

TQM APPROACHES TO INCORPORATING SIMULATION INTO RESIDENTIAL ENERGY RETROFIT PROGRAMS

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ABSTRACT

In 2005, the residential building sector consumed an estimated 21.8 quads of energy, representing a 22% share of total U.S. Primary Energy Consumption, and an estimated 37% of total U.S. Electricity Consumption. The potential for increasing the energy efficiency of residential building stock through targeted energy efficiency retrofit programs is unarguably significant. Energy efficiency retrofit programs (both utility and non-utility funded) have recently been designed to realize these potential gains through incorporating energy simulation. The challenge for residential retrofit programs is to design a cost-effective yet accurate scalable process, which is tailored to individual needs? The utilization of TQM strategies and online data management provide successful vehicles to address this challenge.

INTRODUCTION

Energy modeling tools predict potential measure savings interactively and therefore more accurately than individual measure calculations. When actual performance characteristics of a home are included in the model both pre and post retrofit variants will reflect actual occupant dependent values when using energy modeling tools. The primary use for energy modeling tools in the residential retrofit context is in support an investment decision, e.g. a homeowner purchasing a package of measures or a government agency investing in a package for the homeowner. Driving the investment decision is a level of confidence in the predicted savings. To accurately predict savings, a comparison must be done between actual energy use of a home before retrofit and proposed energy use after retrofit. Modeling provides the target performance information that is necessary for creating continuous improvement.

Despite the accuracy advantages of modeling, this method incurs greater costs over traditional methods of calculating savings. Currently, widespread use in residential energy retrofit programs is obstructed by insufficient contractor training and unrecoverable costs associated with additional time to construct energy models. However, a simple yet powerful modeling interface combined with the use of online applications can reduce both training needs and time to produce energy models. In addition, the latest evolution of modeling tools provide benefits, such as energy ratings, load calculations, and customized sales presentation materials that were not available using traditional calculation methods. For these latest versions to be incorporated in to a successful business model, contractor must be educated on the breadth of quality and cost benefits that these tools can provide. The predictive capabilities of these tools as well as the potential for continual feedback offer contractors the opportunity to develop trust and a long-term relationship with homeowners.

An on-line database tool has recently been developed by the authors to manage the complete spectrum of program activity from audit to invoicing. The tool has been designed to integrate actual weather information and actual utility bills with feedback from energy simulation software. The tool follows a nine-step process based on the Deming approach to TQM (Plan, Do, Study, Act) to support the overall performance of a retrofit program. This system has significantly reduced delivery costs and increased the rate at which energy usage information is gathered and disseminated to participating contractors, program managers, and sponsoring utilities.

In 2003, the state of New Hampshire elected to invest in infrastructure development to improve the New

Hampshire Residential Efficiency program. New Hampshire State laws mandate that jurisdictional utilities offer a basic set of products and services to serve residential efficiency program goals across all utility service areas. The stated goals are to (1) Increase the demand for higher energy efficiency, (2) Strengthen the energy efficiency delivery infrastructure, and (3) Create long term opportunities to harvest savings embedded in existing housing stock. Since the programs inception, over 20,000 ‘trued-up’ residential energy simulation models for retrofits have been created, using the nine step process as described below:

Step 1 - Retrieve Billing Data into an On-line Database: The online database system used in New Hampshire is called OTTER, the Online Tool for Tracking Energy Retrofits. In New Hampshire the investor owned utilities have participated in the development of a data connection between the utility fuel data for program participants and the on-line program database. The OTTER database is structured such that it prevents participating utilities from seeing the customers of other participating utilities. The on-line database pre-formats the utility billing data (2 year history) into a format for input into the energy simulation software.

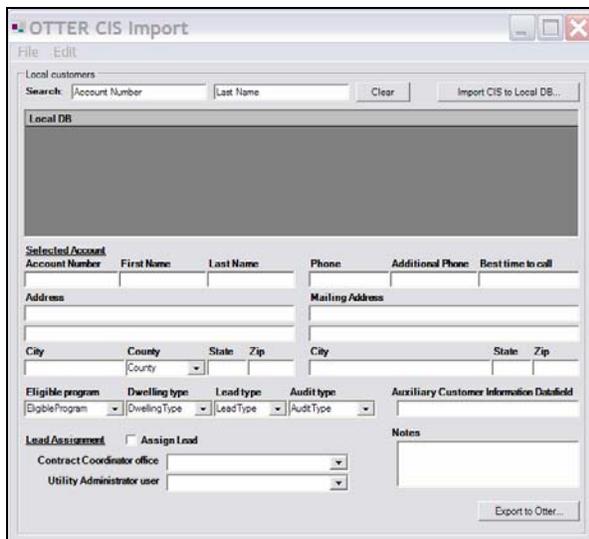


Figure 1 Interface for Utility Data Import

Step 2 - Billing Data Download and Analysis: Participating contractors can access the program website to download the energy and fuel use data of customers who enroll in the program. In the case of NH, when customers enroll in the program, their utility automatically assigns them to a contractor. Ideally, the download of billing data occurs before the contractor visits the residence for the energy audit. Actual

weather data (average daily temperatures) from 157 US sites can be download into the energy simulation software used by program from <http://www.engr.udayton.edu/weather/> and merged with the billing data. With this information, variable base degree day analysis can generate weather independent baseloads and weather-dependent heating and cooling slopes, by fuel type. Unlike PRISM, users must supply the reference temperature used for billing analysis UNLESS a forward energy model to represent the building has been created. When normalized and compared (benchmarked) against similar building types, contractors who take the time to analyze this information will know *prior* to the site visit where significant potentials for energy improvements may for available for that unique homeowner.

Step 3 - Energy Model Creation:

Contractors next visit the job site, collect and then enter data into the building energy modeling program. The contractors in New Hampshire are using the TREAT modeling software, a joint venture between Performance Systems Development and Taitem Engineering. TREAT’s development has been supported by the New York State Energy Research and Development Authority (NYSERDA) and the National Renewable Energy Lab (NREL). The author has worked closely with these agencies to integrate SUNREL and a host of other reporting/data processing algorithms into the TREAT software. The software uses an 8760 hour engine (SUNREL) to calculate room-by- room loads and the resulting temperature distributions. The target market for TREAT software is residential buildings, whose loads are often envelope driven. Studies have indicated that, unlike commercial buildings, infiltration and natural ventilation also contribute significantly to residential energy use. SUNREL contains routines for infiltration based on the effective leakage area of each zone, such as that determined through blower door tests. SUNREL can also model moveable insulation, interior shading control, energy-efficient windows, and many other energy-efficient design strategies. The thermal response of walls in SUNREL is calculated by approximating the wall construction with a thermal network. The network is then solved using the method known as explicit finite differences. This network structure allows for stud/cavity wall constructions that are common in residential construction to be easily modeled.

The TREAT modeling software allows contractors to perform a variety of functions beyond modeling, including energy ratings, load calculations, recording health and safety measurements, and creating

presentation reports for customers that support a whole-house/systems approach and BPI (Building Performance Institute) standards for auditing practices. In addition to disaggregation by end use, the simulation produces normalized (30 year average) predictions for energy consumptions and costs using TMY2 weather data sets to generate the model predicted energy use. The author has developed a flexible XML schema based reporting tool for customized post processing of TREAT results.

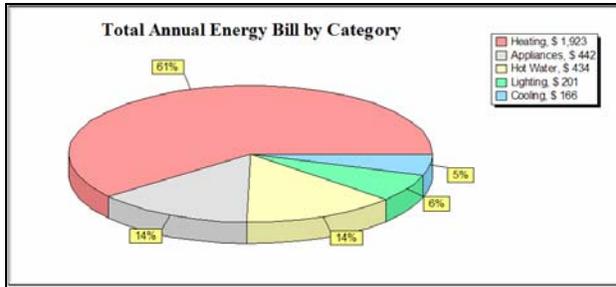


Figure 2 Base Building Energy Cost by End Use

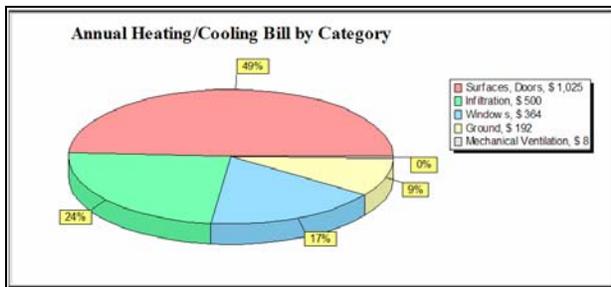


Figure 3 Base Building Weather Dependent Energy Cost by Element

Step 4 - Validation of the Building Energy Model: Energy usage information from the billing data such as total annual consumption, heating and cooling slopes, and reference temperatures are used to ‘true-up’ and validate the building energy model. During the ‘true-up’ process, users adjust appropriate model inputs to line-up model predicted energy usage with normalized billing energy usage for both weather independent and weather dependent end-uses and fuel types. Model ‘True-up’ is an iterative procedure, where changes to the model result in changes to the building’s reference temperature. The software requires the model and the billing analysis to use the same reference temperature, requiring the billing analysis to be recalculated every time the model is modified. The ‘true-up’ process is tightly integrated within the TREAT software environment, providing users with rapid feedback (amounts, % difference, etc). Contractors are trained to first match up weather-independent energy usage

bounded by field observations (lighting counts, plug densities, etc.) then to make adjustments to the weather dependent portions of the model, reducing the amount of unknown data that could result in the energy differences. A properly conducted audit along with discussions with homeowners, etc. will result in a limited number of potential model parameters with ‘unknown’ values which can be adjusted to match the energy consumption. It is here that contractors must use their own professional judgments (bounded by realistic limits set within the software) to make final adjustments to model parameters. Contractors have a secondary motivation not to skew the model input parameters beyond reasonable limits since post construction ‘test-out’ audits and measurements are randomly performed by the utility company, and actual to predicted savings are being tracked for each contractor. This ‘true-up’ provides important information about the pre-retrofit performance of a building relative to expectations and conditions the model so that subsequent estimates of savings will be more accurate.

Electricity	Model		Billing Data	
	Consumption kWh	Cost \$	Consumption kWh	Cost \$
January	546.52	55	571.82	57
February	493.63	49	516.48	52
March	546.52	55	571.82	57
April	528.89	53	553.37	55
May	546.52	55	571.82	57
June	953.91	95	838.24	84
July	1289.96	129	1156.54	116
August	1039.23	104	961.63	96
September	528.89	53	553.37	55
October	546.52	55	571.82	57
November	528.89	53	553.37	55
December	546.52	55	571.82	57
Total	8095.97	810	7992.11	799
Daily Base Load	17.63	2	18.45	2

Figure 4 Comparison of Model Monthly Predicted Energy to Normalized Billing, Before Improvements

Calculate Model	Electricity			Natural gas			Oil #2		More Fuels	
	Heating kWh/year	Cooling kWh/year	Base Load kWh/year	Heating therm/year	Natural gas therm/year	gallons/year	Base Load gallons/year	Heating Slope Bluff/day/sq.ft.	Heating Reference Temperature F.	
Calculate Billing	0.0	1,661.2	6,434.8	1,922.5	434.4	0.0	0.0	15.88	61	
True Up Help	0.0	1,439.3	6,732.7	1,988.7	531.8	NC	NC	15.65	61	
Building Model	0.0	1,661.2	6,434.8	1,922.5	434.4	0.0	0.0	15.88	61	
Billing Data	0.0	1,439.3	6,732.7	1,988.7	531.8	NC	NC	15.65	61	
Percent Difference	NA	13%	5%	3%	23%	NA	NA	1.45%	0%	

Figure 5 Feedback Pane Indicating Model ‘True-Up’ Status, Before Improvements

Step 5 – Generation of Model Improvements: Contractors next build packages of improvements within the model to estimate individual energy conservation measure (ECM) and total package (collections of ECM’s) savings. The ability to accurately model individual improvements and assemble interacted packages of measures that reflect the actual proposed improvements is *critical* at this stage. Subsequently, this savings information will be

used to track actual savings. Therefore the modeling tool needs to work with the contractor to help them propose accurate measures to the customer. Many modeling tools attempt to pre-define a set of measures that the contractor should install. However, these tools, using libraries of standardized measures, cannot take into account diverse conditions in individual buildings that may affect the installation, the non-energy based desires of customers, or limitations imposed by health and safety concerns. As a modeling tool, TREAT has a very flexible measure creation process that allows contractors to model a very wide range of measures accurately. Measures are interacted in contractor defined packages, providing an accurate estimate of the total impact at the meter. More importantly, TREAT supports user-defined measure lives, inflation rates, bank rates, and loan terms and rates for financial analysis of integrated packages. To support the contractors' sales and energy estimation process, simple paybacks, cost/benefit ratios and cash flow impacts are determined for each package.

Improvement Name	Cost \$	Annual Usage MMBtu	Annual Savings MMBtu	Annual Usage \$	Annual Savings \$	Payback Years	SIR
Air sealing with foam + benefits of dense	1000.00	251.87	11.46	3051	115	8.68	2.30
Blow 10" of cellulose in attic	702.00	256.85	6.68	3094	73	9.67	4.13
Dense pack walls	3105.00	203.78	59.55	2543	618	5.03	3.97
Double hung Energy Star Windows	10800.00	252.54	10.80	3083	83	129.72	0.15
Energy Star Refrigerator	550.00	260.41	2.92	3098	68	8.08	1.85
Indirect tank oil boiler	15000.00	253.38	9.95	3056	110	13.63	1.10
Install Condensing boiler 93% eff	6500.00	210.43	52.90	2637	529	12.29	1.63
Low Flow Fixtures	40.00	236.40	26.93	2897	269	0.15	67.30
Oil fired boiler	6000.00	223.83	39.50	2559	608	9.87	2.02
Propane-fired boiler	6000.00	211.34	52.00	3395	-228	NA	NC
Replace cold water valve	150.00	263.33	0.00	3167	0	NA	0.00
Window replacement in/til reduce	1.00	256.77	6.56	3100	66	0.02	1319.80

Figure 6 Model Predictions of Individual Improvement Savings

Package Name	Cost \$	Annual Usage MMBtu	Annual Savings MMBtu	Annual Usage \$	Annual Savings \$	Payback Years	Cash Flow \$ / year	SIR
All measures (boiler no windows)	13547.00	132.33	131.00	1778	1388	9.76	-258	2.34
All measures furnace option	19847.00	143.86	119.48	1932	1235	16.08	-1177	1.42
Boiler DHW tank + Insulation	12807.00	139.98	123.35	1894	1273	10.06	-283	2.32
Boiler w DHW sidearm	8000.00	196.77	66.56	2490	676	11.83	-296	1.53
Insulation & Air Sealing Only	4807.00	185.80	77.53	2363	803	5.99	219	3.65
Savings from Windows only	10801.00	246.01	17.32	3017	149	72.46	-1163	0.28

Figure 7 Model Predictions of Interactive Package Savings

Step 6 - Upload Post Retrofit Performance Predictions:

Once a sale is made, contractors upload their proposed package of improvements including the energy performance predictions. The building description

information and savings estimates are uploaded into the online database through an XML data transfer. This creates a large and valuable database of pre- and post-retrofit building characteristics that is also linked to actual energy usage information. The energy retrofit program has the secondary effect of also becoming a building characterization study, with the energy audit tool being the data collection instrument.

Improvement Detail: Blow 10" of cellulose in attic

Work_Tracking > Work_Tracking_Detail > Improvement_Detail

Surface Insulation: Blow 10" of cellulose in attic

Prev | 1 of 10 | Go | Next

Cost of improvement: \$702.00 (1080 sq.ft.) **Potential rebate amount:** \$702.00 (600 sq.ft.)
Customer cost savings: \$66.00/year **Unit cost total:** \$502.77 (600 items)
Improvement SIR: 2.17 **Other funding amount:** \$0.00
Improvement SIR life: 40.0 years **Utility voucher credit:** \$0.00
Override: Include
Approval: Not reviewed

Customer co-pay: \$0.00 **Calculated TRC:** \$1,048.96 (B/C: 1.49)
Customer payback: 0.0 years **Qualifying rebate amount:** \$702.00

Work Scope

###h11b:600###
Comply with general conditions. Perform blower door test prior to insulating. Record results and date. Perform infrared scan if indoor/outdoor temperature difference is a minimum 15 F, prior to insulating. Inspect walls for damage, including moisture, prior to insulating. If damage or moisture is found, notify owner before proceeding. Inspect walls for live wiring. If found, notify owner before proceeding.

Fuel Type: Electricity **Annual Savings:** 61.00 kWh (0.21 MBtu)
Fuel Type: Natural gas **Annual Savings:** 57.00 Therm (5.68 MBtu)
Fuel Type: Oil #2 **Annual Savings:** 0.00 Gallon (0.00 MBtu)
Fuel Type: Propane **Annual Savings:** 0.00 Gallon (0.00 MBtu)

Applied Rebate Measure Type
Heating and Cooling: Apply attic insulation

Notes

Add

Unit Costs Group	Description	Units	Total price
Cellulose	R12, Attic flat - floored	600 Square Foot	\$456.00

Figure 8 Interface for Upload of Post-Retrofit Savings Predictions

Step 7 - Upload of Post Retrofit Usage Data:

The online database is able to continue to collect energy usage information about the customer from the utility. Information can also be collected directly from customers and fuel suppliers, prompting them with e-mail notifiers to go on-line and enter fuel consumption and delivery data.

Step 8 - Download of Actual Post-retrofit Energy Data:

The actual energy usage information can be downloaded from the program database into the contractor's client based modeling software, allowing the contractor to provide feedback to their customer on the actual energy performance of the building in question. This further positions the contractor as an energy services provider, and helps build the foundation of a long-term energy management relationship with the customer with continuous improvement principles in mind. This step also includes the download of actual weather information (average daily temperatures) for the billing cycle into the client side energy simulation software tool for post construction billing analysis.

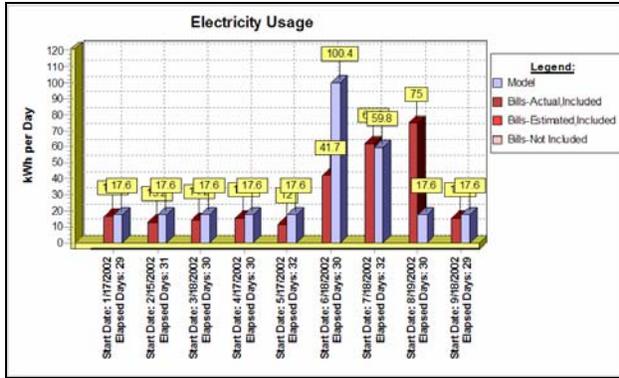


Figure 9 Weather Normalized Comparisons of Estimated (Model Predicted) to Actual Energy Usage

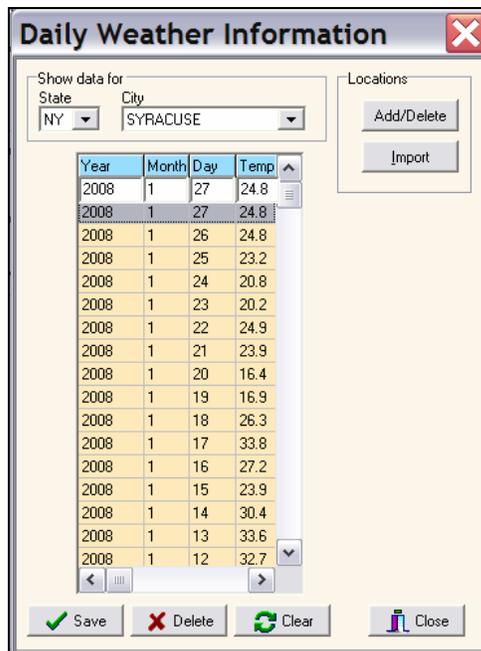


Figure 10- Interface for Import of Actual Weather Data for Weather Normalization

Step 9 - Track Comparisons Over Time Using TQM

The comparisons (actual vs. predicted, weather normalized) are analyzed with trends, and the range of variation and outliers identified. These trends are studied for links to other factors. This comparison takes place using the on-line database of information including predicted baseloads, slopes and reference temperatures vs. actual slopes, baseloads and reference temperatures. The design of the database is such that individual contractors have access limited to their individual data, individual utilities have access limited to their individual data, etc.

LESSONS LEARNED

Program experiences have revealed that the Energy Modeling component is often described as the ‘least favorite’ task for participating residential retrofit contractors. Why? Many contractors despise energy modeling because they see it as adding additional workflow to their existing business model, with little understanding of the value add potential. Without proper training on using the software tool, many contractors rightfully view the modeling and analysis component of programs as a barrier and additional ‘cost of doing business’. Successful retrofit programs must commit to providing software training to help overcome these deeply ingrained perceptions. Software training should be focused on helping contractors become better modelers, balancing detail required for modeling against expected savings, and always mindful of the balance between efforts expended vs. value gained. Parallel investments in building science training for contractors combined with modeling ‘know how’ can lead to analysis investment decisions that are not always intuitive. Without training support this can lead contractors to mistrust the software output.

Additional training for contractors focusing on understanding the ‘ever shrinking pie of waste’ associated with interactive improvement-driven modeling is also strongly recommended for programs. Although more accurate, the quantitative thought process associated with interactive savings differs from the simpler and more traditional ‘deemed savings’ approach that many contractors are used to working within.

FUTURE WORK

Future plans include extending the simulation capabilities to track carbon and source energy savings, along with automating the investment prioritization of solar/renewable measures. All too often renewable ECM’s such as solar hot water and/or photovoltaics are recommended to homeowners cart blank without a rigorous comparison against less sexy or more traditional energy efficiency improvements. Providing homeowners with easy to understand comparisons of measures against one another can help guide wise investment decisions.

CONCLUSION

A nine step process focusing on TQM principles has been developed to support utility and non-utility

managed residential energy retrofit programs. The process relies heavily on the use of whole building energy simulation both to predict savings and increase contractor knowledge. Over 20,000 energy models have been completed using the process. In addition to the New Hampshire Utilities program, several residential energy efficiency initiatives have adopted the process within their programs.

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