr} + 577) > \text{eCDkWh} > (16.3 * \text{Nbr} + 50.5)$	Warning
Gas dryers (therms/y)	$(5.9 * \text{Nbr} + 20.6) > \text{gCDtherms} > (0.877 * \text{Nbr} + 3.09)$	Warning
Gas dryers (kWh/y)	$(12.9 * \text{Nbr} + 45.5) > \text{gCDkWh} > (1.94 * \text{Nbr} + 6.82)$	Warning
Hot water savings (gpd)	$\text{HWgpdSave} < (0.634 * \text{Nbr} + 2.24)$	Warning

¹⁰ For example, if the whole house ventilation fan requirement is 50 cfm continuous and the whole house ventilation system is intermittent with a 33% duty cycle (typical of a fan cyclor system), the ventilation rate during the 33% duty cycle must be 150 cfm for the Rated Home calculations. Software users can be warned of this requirement (and its implementation in the software) but shall not be allowed to override it.