Welcome to the Machine: Integrating Modeling, Benchmarking and Program Savings Evaluation into a Program TQM Process

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ABSTRACT

The paper examines how the process of producing energy savings in energy efficiency programs can be compared to the Total Quality Management approach to process control for an industrial process producing manufactured products. The comparison indicates how a process of continuous feedback and process improvement can be appropriately designed for energy efficiency programs. A combination of software tools was developed to support this ideal process. The system includes building modeling tools, benchmarking tools and online databases, with information flowing between the different components. Appropriate feedback from the system is available to a variety of types of users including program managers, contractors and customers. The system is being implemented in residential energy efficiency programs in New Hampshire, New York and California. The elements of the system are described and the future impacts of this approach are forecasted.

Introduction

Historically, impact evaluation efforts have a delayed effect on the program operations of residential building retrofit initiatives. Timely information on the energy impact of retrofit activities has been difficult and expensive to obtain. As a result of this delay, measurements of energy saving success have focused on overall program impacts, with feedback to the on-the-ground retrofitting process occurring primarily at the program level. This program level information has not provided the kind of feedback at the individual building level that would assist the installing contractors in improving their energy analysis and installation process.

The increased use of building modeling software and performance testing tools, such as blower doors, have helped to reduce the resulting savings guesswork, but these tools do not measure actual success at the meter. Unaddressed problems in buildings can easily interfere with the ability of savings measures to affect performance at the meter and installation quality can also vary across contractors and crews.

Analyzing the retrofit program design in the context of a Total Quality Management (TQM) process offers the opportunity to create a continuous improvement process designed to enhance the savings impact of building retrofits. An ideal control variable for a TQM process would indicate statistical control over the savings creation process. This ideal control variable is the difference between the modeled expected savings and the actual savings. This delta value captures both the variability in the ability to accurately estimate savings and the variability introduced by the quality of the installation activities necessary to actually save the energy.

A set of software tools was developed in order to make the tracking of this control variable cost effective, even in buildings as small as single family buildings. These tools collect billing information from a variety of sources, including web based user input and utility databases, into online program databases. This accumulated fuel data, when combined with basic building and customer characteristics, facilitates a benchmarking process that can target buildings for various levels of investment, and provide feedback on overall program success.

At the individual residential building level, the tools include building energy modeling tools that compare a building's weather normalized fuel data, obtained from the central online database, with the results of hourly energy modeling software. Comparisons can be made between the model of the existing building and pre-retrofit fuel data, for model true up, and eventually between the predicted model and the actual savings, allowing tracking of the TQM control variable. Because billing data is more easily obtained, shorter time periods of analysis and more rapid feedback are feasible.

This new functionality has potential impacts on program design strategies and even business process for energy performance contractors. Integrating data flows and improving the speed and quality of feedback can enhance program savings, reduce the cost of savings evaluation and provide program managers and evaluators with a detailed view of who is saving energy and how. Investments in program installation dollars and training dollars can also be better targeted. From the market transformation perspective, the development of a more automated and quality controlled process for the creation of energy savings is a long term market effect. This paper offers a view of the data flows involved and shows how information from this process can be used to enhance both the depth and quality of program operations feedback while at the same time cost effectively supporting the evaluation process.

This TQM software approach is being implemented in a range of utility and non-utility funded programs in New York, New Hampshire and California, with early benchmarking taking place and initial building models currently being entered. Short term post retrofit data and feedback on contractor by contractor savings performance will be available in summer 2003 in at least one of the projects.

The Fastest Feedback Wins

Fast feedback on operations is increasingly becoming a requirement for survival and success in the increasingly competitive business world. Led by the success of companies like WalMart, more and more companies are looking for ways to reduce the time it takes them to get and use information on their sales and profits, in effect speeding up their rate of evolution. These companies use feedback on performance metrics, such as sales income per square foot, to make decisions, even at the regional and local level on issues such as stocking and product promotion. For example, Disney engineers, when designing new products for sale in the Disney stores, are competing against the income intensity per square foot of the plush toys.[1] The projected income intensity has become a part of the toy design process.

Unfortunately, the energy industry has been lagging far behind in its ability to provide feedback. Homeowners, businesses and energy programs alike have all had extremely limited, slow and expensive to obtain (typically due to labor costs) access to feedback on energy performance. More recently utilities and third parties have begun to offer information services to their large clients, using systems such as advanced meters and Internet access to billing data. And there are pilot projects underway that are bringing these services to residential customers. But residential energy programs, trying to cost effectively serve a large number of small customers, have not had access to such rich sources of rapid feedback.

Energy programs unfortunately have typically not been as successful in enhancing their quality and speed of feedback, usually due to cost effectiveness restraints and an increased demand for greater levels of program impact to address growth in electricity demand. Many programs still rely primarily on measure by measure estimates of savings based on engineering calculations and sometimes including

[1] Private conversation, Elizabeth Woods, former Disney Imagineering design engineer, Ithaca, NY, 2003.

advanced performance measurements such as blower doors. This absence of good feedback has left the programs, their contractors and even their customers without good information on the actual performance of the retrofits performed, therefore crippling their individual and combined ability to improve the savings production process.

Collecting information on energy usage in large numbers of installations and making adjustments, or applying "realization rates" based on fuel bill evaluation, attempts to adjust savings projections and account for factors such as installation quality and measure interaction. But this information often shows up years after the fact, applies towards current efforts the results of the impacts that may be based on standards of practice no longer in use, and shows up as feedback to all the installing contractors most often as reductions in incentive payments, hardly a message to perform at a higher standard of quality.

It's the Meter That Matters

Just as the measure of performance for the retail giants is the income per square foot, there is an ideal measure of performance for energy programs. In the case of both the customer and the program funding source, the ultimate measure of truth of performance is the customer's energy meter. Because of difficulties associated with obtaining and interpreting meter data, there have been a variety of systems developed to try to provide cost effectiveness performance data to programs, in lieu of immediate access to actual energy use information.

Performance testing techniques, such as blower doors, duct blasters and even pressure diagnostics, have helped programs more directly measure their impact at the meter. Instead of measuring how much foam was installed to help seal leaks, many programs now measure the size of the hole that the foam sealed, using a blower door. But it is important to remember that the sealed hole is not directly connected to the meter and there are many intervening systems between the hole and the meter. For example, the location of a hole has a very significant impact on the amount of air leaking across that hole. Holes in the attic will have the most pressure difference across the hole and therefore will leak more than a hole located towards the middle of the building, at or near the neutral pressure plane. Blower doors only measure the total size of the holes, not their location in the building. But crews measuring their success, or even being paid for success based on blower door measurements, do not have an incentive to seal the worst performing holes or any information on the actual at-the-meter performance of their work.

The building science world of house-as-a-system is full of such examples, where something comes between the measurement of the physical installation and its actual performance as measured at the meter, including the performance of the customer.

When evaluated in the context of Quality Management, the use of measure by measure estimates of savings based on indirect measurements tends to push programs towards simple to install measures that can be easily put into buildings by existing contractors and measured with basic physical parameters. And, if the program is subject to long term evaluation, these estimates of savings are eventually adjusted by measurement of actual energy use information from large numbers of program participants. This adjustment puts the contractor who spends extra time in order to install things correctly at financial disadvantage to the contractor who simply increases work output without regard to enhancing quality, and puts in as many widgets as possible. The only check on this trend at the contractor level is the use of specifications and random inspections. But this only secures the minimum performance and does not offer incentives to identify and take action on any savings opportunities outside the specification.

In addition, simply maximizing energy savings is not always in the interest of the customer. For example, the installation of bathroom ventilation fans may be an important way to avoid creating mold when sealing and insulating a house. Unfortunately, this very necessary improvement increases energy use and would not pass an individual measure based cost effectiveness screen. Rewarding maximum savings could also result in contractors, and perhaps programs, avoiding such health and safety measures.

So What Does Timely Feedback Look Like?

The quality assurance for an industrial process, such as the business of creating energy savings, is the ongoing measurement of the output of the process and the comparison of the results of these measurements of control variables to their expected or target values. According to principles of Total Quality Management, information on improving the process comes from examining the variance between the target performance and the actual performance. In the case of a machined part, the routine measurement of the actual part coming off the production line compared to the design provides information on the range of performance variance and the trends of variance. These trends are artifacts of the industrial process and experimentation and analysis of these trends reveals considerable information on how to better control the process. This continuous feedback loop and adjustment of the manufacturing process in Total Quality Management is called "Plan, Do, Study, Act".[2]

The houses coming off the production line of our energy programs are the same as the machinery parts coming off the production line of the manufacturing plant. We predict the performance of each and we try to invest in measuring the actual performance of each so we can improve the program's ability to produce savings while increasing the rate of production and reducing the cost of production.

Even though the desired output from this process is energy savings, simply maximizing the energy savings from each job does not provide information on the quality of the process or the information necessary to improve the process. In residential energy efficiency programs, a particular house might have a greater or lesser potential for energy savings, depending greatly on its pre-existing conditions. Accordingly, the actual level of savings on a house by house basis in retrofit programs may vary dramatically. Simple measures of the absolute value of actual savings do not indicate that there is control over the process of producing savings. And a broad statistical analysis of the relative impact of particular measures across many participants does not indicate if that measure is being installed to its highest cost effective potential.

The barriers to implementing a TQM approach that cost effectively delivers timely feedback on actual at the meter energy savings to multiple levels of the energy efficiency programs have been:

- The modeling ability and trained contractor infrastructure necessary to set increasingly accurate performance targets for the houses being treated
- The ability to cost effectively obtain multiple instances of feedback on a variety of fuel uses from those houses
- The ability to link the feedback information with the performance predictions

[2] Considerable information on the Deming approach to Total Quality Management can be found online. The Deming Electronic Network Website (http://deming.eng.clemson.edu/pub/den/) maintained by Clemson University is an excellent resource.

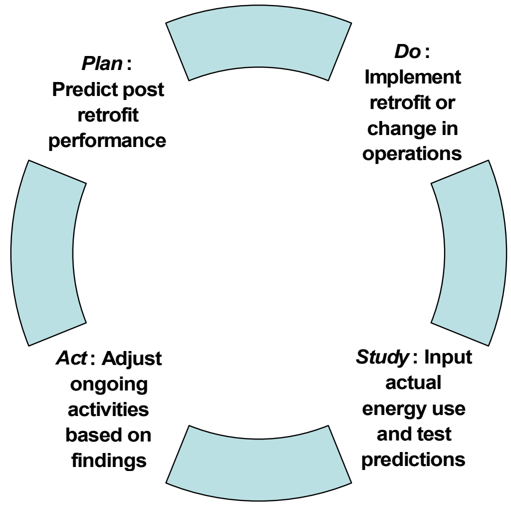

Figure 1. Conceptual implementation of the Total Quality Management cycle into energy efficiency programs.

Modeling as a Barrier

Whole building modeling tools offer the opportunity to measure savings interactively and therefore with more accuracy than with individual measure calculations. The primary use for energy modeling tools in the residential existing building context is in the retrofit decision support process, such as at the kitchen table, where the contractor is sitting down with the customer to sell a job, or when the weatherization agency or utility contractor is making a decision about the design of a cost effective package of measures for a client. The comparison necessary is between a house's actual energy use after retrofit and the house's proposed energy use after retrofit. If the house's actual performance characteristics are a part of the energy model, both the pre and post retrofit energy models can reflect the actual occupant dependent values from before and after retrofit.[3] Modeling provides the target performance information that is necessary for the creating the TQM cycle of continuous improvement.

The difference between projected performance after retrofit and actual performance after retrofit contains information about the actual performance of the retrofits and the accuracy of the modeling process. So adjustments to either will have an impact on the information coming back through the feedback process.

Despite the advantages of modeling, the widespread use of modeling has also been obstructed by the need for contractor training and the cost of the additional time it takes to construct the model. The benefits of combining modeling and a TQM approach are just beginning to be fully explored. The ongoing development of software, the increased speed and capacity of computers and the development of online applications has begun to create new opportunities to apply a TQM approach to energy efficiency programs. And modeling tools have begun to expand beyond modeling to provide other benefits to contractors and programs, such as energy ratings, load calculations, and customized sales presentation materials. These modeling tools are being repositioned with the contractors as support for the business process and not just something they have to do to participate in the program.

[3] Whole building models can also be used to perform energy ratings, scoring a house's standardized projected energy performance, and creating longer term market impact that helps to capture the value of energy improvements in the real estate transaction.

What about the impact occupant behavior has on post retrofit performance? Occupant behavior is a factor frequently used to discount the variability between savings estimates and actual performance of models. Occupants change behaviors, turn up thermostats, leave open windows and do all sorts of things in their search for creature comforts. But we have two things in our favor. First, statistical process control helps us separate out randomly performing variables from variables that are, at least in part, consistently performing. So a crew that is consistently doing a poor job of air sealing attics will show consistency in error in a way that the random customer behavior change will not.

Second, as part of the program process, we are looking to exert an increased level of control over buildings. Not as an act of aggression, but as a way to improve the living environment in the buildings. In whole house programs, such as Home Performance with Energy Star, contractors make performance measurements and use this information to try to take control of the flows of air, heat and moisture through the building. It is the uncontrolled flows of air, heat and moisture that cause problems with comfort, health and safety, building durability and energy efficiency. So when contractors take control of these flows, they generally reduce the need of the occupant to try to overcome performance problems. Measurement of these flows allows the contractor to start to develop control over them.

As an added benefit, buildings that are under control, with reduced air leakage, well insulated surfaces and controlled levels of humidity for example, are actually less responsive to changes in thermostat settings, such as temperature setback. A leaky building will save much more from a temperature setback than a tight building. The rapid heat loss of the leaky building reduces the temperature difference with the outside faster than the slower heat loss of a tight building. So changes in occupant thermostat behavior have less impact in a tighter retrofitted building. Adding insulation has the same effect.

On top of these factors, if the changes in occupant related characteristics are known, changes such as appliances recorded as part of an email communication with the customer, these changes are then reflected in the calculation of the post retrofit energy model. The retrofit process does not eliminate the variation due to occupant behavior, but it should reduce it.

The use of modeling tools also provides training benefits to contractors. In our experience, contractors that have used modeling tools develop a refined sense of what cost effectively saves energy. In the absence of modeling information, contractors tend to rely on semi-mythical perceptions of cost effectiveness. After modeling enough buildings, they begin to better understand the process of saving energy. Real post retrofit energy usage information would further enhance this learning process.

Access to Data and Data Linkages as Barriers

A number of factors have made it difficult to access information from the process. Billing data has been difficult to obtain, is typically obtained long after the retrofit process, and has required sophisticated software to perform weather normalization. Multiple fuels, especially the use of oil, wood or propane, has made data collection even more complicated. Modeling and building performance data has been stored on individual computers in individual files. Accumulating this data into database form for analysis has been costly.

The increased linkage of contractors, customers and energy providers to the Internet has created an opportunity to use online databases as a point for the accumulation and linkage of a variety of sources of data, including fuel bills, modeling information, building and occupant demographics, quality assurance information, etc. The development of common data transfer protocols, such as XML, has made it easier to pass structured information between applications and computing environments.

Sample TQM Process

Implementing the TQM approach requires a number of changes to process and the development of the software and the training to support process. The following sample TQM process was developed by Performance Systems Development, Inc. (PSD) for the utility funded programs in New Hampshire based on the Plan, Do, Study, Act cycle.

1. Billing data fed into online database - The online database system used in New Hampshire is called OTTER, the Online Tool for Tracking Energy Retrofits. In New Hampshire the utilities have participated in the development of a connection between the utility fuel data for program participants and the online program data base. The OTTER database is structured to prevent participating utilities from seeing the customers of other participating utilities. An interface for customers and outside fuel suppliers to enter data for a specific customer is also under development. In the future, connections to advanced interval metering databases may supply even faster access to billing data.
2. Billing data downloaded – Contractors access the program database web site to download energy use data. Ideally, the download of billing data occurs before the contractor visits the building. This provides the contractor with benchmarking information about the building, thereby enhancing their inspection process.
3. Model creation – Contractors visit the job site, collect data and then enter data into the building modeling program. The contractors in New Hampshire are using the TREAT modeling software, a joint venture between PSD and Taitem Engineering. TREAT's development has been supported by the New York State Energy Research and Development Authority and the National Renewable Energy Lab. 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 creates presentation reports for customers that support the whole-house approach.
4. Validate the building model – Energy usage information from the billing data is used to true up and validate the building model. This true up provides information about the pre-retrofit performance of the building relative to expectations and conditions the model so that subsequent estimates of savings are more accurate.
5. Estimate savings – Contractors build packages of improvements and run the model to estimate per measure and package savings. The ability to accurately model individual improvements and assemble interacted packages of measures that reflect the actual proposed improvements is very important 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 him/her propose accurate measures to the customer. Many modeling tools attempt to define the measures that the contractor should install. However, these tools, using libraries of standardized measures, cannot take into account the diverse conditions in individual buildings that may affect the installation, the non-energy based desires of customers, or the limitations imposed by health and safety. 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. In addition to supporting the contractors' sales and energy estimation process, TREAT also allows the contractor to perform an energy rating without entering additional information in a different program.
6. Upload post retrofit performance prediction to online database – Contractors upload their proposed package of improvements including performance prediction. 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 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.

7. Upload post retrofit usage data – The online database continues to collect energy usage information about the customer from the utility. Information can also be collected from customers and fuel suppliers, prompting them with email messages to go online and enter data.
8. Download actual post retrofit data into post retrofit model and compare actual model to actual post retrofit billing data – The usage information can be downloaded into the contractor's modeling software, allowing the contractor to provide feedback to their customer on his/her actual performance. This further positions the contractor as an energy services provider, with a long-term energy management relationship with the customer.
9. Track comparisons over time using TQM statistical trend analysis – The comparisons 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 online database of information. Because of the design of the database, individual contractors have access limited to their individual data, individual utilities have access limited to their individual data, etc.

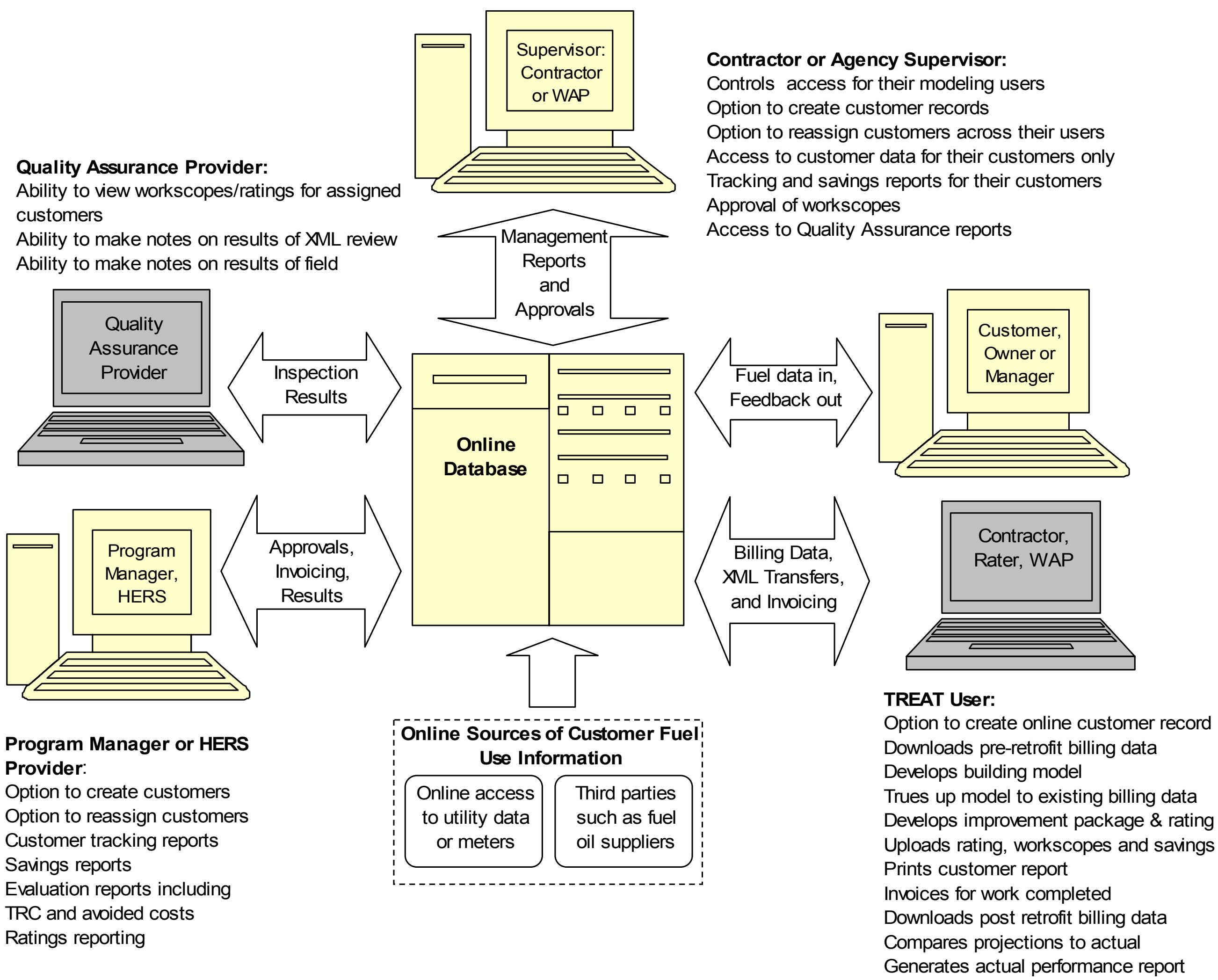

Figure 2. Relationships of various users to the central online database system.

This system meets the feedback requirements of the defined TQM approach. The system reduces the cost and increases the speed of collecting and providing energy usage information to the contractor and program manager.

Integrating TQM into an Energy Program

This type of approach provides significant opportunities for the participating contractors and utilities. But as with any changes, there are issues brought up by the changes that must be addressed. The implementation of the system with the New Hampshire utilities has provided feedback on both opportunities and issues.

The New Hampshire residential efficiency program is looking to use the feedback from TREAT and OTTER to improve the program's performance. This can be done by developing best practices from harvesting salient facts data about how to install measures, contractor's performance, optimizing implementation policy by comparing outcomes across various contractors and across various utilities. The jurisdictional utilities in the State of New Hampshire are mandated to offer a basic set of products and services across all utility service areas.

One of the biggest issues has been the shift from an evaluation process based on measure-by-measure calculations to the whole-house calculations that result from building modeling. For example, total resource cost calculations need to be re-examined since in previous programs that screened measures using a measure by measure calculation, the realization rate was used to help capture interactions between measures. The measure interactions performed by the building modeling tool now include these effects that were captured by the application of the realization rates. Until this is resolved, the effect is that measures are now being penalized twice for interactions, once in the modeling tool and a second time in the realization rate. In addition, individual measure calculations of savings tend to focus on single end uses. The result is a tendency to neglect cooling impacts that may accrue from envelope measures such as windows and insulation. The combined impact is a temporary reduction in the ability to get certain measures approved, at least until the realization rates and the standardized conversion of Btu savings into kW and kWh impacts is re-examined.

The New Hampshire programs anticipate developing a more robust energy efficiency delivery infrastructure that will contribute to the state's market transformation. This market transformation will have both participants and non-participants recognizing the value of energy efficiency so that purchasing patterns are permanently changed. Once developed, this infrastructure will also provide ratings for new construction. For example, selling a home with a higher energy rating will be easier than selling a home with a lower energy rating.

Ratepayer funded, legislatively mandated energy-efficiency programs may be ultimately be replaced by efficiency programs that are profit centers. New Hampshire currently has a window of opportunity for infrastructure development due to the ratepayer funded program. Recognizing that ratepayer funding won't be around forever, New Hampshire's utilities are working to have this market transformation in place prior to the sun-setting of the System Benefits Charge. By working now to increase the demand for higher energy efficiency, and at the same time strengthen the delivery infrastructure, the utilities hope to create a long term opportunity to harvest the savings embedded in the existing housing stock. Using a unified tool that can handle the complete spectrum of program activity from audit through to invoicing as well as provide support for a contractor's future business process outside of program requirements is essential for the long-term adoption of business practices that focus on harvesting energy efficiency.

In addition, the web based reporting system has proven itself to be supple and user friendly. Reviewing work submitted for approval and making the necessary adjustment real-time expedites job completion and helps to improve cash flow for contractors.

Looking Ahead

The goal of the system has been to enhance feedback on results. The system has increased the availability and speed of feedback to program managers, contractors and in the near future, directly to customers. Once the feedback systems are in place, the monitoring of this feedback becomes a joint effort between the contractors, program manager and system designer.

There are a number of ways the information from this system can be used as the results database expands. For example, the system could be used to target training efforts towards contractors who have poor performance, or who might be neglecting the installation of certain types of measures, such as lighting and appliances. In another case, the statistical flow of information might show auditors who are not performing a complete audit on the buildings. Or, performance on estimated savings compared to actual savings might be used as a financial incentive. All of these efforts are secondary but contributing to the primary effort, which is to evaluate the ability of the program to cost effectively create energy savings. Contractors might use the system to experiment with the impact of different sales approaches on their job size and profitability.

Additional opportunities exist to enhance the content and speed of feedback, particularly to customers and contractors. Advanced interval metering, with daily or weekly upload of information to web based databases, could be a source of very rapid feedback information to contractors and customers. At the same time, the potential impact of bringing customers into the feedback cycle is just beginning to be explored. This continuous evolution towards better and better systems for saving energy is the purpose of the feedback system. Intentional and unintentional experiments with changes to the process will continue to provide us with considerable information to enhance savings performance.