GOING BEYOND A RESNET CERTIFICATION FOR CODE-COMPLIANT SIMULATIONS: A SENSITIVITY ANALYSIS OF DETAILED RESULTS OF THREE RESNET-CERTIFIED, CODE-COMPLIANT RESIDENTIAL SIMULATION PROGRAMS

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ABSTRACT

In many states building code officials rely on certified, code-compliant simulations to determine whether or not a residence satisfies the energy code requirements using a performance-path analysis. In the United States, certification of residential code-complaint software is performed by the Residential Energy Services Network (RESNET). Unfortunately, significant differences in results can exist when one compares the ratings from one certified software program to the next. This paper continues the exploration of some of these differences presented in a previously published paper for an analysis of a code-complaint residence in Texas and presents a sensitivity study using several of these RESNET-certified software in two locations in Texas.

INTRODUCTION

In many states building code officials rely on certified, code-compliant simulations to determine whether or not a residence satisfies the energy code requirements using the performance-path of the International Energy Conservation Code (IECC) (IECC 2000, 2001). A performance path analysis requires a building energy simulation to determine whether or not the total annual energy use of a proposed design consumes less energy than a code-compliant reference house. In order to ensure the accuracy and comparability of IECC performance path calculation tools, the RESNET Software Verification Committee has defined a suite of software tests for use in verifying IECC performance compliance software tool accuracy and comparability (Residential Energy Services Network, Inc., 2007). The RESNET Board of Directors has adopted this test suite as the verification tests that shall be used by RESNET to accredit computerized IECC performance compliance tools. The RESNET software verification test suite includes the following tests:

1) **Tier one of the HERS BESTEST:** for testing the building load prediction accuracy of simulation software. The acceptance criteria are based on reference results from three programs: BLAST 3.0, Level 215, DOE2.1e-W54 and SERIRES/SUNREL 5.7.
2) **IECC Code Reference Home auto-generation tests:** for verifying the ability of the software tool to automatically generate the IECC Standard Reference Design Home given only the building information from the proposed home.
3) **HVAC tests:** for verifying the accuracy and consistency with which software tools predict the performance of HVAC equipment, including furnaces, air conditioners, and air source heat pumps. The acceptance criteria are based on reference results from six tools: two DOE-2.1e based programs, two DOE-2.2 based programs, MICROPAS version 6.5 and TRNSYS version 15.
4) **Duct distribution system efficiency tests:** for verifying the accuracy with which software tools calculate air distribution system losses, including the impact of duct insulation, duct air leakage and duct location. The acceptance criteria for these tests were established using ASHRAE Standard 152-2004.
5) **Domestic hot water system performance tests:** for determining 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 (inlet water temperatures) of standard gas-fired domestic hot water systems. The acceptance criteria are based on reference results from three software programs: TRNSYS version 15, DOE-2.1e (v.120) as used by EnergyGauge USA version 2.5, and REM/Rate version 12.

The results of three programs are currently posted on RESNET's National Registry of Accredited IECC Performance Verification Software Tools[1], including Energy Gauge® USA version 2.8, the International Code Compliance Calculator (IC3) version 3.3[2], and REM/Rate REM/Design version 12.7.

IC3, developed by the Energy Systems Laboratory (ESL) of the Texas A&M University System, is a web-based, code-compliance software that calculates the performance of a proposed single family residences according to the Texas Building Energy Performance Standards (TBEPS). The IC3 software has also been approved by the U.S. Environmental Protection Agency (EPA) and Texas Commission on Environmental Quality (TCEQ) for determining above-code compliance for credits toward NOx emissions reductions. IC3 has successfully passed all the RESNET verification tests. Table 1 shows the description of Tier one of the HERS BESTEST (Judkoff and Neymark, 1995) and the IC3 BESTEST results. Complete results for the other four groups of tests can be found in the published report by the ESL (Malhotra, M. et al. 2009).

EnergyGauge® was developed by the Florida Solar Energy Center (FSEC). This software allows a performance-based analysis and includes an economic analysis of proposed energy improvements (EnergyGauge USA, 2010). REM/Rate™ is another residential energy analysis, code compliance and HERs rating software developed by the Architectural Energy Corporation (AEC) specifically for the needs of Home Energy Raters (HERS) providers (REM/Rate, 2009).

Although all three programs have been certified by RESNET, significant differences in results still remain when one compares the ratings from one software to the next. Unfortunately, this can cause confusion and frustration with code officials and homeowners when even small differences can make the difference between a house passing code or not. This paper compares these three software tools using the same proposed house in two locations in Texas using the 2000 IECC[3] as the energy code for the performance approach. Differences in the code-compliance results using the 2000 IECC for all three programs, as well as a sensitivity study on the important parameters are presented and analyzed to identify possible reasons for the differences.

DESCRIPTION OF THE PROPOSED HOUSE AND STANDARD REFERENCE HOUSE

The proposed house used in this analysis is a 2,500 sq. ft., square-shaped, single-story, single-family, detached house facing north, south (front door), east, and west, with a floor-to-ceiling height of 8 feet. The house has a vented attic with a gabled roof pitched at 23 degrees facing the front of the house, which contains the HVAC system and ductwork. The wall construction is a light-weight wood frame with 2x4" studs at 16" on center with a slab-on-grade-floor, which is consistent with an average household determined from builder's surveys by the Texas National Association of Home Builders.

The ceiling insulation is R-30 and wall insulation is R-13. The building has an exterior wall absorptance of 0.55 and roof absorptance of 0.75. The total window area is 12.8% of the total conditioned floor area, equally distributed on all four sides of the house. The windows have no exterior shading, a U-value of 0.47 Btu/hr-sq.ft.°F and solar heat gain coefficient (SHGC) of 0.4. The space temperature set points are 68°F for heating, 78°F for cooling, with a six hour, 5°F set-back/ set-up for winter and summer, respectively. The total internal heat gain is assumed to be fixed at a constant 0.88 kW (3,000 Btu/hr), as required by the 2000 IECC. No occupants are assumed in the simulated house. The air exchange rate of this proposed house is set to a specific leakage area of 0.00057, which was obtained by converting the normalized leakage of 0.57 as proposed in Section 402.1.3.10 of the 2000 IECC[4]. The heating and cooling system efficiency is set to the minimum 2006 Federal standards, which are SEER 13 for the

[1] Website for National Registry of Accredited IECC Performance Verification Software Tools http://www.natresnet.org/programs/iecc_software/directory.aspx, Date visited: 02/20/2010.

[2] The IC3 ver. 4.01.05 was used for the analysis in this paper.

[3] In the analysis, 2000 IECC was used in the standard reference house simulations for the three programs. In the 2000 IECC there is no specific mandatory requirement for duct insulation in Chapter 4 of the 2000 IECC. Therefore, a supply duct insulation of R8 and return duct insulation of R4 were used in the standard reference house simulation as required by the 2001 Supplement in IC3. Software-1 has a choice of either the 2000 IECC and 2001 IECC. However, the simulation results on Software-1 standard reference house were exactly the same when using these two codes. In Software-2, R6 was used for both supply and return duct insulation in the standard reference house.

[4] Specific leakage area (SLA) = L/CFA, where CFA is the conditioned floor area in ft^2 and Leakage Area (L) is defined in accordance with Section 5.1 of ASHRAE 119-1988 (RA 2004) as the leakage area of the space (ft^2) and can be calculated using the following equation: Ln=1000*(L/A)*(H/H0)^0.3, where, Ln = normalized leakage (0.57), H0 = height of a single story (8ft), H = height of the building (ft), A = floor area of the space (ft^2).

air conditioner and an AFUE of 0.78 for the gas furnace. An energy factor of 0.544 was used for the domestic water heater (40 gallon). The size of the DHW was determined by the number of bedrooms and bathrooms based on the information from ASHRAE Applications Handbook[5].

Table 2 provides a detailed listing of the IC3 inputs for the proposed house (located in Houston) and comparable inputs for Software-2 and Software-1. Where one software did not have the same option as the others, the closest values in these programs were used. During this analysis, it was possible to set most of the IC3 parameters to be the same as the inputs required for Software-2 because it provides a detailed summary of all the input parameters used in the simulation. Unfortunately, this was not as straight forward an exercise with Software-1. For example, in this analysis the wall solar absorptance was set to 0.55 in both IC3 and Software-2, but this input is not directly available in Software-1. Instead, the color of the exterior wall is required. Therefore, in this analysis, a “Medium color” was chosen as an alternative to match the input in the other programs.

Several input parameters for the proposed house were found to be different for all three programs, including the number of bedrooms, the Heating Degree Days (HDD), and ceiling and the wall insulation equivalent U-values. For the IC3 and Software-1, the proposed house has four bedrooms while there are no bedrooms in the proposed house in Software-2. The proposed house used in the IC3 analysis assumes no people in the house, which is required in Section 402.1.3.6 of the 2000 IECC. Since Software-2 assumes that the number of bedrooms is equal to the number of people in the house, the field for the input of the total number of bedrooms in Software-2 was entered as zero to match the internal gain settings between the three programs for the proposed house.

The corresponding settings generated by the three software programs for the standard reference house are shown in the Table 2. In this table, the RED font is used to indicate the standard reference house settings which are different from the proposed house. In order to produce an “above code” condition, the window area in the proposed and standard reference house was different. In this analysis the standard reference house has a window area equal to 18% of the conditioned floor area. In Table 2 the standard reference house summary information is not shown for Software-1 because no parameters for Software-1 are available. In Table 2, it can be seen that the different programs simulate the standard reference house differently in several of the important features of the house, including the shape of the house, the framing factor, the window frame, the HVAC system size, the ducts, the internal gains, etc. Unfortunately, these differences lead to large variation in the results of the code- compliance analysis. For example, IC3 contains a duct model, which is based on ASHRAE Standard 152-2004 (Kim, 2006). In IC3, the duct leakage, duct insulation, duct location, etc. are used to calculate the duct distribution efficiency for the HVAC system for both the standard reference house and the proposed house. Software-2 also simulated the ducts in the attic using its own duct model in the proposed house. In contrast, for the standard reference house, a fixed duct distribution efficiency of 0.80 was used and the ducts were assumed to be located in the interior. In addition, in the proposed house Software-2 assumed to have a constant 0.88 kW internal gain, while the reference house had a variable internal gain schedule. In IC3, a constant internal gain schedule of 0.88 kW was applied to both the proposed house and reference house. Other less significant differences in the inputs can be found in Table 2.

[5] This includes information from the 2003 ASHRAE Applications Handbook, p.49.9. Supplemented by Hendron, R., 2008, Building America Research Benchmark Definition, Updated December 19, 2008.

COMPARISON OF SIMULATION RESULTS

Based on the values listed in Table 2, two locations were simulated in this analysis, Houston and Dallas. All simulations used the TMY2 hourly weather data. Figure 1 and Table 3 shows the total energy use and a breakdown of the end use for the proposed house and 2000 IECC standard reference house, as well as the results displayed as the percentage above code from the three programs.

Code Compliance Results for the Proposed House in Houston:

For the proposed house in Houston, IC3 calculated the total annual site energy use to be 74.5 MMBtu, which is almost exactly the same as the Software-2 result of 74.6 MMBtur. The result from Software-1 was 84.3 MMBtu/yr, which is 13% higher than the total annual energy use of IC3 and Software-2. A breakdown of the different end uses shows that IC3 had a very good agreement with Software-2 for the cooling, heating, DHW, and lighting/appliance, while Software-1 shows good agreement only on cooling and DHW, but large differences on heating and lighting/appliance when compared to IC3 and Software-2.

Finally large differences were found in the standard reference house simulation results from the three performance calculators. The IC3 calculated total annual energy use was 77.7 MMBtu, which is similar to the Software-2 total of 71.7 MMBtu (i.e., a difference of 8%). The result from Software-1 was 90.9 MMBtu/yr, which is 17% higher than IC3 and 27% higher than Software-2.

Upon further investigation, the unexpected low energy use of the standard reference house using Software-2 was due to an adjustment in the bedroom input. As previously described, in order to match the internal gain settings among the three calculators for the proposed house, the number of bedrooms in Software-2 was forced to be zero, which did not impact the proposed house simulation, but apparently led to other changes in the calculations to determine other parameters in the standard reference house simulation. For example, the daily hot water usage in the standard reference house in Software-2 was calculated to be 30 gallon per day, which is much less than that of the proposed house and the standard reference house in IC3 and Software-1 (i.e., 70 gallon/day). In Table 3, after adjusting the DHW energy use back to the 70 gallon/day level, that is, 18 MMBtu/yr, the total energy use of the standard reference house increases to 80.2 MMBtu/yr. However, since the DHW heaters may or may not be thermally connected to the conditioned space, the implications on the cooling and heating energy use from this adjustment was not resolved. Therefore, a more detailed understanding of the Software-2 simulation programs is needed to accomplish the comparison with IC3 or Software-1 on the standard reference house.

It is important to note although big difference existed in the energy use of the proposed house and standard reference between Software-1 and Software-2, quite surprisingly the two programs showed very close code-compliance results. The above-code analysis shows the proposed house exceeds the 2000 IECC by 7.3% in Software-1. After adjusting only the DHW energy use in Software-2, the results showed that the proposed house passes the 2000 IECC by 7.0%. In IC3, the proposed house exceeds the 2000 IECC by 4.0%.

Code Compliance Results for the Proposed House in Dallas:

For the next analysis the same proposed house was then entered in the three software programs using Dallas, Texas as the building location. Similar to the house located to Houston, IC3 (86.8 MMBtu/yr) and Software-2 (87.3 MMBtu/yr) had very good agreement in simulating the energy use of the proposed house. Software-1 (100.6 MMBtu/yr) showed a significant difference in the total energy use for the proposed house, about 13 MMBtu/yr or 15% more than IC3 and Software-2. This is mainly due to the larger heating energy use, which was about 40% to 45% higher than that of IC3 and Software-2, respectively.

When comparing the code-compliance results for Dallas, the proposed house passes the 2000 IECC by 1% in IC3 and 6.6% in Software-1. In IC3, the heating energy in the standard reference house is 24.5 MMBtu/yr, which is 1.7 MMBtu less than the proposed house (26.2 MMBtu/yr) due to 130 sq. ft. more window area and the winter-time passive solar impact. However, in Software-1, the heating energy in the standard reference house increased to 42.2 MMBtu/yr, which is 3.7 MMBtu/yr more than the proposed house (38.5 MMBtu/yr). This contributed to the differences in code-compliance values in IC3 (1%) and Software-1 (6.6%). In Software-2 simulation, the hot water usage for the standard reference house was also adjusted for Dallas. The proposed house exceeds the 2000 IECC by 4%, which is between the Software-1 and IC3 simulation results.

SENSITIVITY ANALYSIS

In order to better understand these three code compliance tools and identify possible reasons for the differences shown in the previous sections, a comparative analysis was performed for the three tools by varying several significant parameters, including different sizes of the house, window-to-wall ratio (WWR), wall insulation level, ceiling insulation level, window SHGC, and window U-value, infiltration, SEER for the air conditioner, AFUE for the gas furnace, and energy factor (EF) for the domestic hot water system. All three programs used the same proposed house described in the previous sections in two locations, Houston and Dallas. Figure 2 shows the parameters that were changed in each sensitivity test and the results for the three programs. The results show that IC3 and Software -2 show a very close trend of sensitivity on energy use when changing the sizes of the house, wall insulation, ceiling insulation, window U-value, air conditioner efficiency, NG heating system efficiency, and energy factor of domestic hot water system. In all these areas, except for the wall insulation, Software-1 presents a significant difference in sensitivity when compared to IC3 and Software-2.

For the window SHGC test, the results show that in Houston, the IC3 simulation for the proposed house shows different sensitivity trends than Software -1 and Software-2 when the window SHGC value changes. This is because IC3 model is slightly more sensitive to the cooling energy use associated with varying SHGC values. For the same proposed house in Dallas, IC3 shows a sensitivity closer to Software-2 on varying SHGC values than Software-1, which is the least sensitive on the window SHGC.

In regards to the air leakage of the house, the IC3 simulates the house using Sherman-Grimsrud model (Sherman and Grimsrud 1980) on the infiltration and it presents the highest sensitivity on the Standard Leakage Area. In addition the heating energy use appears to be the most sensitive to the infiltration in IC3.

Another area the three programs do not agree on sensitivity is the window area. When the window-to-wall ratio (WWR) is larger than 20%, the three programs show significantly different changes on the total energy use with varying WWR for both Houston and Dallas. When the WWR is less than 20%, the IC3 sensitivity is closer to that of the Software-2 result.

SUMMARY

This paper provides a detailed comparison of three RESNET accredited IECC Performance Verification Software Tools. In this analysis, the same proposed house was entered into IC3, Software-2 and Software-1, for Houston and Dallas locations, respectively. Due to the different software inputs and output reports, selected input settings were adjusted in order to create a simple, comparative test suite.

The results show that significant differences can exist between these tools when testing the same proposed house. Although the proposed house simulation showed very close results for two of the program, it did not show consistent code-compliance ratings between the three programs, due to the difference in interpreting the 2000 IECC code, the auto-generation mechanism between the proposed house and standard reference house, and other unknown assumptions for the other software. In addition, a sensitivity analysis has been conducted on important parameters for each program to observe the performance of the three tools and to help identify possible reasons for these differences. In summary, IC3 and Software-2 show more similarity in responding to most of tested parameters.

REFERENCE

EnergyGauge USA: Code Compliance and Home Energy Rating Software, ver. 2.8.03, 2010. Florida Solar Energy Center.

IECC 2000. International Energy Conservation Code. International Code Congress, Falls Church, VA, Second printing, January 2001.

IECC 2001. 2001 Supplement to the International Codes. International Code Congress, Falls Church, VA, Second printing, March 2001.

IC3: International Code Compliance Calculator, ver.3.6.1, http://ic3.tamu.edu, Energy Systems Laboratory, Texas A&M University Systems.

Kim, S. 2006. An Analysis of International Energy Conservation Code (IECC)-Compliant Single-Family Residential Energy Use. Ph.D. Dissertation, College Station, TX: Texas A&M University.

Malhotra, M. et al. 2009. Validation of the International Code Compliant Calculator (IC3) Using the RESNET Verification Procedures (No. 07-003), Energy Systems Laboratory Report, ESL-TR-09-12-04, December 2009.

Residential Energy Services Network, Inc., 2007. “Procedure for verification of International Energy Conservation of Code Performance Path Calculation Tools”, RESNET Publication No. 07-003. September 2007.

REM/Rate: The Home Energy Rating Tool, ver. 12.61, 2009. Architectural Energy Corporation.

Ron Judkoff, Joel Neymark, 1995. Home Energy Rating System Building Energy Simulation Test (HERS BESTST), National Renewable Energy Laboratory, NREL/TP-472-7332a, November 1995.

Sherman, M.H. and Grimsrud, D.T., 1980, “Infiltration-Pressurization Correlation: Simplified Physical Modeling,” ASHRAE Transactions, Vol. 86(2), pp. 778-80

Table 1. Tier one of the HERS BESTEST Description and IC3 Test Results

IC3 v3.3	Test Case Description	**Annual Heating Loads**			**Annual Heating Load Deltas**				**Annual Cooling Loads**			**Annual Cooling Load Deltas**				pass/ fail
		range max	range min	Result	Heating	range max	range min	Result	range max	range min	Result	Cooling	range max	range min	Result	
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.	79.48	48.75	57.10	L110-L100	28.12	19.36	23.13	64.88	50.66	62.93	L110-L100	7.84	-0.98	3.62	pass
Case L110	High Infiltration (1.5 ACH). The same as Case L100 with the exception of the infiltration rate, which is increased from its base-case value of 0.67 air changes per hour (ACH) to a value of 1.5 ACH.	103.99	71.88	80.08	L120-L100	-7.67	-18.57	-10.93	68.50	53.70	65.49	L120-L100	0.68	-8.87	-4.74	pass
Case L120	Well-Insulated Walls and Roof. The same as Case L100 except that the wall insulation is increased from R-11 to R-23 and the ceiling insulation is increased from R-19 to R-58.	64.30	37.82	43.54	L130-L100	-5.97	-27.50	-6.93	60.14	47.34	58.26	L130-L100	-13.71	-24.40	-19.62	pass
Case L130	Double-Pane, Low-Emissivity Windows with Wood Frames. The same as Case L100 except that the single-glazed windows are replaced with high-efficiency windows, which have an overall U-factor of 0.30 and an overall Solar Heat Gain Coefficient (SHGC) of 0.335.	53.98	41.82	44.64	L140-L100	-4.56	-24.42	-6.51	45.26	32.95	43.63	L140-L100	-27.14	-38.68	-34.34	pass
Case L140	Zero Window Area. The same as Case L100 except that the windows are replaced with wood frame walls having R-11 insulation.	56.48	42.24	47.43	L150-L100	-3.02	-12.53	-7.80	30.54	19.52	27.40	L150-L100	20.55	8.72	17.45	pass
Case L150	South-Oriented Windows. The same as Case L100 except that the entire 270 sq.ft. of windows is moved to the south face of the home.	71.33	40.95	49.87	L155-L150	6.88	-1.54	2.58	82.33	62.41	82.29	L155-L150	-9.64	-22.29	-19.27	pass
Case L155	South-Oriented Windows with Overhang. The same as Case L150 except that a 2.5 ft. opaque overhang has been included at the top of south exterior wall.	74.18	43.53	53.15	L160-L100	5.10	-3.72	0.03	63.06	50.08	60.29	L160-L100	12.28	3.88	8.11	pass
Case L160	East- and West-Oriented Windows. The same as Case L100 except that all the windows are moved to the east and west faces of the building with 50% (135 sq.ft.) on each face.	81.00	48.78	57.46	L170-L100	17.64	7.12	12.28	72.99	58.61	71.56	L170-L100	-4.83	-15.74	-11.57	pass
Case L170	No Internal Loads. The same as Case L100 except that the internal gains are reduced from 68,261 Btu/day to zero.	92.40	61.03	70.09	L200-L100	107.66	56.39	57.66	53.31	41.83	51.02	L200-L100	21.39	6.63	18.55	pass
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 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.	185.87	106.41	136.40	L202-L200	9.94	-0.51	4.91	83.43	60.25	76.37	L200-L202	14.86	2.03	7.47	pass
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.	190.05	111.32	142.60	L302-L100	14.50	-3.29	7.37	75.96	52.32	62.00					pass
Case L302	Uninsulated Slab-on-Grade. The same as Case L100 except that the floor system is changed from a fully-vented crawlspace to an uninsulated, concrete slab-on-grade.	86.90	56.12	57.80	L302-L304	17.75	5.66	10.01								pass
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.	73.15	46.11	48.36	L322-L100	39.29	15.71	24.96								pass
Case L322	Uninsulated Basement. The same as Case L100 except that the floor system is changed from a fully-vented crawlspace to an uninsulated conditioned basement with 1′0″ of the uninsulated basement wall and the uninsulated floor band joist exposed.	111.69	73.71	92.36	L322-L324	38.22	21.25	27.33								pass
Case L324	Insulated Basement. The same as Case L322 except that R-11 insulation is added at the inside of the basement walls and the floor band joist.	77.47	46.38	55.99												pass

Table 2. Input for the Proposed and Standard Reference House in Three Software

IC3			Software 2			Software 1		
	Proposed House	**2000 IECC**		**Proposed House**	**2000 IECC**		**Proposed House**	**2000 IECC**
PROJECT			**PROJECT**			**PROJECT**		
# Bedrooms	**4**	4	# Bedrooms	**0**	0	# Bedrooms	**4**	
			# Bathrooms	2	2			
# Stories	1	1	# Stories	1	1	# Stories	1	
Building Azimuth	0	0	Rotate Building	0	0			
			Occupancy	Single Family	Single Family	Housing Type	Sng.fam. detached	
Conditioned Area	2500	2500	Conditioned Area	2500	2500	Conditioned Area	2500	
Average Wall Height	8	8	Average Wall Height	8	8	Conditioned Volume	20000	
CLIMATE			**CLIMATE**			**CLIMATE**		
Location	Houston	Houston	Location	Houston	Houston	Location	Houston	
Weather File	TMY2	TMY2	Weather File	TMY2	TMY2			
HDD	**1500**	1500	HDD	**1434**	1434	HDD	**1548**	
SURROUNDINGS			**SURROUNDINGS**			**SURROUNDINGS**		
Shade Trees	None	None	Shade Trees	None	None	Shade Trees	None	
Adjacent Buildings	None	None	Adjacent Buildings	None	None	Adjacent Buildings	None	
FLOORS			**FLOORS**			**FLOORS**		
Type	Slab-on-Grade	Slab-on-Grade	Type	Slab-on-Grade	Slab-on-Grade	Type	Slab	
R-value	0	0	R-value	0	0	R-value	0	
			Equiv. U-value	0.518	0.518			
Area	2500	2500	Area	2500	2500	Area	2500	
Perimeter	200'	200'	Perimeter	200'	200'	Perimeter	200'	
Floor Finish	20% Tile, 80% Carpet	20% Tile, 80% Carpet	Floor Finish	20% Tile, 80% Carpet	20% Tile, 80% Carpet	Floor Covering	Carpet	
ROOF			**ROOF**			**ROOF**		
Configuration	Gable	Gable	Configuration	Gable	Gable			
Attic Description	Full Attic	Full Attic	Attic Description	Full Attic	Full Attic			
Roofing Material	Asphalt shingles	Asphalt shingles	Roofing Material	Composition shingles	Composition shingles			
Roof emissivity	0.9	0.9	Roof Color	Light	White	Roof Color	Light	
Absorptance	0.75	0.75	Solar Absorptance	0.75	0.75			
Roof Ins. R-value	0	0	Roof Deck Ins. Level	0	0			
Roof Framing Factor	7%	7%	Roof Framing Factor	7%	10%			
Ceiling Area	2500	2500	Ceiling Area	2500	2500			
Slope	23 deg.	23 deg.	Slope	5.1/12, 23 deg	5.1/12, 23 deg			
Attic Ventilation Ratio	0.0033	0.0033	Attic Ventilation Ratio	0.0033	0.0033			
CEILING			**CEILING**			**CEILING**		
Type	Under Attic	Under Attic	Type	Under Attic	Under Attic	Type	Blown, Attic	
Area	2500	2500	Area	2500	2500	Gross Area	2500	
R-value	30	30	R-value	30	19.68	R-value	30	
Equivalent U-value	**0.033**	0.033	Equivalent U-value	**0.03**	0.042	Equivalent U-value	**0.034**	0.041
Framing Fraction	7%	7%	Framing Fraction	7%	0%	Framing Factor	7%	
Trusses	Wood	Wood	Trusses	Wood	Wood			
Radiant Barrier	No	No	Radiant Barrier	No	-	Radiant Barrier	No	
WALLS			**WALLS**			**WALLS**		
Type	Frame-Wood	Frame-Wood	Type	Frame-Wood	Frame-Wood	Type	Frame-Wood	
Cavity Ins. R-value	13	11	Cavity Ins. R-value	13	9.42	Cavity Ins. R-value	13	
Equivalent U-value	**0.078**	0.085	Equivalent U-value	**0.086**	0.085	Equivalent U-value	**0.099 (Total: 0.206)**	Total: 0.212
Framing Fraction	25%	25%	Framing Fraction	25%	0%	Framing Factor	25%	
Sheathing R-value	0	0	Sheathing R-value	0	0	Sheathing R-value	0	
Solar Absorptance	0.55	0.55	Solar Absorptance	0.55	0.5	Exterior Color	Medium	
Width x Height	(50 x 8)x4	(50 x 8)x4	Width x Height	(50 x 8)x4	(25 x 8)x8	Gross Area	1600	
DOORS			**DOORS**			**DOORS**		
Orientation	South, North	South, North	Orientation	South, North	Eight			
Width x Height	3' x 6.67'	3' x 6.67'	Width x Height	3' x 6.67'	(0.75 x 6.67)x8	Opaque Area	20*2	
			Type	Insulated	Insulated			
			Storm Door Type	None	None	Storm Door Type	None	
U-value	0.2	0.2	Winter U-value	0.2	0.2	U-value	0.2	
WINDOWS			**WINDOWS**			**WINDOWS**		
U-value	0.47	0.47	NFRC U-value	0.47	0.47	U-value	0.47	
SHGC	0.4	0.4	NFRC SHGC	0.4	0.4	SHGC	0.4	0.4
No. of panes	1 (default)	1 (default)	Type	Single (Clear)	Low-E Double			
Frame	Aluminum w/o break	Aluminum w/o break	Frame	Metal	Vinyl			
Overhang Depth	0	0	Overhang Depth	0	0	Overhang Depth	0	
Overhang Seperation	0	0	Overhang Seperation	0	0	Overhang Seperation	0	
Width x Height	(16' x 5' = 80)x4	(22.5' x 5' = 112.5)x4	Width x Height	(16' x 5' = 80)x4	(14.06'x4' = 56.25)x8	Area	80x4	
Internal Shade	0.9, 0.7	0.9, 0.7	Internal Shade	IECC	Drapes/Blinds	Interior Shading	0.9, 0.7	
			Screening	None	-			
INFILTRATION			**INFILTRATION**			**INFILTRATION**		
Input	SLA = 0.00057	SLA = 0.00057	Input	SLA = 0.00057	nL = 0.57	Input	SLA = 0.00057	
			Equivalent Value	0.00057	0.00057			
Terrain Parameter	Suburban	Suburban	Terrain Parameter	Suburban	Suburban			
Shielding Coefficient	Suburban	Suburban	Shielding Coefficient	Suburban	Suburban			
			Ventilation Air	None	None	Cooling Season Vent.	None	

Table 2. Inputs for the Proposed and Standard Reference House in Three Software (Continued)

IC3		
	Proposed House	**2000 IECC**
COOLING		
Type	Central Unit	Central Unit
SHR (SV-A)	0.623	0.623
SEER	13	13
Capacity kBtu/hr	60	60
Supply CFM	1800	1800
Autosizing option	No	No
HEATING		
Type	Gas Furnace	Gas Furnace
Efficiency	0.78 AFUE	0.78 AFUE
Capacity kBtu/hr	60	60
Autosizing option	No	No
DUCTS		
R-value (S, R)	8, 4	8, 4
Supply Duct Area	675	675
Return Duct Area	125	125
# Returns	1	1
Supply Duct Location	Attic	Attic
Return Duct Location		
Air Handler Location		
Duct Air Leakage	10%+10%	10%+10%
Return Leak Fraction		
Dist. Eff.due to leaks	NA	NA
HOT WATER		
Type	Natural Gas	Natural Gas
Capacity	40	40
Gallons per Day	70	70
EF/Recov. Eff.	0.544 EF, 0.78 RE	0.544 EF, 0.78 RE
Set Temperature	120	120
TEMPERATURES		
Cooling	78F (5F Setup)	78F (5F Setup)
Heating	68F (5F Setback)	68F (5F Setback)
Thermostat	Programmable	Programmable
Seasonal Sch.: Heat	Always	Always
Seasonal Sch.: Cool	Always	Always
APPL. + LIGHTS		
LIGHTING		
Scheduled	Constant	Constant
Released	100%	100%
kWh/yr	3854	3854
Peak W	440	440
MISCELLANEOUS		
Scheduled	Constant	Constant
Released	100%	100%
kWh/yr	3854	3854
Peak W	440	440

Software 2		
	Proposed House	**2000 IECC**
COOLING		
Type	Central Unit	Central Unit
SHR	0.623	0.623
SEER	13	13
Capacity kBtu/hr	60	45.5
Tested Coil Air Flow CFM	1800	1365
Autosizing option	-	-
HEATING		
Type	Gas Furnace	Gas Furnace
Efficiency	0.78 AFUE	0.78 AFUE
Capacity kBtu/hr	60	35.4
Autosizing option	-	-
DUCTS		
R-value (S, R)	8, 4	6, 6
Supply Duct Area	675	675
Return Duct Area	125	125
# Returns	1	1
Supply Duct Location	Attic	Interior
Return Duct Location		
Air Handler Location		
Duct Air Leakage	20%	-
Return Leak Fraction	0.5	0
Dist. Eff.due to leaks	=> Qn = 0.144	80%
HOT WATER		
Type	Natural Gas	Natural Gas
Location	Interior	Interior
Capacity	40	40
Gallons per Day	70	30
EF	0.54	0.59
Set Temperature	120	120
TEMPERATURES		
Thermostat Schedule	IECC 1998/2000	IECC 1998/2000
Cooling	78F (5F Setup)	78F (5F Setup)
Heating	68F (5F Setback)	68F (5F Setback)
Thermostat	Programmable	Programmable
Seasonal Sch.: Heat	Always	Always
Seasonal Sch.: Cool	Always	Always
Seasonal Sch.: Vent	No	Always
APPL. + LIGHTS		
Appliance Schedule	IC3 (User Created)	IECC 1998/2000
LIGHTING		
Scheduled	Constant	
Released	100%	
kWh/yr	3854	
Peak W	440	
MISCELLANEOUS		
Scheduled	Constant	Yes
Released	100%	90%
kWh/yr	3854	8555.5
Peak W	440	1568.9

Software 1		
	Proposed House	**2000 IECC**
COOLING		
Type	Central Unit	
SHR	0.623	
SEER	13	13
Capacity kBtu/hr	60	
HEATING		
Type	Gas Furnace	
Efficiency	0.78 AFUE	
Capacity kBtu/hr	60	
DUCTS		
R-value (S, R)	8, 4	8,4
Supply Duct Area	675	
Return Duct Area	125	
# Returns	1	
Supply Duct Location	Attic	
Return Duct Location		
Air Handler Location		
Duct Air Leakage	20%	
Return Leak Fraction	0.5	
HOT WATER		
Type	Natural Gas	
Location	Interior	
Capacity	40	
Gallons per Day	70	
EF/Recov. Eff.	0.54 EF, 0.78 RE	
TEMPERATURES		
Cooling	78F	
Heating	68F	
Thermostat	Programmable	
APPL. + LIGHTS		
LIGHTING		
Scheduled	Constant	
kWh/yr	3854	
Peak W	440	
MISCELLANEOUS		
Scheduled	Constant	
kWh/yr	3854	
Peak W	440	

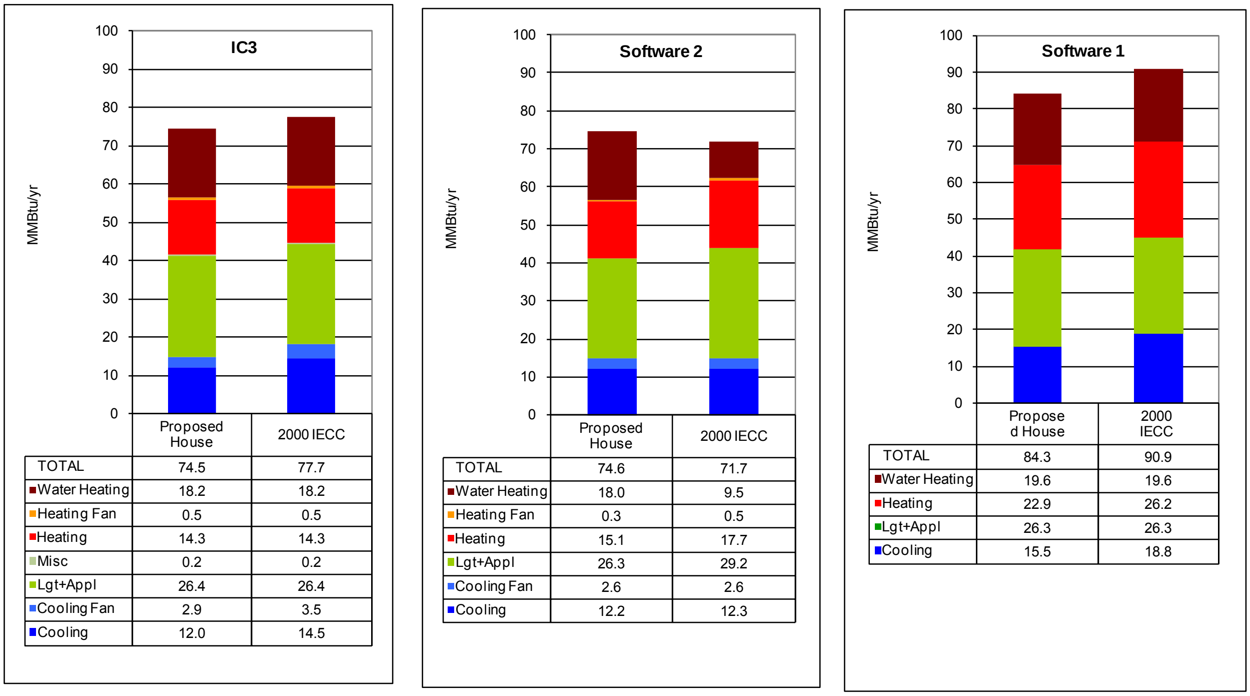

Figure 1. Simulation Results from Three Code Compliance Software (Houston)

Table 3. Simulation Results from Three Code Compliance Software (Houston)

% of Total (IC3 4.01.05)		
Houston, TX	Proposed House	Standard Reference House
Cooling	20.0%	23.2%
Lgt+Appl	35.4%	34.0%
Heating	20.2%	19.4%
DHW	24.4%	23.4%
% Above-code	**4.0%**	**Code**

% of Total (Software 2)		
Houston, TX	Proposed House	Standard Reference House
Cooling	20.0%	20.7%
Lgt+Appl	35.3%	40.7%
Heating	20.7%	25.3%
DHW	24.1%	13.2%
% Above-code	**-4.0%**	**Code**

% of Total (Software 1)		
Houston, TX	Proposed House	Standard Reference House
Cooling	18.4%	20.7%
Lgt+Appl	31.2%	28.9%
Heating	27.2%	28.8%
DHW	23.3%	21.6%
% Above-code	**7.3%**	**Code**

ENERGY USE (MMBtu/yr): Software 2		
	Proposed House	Standard Reference House
Cooling	12.2	12.3
Cooling Fan	2.6	2.6
Lgt+Appl	26.3	29.2
Heating	15.1	17.7
Heating Fan	0.3	0.5
Water Heating	18.0	18.0
TOTAL	**74.6**	**80.2**
Adjusted % Above-code	**7.0%**	

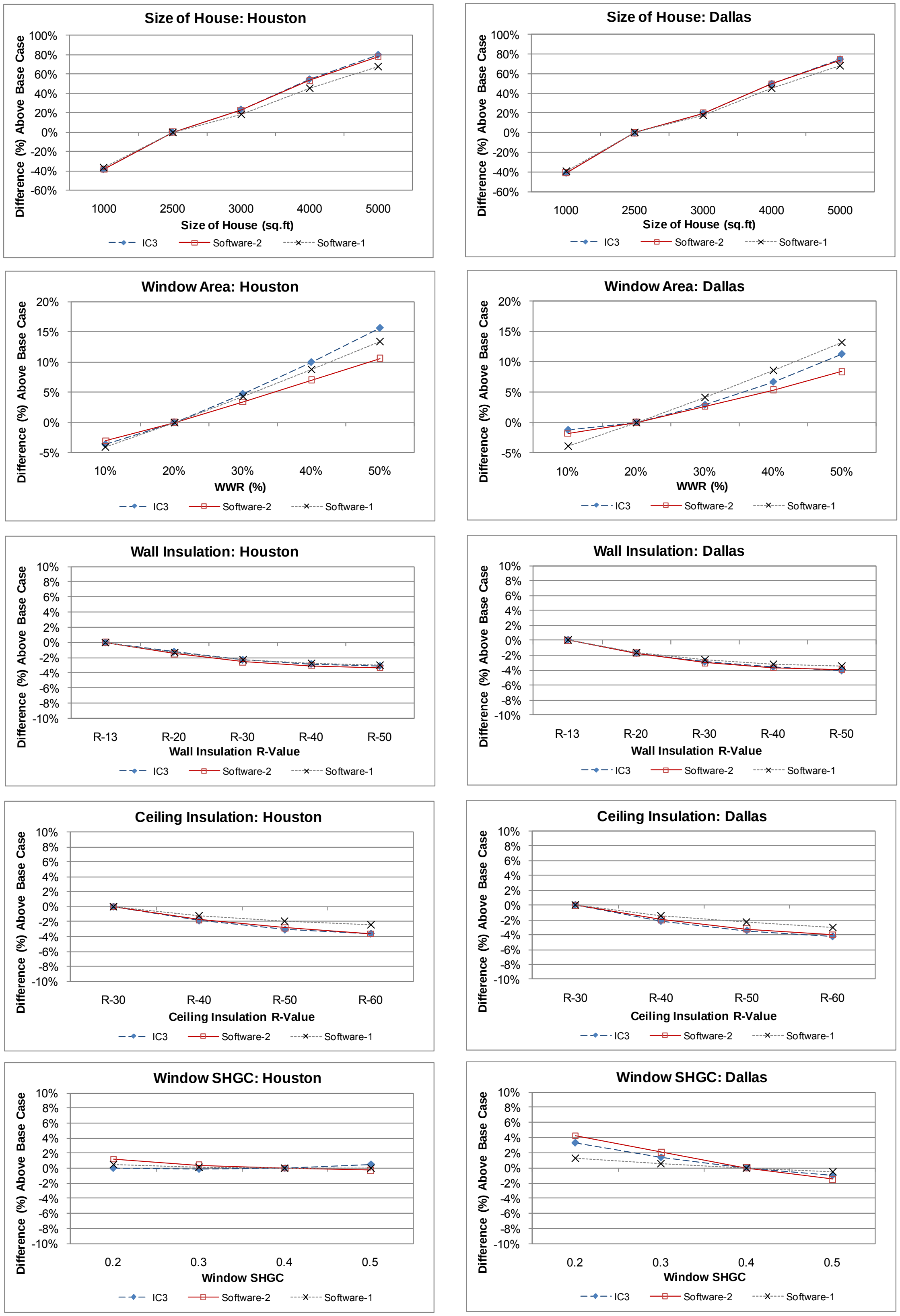

Figure 2. Sensitivity Test Results for Three Programs

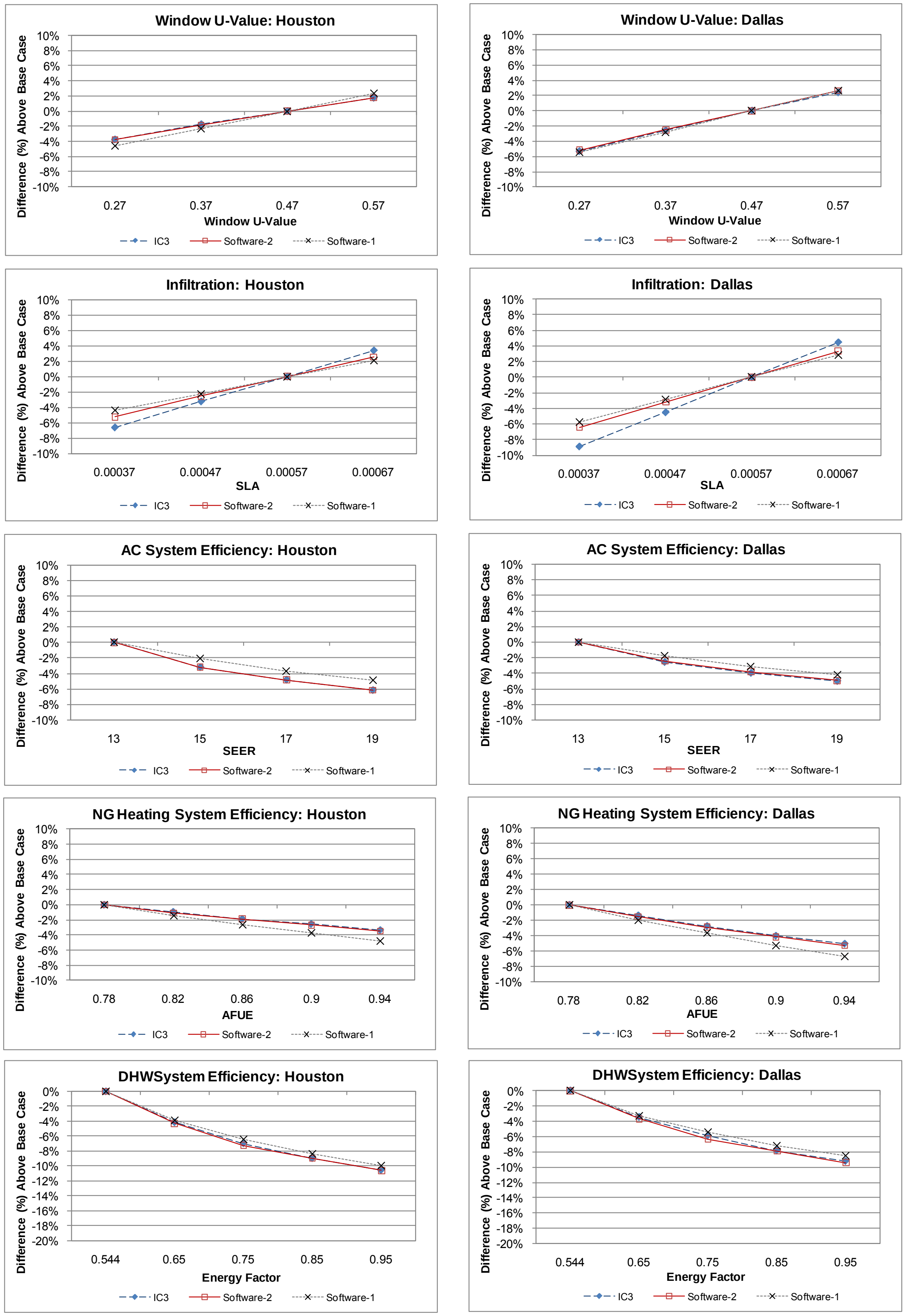

Figure 2. Sensitivity Test Results for Three Programs (Continued)