COMPARING THE PERFORMANCE OF A 2009 IECC CODE- COMPLIANT HOUSE USING CODE-COMPLIANT RESIDENTIAL SIMULATION PROGRAMS

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ABSTRACT

The Residential Energy Services Network (RESNET) is an independent, non-profit organization that helps homeowners reduce energy costs by providing energy efficiency strategies. RESNET performs certification of code-compliance software using a test suite (RESNET 2007). Acceptance variations in the RESNET tests include a provision of minimum and maximum limits of variation on a case-by-case basis or a sensitivity basis. Results are provided for either heating or cooling loads or heating and cooling energy consumption (RESNET 2007). However, significant differences exist in the results obtained from these software programs on performing compliance with the performance path specified in the International Energy Conservation Code (IECC).

This paper is a continuation of an earlier attempt to explore these differences and find out the cause of such discrepancies (Liu et al., 2010). This paper also determines a bandwidth within which variation in results from the different software programs that can be deemed to be acceptable. The paper provides a comparison of four code-compliant software, three of which are RESNET certified. The comparison is performed for three climate zones in Texas. For most cases of the comparison, the results from the three RESNET certified software are within 5% of each other. However, variation in results from the three RESNET certified software programs exceeds 5% in certain cases of ceiling R-values in all climate zones and in certain cases of window-to-wall area ratios in Climate Zone-4.

INTRODUCTION

Previously, a paper by Liu et al. (2010) compared the results from three RESNET certified software programs used for the State of Texas. The previous paper provided a comparison of the 2001 IECC compliant house. The study concluded that significant differences can exist between the selected tools due to differences in interpreting the 2001 IECC, auto-generation of inputs and other assumptions.

This paper summarizes the information provided in a new report that compares the performance of a 2009 IECC compliant house simulated using four code-compliance software programs (Mukhopadhyay et al. 2012). The performance path alternative[1] provided in the 2009 IECC is used by the software programs selected for this analysis (ICC 2009). The performance path analysis provided in the 2009 IECC requires that a building energy simulation be performed to determine whether the annual energy cost of the proposed residence to be less than the annual energy cost of the standard reference design home[2,3].

The four software programs selected are as follows:

- IC3 (version 3.12.1)
- REM/Rate (version 13.0)
- REScheck (version 4.4.3)[4]
- EnergyGauge (version 2.8.05)[5]

As of May 2013, three of the software programs selected for this analysis, (i.e. IC3, REMRate and EnergyGauge) are certified by RESNET to provide compliance with the 2006 IECC (RESNET 2007). However, currently RESNET does not provide certification for the 2009 IECC compliant software programs. As part of its

[1] Section 405, Simulated Performance Alternative, 2009 IECC (ICC 2009).
[2] 2009 IECC, Section 405.3 Performance-based compliance.
[3] The 2009 IECC also provides an exception to Section 405.3, which allows the use of source energy to be substituted for energy costs. The source energy multipliers of 3.16 and 1.1 are recommended for electricity and natural gas usage respectively.
[4] REScheck provides a limited performance approach for compliance with the IECC (Bartlett et al. 2012).
[5] This version of EnergyGauge does not support compliance with the 2009 IECC. Therefore, a 2009 IECC compliant

responsibilities, RESNET performs certification of code-compliance software. The verification is provided in form of a test suite provided by RESNET. Acceptance variations in the tests include a provision of minimum and maximum limits of variation in on a case-by-case basis or a sensitivity basis. Results are provided for either heating or cooling loads or corresponding energy consumption (RESNET 2007).

Although these programs have been extensively used to provide compliance, significant differences have known to occur in the results of the three software programs. It is observed that even the smallest of difference can cause the house to pass the code when using one software program and fail when using another software program.

Therefore, the purpose of this paper is to provide a look at some of the differences in the code-compliance results using 2009 IECC for compliance. This is done by means of a sensitivity analysis that is performed to identify the possible reasons for the differences.

DESCRIPTION OF THE SIMULATION SUITE

In order to compare the performance of the software programs, a sensitivity analysis was conducted. For this purpose, several parameters were selected that were common to the four selected software programs. The analysis proceeded to vary each parameter individually and document the corresponding percentage difference above / below the 2009 IECC code-compliant base-case provided by each of the four simulation programs.

Three cities were selected by this analysis to represent the three climate zones in the State of Texas. These include: Houston, representing Climate Zone 2A; Dallas, representing Climate Zone 3A; and Amarillo, representing Climate Zone 4B. The Climate Zones and the location of cities selected to represent these zones are provided in Figure 1.

The four software programs described in the previous section will be referenced to as: Software 1, Software 2, Software 3 and Software 4, which does not necessarily correspond to the order presented in the section above.

The proposed base-case design house used for this analysis was a 2009 IECC code-compliant[6] house. Details of the house are provided in the next section.

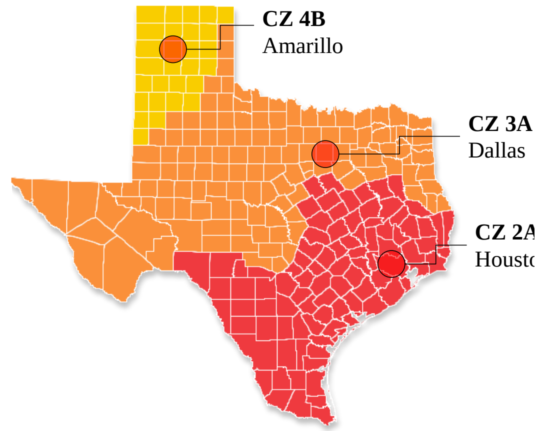

Figure 1: Texas Climate Zones

Parameters used for the sensitivity analysis include the following[7]:

- House size with fixed window area of 60 ft^2: 1,000 ft^2, 2,500 ft^2, 3,000 ft^2, 4,000 ft^2 and 5,000 ft^2.
- House size with fixed window-to-wall area ratio of 15%: 1,000 ft^2, 2,500 ft^2, 3,000 ft^2, 4,000 ft^2 and 5,000 ft^2.
- Window to wall area ratio: 10%, 20%, 30%, 40% and 50%.
- Wall insulation (exterior): R-0 (None), R-3, R-6 and R-9.
- Ceiling insulation: R-30, R-40, R-50 and R-60.
- Window SHGC: 0.2, 0.3, 0.4 and 0.5.
- Window U-value: 0.25, 0.45, 0.65 and 0.75.
- Slab insulation (For Climate Zone 4B): R-0 (Un-insulated slab), R-5, R-10, and R-15.

DESCRIPTION OF THE PROPOSED BASE-CASE HOUSE

Standard Reference House was manually created for this analysis.

[6] Table 405.5.2(1), 2009 IECC, Specifications for the Standard Reference and Proposed Designs.

[7] It should be noted that mechanical equipment trade-offs are not allowed in the performance path compliance in the 2009 IECC. Hence variations in equipment specifications have not been considered for analysis.

The proposed base-case design house implemented for this analysis was a 2009 IECC compliant[8] single-family, single-story house with three bedrooms and a conditioned floor area of 2,500 ft^2. The front of the house faced south. The base-case model had a slab-on-grade floor construction. The window-to-wall area ratio (WWAR) was set at 15%[9]. No exterior shading was implemented in the base-case model[10]. Specifications for the building envelope such as wall insulation, ceiling insulation, slab insulation, glazing details, and specifications for opaque doors were carefully matched to the provisions in the 2009 IECC (ICC 2009)[11,12,13]. In addition, space conditions, infiltration rates, internal heat gains and the thermostat settings used in the base-case model were also matched to the provisions in the 2009 IECC (ICC 2009)[14].

Space conditioning equipment used electricity for space cooling, natural gas space heating and natural gas domestic hot water heating. The efficiencies of mechanical systems in the base-case house were in compliance with the specifications of the 2009 IECC which use 2006 NAECA[15] requirements. The efficiencies included SEER 13 for the air conditioner, an AFUE of 0.78 for the gas furnace, and an Efficiency Factor of 0.594[16] for the domestic hot water heater, which has a tank volume of 40 gallons (Hendron 2008).
The cooling system for the proposed house were sized using 500 ft^2 / ton[17,18]. For the reference home, the cooling system were sized at 500 ft^2 / ton for Software 1 and Software 3, and was auto-sized in Software 2[19]. Finally, the sizing criteria in Software 4 was not provided and hence was not documented in this analysis. The sizing for the Reference house used in the three software programs is provided in Figure 2 and Figure 3 of this paper.

When considering the size of cooling systems, for all house sizes in Climate Zone 2 and Climate Zone 3 and most house sizes in Climate Zone 4, the size of the cooling system for the Reference house is similar in the three Software Programs. However, for larger house sizes in Climate zone 4 (i.e. 4000 ft^2 and 5000 ft^2), the cooling system size is considerably smaller than the cooling system sized using the 500 ft^2/ton rule of thumb in Software 1 and Software 3. It is also noted that for smaller house sizes (i.e. 1000ft^2), the cooling system in the Reference house of Software 2 is consistently bigger than the corresponding system sized using 500 ft^2/ton in Software 1and Software 3. For heating system sizes, the system sizing for the Reference house in Software 2 are consistently bigger than the corresponding systems sized using the 500ft^2/ton rule of thumb in Software 1 and Software 3. The difference in system sizing becomes more prominent on going from Climate Zone 2 to 4.

DHW usage for the base-case house used the specifications of the 2009 IECC[20]. The ducts were located in the attic, and the specifications for duct leakage and the duct insulation were assumed to be in compliance with the 2009 IECC. The consolidated input for the proposed house in the four software programs is provided in Table 1.

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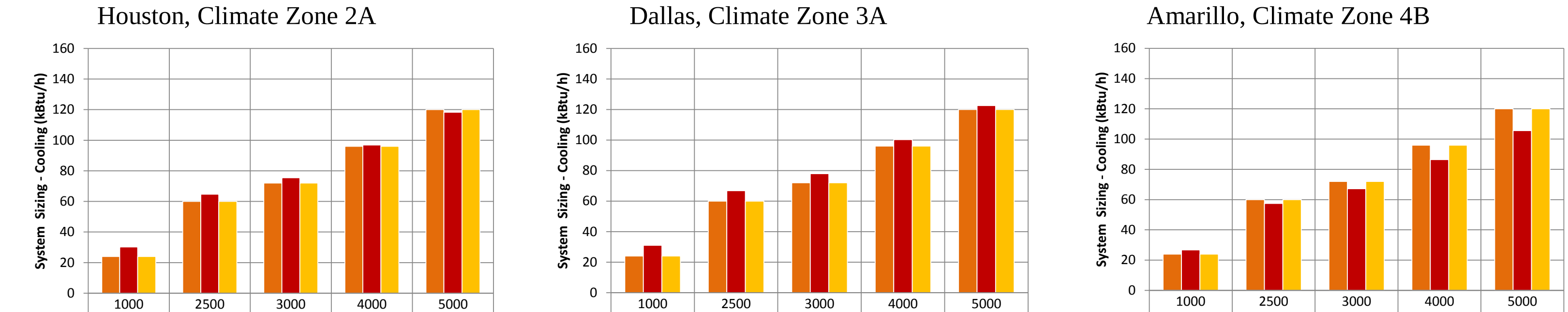
[8] Table 405.5.2(1), 2009 IECC, Specifications for the Standard Reference and Proposed Designs.
[9] Table 405.5.2(1), 2009 IECC, Glazing.
[10] Table 405.5.2(1), 2009 IECC, Glazing.
[11] Table 405.5.2(1), 2009 IECC, Above-grade walls, Ceilings, Foundations, Doors, Glazing.
[12] Table 402.1.1, 2009 IECC, Insulation and Fenestration Requirements by Component.
[13] Table 402.1.3, 2009 IECC, Equivalent U-Factors.
[14] Table 405.5.2(1), 2009 IECC, Air exchange rate, Internal gains, Thermostat.
[15] National Appliance Energy Conservation Act of 1987 with 2006 amendments.
[16] This efficiency was calculated from the equation provided in the Table 504.2, 2009 IECC Minimum Performance of Water Heating Equipment, 40 Gallon Gas-fired Storage water heaters.
[17] This assumption was based on standard practice for HVAC contractors in Texas.
[18] Corresponding heating system was sized at 500 ft2/12000Btu/hr.
[19] For the case of ducts in attic described in this paper, the sizing results obtained from Software 2 are similar to those determined in Software 1 and Software 3. However, this is not the case when ducts are positioned in conditioned space. In this case sizing results from Software 3 are much smaller which in turn impact the percentage above code values (Mukhopadhyay et al. 2012).
[20] Table 405.5.2(1), 2009 IECC, Service water heating.



Houston, Climate Zone 2A (Size of House (sq.ft.))

	1000	2500	3000	4000	5000
Software 1	24.0	60.0	72.0	96.0	120.0
Software 2	30.2	64.7	75.5	96.9	118.3
Software 3	24.0	60.0	72.0	96.0	120.0

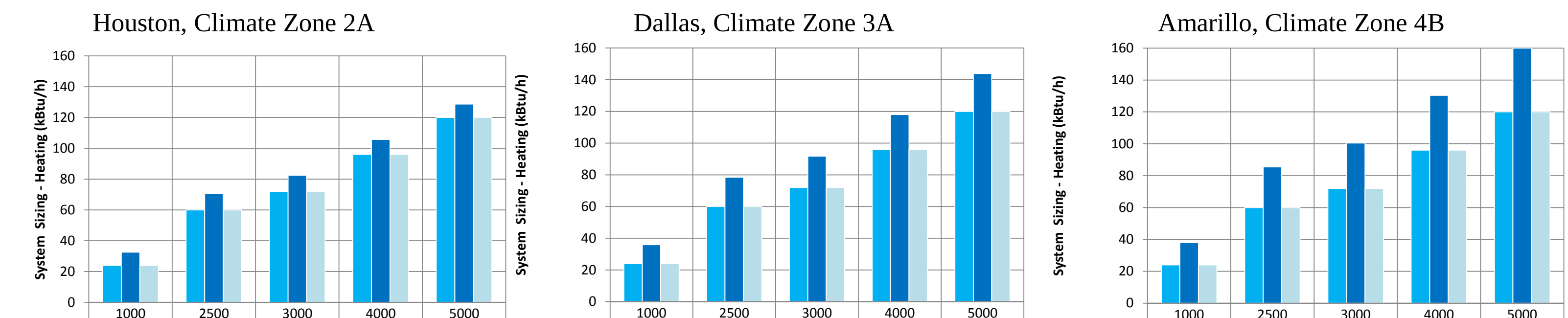
Dallas, Climate Zone 3A (Size of House (sq.ft.))

	1000	2500	3000	4000	5000
Software 1	24.0	60.0	72.0	96.0	120.0
Software 2	31.0	66.8	78.0	100.3	122.6
Software 3	24.0	60.0	72.0	96.0	120.0

Amarillo, Climate Zone 4B (Size of House (sq.ft.))

	1000	2500	3000	4000	5000
Software 1	24.0	60.0	72.0	96.0	120.0
Software 2	26.8	57.5	67.2	86.4	105.6
Software 3	24.0	60.0	72.0	96.0	120.0

Figure 2: Cooling System Sizing for the Standard Reference Home Provided by the Three Software Programs for the Three Climate Zones in Texas



Houston, Climate Zone 2A (Size of House (sq.ft.))

	1000	2500	3000	4000	5000
Software 1	24.0	60.0	72.0	96.0	120.0
Software 2	32.6	70.8	82.5	105.7	128.7
Software 3	24.0	60.0	72.0	96.0	120.0

Dallas, Climate Zone 3A (Size of House (sq.ft.))

	1000	2500	3000	4000	5000
Software 1	24.0	60.0	72.0	96.0	120.0
Software 2	35.9	78.5	91.8	118	143.9
Software 3	24	60	72	96	120.0

Amarillo, Climate Zone 4B (Size of House (sq.ft.))

	1000	2500	3000	4000	5000
Software 1	24.0	60.0	72.0	96.0	120.0
Software 2	38	85.5	100.5	130.4	160
Software 3	24	60	72	96	120.0

Figure 3: Heating System Sizing for the Standard Reference Home Provided by the Three Software Programs for the Three Climate Zones in Texas

Table 1: Input for the Proposed Base-Case House in the Four Software Programs to Comply with the 2009 IECC

IC3 (3.12.1)		REM / Rate (13.00)		REScheck (4.4.3)		EnergyGauge (2.8.05)	
PROJECT							
# Bedrooms	3	# Bedrooms	3			# Bedrooms	3
# Stories	1	# Stories	1			# Stories	1
Building Azumith	South					# Bathrooms	2
Conditioned Area (sqft)	2,500	Conditioned Area (sqft)	2,500	Conditioned Area (sqft)	2,500	Conditioned Area (sqft)	2,500
Average Wall Height (ft)	8					Average Wall Height (ft)	8
		Conditioned Volume (cuft)	20,000			Conditioned Volume (cuft)	20,000
Housing type	Single family detached	Housing type	Single family detached	Housing type	Single family detached	Housing type	Single family
CLIMATE							
Location	CZ 2A - Harris CZ 3A - Tarrant CZ 4B - Potter	Location	Houston Dallas/Fort Worth Amarillo	Location	Houston Dallas Amarillo	Location	CZ 2A - Houston CZ 3A - Dallas CZ 4B - Amarillo
Weather File	TMY2					Weather File	TMY2
HDD	CZ 2A - 1500 CZ 3A - 2000 CZ 4B - 4000	HDD	CZ 2A - 1548 CZ 3A - 2420 CZ 4B - 4240			HDD	CZ 2A - 1434 CZ 3A - 2420 CZ 4B - 4183
FLOORS							
Type	Slab-on-grade	Type	Slab-on-grade	Type	Slab-on-grade Unheated	Type	Slab-on-grade edge insulation
R-value	CZ 2A - R-0 CZ 3A - R-0 CZ 4B - R-10, 2ft	R-value	CZ 2A - R-0 CZ 3A - R-0 CZ 4B - R-10, 2ft	R-value	CZ 2A - R-0 CZ 3A - R-0 CZ 4B - R-10, 2ft	R-value	CZ 2A - R-0 CZ 3A - R-0 CZ 4B - R-10, Ext. insulation
Floor Finish	20% tile, 80% Carpet	Floor Covering	Carpet			Floor Finish	20% tile, 80% Carpet
Area (sqft)	2,500	Area (sqft)	2,500			Area (sqft)	2,500
Perimeter (ft)	200	Full Perimeter (ft)	200	Full Perimeter (ft)	200	Perimeter (ft)	200
		Depth below Grade (ft)	0				
		Total Exposed Perimeter (ft)	200				
		On-Grade Exposed Perimeter (ft)	200				
ROOF							
Configuration	Gable					Configuration	Gable
Attic Type	Full attic					Attic Type	Full Attic
Roofing Material	Asphalt shingles					Roofing Material	Comp. Shingles
						Conditioned Ceiling Footprint Area	2,500 sqft
Roof Emissivity	0.9						
Absorptance	0.75					Absorptance	0.75
Radiant Barrier	No	Radiant Barrier	No			Radiant Barrier	No
Roof Insulation	R-0					Roof Deck Insulation	R-0
						Roof Framing Fraction	0.1
		Attic Exterior (sqft)	2,500				
Slope (Degrees)	23					Slope in inches	5.1/12
		Exterior Color	Medium			Roof Color	Medium
		Clay or Concrete Roofing	No				
		Sub-Tile Ventilation	No				
Attic Ventilation	0.0033					Attic Ventilation	0.0033
CEILING							
Type	Under attic	Type	Blown, attic	Type	Flat ceiling or Scissor Truss	Type	Under attic
R-value	CZ 2A - R-27.8 CZ 3A - R-27.8 CZ 4B - R-32.5	R-value	CZ 2A - R-27.8 CZ 3A - R-27.8 CZ 4B - R-32.5	R-value	CZ 2A - R-30 CZ 3A - R-30 CZ 4B - R-38	R-value	CZ 2A - R-25.75 CZ 3A - R-25.75 CZ 4B - R-30
Framing Factor	7%	Framing Factor	7%			Framing Factor	7%
Area	2,500	Area	2,500	Area	2,500	Area	2,500
Overall U-value	CZ 2A - 0.035 CZ 3A - 0.035 CZ 4B - 0.030	Overall U-value	CZ 2A - 0.035 CZ 3A - 0.035 CZ 4B - 0.030	Overall U-value	CZ 2A - 0.035 CZ 3A - 0.035 CZ 4B - 0.030	Overall U-value	CZ 2A - 0.035 CZ 3A - 0.035 CZ 4B - 0.030
WALLS							
Type	Frame wood	Type	Frame wood	Type	Frame wood 16" O.C.	Type	Frame wood
Cavity Insulation	CZ 2A - R-11.8 CZ 3A - R-11.8 CZ 4B - R-11.8	Cavity Insulation	CZ 2A - R-11.8 CZ 3A - R-11.8 CZ 4B - R-11.8	Cavity Insulation	CZ 2A - R-13 CZ 3A - R-13 CZ 4B - R-13	Cavity Insulation	CZ 2A - R-14.5 CZ 3A - R-14.5 CZ 4B - R-14.5
Overall U-value	CZ 2A - 0.082 CZ 3A - 0.082 CZ 4B - 0.082	Equivalent U-value	CZ 2A - 0.082 CZ 3A - 0.082 CZ 4B - 0.082	Equivalent U-value	CZ 2A - 0.082 CZ 3A - 0.082 CZ 4B - 0.082	Overall U-value	CZ 2A - 0.082 CZ 3A - 0.082 CZ 4B - 0.082
Framing Fraction	25%	Framing Factor	25%			Framing Factor	25%
Sheathing R-value	0					Sheathing R-value	0
Solar Absorptance	0.75					Solar Absorptance	0.75
		Gross Area (sqft)	400 x 4	Gross Area (sqft)	400 x 4	Gross Area (sqft)	400 x 4
Exterior Finish	Brick	Exterior Finish	Brick				
		Exterior Color	Light				
		Location	Between conditioned space and ambient			Adjacent To	Exterior
DOORS							
Orientation	North, south	Orientation	North, south	Orientation	North, south	Orientation	North, south
Area (sqft)	20.01	Opaque Area (sqft)	20.01	Opaque Area (sqft)	20.01	Area (sqft)	20.01
U-value (Btu/hr-sqft-F)	CZ 2A - 0.65 CZ 3A - 0.5 CZ 4B - 0.35	U-value (Btu/hr-sqft-F)	CZ 2A - 0.65 CZ 3A - 0.5 CZ 4B - 0.35	U-value (Btu/hr-sqft-F)	CZ 2A - 0.65 CZ 3A - 0.5 CZ 4B - 0.35	U-value (Btu/hr-sqft-F)	CZ 2A - 0.65 CZ 3A - 0.5 CZ 4B - 0.35
		R-value	1.54				
		Storm Door	No				

Notes:

- Cells marked in yellow indicate information specific to the Climate Zones selected by this analysis.
- In REM/Rate, the exterior walls are specified using the ‘Path Layer’ option provided in the software program. This option allows the user to manually input R-values of different components of the exterior wall, which includes separate input for cavity and framing components of the exterior wall.

Table 1: Input for the Proposed Base-Case House in the Four Software Programns to Comply with the 2009 IECC (Continued)

IC3 (3.12.1)		REM / Rate (13.00)		REScheck (4.4.3)		EnergyGauge (2.8.05)	
WINDOWS & SHADING							
U-value	CZ 2A - 0.65 CZ 3A - 0.5 CZ 4B - 0.35	U-value	CZ 2A - 0.65 CZ 3A - 0.5 CZ 4B - 0.35	U-value	CZ 2A - 0.65 CZ 3A - 0.5 CZ 4B - 0.35	U-value	CZ 2A - 0.65 CZ 3A - 0.5 CZ 4B - 0.35
SHGC	CZ 2A - 0.3 CZ 3A - 0.3 CZ 4B - 0.4 (NR)	SHGC	CZ 2A - 0.3 CZ 3A - 0.3 CZ 4B - 0.4 (NR)	SHGC	CZ 2A - 0.3 CZ 3A - 0.3 CZ 4B - 0.4 (NR)	SHGC	CZ 2A - 0.3 CZ 3A - 0.3 CZ 4B - 0.4 (NR)
No. of Panes	1					No. of Panes	1
Frame Type	Vinyl					Frame Type	Vinyl
Window Area (sqft)	60 x 4	Window Area (sqft)	60 x 4	Window Area (sqft)	60 x 4	Window Area (sqft)	60 x 4
Orientation	Equal area on all orientations	Orientation	Equal area on all orientations	Orientation	Equal area on all orientations	Orientation	Equal area on all orientations
Overhang Depth (ft)	0	Overhang Depth (ft)	0			Overhang Depth (ft)	0
		To Top of Window	0			To Top of Window	0
		To Bottom of Window (ft)	0				
Interior Shade Winter	0.85	Interior Shade Winter	0.85			Interior Shade Winter	0.85
Interior Shade Summer	0.7	Interior Shade Summer	0.7			Interior Shade Summer	0.7
		Adjacent Shading Summer	None				
		Adjacent Shading Winter	None				
INFILTRATION							
Measurement Type	Blower Door	Measurement Type	Blower Door				
Blower Door Values (ACH@50 Pa)	6.99	Heating Season Infiltration (ACH_{50})	7			Proposed ACH@50 Pa	7
		Cooling Season Infiltration (ACH_{50})	7				
		Shelter Class	4				
						Terrain Parameter	Suburban
		2009 IECC Verification	Tested			Sheilding Coefficient	Suburban
		Mechanical Ventilation	No			Ventilation Air	None
COOLING							
Type	Electric	Type	Electric	Type	Electric	Type	Central Unit / Electric
SHR	0.627	SHR	0.627			SHR	0.623
SEER	13	SEER	13	SEER	13	SEER	13
Capacity (kBtu/hr)	60	Capacity (kBtu/hr)	60			Capacity (kBtu/hr)	60
Location	Attic	Location	Attic	Location	Attic	Location	Attic
Supply CFM (CFM/ ton)	360					Tested Coil Air Flow (CFM)	1,800
HEATING							
Type	Natural gas	Fuel Type	Natural gas	Fuel Type	Natural gas	Fuel Type	Natural gas
		System Type	Fuel-fired air distribution	System Type	Fuel-fired air distribution	System Type	Fuel-fired air distribution
AFUE(%)	78	Efficiency (AFUE %)	78	Efficiency (AFUE %)	78	Efficiency (AFUE %)	78
Capacity (kBtu/hr)	60	Capacity (kBtu/hr)	60			Capacity (kBtu/hr)	60
Location	Attic	Location	Attic	Location	Attic	Location	Attic
Auxiliary Energy Use (kWhrs)	0	Auxiliary Energy Use (kWhrs)	0				
DUCTS							
Supply R-value	6	Supply R-value	6			Supply R-value	6
Return R-value	6	Return R-value	6			Return R-value	6
Supply Duct Area (sqft)	675	Supply Duct Area	675			Supply Duct Area (sqft)	500
Return Duct Area	125	Return Duct Area	125			Return Duct Area	125
		# Return	1				
Duct Location	Attic	Duct Location	Attic	Duct Location	Attic	Duct Location	Attic
Duct Tightness Test	Tested	Use Measured Leakage	Yes (CFM@25Pa)			Duct Tightness Test	Anticipated
Duct Leakage to Outdoors (S+R) (CFM@25 Pa)	200	Duct Leakage to Outdoors (S+R) (CFM@25 Pa)	200			Duct Leakage to Outdoors (S+R) (CFM@25 Pa)	200
HOT WATER							
Type	Natural gas	Type	Natural gas			Type	Natural gas
Rated Input (Btu/hr)	36,000						
Capacity (Gallons)	40	Capacity (Gallons)	40			Capacity (Gallons)	40
Water Usage (Gallons / Day)	60	Water Usage (Gallons / Day)	60			Water Usage (Gallons / Day)	60
Energy Factor	0.59	Energy Factor	0.59			Energy Factor	0.59
Recovery Efficiency	0.78	Recovery Efficiency	0.78				
Temperature Settings (F)	120						
TEMPERATURES							
Cooling (F)	75	Cooling (F)	75			Cooling (F)	75
Heating (F)	72	Heating (F)	72			Heating (F)	72
APPLIANCES & LIGHTS							
Schedule	Constant	Schedule	Constant			Schedule	Constant
Lighting (kW)	0.47	Lighting (kW)	0.47			Lighting (kW)	0.47
Equipment (kW)	0.63	Equipment (kW)	0.63			Equipment (kW)	0.63

Note:
Cells marked in yellow indicate information specific to the Climate Zones selected by this analysis.

RESULTS FROM SENSITIVITY ANALYSIS

This section provides the results of the sensitivity tests that were performed for parameters that include House size, Window-to-wall area ratio, Wall insulation, Ceiling insulation, Window SHGC, Window U-value, and Slab R-value. The analysis was performed by changing the value of each parameter and documenting the resultant percentage difference above/below the 2009 IECC Reference house.

Variations in House Size (Fixed window area of 60 ft^2 per orientation):

The comparison for the variation in house size is presented in Figure 4. For the 2,500 ft^2 house, for the three Climate Zones, the results of the four software programs are similar to each other. For the 1,000 ft^2 house, the fixed window area of 60 ft^2 per orientation of the Proposed house is greater than the 15% window-to-floor area ratio limit specified for the Reference house in the 2009

IECC[21]. Hence, the Proposed house is more consumptive than the corresponding Reference house. For Houston, the results from Software 1, Software 2 and Software 3 are consistently lower than the corresponding Reference house (8.8% - 10.6% below code). Results from Software 4 are less sensitive (3.1% below code). For Dallas, the results from Software 2 and Software 3 are consistent with each other (6.3% - 6.6% below code). Results from Software 1 are more sensitive than the results from the other three software programs (10% below code). Results from Software 4 are least sensitive when compared with the results from the other three software programs (2.6% below code). For Amarillo, results from Software 1 and Software 2 are consistent with each other (8.7% - 8.4% below code). Results from Software 3 and Software 4 are consistent with each other (3.6% - 2.7% below code). For house sizes greater than 2,500 ft^2, the results are consistent with each other (within 1% of the code).

Variations in House Size (Fixed window-to-wall area of 15%):

The comparison for the variation in house size is presented in Figure 5. For the 2,500 ft^2 house, for the three Climate Zones, the results of the four software programs are similar to each other. For the 1,000 ft^2, a window-to-wall area ratio of 15% per orientation is greater than the 15% window-to-floor area ratio limit specified for the Reference house in the 2009 IECC. Hence, in this case the Proposed house is more consumptive than the corresponding Reference house. In all Climate Zones, house the difference in the results from the four software programs is within 4%. For all other house sizes, in all Climate Zones, results of the four software programs are similar to each other with differences within 2%.

Variation in Window-to-wall Area Ratio:

The comparison for the variation in window-to-wall area ratios is presented in Figure 6. 60 ft^2 of window area assumed in the Proposed design base-case corresponds to 15% window-to-wall area ratio. For window-to-wall area ratio of 10% and 20% results from the four software programs are similar (within 1% of the code). For window-to-wall area ratios of 30%, 40% and 50% considered for the analysis, the resultant window areas are greater than the 15% window-to-floor area ratio limits specified in the 2009 IECC. Hence the Proposed house is more consumptive than the corresponding Reference house. For Houston, the results of Software 1, Software 2 and Software 3 are similar (for 50% WWAR, 25% - 28.9% below code). Results from Software 4 are least sensitive (for 50% WWAR, 10.5% below code). For Dallas, results of Software 2 and Software 3 are similar (for 50% WWAR, 21.3% - 20% below code). Results from Software 1 are most sensitive (for 50% WWAR, 26.5% below code) and results from Software 4 are least sensitive (for 50% WWAR, 8.5% below code). For Amarillo, results from all four software are different with results from Software 1 being most sensitive (for 50% WWAR, 26.5% below code) and results from Software 4 being least sensitive to change in window area (for 50% WWAR, 8.9% below code). It is also noted that Software 2 and Software 3 provide similar results for Houston and Dallas, for Amarillo, results from Software 3 become less sensitive to variation in window-to-wall area ratio.

Variation in Wall Insulation:

The comparison for the variation in wall insulation is presented in Figure 7. It should be noted that the wall insulation is increased by adding continuous insulation in addition to the R-13 cavity insulation specified in the 2009 IECC. For the 2009 IECC compliant case (R-13+0), the four software programs provide similar answers (within 1% of the code). For cases with greater wall insulation, for Houston, results from the Software 1, Software 2 and Software 3 are similar (for R-13+9 wall insulation, 6% - 6.5% above code). Results from Software 4 are less sensitive than the other software programs (for R-13+9 wall insulation, 3.5% above code). For Dallas and Amarillo, results from Software 1 and Software 2 are similar (for R-13+9 wall insulation, 7.1% - 6.4% above code for Dallas, 8.8% - 7.7% above code for Amarillo). Results from Software 4 are less sensitive than the other software programs (for R-13+9 wall insulation, 3.4% above code for Dallas, 5.4% above code for Amarillo). Results for Software 3 are more sensitive than the other software programs (for R-13+9 wall insulation, 8% above code for Dallas, 11% above code for Amarillo).

[21] Table 405.5.2(1), Glazing, 2009 IECC.

Variation in Ceiling Insulation:
The comparison for the variation in ceiling insulation is presented in Figure 8. For the 2009 IECC compliant case, the four software provide similar answers (within 1% of the code). For ceiling insulation of R-60, results from the four software diverge and are within 9%, with pattern of divergence remaining regardless of the Climate Zone (for R-60 ceiling insulation, 1.9% - 9% above code for Houston, 1.9% - 12% above code for Dallas, 1.8% - 10.7% above code for Amarillo). When considering results from Software 1 and Software 2, variations in results are within 5%. When considering results from Software 1 and Software 3, variations in results are within 5%.

Variation in Window SHGC:
The comparison for the variation in window SHGC is presented in Figure 9. For the 2009 IECC compliant values for SHGC results from the four software programs are consistent for the three Climate Zones (within 1% of the code). For window SHGC of 0.5, for Houston and Dallas, the Proposed house is more consumptive than the corresponding Reference house. The results from the four software programs are within 4% (1.8% - 5.7% below code for Houston, 0.3% - 3.4% below code for Dallas). On the other hand for Amarillo, the Proposed house is as consumptive or more efficient than the corresponding Reference house depending on the software used (Software 3 provides 2.5% savings above code; Software 1, Software 2 and Software 4 provide within 1% savings of the code). For window SHGC of 0.2, for Houston, Dallas & Amarillo results from the four software programs are within 1.4%.

Variation in Window U-value:
The comparison for the variation in window U-values is presented in Figure 10. For the 2009 IECC compliant case, the four software provide similar answers (within 1% of the code). For U-value of 0.75, for Houston, the four software programs show similar results (0.4% - 1.7% below code). For Dallas, Software 1, Software 2 and Software 3 show similar results (4.9%, 5% and 6% below code). Software 4 is the least sensitive (2% below code). Similarly for Amarillo, Software1, Software 2 and Software 3 show similar results (13.9%, 16.1%, 14% below code). Software 4 does not support this input and hence the results from Software 4 was not available. When considering the U-value of 0.25, for Houston, variation in results from Software 1, Software 2 and Software 3 are within 5% of each other with results from Software 2 being the most sensitive (6.3% - 10.1% above code). However, results from Software 4 are least sensitive to the change in U-value (3% above code). For Dallas, the results from the four software programs are within 5% of each other with results from Software 1, Software 2 and Software 3 being similar (6.1% - 8% above code) and results from Software 4 being the least sensitive (2.7% above code) to the change in U-value. For Amarillo, similar trends are observed for the four software programs (2.3% - 5.8% above code).

Variation in Slab R-value:
The comparison of slab R-values is presented in Figure 11. Since there are no requirements in the 2009 IECC for slab insulation in Climate Zone 2 and Climate Zone 3, the analysis is performed only for Amarillo, Climate Zone 4. For the 2009 IECC compliant case the four software programs provide similar results (within 1% of the code). For un-insulated floor slab (R-0), results from Software 1, Software 2 and Software 3 are within 10%. However, results from Software 4 are extremely sensitive with greater than 35% below code compliant base-case. For the slab insulation of R-15, results from Software 1, Software 2 and Software 4 are similar. Software 3 does not support the input for R-15 for the slab. Hence the result from Software 3 was not available.

SUMMARY & DISCUSSIONS

This analysis explores the differences in results obtained from the four software programs that are currently used for performance path compliance with the 2009 IECC in the State of Texas. Three of the Software programs used for the analysis are certified by RESNET. A 2009 IECC compliant house was used to perform the analysis. 500 ft^2/ton of refrigeration (500 ft^2/ 12000 Btu/hr for heating) is used to size the cooling systems in the Proposed house for Software 1, Software 2 and Software 3. When sizing systems for the Reference house, 500 ft^2/ton is used to size the cooling systems in Software 1 and Software 3. However, Software 2 uses a different criteria to size cooling and heating systems.

For variations in parameters such as house size, exterior wall insulation, window SHGC and window U-value, the sensitivity analysis indicates a variation within 5% for the RESNET certified software programs considered for the analysis. However, variation in results from the three RESNET certified software programs exceeds 5% in certain cases of ceiling R-values in all climate zones and in certain cases of window-to-wall area ratios in Climate Zone-4.

It should also be noted that system sizing for Software 1 and Software 3 were set at 500 ft^2/ton for both the reference house and proposed house. Systems for Software 2 was auto-sized. For the condition of ducts in attic, the system sizing for Software 2 were similar to the sizing values of other two software programs. Although system sizing does not play a significant role in the analysis described by this paper, variations in system sizing were the cause of variation in results in cases other than what was selected for this paper such as ducts in conditioned space (Mukhopadhyay et al. 2012).

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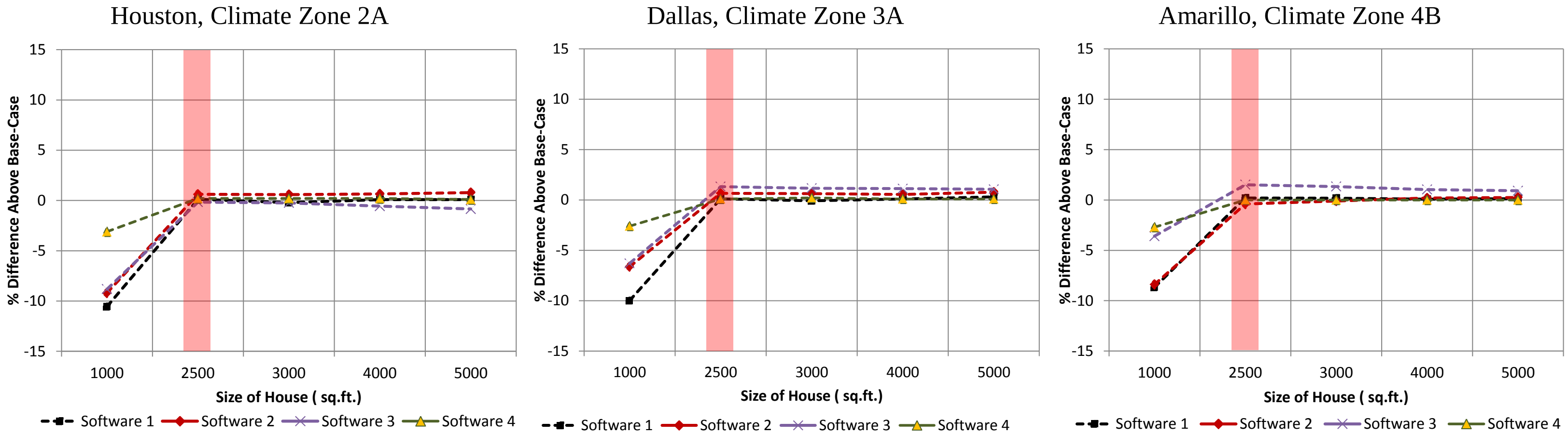

Figure 4: Variation in Size of House (Fixed Window Area)

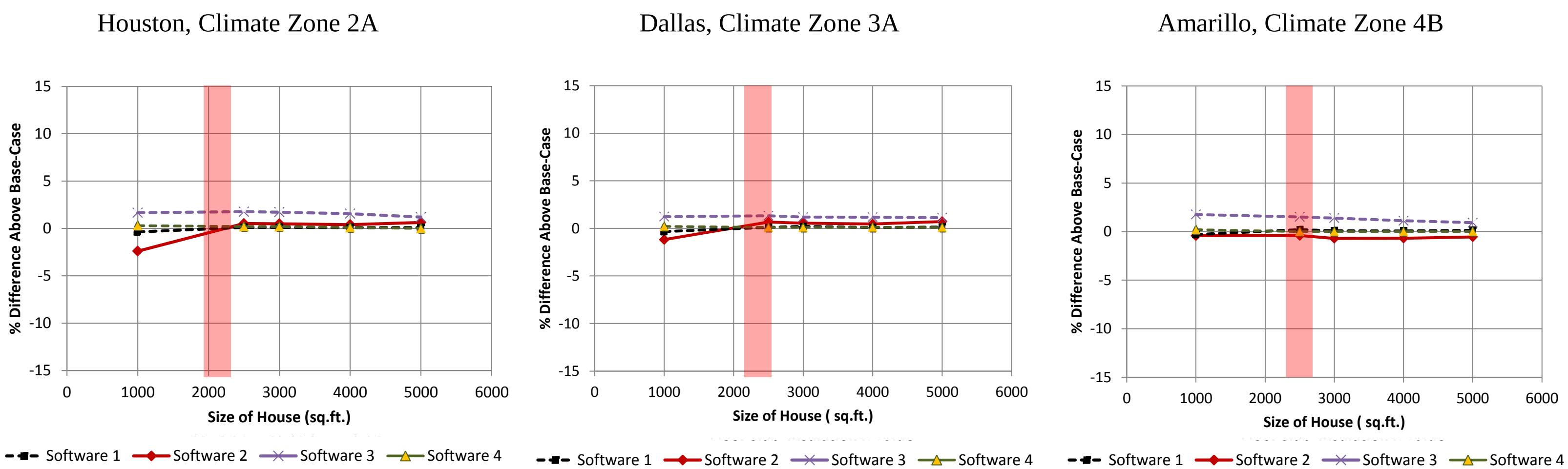

Figure 5: Variation in Size of House (Fixed Window-to-Wall Area Ratio)

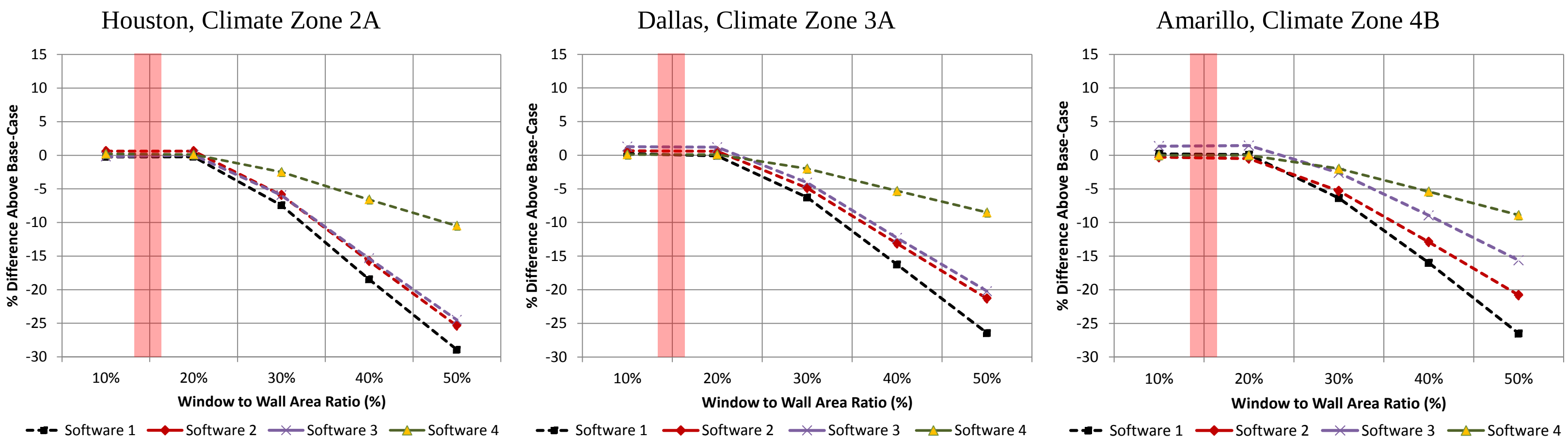

Figure 6: Variation in Window to Wall Area Ratio

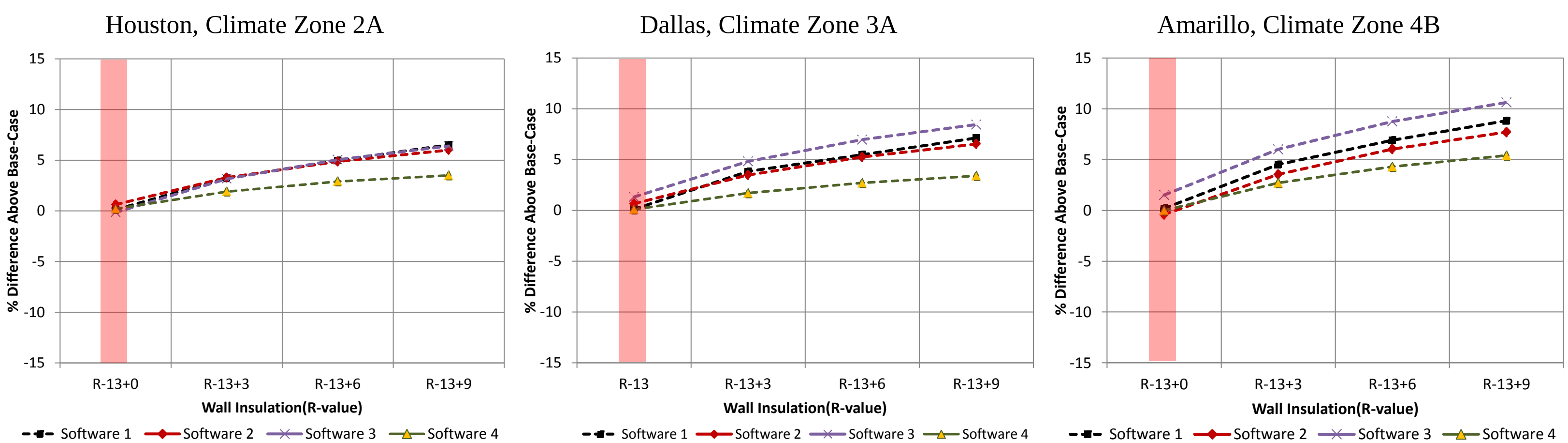

Figure 7: Variation in Wall Insulation

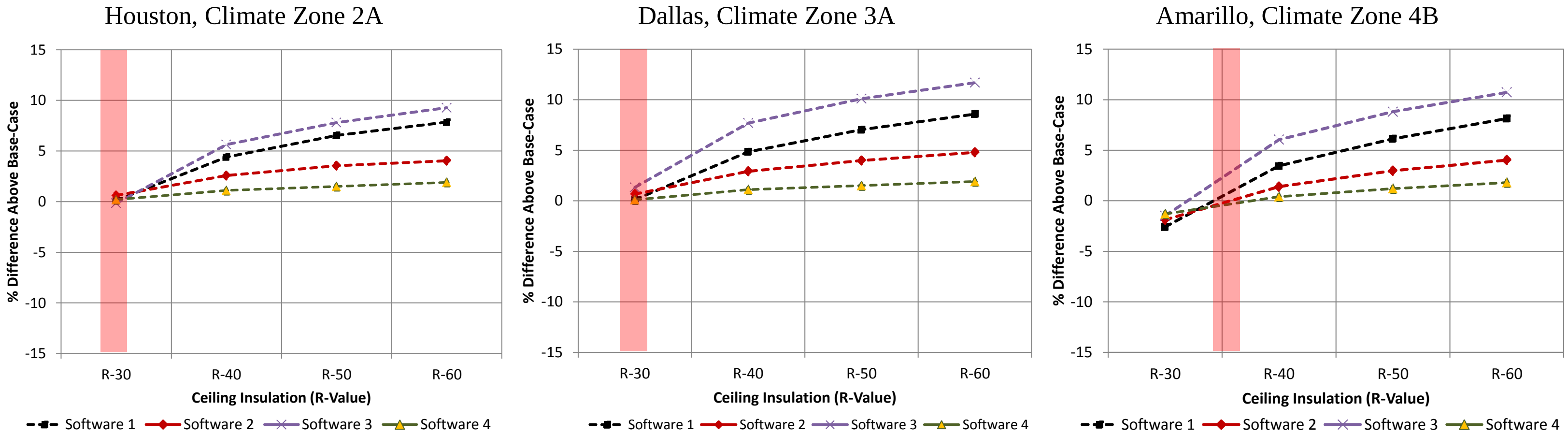

Figure 8: Variation in Ceiling Insulation

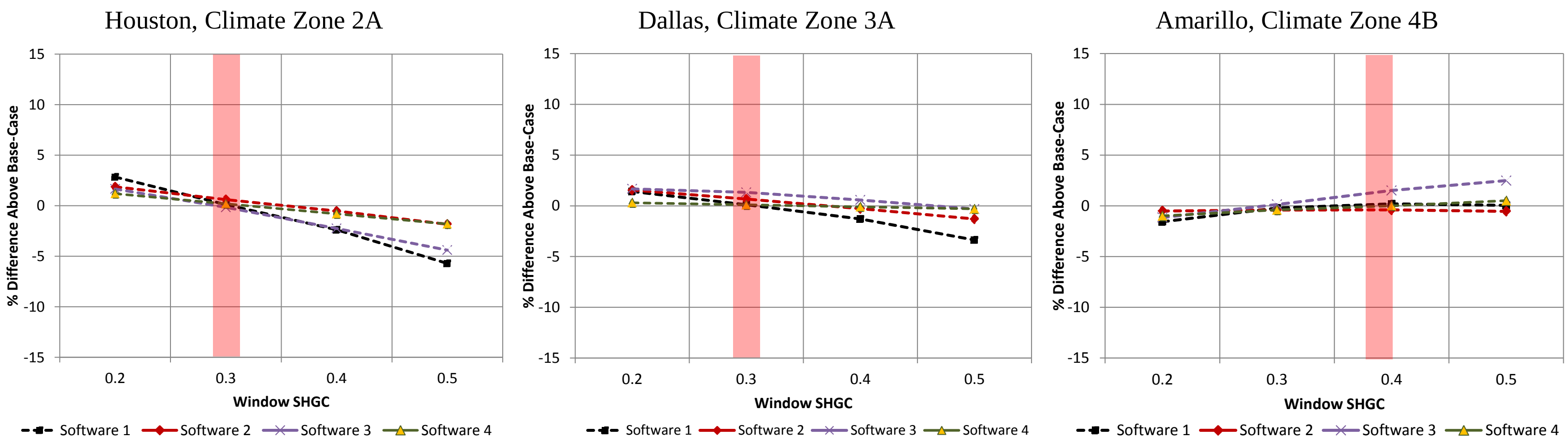

Figure 9: Variation in Window SHGC

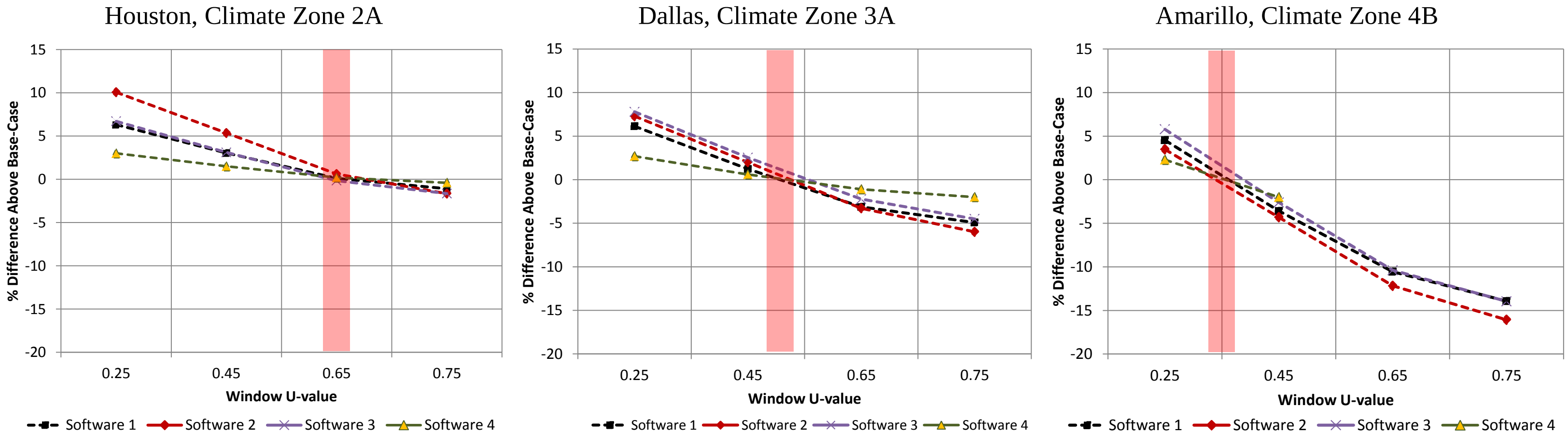

Figure 10: Variation in Window U-values

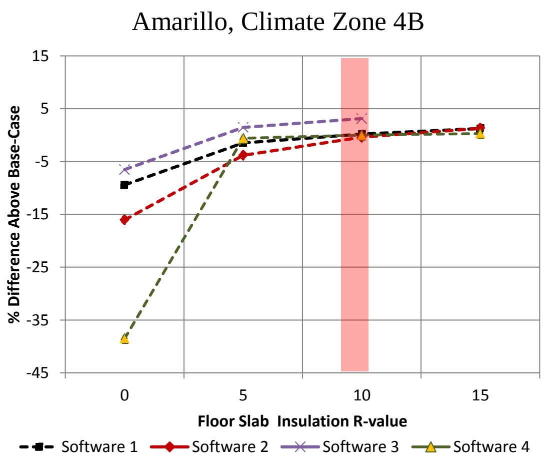

Figure11: Variation in Slab R-Value