Date:	**2/19/2019**		
To:	**Lynn Chamberlin**	Information Release #	**PNNL-SA-141366**
From:	**Mark Halverson, YuLong Xie, and Rosemarie Bartlett**		
Subject:	**Residential Compliance Evaluation Results for the State of Nebraska**		

Background

In early 2017, the Nebraska Energy Office expressed interest in evaluating the construction of new single-family homes in Nebraska using the US Department of Energy's (DOE) low-rise residential evaluation methodology.[1] As part of that methodology, Pacific Northwest National Laboratory (PNNL) was directed by DOE to analyze the data collected in Nebraska. This memorandum provides and discusses the results of PNNL's analysis.

Nebraska's energy code for single-family homes is the 2009 International Energy Conservation Code (IECC). Nebraska's climate zone within the 2009 IECC is Climate Zone 5. Results presented below will be referenced to this code and climate zone. Results are presented for three sets of analyses:

1) Comparison of the key item[2] observations to the minimum code requirements in Nebraska. The results of this analysis are presented as a series of plots accompanied by a brief discussion of each plot. Each plot focuses on an individual key item.
2) Comparison of the energy use intensity (EUI) of a range of 1500 simulations using DOE's single family prototype building to the expected EUI for homes based on the minimum code requirements in Nebraska. The results of this analysis are two EUI plots accompanied by a brief discussion of each plot. The first EUI plot looks at the overall EUI as calculated based on the observations collected in Nebraska. The second EUI plots splits that energy usage into electricity and natural gas components.
3) Calculation of the potential measure level savings that could be achieved if all of the observations of key items had just met the minimum code requirement in Nebraska. The results of this analysis are two measure level savings tables accompanied by a brief discussion of each table. The first table is the annual measure level savings that might be seen in Nebraska. The second table is an extrapolation of the first table to 5-year, 10-year, and 30-year time periods.

[1] https://www.energy.gov/eere/buildings/downloads/residential-building-energy-code-field-study
[2] Key items are defined in the methodology document. Key items are those code requirements that directly impact energy usage of a home, such as the amount of insulation in the walls or roof, or the performance of windows.

Key Item Analysis

Plots are provided for observations as collected for each key item. Duct leakage has two plots, one for observed data and one for adjusted duct leakage based on whether or not ducts were located entirely within conditioned space. Plots for ceiling insulation, frame wall insulation, and basement wall insulation also include a U-factor plot which is based on the combined cavity and continuous wall insulation R-value plus the observed insulation installation quality (IIQ) of the assembly.[3]

1. *Envelope Air Leakage* - The ACH50 plot (Figure 1) indicates that all of the observations meet or exceed the requirement.
2. *High-Efficacy Lighting* - The high-efficacy lighting plot (Figure 2) indicates that the average observation meets the requirement, but there are significant numbers of observations that are both better and worse than the requirement.
3. *Duct Leakage* - The unadjusted duct tightness plot (Figure 3) looks at observations of duct tightness as collected in the field. The average duct tightness is about twice as leaky as the code requirement. In the adjusted duct tightness plot, the duct leakage for any duct located entirely within conditioned space is set to "0" (zero). As the adjusted duct tightness plot (Figure 4) shows, a large number of ducts in Nebraska are located entirely within conditioned space. Based on the adjusted duct leakage, the average duct leakage in Nebraska is less than half of the code requirement.
4. *Ceiling Insulation* - The ceiling R-value plot (Figure 5) indicates that the majority of observations meet or exceed the code requirement, with the average R-value being R-42.8. The ceiling U-factor plot (Figure 6), which includes the influence of insulation installation quality (IIQ), shows that ceiling insulation in Nebraska is not as good as the ceiling R-value plot might indicate. The majority of observations are worse than the code requirement, with an average U-factor of 0.04. A comparison of the R-value and U-factor plots indicates that ceiling IIQ is an issue in Nebraska, as the amount of insulation installed is typically adequate, but the resulting U-factor is not.
5. *Frame Wall Insulation* - The frame wall cavity R-value plot (Figure 7) shows the amount of insulation installed between the framing of walls. The average wall has slightly less insulation than the code requirement for cavity insulation in walls. Some walls have both cavity and continuous insulation. The frame wall continuous R-value plot (Figure 8) shows that there are many walls with a small amount of continuous insulation that is less than the code requirement for a wall with just continuous insulation. The frame wall U-factor plot (Figure 9) combines the observations for both cavity and continuous insulation and includes the impact of IIQ for cavity insulation. The frame wall U-factor plot indicates that the average wall is just slightly worse than the code requirement. This

[3] IIQ is not an explicit requirement in the 2009 IECC, but it was collected as part of this study and is used in the calculation of U-factors for opaque assemblies.

result is most likely a combination of too little insulation in some walls and poor IIQ in other walls.

6. *Window U-Factor* - The window U-factor plot (Figure 10) shows that all observations are at or above code.
7. *Window SHGC* - The window solar heat gain coefficient (SHGC) plot (Figure 11) shows that windows typically have low SHGC in Nebraska, even though there is no code requirement for SHGC in Climate Zone 5. The SHGC for windows in Climate Zone 3 in the 2009 IECC is 0.3 and most of the windows that were observed in Nebraska would meet this requirement.
8. *Basement Wall Insulation* - The basement wall cavity R-value plot (Figure 12) shows that most observations just meet the R-value requirement. A similar result is seen in the basement wall continuous R-value plot (Figure 13). However, the basement wall U-factor plot (Figure 14) shows that the average basement wall does not meet the code requirement. As with above grade walls, the issue is likely IIQ for the cavity insulation plus an inadequate amount of cavity insulation in some basement walls.
9. *Slab on Grade Insulation* - The slab insulation plot (Figure 15) shows that all three slabs were insulated to the code requirement.

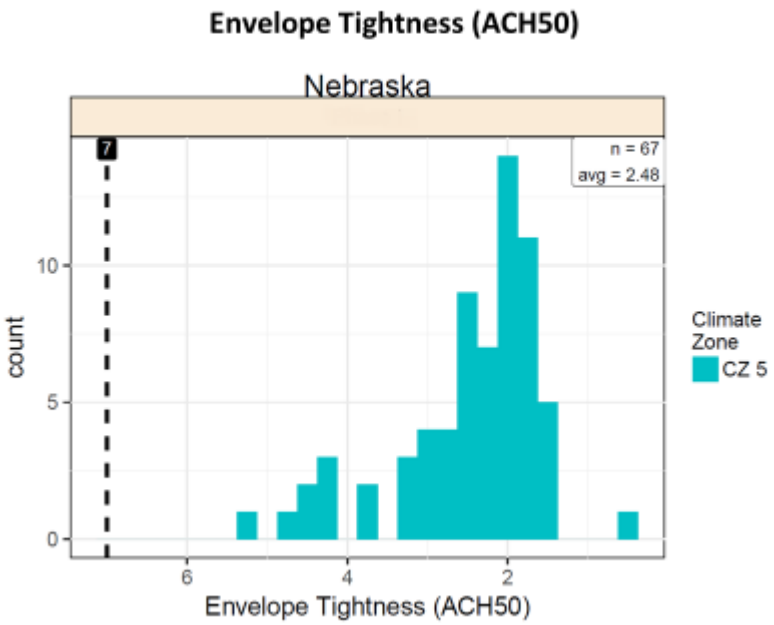

Figure 1. Envelope Tightness in Nebraska

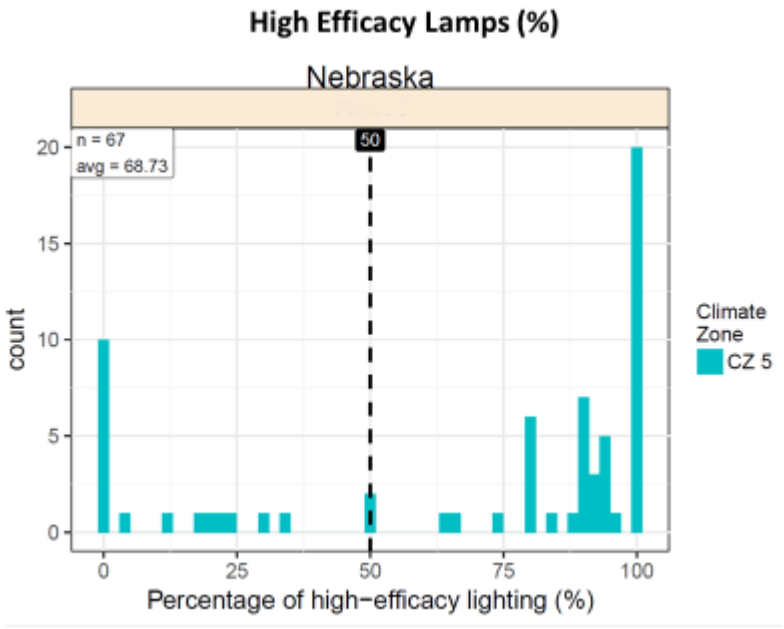

Figure 2. High Efficacy Lamps in Nebraska

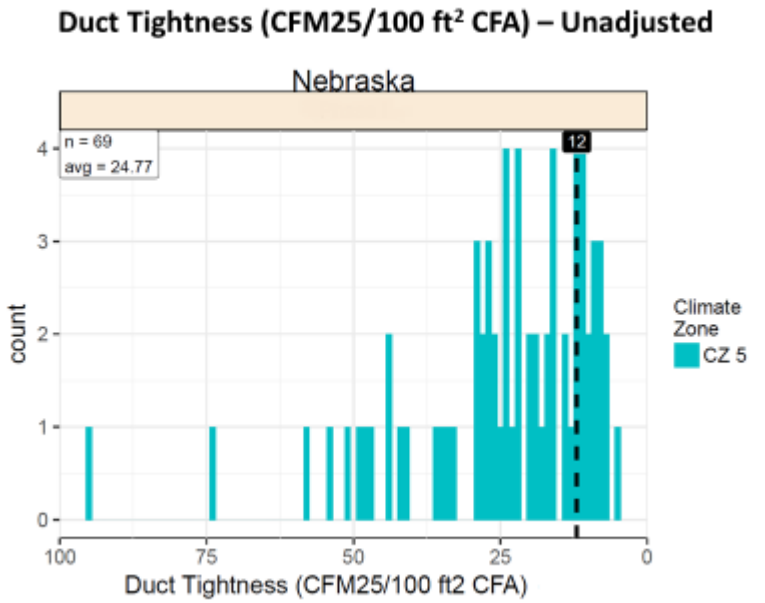

Figure 3. Unadjusted Duct Tightness in Nebraska

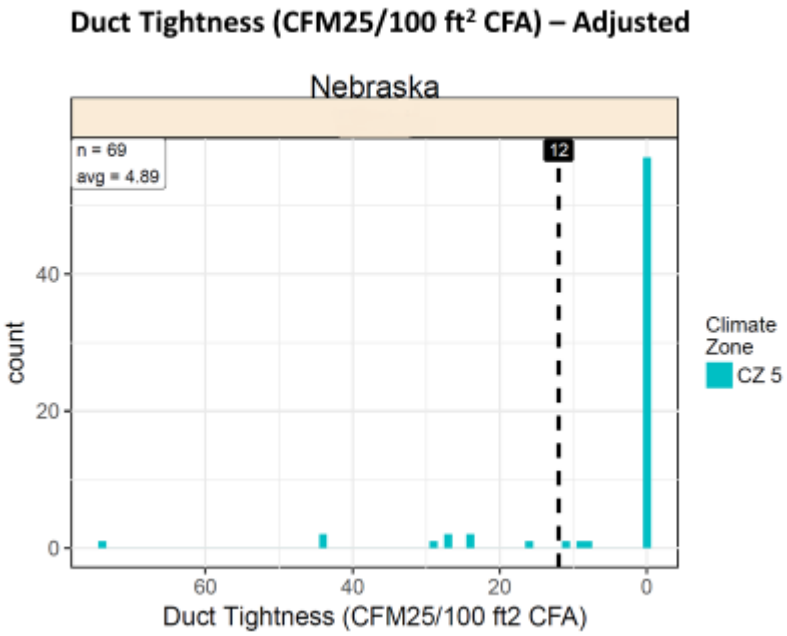

Figure 4. Adjusted Duct Tightness in Nebraska

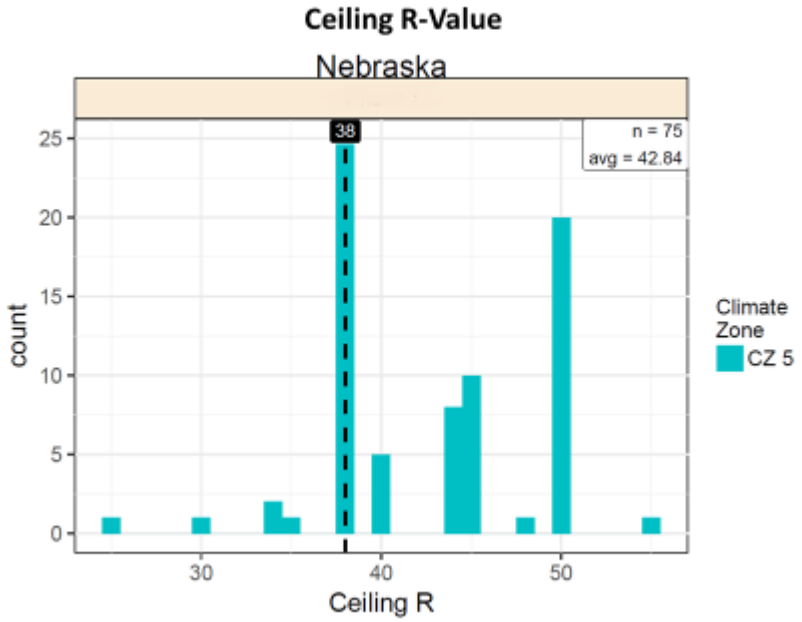

Figure 5. Ceiling R-Value in Nebraska

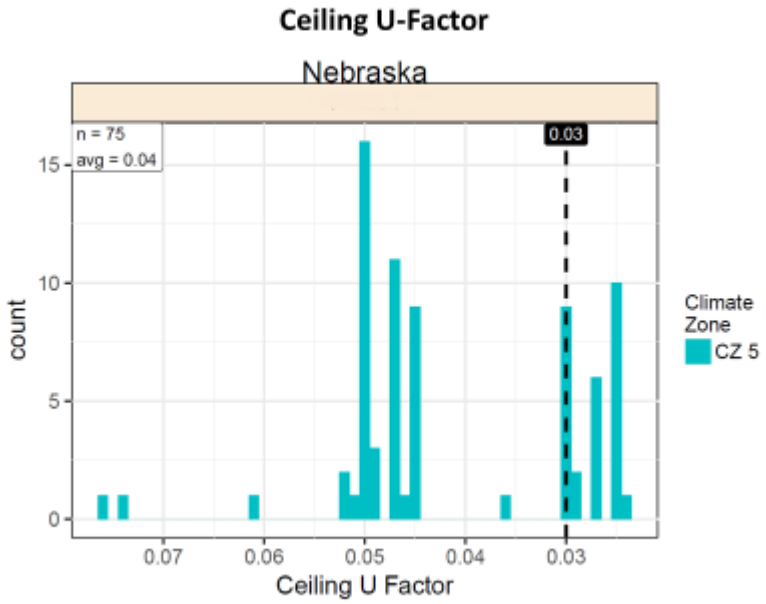

Figure 6. Ceiling U-Factor in Nebraska

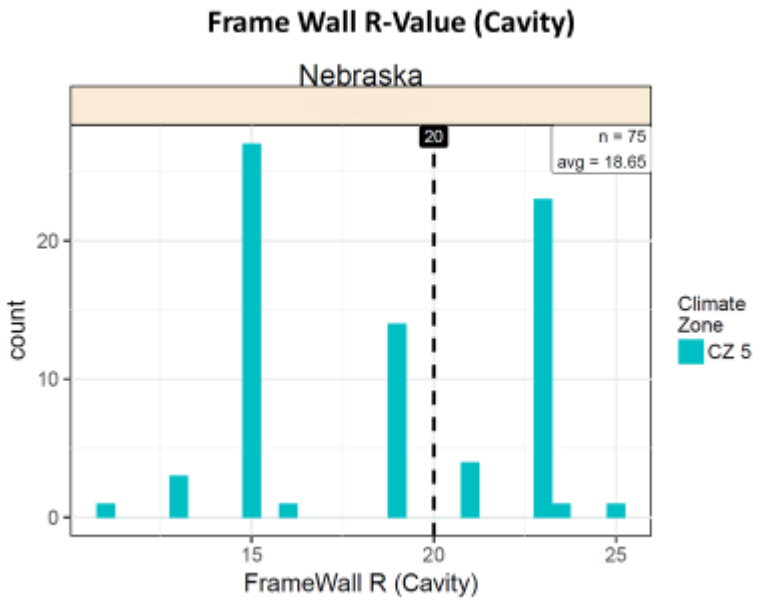

Figure 7. Frame Wall R-Value (Cavity) in Nebraska

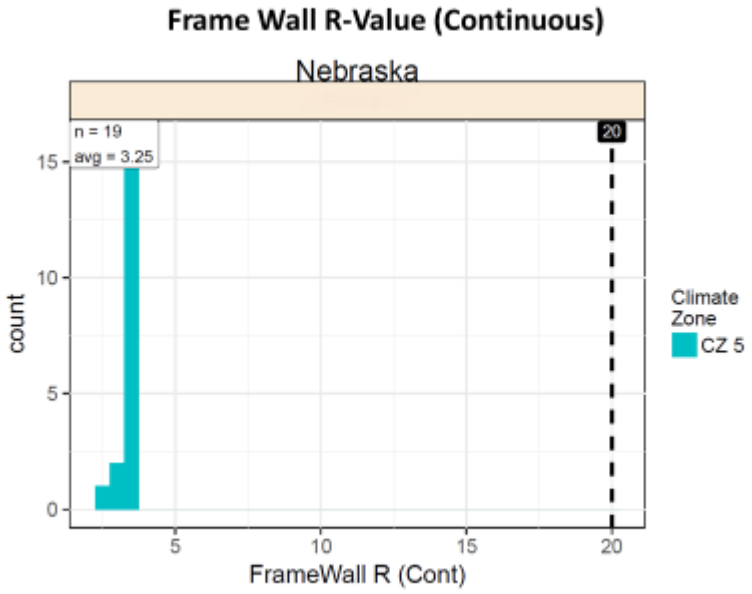

Figure 8. Frame Wall R-Value (Continuous) in Nebraska

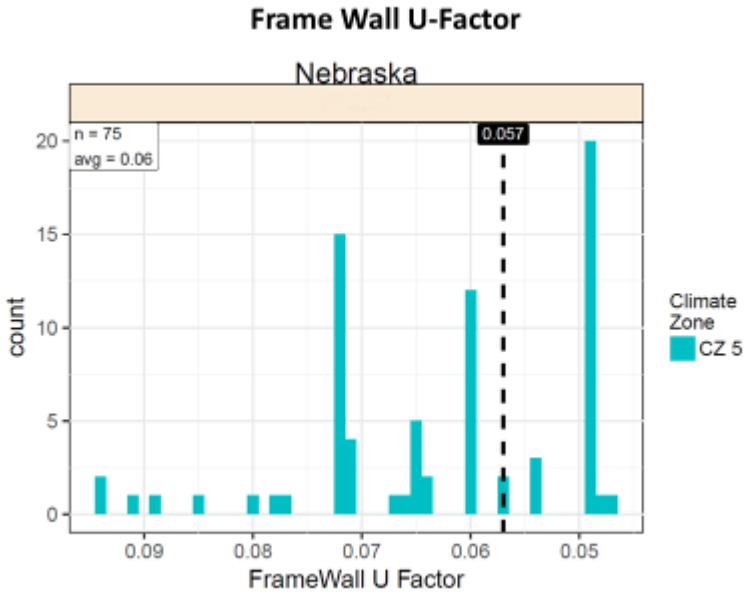

Figure 9. Frame Wall U-Factor in Nebraska

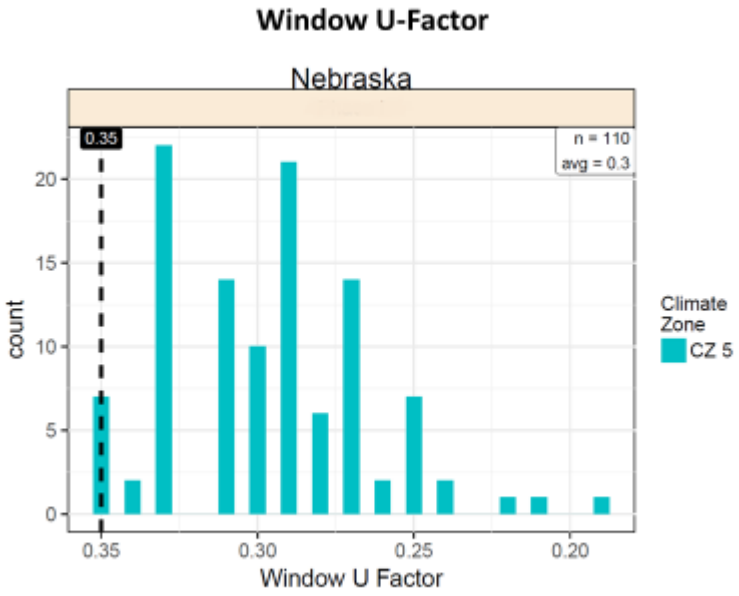

Figure 10. Window U-Factor in Nebraska

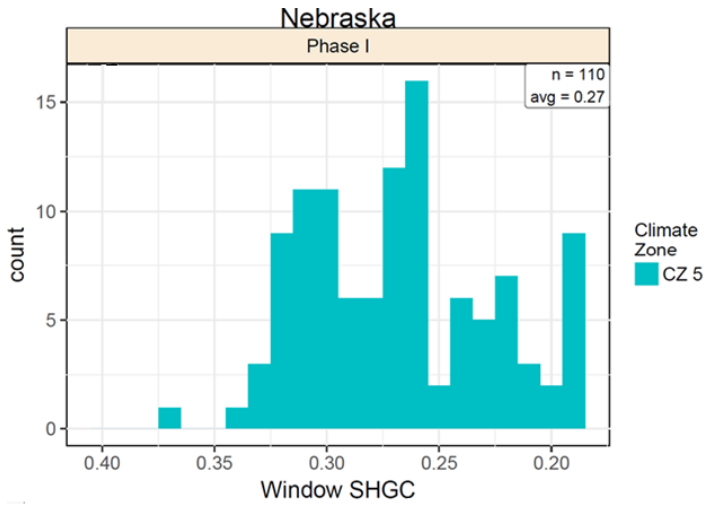

Figure 11. Window SHGC in Nebraska

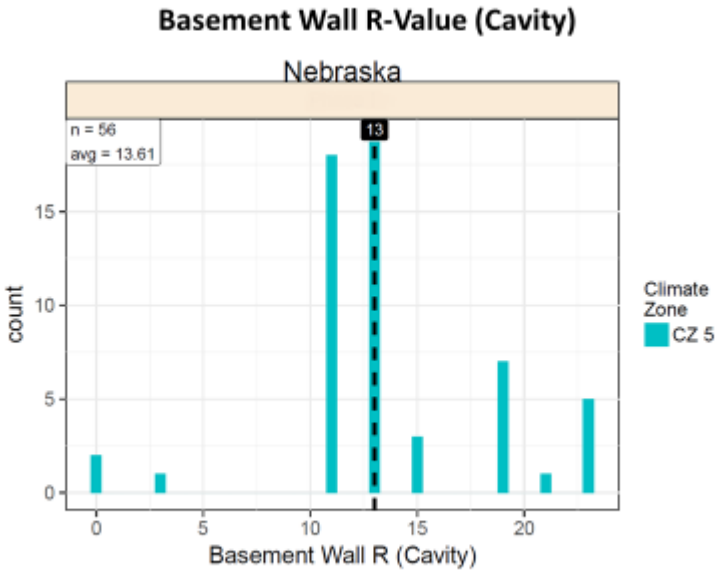

Figure 12. Basement Wall R-Value (Cavity) in Nebraska

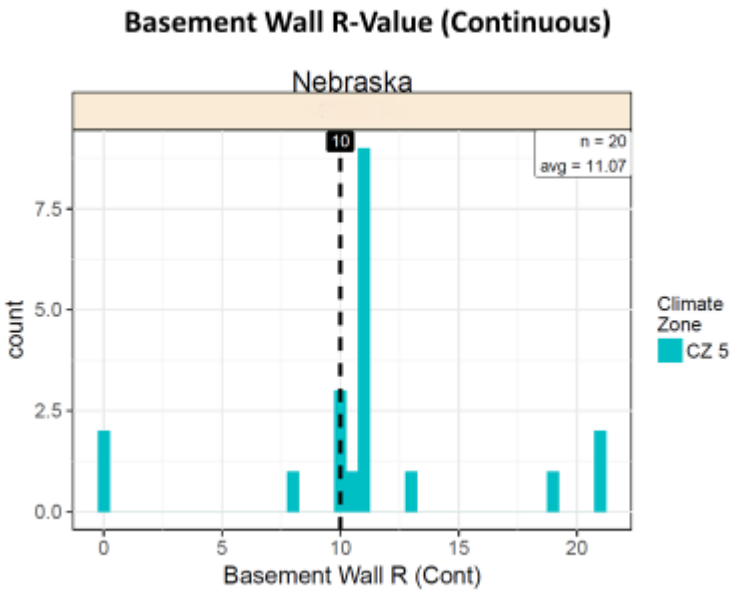

Figure 13. Basement Wall R-Value (Continuous) in Nebraska

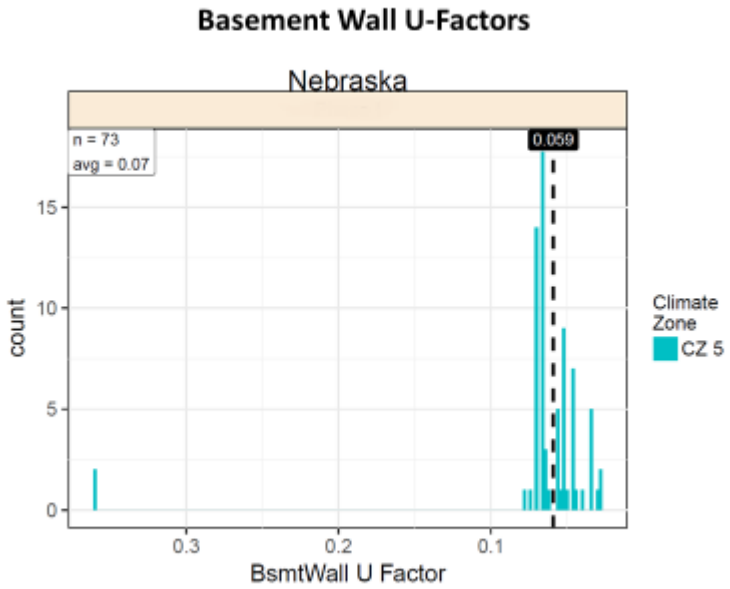

Figure 14. Basement Wall U-Factors in Nebraska

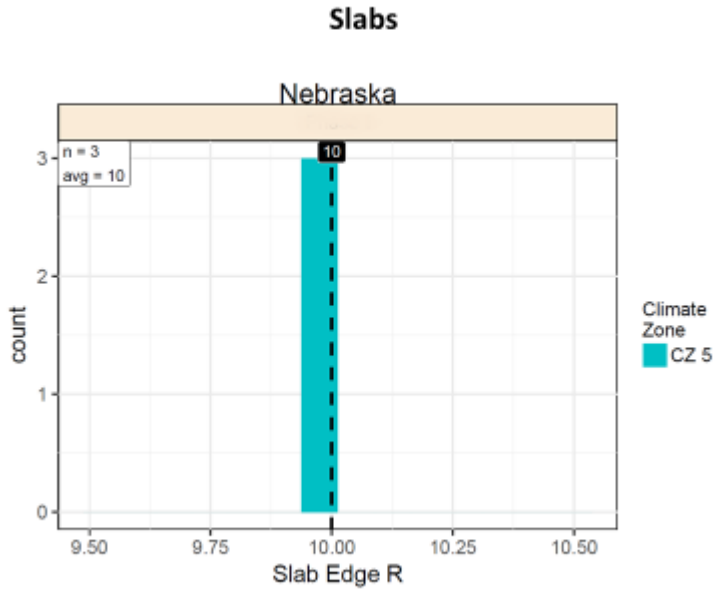

Figure 15. Slab Edge Insulation R-Value in Nebraska

Energy Use Intensity (EUI)

The Nebraska overall EUI plot (Figure 16) indicates that homes in Nebraska have on average an EUI that is about 29% less than homes that meet code. The plot of natural gas and electricity EUI splits (Figure 17) indicates that both natural gas and electricity usage are considerably below what would be required by code.

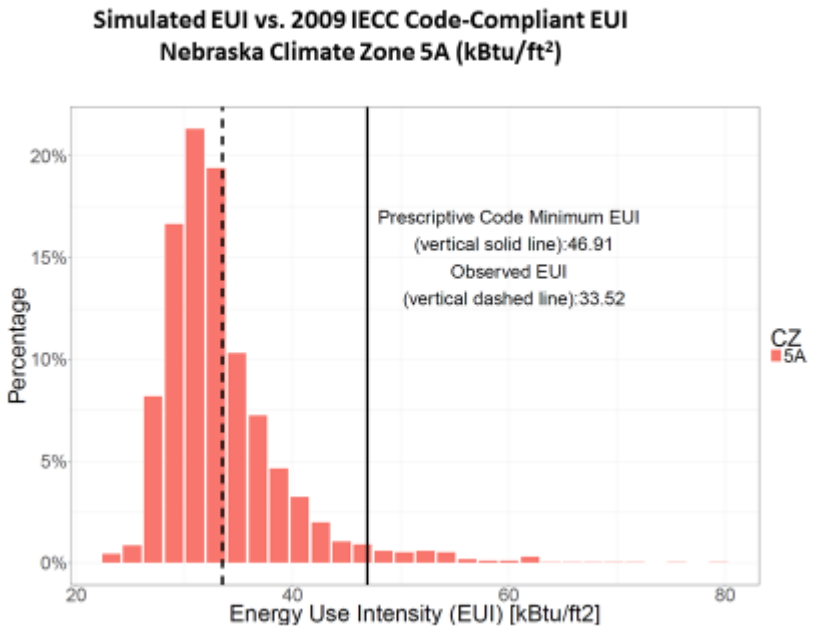

Figure 16. Total Energy Use Intensity in Nebraska

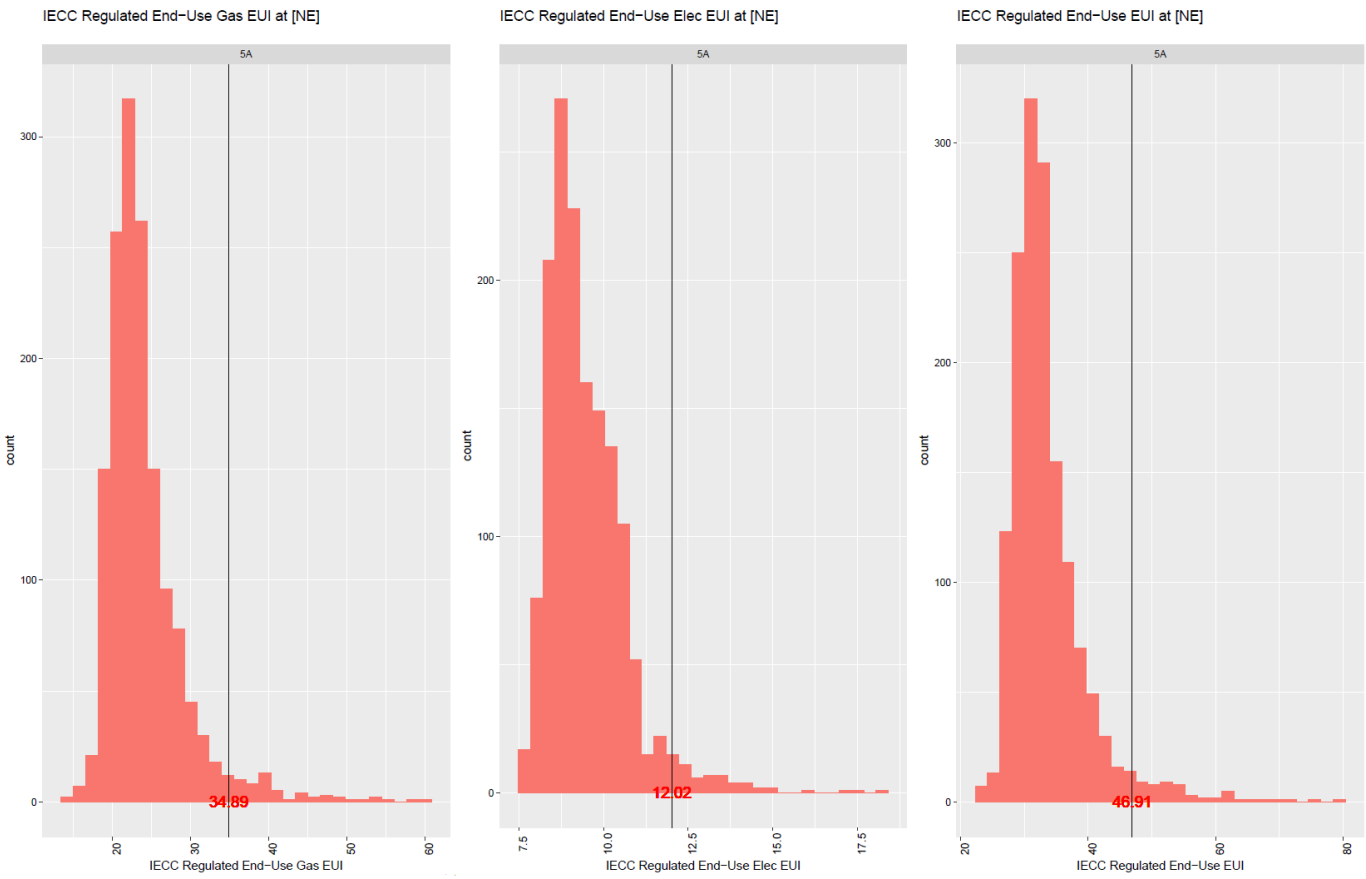

Figure 17. Natural Gas and Electricity Energy Use Intensity in Nebraska

Measure Level Savings

Measure level savings are calculated for any key item where there is at least one observation that failed to meet code. The calculation is based on the U-factor where opaque assemblies such as walls and roofs are being considered. The U-factor of opaque assemblies includes the impact of IIQ.

For Nebraska, the following key items meet the threshold:

- Exterior Wall Insulation
- Duct Leakage
- Ceiling Insulation
- Lighting
- Basement Wall Insulation

Table 1 shows the annual measure level savings for Nebraska. Exterior wall insulation has the most significant measure level savings identified for Nebraska, followed by duct leakage, ceiling insulation, lighting and basement wall insulation. The basement wall insulation contributes only about 4.6% of the total annual energy cost savings, indicating that basement wall insulation is quite minor in the measure level savings calculation.

The basement wall insulation component has negative electricity savings and negative emissions reduction, indicating that electricity usage and emissions would increase if the homes that did not meet code were insulated to the code levels. This is a common observation for basement insulation in climates with hot summers and cool or cold winters, as uninsulated foundation components can be a benefit in hot weather (by providing "free cooling" from the cooler ground (basements) or cooler air (crawlspaces)) , but a detriment in cooler climates. Note that there are both total energy and total energy cost savings associated with foundation insulation and for these reasons foundation insulation remains important.

There are negative natural gas savings on a per home basis associated with high efficacy lighting. This is a common observation when low efficacy lighting is replaced with high efficacy lighting that does not give off as much heat.

Table 1. Measure Level Savings for Nebraska

Measure	Climate Zone	Electricity Savings (kWh/ home)	Natural Gas Savings (therms/ home)	Total Savings (kBtu/home)	Number of Homes	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Ceiling Insulation	5A	121	19	2,362	5,436	12,839	171,418	3,575
Duct Leakage	5A	178	28	3,452	5,436	18,763	250,640	5,232
Exterior Wall Insulation	5A	170	31	3,710	5,436	20,170	259,997	5,027
Lighting	5A	131	-2	237	5,436	1,290	71,120	3,771
Basement Wall Insulation	5A	-2	8	785	5,221	4,097	36,389	-19
TOTAL		**598**	**85**	**10,546**	**5,436**	**57,160**	**789,564**	**17,587**

Table 2 shows the multi-year (5, 10, and 30 year) measure level savings for Nebraska. The values in the table are derived by multiplying the annual savings by 15, 55, and 465 for the 5, 10 and 30 year savings, respectively. This estimate does not consider changes to the numbers of homes built per year, the fuel prices for natural gas and electricity, or changes in the emission factors associated with natural gas and electricity.

Note that the negative emission savings for basement wall insulation also shows up in the multi-year table for emissions reduction associated with foundations.

Table 2. Five Year, 10 Year, and 30 Year Savings for Nebraska

Measure	**Total Energy Savings (MMBtu)**			**Total Energy Cost Savings ($)**			**Total State Emissions Reduction (MT CO2e)**		
	5yr	10yr	30yr	5yr	10yr	30yr	5yr	10yr	30yr
Exterior Wall Insulation	302,546	1,109,334	9,378,916	3,899,952	14,299,823	120,898,500	75,412	276,510	2,337,766
Duct Leakage	281,444	1,031,960	8,724,752	3,759,597	13,785,190	116,547,513	78,487	287,785	2,433,093
Ceiling Insulation	192,591	706,169	5,970,334	2,571,264	9,427,970	79,709,199	53,618	196,601	1,662,171
Lighting	19,356	70,972	600,037	1,066,801	3,911,604	33,070,830	56,564	207,402	1,753,488
Basement Wall Insulation	61,460	225,354	1,905,268	545,840	2,001,413	16,921,036	-280	-1,026	-8,675
TOTAL	**857,397**	**3,143,789**	**26,579,308**	**$11,843,454**	**$43,425,999**	**$367,147,079**	**263,801**	**967,272**	**8,177,843**