



## **RESIDENTIAL ENERGY CODE EVALUATIONS**

### **Review and Future Directions**

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## Section 1. Introduction

The primary goal of this paper is to review existing energy code evaluation studies, and make recommendations for future work in this area. We are not aware of any other literature review that brings together a body of current literature for evaluation purposes.

Our secondary purpose is to address this existing body of literature as it relates to the quantification of the savings gap, which we define as the energy savings foregone due to non-compliance with the energy code adopted in a state or local jurisdiction. We believe that understanding the savings gap is important because it allows us to look beyond compliance rates to the actual impact the energy code has both in terms of energy savings and economic impact on homeowners.

This paper is laid out in four major sections. The following section lays out a brief background of energy codes and their evaluation studies. The second section evaluates existing literature on the basis of several areas we found worth examining: sampling, data collection & analysis, and compliance rates. Section three looks at some of the major findings and recommendations from current literature, and in section four we offer our own recommendations and conclusions. Two appendices follow, summarizing some of the baseline construction characteristics collected in the reviewed literature, as well as a more comprehensive listing of major findings and recommendations in the literature, ordered by state.

## Background

The Energy Policy Act (EPA) of 1992 established a role for the Department of Energy (DOE) to determine whether or not the 1992 Council of American Building Officials (CABO) Model Energy Code (MEC) and the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) Standard 90.1-1989 would improve energy efficiency for residential and commercial buildings respectively. This also applied to subsequent revisions of the code, and DOE is supposed to make a determination within 12 months of the revision of the respective energy codes. Once a positive determination is published in the Federal Register, each state has 2 years to self-certify that it has made revisions to the energy provisions in its building code, so that it meets or exceeds the requirements of the latest iteration of the national models. A state may decline to adopt a *residential* energy code by submitting a statement to the Secretary of DOE, detailing its reasons for doing so. The CABO MEC was last promulgated in 1995 and has since been replaced by the International Energy Conservation Code (IECC). On January 4th 2001, DOE issued a determination that the 1998 and 2000 IECC will improve on energy efficiency, and on July 15th 2002, a positive determination was issued for ASHRAE Standard 90.1-1999.

The majority of states have adopted residential and/or commercial energy codes, and many of them in the mid to late 1970s, prior to EPA requirements.<sup>1</sup> However, implementation and enforcement efforts are not consistent from state to state or from jurisdiction to jurisdiction. Some states rely on state agencies to enforce compliance, while others rely on jurisdictional authorities, and some allow for self-certification by builders. Even in locales where there is a code inspection

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<sup>1</sup> DOE relies on self-certification by states to meet EPA requirements, and not all states have adopted energy codes. An additional complicating factor in home rule states is that state governments frequently cannot require local jurisdictions to adopt energy codes. For a list of currently adopted energy codes and latest developments, visit <http://www.bcap-energy.org/>.

process, anecdotal evidence suggests that energy codes are a much lower priority for enforcement than the health and safety codes, such as fire codes.

Unsurprisingly, evidence from energy code evaluation studies at the state and jurisdictional level suggest that the full potential of energy and cost savings from the implementation of these codes in the United States are not being achieved.

The magnitude of realized energy savings from the adoption of building energy conservation codes is an essential indicator of the impact of those codes and the programs that support them. An analysis of the savings gap can be an important tool in formulating policies aimed at capturing the maximum savings potential in code adoptions.

## **Current Literature**

To date, we have knowledge of residential energy code evaluations conducted for 16 states, and commercial energy code evaluations for 7 states. This paper focuses on residential evaluations for a couple of reasons:

1. Residential structures are far less complex than their commercial counterparts. They generally have a single purpose, to house their residents, and so do not have the complex systems and requirements that are found in commercial structures.
2. Because residential structures are less complex, energy code evaluations are cheaper and less time consuming to conduct, reflected in the fact that residential studies are more abundant. Thus, there is more research and data available for our review.

Although we primarily look at residential evaluations, this paper also seeks to maintain a dialogue on commercial evaluations where appropriate, albeit at the periphery.

The majority of residential evaluations we looked at attempt to typify the average residential structure, usually owner-occupied and single-family, in a state or local jurisdiction. Compliance rates with the adopted energy code they are supposed to have been built to are then assessed. A smaller number of studies attempt to quantify a building's energy use and potential for further savings. In instances in which both existing and new residential construction is evaluated, results are typically broken down into existing and new baseline characteristics. These studies are frequently carried out independently of each other, with different goals and methodologies that make direct comparison difficult, if not impossible. One reason for the dearth of substantial research in this area is that such studies are often expensive to carry out. One well known energy evaluation consultant we spoke to estimates a cost of between US\$500-US\$1,000 per home for site visits alone, which have traditionally been the mainstay data collection technique of prior evaluations.

Once the baseline construction characteristics are obtained, the standard analysis tool is usually code compliance or energy simulation software. There is no standard software used, and the software developers ranged from the U.S government (DOE-2) to private institutions (PRISM) and industry (REM/rate). Finally, a number of evaluations include builder and/or homeowner interviews in order to develop a more complex view of residential construction encompassing its perceived and actual energy efficiency characteristics.

## Section 2. Evaluation Techniques

### 2.1 Sampling

Good sampling practice is the basis for obtaining a statistically valid study. In the case of code evaluations, the costs and extensive cooperation required from external parties usually means that sampling is not a straightforward process. In the ideal case, we would select a large, simple random sample of homes from the population of new (or existing) residential construction in a state or jurisdiction. However, practical limitations often prevent this. Table 1 below summarizes some of the sampling characteristics of studies that we looked at.

State		Baseline Construction Comparison Year	Sample Size	Permits Issued (for year of comparison)	Sample size (percentage of permits issued)	Sample type
AR	Statewide	1997	100	7,160	1.40%	Sample was drawn from new construction building permits and follow up with builders.
CA	Statewide	One year, from July 1999 – June 2000	758 total <sup>2</sup> , 631 (single), 127 (low-rise multifamily)	123,013 (all residential permits)	0.467% (all residential permits)	The sample was developed using data provided by California's Investor-Owned Utilities (IOUs). It encompasses newly constructed homes (occupied between July 1, 1999, and June 30, 2000.
CO	Ft Collins	Multiple, from 1995 – 1998	100 <sup>3</sup>	2,583 <sup>4</sup>	3.87%	Random sampling. Completed homes were evenly split between homes built before and after the code change in 1996. Age of residential construction ranged from 1995-1998.
FL <sup>5</sup>	Statewide	Multiple, from 1999 – 2001	1,612	22,389	7.20%	1 form was randomly selected from every 20 submitted, at least 1 per jurisdiction.
IA I	Statewide	Multiple, no home more than 20 years older than the study (2004)	30	12,235	0.245%	Tens homes chosen from each of the three climate zones, to be compared to 2000 IECC requirements. The initial pool was chosen based on feedback from county and zoning engineers.
IA II	Statewide	Current Construction, 2002	47 (single), 18 (multifamily)	11,841 (single)	0.397%	Goal of collecting 65 single-family homes, with half the sample coming from the Des Moines metropolitan area. 18 homes were replaced with multi-family units when it was determined that they represented a large proportion of homes built in the area.
	Ankeny		12 (single), 8 (multifamily)	688 (single), 50 (multifamily)	1.74% (single), 16.0% (multifamily)	
	Coralville		7 (single)	193 (single)	3.63% (single)	
	Des Moines		4 (single)	342 (single)	1.17% (single)	
	Iowa City		3 (single)	227 (single)	1.32% (single)	
	Johnston		1 (single)	251 (single)	0.398% (single)	
	North Liberty		1 (single)	163 (single)	0.613% (single)	

<sup>2</sup> The study had a total sample size of 801, including high rises and mobile homes, which we do not cover in this review.

<sup>3</sup> This sample can be broken down into 20 homes that were under construction at the time of the evaluation, and 80 homes that were completed. Of the 80 completed homes, 40 were selected for more in depth analysis by an energy rater.

<sup>4</sup> Data for Ft Collins – Loveland, from U.S. Census data.

<sup>5</sup> The number of permits issued for Florida is projected based on reporting that the sample size of 1,612 is 7.2% of the population, U.S. Census data for building permit activity is not used since the sampling in the study is based on the total number of Florida Energy Efficiency Code for Building Construction (FEECBC) Compliance forms (single family) submitted to the Florida Department of Community Affairs (DCA) by local building officials across the state. This covers the time period from 1999-2002. Total number of single family permits issued in the state of Florida for this time period total 331,718.

	Sioux Center		2 (single)	31 (single)	6.45% (single)	
	Waukee		9 (single), 6 (multifamily)	187 (single), 16 (multifamily)	4.81% (single), 37.5% (multifamily)	
	West Des Moines		6 (single), 4 (multifamily)	318 (single), 67 (multifamily)	1.89% (single), 5.97% (multifamily)	
ID	Statewide	1998	104	10,277 (single, statewide), 8,460 (sampled jurisdictions)	1.01% (statewide), 1.22% (sampled jurisdictions)	Samples drawn at random from a distribution proportional to housing starts in the sampled jurisdiction. Counties around Boise account for 69% of residential construction.
LA	Statewide	2000	73	13,109	0.56%	Sample drawn from the five largest population areas, geographically distributed. Project goal of a random sample of 100 homes from all single family residential permits issued in 2000.
MA	Statewide	1999	186	16,191 (single & two family), 15,022 <sup>6</sup> (sampled jurisdictions)	1.15% (statewide), 1.24% (sampled jurisdictions)	Two stage sampling process, selecting residential construction from towns with a probability proportional to the number of homes built in that town In 1999.
MN	Statewide	Multiple, for homes built in 1994, 1998, and 2000.	43			Sample was obtained by a data research firm for building permits issued in 14 Twin Cities metro area municipalities during 1994, 1998, and 2000. A letter of solicitation was sent to homeowners to obtain participation in the study.
MT	Statewide	1998	61	1,485 <sup>7</sup> (statewide), 3,865 (sampled jurisdictions)	4.11% (statewide), 1.58% (sampled jurisdictions)	Samples drawn at random from a distribution proportional to housing starts in the sampled jurisdiction.
NV	Statewide	Current Construction, 2003		33,090		Northern and Southern Nevada, and jurisdictions within them were selected for inclusion in the study based on population and building permit activity. Target of 60 single-family homes from Northern Nevada, and 140 homes in Southern Nevada.
	Northern		59			
	Southern		13			
	Southern II <sup>8</sup>		48			
NY	Long Island	2003	74 (single), 2 (multifamily)	4,129 (single), 1,163 <sup>9</sup> (multifamily)		Combined Long Island sample was drawn from Nassau and Suffolk counties, with an offer of \$100 for participants. Despite the offer of monetary remuneration, there was difficulty in obtaining participants. The study admits a probably self-selection bias but does not believe that it is correlated with the energy efficiency of surveyed homes.
	Nassau		6 (single), 1 (multifamily)	643 (single), 265 (multifamily)		
	Suffolk		68 (single), 1 (multifamily)	3,486 (single), 898 (multifamily)		
OR	Statewide	1998	44 <sup>10</sup>	16,936 (statewide), 16,743 (sampled)	0.260% (statewide), 0.260%	Samples drawn at random from a distribution proportional to housing starts in the sampled jurisdiction.

<sup>6</sup> Study data for building permit activity was obtained from the Massachusetts Institute for Social and Economic Research (MISER), for 351 towns in Massachusetts.

<sup>7</sup> Statewide building permit activity is from U.S. Census data and reported jurisdictional permit activity was provided by Western Construction Monitor<sup>®</sup>. Part of the reason for the large discrepancy in data could be due to urban jurisdictions only being allowed to enforce the building code within a 4.5 mile radius of the city limits. Residential construction outside this boundary does not require a building permit or inspections.

<sup>8</sup> An external vendor provided part of the Nevada sample data to the contractor conducting the study due to difficulties encountered in on-site data collection.

<sup>9</sup> Multifamily permits for New York only for construction with 5 or more units. The sampled multifamily structures had 40 and 35 units in Nassau and Suffolk Counties respectively.

<sup>10</sup> Oregon data was supplemented with an additional 283 homes from a 1994 study, This brings the total sample size up to 327 and 1.95% of 1998 statewide and sampled jurisdictions' building permit activity.

				jurisdictions)	(sampled jurisdictions)	Counties around Portland account for 53% of residential construction.
VT	Statewide	1999	151	2,187	6.90%	
		2002	158	2,451	6.45	
WA	Statewide	1998	157	28,644 (statewide), 27,849 (sampled jurisdictions)	0.548% (statewide), 0.564% (sampled jurisdictions)	Samples drawn at random from a distribution proportional to housing starts in the sampled jurisdiction. Counties around Seattle account for 63% of residential construction.
WI	Statewide	Existing Construction	299	24018	1.24	

Table 1. Sampling Characteristics of Reviewed Evaluations (for single-family homes, unless otherwise noted)

## Sample Sizes and Bias

As is obvious from the table above, current evaluations literature exhibits large variance in both relative and absolute sample sizes as well as sampling methodologies. Small samples should not be dismissed since they can be representative of the population, although they can also be much more susceptible to bias.

Cost and builder resistance are frequently cited as the largest factors influencing sample sizes and the introduction of bias. The Massachusetts study, *Impact Analysis of the Massachusetts 1998 Residential Energy Code Revisions*, echoes the cost sentiment:

Using a simple random sampling approach to select houses for this study would have been very expensive because we would have had to visit each building department to obtain the statistics on new construction permits. To keep sampling costs reasonable, we used a two-stage sampling approach instead.<sup>11</sup>

Additionally, in some states such as Montana, where 60% of residential construction is built outside of code jurisdictions, it could be prohibitively expensive to obtain the information, such as addresses and year of construction, required to draw a substantially sized sample from the full population.

These gaps in access to information serve not only to restrict the sample size, but also introduce selection bias through the utilization of convenience samples, which are samples easily collected even though they are not representative of the population. Such samples are typically introduced by the utilization of records from samples with different population parameters, or records from previous evaluations that have different metrics. With regards to energy code evaluations, the use of a convenience sample can be intimately tied to self-selection bias. This occurs most notably in cases where jurisdictions or builders choose to opt in or out of a study based on their self-interest. It might be reasonable to assume that those who are willing or even eager to have evaluators enter their homes or jurisdictions are likely to be confident that they have a superior quality product or code enforcement environment.

The June 2003 evaluation carried out in Nevada, *Final Report – Volume 1 In-Field Residential Energy Code Compliance Assessment and Training Project*, illustrates some of the practical issues in the field that have resulted in such bias. Section 3.1.4 in the study states:

For Southern Nevada, a field inspection was conducted on only 13 homes from the original sample [of 140 homes]. The low results were due to difficulty in making contact with the individuals that could grant permission to collect data onsite, lack of builder interest in the

<sup>11</sup> *Impact Analysis of the Massachusetts 1998 Residential Energy Code Revisions*, Xenergy Inc, May 2001, Pg. 3-1.

study and a suspicion concerning a perceived link between the results of the study and possible construction defect litigation.

As a direct result of the inability to collect data in Southern Nevada, a contract was put in place with Woods & Associates, a code compliance and U.S. EPA Energy Star program home inspector/rater in Las Vegas, to provide data for 100 typical homes in [the] Southern Nevada sample region. A mix of Energy Star qualifying homes and standard construction homes were included in the sample.<sup>12</sup>

In this instance, self selection bias by the builders led to the study authors using a convenience sample provided by an external vendor which included 48 homes that qualified for ENERGY STAR<sup>13</sup> and Engineering for Life Programs, and 52 homes built to local code requirements and baseline construction practices.<sup>14</sup>

Evaluations have been forthcoming about these sampling issues, and helpful in identifying key areas that can be improved in sampling methodology. In particular, they emphasize the importance of communication in overcoming builder resistance. The aforementioned study for the state of Nevada makes a recommendation that future studies communicate with and gain cooperation from both local homebuilders and building official associations prior to commencement. A study commissioned by the Arkansas Energy Office found that marketing the evaluation as a quality control product to builders whose houses had been selected was an effective way of gaining their cooperation. In particular, the study found that “when [builders were] assured that it was free, had no negative consequences, would not disrupt their construction process and might actually be of some benefit, then they usually agreed to be in the study”.<sup>15</sup>

While sampling is subject to local conditions that are frequently not in an evaluator’s control, in the interest of promoting statistical rigor and transparency, we make the following recommendations:

1. In line with one of the major recommendations from reviewed evaluations, evaluators should work to develop a cooperative relationship and open lines of communication with the building and building officials community prior to initiating evaluations work.
2. Additional statistical analysis should be applied to reported data, such as the reporting of confidence intervals. For example, the Pacific Northwest Study reports that sample sizes for Washington, Montana, and Idaho were established with a 95% confidence interval (8). The confidence interval was relaxed to 90% for Montana to incorporate a smaller sample that was deemed to be highly accurate. While these statistics do not affect the results per se, they establish the reliability of the data, and are good indicators as to how representative the sample is of the population.
3. Future evaluations might be able to skip site visits to new residential construction as it is being built, and survey homeowners directly. This is a possible option if actual energy

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<sup>12</sup> *Final Report – Volume 1 In-Field Residential Energy Code Compliance Assessment and Training Project*, Britt/Makela Group LLC, June 2003, p. 7.

<sup>13</sup> ENERGY STAR homes labeled in Nevada in 2001 accounted for 6% of all new residential construction permits issued.

<sup>14</sup> Interestingly enough, the study notes that the baseline construction homes had better compliance rates than the energy star homes. This highlights one of the issues discussed later in this paper - using compliance rates as a metric for determining energy savings,

<sup>15</sup> *Energy Performance Evaluation of New Homes in Arkansas*, Evan Brown, 1999, p. 4.



consumption data from utility billing is used as a metric for measuring energy savings. There is a much longer discussion of this in Sections 2.2 and 4.

## 2.2. Data Collection & Analysis

Data collection varied among the different studies, depending on the kind of analysis tool that was used as well as the study objectives. Prescriptive building component characteristics (R-values, U-factors, AFUE, SEER, etc) were the most common kinds of data collected, to determine energy code compliance. Data collection for performance oriented characteristics such as duct leakage rates and Natural Air Changes per Hour (NACH) was more sporadic. A number of studies go into even greater detail, collecting data on the penetration of high efficiency components, such as Compact Fluorescent Lighting (CFL) installations, or using infrared imaging to look at insulation installation quality. Tables 2 and 3 below are a sampling of data categories and values that have been collected and analysis tools respectively. A more comprehensive listing of collected data is found in Appendix 1.

State	Type of Data Collected								
	Average House Size	Envelope					Space Heating (AFUE)	Cooling (SEER)	Duct Leakage
		Walls (R-value)	Floor (R-value)	Ceilings (R-value)	Windows (U-factor)	NACH			
AR									
CA	2,329	15.60		30.70	0.60		80.52	10.64	210 (CFM-25)
CO	3,060				Various <sup>16</sup>	5.10 (CFM-50)			1,851 (CFM-25)
FL	2,197								
IA 1									
IA 2	2,441	14.00	12.00 <sup>17</sup>	41.00	0.35	0.26	89.00	11.90	
ID	1,941	14.08	18.51	38.46	0.47		82.00		
LA									
MA	2,538	14.10	18.60	31.50	0.41	0.34	85.60	10.20	182.9 (CFM-25)
MN									
MT	2,504	15.87	15.38	38.46	0.40		83.30		
NV									
NY									
OR									
VT									
WA									
WI	2,638	12.3, 16.6		28.3, 39.4	0.48, 0.42	0.37, 0.25	79.6, 88.7	9.3, 10.2	

Table 2. Sampling of Data Collected, Average Values of Selected Baseline Characteristics.

AR	ARKcheck™ (compliance), Right-J Building Heating & Cooling Load Analysis, REM/Design™ (energy costs estimates)	
CA	MICROPAS Title 24 computer compliance tool	
CO	Infrared imaging, ENERGY SCORE	
FL	None, no analysis software used.	
IA 1	Multiple Regression Analysis & Energy 10	
IA 2	MECcheck	
ID	Sunday®	
LA	Home Energy Rating (REM/rate version 10.2)	
MA	MAScheck (compliance), DOE-2 (energy modeling)	
MN	PRISM (Princeton Scorekeeping Method) Advanced Version 1.0	
MT	Sunday®	
NV	MECcheck	
NY	REScheck (compliance), REM/rate (v.11.2), CheckMe, Right-J Building Heating & Cooling Load Analysis	

<sup>16</sup> Various U-factors were reported according to type of window installed.

<sup>17</sup> R-value reported for basement wall.



OR	<i>Sunday</i> <sup>®</sup>	
VT	VTCheck, based on MECcheck	
WA	<i>Sunday</i> <sup>®</sup>	
WI	Home Energy Rating (REM/rate version 8.46), PRISM	

Table 3. Analysis Tools

There is no consistent protocol for the type of data collected or analysis tool used, and the above tables are only broad summaries of the data. The picture is far more complex when we delve into the minutia of the data. For example, some studies report U-values for windows by type of construction, whereas another may report a simple average U-value for all inspected windows. A study may only collect data for houses that have gas water heaters instead of one that uses electricity.

The inconsistencies in data between studies make cross comparison of studies difficult. Based on the general trends in data collection though, we have three major recommendations.

1. **Building Components.** To aid in data analysis, future evaluations should report average values *as well as* other statistical indicators such as the median and distribution of data. This will allow us to gain a richer view of the complexities that affect energy performance in residential (and commercial) construction. For example, an average R-value for wall insulation can mean very different things across states and markets. In Oregon, we might expect that there be a fairly uniform distribution of this value since the state has adopted a simple prescriptive code that has led to general uniformity in the market. In California however, there is likely to be a much larger variance inherent in this same average value since the state has adopted a complex code that offers more opportunities to trade-off efficiency levels in various building components.

One of the key benefits from reporting on distributions is that policymakers gain insight into market penetration of the various building components. Assuming that there is a commitment to energy code evaluations, observing the changes in distribution of component usage over time series can be helpful in identifying where code upgrades have had the most success as a vehicle for market transformation. Such data would also be useful in identifying areas in which the building community has had difficulty in complying and the trade-off options are frequently used.

There is no doubt that collecting data on the various building components is important to understanding how baseline construction characteristics affect energy efficiency. However, we believe that component data itself is limited in value, especially as a metric for identifying code compliance. The chief problem is that, as briefly mentioned above, trade-off allowances in many energy codes mean that a building with certain components below prescriptive requirements can still be in compliance. Thus, it is important that we look at buildings as a whole, and not just on the basis of its components. Southern California Edison’s recently released “Codes and Standards White Paper on Methods for Estimating Savings”, supports this assertion: “There is a huge variability in the measures installed in buildings ... Consequently, it is not practical to verify savings measure by measure ... savings should be evaluated on the basis of whole building efficiency”<sup>18</sup> Granted that California has a more complex energy code than most states, energy codes increasingly allow for trade-offs or performance measures in lieu of prescriptive requirements.

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<sup>18</sup> CA study, pp. viii – ix.

2. **Analysis Tools.** Whole building energy performance and code compliance is often assessed through the use of software, and as stated above, this is preferable to taking a purely component based approach to determining compliance. However, the use of these analysis tools also raises another issue, which is the use of compliance rates to measure energy savings. Commonly used software packages such as REM/rate generate a rating score independent of house size, meaning that two homes with the same rating but of different size may exhibit substantially different energy consumption patterns. This turns out to be important because although homes are becoming more energy efficient, they have also been steadily increasing in size, effectively negating advances in efficiency<sup>19</sup>.

For the purposes of assessing *real energy savings* from code implementation though, energy simulation software falls short of what we would consider to be an accurate estimate. “Energy and Housing in Wisconsin”, published in November 2000, offers an analysis and critique of heating energy use predictions from REM/rate (version 8.46)<sup>20</sup>:

“The results [figure 1 in this paper] indicate a systematic error in the estimates of heating energy use: the greater the predicted heating energy intensity, the greater the error. For most homes, the error is a moderate overprediction in heating use (on the order of 20 percent), but the software substantially overestimates heating use for a minority of homes that are predicted to have high heating energy intensity. These are mostly homes that have some combination of large uninsulated wall or ceiling areas, high measured air leakage, or heating systems with low estimated seasonal efficiency.”

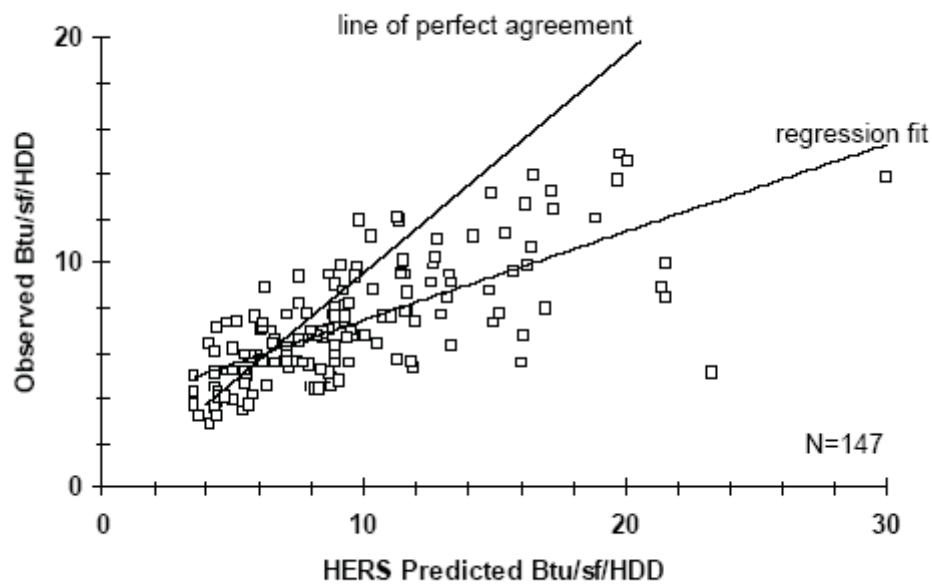


Figure 1: HERS predicted Btu/sf/HDD vs. Observed Btu/sf/HDD.

According to the report, even after accounting for systematic errors, there is “still considerable scatter between the estimated heating use from the rating software and what

<sup>19</sup> Support for this assertion is presented in section 3, findings and recommendations from current literature.

<sup>20</sup> The most current version of REM/rate available is 11.41.

[the study] derived from the [utility billing] data”.<sup>21</sup> Pacific Gas and Electric’s California evaluation, which utilized MICROPAS simulations for measuring compliance, reported compliance in four bands because the degree of the degree of uncertainty associated with the results did not allow for simple compliant/noncompliant segregation of houses.<sup>22</sup> To be fair, we recognize that such software is important to a holistic approach to building, and will become increasingly accurate in future iterations. Additionally, compliance rates are important in any analysis of energy savings (especially when they are not being achieved). However, the largest and most problematic shortcoming of using any energy simulation software is that it cannot predict real world energy usage, due to its inability to capture human behavior.

While the Southern California Edison white paper does not advocate a method for assessing energy savings other than energy simulation software, it does recognize that code evaluation studies need to “include assessments of how code options are adopted by the market, through analysis of a sample of buildings. Standards compliance rates should be verified in the field in a way that allows for *quantifying actual energy savings* [emphasis added]”<sup>23</sup> We would suggest that further research needs to be done in going beyond energy simulation software and utilizing actual energy use data (utility consumption data) as a metric for determining the effectiveness of energy code implementation.

We should note that a number of studies already integrate some utility data into their analysis. Software is needed to analyze this data and segregate loads as well, so consumption data is not a panacea for inadvertent errors from software use. A commonly used software package, PRISM, is known to overestimate heating energy use by about 5% across the board (WI). However, such software is one step closer to actual energy use than an energy simulation, and will also experience improvements in accuracy in future iterations. Perhaps the largest added benefit is that human behavior is captured as well.

3. **Standardized Protocols.** There is a need for national leadership by DOE in developing a set of standard protocols for the type of data collected. Such a move will confer large benefits on future work in this area, and in the quality of information that will be available to policymakers. Standard data sets will allow for cross comparisons from state to state, as well as across time series. As it is, some states such as Massachusetts and Colorado have carried out evaluations that have utilized the same data sets and allow for code impact analysis on baseline construction characteristics. Some other states such as Wisconsin have commissioned studies that look at all existing construction and separate new residential construction from older stock in order to assess changes in baseline characteristics. It is in the interest of both DOE and state energy offices to see this expanded.

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<sup>21</sup> Wisconsin study page 14. A fuller discussion of HERs modeling accuracy can be found in Appendix B of the same study.

<sup>22</sup> These four bands are as follows: non-compliant, indeterminate (-5% to 4% compliance margin), compliant, and overly-compliant.

<sup>23</sup> CA study, p. viii.

### 2.3. Compliance Rates

The majority of the studies we reviewed reported compliance rates, although we found that the definition of compliance rates differed depending on the study. “Compliance rate” for most of the studies may be defined as the percentage of homes that meet or exceed code requirements.

The Pacific Gas and Electric Company (PG & E) study of California residential construction makes a distinction between homes that are compliant, and those that are overly-compliant. Additionally, the study reports on homes for which compliance is indeterminate, that is, homes that are within a –5% to 4% compliance margin. Studies conducted by the Britt/Makela group for the states of Iowa and Nevada may be said to define compliance as the average percentage by which the sampled houses are above or below code requirements. Table 3 below summarizes the reported compliance rates, by state.

State		Code	Compliance Rate	Additional Notes	
AR	Statewide	92 MEC	55%	44% of all homes were within +/- 5% of passing the code.	
	Central		56%		
	Northwest		53%		
CA	Statewide	Title 24	70%	The compliance rate for California makes a distinction between compliant and overly compliant. The value reported here is the total compliance rate for homes that are compliant (57%) and overly-compliant (13%). Additionally, only 12% of homes were found to be non-compliant, and the remaining 17% were found to be indeterminate (defined as within the –5% to 4% compliance margin).	
CO	Ft Collins		Not Reported	Compliance was reported by building components. No overall compliance statistics were reported.	
FL	Statewide		Not Reported		
IA 1	Statewide	2000 IECC	53.3%	The study included homes up to 18 years older than the 2000 IECC, and was designed partially to assess cost of upgrading existing structures to the aforementioned code. Therefore, it is not indicative of energy efficiency characteristics of new residential construction.	
IA 2	Statewide			Compliance for this study defined as the average percentage by which the sampled houses are above or below code requirements.	
		Single-family	1992 MEC		4.63%
			1993 MEC		4.63%
			1995 MEC		2.84%
			1998 MEC		2.84%
	2000 IECC		2.84%		
	Multi-family	1992 MEC	37.49%		
		1993 MEC	37.49%		
		1995 MEC	21.49%		
		1998 MEC	21.49%		
2000 IECC		21.49%			
ID	Statewide	1996 Idaho Residential Energy Standard (IRES)	51.9%	Noticeably lower compliance rate of 31.7% in Boise, 82.9% in the rest of the state.	
LA	Statewide	2000 IECC	65.3%		
MA	Statewide	1998 Massachusetts Residential Energy Code, based on the 1995 MEC	46.4%		
MN					
MT	Statewide	1997 MEC	86.8%	In most of Montana, no energy or building code is enforced. Approximately 60% of the state’s residential construction is built outside of code jurisdiction.	
NV	Statewide			Compliance for this study defined as the average percentage by which the sampled houses are above or below code requirements.	
		Northern	1992 MEC		-10.96%
			1993 MEC		-10.96%
			1995 MEC		-42.09%
			1998 MEC		-42.09%
	2000 IECC		-42.09%		
	Southern	1992 MEC	11.82%		
		1993 MEC	10.36%		

		1995 MEC	9.12%	
		1998 MEC	9.12%	
		2000 IECC	9.12%	
NY	Long Island	2002 New York Residential Energy Code	0%	On average, all houses failed the New York Energy Conservation Code and the 2001 IECC, as determined through REM/rate and REScheck and based on <i>heat loss rate of composite buildings</i> .
		2001 IECC	0%	
OR	Statewide	1993 Oregon Residential Energy Code (OREC)	100%	
VT	Statewide	RBES, based on the 2000 IECC	58% +/- 8%	The 2002 results are a large improvement over the 35-40% compliance rate from a 1995 study. Note however, that there has been some contention over the validity of the baseline construction characteristics reported in the earlier study.
WA	Statewide	1997 Washington State Energy Code (WSEC)	93.6%	
WI	Statewide	Home Energy Rating Score (HERs)		

Table 4. Reported Code Compliance Rates

We are partial to the definition of compliance rates reported by the majority of studies, as the percentage of homes in the sample that meet or exceed minimum code requirements. Average percentages above or below code in and of themselves do not inform us as to what proportion of homes are in compliance, and are susceptible to bias from the inclusion of outlier data points in the sample. Additionally, for the purposes of measuring a savings gap, the loss in energy savings from noncompliance is offset by efficiency gains from over complying houses. Since codes establish a baseline efficiency that *all* houses should meet (unlike a cap and trade system where we might be more interested in the average), we are necessarily interested in houses that do not comply.

For example, the average HERS rating (unadjusted) earned by a single-family detached house in the New York study was 83.6 points. Assuming that an 83 would pass the 2000 IECC, it appears that the average house would in fact pass that code. The reported distributions however, reveal that only 62% of homes received a score of 83 or better (40).

**Table 38 Single-Family Detached – HERS Score Distribution**

HERS Score	Frequency	Percent
77.0 - 77.9	0	0.0%
78.0 - 78.9	1	1.6%
79.0 - 79.9	3	4.8%
80.0 - 80.9	1	1.6%
81.0 - 81.9	4	6.3%
82.0 - 82.9	15	23.8%
83.0 - 83.9	12	19.0%
84.0 - 84.9	14	22.2%
85.0 - 85.9	8	12.7%
86.0 - 86.9 (Energy Star)	2	3.2%
87.0 - 87.9 (Energy Star)	2	3.2%
88.0 - 88.9 (Energy Star)	1	1.6%
<b>Total</b>	<b>63</b>	<b>100.0%</b>

Fig 2. HERS Score Distribution – Long Island, New York.

As the figure below from the Xenergy Inc. Massachusetts study shows, noncompliance does not necessarily mean we can assume a complete loss of energy savings. Rather, most noncomplying homes can usually be brought into compliance with the implementation of a few efficiency measures.

**Figure 5-2**  
**Code Compliance Distribution**

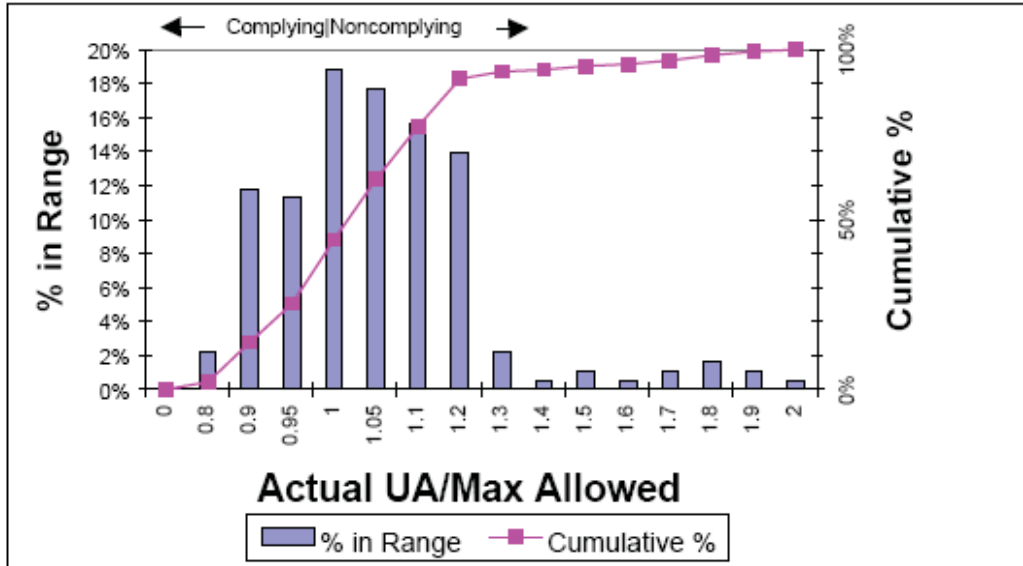
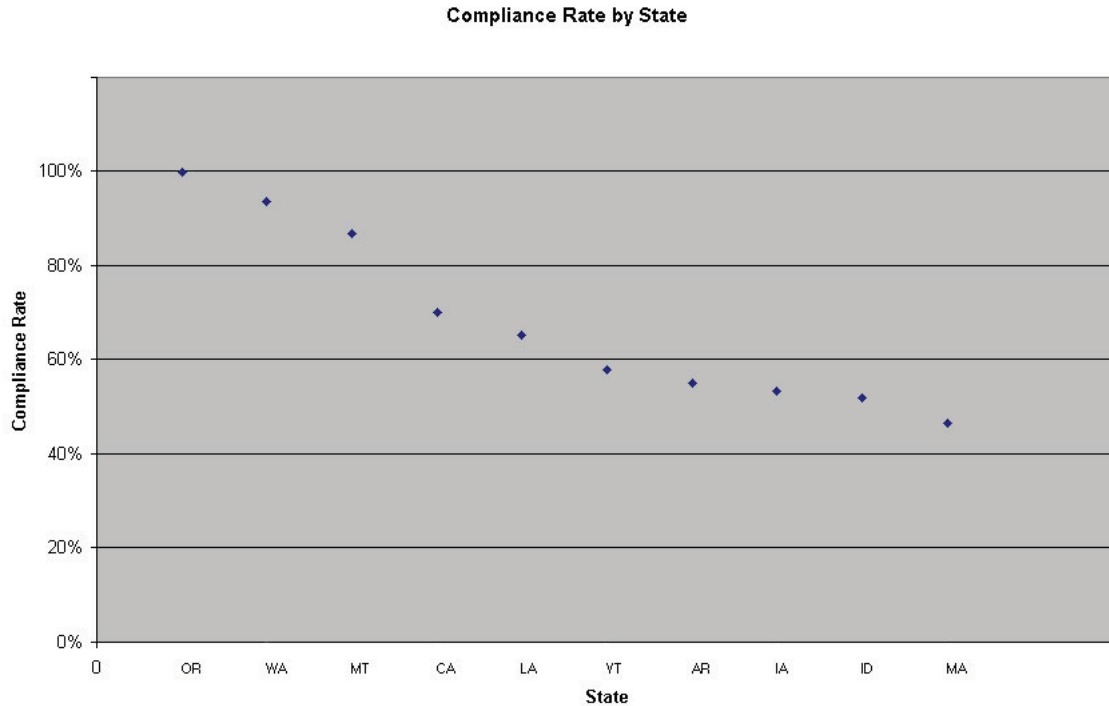


Fig 3. Code Compliance Distribution Chart. Values equal to or less than 1.0 indicate code compliance.

### Section 3. Major Findings and Recommendations – Current Literature

As described in the previous section, the general trend in terms of code compliance is that the Pacific/Western states exhibit higher compliance rates.



We could speculate however that higher rates of compliance are not surprising in states like California, which exhibits a preponderance of high gas prices and rolling blackouts, coupled with high profile energy related events such as the Enron scandal, serve to keep energy efficiency as a high priority in both the public and political consciousness. California has traditionally been a leader in developing progressive energy efficiency policies that continue to raise the bar for the rest of the country. In addition, the state has put in place aggressive support programs. Oregon has a stringent prescriptive code that has gained good traction in the building community due to its consistency, ease of use, and availability of components meeting code requirements. Strong educational support and communication with builders is exemplified with builders’ guides in Washington.

Some of the major issues consistently raised by the reviewed evaluations are examined as follows:

1. **Larger Homes.** Studies that compared new residential construction to existing structures (or baseline characteristics collected from prior evaluations) often indicated that improvements in efficiency were offset by increases in home size. The Wisconsin study noted “new homes use 23 percent less heating energy per square foot than older homes, but they are also 22 percent larger”<sup>24</sup>, effectively canceling out energy savings from increased efficiency. This finding on home sizes is echoed by the study on Pacific

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<sup>24</sup> WI study. p. i.

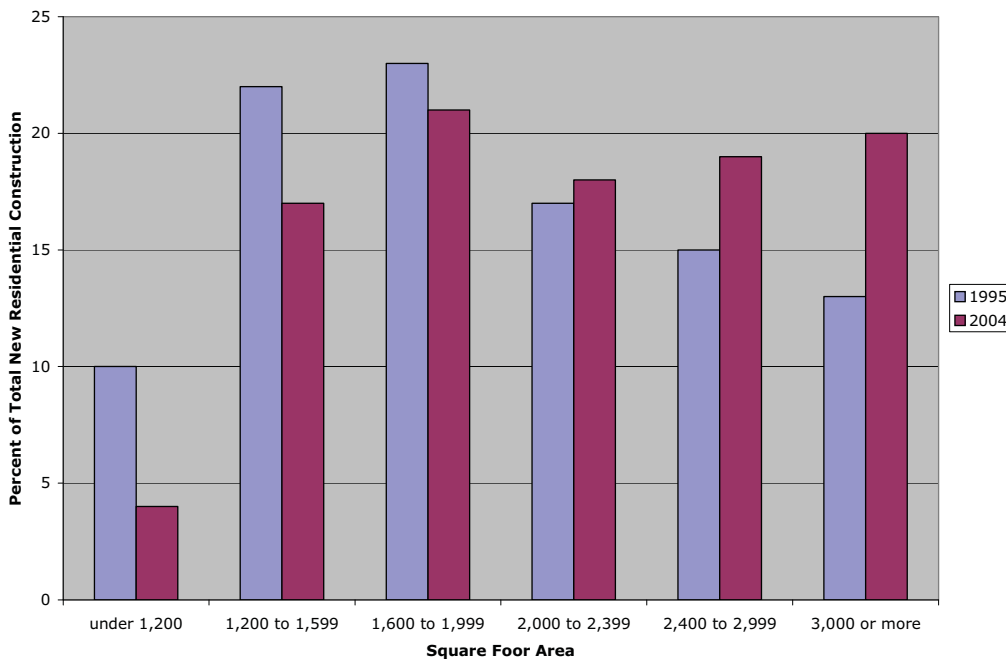


Northwest states found that Oregon housing grew approximately 15% between 1994 and 1999, and that floor area in the region (including Oregon, Washington, Montana, and Idaho) grew 22% from 1986.<sup>25</sup> This study later notes that had home sizes remained constant, new construction energy use would have dropped by 50%.<sup>26</sup> The 2002 Vermont study notes:

“The potential impact of these efficiency gains, however, is offset by some other significant trends. The pressure to build larger homes appears to be continuing, and the new homes in this sample, particularly the large homes, tend to have a much larger proportion of glazing than found in the previous study”.<sup>27</sup>

The final report on “Evaluating Minnesota Homes”, from 2002, helps to illustrate this point. The study found that “the average 2000 home in [the study] sample uses 25% less energy to heat than the average 1994 home and 5% less than the average 1998 home”. However, these figures are based on Btu per square foot per degree-day (Btu/SF/DD), and once the average house sizes are taken into account (easily culled from the PRISM data in Appendix C), a quick calculation reveals that the 1994 home requires 12,581 Btu/DD on average, while the average 2000 home requires 13,244 Btu/DD. There is no doubt that newer construction is more energy efficient, but taking the larger average house sizes into account means an *increase* in heating energy use of 5.27%. As shown in the graph below, the distribution of large homes in new residential construction has shifted noticeably over the ten-year period from 1995 to 2004. Over this same period of time, housing permits issued in the United States for single family residential structures increased from 997,268 to 1,596,443, a 60% increase.

**Percent Distribution of Square Foot Area in New Residential Construction**



<sup>25</sup> OR study. p. vi.

<sup>26</sup> OR study. p. x.

<sup>27</sup> VT study. p. 1-2.

Fig 4. Percent distribution of Floor Area in New Residential Construction.

We can expect that average home sizes continue to show an upward trend, especially given the explosive growth of the housing market over the last couple of years (most of the increase in yearly housing permit data came between 2001 and 2004). While home size clearly cannot be regulated, policymakers need to keep these findings in mind when formulating strategies geared towards reigning in total energy use.

- Excessive Oversizing of HVAC Equipment.** Oversizing of HVAC equipment is a commonly cited finding that has real implications for individual homeowners and states as a whole. Use of oversized HVAC equipment results in higher electricity loads across the grid, as well as shorter equipment life span and both higher initial and maintenance costs. The endemic nature of this problem is best illustrated by the following findings:

Arkansas: Average heating system was approximately twice the size needed to meet the cooling load. 43% were between two and three times the needed size, and 5% were *more than three times* larger than needed.

Colorado: 70% of home furnaces were excessively oversized, and 100% of air conditioners. Furnaces were on average 158% the minimum required size, and air conditioners were on average 208% the minimum required size.

Idaho: Gas furnaces are on average 192% the needed size.

Massachusetts:

Montana: Gas furnaces are on average 160% the needed size.

New York: Single-family heating systems were on average oversized by almost 90%, and cooling systems by 70%.

Oregon: Gas furnaces are on average 278% the needed size.

Vermont: Median oversizing of heating equipment was 81%.

Washington: Gas furnaces are on average 216% the needed size.

There is additional evidence that consumers and builders are not aware of their options and the benefits of properly sized equipment. Given that HVAC equipment accounts for between 40%-60% of energy used in commercial buildings, there are obviously savings to be had in this area.<sup>28</sup>

- Compact Fluorescent Lighting (CFL) Penetration.** Several studies found that CFL penetration was less than expected, which is notable since replacing incandescent bulbs with CFLs is inexpensive and returns immediate energy savings. In Long Island, New York, CFLs were found to occupy 3% of all light fixtures (34). In Wisconsin 13% of all homes had CFLs in one or more high use locations, representing just 5% of all fixtures,

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<sup>28</sup> DOE data.

despite the fact that 72% of homeowners interviewed were aware of CFLs (26). The same study suggested that dissatisfaction with CFL performance was one reason for the low penetration rate. Evaluators in Vermont found that CFLs accounted for 8% of light fixtures for all surveyed homes, but that the penetration rate was effectively doubled to 16% in houses participating in the Vermont Star Homes and utility efficiency programs. According to the study, “rebates for CFL fixtures and technical assistance provided by the efficiency programs have been effective at promoting these products (VT 1-4).”

4. **Need for Consumer/Builder Education.** Interviews conducted with both homeowners and builders reveal misconceptions about the use of energy efficiency measures in their homes. Perhaps unsurprisingly, the majority of builders who were interviewed as part of evaluations claimed that their homes were built to exceed energy codes, and a portion even claimed benefits from current attendance at then-defunct training sessions. The Pacific Northwest study found that “approximately three-fourths of the builders interviewed in each state said that they often exceeded the energy codes”, however, “the data from the characteristics survey suggests that very few components exceed the code, and most components were selected to meet minimum code requirements”.<sup>29</sup>

A market actor survey (shown below) conducted by Xenergy, Inc. in Massachusetts gauged the energy efficiency knowledge of various market players. Builders were rated across the board as having poor to fair knowledge of energy efficiency, significant since they carry out the actual construction of the homes. In fact, 25% of builders interviewed in Colorado felt that the Ft. Collins energy code had no value at all,<sup>30</sup> and almost 64% of builders in the Northwest indicated they had never participated in any training on energy efficiency building practices (NW B-51).

Rated	Designer	Developer	Builder	Supplier	Local Code Officials
Designer	Good to Excellent	Fair	Poor to Fair	Fair to Good	Fair to Good
Developer	Good to Excellent	Good	Poor to Fair	Good	Good to Excellent
Builder	Good	Good	Good to Very Good	Good to Excellent	Fair to Good
Supplier	Excellent	Good	Poor to Fair	Very Good	Good to Very Good
Local Code Officials	Good to Very Good	Fair to Good	Poor to Fair	Good	Good to Very Good

Table 5. Assessment of Market Players’ Energy-Efficiency Knowledge in Massachusetts.<sup>31</sup>

It is worth noting that a couple of studies found a further weak link in builder-contractor interactions. The aforementioned Massachusetts study recommended education on heating and cooling equipment sizing be targeted at contractors that install them since “decisions about equipment sizing are often made by these contractors, rather than the builder, and [the study’s surveys] showed that oversizing of heating equipment was very common”.<sup>32</sup> Additionally, the Arkansas study found that problems were typically found

<sup>29</sup> OR study. p. ix.

<sup>30</sup> CO study. p. 22.

<sup>31</sup> Reproduced from MA study. p. 6-3.

<sup>32</sup> MA study. p. 7-8.

in areas where the work of one subcontractor met that of another, such as where framing and drywall contractors met HVAC contractors. The study further suggested that:

It is important that builders understand that all of their subcontractors have substantial and sometimes negative impacts on the safe and efficient operation of a home. The builders need to know what the problem areas are so they can to (*sic.*) work more closely with their subcontractors to instruct and monitor exactly how they want their job to be done.<sup>33</sup>

These findings demonstrate the necessity for adequate and even aggressive training programs for builders in energy efficiency measures and code compliance. However, it is important to understand that the lack of builder knowledge or interest in energy efficiency is very much driven by the same consumer characteristics. Less than half the builders in the Massachusetts study claimed there was homebuyer interest in energy efficiency, resulting in less than a third of the builders using such features are part of marketing their products. Since builders are sensitive to market demand, shifting consumer preference to energy efficient options is integral to shifting baseline construction characteristics in the same direction. This is obviously not a straightforward process, and Smil makes the observation that:

Any voluntary effort aimed at reduced energy consumption is predicated on the informed readiness of consumers to adopt less wasteful arrangements or to buy more efficient convertors ... In reality, we need to consider not only the lack of information, misunderstandings, outright ignorance, and pure disinterest regarding the understanding of available choices, but also a peculiar economic calculus attached to energy efficiency, as well as peculiar pricing of energy.<sup>34</sup>

In short, consumers do not purchase efficient equipment that will pay back for itself and offers additional savings well into the future, because of ignorance, misconceptions, or a preference for savings in initial capital instead of lifetime costs.<sup>35</sup> Homeowner interviews support monetary savings as a main driving force for the adoption of energy efficiency features (WI 36) and bring to light some misconceptions. 22% of homeowners in Wisconsin felt that replacing windows and doors was the most effective thing they could do to save energy, while only 6% cited reducing air leakage (37). One set of these homeowners even expressed incredulity at energy savings estimates from reducing air leakage since they had recently spent \$11,000 on replacing windows and would not believe they still had a leaky house (blower door data showed 0.55 natural air changes per hour)(39).

In fact, evaluations provide evidence that excessive leakages are frequently the source of dissatisfaction with home performance, although homeowners are not aware this is the case. 68% of respondents were critical of their homebuilder's quality of work in the New York Long Island residential survey, frequently citing high energy bills and differential heating and cooling of various parts of the house as their primary complaints (44). Problems that energy raters subsequently found included major building science errors and large, leaky ducts.

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<sup>33</sup> AR study. p. 8.

<sup>34</sup> Vaclav Smil, *Energy at the Crossroads*, p. 328.

<sup>35</sup> Smil, p. 328.

There is a glaring need to both homeowner and builder education so that consumers and builders understand:

- a. They have energy efficiency options with the potential to offer substantial lifetime savings. Some options, such as using correctly sized HVAC equipment offer immediate and lifetime savings to both homeowners and builders.
- b. The benefits of a systems approach to building rather than focusing only on components.

5. **Low-Income Housing.** Low-income housing is typically older and smaller than the average house. It is also more inefficient in relative, and surprisingly in some cases absolute, energy usage. In the Louisiana study's analysis of homes built in the same year according to size, a home from 1,000 to 1,400 square feet was found to incur a cost of \$814 a year for heating, cooling, and hot water. This was more than the absolute energy costs for homes ranging from 1,400 to 2,700 square feet (\$614-\$709).<sup>36</sup> It was speculated that this was because small houses function as starter homes for first time home-buyers and thus first cost is of more importance than actual operating costs. The Wisconsin study supports this finding, stating "owner-occupied, low-income homes are 16 percent smaller on average than other homes, but they require more energy per square foot for heating. As a result, overall energy bills ... are about the same as for the general population".<sup>37</sup>

To test this assertion, we ran a simple regression on the PRISM data from the Minnesota study with Btu/SF as the dependent variable, house size (square footage), and year of construction as a dummy variable.

$$\text{BTU/SF}_i = \beta_1 \text{SF}_i + \alpha_1 \text{C1}_i + \epsilon_i$$

Where:

**BTU/SF** is the dependent variable. Btu per square foot per degree day used for heating.

**SF** is an independent variable for house size in square feet.

**C1** is a dummy variable that assumes a value of 1 when a home is built to Category 1, and 0 otherwise.

$\epsilon_i$  is the residual error term.

Estimating the regression again using a semi-log form results in a small increase in the *adjusted R<sup>2</sup>* from 0.33 to 0.35, indicating that this is a slightly better fit. More importantly, this matches up well with our theory and evidence from evaluations indicating that the relationship between efficiency and house size is not linear. Rather, increases in house size causes Btu/sf to decrease at an increasing rate. (i.e. the larger the house the more efficient it is expected to be.)

$$\text{Log}(\text{BTU/SF}_i) = 1.84 - 0.000141\text{SF}_i - 0.152\text{C1}_i$$

$$\text{Adjusted } R^2 = 0.35$$

Our findings indicate that smaller homes are consistently less efficient (i.e. – more energy intensive per square foot) than larger homes.) However, the difference between smaller

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<sup>36</sup> Keep in mind our earlier caveat about REM/rate overestimating energy costs, especially for underinsulated, etc homes. This is part of the reason why we test this hypothesis on the MN data.

<sup>37</sup> WI study. p. 42.

and larger homes diminishes when they are built under the requirements of a more stringent energy code.

The adjusted  $R^2$  value of 0.35 indicates the presence of variation in the data unexplained by the regression model. This is to be expected since we utilized a small sample size (43) with inherent large variability. One of the contributing factors to the variability is that smaller houses could also be more expensive and better built, depending on geographic location. It is important to keep in mind that the adjusted  $R^2$  is only one measure of the overall quality of our regression, and can change dramatically depending on the type of data we are analyzing. A good fit for time series data typically yields an adjusted  $R^2$  value of above 0.90, whereas a good fit for cross sectional data could have an adjusted  $R^2$  value of about 0.50.

Given the type and size of data used, we are confident at the very least in the direction of correlations (i.e. newer code year and larger houses tend to be more efficient). Significantly, the better fit of the semi-log form in the regression does indicate that the efficiency of houses *increases at an increasing rate* as size increases. Evidence from the Wisconsin and Louisiana study corroborate these findings.

We decided to look at regressions within houses built to different codes to look at the relationship between house sizes. The only difference in these regressions is the absence of a dummy variable for code vintage. These regressions yielded much better adjusted  $R^2$  values (close to what we would expect for a good fit, for cross sectional data), and the F-statistics results indicate that the regression equations are highly significant (at the 99% confidence level).

### Code year C1

Similar to our initial regression, we find that the semi-log form is a better fit. Our estimation yields the following results:

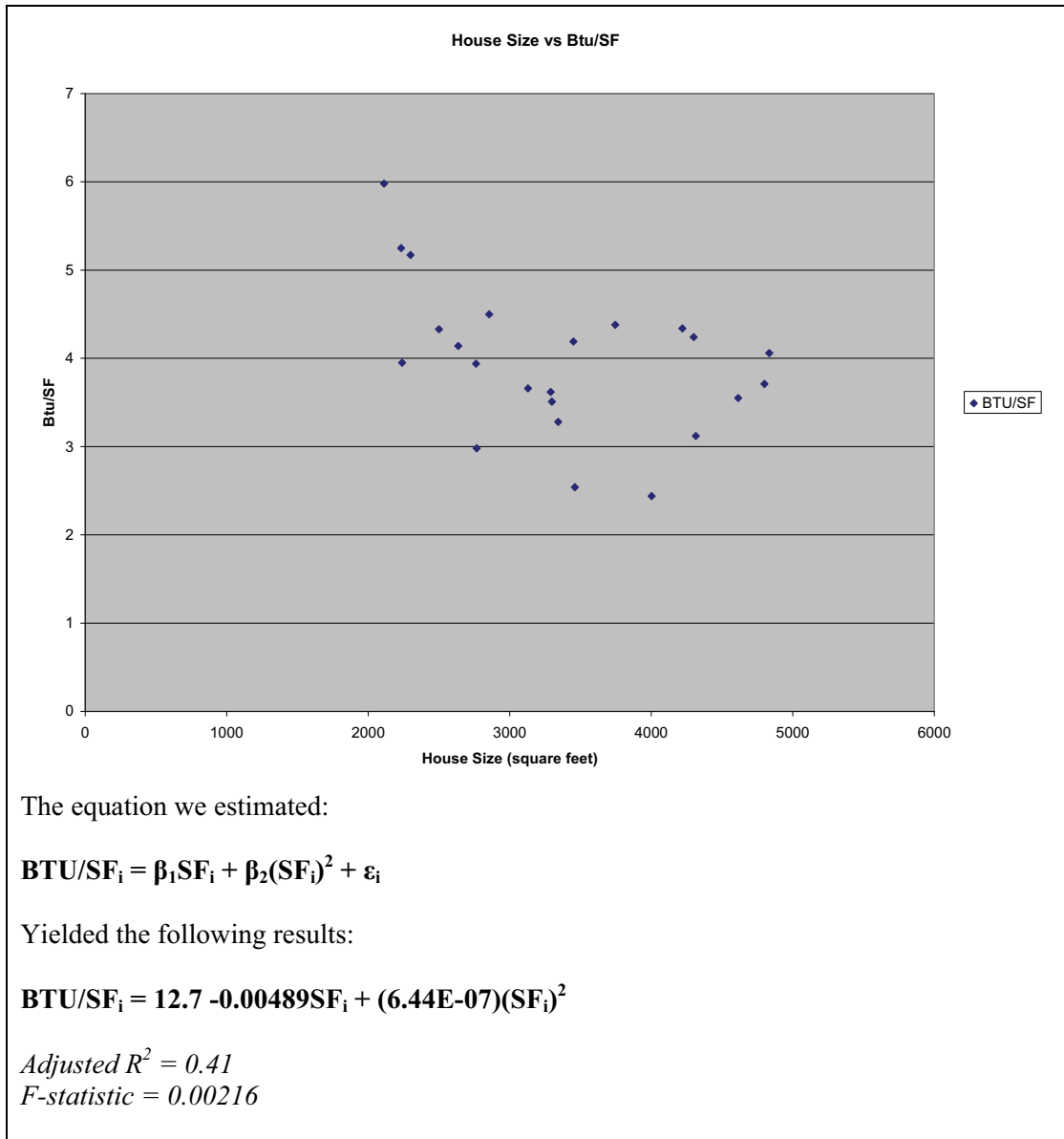
$$\mathbf{\text{Log}(\text{BTU}/\text{SF}_i) = 2.17 - 0.000259\text{SF}_i}$$

$$\text{Adjusted } R^2 = 0.48$$

$$F\text{-statistic} = 0.00244$$

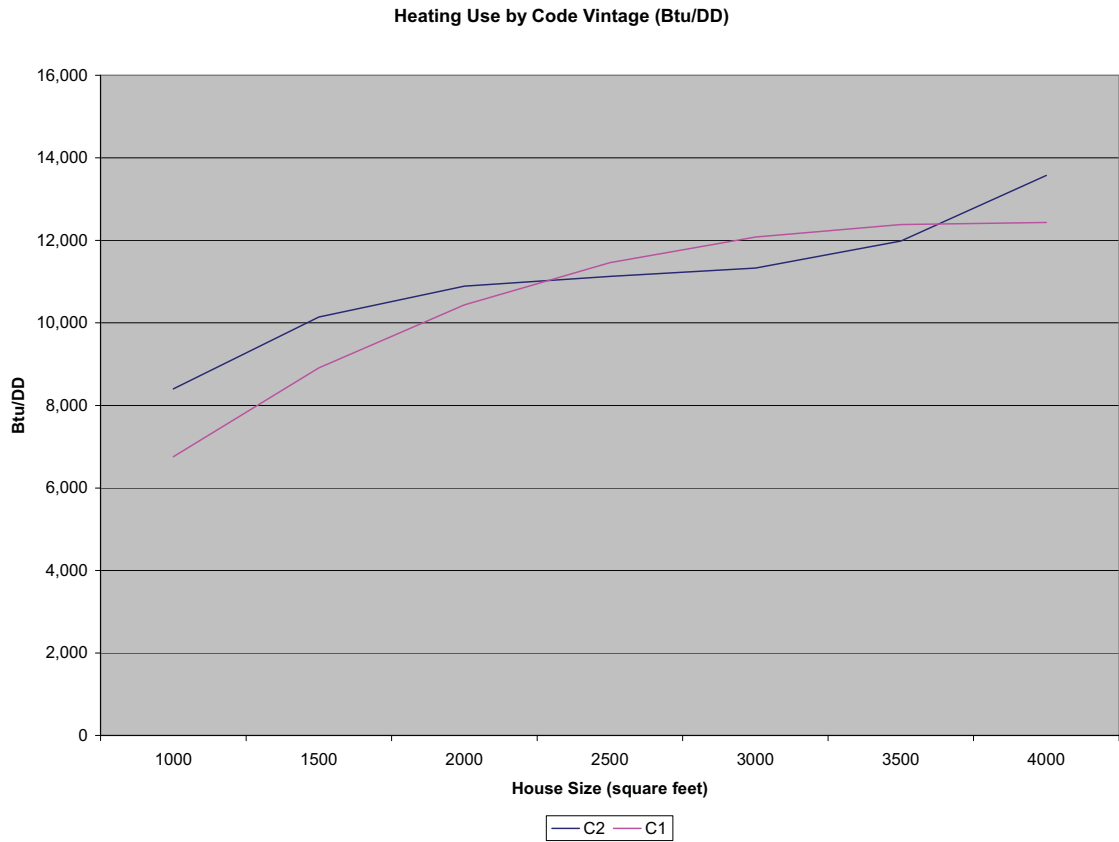
### Code Year C2

Estimations for houses built to category 2 (C2) using the semi-log functional form consistently yielded extremely low adjusted  $R^2$  values. The distribution of data points in the scattergraph, as shown below, indicated that the regression estimation should in fact have assumed a polynomial form.





## Comparing efficiency of houses built to code year C1 and C2:



These results suggest that the lack of energy efficiency features in these houses essentially act as a regressive tax on low-income and possibly first time homebuyers, since their homes are likely to be both relatively and absolutely less efficient. Certainly the capital costs of more efficient equipment and/or insulation form a larger percentage of income. The Wisconsin study estimates that the “median low-income homeowner spends seven to ten percent of household income on energy costs, compared to two to three percent for all households”.<sup>38</sup> More in-depth research into the specific circumstances influencing energy efficiency in low-income housing would be needed before we can draw any concrete conclusions - although we have established correlations between home age, square footage and energy costs, these are not causal factors.

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<sup>38</sup> WI study. p. 42.

## Section 4. Recommendations and Further Study

Throughout this paper we have made several recommendations about sampling and analysis, which we reiterate here.

1. Since it is so critical to acquire a large and broad enough sample, researchers must gain the trust and cooperation of builders and building officials. This should be done by open and frequent communications with the express purpose of clarifying the course of study and identifying willing participants.
2. Common analysis tools should be applied to data to indicate its credibility. Confidence intervals, descriptions of sampling procedure and protocols, reporting of median and distributions in addition to averages, etc. help to validate a study's reliability.
3. Creative alternatives to traditional site-visit based evaluations should be investigated. These may allow for more cost-effective data collection with a direct focus on energy use.
4. Evaluate whole building energy use rather than compliance through components, particularly in jurisdictions where component trade-off is a prevalent compliance method.
5. There should be movement toward standardizing an approach to conducting code compliance evaluations, with the US Department of Energy the logical candidate to take the lead. Such standardization would allow for a better understanding of the impact of codes nationally, as well as lowering the cost and work associated with conducting an analysis for any state or region that chooses to perform one.

### Further Research

Our review of current literature has led us to believe that there needs to be research into the use of real energy consumption based data as a metric for the success of residential (and commercial) energy codes. The primary source of such data would be utility bills for natural gas and electricity usage. At present there is no national standard protocol for the utilization of consumption data in code evaluations, but we believe such data has the potential to be more cost efficient and to yield larger, more representative sample sizes than current evaluation techniques.

As we stated in our introduction to this paper, on-site evaluations can be prohibitively expensive, and thus a limiting factor in sampling methodology and data collection efforts. There is evidence throughout the reviewed literature that supports this assessment. A 2002 study in Vermont calls for revising the strategy for site visits because “measuring and documenting the areas and characteristics ... for determining compliance through the VTCheck software<sup>39</sup> composed a very large and time consuming part of site visits ... This decision to collect this detailed information limited the possibilities of investigating other issues”.<sup>40</sup> In fact, the same issue was raised in an earlier (1995) Vermont study, although concern about the statistical validity of the baseline characteristics in that earlier study resulted in the 2002 study taking the same approach.

While consumption based data holds promise in terms of sampling and data collection, we also believe that it has an even more significant role to play from the macro perspective. A 1999 study by the RAND Institute for the Department of Energy (DOE) speaks to our motivation:

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<sup>39</sup> VTCheck software is based on MECcheck.

<sup>40</sup> *Vermont Residential New Construction 2002: Baseline Construction Practices, Code Compliance, and Energy Efficiency*. West Hill Energy & Computing, January 2003, p. 10-8.

[RAND's] analysis shows that there is significant variation in the energy efficiency performance of states with different codes, and that it appears that states with codes that go beyond the Council of American Building Officials (CABO) Model Energy Code (MEC)<sup>41</sup> may perform better. The results have a bearing on the current push to benchmark state residential energy codes against the MEC. The states listed in the *group 1*<sup>42</sup> category largely base their energy code on the MEC. Facilitating the adoption of a code, even a stringent code, is not sufficient to guarantee reductions in residential energy use because total residential energy use depends on many factors beyond the control of the energy code. More analysis is needed to evaluate the reasons for these variations and help guide DOE policy and working relationships with the states.<sup>43</sup>

The various complex interactions that shape the energy efficiency characteristics of residential (and commercial) buildings require us to go beyond an insular view that looks only at building components to the larger energy picture – how the energy codes are performing in practice and not just simulations. It has been well documented that a home may fail prescriptive requirements of a code and yet pass performance based standards. As such, even compliance rates as the ultimate metric of the success of code implementation efforts may fail to get to the heart of the matter, which is, has energy been saved? As the aforementioned RAND study succinctly states, “The purpose of a residential energy code is ... to cost-effectively reduce energy consumption. Therefore, it is important to consider the performance of the codes as measured by the decline in per capita energy consumption and percent change in per capita energy consumption”.<sup>44</sup>

An additional benefit of utility data is the possibility of simultaneously tracking electricity leakages from standby electronic devices. In 1997, it was estimated that such loads accounted for 5% of all residential energy use (Smil 328?). Given the even greater prevalence of DVD players, mp3 music players and laptop computers commonly used alongside existing desktop computers, we can expect that they presently consume even greater absolute amounts of energy, and possibly a greater percentage of total residential loads. While most such appliances are not, and likely never will be, covered by building energy codes, it is important for us to understand the impact of these loads for future broader policy and code development.

The 2002 Ft Collins, Colorado study, *Evaluation of New Home Energy Efficiency*, breaks the issue down into two questions:

1. Is it there? – This refers to the traditional prescriptive code focus.
2. Does it work? – Referring to a performance based perspective of codes through looking at characteristics such as air sealing.

The same study also conducts extensive site evaluations, integrating the use of utility bills to measure energy savings from the 1996 code change. It was found that for various reasons, energy savings were less than half of the savings anticipated in the energy and economic modeling at the time of the code change.<sup>45</sup>

We would argue for a similar approach but using larger quantities of utility-based consumption data as the starting point. In such a case, we could ask:

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<sup>41</sup> In 1998, the MEC was revised and became the International Energy Conservation Code (IECC).

<sup>42</sup> *Group 1* category states are states with energy codes based on site energy consumption.

<sup>43</sup> *Measures of Residential Energy Consumption and their Relationships to DOE Policy*. David Ortiz and Mark Allen Bernstein, November 1999, p. xix.

<sup>44</sup> Ortiz and Bernstein, p. 32.

<sup>45</sup> There is evidence that such overestimates are in fact, very commonplace.

1. Does it work? – Does actual energy consumption data show that the implementation of the energy code has made a difference, or is there a large savings gap?
2. Is it there? – Why are certain homes underperforming? What are the characteristics of these homes? Is the savings gap due to noncompliance or other issues? Are there high loads from equipment or appliances not covered by codes?

Our recommendation is not intended to suggest that baseline construction characteristics are unimportant. Rather, we are advocating for developing an approach that can measure real world energy performance in a statistically rigorous manner at reduced cost. Once there is a broad energy performance and code compliance picture, additional resources can potentially be focused on understanding why certain buildings underperform or what kinds of policy initiatives need to be put in place to maximize energy savings.

It is important too, that when looking at energy savings we consider changes in both relative *and total* energy consumption patterns. As Rudin points out in a 1999 article detailing the relationship between energy efficiency and the environment, “our environment does not respond to miles per gallon; it responds to gallons”.<sup>46</sup> In thinking about future evaluations work, it is important to keep in mind that the environment (and one can argue, the economy and national security) does not respond to Btu per square foot of conditioned space, but total Btu.

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<sup>46</sup> Andrew Rudin, 1999. How improved energy efficiency harms the environment.