THE INTERNATIONAL CODE-COMPLIANT CALCULATOR (IC3) v4.5.6

RESULTS OF RESNET VERIFICATION PROCEDURES (NO. 002-2020)

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Feb 2022

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Disclaimer

EXECUTIVE SUMMARY

This report presents the Energy Systems Laboratory's (ESL) web-based software tool - International Code Compliance Calculator (IC3), v4.5.6, test suites result of the Residential Energy Services Network (RESNET) verification procedures - RESNET Publication No. 002-2020 (RESNET 2020). These tests were developed using the RESNET Standard ANSI/RESNET/ICC 301-2019 (RESNET, 2018), Addendum A (RESNET, 2021a), and Addendum B (RESNET, 2021b).

The web-based IC3 software can be used to determine code-compliance of single residences under the Texas Building Energy Performance Standards (TBEPS). IC3 includes both the performance path and the Energy Rating Index (ERI) path of the 2015 IECC, the 2015 IECC with Austin amendments, the 2015 IECC with North Central Texas Council of Governments (NCTCOG) amendments, the 2018 IECC, the 2021 IECC, and 2021 IECC with Austin Energy amendments. The user-interface of IC3 was designed to ensure simple and quick input through reduced user input fields and provide either a code-compliance percent above/below code report or a ERI score for residential buildings located in Texas.

The RESNET verification procedure contains a suite of verification tests that are required for RESNET accreditation of HERS software tools. The procedure was developed to ensure the accuracy and comparability of different software to be used for verification of tax credits and Home Energy Ratings (HERS). In the RESNET verification procedure, the home configuration and operating conditions for the Rated Home and Reference Home are specified by RESNET (2020).

The RESNET verification procedures are based on six suites: 1) ANSI/ASHRAE Standard 140-2017, Class II, Tier 1 Tests; 2) HERS Reference Home Auto-Generation Tests; 3) HERS Method Test; 4) HVAC Tests; 5) Duct Distribution Efficiency (DSE) Tests; 6) Hot Water System Performance Tests. The specifications and acceptance criteria of each test suite and the test results of IC3 are presented in Section 1.1 through 1.6 of this report.

The IC3 software includes a section that allows to replicate all of the RESNET verification test suites. The section is managed by a small database with all the test cases required for the RESNET, each case can be loaded and run it as the user wish. Similar to the RESNET classification verification tests, IC3 provides the six categories options of the test suites.

The application of the RESNET verification procedures results showed that the IC3 software complies with all and each one of the six RESNET suite tests used for accreditation purposes, including the estimation of the RESNET HERS acceptance criteria.

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1. RESULTS OF THE RESNET VERIFICATION TEST SUITE

The RESNET software verification test suite includes the following six test suites. The specifications and acceptance criteria of each test suite and the test results of IC3 are presented in Section 1.1 through 1.6.

1) **ANSI/ASHRAE Standard 140-2017, Class II, Tier 1 Tests:** This test procedure has been adopted by RESNET and is a requirement for all software programs to be accredited.

2) **IECC Code Reference Home Auto-Generation Tests:** This test is used for verifying the ability of the software tool to automatically generate the HERS Reference Design Home given only the building information from the Proposed Homes.

3) **HERS Method Tests**: This test suite is used for verifying that software tools can accurately calculate the HERS Index that is used as the numerical indicator of relative performance for a home. The acceptance criteria for these tests were established using RESNET Standard ANSI/RESNET/ICC 301-2019 (RESNET, 2018), Addendum A (RESNET, 2021a), and Addendum B (RESNET, 2021b).

4) **HVAC Tests:** This test suite is used for verifying the accuracy and consistency of software tools predict to the performance of HVAC equipment, including furnaces, air conditioners, and air-source heat pumps.

5) **Duct Distribution System Efficiency Tests:** This test suite is used for verifying the accuracy of software tools that calculate the air distribution system losses, including the impact of duct insulation, duct air leakage, and duct location.

6) **Hot water System Performance Tests:** This test suite is used to determine the ability of the software to accurately predict domestic hot water system energy use, including: the domestic hot water usage rate (gallons per day) and the climate impacts (i.e., inlet water temperatures) of standard gas-fired domestic hot water systems.

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

The following test cases are included in Tier one of the HERS BESTEST (Judkoff and Nemark, 1995) procedure:

- **Case L100:** *The Base-Case Building*. This is a 1,539 sq.ft., single-story, wood-frame, fully-vented crawlspace home with 270 sq.ft. of single-glazed windows (distributed with 90 sq.ft. on the north and south faces and 45 sq.ft. on the east and west faces). The walls have R-11 cavity insulation and the ceiling and floor have R-19 insulation.

- **Case L110:** *High Infiltration (1.5 ACH)*. The same as Case L100 with the exception that the infiltration rate is increased from its base-case value of 0.67 Air Changes per Hour (ACH) to a value of 1.5 ACH.

- **Case L120:** *Well-Insulated Walls and Roof*. The same as Case L100 except that the wall cavity insulation is increased from R-11 to R-18 with R-7.2 continuous exterior insulation and the ceiling insulation is increased from R-19 to R-57.

- **Case L130:** *Double-Pane, Low-Emissivity (Low-E) Windows with Wood Frames*. The same as Case L100 except that the single-glazed windows are replaced with high-efficiency Low-E windows, which have an overall U-factor of 0.30 and an overall Solar Heat Gain Coefficient (SHGC) of 0.335.

- **Case L140:** *Zero Window Area*. The same as Case L100 except that the windows are replaced with wood frame walls having R-11 insulation.

- **Case L150:** *South-Oriented Windows*. The same as Case L100 except that the entire 270 sq.ft. of windows is moved to the south side of the home.

- **Case L155:** *South-Oriented Windows with Overhang*. The same as Case L150 except that a 2.5 ft. opaque, horizontal overhang has been included at the top of south exterior wall.

- **Case L160:** *East- and West-Oriented Windows*. The same as Case L100 except that all the windows are moved to the east and west sides of the building with 50% window-to-wall ratio (135 sq.ft.) on each side.

- **Case L170:** *No Internal Loads*. The same as Case L100 except that the internal gains are reduced from 68,261 Btu/day to zero.

- **Case L200:** *Energy Inefficient*. The same as Case L100 except for: i) Infiltration rate is increased from 0.67 ACH to 1.5 ACH, ii) Exterior wall cavity insulation is replaced by an air gap, iii) Crawlspace floor insulation is removed, and iv) Ceiling insulation is reduced from R-19 to R-11.

- **Case L202:** *Low Exterior Solar Absorptance*. The same as Case L200 except that the solar absorptance of the roof and walls is reduced from 0.6 to 0.2.

- **Case L302:** *Uninsulated Slab-on-Grade*. The same as Case L100 except that the floor is changed from a fully-vented crawlspace to an uninsulated, concrete slab-on-grade.

- **Case L304:** *Insulated Slab-on-Grade*. The same as Case L302 except that R-5.4 exterior foundation insulation is added around the slab perimeter.

- **Case L322:** *Uninsulated Conditioned Basement*. The same as Case L100 except that the floor system is changed from a fully-vented crawlspace to an uninsulated conditioned basement with 8′ 0″ of the uninsulated basement wall and an uninsulated main floor (basement ceiling).

- **Case L324:** *Insulated Conditioned Basement*. The same as Case L322 except that R-11 insulation is added to the inside of the basement walls.

Case L100 is the base case against which most other cases are compared to determine if the rating tool can accurately determine the energy differences due to changes in building configuration. With the exception of Cases L302, L304, L322, and L324, each of the above test cases was simulated using Colorado Springs, CO weather data to evaluate heating energy loads and in Las Vegas, NV weather conditions to evaluate the cooling loads. Table 1 shows the results of ASHRAE STANDARD 140 Tests and contains the results of 26 tests conducted with the IC3 software. The pale-yellow column in Table 1 represents IC3 simulation results. The pale-green column shows whether or not the IC3 results passed the tests.

Table 1: Results of ASHRAE STANDARD 140 Tests

ASHRAE Std. 140 results for: (for use with Pub 002-2020) **Software Name:** IC3 V4.5.6

User input data fields indicated by pale yellow

Test result fields indicated by pale green

Annual Heating Loads: Colorado Springs, CO

Heating	range max	range min	Result	pass/fail
L100AC	79.48	45.28	58.97	pass
L110AC	103.99	71.51	82.37	pass
L120AC	64.30	33.76	45.91	pass
L130AC	53.98	37.75	45.59	pass
L140AC	56.48	43.24	49.93	pass
L150AC	71.33	35.50	52.80	pass
L155AC	74.18	39.17	55.48	pass
L160AC	81.00	45.63	59.30	pass
L170AC	92.40	54.16	71.68	pass
L200AC	185.87	106.41	136.21	pass
L202AC	190.05	111.32	141.70	pass
L302XC	90.52	14.52	59.81	pass
L304XC	75.32	18.84	50.36	pass
L322XC	118.20	16.79	92.80	pass
L324XC	80.04	30.50	58.02	pass

Annual Heating Load deltas: Colorado Springs, CO

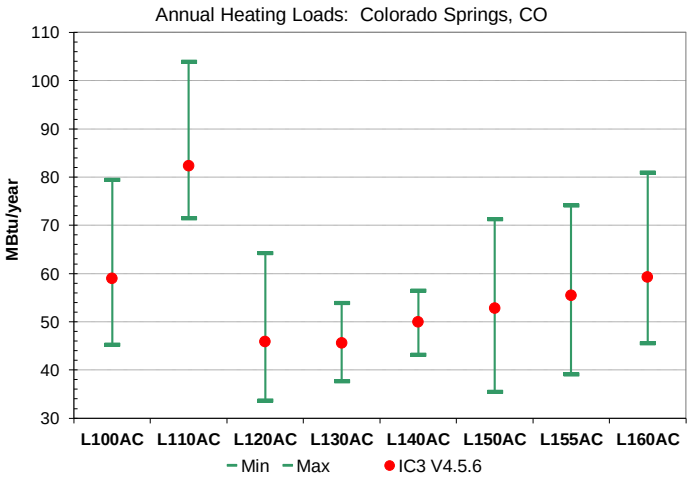
Heating	range max	range min	Result	pass/fail
L110AC-L100AC	28.12	18.66	23.40	pass
L120AC-L100AC	-7.67	-18.57	-13.06	pass
L130AC-L100AC	-5.68	-27.50	-13.38	pass
L140AC-L100AC	1.86	-24.42	-9.04	pass
L150AC-L100AC	-3.02	-12.53	-6.17	pass
L155AC-L150AC	6.88	-1.54	2.69	pass
L160AC-L100AC	5.10	-3.72	0.33	pass
L170AC-L100AC	17.64	7.12	12.72	pass
L200AC-L100AC	107.66	56.39	77.25	pass
L202AC-L200AC	11.10	-0.51	5.49	pass
L302XC-L100AC	14.50	-31.96	0.84	pass
L302XC-L304XC	17.75	-4.60	9.44	pass
L322XC-L100AC	39.29	-31.30	33.83	pass
L322XC-L324XC	38.27	-14.25	34.78	pass

Annual Cooling Loads: Las Vegas, NV

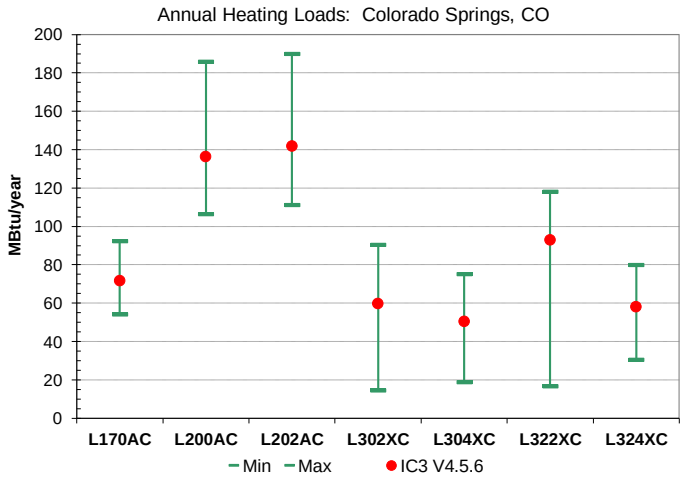
Cooling	range max	range min	Result	pass/fail
L100AL	64.88	39.53	63.63	pass
L110AL	68.50	43.86	66.75	pass
L120AL	60.14	38.08	58.78	pass
L130AL	45.26	29.19	43.31	pass
L140AL	30.54	19.44	28.27	pass
L150AL	82.33	48.53	79.86	pass
L155AL	63.06	33.19	61.53	pass
L160AL	72.99	49.62	72.27	pass
L170AL	53.31	32.00	52.05	pass
L200AL	83.43	52.49	73.45	pass
L202AL	75.96	44.99	63.53	pass

Annual Cooling Load deltas: Las Vegas, NV

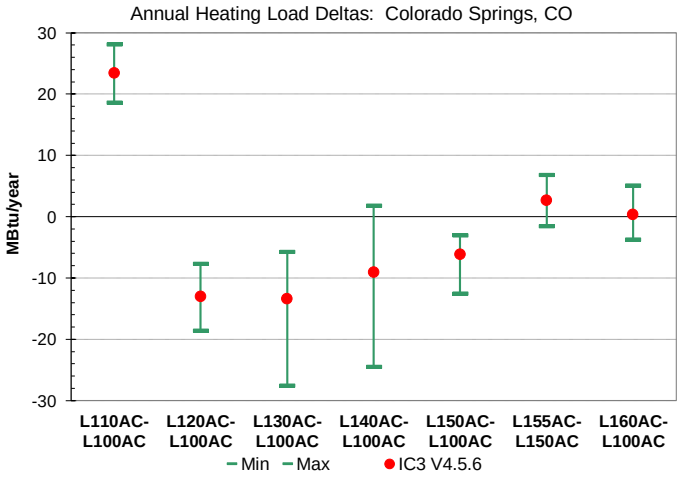
Cooling	range max	range min	Result	pass/fail
L110AL-L100AL	7.84	-0.98	3.12	pass
L120AL-L100AL	0.68	-8.67	-4.85	pass
L130AL-L100AL	-9.53	-24.40	-20.32	pass
L140AL-L100AL	-19.76	-38.68	-35.36	pass
L150AL-L100AL	20.55	8.72	16.23	pass
L155AL-L150AL	-9.64	-22.29	-18.33	pass
L160AL-L100AL	12.58	3.88	8.65	pass
L170AL-L100AL	-4.83	-15.74	-11.58	pass
L200AL-L100AL	21.39	6.63	9.82	pass
L200AL-L202AL	14.86	2.03	9.92	pass



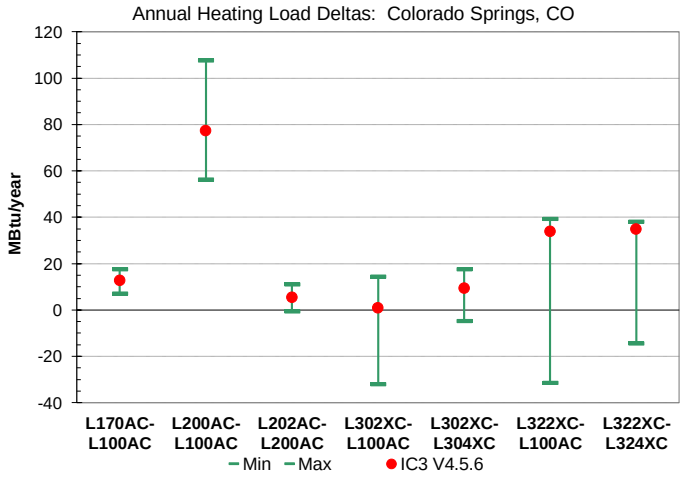
(a) Heating Load Results for Test Cases L100-L160



(b) Heating Load Results for Test Cases L170-L324

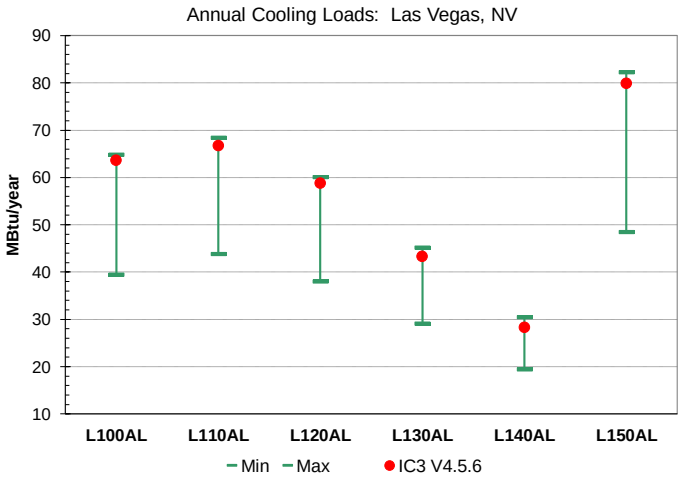


(c) Heating Load Differential Results for Test Cases L110 – L160

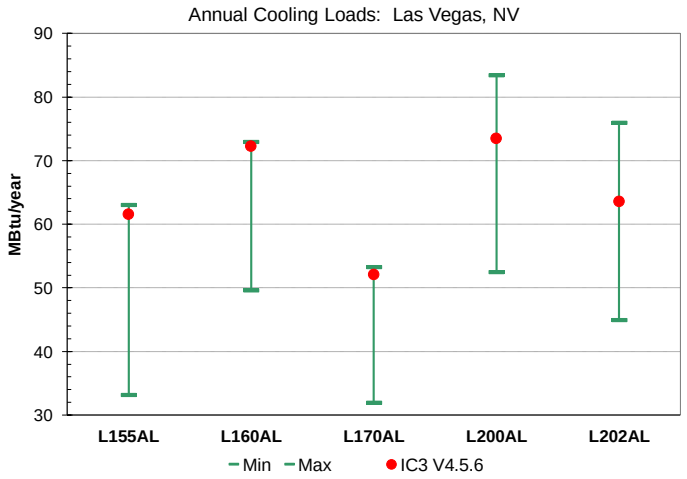


(d) Heating Load Differential Results for Test Cases L170 – L324

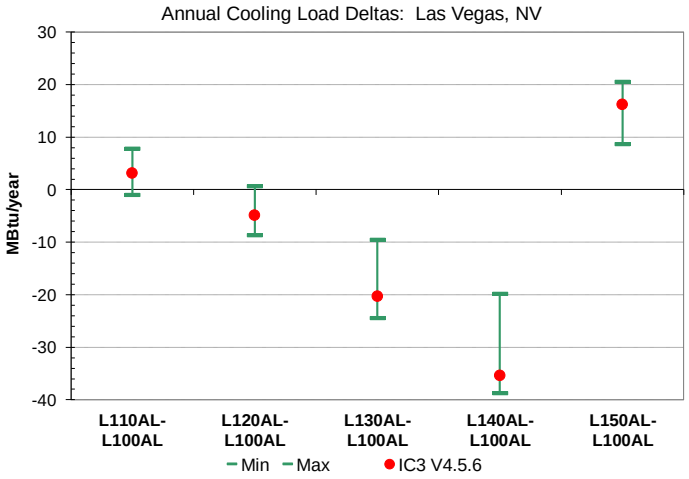
Figure 1: Heating Load and Heating Load Differential Results Using IC3 in Colorado Springs, CO



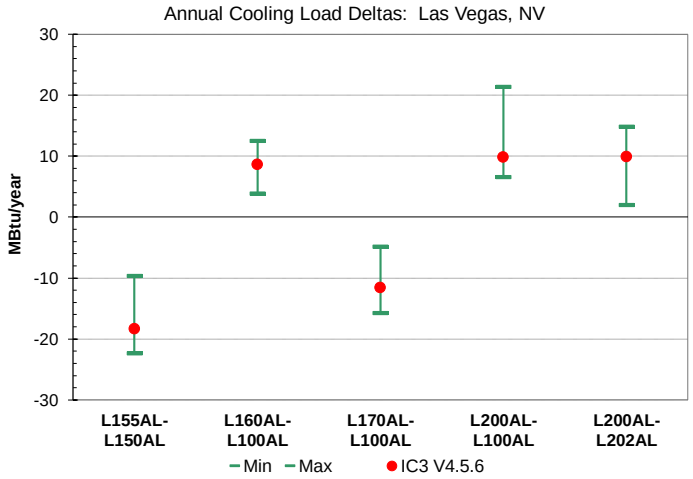
(a) Cooling Load Results for Test Cases L100-L150



(b) Cooling Load Results for Test Cases L155-L202



(c) Cooling Load Differential Results for Test Cases L110 – L150



(d) Cooling Load Differential Results for Test Cases L155 – L202

Figure 2: Cooling Load and Cooling Load Differential Results Using IC3 in Las Vegas, NV

1.2. 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.

The test suite for the auto-generation of the HERS are provided in Table 2. The tests include the following cases:

- **Test Case 1.** HERS BESTEST Case L100 with 3 bedrooms, located in Baltimore, MD. The house has a 3.0 ACH50, an 82% AFUE gas furnace and a SEER 11 central air conditioner, no whole-dwelling mechanical ventilation, and a gas range/oven and clothes dryer. All other appliances are electric.

- **Test Case 2.** HERS BESTEST Case L100 with 3 bedrooms, 3.0 ACH50, configured on an un-vented crawlspace with R-7 crawlspace wall insulation, located in Dallas, TX. This house has a 7.5 HSPF electric heat pump, a SEER 12 air conditioner, and an exhaust-only whole-dwelling mechanical ventilation. All appliances are electric.

- **Test Case 3.** HERS BESTEST Case L304 with 2 bedrooms located in Miami, FL, 5.0 ACH50, has electric strip heating (COP=1), a SEER 15 central air conditioner, and a balanced whole-dwelling mechanical ventilation without energy recovery. All appliances are electric.

- **Test Case 4.** HERS BESTEST Case L324 with 4 bedrooms, located in Colorado Springs, CO, 3.0 ACH50, and has a 95% AFUE gas furnace, no air conditioning, balanced whole-dwelling mechanical ventilation with a 60% heat recovery system, and a gas range/oven and clothes dryer. All other appliances are electric.

- **Test Case 5.** e-Ratio Tests. Recreate or store the Reference Homes (Reference Home A) created in Tests 1 through 4 as Rated Homes (Rated Home B), with the following modification: Rated Home B is identical to Reference Home A, except that it has a balanced mechanical ventilation system without heat recovery and a fan efficiency of 0.7 W/CFM. Note: Rated Home B still has the same mechanical ventilation flow rate as Reference Home A. These tests are specifically designed to yield an e-Ratio of 1.0.

The minimum acceptance criteria for the software include:

1) The ability to recreate or store the test case Standard Reference Designs as if they were Proposed Homes such that they also can be simulated and evaluated as the Proposed Homes;
2) The ability to report, at a minimum, the values for the Reference Home listed in the column 1 of Table 2; and
3) The energy use e-Ratio, calculated separately from the simulation results for heating and cooling is ± 0.5%, where:

$$e - Ratio = \frac{Total\ Normalized\ Modified}{Total\ Reference\ Load}$$

Table 2 lists the acceptance criteria and the results using IC3 for HERS. The pale-yellow columns in Table 2 show the IC3 reference results, which satisfies all the criteria for these test suites.

Table 2: Acceptance Criteria for Reference Home Auto-Generation Test Cases 1-4 and Corresponding Results from IC3

HERS 2019A Auto Generation Test Results: **Software Name:** IC3 V4.5.6
(last revised: 06/13/2020)

User input data fields indicated by pale yellow

		CZ4		CZ3		CZ1		CZ5
Reference Home Building Component	**Test 1**	**Results**	**Test 2**	**Results**	**Test 3**	**Results**	**Test 4**	**Results**
Above-grade walls (U_o)	0.082	0.082	0.082	0.082	0.082	0.082	0.06	0.06
Above-grade wall solar absorptance (α)	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Above-grade wall infrared emittance (ε)	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Basement walls (U_o)	n/a	n/a	n/a	n/a	n/a	n/a	0.059	0.059
Above-grade floors (U_o)	0.047	0.047	0.047	0.047	n/a	n/a	n/a	N/A
Slab insulation R-Value	n/a	n/a	n/a	n/a	0	0	0	0
Ceilings (U_o)	0.03	0.03	0.035	0.035	0.035	0.035	0.03	0.03
Roof solar absorptance (α)	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Roof infrared emittance (ε)	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Attic vent area* (ft^2)	5.13	5.13	5.13	5.13	5.13	5.13	5.13	5.13
Crawlspace vent area* (ft^2)	n/a	n/a	10.26	10.26	n/a	n/a	n/a	N/A
Exposed masonry floor area * (ft^2)	n/a	n/a	n/a	n/a	307.8	307.8	307.8	307.8
Carpet & pad R-Value	n/a	n/a	n/a	n/a	2	2	2	2
Door Area (ft^2)	40	40.02	40	40	40	40	40	40
Door U-Factor	0.4	0.4	0.65	0.65	1.2	1.2	0.35	0.35
North window area* (ft^2)	69.26	69.26	69.26	69.26	69.26	69.26	102.63	102.63
South window area* (ft^2)	69.26	69.26	69.26	69.26	69.26	69.26	102.63	102.63
East window area* (ft^2)	69.26	69.26	69.26	69.26	69.26	69.26	102.63	102.63
West window area* (ft^2)	69.26	69.26	69.26	69.26	69.26	69.26	102.63	102.63
Window U-Factor	0.4	0.4	0.65	0.65	1.2	1.2	0.35	0.35
Window $SHGC_o$ (heating)	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Window $SHGC_o$ (cooling)	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
SLA_o* (ft^2/ft^2)	0.00036	0.00036	0.00036	0.00036	0.00036	0.00036	0.00036	0.00036
Sensible Internal gains* (Btu/day)	55,115	55,109	52,470	52,465	47,839	47,835	82,691	82,682
Latent Internal gains* (Btu/day)	13,666	13,658	12,568	12,562	9,152	9,147	17,769	17,756
Labeled heating system rating and efficiency	AFUE = 78%	78%	HSPF = 7.7	7.7	HSPF = 7.7	7.7	AFUE = 78%	0.78
Labeled cooling system rating and efficiency	SEER = 13	13	SEER = 13	13	SEER = 13	13	SEER = 13	13
Air Distribution System Efficiency	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Thermostat Type	Manual	Manual	Manual	Manual	Manual	Manual	Manual	Manual
Heating thermostat settings	68 F (all hours)	68 F	68 F (all hours)	68 F	68 F (all hours)	68	68 F (all hours)	68 F
Cooling thermostat settings	78 F (all hours)	78 F	78 F (all hours)	78 F	78 F (all hours)	78	78 F (all hours)	78 F
Mechanical ventilation (kWh/y) (±0.1%)	0	0	222.1	222.1	288.1	288	763.4	763.3
DHW pipe length refPipeL (±0.1 ft)	88.5	88.5	88.5	88.5	88.5	88.5	98.5	98.5
DHW loop length refLoopL (±0.1 ft)	156.9	157	156.9	157	156.9	157	176.9	177
e-Ratio		0.998		0.999		0.999		1.000

1.3. 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) and the applicable manufacturers equipment performance ratings (MEPR). All are calculated according to the requirements in ANSI/RESNET 301-2019 (RESNET 2018), including Addendum A (RESNET 2021a), and Addendum B (RESNET 2021b).

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

- **Test Case 1** Case L100A-01: Using the HERS BESTEST 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.

- **Test Case 2** Case L100A-02: Identical to Case L100A-01 except for the following:
  i. Hot water heater is changed to a tankless natural gas heater with EF = 0.82.
  ii. Range/oven and clothes dryer are changed to standard natural gas.

- **Test Case 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.

- **Test Case 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.

- **Test Case 5** 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.

The minimum acceptance criteria for the software include:
That the difference between the HERS Indices calculated by the IC3 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.

Table 3 shows the results of IC3 (pale-yellow color), which include the HERS index results, reference home end use loads (REUL), reference home end use energy consumption (EC_r), rated home end use energy consumption (EC_x), and IAD_{save}. The pale-green column in Table 3 shows that the IC3 passed the HERS Method Tests.

Table 3: Results of HERS Method Tests

HERS 2019A Method Tests **Software Name:** **IC3 V4.5.6**

User input data fields indicated by pale yellow
Test result fields indicated by pale green

Test Case	HERS Index	Reference Home End Use Loads (REUL)			Reference Home End Use Energy Consumption (EC_r)			Rated Home End Use Energy Consumption (EC_x)				IAD_{SAVE} (%)	HERS Index Tests	Manufacturer's Equipment Performance Rating (MEPR)					
														Heating		Cooling		Hot Water	
		Winter (MBtu)	Summer (MBtu)	Hot Water (MBtu)	Heating (MBtu)	Cooling (MBtu)	Hot Water (MBtu)	Heating (MBtu)	Cooling (MBtu)	Hot Water (MBtu)	L&A (MBtu)			Fuel	MEPR	Fuel	MEPR	Fuel	MEPR
L100A-01	130.47	23.98	10.91	10.75	16.68	2.39	11.84	27.76	3.57	12.40	16.76	-11.07%	PASS	elec	6.80	elec	10.00	elec	0.88
L100A-02	123.31	23.13	10.85	10.75	16.14	2.26	18.60	27.21	3.55	14.31	18.96	-11.66%	PASS	elec	6.80	elec	10.00	gas	0.82
L100A-03	128.74	23.95	10.30	8.59	40.74	2.25	9.71	65.35	3.43	10.28	17.94	-11.80%	PASS	gas	78%	elec	10.00	elec	0.88
L100A-04	121.87	22.71	11.15	12.85	15.94	2.37	13.93	21.73	3.66	14.48	17.85	-16.12%	PASS	elec	9.85	elec	10.00	elec	0.88
L100A-05	119.95	23.13	10.85	10.75	39.39	2.26	11.85	55.30	3.85	12.40	18.67	-16.53%	PASS	gas	96%	elec	10.00	elec	0.88

1.4. HVAC Tests

The HVAC test suite includes two sets of test cases: 1) Test Suite 1: for air-conditioning systems, using Las Vegas, NV as the building location, and 2) Test Suite 2: for heating systems, using Colorado Springs, CO as the building location. Table 4 lists the test specifications for all test cases. All tests are to be performed using the HERS BESTEST Case L100, and assume zero duct leakage. All ducts and air handlers are in conditioned space. For these tests, the tool must be capable of generating HVAC results using, at a minimum, system type and efficiency as inputs.

The pale-yellow column in Table 5 listed the results from IC3, and the pale-green column indicates that all the IC3 results passed the HERS HVAC Tests. Figure 3 shows the acceptable ranges of percent change for heating/cooling energy use and IC3 results. All IC3 results fall within the acceptable limits.

Table 4: HVAC Test Specifications

Test #	System Type	Capacity	Efficiency
Test Suite 1 – Air conditioning Systems (Location: Las Vegas, NV)			
HVAC1a (Base case)	Air cooled air conditioner	38.3 kBtu/h	SEER = 10
HVAC1b			SEER = 13
Test Suite 2 – Heating Systems (Location: Colorado Springs, CO)			
HVAC2a (Base case)	Gas Furnace	56.1 kBtu/h	AFUE = 78%
HVAC2b			AFUE = 90%
HVAC2c (Base case)	Air Source Heat Pump		HSPF = 6.8
HVAC2d			HSPF = 9.85
HVAC2e	Electric Furnace		COP = 1

Table 5: Results of HVAC Tests

RESNET HVAC Test Suite Results: **Software Name:** IC3 V4.5.6

User input data fields indicated by pale yellow
Test result fields indicated by pale green

Results

Cooling tests:

Case	Cool	Cool Fan	Cool Tot	% change	Criteria min	Criteria max	
HVAC-1a	7672	1704.963	9376.963	---			
HVAC-1b	5684	1704.963	7388.963	-21.20%	-21.24%	-17.38%	pass

Heating tests:

Case	Heat	Heat Fan	Heat Tot	% change			
HVAC-2a	908	1098.931	94.55	---			
HVAC-2b	786	1098.931	82.35	-12.90%	-13.30%	-11.57%	pass

Case	Heat	Heat Fan	Heat Tot	% change			
HVAC-2c	11048	1299.671	12347.67	---			
HVAC-2d	8616	993	9609	-22.18%	-29.03%	-16.73%	pass
HVAC-2e	21032	1098.965	22130.97	79.23%	41.81%	80.81%	pass

Plot Data:

	HVAC-1b	HVAC-2b	HVAC-2d
min	-21.24%	-13.30%	-29.03%
max	-17.38%	-11.57%	-16.73%
avg	-19.31%	-12.43%	-22.88%
Result	-21.20%	-12.90%	-22.18%

	HVAC-2e
min	41.81%
max	80.81%
avg	61.31%
Result	79.23%

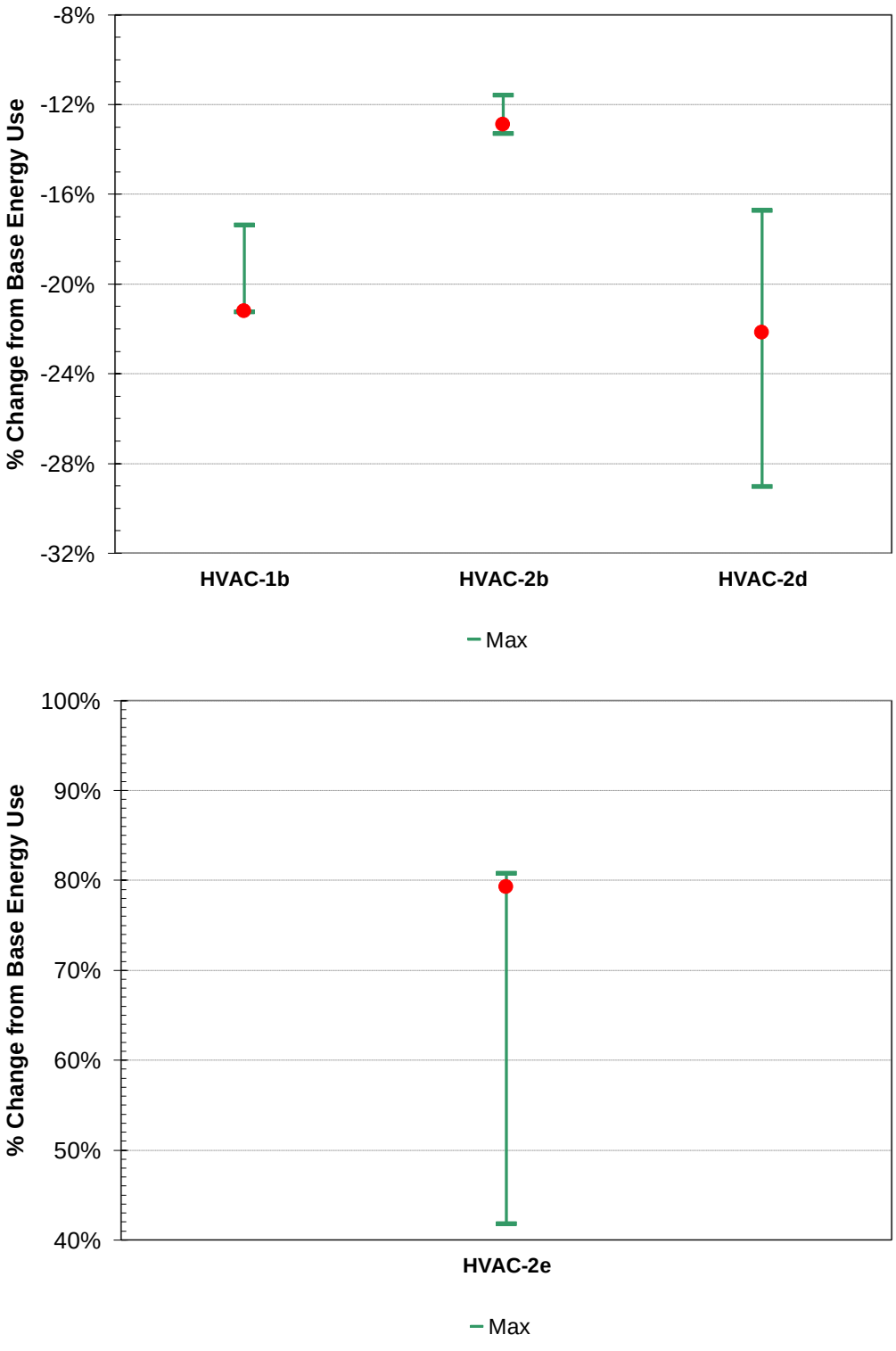


Figure 3: Percent Heating/Cooling Energy Use Change Using IC3 for HVAC Test Cases

1.5. Duct Distribution System Efficiency (DSE) Tests

The Duct Distribution System Efficiency (DSE) test suite includes two sets of test cases: 1) Heating Comparison Test Cases: these test cases use the HERS BESTEST Case L322 configured with an unconditioned basement with R-11 insulation and a 13% framing fraction in the floor joists of the main floor, and no basement wall insulation; and 2) Cooling Comparison Test Cases: these test cases use the HERS BESTEST Case L100.

Table 6 lists the test case-specific input parameters, which include system capacity, duct location, duct leakage, and duct R-value. All tests assume a 78% AFUE natural gas forced-air furnace and a SEER 10 forced-air cooling system. The system capacities are modified as shown in Table 6. The coil air flow is altered accordingly using a value of 360 CFM/ton of capacity. For all tests, the supply duct area is 20% of the conditioned floor area and the return duct area is 5% of the conditioned floor area. The duct leakage is modeled as specified in Table 6, with the supply and return leakage fractions set at 50%. To consider the air-film-resistance in the supply and return ducts, values of thermal resistance of R-1.5 and R-7 were used for uninsulated (R=0) and insulated (R=6) ducts, respectively.

The pale-yellow column in Table 7 shows the IC3 results of the Duct Distribution System Efficiency Tests, and the pale-green column indicate that the IC3 results passed the HERS DSE tests. Figure 4 shows the bounds criteria for these tests and the test results using IC3. The results show that IC3 results are within the acceptable ranges for all test cases.

Table 6: DSE Test Specifications

Test #	System Capacity	Duct Location	Duct Leakage	Duct R-value
Heating Comparison Test Cases (Location: Colorado Springs, CO)				
HVAC3a (Base case)	46.6 kBtu/h	100% conditioned	None	R-0
HVAC3b	56.0 kBtu/h	100% in basement	None	R-0
HVAC3c	49.0 kBtu/h	100% in basement	None	R-6
HVAC3d	61.0 kBtu/h	100% in basement	250 cfm_{25}	R-6
Cooling Comparison Test Cases (Location: Las Vegas, NV)				
HVAC3e (Base case)	-38.4 kBtu/h	100% conditioned	None	R-0
HVAC3f	-49.9 kBtu/h	100% in attic	None	R-0
HVAC3g	-42.2 kBtu/h	100% in attic	None	R-6
HVAC3h	-55.0 kBtu/h	100% in attic	250 cfm_{25}	R-6

Table 7: Results of Duct Distribution System Efficiency Tests

DSE Test Suite Results **Software Name:** IC3 V4.5.6

User input data fields indicated by pale yellow
Test result fields indicated by pale green

Results:

Base Cases	Heat/cool	Fan	Total	% change	
HVAC-3a	654	794.553	68.11	---	base for cases 3b - 3d
HVAC-3e	5978	1349.028	7327.028	---	base for cases 3f - 3h

					Criteria:			
Test Cases	Heat/cool	Fan	Total	% change	max	avg	min	Pass/Fail
HVAC-3b	831	1007.92	86.54	27.1%	31.4%	26.4%	21.4%	pass
HVAC-3c	702	852.364	73.11	7.3%	12.5%	7.5%	2.5%	pass
HVAC-3d	768	934.339	79.99	17.4%	25.0%	20.0%	15.0%	pass
HVAC-3f	7680	1737.221	9417.221	28.5%	36.2%	31.2%	26.2%	pass
HVAC-3g	6468	1464.442	7932.442	8.3%	16.5%	11.5%	6.5%	pass
HVAC-3h	7411	1673.486	9084.486	24.0%	31.1%	26.1%	21.1%	pass

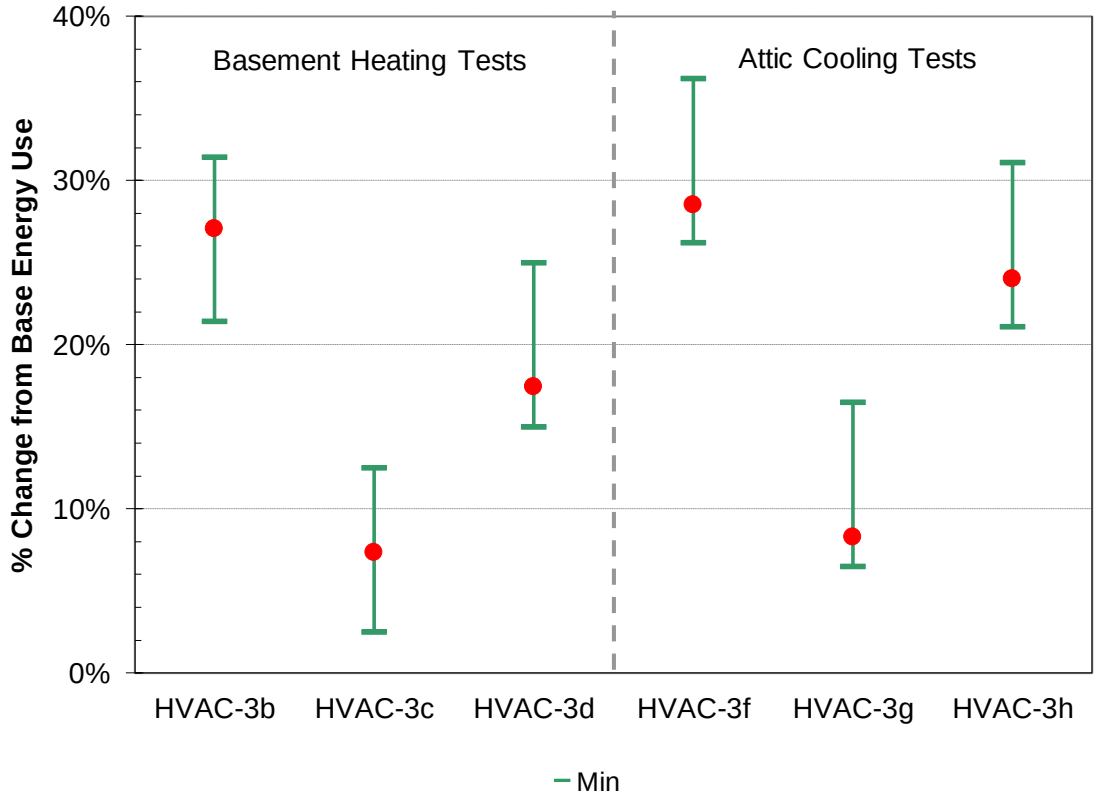


Figure 4: Percent Heating/Cooling Energy Use Change Using IC3 for DSE Test Cases

1.6. Hot Water System Performance Tests

The Hot Water System Performance test suite includes two sets of three tests for: a cold climate location, Duluth, MN and a hot climate location, Miami, FL.

The test homes are all based on the ASHRAE Standard 140 Case L100A building, as modified below. Internal gains, climate data, and other such assumptions specified in ANSI/RESNET 301-2019 (RESNET 2018) and Addendum A (RESNET 2021a) shall supersede any conflicting specifications from ASHRAE Standard 140.

DHW performance tests for the following cases listed below, located in Colorado Springs, CO:
Test 1: 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

Test 2: Case L100AD-HW-02 (distribution base case)

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

Test 3: Case L100AD-HW-03

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

Test 4: Case L100AD-HW-04

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

Test 5: Case L100AD-HW-05

- Same as Case L100AD-HW-02 except with recirculation listed below
  a. Control = none
  b. 50 W pump
  c. Loop length is same as reference loop length
  d. Branch length is 10 ft
  e. All hot water pipes insulated to R-3

Test 6: Case L100AD-HW-06

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

Test 7: Case L100AD-HW-07

- Same as Case L100AD-HW-02 except with Drain Water Heat Recovery
  a. DWHR efficiency = 54%
  b. All showers connected to DWHR unit
  c. DWHR preheats both hot and cold supplies for showers

Test 8 to test 14: Cases L100AM-HW-01 through L100AM-HW-07
Same as Cases L100AD-HW except climate location = Miami, FL (TMY3 site 722020, MIAMI INTL AP)

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:

*% Change = (base - alternative) / (base) * 100*

The IC3 DHW test results are shown in pale-yellow column in Table 8, which passed the requirement in HERS DHW tests. IC3 results are within acceptable limit for all cases.

Table 8: Results of Hot Water System Performance Tests

RESNET Pub 002-20 DHW Test Results:

Software Name:	IC3 V4.5.6

User input data fields indicated by pale yellow

Test result fields indicated by pale green

Test Case Results:

Minnesota	**DHW Energy** [therms]	**Recirc Pump** [kWh]
L100AD-HW-01	194.3	
L100AD-HW-02	258.8	
L100AD-HW-03	172.9	
L100AD-HW-04	250.5	
L100AD-HW-05	546.6	438
L100AD-HW-06	226.8	5
L100AD-HW-07	206.0	

Florida	**Energy** [therms]	**Pump** [kWh]
L100AM-HW-01	109.1	
L100AM-HW-02	135.0	
L100AM-HW-03	90.1	
L100AM-HW-04	131.8	
L100AM-HW-05	294.2	438
L100AM-HW-06	122.0	5
L100AM-HW-07	120.0	

Test Case Pass/Fail Criteria

Duluth MN Cases:	**MBtu/y**	**Range Min**	**Range Max**	**Pass/Fail**
L100AD-HW-01	19.43	19.34	19.88	pass
L100AD-HW-02	25.88	25.76	26.55	pass
L100AD-HW-03	17.29	17.27	17.65	pass
L100AD-HW-04	25.05	24.94	25.71	pass
L100AD-HW-05	56.16	55.93	57.58	pass
L100AD-HW-06	22.69	22.61	23.28	pass
L100AD-HW-07	20.60	20.51	21.09	pass
Miami FL Cases:	**MBtu/y**	**Range Min**	**Range Max**	**Pass/Fail**
L100AM-HW-01	10.91	10.87	11.12	pass
L100AM-HW-02	13.50	13.47	13.79	pass
L100AM-HW-03	9.01	8.94	9.20	pass
L100AM-HW-04	13.18	13.15	13.46	pass
L100AM-HW-05	30.91	30.84	31.55	pass
L100AM-HW-06	12.22	12.19	12.48	pass
L100AM-HW-07	12.00	11.95	12.23	pass
MN Delta Cases:	**%Change**	**Range Min**	**Range Max**	**Pass/Fail**
MN (1-2 delta)	-33.19%	-33.92%	-32.59%	pass
MN (1-3 delta)	11.03%	10.60%	11.49%	pass
MN (2-4 delta)	3.19%	3.13%	3.22%	pass
MN (2-5 delta)	-117.02%	-118.39%	-115.70%	pass
MN (2-6 delta)	12.31%	12.08%	12.46%	pass
MN (2-7 delta)	20.38%	20.14%	20.78%	pass
FL Delta Cases:	**%Change**	**Range Min**	**Range Max**	**Pass/Fail**
FL (1-2 delta)	-23.78%	-24.44%	-23.47%	pass
FL (1-3 delta)	17.38%	16.99%	18.01%	pass
FL (2-4 delta)	2.33%	2.30%	2.37%	pass
FL (2-5 delta)	-129.03%	-130.29%	-127.53%	pass
FL (2-6 delta)	9.46%	9.30%	9.57%	pass
FL (2-7 delta)	11.13%	11.12%	11.39%	pass
MN-FL Delta Cases	**%Change**	**Range Min**	**Range Max**	**Pass/Fail**
MN-FL (01)	43.87%	43.21%	44.60%	pass
MN-FL (02)	47.84%	47.18%	48.56%	pass
MN-FL (03)	47.88%	47.28%	48.70%	pass
MN-FL (04)	47.38%	46.73%	48.12%	pass
MN-FL (05)	44.95%	44.35%	45.67%	pass
MN-FL (06)	46.14%	45.51%	46.85%	pass
MN-FL (07)	41.78%	41.23%	42.42%	pass

2. SUMMARY

The ESL's web-based software tool IC3 v 4.5.6 software has been tested using the RESNET verification procedures - RESNET Publication No. 002-2020 (RESNET, 2020). The RESNET accreditation procedure consists of a set of verification tests separate in six suites: 1) ANSI/ASHRAE Standard 140-2017, Class II, Tier 1 Tests; 2) HERS Reference Home Auto-Generation Tests; 3) HERS Method Tests; 4) HVAC Tests; 5) Duct Distribution System Efficiency Tests; and 6) Hot water System Performance Tests.

To test the IC3 using the RESNET verification test suite, the software includes a password protected section that allows to replicate all of the RESNET required the test runs. The section is managed as a small database that includes all the test cases required for the RESNET verification, each case can be loaded and run it to the user wish. All the RESNET verification test cases in the IC3 section were divided into six categories corresponding to the six suites of the verification procedures.

The RESNET verification procedures were tested on IC3 simulation program and the results showed that it complies with all and each one of the six RESNET suite tests used for accreditation purposes, including the estimation of the RESNET HERS acceptance criteria for all test suites.

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