How do Enhanced Code Requirements Influence Compliance and Building Efficiency? A Massachusetts Case Study

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ABSTRACT

Massachusetts is currently adopting a new base energy code every two-to-three years that is based on the International Energy Conservation Code (IECC). About one-half of the municipalities in the state must comply with the base energy code while the other half must comply with the stretch code; the stretch code is a voluntary performance-based code that strives to achieve approximately 20% improvement over the 2009 IECC (and soon the 2015 IECC).

Using onsite inspections, the Massachusetts Program Administrators (PAs) have developed (or are in the process of developing) compliance rates for new single-family homes built under the following time series of compliance cycles:

- Homes built at the end of the 2006 IECC cycle
- Homes built at the beginning of the 2009 IECC cycle
- Homes built at the end of the 2009 IECC cycle
- Homes built at the beginning of the 2012 IECC cycle
- Homes built under the stretch code

This time series of compliance rates can be used to answer some critical questions:

- How have the PAs' efforts influenced code compliance?
- How has compliance changed over time from one code to another?
- What requirements appear to be driving changes in compliance rates?
- What is the influence of administrative compliance items vs. items that directly affect energy efficiency?

This paper seeks to begin answering these questions and to provide detailed information regarding compliance trends in residential new construction over time that should be valuable to the building energy codes community.

Introduction

The state of Massachusetts is currently adopting a new base energy code every two-to-three years based on the International Energy Conservation Code (IECC). Over the past few years the state has implemented the 2006 IECC, the 2009 IECC, and the 2012 IECC. Beginning in 2009 the state also implemented what is known as the stretch energy code, a voluntary performance-based code that requires a HERS rating along with the 2009 IECC mandatory requirements. Moving forward, it is expected that the stretch code will be adjusted to show 20% improvement over the 2015 IECC base-code in Massachusetts; the stretch code was not updated with the 2012 IECC but it is expected to be updated when the 2015 IECC is adopted later this year.

Beginning in 2011, the Massachusetts Electric and Gas Program Administrators (PAs) began measuring compliance with the energy code for new single-family homes built outside of the Massachusetts Residential New Construction (RNC) program.[1] The PAs have conducted studies to determine compliance with single-family homes built at the end of the 2006 IECC cycle and the beginning of the 2009 IECC cycle (NMR 2012a; NMR 2012b). There is also an ongoing study that measures compliance for homes built at the end of the 2009 IECC cycle, the beginning of the 2012 IECC cycle, and under the stretch code. These studies serve a number of purposes ranging from updating the RNC program baseline to informing the potential savings from code compliance enhancement efforts. These studies are based on onsite inspections of occupied homes. This approach is taken in order to recruit homeowners and avoid the potential bias suggested in other studies that recruiting builders leads to participation from only builders who believe their homes are energy-efficient (NMR 2004). These studies have incorporated a series of onsite protocols to account for the fact that a post-occupancy inspection involves a number of hard-to-observe measures (e.g., wall insulation and slab insulation) that can be difficult to visually verify.

This paper details the compliance results for homes built at the end of the 2006 IECC cycle, the beginning of the 2009 IECC cycle, the end of the 2009 IECC cycle, the beginning of the 2012 IECC cycle, and homes built under the stretch code. The results are presented using two separate code compliance methodologies, the "PNNL approach", developed by Pacific Northwest National Laboratory (PNNL), and the "NMR approach", developed by NMR Group (NMR) in conjunction with the Massachusetts PAs and the Massachusetts Energy Efficiency Advisory Council (EEAC). *Please note that some of these findings are preliminary and they have not yet been publicly reviewed.*

Specifically, this paper seeks to answer the following questions:

- How has compliance changed over time from one code to another?
- What requirements appear to be driving changes in compliance rates?
- What is the influence of administrative compliance items vs. items that directly affect energy efficiency?

[1] While this paper focuses on residential compliance findings, it is worth noting that the PAs have also begun developing a time series of compliance results for the commercial sector.

Moving forward, this research will identify what influence the PAs code compliance enhancement trainings have had on overall compliance. The influence of these trainings will be weighed against other factors such as natural market adoption (NOMAD), code trainings conducted by other entities, and other PA-sponsored energy efficiency programs.

Comparison of Key Code Requirements

In order to understand the code compliance results presented in this paper it is important to understand how key code requirements vary by code. As shown in Table 1, the key differences between the 2006 IECC and the 2009 IECC are found in the wall insulation, air infiltration, duct leakage, duct insulation, and lighting requirements. The 2012 IECC has increased requirements over the 2009 IECC for ceiling insulation, fenestration U-factor, air infiltration, duct leakage, and lighting. As previously mentioned, the stretch code is a performance-based code that is founded in the 2009 IECC.

Table 1. Comparison of 2006 IECC, 2009 IECC, 2012 IECC, and Stretch Code Requirements for Climate Zone 5 and Marine 4

Measure	2006 IECC requirement	2009 IECC requirement	2012 IECC requirement	Stretch code requirement
Wall insulation	R-19 or R-13+5 (U-.060)	R-20 or R-13+5 (U-.057)	R-20 or R-13+5 (U-.057)	No requirement*
Ceiling insulation	R-38 (U-.030)	R-38 (U-.030)	R-49 (U-.026)	No requirement*
Floor R-value	R-30 (U-.033)	R-30 (U-.033)	R-30 (U-.033)	No requirement*
Foundation wall R-value	R-10/13 (U-.059)	R-10/13 (U-.059)	R-15/19 (U-.050)	No requirement*
Slab R-value	R-10, 2ft	R-10, 2ft	R-10, 2ft	No requirement*
Fenestration U-factor	U-0.35	U-0.35	U-0.32	No requirement*
Air infiltration	Requires air sealing but there is no testing option. Compliance is assessed through visual inspection.	Requires air sealing. Compliance is assessed through visual inspection or air infiltration testing (7 ACH50)	Requires air sealing. Compliance is assessed via air infiltration testing (3 ACH50)	Requires air sealing. Compliance is assessed through visual inspection or air infiltration testing (7 ACH50)
Duct leakage	Requires duct sealing but there is no testing option. Compliance is assessed through visual inspection.	Requires duct sealing which is assessed through duct leakage testing (8 CFM25/100 ft^2 leakage to the outside)	Requires duct sealing which is assessed through duct leakage testing (4 CFM25/100 ft2 of total leakage)	Requires duct sealing which is assessed through duct leakage testing (8 CFM25/100 ft^2 leakage to the outside)
Duct insulation	Supply and return ducts insulation to a minimum of R-8. Ducts in floor trusses shall be insulated to R-6.	Supply ducts in attics shall be insulated to a minimum of R-8. All other ducts shall be insulated to a minimum of R-6.	Supply ducts in attics shall be insulated to a minimum of R-8. All other ducts shall be insulated to a minimum of R-6.	No requirement*
Lighting	n/a	50% high efficacy lamps in permanently installed fixtures	75% high efficacy lamps in permanently installed fixtures	No requirement*

*The stretch code requires that homes comply with the mandatory requirements of the 2009 IECC and have a HERS score of 70 (for homes < 3,000 ft^2) or 65 (for homes ≥ 3,000 ft^2). These measures are not associated with mandatory requirements.

Code Compliance Methodologies

This paper uses two separate methodologies to assess compliance with the energy code.

- The code compliance checklist methodology developed by Pacific Northwest National Laboratory (PNNL), referred to as the "PNNL approach"
- An alternative methodology developed by NMR, the Massachusetts PAs, and the Massachusetts EEAC, referred to as the "NMR approach"

PNNL Approach

The 2006 IECC, 2009 IECC, and 2012 IECC PNNL checklists were used to assess energy code compliance for single-family homes in Massachusetts (DOE BECP, 2010).[2] The checklists were developed by PNNL as a way for states to consistently measure progress toward the American Recovery and Reinvestment Act (ARRA) requirement that states receiving federal funding should achieve 90% compliance with the 2009 IECC by 2017. The checklists score code compliance requirements on a point system; each measure is assigned a value of one, two, or three points based on its relative importance. Building-level checklist compliance is calculated as the total points for items marked compliant divided by total points for items marked either compliant or not compliant. This way, homes are not penalized if an item is not applicable or not observable.

The PNNL approach is beneficial in that it accounts for all aspects of the code including key energy-related criteria, the compliance path (i.e., prescriptive, UA trade-off, or performance) utilized by builders,[3] and the administrative and non-energy related requirements that are not captured in the NMR approach.[4]

It is important to note that the checklist is populated differently depending on the compliance approach the builder has selected. Under the prescriptive approach, applicable and observable items are simply marked as compliant or non-compliant. Under the trade-off or performance approaches, certain measures may be marked as compliant, even if they do not meet the prescriptive compliance levels identified in the checklist, as long as they are consistent with how the builder designed the building to comply.

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[2] The 2006 IECC checklist is no longer publicly available.

[3] The prescriptive path is considered the simplest compliance path and requires that the builder simply meet or exceed all code requirements. The UA trade-off path allows trade-offs whereby some envelope efficiency measures can fall below code requirements if balanced by other envelope measures that exceed code requirements. The performance path is based on energy modeling results and allows for crediting energy efficiency measures not accounted for the in the other paths such as renewable energy.

[4] Some examples of administrative or non-energy related requirements include posting a code compliance certificate on or near the electric panel, having construction drawings that demonstrate compliance with the code, and providing the R-values for all installed insulation.

NMR Approach

The NMR approach uses energy models to develop a scoring system that is more calibrated to estimated energy consumption than the PNNL approach. Unlike the PNNL approach, the NMR approach focuses only on code requirements that directly impact energy consumption. The methodology does not account for administrative or non-energy related code requirements and it does not consider the compliance path utilized by the builder.

This approach utilizes REM/Rate™ energy consumption estimates to determine the relative importance of various code-related building components.[5] The consumption estimates of individual measures are compared to the overall estimated consumption for a sample of homes in order to develop a detailed point system that is calibrated to overall estimated energy consumption. We developed unique point systems for each code being considered as part of the study; this was done to account for the fact that codes vary in terms of what is required and what level of efficiency is required. Specifically, the sample of homes built under the 2006 IECC were used to develop the 2006 IECC point system, the 2009 IECC homes were used to develop the 2009 IECC point system, and the same approach was taken for the 2012 IECC and stretch code samples.

The point system is developed on a ten-point scale where the most important measure (in terms of relative estimated energy consumption for the entire sample of homes) receives a total achievable score of ten points. Other measures are compared to the most important measure to develop a total achievable point value between zero and ten points. The following formula provides an example of how the total possible points for each measure are developed (in this case assuming above-grade wall insulation was the most important measure in terms of relative consumption):

$$Points_{Possible} = \frac{(P_{TC} \times 10)}{AG_{TC}}$$

Where:

$$P_{TC} = Percentage\ of\ Total\ Consumption$$
$$AG_{TC} = Above - Grade\ Wall\ Pecentage\ of\ Total\ Consumption$$

Once the point system is developed, two models are used to calculate compliance for each home. One model is an "as built" model, or a model that represents the home as it actually exists, and the other model is a "code built" model that represents the same home built to meet prescriptive code requirements. The measure-level percentage change between the code-built models and as-built models is used to assign a point value to each of the measures included in this methodology. If the as-built model exceeds the code for a given measure (less consumption), that measure is provided with the total possible points. If the as-built model is less efficient than code, then the measure is provided with partial credit depending on the percentage change of the as-built consumption relative to the code-built consumption. The following formulas are used for these calculations:

$$PC_{Base} = \frac{(CB_{Cons} - AB_{Cons})}{AB_{Cons}}$$

[5] REM/Rate is an energy modeling tool that is used to develop Home Energy Rating Scores (HERS) and to support many residential new construction programs.

Where:

$$PC_{Base} = Percentage\ difference\ between\ "code - built"\ and\ "as - built"\ models$$
$$AB_{Cons} = As - built\ consumption$$
$$CB_{Cons} = Code - built\ consumtpion$$

And:

$$If\ PC_{Base} < 0\ then,$$
$$Points_{Scored} = 1 - |PC_{Base}| \times Points_{Possible}$$
$$If\ PC_{Base} > 0\ then\ Points_{Scored} = Points_{Possible}$$

Specifically, this methodology includes points and compliance calculations for the following building components:

- Roof insulation and installation quality
- Above-grade wall insulation and installation quality
- Foundation wall insulation and installation quality
- Window efficiency
- Frame floor insulation and installation quality
- Slab insulation and installation quality
- Air leakage
- Duct leakage and insulation
- Lighting efficiency

Table 2 presents the total possible points for each of the applicable building components within each sample of homes.

The number of points applied to individual components varies depending on the sample of homes and the code that is under consideration. For example, the distribution of points for the 2006 IECC compliance estimate differs from the 2009 IECC estimates primarily because certain measures (i.e., air infiltration and lighting efficiency) are not applicable to the 2006 IECC. The total possible points per measure varies between the samples because the relative impact of the measures shifts between different codes and also between different samples of homes; hence it is critically important for the sample to represent the market. The relative number of possible points across the codes is not a critical comparison as the objective of this methodology is to compare compliance percentages (which are all compared on a 0% to 100% scale) across the codes; the total possible points simply provide an anchor with which to calculate the compliance percentages. This approach is similar to the PNNL scoring system, where the total possible points varies across different codes due to the number and importance of various code requirements; the PNNL method also re-scales everything on a 0% to 100% scale making compliance scores across codes comparable.

Table 2: Total possible points by measure for each sample of homes

Measure	2006 IECC	2009 IECC	2012 IECC	Stretch Code
Lighting	n/a	5.3	6.1	5.6
Ceiling insulation and installation	4.4	6.1	4.8	4.2
Above grade wall insulation and installation	10.0	10.0	10.0	8.5
Foundation wall insulation and installation	1.2	1.2	1.2	1.2
Window and skylight U-factor	9.3	9.0	9.8	10.0
Frame floor insulation and installation	3.2	4.6	4.3	2.9
Slab insulation and installation	0.3	0.5	0.8	0.6
Air leakage	n/a	9.3	7.8	8.0
Duct leakage and insulation	6.9	8.1	6.7	5.8
Total achievable points	35.4	54.0	51.6	46.8

Detailed Findings

This section presents detailed findings for each of the compliance methodologies. The findings represent homes built at the end of the 2006 IECC cycle, the beginning of the 2009 IECC cycle, the end of the 2009 IECC cycle, the beginning of the 2012 IECC cycle, and homes built under the stretch code. *As previously mentioned, some of these findings are preliminary and have not yet been publicly reviewed.*

Throughout this section statistically significant differences at the 90% confidence level are noted using letters of the alphabet in superscript. In other words, there is a 90% probability that the compared results are truly different from each other, and only a 10% probability that observed difference happened by chance. Within figures and tables each letter is noted twice corresponding to the categories that are identified as significantly different. For example, in Figure 1 below a superscript *a* indicates significantly different compliance results between the end of the 2006 IECC cycle and the beginning of the 2009 IECC cycle. Similarly, a superscript *b* indicates significantly different compliance results between the beginning and end of the 2009 IECC cycle.

PNNL Approach Findings

Figure 1 presents compliance rates using the PNNL approach. The compliance rates are presented for the overall sample of homes within each study group as well as for the various compliance paths that builders can use to achieve compliance in Massachusetts.

Using the PNNL approach, compliance rates are significantly higher at the end of the code cycles (76% at the end of the 2006 IECC cycle and 70% at the end of the 2009 IECC cycle) than they are at the beginning of a code cycle (63% at the beginning of the 2009 IECC cycle and 63% at the beginning of the 2012 IECC). This may be partially due to the fact that it takes time for builders and subcontractors to understand and adapt to new code requirements.

As shown, the majority of builders within each of the sample groups use the UA trade-off approach (typically using the REScheck™ software) to show compliance with the energy code. This compliance path allows builders to exceed the code in certain areas and fall below the code in others so long as the overall efficiency of the building is not compromised.[6] The performance path works in a very similar way. These paths show much higher compliance than homes that were built under the prescriptive compliance path.

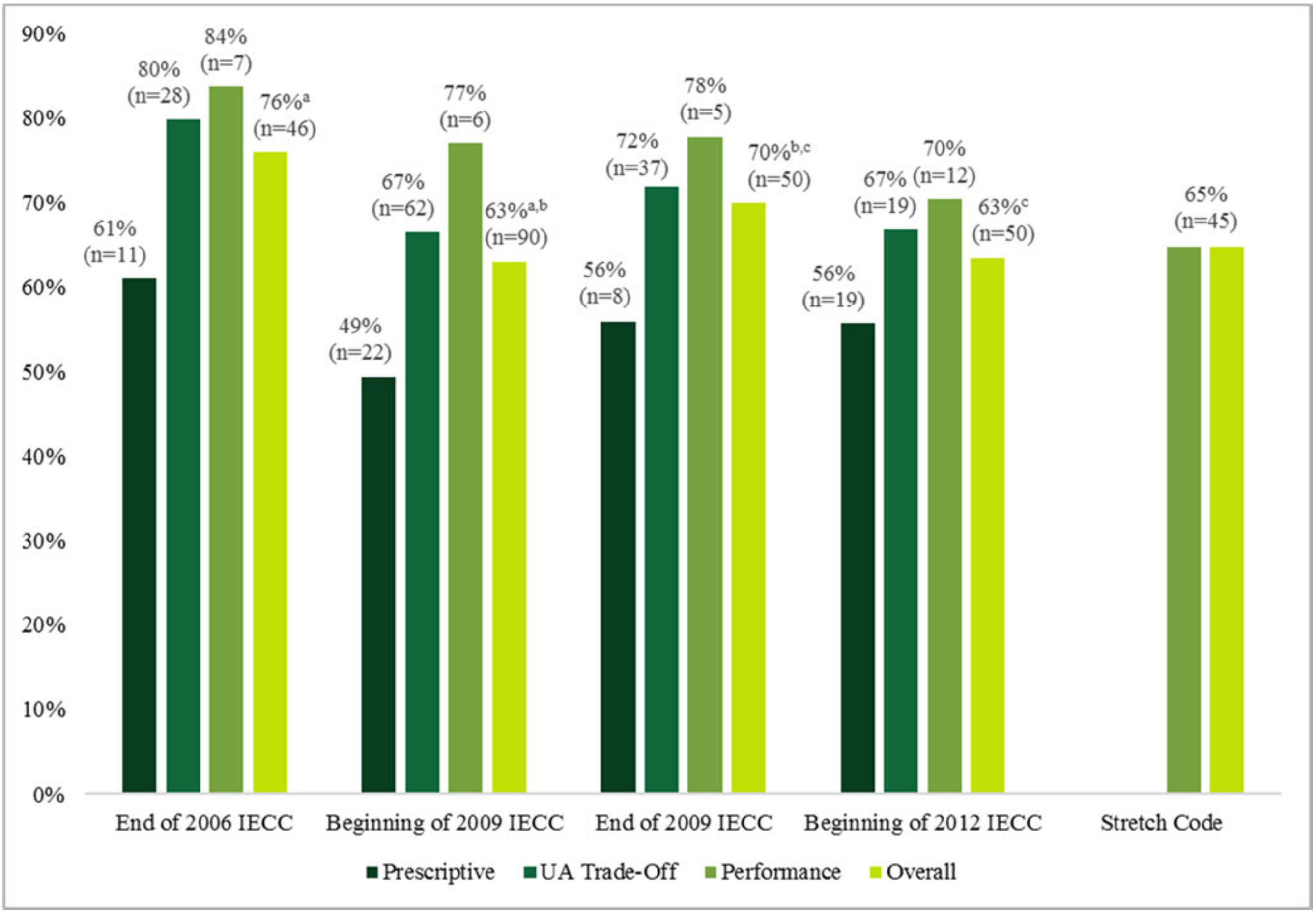

Figure 1. Compliance rates by compliance path using the PNNL approach

NMR Approach Findings

Table 3 shows the total compliance levels for each of the samples considered in this paper. Once again, we see significantly higher compliance at the end of the 2009 IECC cycle

[6] Under the 2006 IECC REScheck allowed trade-offs between the shell and mechanical equipment efficiencies; beginning with the 2009 IECC REScheck only allowed trade-offs with envelope measures.

than we do at the beginning of the 2009 IECC or 2012 IECC cycle.[7] This increase may be partially due to the fact that market actors become increasingly aware of code requirements and adapt to them over the course of a code cycle.

Table 3: Total compliance using the NMR approach

Sample	n	Total Compliance
End of 2006 IECC	48	81%[a]
Beginning of 2009 IECC	74	86%[a,b]
End of 2009 IECC	50	89%[b,c,e]
Beginning of 2012 IECC	50	83%[c,d]
Stretch Code	46	93%[d,e]

[a,b,c,d,e] Statistically significant at the 90% confidence level.

Figure 2 details the average measure-level compliance for each of the components considered under the NMR approach.[8] Note, that air leakage and lighting requirements do not apply to the 2006 IECC and therefore results have been excluded for that sample. When reviewing these results it is important to note which measures underwent changes from one code cycle to the next. For example, the air leakage, duct leakage, and lighting requirements all changed significantly from the 2009 IECC to the 2012 IECC.

A few key takeaways when considering the measure-level compliance results from Figure 2:

- Compliance with ceiling insulation requirements has steadily improved over time. Compliance even improved from the end of the 2009 IECC cycle to the beginning of the 2012 IECC cycle when the code requirement shifted from R-38 to R-49. While the change over the 2009 IECC cycle is not statistically significant, the improvement from the end of the 2009 IECC cycle to the beginning of the 2012 IECC cycle is significant at the 90% confidence level.
- Compliance with frame floor insulation requirements (which has not changed from the 2006 IECC to the 2012 IECC) has steadily improved over time. Homes built under the stretch code have significantly higher compliance with this requirement than homes built at the end of the 2006 IECC cycle. and homes built at the beginning of the 2009 IECC cycle.
- Requirements for foundation insulation, ceiling insulation, air leakage, duct leakage, window U-factor, and lighting all underwent changes from the 2009 IECC to the 2012

[7] The increase in code compliance from the end of the 2006 IECC to the beginning of the 2009 IECC appears to be driven by the inclusion of the air leakage requirement in the 2009 IECC. Compliance with the air leakage requirement, which is a high impact measure, was very high at the beginning of the 2009 IECC cycle and helped drive compliance upward for that sample of homes.

[8] Given the number of comparisons presented in Figure 2 significant differences are not highlighted within the figure. Instead, they are highlighted in the bulleted list that details the findings from Figure 2.

IECC. Compliance with the air leakage, duct leakage, and lighting requirements is significantly lower for homes built at the beginning of the 2012 IECC than it is for homes built at the end of the 2009 IECC cycle and homes built under the stretch code.

- Some measures (i.e, ceiling insulation, duct insulation and leakage, and wall insulation) improved from the beginning of the 2009 IECC to the end of the 2009 IECC while others showed negligible improvement or actually worsened over time (i.e., slab insulation, frame floor insulation, lighting, air leakage, and windows). Only changes in wall insulation were significantly different between the beginning and end of the 2009 IECC cycle.
- Surprisingly, compliance with stretch code homes is similar to compliance for homes built at the end of the 2009 IECC cycle for ducts and air leakage. This is somewhat unexpected given that the stretch code requires a HERS rater to test the performance of these components. The similarity between the two samples is partially due to the fact that, under the NMR approach, homes receive full points for a given measure regardless of whether they exceed the code requirement by a little bit or a by a lot. These measures have high compliance rates under both of these samples and therefore the overall compliance is not significantly different. That said, the raw data shows that stretch code homes are in fact more efficient than homes built at the end of the 2009 IECC for these building components.

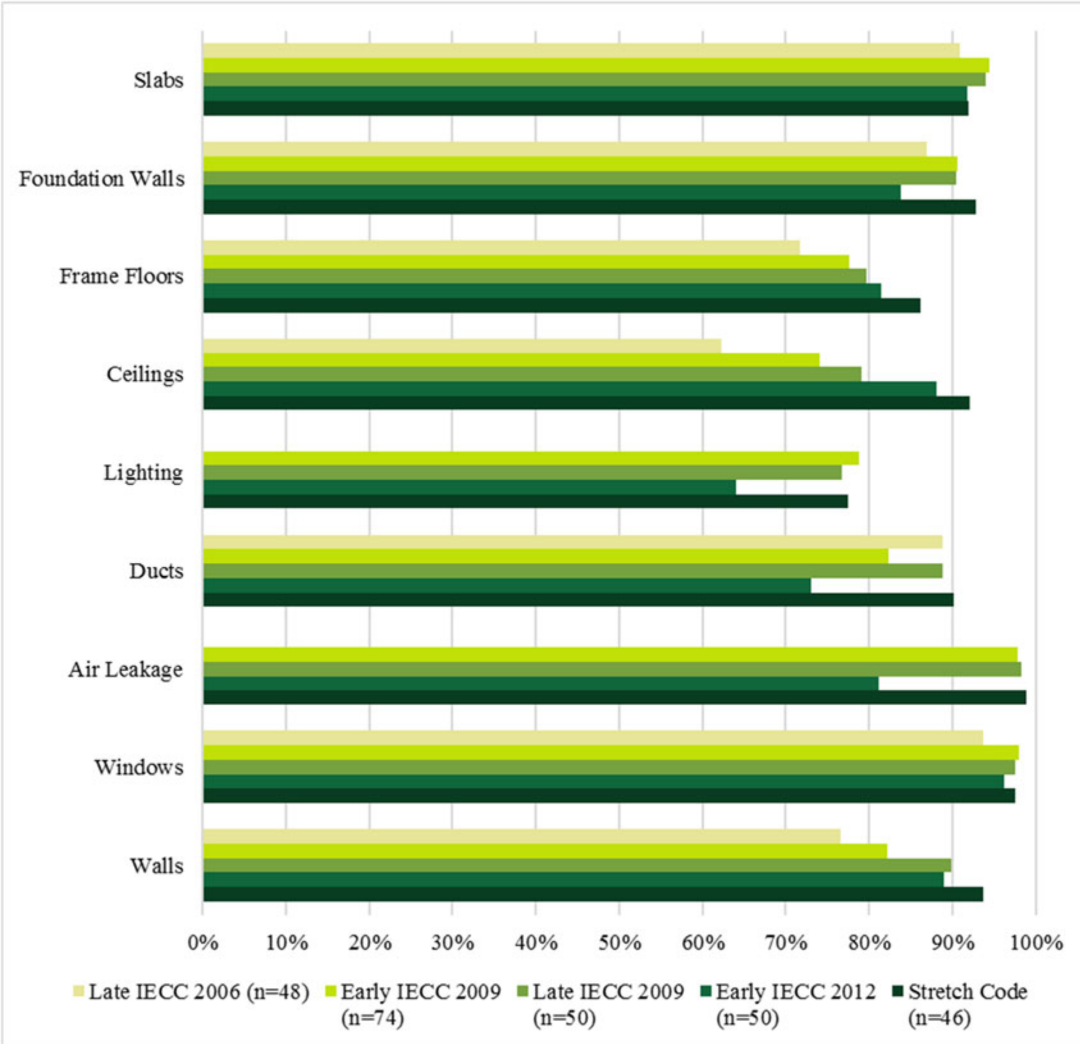

Figure 2. Average measure-level compliance using the NMR approach

Summary and Conclusions

Below is a list of the key conclusions from the results presented in this paper:

- Compliance with administrative and non-energy related items, considered in the PNNL approach, may be driving the lower compliance rates under the PNNL approach when compared to the NMR approach. This would be consistent with the findings from a recent NMR paper reviewing code-related documentation at building departments (NMR 2015).
- Both the PNNL and NMR methodologies show statistically significant increases in compliance from the beginning to the end of code cycles.
- The time series of measure-level compliance trends are inconsistent. Some measures (e.g., ceiling insulation and frame floor insulation) have improved steadily over time while others (e.g., slab insulation and window U-factor) have shown negligible changes over time.

- The increased stringency of 2012 IECC requirements on air leakage, duct leakage, and lighting efficiency have resulted in significantly lower compliance rates for homes built under the beginning of the 2012 IECC when compared to homes built at the end of the 2009 IECC.

The Massachusetts PAs are developing one of the most comprehensive sets of code compliance results in the country. Tracking code compliance results over time provides insight into critical questions that would otherwise go unanswered. These results begin to show what NOMAD is for certain measures and for compliance overall. Moving forward the PAs will be able to leverage this information to inform code compliance trainings as part of their Code Compliance Support Initiative (CCSI) and to inform their estimates of savings calculations from enhanced compliance with the energy code.

As previously mentioned, it is important to remember that many of these results are preliminary and may be subject to change upon further review. That said, the trends shown in this paper are likely to hold and that alone should provide value to the building energy codes community.

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