FSEC Energy Research Center

UNIVERSITY OF CENTRAL FLORIDA

Relative International Energy Conservation Code (IECC) Energy Impacts by Compliance Path

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Executive Summary

Under Task 4 of contract No. DE-EE0008699 with the U.S. Department of Energy, the FSEC Energy Research Center has conducted building energy simulation analysis examining energy use implications of 2018 International Energy Conservation Code (IECC). The intent of the study is to evaluate the relative energy impacts and estimated energy use for IECC-compliant homes by compliance method – differentiating between prescriptive and performance-based methods – and compare results for each climate zone.

The building energy simulation study is conducted using an in-house version of EnergyGauge® USA (v.6.2), which is a DOE-2E-based building energy simulation engine coupled with a user-friendly graphical user interface. EnergyGauge USA is explicitly designed to perform IECC code compliance and Energy Rating Index functions and has been certified by the Residential Energy Services Network (RESNET) as an accredited HERS Software Tool.[1]

The analysis comprises comparisons between the 2018 IECC prescriptive R-Value compliance provisions, the Total UA Alternative provisions (Sections R402-R404), the Simulated Performance Alternative provisions (Section R405) and the Energy Rating Index Alternative compliance provisions (Section R406). The residential buildings architypes, developed by Pacific Northwest National Laboratory (PNNL) for U.S. DOE Energy Code cost-effectiveness studies, are used for the analysis along with the 14 representative climates of the contiguous U.S. from the same reference.[2]

A separate task under this contract (Task 3) examines the Energy Code gaps and issues with respect to prescriptive versus performance-based 2018 IECC compliance.[3] That task identifies issues related to envelope leakage, air distributions system leakage and mechanical ventilation, which could impact consistencies between prescriptive and performance-based compliance methods. As a result, this study evaluates how these issues impact differences between the prescriptive and performance-based code compliance.

The findings from the study indicate that there are sometimes significant differences between alternative prescriptive provisions, with the R-Value specifications being more stringent than the UA Alternative specifications in many of the climate locations. Analysis also shows that there is very significant difference between IECC Section R406 and its referenced ANSI Standard for the calculation of ERI due to the R406.3 exception to that referenced ANSI Standard. Evaluation of the window provisions also shows significant differences between the prescriptive and the performance provisions of the IECC with the Total UA Alternative being far less stringent than the Simulated Performance Alternative.

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[1] RESNET Publication 002-2020, "Procedures for Verification of RESNET Accredited HERS Software Tools." Residential Energy Services Network, Oceanside, CA, June 2020.
[2] Taylor, Mendon & Fernandez, "Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes." Report No. PNNL-21294 Rev 1, August 2015.
[3] Stacey, J. and M. Britt, "Task 3. International Energy Code Gaps and Issues Identification." International Code Council, 500 New Jersey Avenue, NW, 6th Floor, Washington, DC 20001. https://www.iccsafe.org/wp-content/uploads/20-18991_CORP_GR_IECC_Gaps_RPT_Final.pdf

Relative International Energy Conservation Code (IECC) Energy Impacts by Compliance Path

Task 4: Market Driven Residential Energy Codes:
Comparing Performance in a Changing Technological Environment
(DE-EE0008699)

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March 4, 2021

Background

The U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy contracted the FSEC Energy Research Center to evaluate the relative energy impacts and estimated energy use for International Energy Conservation Code (IECC) compliant homes by compliance method – differentiating between *prescriptive* and *performance*-based methods – and compare results for each climate zone. The project team adaptes prototype homes used by Pacific Northwest National Laboratories (PNNL) in previous DOE energy code analyses to evaluate prescriptive and performance compliance methods of the 2018 IECC.[4] These building prototypes are used to conduct simulation studies of the relative energy use and environmental impacts in all climate regions for 2018 IECC compliant homes. This builds on the DOE energy code analysis performed by PNNL for the IECC. This task addresses the primary research question: Does selection of the compliance path (prescriptive or performance) significantly influence home energy use? Or, alternatively phrased: Do homes complying via the performance path use less energy than homes complying via prescriptive methods?

The prescriptive versus performance-based compliance question is also addressed by another task in this project (Task 1) via utility billing analysis. Task 1 addresses the question from the perspective of measured performance while this task addresses the question from a modeling and simulation perspective. Each of these tasks informs the other task in ways that make project results more meaningful and comprehensive.

Abstract

The EnergyGauge® USA (v.6.2) residential building energy simulation software tool is used to examine energy impacts in two-story, 2,376 ft^2, single-family homes configured in accordance with the minimum requirements of Section R402-R404 of the 2018 IECC in 14 representative U.S. cities.[4] EnergyGauge USA is a RESNET-accredited HERS software tool capable of evaluating not only the HERS Index and the IECC Section R406 Energy Rating Index Compliance Alternative but also the IECC Section R405 Simulated Performance Alternative as well as the IECC Section R402 R-Value and Total UA Alternative prescriptive methods along with all of the IECC mandatory minimum requirements of all of these compliance methods.

[4] Taylor, Mendon & Fernandez, "Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes." Report No. PNNL-21294 Rev 1, August 2015.

Simulations for each home prototype are conducted using three foundation types: Slab-on-grade (SOG), crawlspace and basement. For each prototype and foundation type, each of the IECC compliance methods is evaluated on the basis of pass/fail and on the basis of performance comparison. For example, where the code evaluation is via the Total UA Alternative, the IECC baseline Total UA value is compared against the prototype Total UA value to determine the compliance ratio between the prototype and the IECC baseline. A similar comparison is conducted for the R405 Simulated Performance Alternative. Additionally, the R406 Energy Rating Index Compliance Alternative (ERI) is compared against the HERS Index for each prototype and each foundation configuration.

Methodology

Two-story, 2,376 ft^2, 3-bedroom frame homes are configured on three foundation types in 14 representative climates to simulate energy impact differences between prescriptive and performance-based IECC compliance paths across seven of the eight IECC climate zones of the United States. Climate zone 8, representing only Alaska, is not considered in this analysis due to the fact that so few new single-family building permits are issued in Alaska. Prototype homes are configured in accordance with the methodology developed by PNNL for IECC code development analysis.[5]

Window areas in the prototypes are configured to match the *Standard Reference Design* specification of 15% window-to-floor area with equal area facing in each of the cardinal orientations. Three different foundation types are used: slab-on-grade, crawlspace and full basement. For basement foundations, the basement is assumed to be unfinished and unconditioned in climate zones 1-3 and to be finished and conditioned in climate zones 4-7. Crawlspace foundations are always assumed to be vented in accordance with the IECC *Standard Reference Design* specification. A total of 42 prototype home configurations are considered by the analysis.

Tables 1 through 4 present the characteristics for the 42 different home configurations used in the simulation analysis.

Table 1. Baseline Prototype Configuration

Component	Value
1st floor area (ft^2)	1,188
2nd floor area (ft^2)	1,188
Basement floor area (ft^2)*	1,188
Total floor area (ft^2)	2,376
Total volume (ft^3)	20,196
N-S wall length (ft)	54
E-W wall length (ft)	22
1st floor wall height (ft)	8
Height between floors (ft)	1
2nd floor wall height (ft)	8
Door area (ft^2)	42
Window/floor area (%)	15%
Total window area (ft^2)	356.4

[5] *Ibid*

Table 1. Baseline Prototype Configuration

Component	Value

* Where foundation type is basement

Table 2: 2018 IECC Component Insulation Values (SOG homes)

LOCATION	IECC CZ	Ceiling R-Value	AG Wall R-Value	Found. type	Slab R-Value	Fenestration U-Factor	Fenestration SHGC
Miami, FL	1A	30	13	SOG	none	0.50	0.25
Houston, TX	2A	38	13	SOG	none	0.40	0.25
Phoenix, AZ	2B	38	13	SOG	none	0.40	0.25
Memphis TN	3A	38	13+5	SOG	none	0.32	0.25
El Paso, TX	3B	38	13+5	SOG	none	0.32	0.25
San Francisco, CA	3C	38	13+5	SOG	none	0.32	0.25
Baltimore, MD	4A	49	13+5	SOG	10, 2 ft.	0.32	0.40
Albuquerque, NM	4B	49	13+5	SOG	10, 2 ft.	0.32	0.40
Salem, OR	4C	49	13+5	SOG	10, 2 ft.	0.30	0.40
Chicago, IL	5A	49	13+5	SOG	10, 2 ft.	0.30	0.40
Boise, ID	5B	49	13+5	SOG	10, 2 ft.	0.30	0.40
Burlington, VT	6A	49	13+10	SOG	10, 4 ft.	0.30	0.40
Helena, MT	6B	49	13+10	SOG	10, 4 ft.	0.30	0.40
Duluth, MN	7A	49	13+10	SOG	10, 4 ft.	0.30	0.40

Table 3: 2018 IECC Component Insulation Values (Crawlspace homes)

LOCATION	IECC CZ	Ceiling R-Value	AG Wall R-Value	Found. type	Floor R-Value	Fenestration U-Factor	Fenestration SHGC
Miami, FL	1A	30	13	Crawl	13	0.50	0.25
Houston, TX	2A	38	13	Crawl	13	0.40	0.25
Phoenix, AZ	2B	38	13	Crawl	13	0.40	0.25
Memphis TN	3A	38	13+5	Crawl	19	0.32	0.25
El Paso, TX	3B	38	13+5	Crawl	19	0.32	0.25
San Francisco, CA	3C	38	13+5	Crawl	19	0.32	0.25
Baltimore, MD	4A	49	13+5	Crawl	19	0.32	0.40
Albuquerque, NM	4B	49	13+5	Crawl	19	0.32	0.40
Salem, OR	4C	49	13+5	Crawl	30	0.30	0.40
Chicago, IL	5A	49	13+5	Crawl	30	0.30	0.40
Boise, ID	5B	49	13+5	Crawl	30	0.30	0.40
Burlington, VT	6A	49	13+10	Crawl	30	0.30	0.40
Helena, MT	6B	49	13+10	Crawl	30	0.30	0.40
Duluth, MN	7A	49	13+10	Crawl	38	0.30	0.40

Table 4: 2018 IECC Component Insulation Values (Basement homes)

LOCATION	IECC CZ	Ceiling R-Value	AG Wall R-Value	Found. type	BG Wall R-Value	Floor R-Value	Fenestration U-Factor	Fenestration SHGC
Miami, FL	1A	30	13	U-bsmt	0	13	0.50	0.25
Houston, TX	2A	38	13	U-bsmt	0	13	0.40	0.25
Phoenix, AZ	2B	38	13	U-bsmt	0	13	0.40	0.25
Memphis TN	3A	38	13+5	U-bsmt	0	19	0.32	0.25
El Paso, TX	3B	38	13+5	U-bsmt	0	19	0.32	0.25
San Francisco, CA	3C	38	13+5	U-bsmt	0	19	0.32	0.25
Baltimore, MD	4A	49	13+5	C-bsmt	10 (ext)	0	0.32	0.40
Albuquerque, NM	4B	49	13+5	C-bsmt	10 (ext)	0	0.32	0.40
Salem, OR	4C	49	13+5	C-bsmt	15 (ext)	0	0.30	0.40
Chicago, IL	5A	49	13+5	C-bsmt	15 (ext)	0	0.30	0.40
Boise, ID	5B	49	13+5	C-bsmt	15 (ext)	0	0.30	0.40
Burlington, VT	6A	49	13+10	C-bsmt	15 (ext)	0	0.30	0.40

Table 4: 2018 IECC Component Insulation Values (Basement homes)

LOCATION	IECC CZ	Ceiling R-Value	AG Wall R-Value	Found. type	BG Wall R-Value	Floor R-Value	Fenestration	
							U-Factor	SHGC
Helena, MT	6B	49	13+10	C-bsmt	15 (ext)	0	0.30	0.40
Duluth, MN	7A	49	13+10	C-bsmt	15 (ext)	0	0.30	0.40

Where the basement is finished and conditioned, the total conditioned floor area of the prototype home is increased by 1,188 ft^2 to a total conditioned floor area of 3,564 ft^2.

All 2018 IECC mandatory minimums and R405 requirements are also included in the baseline prototype configurations. These mandatory minimums and R405 requirements are shown in Table 5. The baseline prototypes also assumes NAECA minimum federal heating, cooling and service hot water system efficiencies.

Table 5. Baseline prototype mandatory minimum and R405 assumptions

Characteristic	Baseline prototype configuration
Envelope leakage	CZ 1-2: 5.0 ach at 50 Pa pressure CZ 3-7: 3.0 ach at 50 Pa pressure
Internal Gains	Btu/day = 17,900 + 23.8*CFA + 4104*Nbr
Duct location	Attic for slab-on-grade and crawlspace homes Basement for basement homes
Tested duct leakage	4 cfm per 100 ft^2 CFA at 25 Pa pressure
Duct insulation	IAW Section R403.3.1
Factory sealed air handlers	All prototypes
Mechanical ventilation rate	Fan cfm = 0.01 * CFA + 7.5*(Nbr+1)
Mechanical ventilation fan efficiency	kWh/y = (1/e_f) * (0.0876*CFA+65.7*(Nbr+1))
Equipment Sizing	ACCA Manual J, eighth Edition
Lighting efficiency	90% high efficiency (= 60 lumens/Watt)
Thermostat type and settings	Manual: 75 ºF cooling; 72 ºF heating

Simulations for each home prototype are conducted using three foundation types: slab-on-grade, crawlspace and basement. For each prototype and foundation type, each of the IECC compliance methods are evaluated on the basis of pass/fail and on the basis of performance comparison. For example, where the code evaluation is via the Total UA Alternative, the IECC prototype Total UA value is compared against the baseline Total UA value to determine the compliance ratio for the prototype. For example, if the Total UA Alternative value is 300 and the IECC prototype Total UA value is 320, the UA compliance ratio equal to 300/320 = 0.94. Thus, acompliance ratio less than or equal to 1.0 represents code compliance and one greater than 1.0 represents non-compliance. Similar compliance ratio comparisons are conducted for the R405 Simulated Performance Alternative. Additionally, the R406 Energy Rating Index Compliance Alternative (ERI) is compared against the HERS Index for each baseline prototype and each foundation configuration.

Findings

Total UA Alternative Method

The baseline prototypes are all configured using the envelope insulation values of 2018 IECC Table R402.1.2, which for non-fenestration, are expressed as R-Values. For EnergyGauge simulations these R-Value inputs often result in slightly to moderately different U-Factors than the U-Factors from Table R402.1.4. The U-Factor calculations using the EnergyGauge envelope assembly characteristics are shown in Table 6 through Table 9.

Table 6. EnergyGauge U-Factors for Table R402.1.2 Frame Wall Assemblies

R402.1.2 Walls	R-13		R-13+5		R-13+10	
Components:	frame	cavity	frame	cavity	frame	cavity
outdoor air film	0.17	0.17	0.17	0.17	0.17	0.17
1” stucco	0.20	0.20	0.20	0.20	0.20	0.20
building paper	0.06	0.06	0.06	0.06	0.06	0.06
insulation	---	---	5.00	5.00	10.00	10.00
5/8” plywood	0.78	0.78	0.78	0.78	0.78	0.78
wall framing	4.37	---	4.37	---	4.37	---
insulation	---	13	---	13	---	13
gypsum drywall	0.45	0.45	0.45	0.45	0.45	0.45
indoor air film	0.68	0.68	0.68	0.68	0.68	0.68
Sum R	6.72	15.34	11.72	20.34	16.72	25.34
Frame fraction	0.23	0.77	0.23	0.77	0.23	0.77
UA	0.0343	0.0502	0.0196	0.0379	0.0138	0.0304
EGUSA U-Factor:	**0.084**		**0.057**		**0.044**	
R402.1.4 U-Factor:	**0.084**		**0.060**		**0.045**	

Table 6 shows the U-Factor calculation for three wall systems specified by Table R402.1.2: an R-13 wall system for climate zones 1-3, an R-13+5 wall system for climate zones 3-5 and an R-13+10 wall system for climate zones 6-8. Note that the U-Factors from Table 402.1.4 for these climate zones are 0.084, 0.060 and 0.045, respectively. As a result, the 2,185.6 ft^2 frame wall assembly, which achieves no UA benefit in climate zones 1 & 2 for the R-13 wall system, achieves a UA benefit of -6.56 Btu/h·°F in climate zones 3-5 and a more modest UA benefit of -2.19 Btu/h·°F in climate zones 6-8.

Table 7. EnergyGauge U-Factors for Table R402.1.2 Ceilings/Roof Assemblies

R402.1.2 Ceilings/Roofs	R-30		R-38		R-49	
Component	frame	cavity	frame	cavity	frame	cavity
outdoor air film	0.17	0.17	0.17	0.17	0.17	0.17
roof	1.68	1.68	1.68	1.68	1.68	1.68
attic (2017 HOF)	1.37	1.37	1.37	1.37	1.37	1.37
insulation	17.75	30	25.75	38	36.75	49
ceiling framing	4.37	---	4.37	---	4.37	---
gypsum drywall	0.45	0.45	0.45	0.45	0.45	0.45
indoor air film	0.76	0.76	0.76	0.76	0.76	0.76
Sum R	26.55	34.43	34.55	42.43	45.55	53.43
Frame fraction	0.11	0.89	0.11	0.89	0.11	0.89
UA	0.0041	0.0258	0.0032	0.0210	0.0024	0.0167
EGUSA U-Factor:	**0.030**		**0.024**		**0.019**	
R402.1.4 U-Factor:	**0.035**		**0.030**		**0.026**	

Table 7 shows a considerable difference between ceiling/roof assembly U-Factors calculated using the EnergyGauge assembly configurations and the U-Factors given by 2018 IECC Table R402.1.4 with every climate gaining the benefit of a vented attic system in the Total UA Alternative method. As a result, the 1,188 ft^2 ceiling/attic/roof for the EnergyGauge prototype achieves a UA benefit of -5.94 Btu/h·°F in climate zone 1, -7.13 Btu/h·°F in climate zones 2 and 3 and -8.32 Btu/h·°F in climate zones 4-8.

Table 8. EnergyGauge U-Factors for Table R402.1.2 Crawlspace Floor Assemblies

R402.1.2 Floors	R-13		R-19		R-30		R-38	
Component	frame	cavity	frame	cavity	frame	cavity	frame	cavity
crawl air film	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
floor framing	6.87	---	6.87	---	6.87	---	6.87	---
insulation	0.00	13	0	19	0	30	0	38
floor decking	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
carpet & pad	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08
indoor air film	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Sum R	11.76	17.89	11.76	23.89	11.76	34.89	11.76	42.89
Frame fraction	0.13	0.87	0.13	0.87	0.13	0.87	0.13	0.87
UA	0.0111	0.0486	0.0111	0.0364	0.0111	0.0249	0.0111	0.0203
EGUSA U-Factor:	**0.060**		**0.047**		**0.036**		**0.031**	
R402.1.4 U-Factor:	**0.064**		**0.047**		**0.033**		**0.028**	

Table 8 shows a mix of differences between the crawlspace floor assembly U-Factors calculated using the EnergyGauge assembly configurations and the U-Factors given by 2018 IECC Table R402.1.4. As a result, the 1,188 ft^2 floor assemblies of the EnergyGauge prototype achieve a UA benefit of -4.75 Btu/h·°F in climate zones 1and 2 with R-13 floor assemblies, achieve no UA benefit or detriment in climate zones 3 and 4 with R-19 floor assemblies and a UA detriment of 3.56 Btu/h·°F in climate zones 5-8 with R-30 and R-38 floor assemblies.

Table 9. Slab-on-Grade U-Factors for baseline prototypes

R402.1.2 Slab Floors	**R-0**	**R-10, 2**	**R-10,4**
EGUSA U-Factor:	1.042	0.767	0.684
R402.1.4 U-Factor:	N/A	N/A	N/A
RES*check* U-Factor:	1.042	0.767	0.684

Table 9 provides the slab-on-grade U-Factors used for the EnergyGauge results. These U-Factors are derived from the RES*check* Technical Support Manual using the following F-factor Equation (3.25) and the corresponding Table 3.37 Coefficients for Slab F-Factor Equation.[6]

$$\text{F-factor} = \text{intercept} + \text{coef 1} * \text{depth} + \text{coef 2} * \text{depth}^2$$

where:

intercept = 1.042

depth = total depth of insulation from slab edge

where for R-10 insulation, the coefficients are

coef 1 = -0.1855

coef 2 = 0.0240

[6] Schultz, R.W., R. Bartlett and Z.T. Taylor, "RES*check* Technical Support Document." Pacific Northwest National Laboratory, Report No. PNNL-28584, March 2019.

Table 10. EnergyGauge U-Factors for Table R402.1.2 Basement Wall Assemblies

R402.1.2 Basement Walls:	R-0		R-5 continuous		R-10 continuous		R-15 continuous	
Component	frame	cavity	frame	cavity	frame	cavity	frame	cavity
ext. insulation	0.00	0.00	5.00	5.00	10.00	10.00	15.00	15.00
8" Block	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
insulation (air)	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
gypsum drywall	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
indoor air film	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Sum R	3.15	3.15	8.15	8.15	13.15	13.15	18.15	18.15
Frame fraction	0.11	0.89	0.11	0.89	0.11	0.89	0.11	0.89
UA	0.0347	0.2827	0.0134	0.1093	0.0083	0.0677	0.0060	0.0491
EGUSA U-Factor:	**0.247**		**0.123**		**0.076**		**0.055**	
RES*check* U-Factor:	**0.149**		**0.079**		**0.055**		**0.043**	
R402.1.4 U-Factor:	**0.360**		**0.091**		**0.059**		**0.050**	

Table 10 shows the calculated U-Factors for the EnergyGauge basement wall assemblies without accounting for soil resistance. EnergyGauge assumes that the basement insulation is exterior to the wall and that the wall interior is configured with interior drywall on 3/4” furring in all cases. Table 10 also shows the U-Factor calculation in accordance with the RES*check* Technical Support Document calculation methodology assuming the total depth below ground for the basement walls is 7 feet.[7] The RES*check* U-Factor calculations are accomplished assuming the same interior basement wall finish used in the EnergyGauge configuration. EnergyGauge baseline prototypes assume an exterior wall insulation complying with the continuous wall insulation requirements of 2018 IECC Table R402.1.2.

Only homes in climate zones 4-7 are simulated with conditioned basements. For the Total UA Alternative compliance method, the 1,216 ft^2 basement wall assemblies in these homes achieve a UA benefit of -7.30 Btu/h·°F in climate zone 4 (except 4C) and achieve a UA benefit of -11.58 Btu/h·°F in climate zones 4C-7.

In its Simulated Performance Alternative calculations for these prototypes, EnergyGauge also locates 7 feet of the 8 foot high basement wall below grade. However, EnergyGauge does not make the assumptions made by the RES*check* Total UA Alternative Uo methodology for the IECC *standard reference design* case. For example, EnergyGauge assumes that the Table 402.1.4 U-Factor *standard reference design* requirement of 0.050 for climate zones 4C through 8 is met by only the basement wall system and its interior finishes and indoor film coefficient. As a result, the *standard reference design* case is more efficient than the *proposed design* case in the EnergyGauge R405 Performance Alternative simulations.

[7] *ibid*

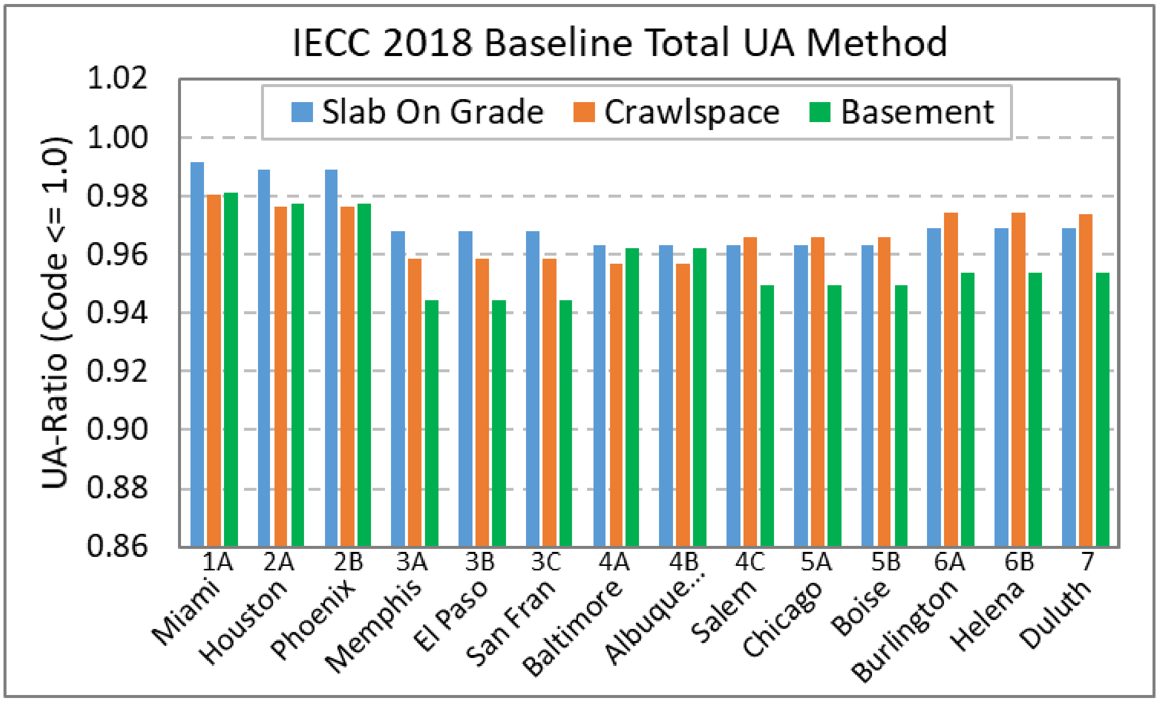

Figure 1. Total UA Alternative compliance ratios for the 42 baseline prototypes.

Figure 1 presents the Total UA Alternative compliance ratios (baseline prototype Total UA divided by Table 402.1.4 Total UA) for the 42 baseline prototypes in this study. A few items in Figure 1 are of note. First, there is little if any difference between basement compliance ratios for basements and crawlspaces in climate zones 1, 2 & 4 (except 4C). However, there is a significant difference in climate zones 3 and 4C-7, with basements exhibiting a smaller compliance ratio. Finally, for climate zone 4 (except 4C), all three foundation types show almost identical UA compliance ratios.

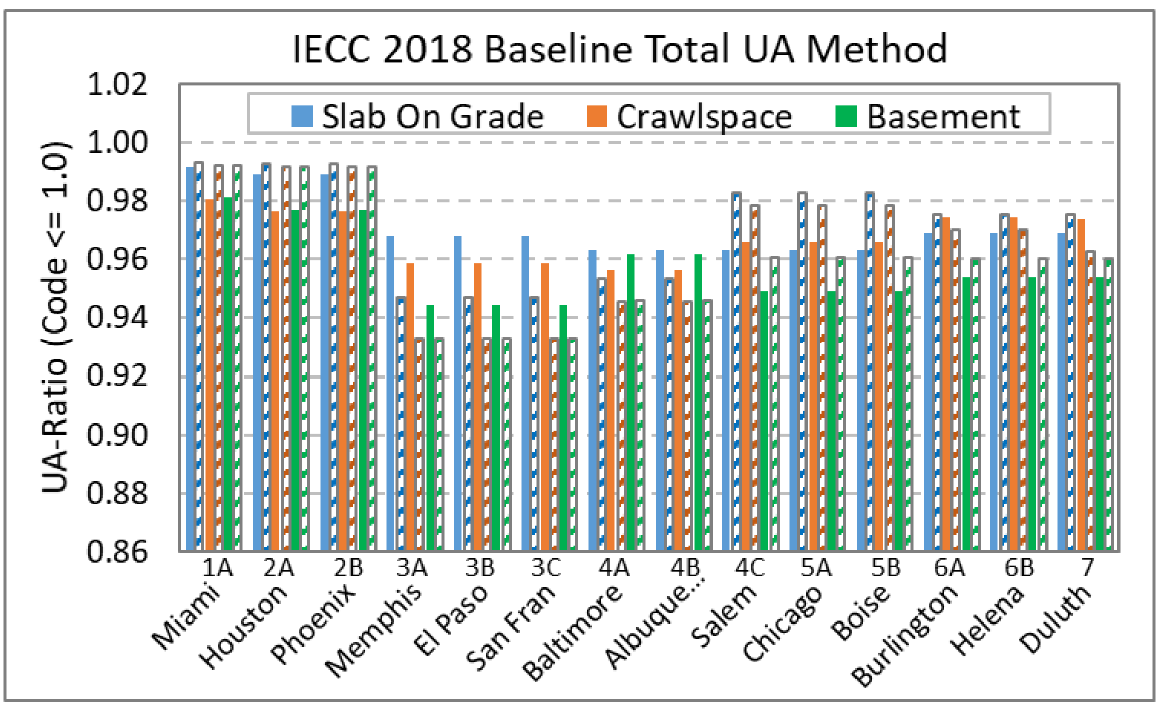

Figure 2. Total UA Alternative compliance ratios showing EnergyGauge results alongside RES*check* results with striped bars of the same color.

Figure 2 provides a comparison of the treatment of the IECC UA Alternative compliance method using both EnergyGauge and RES*check*. While there is some difference in the two sets of results, both sets tend to have the same climatic response with the RES*check* results being slightly more pronounced with respect to climate.

Simulated Performance Alternative Method

The 2018 IECC Section R405 Simulated Performance Alternative provides for comparison of a *proposed design* building with a *standard reference design* building of basically the same geometry in accordance with a set of building configuration provisions (sometimes called the "rule set") that specify how each energy feature of both building designs are to be treated in a comparative detailed energy simulation.

For the Simulated Performance Alternative, compliance is determined by energy cost, with energy prices "taken from a source *approved* by the *code official*, such as the Department of Energy, Energy Information Administration's State Energy Data System Prices and Expenditures reports." Table 11 provides the most recent prices reported by this source. These prices are used to determine the energy costs for the *proposed design* and the *standard reference design* for each of the baseline prototypes simulated. In addition, Table 10 includes statewide average electricity CO_2 emission factors.

Table 11. 2019 Statewide Average Electric and Gas Prices and 2018 Statewide CO_2 Emission Factors by Climate Location

Location	IECC CZ	\$/kWh[8]	\$/therm[8]	lbCO_2/kWh[8]	lbCO_2/therm[9]
Miami, FL	1A	\$0.1170	\$2.095	0.9940	11.76
Houston, TX	2A	\$0.1176	\$1.023	1.1926	11.76
Phoenix, AZ	2B	\$0.1243	\$1.301	1.3129	11.76
Memphis, TN	3A	\$0.1087	\$0.911	0.6264	11.76
El Paso, TX	3B	\$0.1176	\$1.023	1.1926	11.76
San Francisco, CA	3C	\$0.1915	\$1.249	0.3756	11.76
Baltimore, MD	4A	\$0.1312	\$1.210	0.6321	11.76
Albuquerque, NM	4B	\$0.1251	\$0.617	1.6871	11.76
Salem, MA	4C	\$0.1101	\$0.961	0.3925	11.76
Chicago, IL	5A	\$0.1303	\$0.775	1.1144	11.76
Boise, ID	5B	\$0.0989	\$0.627	0.1636	11.76
Burlington, VT	6A	\$0.1771	\$1.267	0.0040	11.76
Helena, MT	6B	\$0.1113	\$0.684	2.3149	11.76
Duluth, MN	7	\$0.1304	\$0.777	0.9543	11.76

Note in Table 11 that there is a relatively wide range of both electric and gas prices as well as electric CO_2 emission factors. The IECC offers an alternative to the use of energy costs. Energy source multipliers of 3.16 for electricity and 1.1 for natural gas can be used instead. The use of source energy values provides greater consistency than the use of energy costs and that factor is also examined briefly by this study.

Figure 3 shows results for the baseline prototype homes when complying via the

[8] EIA 2019 Average Price per kWh for Total Electric Industry by State, EIA 2019 Average Residential Price per thousand cubic feet of natural gas by state and EIA 2018 Average electric CO_2 emissions by state.
[9] AP 42, Fifth Edition, Volume I, Chapter 1: External Combustion Sources, Section 1.4, Table 1.4-1 & Table 1.4-2 https://www3.epa.gov/ttn/chief/ap42/ch01/index.html

Simulated Performance alternative of Section R405 of the 2018 IECC using energy cost as the measure of compliance.

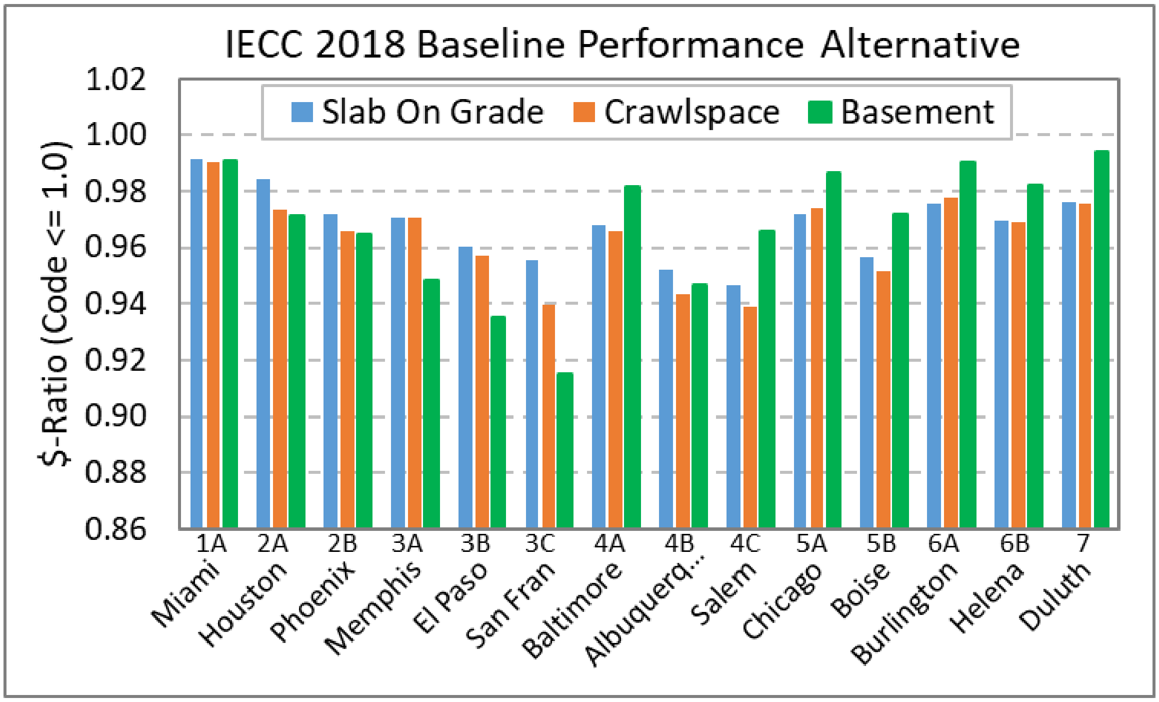

Figure 3. Simulated Performance Alternative compliance ratios for the baseline prototypes.

The Simulated Performance Alternative compliance ratios are based on the total energy cost estimates for the baseline prototypes (*proposed design*) as compared against the total energy cost estimates for the *standard reference design*.

Note that the difference between Figure 1 and Figure 3 is sometimes striking. The conditioned basement foundation cases in climate zones 4-7 are an illustrative example. The difference between the crawlspace foundation and the basement foundation have changed position, with the basement foundation having a larger compliance ratio than the crawlspace in Figure 3 rather than a smaller compliance ratio than the crawlspace as shown in Figure 1. This difference could be due to the fact that the basements in climate zones 4-7 are conditioned and those in climate zones 1-3 are unconditioned. For climate zone 3C (San Francisco), when comparing Figure 1 and Figure 3, the rather large impact of the marine climate is evident for all three foundation types and especially so for the unconditioned basement foundation. Climate zones 1 and 2 show reasonably similar Performance Alternative compliance ratios for all three of the foundation types.

As previously noted, Figure 3 compliance ratios are expressed as energy cost ratios ($-ratio) such that compliance must be equal to or less than 1.0. Additionally, one minus the $-ratio equals the fractional energy cost savings as compared to the IECC *standard reference design* such that if the compliance ratio equals 0.95, the fractional energy cost savings is 0.05 or 5% of the total energy cost for the code *standard reference design*.

In addition to energy cost savings, the simulation analysis examines the percentage savings achieved by the crawlspace prototype homes as a function of other metrics that can be used to determine savings. Each of the crawlspace prototypes is configured with natural gas heating equipment and four metrics are examined: energy cost as specified by

Section R405 of the IECC, source energy as provided in R405 exception and using CO_2 emissions and site energy use as comparators.

Figure 4 illustrates that there may not be a consistent metric for the determination of both energy and environmental savings. Energy cost and source energy use appear to be reasonably consistent metrics across climates. However, there does not appear to be consistency between source energy use and CO_2 emissions in many locations. This was an unexpected outcome.

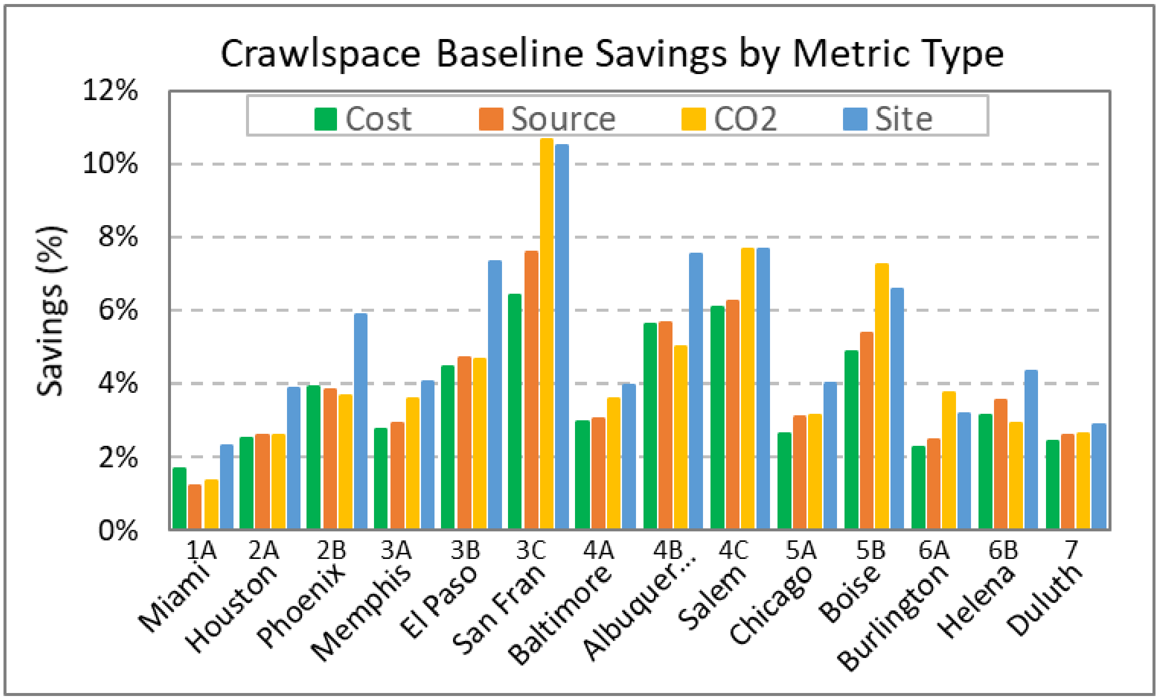

Figure 4. Baseline crawlspace prototype savings as a function of metric type.

Energy Rating Index Compliance Alternative

The Energy Rating Index (ERI) Compliance Alternative was added as a new IECC compliance path in the 2015 edition. In the 2018 IECC, this compliance alternative is more fully defined by the specification that the ERI shall be determined in accordance with RESNET/ICC 301.[10] However, the 2018 IECC specification adds an additional provision requiring the ventilation rate in the IECC ERI Reference Design to be significantly less than the ventilation rate for the RESNET/ICC 301 ERI Reference Design. Since the minimum ventilation rate for the ERI Rated Design case is not altered, this alteration of the ERI Reference Design rate causes the IECC ERI Reference Design to be much more efficient than the RESNET/ICC 301 Reference Design. Thus, the IECC R406 ERI calculation yields a larger ERI than does the RESNET/ICC 301 Standard. For convenience in distinguishing between the two values, they are referred to as the R406 ERI and the HERS Index, respectively.

[10] ANSI/RESNET/ICC 301-2014, "Standard for the Calculation and Labeling of the Energy Performance of Low-Rise Residential Buildings using an Energy Rating Index."

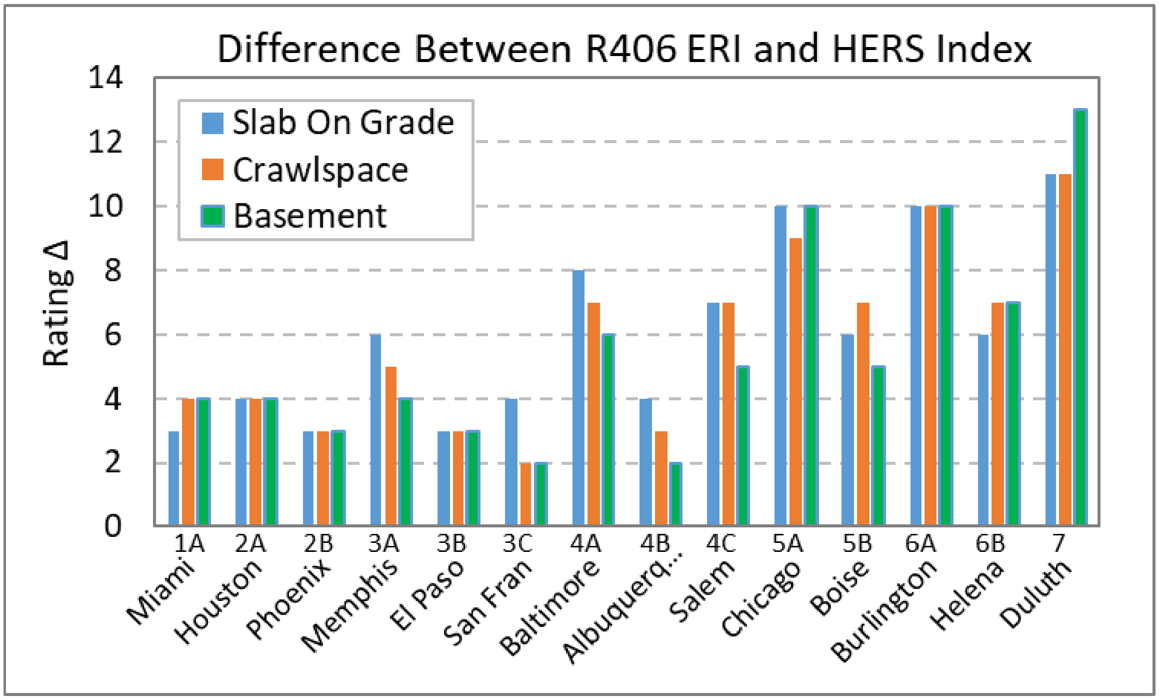

Figure 5. Differences between R406 ERI and HERS Index for 42 prototypes.

Figure 5 shows that the R406 ERI is always larger than the HERS Index. While there are some differences shown for foundation type, it appears that all differences increase as the climate locations become colder.

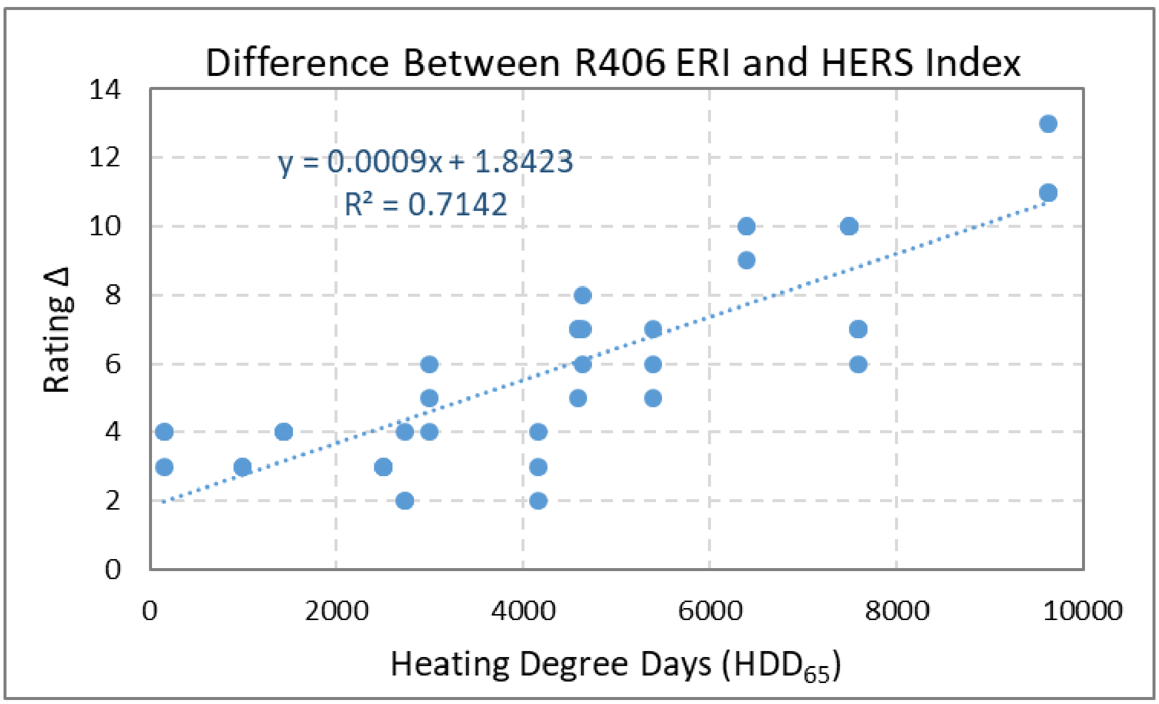

Figure 6. Correlation between Rating differenced and Heating Degree Days

As anticipated, Figure 6 makes it clear that the increases in R406 ERI as compared with the HERS Index are largely due to the coldness of the climate, with more than 70% of the Rating differences explained by the heating degree day (HDD_{65}) data. None of the baseline prototypes can comply using the Energy Rating Index Compliance Alternative, regardless of which index is selected to determine compliance. Table 12 provides the maximum Energy Rating Index requirements of Table R406.4 of the 2018 IECC. These Energy Rating Indices state that the normalized energy load of the Rated Design must be 57%-62% of the energy load of the ERI Reference Design. Since the ERI Reference Design is based on the minimum energy efficiency criteria of the 2006 IECC and the minimum national appliance and equipment standards in place in 2006, compliance with the ERI values provided in Table 12 represents 38%-43% savings over these 2006 standards.

Table 12. 2018 IECC Energy Rating Index Compliance Requirements

Climate Zone	Maximum Energy Rating Index
1	57
2	57
3	57
4	62
5	61
6	61
7	57
8	57

The baseline prototypes reported here use current NAECA minimum standard appliance and equipment efficiencies so no real advantage in Rating Index for high efficiency appliances or equipment is achieved by these prototypes. As shown in Figure 7, none of the prototypes is able to comply via the 2018 IECC Energy Rating Index Compliance Alternative.

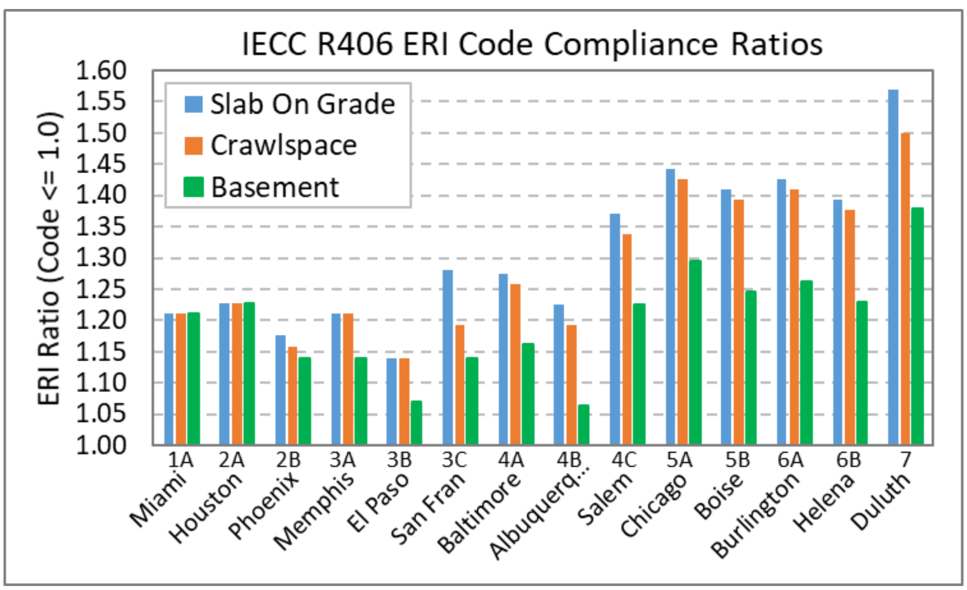

Figure 7. Baseline prototype IECC Rating Index compliance ratios.

Figure 7 shows that the ERI compliance ratios for these prototypes are significantly greater than the 2018 IECC compliance requirements with some indices more than 40% greater than the maximum allowed by Table R406.4. However, it is important to point out that the ERI Compliance Index values shown in Table 12 are designed to account for enhanced equipment efficiencies. The 2018 IECC Simulated Performance Alternative does not take enhanced equipment efficiencies into account so if greater efficiency heating, cooling, hot water equipment and appliances are used, the ERI ratios shown in Figure 7 will be reduced. Further, there are significant differences based on foundation type with basement foundations being the most common outlier.

Code Gaps and Issues

A separate task of this project identifies a number of IECC Code issues for which compliance verification is important.[11] These issues include new IECC testing requirements for envelope leakage and air distribution system leakage, where compliance verification is particularly important. This analysis considers each of these issues. In addition, window area impacts are considered. Only the crawlspace foundation type is used in these analyses. For most climates, this foundation represents the median performance compliance option (see Figure 3).

For the identified items, an impact analysis is conducted to see how each factor might alter compliance. Tables 12 through 14 provide the simulation alternatives used for these analyses. The highlighted columns represent the IECC requirement for each of the three energy features evaluated.

Table 12. Envelope leakages for air tightness evaluations.

Climate Zone	Simulated Envelope Leakages (ACH50)					
1-2	1.25	2.5	5.0	7.5	10.0	12.5
3-8	0.75	1.5	3.0	4.5	6.0	7.5
% Change in leakage	-75%	-50%	0%	+50%	+100%	+150%

Table 13. Duct leakages for distribution system evaluations.

Climate Zone	Simulated Duct Leakages (cfm25/100ft^2)					
1-8	0	2	4	6	8	10
% Change in leakage	-100%	-50%	0%	+50%	+100%	+150%

Table 14. Window Areas for window area evaluations.

Climate Zone	Simulated Window Areas (% W/CFA)					
1-8	5%	10%	15%	20%	25%	30%
% Change in W/CFA	-67%	-33%	0%	+33%	+67%	+100%

Because all of the baseline crawlspace prototypes are somewhat better than the minimum code requirement, with compliance $-Ratio values ranging from 0.94 in San Francisco to 0.99 in Miami (see Figure 3), compliance ratio results for the simulations in this section are normalized such that the code requirements shown in Tables 12 through 14 (highlighted columns with 0% change) produce a normalized compliance ratio of unity.

Envelope Air Tightness Evaluations

For the envelope air tightness evaluations, there are two basic climate considerations

[11] Stacey, J. and M. Britt, “Task 3. International Energy Code Gaps and Issues Identification.” International Code Council, 500 New Jersey Avenue, NW, 6th Floor, Washington, DC 20001. https://www.iccsafe.org/wp-content/uploads/20-18991_CORP_GR_IECC_Gaps_RPT_Final.pdf

because the code requirement for envelope leakage is different for climate zones 1-2 than it is for climate zones 3-8. For climate zones 1-2, the IECC requires maximum envelope leakage of 5 ach50 (5 air exchanges per hour at a 50 Pascal pressure difference). For climate zones 3-8, this maximum envelope leakage is reduced to 3 ach50. Both of these envelope leakage maximums represent relatively tight homes with natural infiltration rates that are less than 0.15 air changes per hour (ach). As a result, the IECC requires that buildings be provided with mechanical ventilation in accordance with the requirements of the *International Residential Code* or the *International Mechanical Code*, as applicable. Both of these codes require mechanical ventilation rates in accordance with Equation 1.

$$Qfan = 0.01 * CFA + 7.5 * (Nbr+1) \qquad \text{Eq. 1}$$

where:
Qfan = mechanical ventilation fan air flow, cfm
CFA = conditioned floor area, ft^2
Nbr = number of bedrooms

Table R405.5.2(1) of the 2018 IECC uses this same equation as the mechanical ventilation requirement for the *standard reference design* and this mechanical ventilation rate was maintained for all of the *proposed design* alternative envelope leakage alternatives shown in Table 12. Therefore, results show only the impact of alternative envelope leakage without any change in the mechanical ventilation rates.

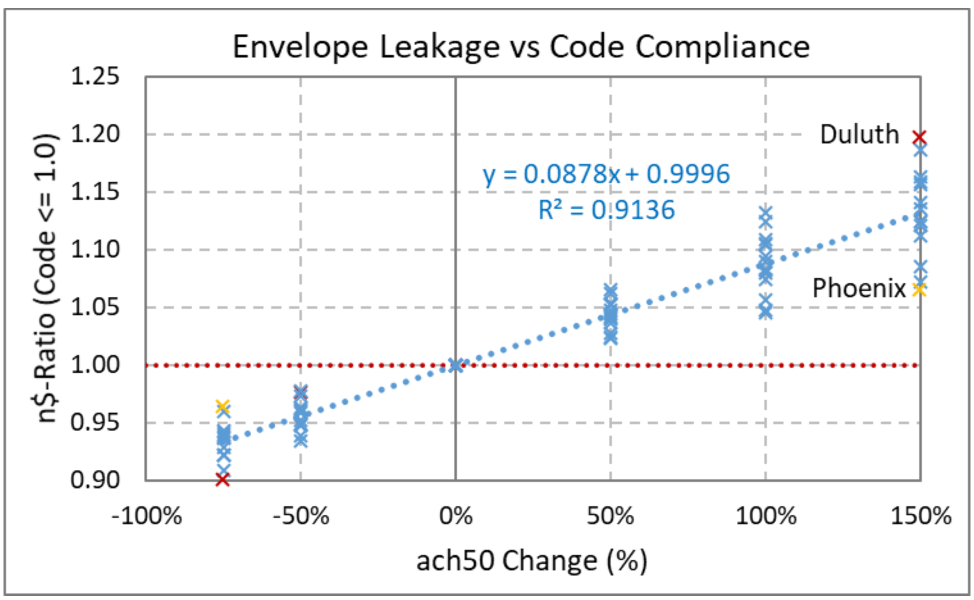

Figure 8. Normalized compliance ratios for various envelope leakages.

Figure 8 shows results of the envelope air tightness evaluation. For each climate, the data are linear with respect to the percentage change in ach50. Climate is a significant driver where Duluth, MN (red symbol), with the smallest n$-Ratio at -75% and the largest n$-Ratio at 150% has the steepest slope and Phoenix, AZ (yellow symbol), with the largest n$-Ratio at -75% and the smallest n$-Ratio at 150% has the gentlest slope. The climate impacts are large but the regression equation still explains almost 92% of the variance. It is also apparent that there are code savings available for reduced envelope leakage. The smallest envelope leakage shown in Figure 8 is the maximum allowed envelope leakage for PHIUS (Passive House Institute, US) certification, which for the building geometry used here is 0.74 ach50 or about -75% change from code requirements. Achieving

PHIUS envelope tightness certification for this home leads to approximately 3.3% IECC code savings in Phoenix, AZ, and approximately 9.6% IECC code savings in Duluth, MN, with an average of 6.4% IECC code savings across all 14 climates.

On the other side of the ledger, prior to the adoption of envelope leakage criteria within the IECC, typical envelope leakages likely were in the 100% - 150% range shown in Figure 8. Therefore, in the absence of adequate testing and verification, standard practice likely leads to 5-10% greater energy costs in homes.

Air Distribution System Leakage

Table R405.5.2(1) of the 2018 IECC specifies that if duct leakage is tested in the *proposed design* home, the *standard reference design* home shall have duct leakage of 4 cfm per 100 ft^2 of *conditioned floor area* at a pressure difference of 25 Pascal (4 cfm25/100ft^2). Section R403.3.3 also has a mandatory requirement that duct systems be tested for total leakage at either rough-in or post-construction. However, the actual amount of allowed duct leakage is a prescriptive requirement rather than a mandatory requirement. Therefore, when compliance is determined via the R405 Simulated Performance Alternative, there is no upper or lower duct leakage limit in the *proposed design* home.

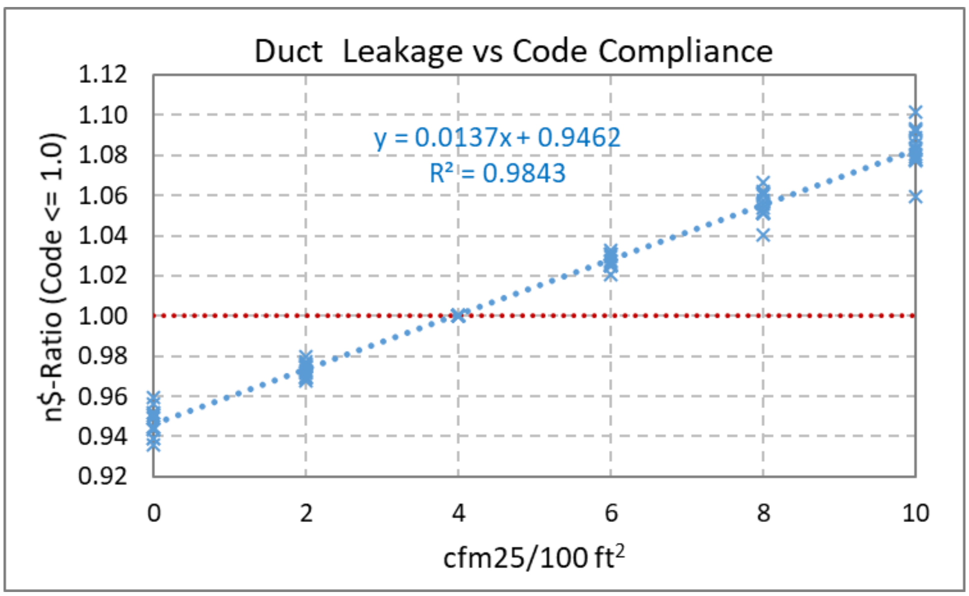

Figure 9. Normalized compliance ratios for various quantities of duct leakage.

Figure 9 shows the normalized compliance ratio impact of duct leakage in *proposed design* homes with alternative duct leakage quantities that vary from the *standard reference design*. The data show that Albuquerque, NM, with the smallest n$-Ratio at 0 cfm25/100$ft^2$ and the largest n$-Ratio at 10 cfm25/100$ft^2$ has the steepest slope and Phoenix, AZ, with the largest n$-Ratio at 0 cfm25/100$ft^2$ and the smallest n$-Ratio at 10 cfm25/100$ft^2$ has the gentlest slope. The air distribution system data are less climate dependent than the envelope air tightness data with more than 98% of the variance explained by the regression equation. Figure 9 also shows that eliminating air distribution system leakage results in annual energy cost savings of 4.0% in Phoenix, AZ, to 6.4% in Albuquerque, NM, with average savings across all climates of 5.3%

Prior to the adoption of air distribution system leakage criteria within the IECC, typical air distribution system leakages likely were in the 8-10 cfm25/100ft^2 range shown in

Figure 9. Coincidentally, the Distribution System Efficiency (DSE) of 0.88 provided in Table R405.5.2(2) of 2018 IECC for forced air systems with untested distributions systems located in conditioned space corresponds to air distribution system leakage in the range of 8-10 cfm25/100ft^2. Therefore, in the absence of adequate testing and verification, standard practice likely would lead to 5-10% greater energy costs in homes.

Window Area Evaluation

Window area is treated differently in different sections of the 2018 IECC. For prescriptive compliance, the UA of the proposed *building* is compared against the UA resulting from multiplying the U-Factors in Table R402.1.4 by the same assembly areas as in the proposed *building*. Thus, window area in the proposed *building* is treated as any other envelope component with its UA evaluated against the UA of the same window area in the IECC Total UA calculation. As a result, the window area can become exceedingly large without unduly impacting compliance using the Total UA Alternative. Table 15 provides the Total UA Alternative compliance ratios for the 14 baseline prototypes in this analysis. Note that all of these homes are able to comply with the Total UA Alternative even with 30% window/floor area percentage.

Table 15. Total UA compliance-ratio by window/floor area percentage.

Location	5%	10%	15%	20%	25%	30%
Miami	0.976	0.978	0.981	0.982	0.984	0.985
Houston	0.972	0.974	0.976	0.978	0.980	0.981
Phoenix	0.972	0.974	0.976	0.978	0.980	0.981
Memphis	0.948	0.954	0.958	0.963	0.966	0.969
El Paso	0.948	0.954	0.958	0.963	0.966	0.969
San Fran	0.948	0.954	0.958	0.963	0.966	0.969
Baltimore	0.946	0.952	0.957	0.961	0.965	0.968
Albuquerque	0.946	0.952	0.957	0.961	0.965	0.968
Salem	0.956	0.961	0.966	0.969	0.973	0.975
Chicago	0.956	0.961	0.966	0.969	0.973	0.975
Boise	0.956	0.961	0.966	0.969	0.973	0.975
Burlington	0.967	0.971	0.974	0.977	0.979	0.981
Helena	0.967	0.971	0.974	0.977	0.979	0.981
Duluth	0.966	0.970	0.974	0.977	0.979	0.981

Table 16 shows the Table 15 data normalized to the window/floor area percentage specified as the maximum window/floor area percentage in Table R405.5.2(1) (2018 IECC) for the *standard reference design* against which the *proposed design* is compared to determine compliance. Thus, all the values in the 15% column are unity.

Table 16. Normalized Total UA-ratio by window/floor area percentage

Location	5%	10%	15%	20%	25%	30%
Miami	0.995	0.998	1.000	1.002	1.003	1.004
Houston	0.995	0.998	1.000	1.002	1.003	1.005
Phoenix	0.995	0.998	1.000	1.002	1.003	1.005
Memphis	0.989	0.995	1.000	1.005	1.008	1.011
El Paso	0.989	0.995	1.000	1.005	1.008	1.011
San Fran	0.989	0.995	1.000	1.005	1.008	1.011

Table 16. Normalized Total UA-ratio by window/floor area percentage

Location	5%	10%	15%	20%	25%	30%
Baltimore	0.988	0.995	1.000	1.005	1.008	1.012
Albuquerque	0.988	0.995	1.000	1.005	1.008	1.012
Salem	0.990	0.995	1.000	1.004	1.007	1.010
Chicago	0.990	0.995	1.000	1.004	1.007	1.010
Boise	0.990	0.995	1.000	1.004	1.007	1.010
Burlington	0.992	0.997	1.000	1.003	1.005	1.007
Helena	0.992	0.997	1.000	1.003	1.005	1.007
Duluth	0.992	0.996	1.000	1.003	1.005	1.008

Table 16 clearly shows that doubling window area from 15% to 30% of window/floor area percentage has little impact on the Total UA compliance ratio with an average UA-ratio increase of only 0.009 (less than 1%).

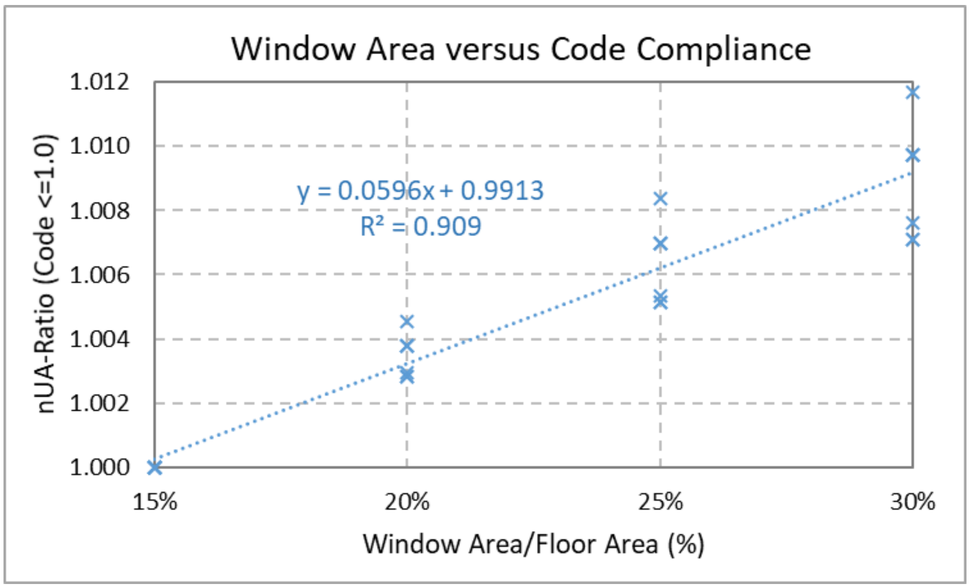

Figure 10. Normalized Total UA-ratio for window/floor area alternatives.

Figure 10 shows Table 16 data in graphic format. Since Total UA values are identical for homes in the same climate zone, there appear to be fewer data points than shown in Table 16 but that is because many of the data points overlap. More than 90% of the data variance is explained by the regression equation.

Window area impacts using the Simulated Performance Alternative are given in Table 17.

Table 17. Performance $-ratio by window/floor area percentage

Location	5%	10%	15%	20%	25%	30%
Miami	0.987	0.991	0.990	1.021	1.048	1.073
Houston	0.967	0.972	0.973	1.009	1.043	1.077
Phoenix	0.978	0.973	0.966	1.001	1.033	1.065
Memphis	0.958	0.966	0.971	1.011	1.050	1.089
El Paso	0.955	0.958	0.957	0.997	1.037	1.078
San Fran	0.929	0.933	0.939	0.978	1.018	1.059
Baltimore	0.953	0.961	0.966	1.002	1.039	1.078

Table 17. Performance $-ratio by window/floor area percentage

Location	5%	10%	15%	20%	25%	30%
Albuquerque	0.936	0.940	0.944	0.985	1.030	1.080
Salem	0.927	0.934	0.939	0.986	1.031	1.074
Chicago	0.964	0.971	0.974	1.006	1.037	1.070
Boise	0.947	0.948	0.951	0.992	1.032	1.071
Burlington	0.968	0.974	0.978	1.018	1.057	1.097
Helena	0.963	0.968	0.969	1.004	1.041	1.083
Duluth	0.968	0.971	0.976	1.015	1.054	1.094

Table 17 also shows that homes in five locations with 20% window/floor area percentages would still comply with the Section R405 Simulated Performance Alternative. However, in all climates the energy costs of homes with 25% or 30% window/floor area exceed the R405 standard reference and would not comply. Also, our simulations modeled homes with windows distributed equally on four sides as in the standard reference design. If modeled with unfavorable glass orientations the R405 method would show even greater difficulty complying, whereas the Total UA method totally ignores solar gain by orientation. When Table 17 data are normalized to the 15% window/floor area maximum of the *standard reference design* as specified by Section R405, the data shown in Table 18 are obtained where the 15% column is unity.

Table 18. Normalized Performance $-ratio by window/floor area percentage

Location	5%	10%	15%	20%	25%	30%
Miami	0.996	1.000	1.000	1.031	1.058	1.083
Houston	0.994	0.999	1.000	1.037	1.072	1.106
Phoenix	1.013	1.007	1.000	1.036	1.070	1.103
Memphis	0.987	0.995	1.000	1.041	1.082	1.121
El Paso	0.998	1.001	1.000	1.042	1.084	1.126
San Fran	0.989	0.994	1.000	1.041	1.083	1.127
Baltimore	0.986	0.995	1.000	1.038	1.076	1.116
Albuquerque	0.992	0.997	1.000	1.044	1.092	1.145
Salem	0.988	0.994	1.000	1.050	1.097	1.144
Chicago	0.989	0.997	1.000	1.033	1.065	1.099
Boise	0.995	0.997	1.000	1.043	1.084	1.126
Burlington	0.990	0.996	1.000	1.041	1.081	1.122
Helena	0.994	0.999	1.000	1.036	1.074	1.117
Duluth	0.992	0.995	1.000	1.041	1.081	1.122

Figure 11 provides a graphical representation of most of the data shown in Table 18. The 5% and 10% columns are not plotted in the chart because they are discontinuous with respect to the remainder of the data. Additionally, as shown in Table 18, they are virtually equivalent to the data in the 15% column.

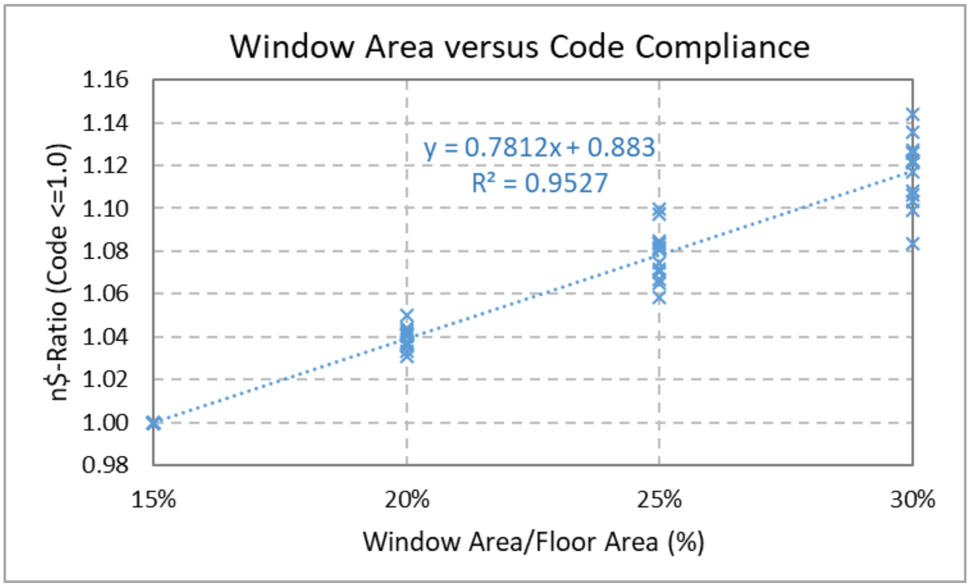

Figure 11. Normalized Performance $-ratio for window/floor area alternatives.

The data shown in Table 18 makes clear another complication of Section R405 with respect to window area. The *standard reference design* window area is not always 15% of the floor area. It is only 15% of the floor area if the *proposed design* window area is equal to or greater than 15% of the floor area. If the *proposed design* window area is less than 15% of the floor area, then the *standard reference design* window area is reduced to be equal to the *proposed design* window area.

Therefore, for the 5% and 10% columns in Tables 17 and 18, the compliance ratio is virtually equivalent to the compliance ratio of the 15% column because the *standard reference design* window areas are also 5% or 10% of the floor area. This fact has the impact of not appropriately crediting the reduced energy use for window areas that are less than 15% of the floor area but making it more difficult for homes with window areas greater than 15% of the floor area to comply using the Simulated Performance Alternative.

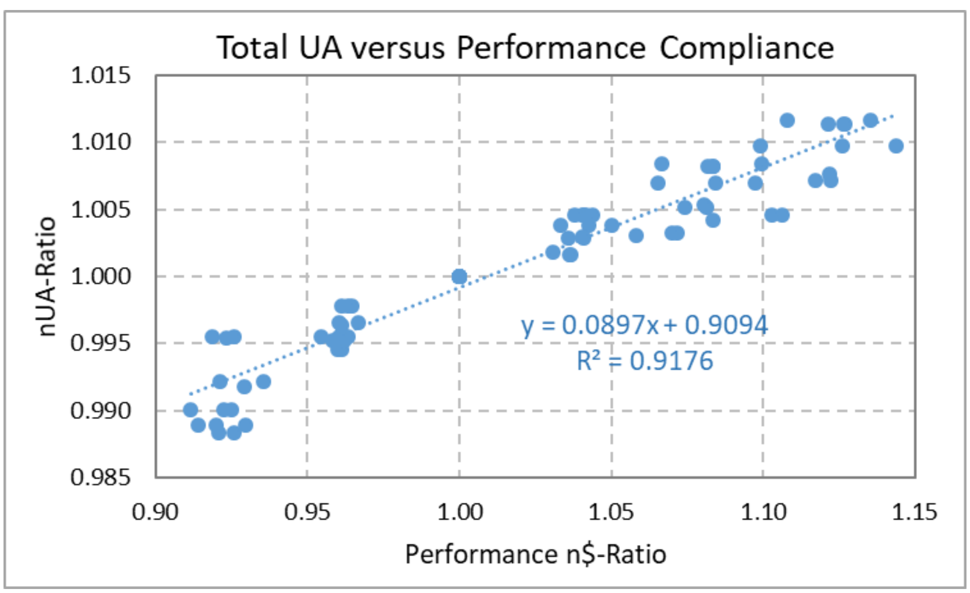

Figure 12. Comparison of Total UA and Simulated Performance Alternative compliance for window/floor area alternatives showing difference between x-axis and y-axis scales.

Figure 12 shows the relationship between the normalized compliance ratios using the Total UA Alternative and the Simulated Performance Alternative for the window/floor area alternatives examined by this evaluation. For these data, the 5% and 10% window area is compared against the 15% window area for the Simulated Performance Alternative data set so that the two compliance methodologies can be compared across the entire range. The principal finding is that the Total UA Alternative very poorly represents the energy impact of window area with about an order of magnitude difference in their compliance ratios.

Finally, the correlation regression equations shown in Figure 10 and Figure 11 can be used to show the average normalized compliance ratios for each of these compliance methods on the same simple chart. Figure 13 provides this plot.

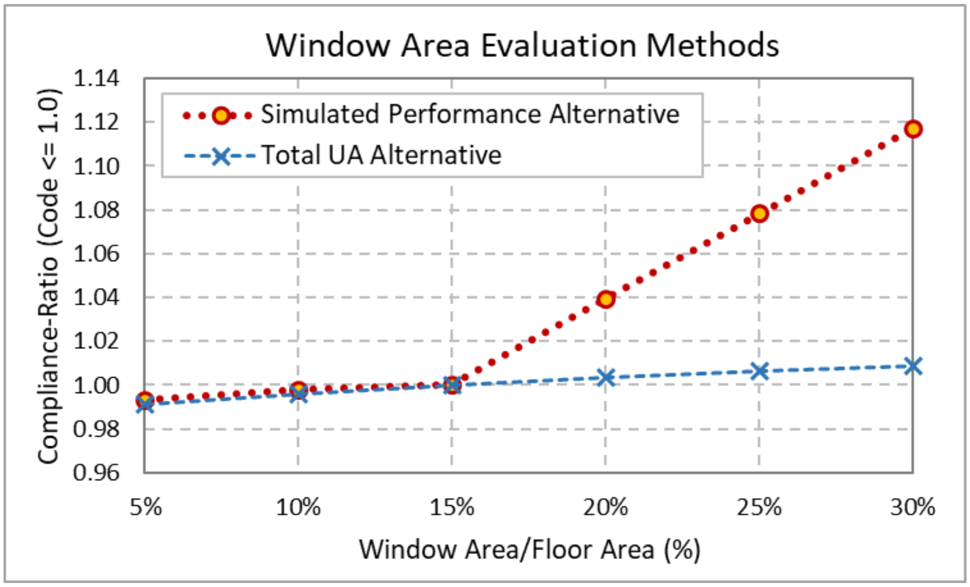

Figure 13. Normalized compliance ratios for window area evaluations.

Figure 13 clearly shows both the discontinuity of the R405 Simulated Performance Alternative where the *standard reference design* window area floats with the *proposed design* window areas below 15% of the floor area. The figure also clearly shows the significant difference in compliance ratios between the Total UA Alternative and the Simulated Performance Alternative for window/floor area ratios greater than 15%.

Conclusions

One of the technical questions raised by this study is whether homes complying via the performance path use less energy than homes complying via the prescriptive path. This question is difficult to answer with only simulation analysis because the thermal characteristics of the standard reference design home in the Simulated Performance Alternative are identical to the thermal characteristics specified by Table R402.1.4, which determine prescriptive compliance via the Total UA Alternative.

The simulation analysis cannot draw thosesuch conclusions across the board. However, Task 1 of this project will provide utility billing analysis that will be of significant benefit in understanding the energy performance distinctions between the prescriptive and performance-based energy code compliance pathways.

Even though the distinctions are largely unanswerable through Task 4 simulations, There are some differences in the compliance paths that show greater ease of compliance with one methodology than another depending on home characteristics. Figure 13 clearly shows that the Simulated Performance Alternative would encourage much less energy use than the Total UA Alternative wherever window areas exceed 15% of the conditioned floor area. Normalized to a 15% baselineAs shown in Table 18, homes with 30% glass/floor ration trying to comply can behave normalized compliance ratios 8 to 14% higherlarger using R405the Simulated Performance Alternative, where as the normalized Total UA Alternative comparison stayscompliance ratio, as shown in Table 16, never exceeds 1.2% regardless of climate. .

A detailed comparison of the Simulated Performance Alternative as compared with the Total UA Alternative is shown in Figure 14, which plots the Total UA compliance ratios against the Simulated Performance compliance ratios. Regression of these data show that, at best, only 40-50% of the variance is explained by linear regression. For basements, the regression coefficient is much poorer at only about 15% but this partially could be due to the fact that the basements are unconditioned in climate zones 1-3.

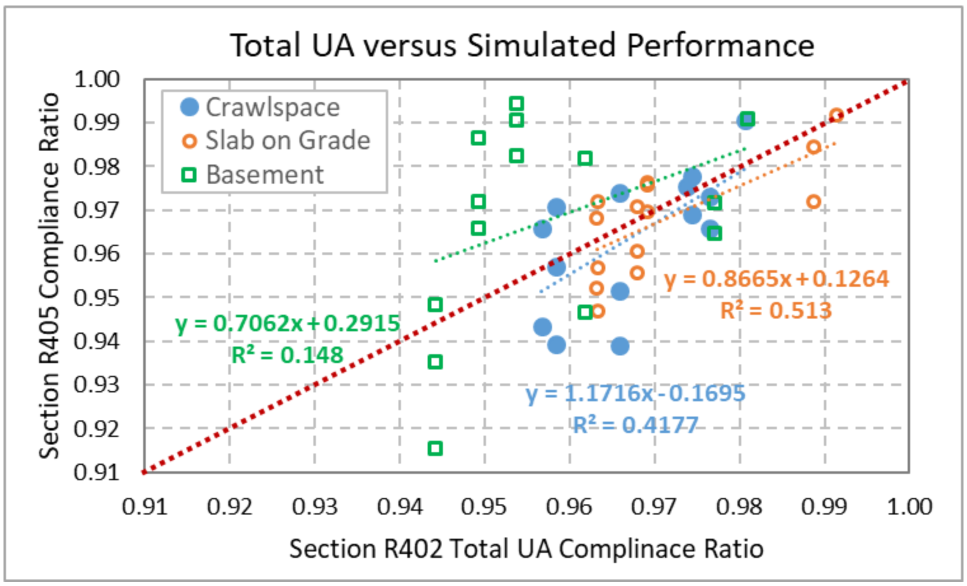

Figure 14. Comparison of the Simulated Compliance Alternative and the Total UA Alternative.

The following additional conclusions are drawn from the analysis reported.

- As shown in Figure 1, Total UA calculations are more stringent in climate zones 1 and 2 due to the difference in the Equivalent UA values provided in Table R402.1.4 as compared with the R-Value requirements of Table R402.1.2. And as shown in Figure 2, this is true for both EnergyGauge implementations as well as RES*check* implementations of the Total UA Alternative method.
- In general, Total UA calculations are less stringent than R-Value requirements of Table R402.1.2 for all climate zones. This ranges from about 1% in climate zone 1 to as much as 5% in climate zone 3.
- As shown in Figure 3, the Simulated Performance Alternative is also less stringent than R-Value requirements of Table R402.1.2 for all climate zones. This ranges from about 1% in climate zone 1 to as much as 7% in climate zone 3C. This result is principally due to the fact that the *standard reference design* home

for the Simulated Performance Alternative takes its envelope component thermal characteristics from Table R401.1.4 for U-Factor equivalence.

- The 2018 IECC Energy Rating Index (ERI) Alternative compliance path (R406) is complicated by the fact that the ERI reference standard (ANSI/RESNET/ICC 301-2014) is modified by an exception in Section R406.3 of the 2018 IECC. As shown in Figure 5, this R406.3 exception causes the R406 ERI to be considerably larger than the ANSI/RESNET/ICC 301 ERI, especially so in northern climates where it can be 10-12 points greater. As shown in Figure 7, this makes it significantly more difficult to comply with the 2018 IECC using the ERI Alternative compliance path.
- Envelope leakage and air distribution system leakage can have significant impacts on the energy performance of homes complying with the minimum insulation requirements of the IECC. Both of these energy features are relatively new attributes of the IECC and neither lend themselves to visual verification but instead require pressurization testing for verification. Both are also climate sensitive with colder climates showing greater sensitivity than warmer climates.
- With respect to envelope leakage, analysis results shown in Figure 8 indicates an average 8.8% change in Energy Code compliance ratio (n$-Ratio) per percentage change in envelope leakage. Thus, a change from 3 ach50 to 6 ach50 would result in a cost increase of $199 per year in Duluth, MN – more than enough to justify the envelope testing necessary to ensure the envelope tightness required by the IECC.
- For air distribution system leakage (duct leakage), results are less climate sensitive than for envelope leakage. Nonetheless, the energy penalty for leaky ducts, as shown in Figure 9, is significant and for the worst case climate of Albuquerque the annual energy cost increase compared with the code maximum would be 10.2% or about $134 per year.