Final Report on Energy Impacts of Commercial Building Code Compliance in Rhode Island

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Executive Summary

This analysis is intended to provide a mechanism to quantify the energy impacts of energy code compliance patterns seen in recent field data collection and analysis of building characteristics. Guidance on energy impacts of different code provisions and compliance rates can identify where the market has been able to incorporate better technologies or has responded effectively through utility incentives, and those areas where additional support, incentives, training, or enforcement might be warranted.

The analysis in this report is based on field work conducted in 2016 by DNV-GL. The field analysis surveyed 21 commercial buildings located in the state of Rhode Island in order to estimate the state-wide energy code compliance rates. In this study, the energy impacts of compliance have been evaluated by using the results of field observation to guide an energy modeling analysis which compares the predicted energy use of a set of building prototypes (office, retail, and school) which just meet code requirements with a set of prototypes that have the performance characteristics observed in the field study of compliance rates. (The analysis essentially evaluates the prototypes as if they were being compared to the requirements of the modeled performance path in code.)

Results of the analysis are also compared to the results of a comparable analysis conducted in 2014. This comparison can help identify trends in compliance in response to a change in code baseline that has occurred since the previous analysis.

The analysis includes the development of data tools which can be used by evaluators to assess individual energy impacts of code compliance characteristics by building type, building characteristic, and code version. The results of thousands of simulations are combined into a data spreadsheet that can be evaluated for individual building types and components, or for the sample of buildings as a whole. This report includes an explanation of how the analysis was conducted, the terminology used in the analysis and tool, how the tools are structured, and a series of observations about the results of the analysis. Samples of the data output of the tools are also provided in tables in the text and appendices.

Overall, this analysis suggests that compliance patterns with the energy code in Rhode Island buildings are generally meeting the intent of the code with respect to overall (modeled) energy use characteristics. In all building types analyzed, the prototypes modeled with the building characteristics identified in the field study perform better overall with respect to energy use than code baseline prototypes. Though some building characteristics do not meet code requirements, most notably lighting controls and some envelope characteristics, overall this is more than made up for by the energy savings from lower LPD's and installed heating and cooling efficiencies that lead to significant total building energy savings above code. This pattern is true for all of the analyzed prototypes and HVAC system configurations, compared to multiple code baselines.

At the same time, in the context of a failure to meet prescriptive code requirements, the individual building features that do not meet code requirements do have an energy penalty associated with them. These opportunities represent approximately 5 to 7% of total building energy use. This represents an opportunity for improved compliance with prescriptive code requirements to reduce overall building energy use. It should be noted however that these potential savings would only be applicable to projects following the prescriptive path in code.

Table i below shows the overall weighted results of the analysis by project type and HVAC configuration. The first two results columns show overall building energy performance relative to code requirements based on the building characteristics identified in the field. The presence of missing values in the data set has led to two different approaches to the data. In the left column, missing data points are assumed to have the value of the average of collected data for each characteristic. In the second column, missing data is assigned a neutral value equal to baseline code compliance. The third column represents the energy impact of only the non-compliant building elements, assuming all other components just meet code.

Weighted Savings Percentage Compared to 2012 Code				
Building Type	**HVAC System**	**Available Data**	**Minimally Compliant**	**Only Under-Compliance**
Office	Pkg. Gas Furnace & DX Cooling	**-12.54%**	**-9.63%**	**7.08%**
	Pkg. Heat Pump	**-12.57%**	**-8.49%**	**6.52%**
	Pkg. Variable Air Volume System	**-13.82%**	**-10.94%**	**7.00%**
	Built-up Variable Air Volume System	**-15.75%**	**-11.23%**	**7.58%**
Retail	Pkg. Gas Furnace & DX Cooling	**-13.07%**	**-13.32%**	**5.56%**
	Pkg. Heat Pump	**-15.58%**	**-14.57%**	**5.92%**
School	Pkg. Gas Furnace & DX Cooling	**-6.92%**	**-7.13%**	**5.17%**
	Pkg. Variable Air Volume System	**-7.71%**	**-7.29%**	**5.53%**
	Water Source Heat Pump	**-6.47%**	**-6.52%**	**5.33%**

Table i: Weighted Energy Performance Savings

The values in Table I are compared to 2012 code based on energy modeling analysis of field characteristics. ‘Under-compliance’ represents the savings impact of ONLY non-complying building components, ignoring impact of ‘better-than-code’ features. Negative values (blue) represent performance better than code requirements. Positive values (red) represent excess energy use over code requirements.

Data on individual building types, other code baselines, and individual component compliance rates are found in tables and text in the main report, and in the accompanying data files.

Overview

Energy codes represent a powerful policy tool to drive improvements in the energy performance of new buildings. Recent increases in code stringency have figured into larger policy goals to address broad reductions in energy use in the building sector. The broad energy code landscape includes participation and influence by utility programs that support stringent codes directly, and that support adoption of technical strategies and building features that can be incorporated into codes.

To achieve the intended savings, it is important to ensure a high degree of compliance with energy codes in the marketplace. Significant resources are spent by jurisdictions across the country to enforce energy code provisions. Additional resources are spent to evaluate the degree to which projects comply with code provisions.

Typically, the analysis of compliance rates focuses on individual building characteristics to determine whether these individual components meet code requirements. This information is often collected in field studies that evaluate building characteristics once the projects are completed. The results of these studies are reported as compliance rates, both with individual code requirements, and as a whole building assessment of whether all of the code requirements have been met in any given building.

Although this approach to analyzing energy code compliance can identify enforcement and compliance issues, it does not provide a mechanism to quantify the energy impact of these characteristics. This analysis is intended to provide a mechanism to quantify the energy impacts of energy code compliance patterns seen in recent field data collection and analysis of building characteristics. Guidance on energy impacts of different code provisions and compliance rates can identify where the market has been able to incorporate better technologies or has responded effectively through utility incentives, and those areas where additional support, incentives, training, or enforcement might be warranted.

In this study, the energy impacts of compliance have been evaluated by using the results of field observation to guide an energy modeling analysis which compares the predicted energy use of a set of building prototypes which just meet code requirements with a set of prototypes that have the performance characteristics observed in the field study of compliance rates.

Results of the analysis are also compared to the results of a comparable analysis conducted in 2014. This comparison can help identify trends in compliance in response to a change in code baseline that has occurred since the previous analysis.

Introduction

This analysis uses the survey responses from a field study of building energy code compliance and a building energy modeling approach to estimate how compliance rates affect the overall energy use of commercial buildings.

The purpose of this analysis is to explore the energy impacts of building energy code compliance rates identified in a recent field data collection on building energy code compliance characteristics. The energy impacts of compliance have been evaluated by using the results of field observation to guide an energy modeling analysis which compares the predicted energy use of a set of building prototypes which just meet code requirements with a set of prototypes that represent the performance characteristics observed in the field study.

A key outcome of this analysis is the development of data tools which can be used by evaluators to assess individual energy impacts of code compliance characteristics by building type, building characteristic, and code version. The results of thousands of simulations are combined into a data spreadsheet that can be evaluated for individual building types and components, or for the sample of buildings as a whole. This report includes an explanation of how the analysis was conducted, the terminology used in the analysis and tool, how the tools are structured, and a series of observations about the results of the analysis. Samples of the data output of the tools are also provided in tables in the text and appendices.

The analysis in this report is based on field work conducted in 2016 by DNV-GL. The field analysis surveyed 21 commercial buildings located in the state of Rhode Island in order to estimate the state-wide compliance rates[1].

Description of the Analysis Process

The analysis process is comprised of three different parts:

- Calculation of "code compliance factors" using the field data gathered by DNV-GL
- Simulation of prototypical building energy models
    - Modeled as being code compliant
    - De-rated using the calculated compliance factors
- Post-processing of the simulation results

All of the analysis results are included in a set of data tools that allow users to sort and review different buildings types and code baselines in the context of this analysis. The data tools are described in the Tools section below.

Code Compliance Factor Calculation

Conventional field analysis of code compliance is used to determine a code compliance rate, which identifies what percentage of buildings or building components meet with code requirements. In this analysis, to assess the energy impact of building compliance characteristics, compliance rates are converted to compliance factors. In determining compliance factors, the alignment/variance of each individual building component relative to code requirements is expressed as a ratio of the performance of the building characteristic to the performance required by the code. These ratios are weighted by floor area and project type (i.e. building use type and size category) population within each code version. The weighted ratio is referred to as a compliance factor. The compliance factors are averaged across code versions to determine an overall compliance factor for each building characteristic in the sample.

As discussed above, code compliance factors have been calculated for all the building components included in

[1] Rhode Island Commercial Energy Code Compliance Study, DNVGL, October 25th 2016

Table 1. Depending on the requirement, either “Method 1”, “Method 2” or “Method 3” has been used to calculate the compliance factors.

- Method 1, used when a lower value indicates greater energy efficiency, such as fenestration U-factor or installed lighting power density:

$$(Compliance\ Factor) = \frac{(Code\ Value)}{(Actual\ Value)}$$

- Method 2, used when a higher value indicates greater energy efficiency, such as furnace AFUE, air conditioner EER or water heater EF:

$$(Compliance\ Factor) = \frac{(Actual\ Value)}{(Code\ Value)}$$

- Method 3, used when the determination of compliance is either true or false without any increase or decrease of performance with respect to the applicable code. For example, if an economizer is required then its compliance determination can only be true (it is installed) or false (it is not installed):
  - If the component has no code requirement, then the compliance factor is 1.
  - If the component has code requirements and …
    - … The requirement is met, the compliance factor is 1.
    - … The requirement is not met, the compliance factor is 0.

The compliance factor represents the degree to which each building component meets or fails to meet energy code requirements. A factor above 1.0 suggests that on average the buildings are exceeding code requirements for this component, while a factor below 1.0 suggests that the buildings are failing to meet minimum code requirements. A factor of 1.0 represents component performance that exactly meets code requirements.

Because the goal of the study is to determine the energy impact of code compliance, the compliance factors represent a degree of performance that can be incorporated into the energy modeling analysis. For example, if the energy code required R-21 wall insulation, and the average wall insulation performance of the sample were R-19, the compliance factor (19/21) would be 0.90. In the analysis of the building prototypes, the wall insulation performance would be modeled as 0.9 times the code requirement to demonstrate the impact of the observed compliance characteristics on overall component and building energy use. Note that for some building characteristics, the field data suggests that on average projects are performing better than code requires (referred to as over-compliance). In these cases, the compliance factor may exceed 1.0.

Some building components are referred to as binaries, meaning that they are either included in the building or not. These building components can only be either compliant (compliance factor of 1) or non-compliant (compliance factor of 0). This is for example the case for an HVAC system air-side economizer, if an economizer is required and the building HVAC system has an economizer, the compliance factor for this particular case would be 1. However, if no economizer is present the factor would be 0. Alternatively, if no economizer is required, the HVAC system would always be compliant hence its compliance factor would be 1. However, the maximum value for these types of variables is a compliance factor of 1.0; over-compliance cannot be accounted for in these variables. For a more detailed description of how “binaries” are handled, please refer to the

Post-processing of the Simulation Results section of this report.

Table 1 - Building Components Used for Code Compliance Factors Calculations

Category	Component	Compliance Factor Calculation Method
Vertical Fenestration	U-Factor	Method 1
	Solar Heat Gain Coefficient (SHGC)	Method 1
	Visible Transmittance (VT)	Method 1
	Window-to-Wall Ratio (WWR)	Method 1
Horizontal Fenestration	U-Factor	Method 1
	Solar Heat Gain Coefficient (SHGC)	Method 1
	Visible Transmittance (VT)	Method 1
Opaque Surfaces - Wall	U-Value	Method 1
Opaque Surfaces - Roof	U-Value	Method 1
Opaque Surfaces - Floors	U-Value	Method 1
Opaque Surfaces – Slab Edge	Insulation R-Value	Method 2
	Insulation Depth	Method 2
Lighting	Lighting Power Densities	Method 1
	Lighting Control: Bi-Level	Method 3
	Lighting Control: Occupancy Sensors and/or Timers[1]	Method 3
	Lighting Control: Daylighting[1]	Method 3
	Exterior Lighting	Method 1
HVAC	Demand Control Ventilation (DCV)[1]	Method 3
	Plenum Insulation	Method 2
	Pipe Insulation	Method 2
	Heat Pump Supplemental Heat	Method 3
	Ducts and Plenum Seals	Method 3
	Air-side Economizer[1]	Method 3
	Central Fan Variable Speed Drive	Method 3
	Heat Rejection Variable Speed Drive	Method 3
	Boiler Leaving Temperature Reset	Method 3
	Energy Recovery	Method 3
	Heating Efficiency	Method 2
	Cooling Efficiency	Method 2
Infiltration	Air Barrier	Method 3
	Air Barrier Connected to All Surfaces	Method 3
	Weather seals	Method 3
	Window Air Leakage	Method 1
	Vestibule	Method 3
	Self-Closing Doors	Method 3
Service Hot Water	Efficiency	Method 2
	Pipe Insulation	Method 2

Note 1: assumed to be a binary

Some building components for which compliance factors are calculated are not explicitly modeled. When this is the case their compliance factors are bundled together and the average value is used in the energy modeling process. For example, the individual building components in the infiltration category (weather seals, window air leakage, etc.) are not explicitly modeled, however, in the modeling process, the infiltration rates are adjusted by the average compliance factor for all infiltration components. Compliance factors were also combined together where different technologies are used to accomplish the same task. For example, heat pumps, boilers and furnaces are different technologies used for space heating. However, due to the small number of observations, all individual compliance factors for each heating equipment observation were combined to create a single heating equipment efficiency compliance factor that was used in all simulations.

The weighted compliance factors for all of the individual building components are shown in Table 2.

Table 2: Compliance Factor by Component

Weighted Average of Compliance Factors Including Overcompliance.

Base Code	IECC 2012	Compliance Factor Based on Available Data: Code Specific Compliance Overall	Compliance Factor Based on Available Data: 2012 Compliance Overall	Compliance Factor Assuming Missing Data Points are Minimally Compliant: Code Specific Compliance Overall	Compliance Factor Assuming Missing Data Points are Minimally Compliant: 2012 Compliance Overall
Vertical Fenestration	U-Factor	1.08	0.90	0.99	0.98
	SHGC	1.74	1.47	1.16	1.16
	VT	1.20	1.00	1.00	1.00
Horizontal Fenestration	U-Factor	1.07	1.03	1.03	1.03
	SHGC	1.13	1.13	1.02	1.02
	VT	0.79	0.79	0.95	0.95
Slab Edge	Slab Depth	0.96	0.97	0.97	0.97
	Slab R-Value	1.03	1.03	1.03	1.03
Wall	Wall R-Value	1.13	1.12	1.15	1.13
Floors	Floor R-Value	0.70	0.70	0.70	0.70
Roof	Roof R-Value	0.97	0.84	0.97	0.84
Lighting	LPD	1.87	1.86	1.76	1.74
	Occ Sensor or Timer	0.96	0.95	0.93	0.92
	Daylighting	1.00	1.00	1.00	1.00
	Bi-Level	0.64	0.64	0.93	0.93
HVAC	DCV	0.96	0.96	0.96	0.96
	Plenum Insulation	0.95	0.95	0.97	0.97
	Fan Power	1.00	1.00	1.00	1.00
	HVAC Pipe Insulated	1.00	1.00	1.00	1.00
	Heat Pump Sup Heat	0.97	0.97	0.98	0.98
	Ducts and Plenum Sealed	1.00	1.00	1.00	1.00
	Economizer	0.97	0.97	0.97	0.97
	VFD or Vane Axial Fan	0.97	0.97	0.98	0.98
	Heat Rejection VFD	0.96	0.96	0.97	0.97
	Boiler Reset	1.00	1.00	1.00	1.00
	ERV	0.91	0.91	0.91	0.91
	Heating Efficiency	1.17	1.24	1.16	1.23
	Cooling Efficiency	1.10	1.10	1.10	1.10
Infiltration	Air Barrier	0.99	0.99	1.00	1.00
	Barrier Con. to All Surf.	0.92	0.92	0.92	0.92
	Weatherseals	0.94	0.94	0.94	0.94
	Window Air Leakage	1.13	1.34	1.03	1.12
	Vestibule	1.00	1.00	1.00	1.00
	Self-Closing Door	1.00	1.00	1.00	1.00
SHW	SHW Efficiency	1.20	1.20	1.19	1.19
	Pipe Insulation	1.14	1.50	1.13	1.50
Additional Compliance Factors (2017):					
Vertical Fenestration	WWR	1.00	1.00	1.00	1.00
Lighting	Exterior	1.36	1.36	1.36	1.36

Table 3 shows a summary of the different compliance factors that have been calculated for each building component.

Table 3 - Different Code Compliance Factors Calculations

Compliance Calculation	Code	Abbreviation
"Non-verifiable" = Average	Applicable Code	AvgAC
	IECC 2009	Avg09
	IECC 2012	Avg12
"Non-verifiable" = Minimally Compliant	Applicable Code	NV1AC
	IECC 2009	NV109
	IECC 2012	NV112
Overcompliance	Applicable Code	CR1AC
	IECC 2009	CR109
	IECC 2012	CR112

Code Baseline

The buildings in the study were built to two different versions of the International Energy Efficiency Code (IECC); 2009 and 2012. The more recent version is more stringent than the older version, by approximately 10-15% of total energy use depending on building type. In assessing code compliance characteristics, results must be compared to the code under which the project was built. But to assess larger market compliance patterns, it is also useful to compare compliance results to successive code baselines. In the tool developed by this analysis, performance patterns can be evaluated either in comparison to the code under which the buildings in the sample were built, or to a standardized code baseline of either IECC2009 or IECC2012. This flexibility allows additional observations of the impact of changing code compliance patterns, and a better understanding of whether the market is adapting to new code requirements. The tool also includes the results of a similar analysis conducted three years ago that compares compliance of a previous sample to older versions of the code baseline.

Missing Data

The field data collection process was not able to identify all compliance characteristics for all buildings. In the cases where building characteristic information is missing, two different evaluation strategies were adopted to represent a range of outcome on performance. In the first scenario, all building components are assumed to meet code requirements unless there is specific, observed data to the contrary. For example, if the code requires wall insulation of R-21, this value is assumed for all projects in which there is not a specific insulation value observed in the field data. This approach means that the compliance factor calculation is weighted toward a default condition of compliance when data is missing. In the tables, this approach is referred to as the *Minimally Compliant* approach, meaning that missing values are assumed to comply with code.

In the second scenario, all missing values are assumed to align with the average of the observed values. Using the wall insulation example, if the average wall insulation level in the projects where this data was collected was R-19, then the insulation values for all of the missing projects is also assumed to be R-19. This approach is referred to as the *Available Data* approach. It shifts the weighted compliance factor toward the average observed value.

The answers to each survey question used in the analysis have been first flagged as being valid, "not applicable"[2] or "non-verifiable"[3]. A missing or incomplete value can be either "not

[2] #N/A in Microsoft Excel

[3] Abbreviated to "N/V" in the calculations

applicable” or “non-verifiable”. If an answer has been flagged as “not applicable”, it won’t be taken into account in the calculation of compliance factors. If the answer has been flagged as “non-verifiable”, it will be handled using two different approaches as described below, and because these two methods can lead to different compliance factors, both methods have been included in the results of the analysis.

- The first method assumes that all “non-verifiable” values are minimally compliant which correspond to a compliance factor of 1. This method is referred to as “NV1” or Minimally Compliant.
- The second approach considers that all “non-verifiable” values are equal to the average of the response. For example, if for a particular surveyed building the overall fenestration U-Factor was not reported or could not be calculated, then the overall average fenestration U-Factor across all surveyed buildings is computed and used in place of the “non-verifiable” value. This method is referred to as “Avg” or Available Data.

Representative Sample

The sample used in the field analysis was designed to provide a representative sample of the building stock in considering code compliance rates. But at each individual building site in the field study, data was not always collected for all of the individual building characteristics related to compliance. This led to a number of missing observations in the data that was available for this analysis. For some types of measures, most notably fenestration characteristics, the missing observations represented a large percentage of the sample. In Table 4, the number of observations available and missing is indicated by measure type. (Building characteristics with a large percentage of missing observations are shaded relative to the percent of missing data.) For all types of fenestration characteristics, close to 90% of the sample was missing data on fenestration performance characteristics. Missing data was also significant for exterior lighting systems, and to a lesser extent for certain types of HVAC system characteristics, like boiler reset characteristics and the presence of variable frequency drives. The degree of missing data for individual characteristics should be kept in mind when considering the energy impact of compliance patterns by individual characteristic. To help assess the variability of observations, Table 4 also shows the range of values for the compliance factors (low and high) in each characteristic. (Note that low compliance factor values of 0.00 represent binary values that were not compliant, such as “required occupancy sensors are not installed…”).

In the compliance factor table, it should also be noted that individual building characteristics might not be applicable to all buildings in the sample, such as buildings without slabs. Conversely, multiple values for individual characteristics might be applicable to individual buildings, such as multiple lighting zones within a single building.

Table 4: Evaluation of Missing Data by Component

Number of Observations and Data Range

		# of valid observations	# of valid buildings	# of non-valid observations	% of non-valid obersvations	lowest comp. factor, AC	highest comp. factor, AC
Vertical Fenestration	U-Factor	3	3	18	86%	0.91	1.57
	SHGC	2	2	19	90%	1.05	2.00
	VT	2	2	19	90%	1.00	1.00
Horizontal Fenestration	U-Factor	2	2	19	90%	1.00	1.50
	SHGC	2	2	19	90%	1.00	1.33
	VT	2	2	19	90%	0.67	1.00
Slab Edge	Slab Depth	17	17	4	19%	0.00	2.00
	Slab R-Value	16	16	5	24%	0.00	2.00
Wall	Wall R-Value	19	19	2	10%	0.68	2.56
Floors	Floor R-Value	8	8	13	62%	0.00	2.40
Roof	Roof R-Value	18	18	3	14%	0.49	1.27
Lighting	LPD	37	20	8	18%	0.20	8.82
	Occ Sensor or Timer	45	21	0	0%	0.00	1.00
	Daylighting	44	20	1	2%	1.00	1.00
	Bi-Level	44	20	1	2%	0.00	1.00
HVAC	DCV	20	20	1	5%	0.00	1.00
	Plenum Insulation	11	11	10	48%	0.63	1.25
	Fan Power	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	HVAC Pipe Insulated	15	15	6	29%	1.00	1.00
	Heat Pump Sup Heat	12	12	9	43%	0.00	1.00
	Ducts and Plenum Sealed	14	14	7	33%	1.00	1.00
	Economizer	14	14	7	33%	0.00	1.00
	VFD or Vane Axial Fan	11	11	10	48%	0.00	1.00
	Heat Rejection VFD	7	7	14	67%	0.00	1.00
	Boiler Reset	7	7	14	67%	1.00	1.00
	ERV	15	15	6	29%	0.00	1.00
	Heating Efficiency	36	16	4	10%	0.98	1.28
	Cooling Efficiency	40	19	4	9%	0.81	1.42
Infiltration	Air Barrier	17	17	4	19%	0.00	1.00
	Barrier Con. to All Surf.	19	19	2	10%	0.00	1.00
	Weatherseals	20	20	1	5%	0.00	1.00
	Window Air Leakage	2	2	19	90%	1.00	1.16
	Vestibule	20	20	1	5%	1.00	1.00
	Self-Closing Door	20	20	1	5%	1.00	1.00
SHW	SHW Efficiency	14	14	7	33%	1.19	1.24
	Pipe Insulation	18	18	3	14%	0.00	3.00
Additional Compliance Factors (2017):							
Vertical Fenestration	WWR	20	20	1	5%	0.79	1.00
Lighting	Exterior	4	4	17	81%	0.67	1.82

Under-compliance

To estimate the impact of the aspects of the buildings which fail to meet code requirements, a third calculation method has been included in the analysis. This method focuses only on characteristics which fail to meet minimum code requirements. All compliance factors that perform better than code (value greater than 1) are set to just equal code requirements (compliance factor equals 1). This removes over-compliance from the analysis and focuses only on undercompliance characteristics. The energy impacts of the non-complying characteristics are then evaluated. This method is referred to as “Only Undercompliance” in the results of the analysis.

Missing, incomplete or non-verifiable data for under-compliance only is handled the same way as the “Avg” method presented above (see Code Baseline
The buildings in the study were built to two different versions of the International Energy Efficiency Code (IECC); 2009 and 2012. The more recent version is more stringent than the older version, by approximately 10-15% of total energy use depending on building type. In assessing code compliance characteristics, results must be compared to the code under which the project was built. But to assess larger market compliance patterns, it is also useful to compare compliance results to successive code baselines. In the tool developed by this analysis, performance patterns can be evaluated either in comparison to the code under which the buildings in the sample were built, or to a standardized code baseline of either IECC2009 or IECC2012. This flexibility allows additional observations of the impact of changing code compliance patterns, and a better understanding of whether the market is adapting to new code requirements. The tool also includes the results of a similar analysis conducted three years ago that compares compliance of a previous sample to older versions of the code baseline.

Missing Data

The field data collection process was not able to identify all compliance characteristics for all buildings. In the cases where building characteristic information is missing, two different evaluation strategies were adopted to represent a range of outcome on performance. In the first scenario, all building components are assumed to meet code requirements unless there is specific, observed data to the contrary. For example, if the code requires wall insulation of R-21, this value is assumed for all projects in which there is not a specific insulation value observed in the field data. This approach means that the compliance factor calculation is weighted toward a default condition of compliance when data is missing. In the tables, this approach is referred to as the *Minimally Compliant* approach, meaning that missing values are assumed to comply with code.

In the second scenario, all missing values are assumed to align with the average of the observed values. Using the wall insulation example, if the average wall insulation level in the projects where this data was collected was R-19, then the insulation values for all of the missing projects is also assumed to be R-19. This approach is referred to as the *Available Data* approach. It shifts the weighted compliance factor toward the average observed value.

The answers to each survey question used in the analysis have been first flagged as being valid, “not applicable” or “non-verifiable”. A missing or incomplete value can be either “not applicable” or “non-verifiable”. If an answer has been flagged as “not applicable”, it won’t be taken into account in the calculation of compliance factors. If the answer has been flagged as “non-verifiable”, it will be handled using two different approaches as described below, and because these two methods can lead to different compliance factors, both methods have been included in the results of the analysis.

- The first method assumes that all “non-verifiable” values are minimally compliant which correspond to a compliance factor of 1. This method is referred to as “NV1” or Minimally Compliant.
- The second approach considers that all “non-verifiable” values are equal to the average of the response. For example, if for a particular surveyed building the overall fenestration U-Factor was not reported or could not be calculated, then the overall average fenestration U-Factor across all surveyed buildings is computed and used in place of the “non-verifiable” value. This method is referred to as “Avg” or Available Data.

Representative Sample

The sample used in the field analysis was designed to provide a representative sample of the building stock in considering code compliance rates. But at each individual building site in the field study, data was not always collected for all of the individual building characteristics related to compliance. This led to a number of missing observations in the data that was available for this analysis. For some types of measures, most notably fenestration characteristics, the missing observations represented a large percentage of the sample. In Table 4, the number of observations available and missing is indicated by measure type. (Building characteristics with a large percentage of missing observations are shaded relative to the percent of missing data.) For all types of fenestration characteristics, close to 90% of the sample was missing data on fenestration performance characteristics. Missing data was also significant for exterior lighting systems, and to a lesser extent for certain types of HVAC system characteristics, like boiler reset characteristics and the presence of variable frequency drives. The degree of missing data for individual characteristics should be kept in mind when considering the energy impact of compliance patterns by individual characteristic. To help assess the variability of observations, Table 4 also shows the range of values for the compliance factors (low and high) in each characteristic. (Note that low compliance factor values of 0.00 represent binary values that were not compliant, such as "required occupancy sensors are not installed…").

In the compliance factor table, it should also be noted that individual building characteristics might not be applicable to all buildings in the sample, such as buildings without slabs. Conversely, multiple values for individual characteristics might be applicable to individual buildings, such as multiple lighting zones within a single building.

Table 4: Evaluation of Missing Data by Component

Number of Observations and Data Range

		# of valid observations	# of valid buildings	# of non-valid observations	% of non-valid obersvations	lowest comp. factor, AC	highest comp. factor, AC
Vertical Fenestration	U-Factor	3	3	18	86%	0.91	1.57
	SHGC	2	2	19	90%	1.05	2.00
	VT	2	2	19	90%	1.00	1.00
Horizontal Fenestration	U-Factor	2	2	19	90%	1.00	1.50
	SHGC	2	2	19	90%	1.00	1.33
	VT	2	2	19	90%	0.67	1.00
Slab Edge	Slab Depth	17	17	4	19%	0.00	2.00
	Slab R-Value	16	16	5	24%	0.00	2.00
Wall	Wall R-Value	19	19	2	10%	0.68	2.56
Floors	Floor R-Value	8	8	13	62%	0.00	2.40
Roof	Roof R-Value	18	18	3	14%	0.49	1.27
Lighting	LPD	37	20	8	18%	0.20	8.82
	Occ Sensor or Timer	45	21	0	0%	0.00	1.00
	Daylighting	44	20	1	2%	1.00	1.00
	Bi-Level	44	20	1	2%	0.00	1.00
HVAC	DCV	20	20	1	5%	0.00	1.00
	Plenum Insulation	11	11	10	48%	0.63	1.25
	Fan Power	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	HVAC Pipe Insulated	15	15	6	29%	1.00	1.00
	Heat Pump Sup Heat	12	12	9	43%	0.00	1.00
	Ducts and Plenum Sealed	14	14	7	33%	1.00	1.00
	Economizer	14	14	7	33%	0.00	1.00
	VFD or Vane Axial Fan	11	11	10	48%	0.00	1.00
	Heat Rejection VFD	7	7	14	67%	0.00	1.00
	Boiler Reset	7	7	14	67%	1.00	1.00
	ERV	15	15	6	29%	0.00	1.00
	Heating Efficiency	36	16	4	10%	0.98	1.28
	Cooling Efficiency	40	19	4	9%	0.81	1.42
Infiltration	Air Barrier	17	17	4	19%	0.00	1.00
	Barrier Con. to All Surf.	19	19	2	10%	0.00	1.00
	Weatherseals	20	20	1	5%	0.00	1.00
	Window Air Leakage	2	2	19	90%	1.00	1.16
	Vestibule	20	20	1	5%	1.00	1.00
	Self-Closing Door	20	20	1	5%	1.00	1.00
SHW	SHW Efficiency	14	14	7	33%	1.19	1.24
	Pipe Insulation	18	18	3	14%	0.00	3.00
Additional Compliance Factors (2017):							
Vertical Fenestration	WWR	20	20	1	5%	0.79	1.00
Lighting	Exterior	4	4	17	81%	0.67	1.82

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Prototypical Building Energy Models Simulation

In this analysis the commercial building stock is represented by three different prototypical building energy models: an office, a stand-alone retail and a primary school building. The prototypes are based on the “Commercial Prototypes Building Models” developed by PNNL for the United-States Department of Energy[4]. The prototypes have been initially created for the whole-building energy simulation program EnergyPlus. Since the program used for this analysis is DOE-2, the prototypes had to be converted to be used with DOE-2.

The simulations for this analysis have been performed using the batch simulation capabilities of eQUEST[5] which automatically modifies and runs DOE-2 input files based on structured data stored in comma separated files (CSV). For Rhode Island, close to 2,600 simulations have been performed.

Each prototype has been modeled with different HVAC systems as shown in Table 5.

Table 5 - Prototype HVAC Systems

Prototype	Area (ft2)	HVAC systems
Office	54,000	• Packaged VAV (PVAV) • Built-up VAV (VAVS) • Single zone systems, gas furnace and direct expansion cooling (PVVT) • Single zone systems, heat pump (PVVT-HP)
Retail	25,000	• Single zone systems, gas furnace and direct expansion cooling (PVVT) • Single zone systems, heat pump (PVVT-HP)
School	74,000	• Packaged VAV (PVAV) • Water-loop heat pumps (WLHP) • Single zone systems, gas furnace and direct expansion cooling (PVVT)

Post-processing of the Simulation Results

The simulation results for Rhode Island are included in a common Microsoft Excel workbook where the energy savings for each combination of state, building type, HVAC system and reference code version can be observed. The results are shown in terms of percentage savings, energy use intensity and overall energy use.

Binary Calculation

As mentioned in the Code Compliance Factor Calculation section, some building components are considered to be binaries, meaning that they are either included in the building, or not. Compliance factors for such components cannot be implemented directly in the simulation process.

The impact of the compliance rates on each individual binary component has been estimated by weighting, using the compliance factors, the simulated prototype energy use of the case where the binary is included and the case where it is not as shown below:

$$\begin{aligned}(Binary\ Energy\ Use) &= (Simulated\ Energy\ Use\ Including\ the\ Binary) * (Compliance\ Factor) \\ &+ (Simulatied\ Results\ Excluding\ the\ Binary) * (1 - Compliance\ Factor)^{6}\end{aligned}$$

When the impact of all compliance rates is of interest, the method described above cannot work. The impact of each binary relative to each other must first be estimated before being weighted by its compliance factors.

[4] https://www.energycodes.gov/development/commercial/prototype_models#90.1

[5] Latest build of the 3.64 version

[6] "Simulated Energy Use Including the Binary": only if required by code.

The impact of each binary relative to each other has been estimated using a 2^3 factorial experiment approach[7]. Such an experiment is composed of three factors, each having two levels of variation (for example: efficiency (low/high), operation (on/off), etc.) that impact the output of the experiment.

In the context of this analysis:

- Factors: the three binary components (lighting control, demand control ventilation and air-side economizer)
- Level: binary included, binary not included

The experiment is performed for each combination of building type, HVAC system, code of reference and compliance factor calculation method.

The results of the experiment are normalized to create weights for each binary component which can then be used in conjunction with the compliance factors to estimate the simulated energy use of all compliance rates.

$$(All\ Compliance\ Rates\ Energy\ Use) = (Simulated\ Energy\ Use)_{All\ Comp.\ Rates,\ Excl.\ Bin.}(W_L(1-C_L) + W_D(1-C_D) + W_E(1-C_E)) + (Simulated\ Energy\ Use)_{All\ Comp.\ Rates,\ Incl.\ Bin.}(W_L C_L + W_D C_D + W_E C_E)^8$$

Where:

- W_L, W_D, and W_E are respectively the lighting control, DCV and economizer weights calculated using the 2^3 factorial experiment.
- C_L, C_D, and C_E are respectively the lighting control, DCV and economizer compliance factors.

Terminology Reference

This section summarizes the terminology used in this report for quick reference.

Compliance characteristics are evaluated and described in various different contexts in this analysis. The following list of terms provides a reference for how each term is used in the analysis and tools.

Compliance Factor: Conversion of the field compliance rate into a performance factor applied to building characteristics relative to code compliance. A factor below 1.0 means the building component does not meet minimum code requirements. 1.0 is exactly at code. A factor above 1.0 means the building characteristics is better than required by code. This is also referred to as 'over-compliance'.

Savings Percentage: when negative, this means that the building type or building characteristics uses less energy and performs better than code requires. When positive, the savings percentage means that the building is not meeting code requirements and is using more energy than code allows.

[7] A factorial experiment is a method used in statistics to evaluate the effect of several factors (having discrete possible values) on the response variable of a system or an experiment, as well as the interaction with each other on the response.

[8] "All Compliance Rates, Including Binaries": only if required by code.

Building Prototypes: All energy analysis is conducted on building prototypes representing common building types rather than specific buildings in the sample. These prototypes are based on national building models developed by the National Renewable Energy Laboratory (NREL) to represent building typologies. The characteristics of the prototypes are modified using characteristics and compliance factors derived from the observations in the field study.

Building characteristic data is evaluated against several different code conditions, as follows:

- ***Applicable Codes***[9] (or code-specific) refers to the code under which individual buildings in the sample were permitted. There were two different code versions represented in the sample. Data in this section refers to the relationship of the individual building characteristics to the code under which they were built.
- ***2009 Compliance*** compares all building characteristics to the requirements of the 2009 IECC, regardless of which code they were built under.
- ***2012 Compliance*** compares all building characteristics to the requirements of the 2012 IECC, regardless of which code they were built under.

Under each of the code conditions described above, the data is analyzed for three different compliance assumptions:

- ***Available Data***-In this analysis, the average observed characteristics of the field data is applied to all of the missing field data characteristics. For example, if the average wall R-value of the ten buildings where this condition was observed was R-11, all buildings in the sample were assumed to have R-11 walls.
- ***Minimally Compliant***-In this analysis, all building characteristics were assumed to comply exactly with code requirements unless specific data to the contrary was present. In the R-value example above, the wall R-value of the ten buildings with data would be averaged with the remaining buildings in the sample assumed to meet code R-value requirements.
- ***Only Under-compliance***-In this analysis, the energy impacts are evaluated ONLY on the components of the buildings which do not meet code requirements. This analysis represents the impact of non-compliance in the sample, ignoring building components which exceed compliance requirements. This analysis suggests the energy opportunity represented by improved compliance rates without accounting for beyond code performance in other building attributes.

The following abbreviations are used for HVAC systems in this analysis:

- ***PVVT***: packaged single zone DX RTU w/gas heat
- ***PVVT-HP***: packaged single zone RTU heat pump
- ***PVAV***: packaged DX VAV RTU serving multiple zones with hot water heat/terminal reheat
- ***VAV***: central built-up VAV serving multiple zones with chilled water cooling and hot water heat/terminal reheat
- ***WLHP***: single zone water source heat pump (water to air) with central condenser water loop

Data Analysis Tools

The analysis results for this project are contained in three data spreadsheets which can be manipulated to review different aspects of the results and analysis. Each tool contains different aspects of the data, as described below. Highlights and summary tables from these tools are provided throughout the text of this report.

[9] The sample includes 13 buildings permitted under the IECC 2009 and 8 permitted under the IECC 2012.

RI-CodeAnalysis-ComplianceAnalysis

This tool contains information about the compliance factors that were generated from the field data and used in the energy modeling analysis to represent compliance characteristics of each individual building component. The compliance factors represent the level of code compliance seen in the field sample, by individual building component. The main reference worksheet is the '*Main Comparison Table*' tab. The following information is contained in this file:

- Compliance factor information for all building components for which field data was provided.
- Weighted compliance factors for each building size range and scenario by which missing values were assigned.
- Alternate values (using drop down menu) for IECC 2009 and IECC 2012 code baseline.

RI-CodeAnalysis-ComplianceFactorComparison

This tool compares data from the current study with results from the previous study in 2014. The tool includes information about the number of observations in the field data that allow the user to consider how well-represented the building characteristics are in the study. The main reference worksheet tab is the '*Weights Comparison*' tab. The following data is included:

- Side-by-side comparison of compliance factors from the 2017 study with the values from the 2014 study
- Information about how many missing values are present in the data, the range of values of the compliance factors for each component, and the number of observations present in the data
- Compliance factor comparison between different code baselines (2007, 2009, 2012).

RI-CodeAnalysis-WeightedSavings

This tool contains the main results from the energy impacts analysis. There are two key worksheets in this tool. The '*Master Table*' worksheet contains weighted data for all of the building prototypes and HVAC variants in a single table. This tab includes the following:

- Total building energy impact for all building components modeled together, for both approaches to missing data.
- Energy impact of only those building components that do not meet code requirements, bundled together into total building energy use impact.
- Comparison to different code baselines (2009, 2012) for the above.

The second worksheet; '*Energy Savings*', shows component energy savings for each component, by building type. This worksheet also includes tables showing percent savings, total energy, energy by building area, and fuel type. Drop down menus at the top of the page allow users to select building type, HVAC configuration, and code version. The tables on this tab are then populated from the lookup data in subsequent worksheets. Data includes:

- Percent savings by component, including under-compliance impact
- Savings by component per building area
- Total energy savings by component
- Individual fuel type savings (for all metrics above)
- Total building savings for each category above
- All permutations of code baseline, missing data assumptions, etc.

Description of Analysis Results

Individual Component Results

The compliance review tool contains results for each of the three building prototypes, with two to four different HVAC system types per prototype, for each one of the 15 individual measures.

These results are compared to three code baseline conditions, using two different assumptions about how the missing values should be treated, plus an analysis of non-complying features only. Impacts are described by percentage, square foot, total energy and fuel type. Taken together this represents, a wealth of data that is difficult to describe or represent fully in a summary report, and deeper analysis should rely on the data tool itself. However, the following data and description provides a summary of how the results can be considered for individual measure savings. Two examples are highlighted.

Table 6 shows energy savings characteristics for the school building prototype with a water source heat pump system. Individual building components are listed in the left column. In some cases, these components represent combined individual compliance factors for elements such as all lighting control requirements. The next set of columns shows a comparison to applicable codes (representing a weighted average of the requirements of the code under which the buildings in the sample were built), while the final set of columns shows a comparison to the requirements of the 2012 IECC for all cases.

For each set of code comparisons, the first two columns of results represent the different ways that missing values were accounted for. In the Available Data column, missing values are converted to the average of observed values. In the Minimally Compliant column, the missing values are assumed to be equal to code requirements. The final column in each section, Only Under-compliance, shows the energy savings impacts only of the building characteristics that do not meet code requirements, omitting the impact of better than code compliance within some of the sample. The purpose of this column is to demonstrate the potential energy savings available if these elements more consistently met code requirements.

The bottom row of the table shows the total energy performance impact on the building prototype of all of the individual measure characteristics considered together in the modeling analysis. This summary row is also included in Table 8 which summarizes total building compliance impacts for all prototype configurations.

Compliance characteristics are color coded: red cells represent performance that does not meet code requirements, resulting in increased energy use compared to code (positive energy use values), blue cells represent performance that is better than code, resulting in reduced energy use (negative energy use values).

Table 6: Total Savings Percentage for School Building Prototype with a Water Source Heat Pump Mechanical System

Total % Savings

School Building with Water Source Heat Pump

	Applicable Codes			2012 Compliance		
	Available Data - AC	Minimally Compliant - AC	Only Undercompliance - AC	Available Data - 12	Minimally Compliant - 12	Only Undercompliance - 12
Infiltration	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Wall Insulation	-0.25%	-0.28%	0.18%	-0.23%	-0.25%	0.18%
Roof Insulation	0.22%	0.22%	0.76%	1.29%	1.29%	1.40%
Fenestration	0.17%	0.51%	0.73%	0.74%	0.51%	1.29%
Slab	0.00%	0.00%	0.02%	0.00%	0.00%	0.02%
LPD	-3.81%	-3.55%	0.76%	-3.79%	-3.50%	0.88%
Light Controls	1.05%	1.05%	1.05%	1.05%	1.05%	1.05%
Exterior Lighting	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Cooling Efficiency	-1.12%	-1.12%	0.00%	-1.12%	-1.12%	0.00%
Heating Efficiency	-2.08%	-1.93%	0.00%	-2.93%	-2.81%	0.00%
Fan Horsepower	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Duct Leakage	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Economizer	0.07%	0.07%	0.07%	0.07%	0.07%	0.07%
DHW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DCV	0.15%	0.15%	0.15%	0.15%	0.15%	0.15%
All Compliance Rates	**-6.96%**	**-6.58%**	**3.97%**	**-6.47%**	**-6.52%**	**5.33%**

Negative numbers indicate performance better than code requirements. Positive numbers indicate percent by which code requirements are not met.

Table 7: Total Savings Percentage for Office Building Prototype, with a Package Variable Air Volume Mechanical System.

Total % Savings

Office Building with Package Variable Air Volume System

	Applicable Codes			2012 Compliance		
	Available Data - AC	Minimally Compliant - AC	Only Undercompliance - AC	Available Data - 12	Minimally Compliant - 12	Only Undercompliance - 12
Infiltration	0.00%	0.03%	0.03%	-0.03%	0.00%	0.03%
Wall Insulation	-0.48%	-0.58%	0.38%	-0.44%	-0.48%	0.38%
Roof Insulation	0.10%	0.10%	0.35%	0.58%	0.58%	0.62%
Fenestration	-4.11%	0.13%	3.58%	-2.44%	0.48%	4.51%
Slab	0.01%	0.00%	0.03%	0.00%	0.00%	0.02%
LPD	-2.34%	-2.23%	0.58%	-2.34%	-2.21%	0.65%
Light Controls	0.55%	0.55%	0.55%	0.55%	0.55%	0.55%
Exterior Lighting	-0.25%	-0.25%	0.13%	-0.25%	-0.25%	0.13%
Cooling Efficiency	-0.91%	-0.91%	0.00%	-0.91%	-0.91%	0.00%
Heating Efficiency	-4.71%	-4.45%	0.00%	-6.26%	-6.05%	0.00%
Fan Horsepower	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Duct Leakage	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Economizer	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%
DHW	-1.61%	-1.54%	0.00%	-1.61%	-1.54%	0.00%
DCV	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
All Compliance Rates	**-13.88%**	**-9.94%**	**5.80%**	**-13.82%**	**-10.94%**	**7.00%**

Observations

At the highest level, this analysis suggests that compliance patterns with the energy code in Rhode Island buildings are generally meeting the intent of the code with respect to overall (modeled) energy use characteristics. In all building types analyzed, the prototypes modeled with the building characteristics identified in the field study perform better than code baseline prototypes. For example, in the school building prototype with a water source heat pump, the building exceeds the performance requirements of the energy code in either compliance baseline (2009 or 2012), by approximately 7%. Though some building characteristics do not meet code requirements, most notably lighting controls and some envelope characteristics, overall this is more than made up for by the energy savings from lower LPD's and installed heating and cooling efficiencies that lead to significant total building energy savings above code. All of the other prototypes and HVAC system configurations show similar results to varying degrees, as shown in the tables included in this report and accompanying data files.

At the same time, the individual building features that do not meet code requirements do have an energy penalty associated with them. In this case the combined energy impact of the non-complying characteristics is between 3.5 and 4.8 percent of total building energy use. This represents an opportunity for improved compliance characteristics to improve overall building energy use.

When considering individual building characteristics, there are a number of key issues that this analysis highlights.

1) For every building type analyzed, lighting LPD on average is significantly better than energy code requirements, leading to substantial energy savings. The fact that buildings are routinely achieving savings over code represents an opportunity for code advancement to codify these energy savings. (Lack of code stringency in this area also has adverse energy use implications when projects submit using the performance path, as discussed below.) Although energy savings from lower installed lighting levels is partially offset by an increase in heating energy needs (primarily in the gas consumption category), the savings from lighting levels better than code is the biggest category of better than code performance in this analysis. Note however that there are still a few buildings in the sample failing to meet code LPD requirements. Given the degree to which most of the buildings outperform these requirements, failure to comply with LPD requirements represents a significant outlier from a compliance perspective, and an opportunity for better enforcement in those cases.
2) While overall lighting energy use is substantially better than code requires, there is significant non-compliance with lighting control requirements in code. In office buildings, failure to comply with lighting control requirements represents one of the biggest opportunities for energy savings associated with better compliance.
3) For all system types utilizing natural gas as a heating fuel, the field data suggests that projects are routinely installing gas heating equipment that is performing better than minimum code requirements. This is not surprising since the heating equipment that is available in the market has evolved toward higher efficiency over the past 30 years, while the federally pre-empted equipment efficiency requirements in code have not kept pace (!) with these advances.
4) Fenestration performance in this analysis is based on very few and highly variable field observations, and should not be considered a good indicator of compliance characteristics. It is hard to understand how enforcement of glazing performance requirements can be very effective when it is so difficult to determine glazing

performance characteristics in the field. This may be an area worth additional focus from an enforcement/incentive perspective.

5) The compliance with other envelope performance requirements (insulation) is surprisingly variable in the data. Although the analysis of field characteristics does not reveal large energy penalties from non-compliance, there is still a fairly widespread lack of compliance with insulation requirements, particularly for floor and roof assemblies, particularly in school building types.

While the analysis suggests an overall level of building performance better than code, there are still individual characteristics in the analysis that do not perform as well as the code requires. These are highlighted in the tables and text as the excess energy use associated with ‘only undercompliance’. Since projects following a prescriptive code are required to meet all individual code requirements, these energy impacts of undercompliance represent real opportunities for increased savings from better code compliance.

However, there is a caveat to the energy opportunity represented by non-compliance. While the majority of projects utilize the prescriptive path in the energy code, as identified in the DNV-GL field study and confirmed in many other jurisdictions around the country, the modeled performance pathway in the energy code is an allowable compliance method. The performance pathway tends to be used by large and complex commercial building projects to increase the flexibility of code compliance options. For those buildings following the performance path, the relative leniency of LPD requirements relative to market practice represents a significant opportunity to downgrade other building performance elements from code baseline, while overcompliance with lighting requirements insures overall building compliance.

If the buildings represented in this analysis followed the modeled performance pathway, the fact that they performed better than the overall energy targets of code compliance would mean that the ‘Only Under-compliance’ values represented here would not represent an opportunity for improved compliance savings, since the buildings would already perform better than the code baseline.

Weighted Results by Prototype

The high level observations of this analysis can best be evaluated in Table 8. This table includes a summary of energy performance results for all of the prototypes evaluated, including each permutation of system type in the analysis. The top table compares the analysis results to the 2012 IECC baseline, while the lower table compares results to the 2009 baseline. These results demonstrate the overall energy impact of the compliance patterns identified in field studies when these characteristics are modeled on building prototypes.

What is clear is that overall, the building characteristics lead to energy performance across the prototypes that is better than the code baseline. The weighted savings percentage for all prototype permutations ranges from seven percent better than code for one of the school prototypes to over 14% better than code for a retail prototype. Despite certain characteristics that do not meet code requirements, the overall energy performance of the buildings more than makes up for any non-compliant characteristics. This approach could be considered to represent a compliance strategy based on energy modeling. In an energy modeling approach to code compliance, projects must demonstrate that the building’s overall energy use will be less than that of a baseline building that just meets code requirements. This analysis suggests that although certain elements of the prototype buildings in the study do not meet code requirements, the overall energy use of the buildings is less than that of a baseline building which just meets code.

Note that despite the option of following an energy code analysis path to meet energy code requirements, the majority of projects are submitted using a compliance pathway other than the prescriptive pathway. (Future analysis should gather data on which compliance pathway was followed by individual project types.) Projects that follow the prescriptive path are required to meet all of the prescriptive requirements, and are not allowed to trade off better performance in some areas for worse than code performance in others. So despite the fact that the buildings overall use less energy than buildings that just meet code, there is still a non-compliance issue to be discussed. To evaluate this aspect of the buildings, the characteristics which do not meet code requirements were analyzed independently in the category 'Only Under-compliance'.

In Table 8, the far right column shows the impact of the non-compliant characteristics of the prototype buildings in the analysis. (Data for individual fuels is included in the accompanying data sheets.) This column shows the energy impact of only those elements of the prototype buildings that do not meet code requirements, ignoring building elements that perform better than code. Since the vast majority of buildings submit for energy code compliance using the prescriptive path, these energy impacts can be considered to represent the energy consequence of non-compliance in this analysis.

In the under-compliance category, significant additional energy savings remain if improved compliance with prescriptive requirements were achieved. The additional savings potential for the IECC 2012 baseline ranges from 4[illegible]% to 7.6% in the weighted performance average of the different building prototypes analyzed.

Table 8: Weighted Savings by Prototype Building, compared to 2012 and 2009 Code Baseline

Weighted Savings Percentage		**Compared to 2012 Code**		
Building Type	**HVAC System**	**Available Data - 12**	**Minimally Compliant - 12**	**Only Undercompliance - 12**
Office	Pkg. Gas Furnace & DX Cooling	-12.54%	-9.63%	7.08%
Office	Pkg. Heat Pump	-12.57%	-8.49%	6.52%
Office	Pkg. Variable Air Volume System	-13.82%	-10.94%	7.00%
Office	Built-up Variable Air Volume System	-15.75%	-11.23%	7.58%
Retail	Pkg. Gas Furnace & DX Cooling	-13.07%	-13.32%	5.56%
Retail	Pkg. Heat Pump	-15.58%	-14.57%	5.92%
School	Pkg. Gas Furnace & DX Cooling	-6.92%	-7.13%	5.17%
School	Pkg. Variable Air Volume System	-7.71%	-7.29%	5.53%
School	Water Source Heat Pump	-6.47%	-6.52%	5.33%

Weighted Savings Percentage		**Compared to 2009 Code**		
Building Type	**HVAC System**	**Available Data - 09**	**Minimally Compliant - 09**	**Only Undercompliance - 09**
Office	Pkg. Gas Furnace & DX Cooling	-20.58%	-15.65%	2.99%
Office	Pkg. Heat Pump	-20.25%	-14.50%	3.40%
Office	Pkg. Variable Air Volume System	-20.83%	-16.27%	2.02%
Office	Built-up Variable Air Volume System	-23.64%	-17.10%	2.08%
Retail	Pkg. Gas Furnace & DX Cooling	-19.32%	-17.77%	3.22%
Retail	Pkg. Heat Pump	-22.35%	-19.36%	4.40%
School	Pkg. Gas Furnace & DX Cooling	-12.15%	-11.20%	2.29%
School	Pkg. Variable Air Volume System	-15.31%	-13.28%	2.48%
School	Water Source Heat Pump	-12.69%	-11.34%	2.33%

Negative values indicate performance better than code requirements. Positive values indicate percent by which code requirements are not met.

Comparison to Previous Results

A similar analysis was conducted on a set of buildings in Rhode Island in 2014, and the results of the current study can be compared to the results from the previous analysis. In Table 9 the compliance factors for each measure are compared between the current analysis and the previous analysis for each set of compliance variations. The results from the current study and the 2014 analysis are paired by column, with the more current results on the right side of each set of columns. Compliance factors which have decreased are highlighted in all cases.

Reviewing the data in the table, it is clear that the compliance factors for many building performance elements are not as high as in the previous analysis. However, most of the changes are either small, or the compliance factor value still remains above 1.0, meaning that the building characteristic in question is still better than code requirements.

One example to consider is that the degree to which building cooling system efficiency exceeds code requirements has decreased, though this component still performs better than code requirements. This suggests that the code requirements have partly caught up to industry practice in this area, but that based on the field sample, this component still performs better than code requires.

Other examples, such as the compliance factors for vestibules and self-closing doors, suggest that more attention might have been paid to these elements in field analysis for the current study than in the previous filed study, since the previous values show no non-compliance in the sample.

The values in this table should also be considered in the context of sample size and number of observations for each component, as discussed in the Representative Sample section above.

Table 9: Comparison of Compliance Factors to Results from 2014 Analysis

Scenario:		Missing value = Average collected value						Missing value = Minimally compliant						Only under-compliance					
		Applicable Code		IECC 2009		IECC 2012		Applicable Code		IECC 2009		IECC 2012		Applicable Code		IECC 2009		IECC 2012	
Building Component	Characterisitc	2014 Study	2017 Study	2014 Study	2017 Study	2014 Study	2017 Study	2014 Study	2017 Study	2014 Study	2017 Study	2014 Study	2017 Study	2014 Study	2017 Study	2014 Study	2017 Study	2014 Study	2017 Study
Vertical Fenestration	U-Factor	1.66	1.08	1.72	1.23	1.72	0.90	1.10	0.99	1.11	1.05	1.11	0.98	1.00	0.96	1.00	1.00	1.00	0.89
	SHGC	1.09	1.74	1.09	1.89	1.09	1.47	1.01	1.16	1.01	1.16	1.01	1.16	0.95	1.00	0.95	1.00	0.95	1.00
	VT	1.00	1.20	1.00	1.30	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	WWR	#N/A	1.00	#N/A	1.00	#N/A	1.00	#N/A	1.00	#N/A	1.00	#N/A	1.00	#N/A	0.97	#N/A	1.00	#N/A	0.97
Horizontal Fenestratio	U-Factor	1.28	1.07	1.09	1.19	1.09	1.03	1.02	1.03	1.00	1.03	1.00	1.03	1.00	1.00	1.00	1.00	1.00	1.00
	SHGC	1.29	1.13	1.00	1.13	1.00	1.13	1.10	1.02	1.00	1.02	1.00	1.02	1.00	1.00	1.00	1.00	1.00	1.00
	VT	1.00	0.79	1.65	0.79	1.65	0.79	1.00	0.95	1.03	0.95	1.03	0.95	1.00	0.79	1.00	0.79	1.00	0.79
Slab Edge	Slab Depth	0.85	0.96	1.09	0.97	1.09	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.56	0.94	0.71	0.95	0.71	0.95
	Slab R-Value	0.79	1.03	0.75	1.03	0.75	1.03	0.95	1.03	0.95	1.03	0.95	1.03	0.79	0.97	0.75	0.97	0.75	0.97
Wall	Wall R-Value	1.54	1.13	1.21	1.18	1.21	1.12	1.33	1.15	1.11	1.20	1.11	1.13	0.95	0.92	0.93	0.92	0.93	0.92
Floors	Floor R-Value	0.57	0.70	0.61	0.70	0.61	0.70	0.58	0.70	0.59	0.70	0.59	0.70	0.48	0.45	0.45	0.45	0.45	0.45
Roof	Roof R-Value	1.11	0.97	1.07	1.04	1.07	0.84	1.06	0.97	1.01	1.04	1.01	0.84	0.85	0.90	0.80	0.94	0.80	0.83
Lighting	LPD	2.20	1.87	1.81	1.89	1.81	1.86	2.15	1.76	1.82	1.77	1.82	1.74	0.96	0.92	0.96	0.92	0.96	0.91
	Occ Sensor or Timer	0.92	0.96	0.86	0.95	0.86	0.95	0.92	0.93	0.86	0.94	0.86	0.92	0.92	0.93	0.86	0.92	0.86	0.92
	Daylighting	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Bi-Level	0.38	0.64	0.44	0.64	0.44	0.64	0.38	0.93	0.44	0.93	0.44	0.93	0.38	0.64	0.28	0.64	0.28	0.64
	Exterior	#N/A	1.36	#N/A	1.36	#N/A	1.36	#N/A	1.36	#N/A	1.36	#N/A	1.36	#N/A	0.88	#N/A	0.88	#N/A	0.88
HVAC	DCV	1.00	0.96	1.00	0.96	1.00	0.96	1.00	0.96	1.00	0.96	1.00	0.96	1.00	0.96	1.00	0.96	1.00	0.96
	Plenum Insulation	0.48	0.95	0.48	0.95	0.48	0.95	0.48	0.97	0.48	0.97	0.48	0.97	0.48	0.88	0.48	0.88	0.48	0.88
	Fan Power	0.92	1.00	2.07	1.00	2.07	1.00	0.92	1.00	2.08	1.00	2.08	1.00	0.91	1.00	0.78	1.00	0.78	1.00
	HVAC Pipe Insulated	0.95	1.00	0.95	1.00	0.95	1.00	0.95	1.00	0.95	1.00	0.95	1.00	0.95	1.00	0.95	1.00	0.95	1.00
	Heat Pump Sup Heat	1.00	0.97	1.00	0.97	1.00	0.97	1.00	0.98	1.00	0.98	1.00	0.98	1.00	0.97	1.00	0.97	1.00	0.97
	Ducts and Plenum Sealed	0.90	1.00	0.90	1.00	0.90	1.00	0.92	1.00	0.92	1.00	0.92	1.00	0.90	1.00	0.90	1.00	0.90	1.00
	Tape or Mastic	0.80	#N/A	0.80	#N/A	0.80	#N/A	0.88	#N/A	0.88	#N/A	0.88	#N/A	0.80	#N/A	0.80	#N/A	0.80	#N/A
	Economizer	0.82	0.97	0.82	0.97	0.82	0.97	0.82	0.97	0.82	0.97	0.82	0.97	0.82	0.97	0.82	0.97	0.82	0.97
	VFD or Vane Axial Fan	0.94	0.97	0.94	0.97	0.94	0.97	0.94	0.98	0.94	0.98	0.94	0.98	0.94	0.97	0.94	0.97	0.94	0.97
	Heat Rejection VFD	0.81	0.96	0.76	0.96	0.76	0.96	0.81	0.97	0.76	0.97	0.76	0.97	0.81	0.96	0.76	0.96	0.76	0.96
	Boiler Reset	0.87	1.00	0.87	1.00	0.87	1.00	0.93	1.00	0.93	1.00	0.93	1.00	0.91	1.00	0.91	1.00	0.91	1.00
	ERV	1.00	0.91	1.00	0.91	1.00	0.91	1.00	0.91	1.00	0.91	1.00	0.91	1.00	0.91	1.00	0.91	1.00	0.91
	Heating Efficiency	1.11	1.17	1.11	1.24	1.11	1.24	1.11	1.16	1.11	1.23	1.11	1.23	1.00	1.00	1.00	1.00	1.00	1.00
	Cooling Efficiency	2.01	1.10	1.81	1.10	1.81	1.10	2.01	1.10	1.81	1.10	1.81	1.10	1.00	1.00	0.99	1.00	0.99	1.00
Infiltration	Plans - Air Barrier	0.75	#N/A	0.70	#N/A	0.70	#N/A	0.86	#N/A	0.78	#N/A	0.78	#N/A	0.74	#N/A	0.70	#N/A	0.70	#N/A
	Plans - Air Barrier Connected to All Walls	0.80	#N/A	0.77	#N/A	0.77	#N/A	0.91	#N/A	0.83	#N/A	0.83	#N/A	0.80	#N/A	0.77	#N/A	0.77	#N/A
	Plans - Weatherseals	0.77	#N/A	0.77	#N/A	0.77	#N/A	0.84	#N/A	0.84	#N/A	0.84	#N/A	0.77	#N/A	0.77	#N/A	0.77	#N/A
	Installed - Air Barrier	0.73	#N/A	0.53	#N/A	0.53	#N/A	0.95	#N/A	0.95	#N/A	0.95	#N/A	0.53	#N/A	0.53	#N/A	0.53	#N/A
	Installed - Air Barrier Connected to All Walls	0.68	#N/A	0.43	#N/A	0.43	#N/A	0.92	#N/A	0.92	#N/A	0.92	#N/A	0.43	#N/A	0.43	#N/A	0.43	#N/A
	Installed - Weatherseals	0.69	#N/A	0.69	#N/A	0.69	#N/A	0.89	#N/A	0.89	#N/A	0.89	#N/A	0.69	#N/A	0.69	#N/A	0.69	#N/A
	Air Barrier	#N/A	0.99	#N/A	0.99	#N/A	0.99	#N/A	1.00	#N/A	1.00	#N/A	1.00	#N/A	0.99	#N/A	0.99	#N/A	0.99
	Barrier Con. to All Surf.	#N/A	0.92	#N/A	0.92	#N/A	0.92	#N/A	0.92	#N/A	0.92	#N/A	0.92	#N/A	0.92	#N/A	0.92	#N/A	0.92
	Weatherseals	#N/A	0.94	#N/A	0.94	#N/A	0.94	#N/A	0.94	#N/A	0.94	#N/A	0.94	#N/A	0.94	#N/A	0.94	#N/A	0.94
	Window Air Leakage	3.36	1.13	3.36	1.34	3.36	1.34	1.32	1.03	1.32	1.12	1.32	1.12	1.00	0.96	1.00	1.00	1.00	1.00
	Roof Penetration	0.96	#N/A	0.96	#N/A	0.96	#N/A	0.96	#N/A	0.96	#N/A	0.96	#N/A	0.96	#N/A	0.96	#N/A	0.96	#N/A
	Vestibule	1.00	0.63	1.00	0.63	1.00	0.63	1.00	0.63	1.00	0.63	1.00	0.63	1.00	0.63	1.00	0.63	1.00	0.63
	Self-Closing Door	1.00	0.63	1.00	0.63	1.00	0.63	1.09	0.63	1.09	0.63	1.09	0.63	1.00	0.63	1.00	0.63	1.00	0.63
SHW	SHW Efficiency	1.00	1.18	1.00	1.18	1.00	1.18	1.00	1.19	1.00	1.19	1.00	1.19	1.00	0.99	1.00	0.99	1.00	0.99
	Pipe Insulation	0.95	1.14	0.56	0.77	0.56	1.50	0.95	1.13	0.56	0.76	0.56	1.50	0.51	0.82	0.51	0.68	0.51	0.91

Conclusions

This analysis used the results of field data from a recent study of building energy code compliance characteristics to analyze the energy impacts of the compliance patterns seen in the field data. The findings of this analysis demonstrate two key characteristics of energy code compliance patterns that represent two somewhat contradictory sides of the compliance issue.

First, despite the presence of specific building elements that do not comply with energy code requirements, the overall impact of this non-compliance on prototype buildings with these characteristics does not suggest that the buildings as a whole exceed code energy use allowances. Instead, other building features that outperform energy code requirements more than offset the energy impacts of non-compliance, leading to overall building performance that is substantially better than the code requires.

Second, despite the overall performance of the buildings better than code, there are still elements of the buildings that represent opportunities for improved energy outcomes through better code compliance. The vast majority of projects follow the prescriptive path of the energy code, which requires that all building elements meet individual code requirements, rather than allowing energy tradeoffs among individual components. Improved compliance with prescriptive requirements will lead to improved energy performance in the building stock.

The information presented in this report and in the accompanying data files may allow administrators and policymakers to focus on compliance issue with the most significant potential energy benefits, and to identify potential areas where additional training or incentive resources might have positive impacts on sector energy use.