A Tale of Two States: Detailed Characterization of Residential New Construction Practices in Vermont and Iowa

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Utilities in Vermont and Iowa have recently completed detailed assessments of new construction practices in their respective states. These assessments included extensive on-site analysis of homes built during the early- to mid-1990s. In Vermont, over 700 data points were collected from each of 200 homes surveyed in early 1995. In Iowa, over 150 data points were gathered for each of 135 homes surveyed during the Spring of 1994.

This paper presents and compares key findings from each survey, examining such issues as insulation levels, air leakage rates, and the use of mechanical ventilation. Results from the two surveys provide a unique resource for understanding and quantifying current building practice with respect to energy efficiency. In comparing results from the two states, one area of particular interest is the assessment of compliance with Model Energy Code standards. In Iowa, only 7% of homes surveyed passed the 1989 Model Energy Code, the code in effect in the state when the homes were constructed. In contrast, analysis suggests that approximately 67% of the homes surveyed in Vermont—which does not have a state-wide building code—would meet the more stringent 1993 Model Energy Code standards.

INTRODUCTION

In 1995, residential buildings in the United States (U.S.) consumed 18.1 quadrillion Btu's of energy—more than 20% of total U.S. annual energy consumption (EIA 1996).[1] There are significant societal costs associated with this level of consumption. To begin with, national expenditures on residential energy consumption were more than \$120 billion in 1995—an average of \$1227 per household (EIA 1996). There are also significant environmental costs associated with residential energy consumption, particularly air emissions resulting from the burning of fossil fuels (the vast majority of residential energy is provided by the burning of fossil fuels, either in the home—as in the case of natural gas, oil, propane and kerosene—or in utility power plants which convert fossil energy into electricity that is delivered to the home).

These costs have spurred significant effort to promote greater energy efficiency in residential buildings. Much of these efforts have focused on opportunities for improving the efficiency of new construction. Although the number of new housing starts in any given year is small in comparison to the number of existing homes, their cumulative effect over time can be quite substantial. For example, although the 1.56 million U.S. housing starts in 1995 represented less than 1.6% of the total number of residential households in that year, homes built after 1995 will represent nearly 30% of total residential households by the year 2015 (EIA 1996).

In addition, although the average new home is usually more energy efficient than the typical existing home, the opportunities for achieving cost-effective energy savings from new homes remain both substantial and critically important. There are several reasons for this. First, although new homes generally have more efficient building envelopes than existing homes, their energy use is not proportionately lower because they are often larger and typically have higher saturations of energy consuming appliances, such as central air conditioners. Second, and more importantly, the cost of efficiency upgrades is usually much lower and the savings that can be achieved from efficiency measures is often higher at the time of new construction. As a result, many efficiency measures that might have been cost-effective to install at the time of construction may not be cost-effective to retrofit after construction is complete. Put another way, the new home construction process offers a unique ''window of opportunity'' for addressing cost-effective efficiency potential. Finally, there are substantial market barriers to the installation of cost-effective efficiency measures in new construction. Perhaps foremost among these is the fact that the designers and builders who make efficiency investment decisions for new homes will typically not have to bear the energy costs associated with those decisions.[2]

For these reasons, many view new construction as a very important opportunity for affecting the long-term efficiency of the residential housing stock. This interest has manifested itself in many ways, including the development of utility demand-side management (DSM) programs targeted at the residential new construction market, a growing interest in home energy rating systems and energy efficient mortgages, and perhaps most significantly in recent years, advocacy for more comprehensive and aggressive energy standards in building codes. Building codes are seen as particularly important because they are intended to apply to every home that is built within a jurisdiction. Indeed, some view energy codes as critical determinants of the efficiency of residential new construction (Alliance to Save Energy 1995).

Planning for or assessment of the effectiveness of DSM programs, energy codes, or any other mechanism intended to address efficiency in new construction must be built on assumptions regarding baseline practice. This often proves to be problematic because reliable data gathered through detailed, on-site surveys are seldom available. Recently completed surveys from Iowa and Vermont provide a valuable, if anecdotal, resource for such assessments. They also raise important questions about the extent to which adoption of strong codes, in itself, leads to efficient new construction.

METHODOLOGY

In presenting results from Iowa, the authors have relied heavily on the report on the Iowa survey that was prepared by the contractors that carried it out. Additional survey data and insights into the Iowa survey results were received by the Vermont Energy Investment Corporation during work on utility demand-side management program design for the residential sector that was conducted in 1994 and 1995 on behalf of the Iowa Office of Consumer Advocate. The work involved extensive interaction with each of the utilities that sponsored the Iowa survey.

In presenting results from Vermont, the authors have relied almost exclusively on data that either they or their colleagues directly collected or analyzed. Together, the authors represent the organizations that sponsored the Vermont survey, carried it out, and analyzed the results.

Iowa Residential New Construction Baseline Study

In February 1994, the four investor-owned utilities operating in Iowa at the time—Midwest Power, IES Utilities, Interstate Power and Iowa-Illinois Gas and Electric (collectively calling themselves the ''Iowa Joint Utility Task Force'')—commissioned a study of baseline new construction practices in the state. Two consulting firms—Kemper Management Services, Inc. and Southern Electric International—were chosen to conduct the study.

Between early March 1994 and late May 1994, the contractors conducted on-site surveys of 135 single family homes. Survey sites were selected at random from customer account lists provided by the utilities. Thirteen different cities were represented in the sample. The city with the largest number of surveyed sites was Des Moines (49 sites). Davenport/Bettendorf (23 sites), Dubuque (14 sites), Cedar Rapids (13 sites), Iowa City (8 sites) and Sioux City (5 sites) collectively accounted for most of the rest of the sample. All but four of the homes surveyed were built between 1991 and 1993 (KMS/SEI 1994).

Over 150 data points were gathered from each of the 135 homes surveyed. This included general information about the home, such as location, age, style and dimensions; demographic information about the current occupants; data on building shell characteristics such as insulation levels, window types and door types; infiltration and duct leakage rates, as estimated by blower door tests;[3] HVAC equipment types, capacities and efficiencies (rated); thermostat settings; and appliance types, capacities and efficiencies. In addition, the contractors calculated design heating and cooling loads using RBEP2 energy analysis software. The contractors also assessed compliance with the 1989 Model Energy Code—the energy code in effect in Iowa at the time the homes were built—for each home.[4]

Most of the 135 surveys were completed by the same two-person survey team using two data collection forms, ''one for construction and HVAC equipment and one for demographic and appliance information'' (KMS/SEI 1994). Subsequent use of off-site reference materials was often necessary to estimate some efficiency characteristics (e.g. window U-values, HVAC equipment efficiencies and appliance efficiencies) from manufacturer data, equipment model numbers or other data collected on site.

The quality of the survey data was checked several times prior to any statistical analysis. The first check was performed immediately after survey forms were completed to account for missing data entries and both identify and verify the accuracy of unusual entries. A second check of the building envelope data was performed prior to calculation of design heating and cooling loads. A third check of the envelope data was performed as part of the assessment of code compliance. After the data were entered into a SPSS database, the software was used to conduct a fourth check for missing or outlying data points. Finally, a visual fifth check for unusual entries was conducted of the entire electronic database. Whenever necessary throughout this process, the surveyors were contacted to confirm data entries (KMS/SEI 1994).

A report presenting both the tabulated results from the survey and a discussion of the analyses performed was published in June 1994 (KMS/SEI 1994). The survey results subsequently became the cornerstone of efforts by each of the Iowa utilities to determine which new construction efficiency upgrades were cost-effective. Between June 1995 and February 1996, each of the three investor-owned utilities in Iowa—IES Utilities, Interstate Power and MidAmerican Energy Corporation[5]—filed Energy Efficiency plans that included residential new construction programs that were based on these analyses.

Vermont Residential New Construction Baseline Survey

In the Fall of 1994, the three largest utilities in Vermont—Central Vermont Public Service (CVPS), Green Mountain Power (GMP) and Citizens Utilities (CU)—commissioned a survey of baseline new construction practices in the state. Field data were collected by Energy Rated Homes of Vermont (ERH/VT), an initiative of the Vermont Energy Investment Corporation.

ERH/VT was charged with completing 200 on-site surveys. The 200 surveys were divided as follows: 100 in CVPS' service territory, 80 in GMP's service territory and 20 in CU's service territory. Each utility also provided more specific numerical targets for districts within their service territories.

ERH/VT completed the on-site surveys by early Spring of 1995. The sites surveyed in each utility district were randomly selected from lists of new customers in each district that were provided by the utilities. All of the homes surveyed were built in either 1993 or 1994. All but 24 of the homes were single family homes.

Over 700 data points were collected for each home surveyed. This included general information about the home, such as location, age, style, dimensions and fuel suppliers; demographic information about the current occupants; data on building shell characteristics such as insulation types, insulation levels, window and door types, and building orientation; infiltration rate as measured by a blower door; heating equipment types, capacities and both rated and estimated seasonal efficiencies[6]; data on mechanical ventilation; and appliance and lighting information. In addition, ERH/VT provided an energy rating for each home.

Most of the survey data was collected by three inspectors with experience in conducting home energy ratings (an additional six inspectors each conducted a comparatively small number of surveys). Each auditor worked from the same extensive data collection form. The average survey took approximately three hours to complete.

Once collected, the survey data were checked, entered into a Paradox database and then re-checked. The data were then tabulated and analyzed by the sponsoring utilities. They have subsequently been used by the Governor's Task Force on Energy Efficiency Standards to examine issues related to a proposed state-wide energy code for residential new construction (State of Vermont 1995). They have also been used in the design and screening of utility new construction DSM programs.

As part of this effort, an assessment has been made of how baseline new construction practices in Vermont compare to the 1993 Model Energy Code standards. This has been done in two ways. First, a ''composite home'' (i.e. a hypothetical home with characteristics equal to the average of the 200 homes surveyed) was analyzed with MECcheck software. Second, an estimate was made of the Vermont energy rating score that a home meeting the minimum standards of the 1993 Model Energy Code would achieve.[7] Since an energy rating was conducted for each home surveyed, it was then possible to estimate the number of surveyed homes that met or exceeded the 1993 Model Energy Code's efficiency standards.

RESULTS

What follows is a summary presentation of the key findings from both the Iowa and Vermont surveys. Although both surveys examined a number of different energy end uses, the principal focus of this paper is on building shell and HVAC system efficiency.

Discussion of Iowa Results

Table 1 provides a summary of average new construction characteristics in Iowa as revealed by the Iowa baseline study. The most striking finding is that 93% of the homes surveyed did not pass the 1989 Model Energy Code, the code in effect in Iowa at the time the homes were constructed. The most important reason for this failure appeared to be the absence of proper insulation of basement walls. However, 54% of the homes surveyed would still have failed code even if they had proper basement wall insulation. According to the consultants who conducted the study, ''Glass area and/or low glass and wall U-values were the primary reason for failure within this group.'' (KMS/SEI 1994, 1–2)

Performance in areas that are not the primary focus of the Model Energy Code was mixed. On the positive side, the average AFUE for heating equipment installed in the surveyed homes was 85.4%, or more than seven percentage points above the current minimum federal standard for gas furnaces (the dominant heating equipment type in Iowa).[8]

Table 1. *Iowa Residential New Construction Survey Results*

BUILDING DESIGN	
% of homes with basements	98%
% of homes with ducts	100%
% of homes with central cooling	94%
% of homes with mechanical ventilaton	n.a.
BUILDING DIMENSIONS	
Average floor area above basement	1760 ft^2
Average basement floor area	1167 ft^2
Average conditioned floor area	2927 ft^2
Average conditioned volume	24,915 ft^3
Average attic area	1260 ft^2
Average net wall area (excluding basements)	1742 ft^2
Average window area	186 ft^2
Average foundation/basement wall area	1157 ft^2
Average % foundation/basement wall area above grade	25%
BUILDING SHELL EFFICIENCY	
Average ceiling flat insulation R-value	R-37
Average wall insulation R-value	R-19
Average band-joist insulation R-value	R-15
% of basements with above grade insulation	11%
% of basements with below grade insulation	18%
% of windows that are low-e	53%
Average window R-value	R-2.2
Average air leakage rate (natural)	0.39 ACH
HVAC SYSTEM EFFICIENCY	
Average heating equipment rated efficiency	85.4% AFUE
Average cooling equipment rated efficiency	10.4 SEER
Average cooling equipment capacity as % of design load	155%
% of ducts sealed	3%
% of ducts insulated	3%
Average duct leakage rate (subtraction method)	118 CFM_{50}
% of homes with setback thermostat	44%
COMPLIANCE WITH CABO/MEC	
% of homes passing 1989 MEC	7%

Source: KMS/SEI 1994; Barakat & Chamberlin 1995.

This suggests that condensing furnaces have been installed in a substantial number of new homes, a result that may be partially attributable to the long-standing high-efficiency furnace rebate programs offered by gas utilities throughout the state.

It should also be noted that nearly half of the homes surveyed had programmable thermostats and that virtually all of them were in the proper location and were being used by the current occupants.[9] This result may also have been significantly influenced by utility demand-side management programs.

In contrast, despite the existence of state-wide utility-sponsored rebates for high efficiency units, the average efficiency of central air conditioners installed in surveyed homes was only SEER 10.4, or just barely above current federal efficiency standards. In addition, the average central air conditioner was oversized by approximately one-ton (or 55%), a condition which various other studies have suggested lowers operating efficiency and leads to significantly higher summer peak demands for electric utilities (Proctor, Katsnelson and Wilson 1995, Treidler and Modera 1994, Neal and O'Neal 1992).

It also appears as if relatively little effort has gone into maximizing the efficiency of ducted distribution systems, as virtually none of the supply or return ducts in the surveyed homes had been either sealed or insulated. Duct leakage *to the outside* was estimated to be approximately 118 CFM_{50}. However, this probably understates the magnitude of duct losses for two reasons. First, as the consultants who conducted the study explained, because basements were assumed to be part of the conditioned space (even though the vast majority did not have insulated walls) ''any leakage into the basement was not counted as a loss'' (KMS/SEI 1994, 3–1). Second, duct leakage to the outside was calculated using the ''subtraction method'' (a comparison of blower door readings with (1) all registers and grills open, and (2) all registers and grills sealed), which can significantly underestimate leakage to the outside (Modera 1993).

Finally, air leakage rates appear to be fairly low (an estimated seasonal average natural infiltration rate of 0.39 air changes per hour (ACH)). However, it should be noted that ACH values were uniformly calculated assuming basements were part of the conditioned space (i.e. including basement volume in the conditioned volume). The consultants who conducted the study estimated that the average infiltration rate would have been about 50% higher (0.59 or 0.60 ACH) had the basements not been considered part of the conditioned space (KMS/SEI 1994).

Discussion of Vermont Results

Table 2 provides a summary of average new construction characteristics in Vermont as revealed by the Vermont baseline study. Of particular interest is the finding that the average home was approximately 12% more efficient than required by the 1993 Model Energy Code and that two-thirds of the homes surveyed would have met or exceeded the 1993 Model Energy Code's efficiency standards. Among the one-third of the Vermont homes that would not have complied with the 1993 Model Energy Code standards, the most common reasons, in order of importance, were inadequate basement insulation, failure to install low-e windows, and/or failure to install water heater insulation measures (State of Vermont 1995).[10]

Performance in areas outside of the principal focus of the Model Energy Code was generally fairly good, although there are clearly some areas in which typical building practices could be improved. On the positive side, nearly 85% of the homes surveyed heat with boilers, rather than furnaces. This has several advantages. First, heating system distribution losses are likely to be substantially lower than in Iowa and numerous other states where forced-air distribution systems are the norm. Second, hydronic heating is easier to zone than forced air systems. Finally, nearly 70% of the homes surveyed in Vermont also used their boilers for water heating, the majority with highly-efficient, indirect-fired storage tanks as a zone off the boiler. The Vermont preference for hydronic heating systems is probably driven, at least in part, by Vermont's relatively cool summers, which effectively preclude the need to install ducted distribution systems for central air conditioning. Indeed, in contrast with Iowa where almost all new homes have central cooling, none of the 200 homes surveyed in Vermont had central air conditioning.

Vermont homes also appear to be fairly tight, with an estimated seasonal average natural infiltration rate of 0.38 ACH. This value is similar to the average value reported for Iowa (0.39 ACH). As in the Iowa study, the ACH value for the Vermont homes was calculated assuming that the basement volume was part of the conditioned volume of the home. However, in contrast with Iowa, the majority homes in the Vermont survey had insulated basements.

As noted in the report of the Governor's Task Force, ''Vermont's energy efficient and tight building practices give rise to strong concerns about indoor air quality in some homes'' (State of Vermont 1995). More than half of the surveyed homes had air leakage rates of less than 0.35 ACH, the level at which the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) recommends installation of mechanical ventilation, yet only 7% had mechanical ventilation systems.

Table 2. *Vermont Residential New Construction Survey Results*

BUILDING DESIGN	
% of homes with basements	93%
% of homes with ducts	15%
% of homes with central cooling	0%
% of homes with mechanical ventilaton	7%
BUILDING DIMENSIONS	
Average floor area above basement	n.a.
Average basement floor area	n.a.
Average conditioned floor area	2352 ft^2
Average conditioned volume	18,848 ft^3
Average attic area	972 ft^2
Average net wall area (excluding basements)	2714 ft^2
Average window area	258 ft^2
Average foundation/basement wall area	997 ft^2
Average % foundation/basement wall area above grade	25%
BUILDING SHELL EFFICIENCY	
Average ceiling flat insulation R-value	R-36
Average wall insulation R-value	R-19
Average band-joist insulation R-value	R-17
% of basements with above grade insulation	66%
% of basements with below grade insulation	63%
% of windows that are low-e	76%
Average window R-value	R-2.4
Average air leakage rate (natural)	0.38 ACH
HVAC SYSTEM EFFICIENCY	
Average heating equipment rated efficiency	82.1% AFUE
Average cooling equipment rated efficiency	n.a.
Average cooling equipment capacity as % of design load	n.a.
% of ducts sealed	3%
% of ducts insulated	88%
Average duct leakage rate (subtraction method)	n.a.
% of homes with setback thermostat	1%
COMPLIANCE WITH CABO/MEC	
% of homes passing 1993 MEC	67%

Source: State of Vermont 1995; Authors' analysis of raw data 1996.

One additional area for improvement is in the installation of programmable thermostats, which the Vermont study suggests are only very rarely installed.

CONCLUSIONS

Residential new construction in Vermont appears to be more efficient than in Iowa. This conclusion is made all the more striking by the fact that Iowa had a state-wide energy code in place when the homes included in its survey were built, but Vermont did not.[11] This suggests that the efficiency of new construction is not necessarily correlated with the requirements of energy codes. Put another way, having strong energy codes on the books does not guarantee energy efficient new construction.

Additional research would be necessary to explain the underlying reasons for differences between new construction practices in Iowa and Vermont. Among the possible factors that may be worthy of future investigation are:

- *Fuel Costs*—Winters in Vermont are roughly 15% to 25% more severe than in Iowa.[12] In addition, typical heating fuel prices in Vermont, where oil is the most common heating fuel, are about 30% higher than in Iowa, where the vast majority of homes have gas heat.[13]

- *Act 250*—Although Vermont does not have a state-wide building code, its does have a land-use planning law, commonly referred to as Act 250, which requires some new developments to meet environmental standards, including energy efficiency standards, as a condition for receiving a building permit. Roughly one-third of the homes in the Vermont baseline study required Act 250 permits. However, the average efficiency of the Act 250 homes was not appreciably different from the average efficiency of those that did not require such a permit (State of Vermont 1995).

- *Utility Efficiency Programs*—Approximately one-quarter of all homes surveyed for the Vermont baseline study had participated in utility residential new construction programs (State of Vermont 1995). The authors are unaware of information regarding the number of homes in the Iowa baseline survey that had participated in utility demand-side management programs.[14]

- *Home Energy Ratings and Energy Efficient Mortgages*—Approximately 8% of the sites surveyed for the Vermont baseline study had previously received ratings from ERH/VT.[15] None of the homes in the Iowa baseline survey received an energy rating, as Iowa's home energy rating program has only just recently gotten off the ground.

- *Custom Building*—Data regarding the prevalence and relative importance of custom-built homes in the Iowa and Vermont baseline survey samples are not currently available.

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ENDNOTES

1. Direct consumption was 10.4 quadrillion Btu's; electricity-related losses accounted for an additional 7.7 quadrillion Btu's.

2. This ''split incentives'' problem does not exist for the substantial number of existing home-owners who might consider making retrofit efficiency upgrades (although a similar problem does plague the rental housing market).

3. Duct leakage was estimated by using the ''subtraction method'' (i.e. the difference between (1) blower door measured infiltration to the home when registers and grills are not sealed, and (2) infiltration when they are sealed).

4. This was done by ''entering data into a Microsoft Excel spreadsheet to calculate U $\times$ A values for the building envelope'' for comparison with code requirements (KMS/SEI 1994, 2–4).

5. Iowa-Illinois Gas and Electric and Midwest Power merged to form the MidAmerican Energy Corporation after the new construction baseline survey had been commissioned.

6. AFUE ratings were adjusted downward to reflect such things as expected distribution losses and boiler water content. On average, the adjusted seasonal efficiency

was on the order of four to five percent lower than the rated AFUE (Faesy 1996).

7. Efforts to determine where a CABO/MEC home would place on the rating scale were complicated by the fact that the ERH/VT home energy rating includes more and different measures than CABO/MEC standards. Thus, the Task Force's estimate of the energy rating score a CABO/MEC home would achieve—68 points (a ''four-star'' rating)—is only an approximation.

8. This is more impressive than it might initially seem, as 28% of the homes surveyed were built prior to 1992, the year the current federal standards went into effect.

9. The average setback was 5.9 degrees Fahrenheit for approximately eight hours each day.

10. It is estimated that 30% of surveyed homes would have needed basement wall insulation to comply with the 1993 Model Energy Code standards, 25% would have needed to upgrade to low-e windows, and 20% would have needed a water heater insulation package. As only one-third of all surveyed homes would not have met the 1993 Model Energy Code standards, there is obviously considerable overlap among these deficiencies. Indeed, many homes would have needed all three of these upgrades in order to meet the 1993 Model Energy Code standards.

11. A recent study by the Alliance to Save Energy gave Vermont a ''D'' grade for its energy code efforts; Iowa received a ''B'' (ASE 1995).

12. The average number of heating degree days per year in Vermont ranges roughly from 7000 to 10,000, depending on location within the state. The average number of heating degree days per year in Iowa ranges roughly from 6000 to 8000.

13. Residential gas prices in Iowa are typically about $4.50 to $5.00 per million Btu ($0.45 to $0.50 per therm). In contrast, residential oil prices in Vermont are typically about $6.50 per million Btu (about $0.90 per gallon).

14. At the time the homes included in the Iowa baseline study were built, gas furnace and central air conditioner rebate programs were common throughout the state. However, at that time, only one of the four utilities that sponsored the study had a demand-side management program targeted to building shell upgrades in the residential new construction market.

15. This is smaller than ERH/VT's state-wide penetration rate. In 1994, ERH/VT performed about 350 energy ratings for new homes (Faesy 1996). This represented roughly 15% of the nearly 2300 new housing units built in Vermont in 1994 (Walsh 1996).

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