Least Cost Path to Achieving 50% Reduction in Residential Energy Use (in Heating Climates)

Jan Harris, X Prize Foundation
Michael Blasnik, Blasnik and Associates

ABSTRACT

This paper describes the findings of a project performed for the New York State Research and Development Authority to determine the least cost path, using conventional approaches, toward achieving a Home Energy Rating System (HERS) score of 90 (index of 50) or better in New York State homes. The study shows that savings of 50% above the Energy Conservation Code of New York State can be cost effectively achieved with currently available technologies and techniques.

For an additional mortgage payment of $37/month monthly energy bills can be reduced by $136, for a net savings of nearly $100/month. This is achieved by building a thermally efficient shell, using high efficiency mechanical systems and ENERGY STAR lights and appliances.

Purpose

The purpose of the study was to determine and to explain the least cost path to achieving high levels of energy efficiency in single family detached residential new construction. The study focused on conventional design and construction methods, materials, and mechanical systems that lead to substantial (50% or better) reduction in energy use as projected using Home Energy Rating System (HERS) modeling software. (It should be noted that there are other approaches to achieving large reductions in energy consumption associated with homes; people can choose to live in smnaller houses, live closer to where they work, integrate renewable energy systems into their homes or make behavioral changes that result in significant energy savings. These behavioral and renewable approaches are numerous, valid and reasonable, but not the subject of this report, which is focused primarily on efficiency options.)

Description of Study

Energy efficiency measures were evaluated in several ways and prioritized based on their incremental costs and associated savings. This report describes a least cost path, using conventional approaches, to achieving a HERS score1 of 90 or better using RESNET accredited rating software2 to determine HERS score3. The following methodology was used:

---

1 In 2006, with the release of REM/*Rat*e version 12, most programs switched from using a HERS score to a HERS index. New York state chose to stick with the score. A conversion is outlined on page 4.

2 This report used REM/*Rate* v.12.3 as the NY ENERGY STAR Labeled Homes program uses this software esclusively. See www.resnet.us/programs/software/directory.htm for a complete list of accredited software.

1. Review survey data obtained from builders and establish baseline reference home against which to evaluate savings of advanced efficiency measures
2. Analyze REM/*Rate* files on 1,971 NYS ENERGY STAR homes to determine most common efficiency measures used to achieve a HERS score or 90 or better
3. Interview those involved in the design and construction of 90+ homes to learn their preferred approaches
4. Review current literature on cost effective efficiency measures
5. Interview builders and key trade allies to gather additional cost data
6. Assess multiple combinations of efficiency measures in REM/*Rate* to determine least cost package of measures that achieves a HERS score of 90 or better
7. Conduct billing analysis of ENERGY STAR homes to assess accuracy of REM/*Rate* consumption and savings estimations

Results

Table 1 shows the package of efficiency measures found to be most cost effective and attainable by conventional builders, sorted in order of cost effectiveness as measured by the ratio of the present value of projected savings to the present value of loan payments for efficiency measures, or benefit cost ratio (B/C):

[3] The HERS Score defines the reference home as a score of 80 and then calculated the score as a one point adjustment for each 5% difference in projected energy usage. Homes projected to use 50% less energy than the reference home would get a score of 90 (50% savings divided by 5% per point = 10 points better than 80). A HERS score of 84 or higher qualifies a home to be ENERGY STAR .

Table 1. Efficiency Measures Ranked in Order of Cost Effectiveness

Energy Efficiency Measure	Incremental Cost	Annual Savings	Change in Monthly Cash Flow in Year 1	B/C	Change in HERS score	$/Point	Details
All ducts inside the thermal envelope	$0	$344	-$28.67	∞	2	$0.00	Locate ducts (and preferably all mechanical systems) within the thermal envelope. Avoid putting ducts in attics or unheated crawl spaces. Simplify layout of distribution systems. A central trunk with few branches can save thousands of dollars on unneeded equipment.
½ window area on south wall	$0	$131	-$10.83	∞	0.6	$0.00	Orient a majority of windows toward the south. Specify low emissivity coating and argon filled windows. Windows on the south should have higher solar heat gain coefficient, and on the west should have lower SHGC.
Advanced framing and insulated concrete forms	$0	$100	-$8.33	∞	0.6	$0.00	The most cost-effective approach to achieving an energy efficient wall structure, using relatively conventional approaches, is to apply 2" of rigid foam continuous exterior insulation, regardless of framing method or cavity insulation type. Advanced framing, or optimum value engineering - (OVE) framing - involves the reduction of framing members by going from 16" to 24" o.c. spacing, as well as other techniques, and uses approximately 30% fewer pieces. This should lessen labor costs and framing time as well as allowing for higher levels of insulation and reduced thermal bridging. Insulated Concrete Forms (ICFs) were chosen as the recommended efficiency measure for foundation walls because they are the least cost path to achieve an R-22.5 insulation value if finishing the basement in the future, which often occurs.
Programmable Thermostat	$20	$25	-$1.95	18.83	0.2	$100.00	Using a thermostat programmed to turn down the heat when the occupants are not at home is a very cost effective energy saver.
ENERGY STAR Lights and appliances	$425	$240	-$17.15	8.83	0.6	$708.33	Electricity savings for lights and appliances can be significant. Lighting and appliance upgrades for the 90+ home in this analysis include 75% fluorescent lighting and ENERGY STAR labeled appliances.
Reduce air leakage	$298	$153	-$10.75	8.02	1.2	$248.67	While homeowners can and will change most things in a house, it is difficult and expensive to make changes to the thermal shell after initial construction. Meticulous attention to sealing, caulking and foaming all shell penetrations and verifying performance with a blower prior to drywall is the best way to ensure a tight house. Advanced air sealing must go hand in hand with mechanical ventilation, or by solving one problem you may be creating several more.
U-value .3 Windows	$325	$151	-$9.83	4.95	0.8	$406.25	Windows are the building's weakest link in its thermal shell, as well as being one of the most expensive building components. Glazings should be used wisely to frame for views and to harvest passive gains. Most window brands and sellers these days have common units in stock in the range of U.29 to U.33.
Furnace 78% to 94%efficiency rating	$1,785	$471	-$27.26	4.12	2.8	$637.50	Heating, Ventilating and Air Conditioning (HVAC) equipment should be designed appropriately for the specific building. When a building's shell is air tight and well insulated, the heating and cooling loads are considerably reduced. This allows for use of smaller, cheaper HVAC equipment. Size HVAC equipment according to the calculated heat loss of your building, not the installer's rule of thumb. Use only the distribution that you need. Purchase a high efficiency furnace or boiler; the savings far outweigh the increase in cost.
On Demand WH	$500	$75	-$2.89	2.34	1.2	$416.67	Going from a standard 40 gallon natural gas water heater, with a federal minimum energy factor of 56%, to a tankless on-demand water heater with an EF of 81%, saves 44% of water heating energy use. Using a high efficiency boiler to heat a hot water storage tank for domestic water heating is also a sound approach. Solar water heating is a cost effective measure that was not covered in this report.
R-60 Attic insulation	$860	$107	-$3.14	1.94	0.6	$1,433.67	With a truss system, when insulation is blown in, increasing insulation levels to R-60 can be accomplished at a modest cost increase.
Drainwater heat recovery	$800	$27	$3.12	0.67	0.6	$1,333.33	Drainwater heat recovery involves running waste water through a heat exchanger to give its heat to the cold water coming in to the water heater.
Air Conditioning efficiency from SEER 13 to 15	$500	$8	$2.69	0.25	0.8	$625.00	Make sure your HVAC equipment installer verifies the refrigerant charge level and air flow rate to ensure you actually get the rated efficiency of your central AC unit.
Totals	**$5,514**	**$1,630**	**-$98.81**	**4.62**	**10**		

New York State Energy Star Home Completed Building Data Acquisition and Analysis

Team member Conservation Services Group (CSG) is the ENERGY STAR™ Labeled Homes program administrator for New York State. CSG maintains a database with detailed information about each of the ENERGY STAR™ homes built in New York since 2004. The database was analyzed to identify the characteristics associated with homes receiving various HERS scores. These scores were broken into two categories; those receiving a score of 90 points or more and those receiving a score of less than 90.

Energy ratings for the ENERGY STAR™ Labeled Homes program in New York are done using the REM/*Rate* software. REM/*Rate* stores all of the data inputs and outputs from each rating in a database that contains more than 800 data fields across more than 50 tables. During 2006, the program switched from using REM/*Rate* version 11 to version 12, which involved several notable changes. The two databases (versions 11 and 12) provided by program administrator CSG contained data on 2,117 ENERGY STAR Homes built from 2004 through late 2006. The focus of this project is on single family detached homes, so we removed 146 units from the analysis (nearly all town homes) leaving 1,971 homes in the analysis.

The technical changes in the ratings standards and reference home complicate any direct translation between the old HERS Score and the new HERS Index. RESNET recommends a conversion formula of:

$$\text{HERS score} = 80 + (100 - \text{HERS Index})/5$$

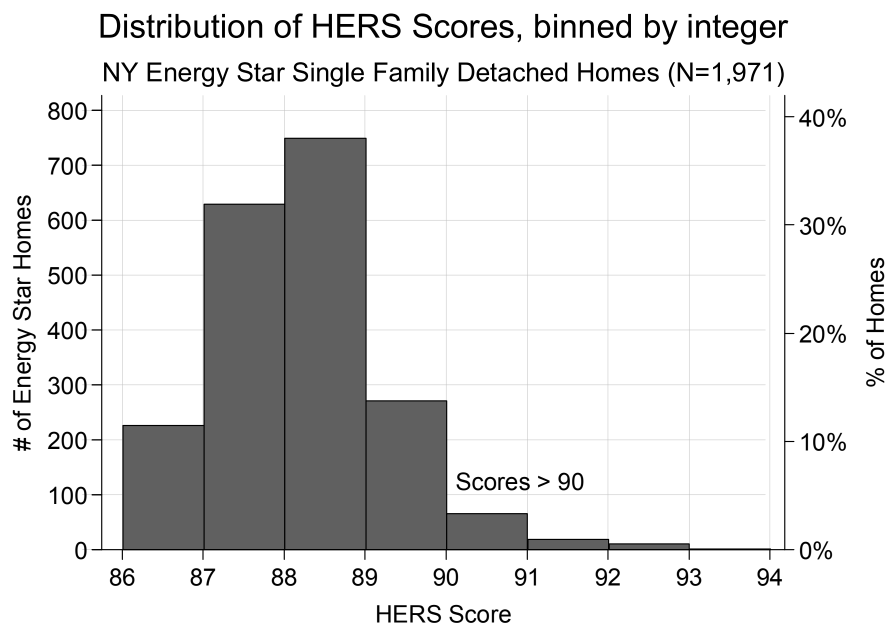
for converting version 12 HERS Index to a HERS score. We were, however, trying to compare version 12 HERS Indexes with version 11 HERS scores in 422 of our 1,971 REM/*Rate* files. As a result of the change in baseline to a more stringent baseline home, we employed the following formula to convert the version 12 Index results to the version 11 Scores:

$$\text{HERS Score} = 82 + (100 - \text{HERS Index}) / 5$$

The two point difference is the estimated impact of the upgrade in the baseline. For example version 12 baseline is SEER 13 AC while version 11 baseline is SEER 10. Again it should be noted that this is an imperfect conversion.

The majority of homes had REM/*Rate* energy modeling scores of between 87 and 89, with more than a third scoring between 88 and 89 and nearly 30% scoring between 87 and 88. Very few homes had scores greater than 90. Figure 1 below shows the distribution of HERS scores.

Figure 1. Distribution of REM//Rate HERS Scores, Binned by Integer



The projected total annual loads for heating, cooling and water heating averaged 85 MMBtu for the 90+ homes (after house size adjustment[4]) and 105 MMBtu for the sub 90 homes. The 90+ homes had 19% smaller projected loads than the sub 90 homes. As Table 2 below shows, the difference in projected heating loads was 24%, the difference in projected water heating loads was 29% and the difference in projected cooling loads was negative 86% due in part to differences in central air conditioning penetration.

[4] There was a strong inverse relationship between floor area and heating usage per square foot of floor area – larger homes use less heating energy per square foot of floor area, which makes sense given that heat loss occurs primarily through the shell area, which tends to grow more slowly than floor area. Therefore, we normalized usage by shell area, which did not exhibit this strong relationship.

Table 2. Projected Loads

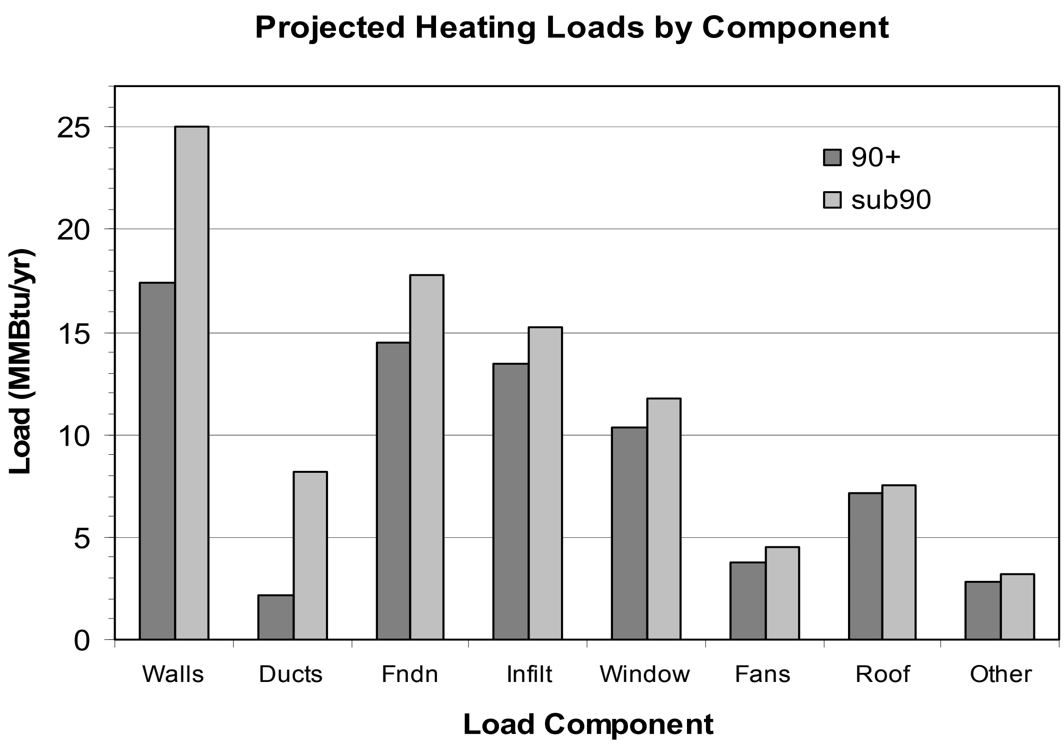
	Projected Usage (MMBtu/yr)		*"Savings"*	
Load	90+	Sub90	MMBtu	%
Total Loads (Ht/Cl/HW)	**84.8**	**105.3**	20.5	19%
Reference Load	171.7	179.0	7.3	4%
Savings (vs. Reference)	86.9	73.7	13.2	18%
% Savings (vs. Reference)	51%	41%		
Heating Load	**57.9**	**76.3**	18.4	24%
Reference Heating Load	134.6	143.3	8.7	6%
Savings vs. Reference	76.7	67.0	9.7	14%
% Savings	57%	47%		
Heating Components:				
Walls	17.4	25.0	7.6	30%
Foundation	14.5	17.8	3.3	19%
Roof / Attic	7.2	7.5	0.3	4%
Windows	10.4	11.8	1.4	12%
Infiltration	13.4	15.2	1.8	12%
Fans	3.8	4.5	0.8	18%
Ducts	2.1	8.2	6.0	73%
Internal Gains	-13.8	-16.9	-3.1	-18%
Other	2.9	3.2	0.3	9%
Cooling Load (All Homes)	6.9	**3.7**	-3.2	-86%
Reference Cooling Load	9.3	7.3	-2.0	-27%
Savings vs. Reference	2.5	3.7	-1.2	-32%
% Savings	26%	50%		
Major Cooling Components:				
Windows	7.2	3.6	-3.6	-102%
Infiltration	-0.7	-0.4	0.3	-74%
Roof / Attic	0.3	0.2	-0.2	-101%
Water Heating Load	20.0	**25.3**	5.3	21%
Reference DHW Load	27.8	28.3	0.5	2%
Savings vs. Reference	7.8	3.0	4.8	160%
% Savings	28%	11%		

The reference home loads for calculating the energy rating were about 4% smaller for the 90+ homes after adjusting for house size. The projected loads averaged 51% smaller than the reference home for the 90+ homes and 41% smaller than the reference home for the sub 90 homes.

The majority of the building loads are associated with heating. Projected heating savings compared to the reference home averaged 57% for 90+ homes and 47% for sub90 homes.

Figure 2 shows the average projected heating loads for each building component for the 90+ and sub90 homes, except for the internal gain estimates which are negative. The components are ordered by the size of the load difference between the two groups of homes.

Figure 2. Average Projected Heating Loads by Building Component: 90+ vs. sub90 Homes



Walls and ducts are projected to provide the majority of the heating savings relative to the sub 90 homes while foundation and infiltration losses also contributed to the difference.

Summary of Features Associated with 90+ Ratings

In addition to the analysis of each component of the projected loads, we also tabulated the frequency of certain efficiency "features" in the 90+ and sub 90 homes to identify common combinations that contributed to 90+ scores. The list below shows the most common sets of five energy features listed in order of frequency:

Wall: wall R-value greater than 16;
Duct: non-default duct losses (either hydronic or leakage tested);
DHW: non-conventional water heater
Window: window R-value greater than 3; and,
GSHP: ground source heat pump

Costs and Savings of Efficiency Measures

Table 3 below is the list of all efficiency measures analyzed. The first twelve items represent the least cost package of measures to get to a HERS score of 90 described in table 1 above. The change in HERS scores is not additive because of interactive effects of measures. The measures are listed in order of benefit/cost ratio, but can be re-ordered depending on the desired perspective. For example a home owner might want them prioritized by their change to monthly cash flow, or a builder might order the measures in terms of $/point, or a developer might rank them by first cost.

Table 3. Efficiency Measure Cost and Savings Summary

LIST OF ALL MEASURES						
Measure	Incremental Cost	Annual Savings	Change in Monthly Cash Flow in Year 1	B/C	Change in HERS score	$/point
Ducts w/in thermal env	$0	$344	-$28.67	∞	2	$0.00
Window Orientation	$0	$131	-$10.83	∞	0.6	$0.00
OVE framing, FG grade 1	$0	$100	-$8.33	∞	0.6	$0.00
Programmable T stat	$20	$25	-$1.95	18.83	0.2	$100.00
Lights and Appliance	$425	$240	-$17.15	8.83	0.6	$708.33
Infiltration-.5 to .15 EOV	$298	$153	-$10.75	8.02	1.2	$248.67
U.3 Windows	$325	$151	-$9.83	4.95	0.8	$406.25
Furnace 78 to 94	$1,785	$471	-$27.26	4.12	2.8	$637.50
On Demand WH	$500	$75	-$2.89	2.34	1.2	$416.67
R-60 Attic	$860	$107	-$3.14	1.94	0.6	$1,433.67
Drainwater heat recovery	$800	$27	$3.12	0.67	0.6	$1,333.33
AC SEER 13 to 15	$500	$8	$2.69	0.25	0.8	$625.00
MEASURES ABOVE ARE LEAST COST PATH TO HERS 90						
.5 to .35 ACH	$273	$182	-$13.33	10.4	1	$273.40
.5 to .15 HRV	$2,773	$103	$10.04	0.58	1.2	$2,311.17
ICF foundation walls	$3,000	$129	$9.40	0.67	0.8	$3,750.00
Above grade wall 2" foam	$2,525	$301	-$8.13	1.86	1.6	$1,578.13
Window U-value to .2	$6,240	$245	$21.49	0.61	1.4	$4,457.14
Solar water heating	$7,000	$205	$29.93	0.46	1.6	$4,375.00

Energy Use Data Analysis

We analyzed gas and electric energy consumption data of a sample of ENERGY STAR homes as part of this project to help assess whether differences in HERS scores are related to differences in actual energy usage and to explore for potential patterns in any discrepancies that may be related to building characteristics. This consumption analysis was a relatively small part of the overall project and should not be considered in any way a comprehensive evaluation of the effectiveness of NY ENERGY STAR Homes. No data was collected on non-ENERGY STAR new homes for comparison.

Comparison of actual energy use to REM/*Rate* predicted energy use (utilizing the HERS rating process) showed the REM/*Rate*-predicted usage averaged about 10% greater than the actual usage. The analysis further showed that increasing the HERS score from 86 to 90 does not directly correlate to less energy use. There are too many variables including the algorithyms in the software, the raters diligence in gathering data, the data itself, the small sample size, etc. to draw definitive conclusions from this. However, it is a disturbing finding.

The average heating overprediction of about 10% could be due to many factors, such as bias in the assumed thermostat settings or in other assumptions or algorithms. The Only other large study of actual versus REM/rate modeled energy use, performed in Wisconsin, found a similar over-prediction, which they attributed to the default duct leakage penalty in the HERS regulations.

The normalized (for weather and house size) heating usage was predicted to decline by about 20% from the lowest scoring bin to the highest scoring bin, but the actual normalized heating usage appears to fluctuate without a pattern and the highest scoring homes actually have greater heating usage intensity than the lowest scoring homes.

Although the sample size is relatively small, this finding is somewhat disturbing since it implies that the HERS scores do not correspond to any real world improvement in efficiency – at least within the range of scores among these ENERGY STAR homes.

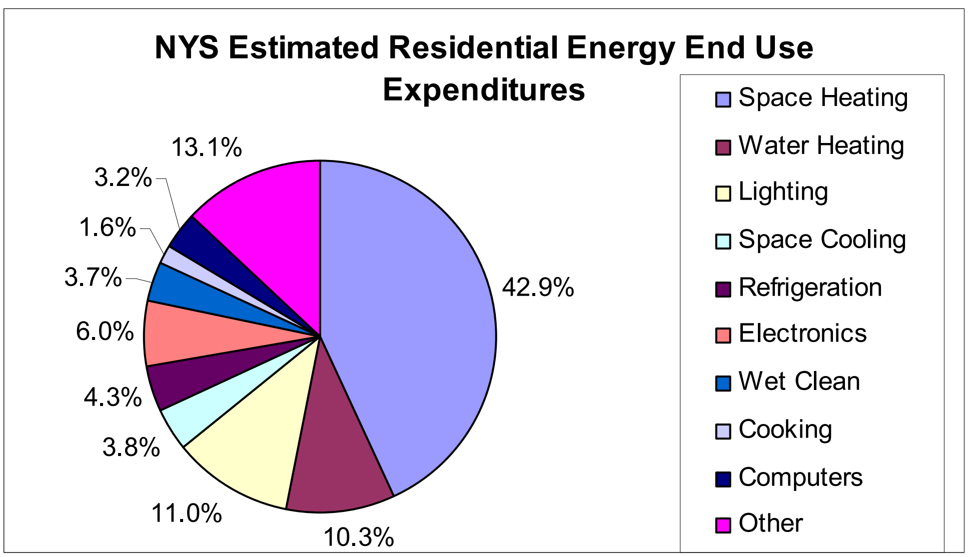
Overall Energy Usage

The total actual energy usage for these ENERGY STAR homes averaged 106.9 MMBtu of gas usage and 11,040 kWh of electric usage. The overall gas and electric usage is estimated to cost about $3,500 per year (in 2006) in these homes with nearly half coming from the electric bill even though all of the homes had gas heating and water heating.

The absolute level of energy usage in these homes is actually somewhat higher than the typical residential customer in upstate New York, especially for electric usage. The large size of the homes helps explainwhy this occurs. The natural gas savings which may accrue from the more efficient new construction are offset by the larger size of the homes. Electric baseload efficiency was not very well addressed by ENERGY STAR when these homes were completed in 2005 and the potential for gains is limited to some extent by the proportion of the electric use that is associated with homeowner-purchased appliances and other end uses not installed by the builder.

Figure 3 below shows the approximate break down of energy use by end use for single family detached homes in New York State. As the thermal shell becomes more efficient, hot water and electric loads become a larger percentage of total energy use.

Figure 3. Energy Use by End Use in NYS



Conclusions

There are numerous technologies, methods and materials currently available and in use to achieve high levels of energy efficiency in residential new construction. There are also multiple information resources on how to integrate these approaches into design and construction practices. Many builders are familiar with energy efficient construction techniques. However, there is a common sentiment that they can't convince their clients that advanced energy efficiency approaches are worth the extra investment. Virtually all production and custom home builders seem satisfied building to meet minimum code standards. Relatively few have implemented ENERGY STAR certification as a standard or as an optional feature. Many builders have been in the business for generations, and believe that the homes they build are "good enough." Builder education is only one of many barriers to broader implementation of high performance building. The primary challenge facing NYSERDA and others in the business of facilitating market transformation is in getting people to understand efficiency, value it, demand it and implement it. The problem is sociological not technological. This paper aims to lay out the case, in dollars and cents, to facilitate a decision to incorporate efficiency in new home plans.

The approach in this report was to find the least cost path to energy efficiency using commonly available materials and relatively conventional approaches to building. A HERS score of 90 can be achieved with a conventionally framed house if air sealing is implemented as outlined in the ENERGY STAR thermal bypass checklist, mechanical ventilation is included to enable the savings to be claimed from reduced air leakage, readily available U.3 windows are used, attics are insulated to R-60, high efficiency mechanical equipment is specified such as readily available 94% efficient furnace, (with all ducts inside the thermal envelope), and an on demand water heater with an EF of 81% or better is used. (A high efficiency boiler with a storage tank for domestic hot water is also a great approach. Additionally, ductless mini split air conditioning systems which concentrate the cooling where you need it are a great alternative to central air conditioning.) As REM/*Rate* version 12 or higher calculates the whole house energy use in assigning a HERS score, our conceptual house uses readily available cost competitive ENERGY STAR appliances and a majority of fluorescent lighting.

In addition to the list of cost effective efficiency measures shown on page three, our analysis leads to several other conclusions:

- Getting to a HERS score of 90 is much more difficult now, under REM/*Rate* version 12, than it was under REM/*Rate* version 11 as a result of changes to the reference (baseline) home resulting from codes and standards revisions such as increasing air conditioning SEER rating requirements from 10 to 13, higher water heating standards, and a tighter infiltration rate
- The average HERS rating for participants in the New York State ENERGY STAR Homes Program is well above the 84 point minimum
- REM/*Rate* overestimated average gas heating usage by about 10% when compared to actual consumption. Heating load estimates for walls, attics, windows, and infiltration were all related to measured gas usage but projected loads from measured duct leakage and from foundations were not found to be related to measured gas usage.
- Actual energy usage data was obtained and compared to REM modeled energy use projections. The analysis shows that in the 86 to 90 score range, there is no correlation between higher HERS scores and actual efficiency improvement

Conceptual Design for High Performance Building

Taking results from our REM/*Rate* analysis, builder surveys and interviews, expert interviews and field visits, a conceptual house was designed in REM/*Rate* that incorporates the most cost effective efficiency measures to get to a HERS score of 90. The primary elements that lead to advanced levels of energy efficiency are summarized in Table 4. We have created three dimensional illustrations of a simple house integrating these measures and included them here in Figure 4 and Figure 5.

Table 4. 90+ Concept House Summary of Design Elements

Thermal Shell		
Foundation	2" of rigid foam on the exterior. Or ICF's or equivalent	
Walls	2 X 6 24" o.c. framing with fill insulation and 2" Continuous rigid foam exterior	
Windows	U-.3 or better	
Doors	Pre-hung insulated	
Ceilings	R-60	
Infiltration Measures	Achieve infiltration of .15 ACH natural	Add mechanical ventilation
Mechanical Systems		
Furnace	AFUE 90 or better	
Ducts	Located within the thermal envelope	Sealed. Insulation not necessary
Boiler	AFUE 90 or better	Include indirect water heater
Water Heating	EF of 81 or better	Consider indirect or instantaneous
Drainwater heat recovery		
Lights and Appliances		
ENERGY STAR Lighting	Fluorescent bulbs and fixtures in 50% of locations.	
ENERGY STAR™ Appliances	ENERGY STAR Refrigerator, washing machine, dishwasher, ceiling fans	

Figure 4. Energy Efficient Shell Measures

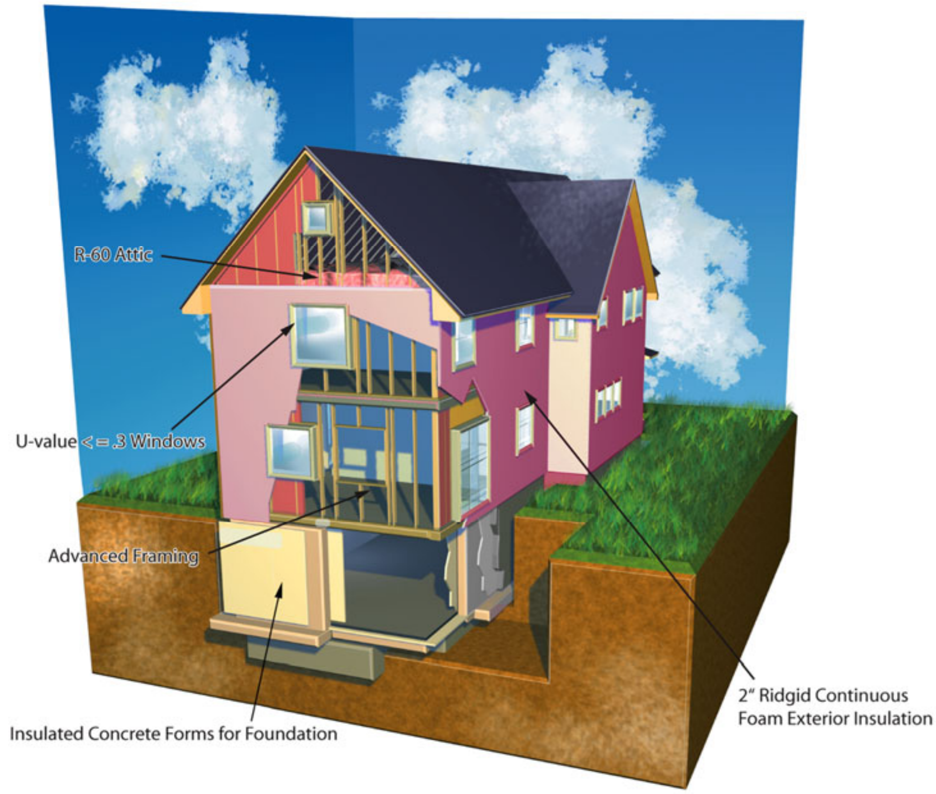


Figure 5. Energy Efficient Mechanical Measures