TECHNICAL AND PRACTICAL PROBLEMS OF DEVELOPING AND IMPLEMENTING AN IMPROVED RETROFIT AUDIT

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ABSTRACT

Oak Ridge National Laboratory developed a retrofit audit suitable for use in the Low-Income Weatherization Assistance Program. The audit selects the most cost-effective retrofits from among about a dozen building shell and heating system retrofits. The audit was field tested this past winter on 35 single-family houses in Wisconsin. This paper describes the important technical problems encountered in developing and implementing an accurate audit.

Two types of technical problems were observed. The first type is that the best models available for determining the energy savings of some retrofits produce unreliable results. The second technical problem was related to the audit data; some of the data needed to make accurate energy savings estimates were difficult to obtain or were dependent on auditor judgement. The practical problems included policy or equity questions and difficulties encountered in implementing the audit.

This paper discusses the various types of research needed. The discussion also serves to focus attention on the issues, which, it is hoped, will stimulate development of ideas for dealing with these technical and practical problems.

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INTRODUCTION

Oak Ridge National Laboratory and Wisconsin Energy Conservation Corporation have developed and field tested a retrofit audit[1] for the U.S. Department of Energy's (DOE's) Office of Buildings and Community Systems. This audit was used to select the most cost-effective combination of building shell and heating system retrofits for 35 individual houses in a field test performed in Wisconsin during the winter of 1985-86. The combined retrofit field test was performed in the context of the Low-Income Weatherization Assistance Program (WAP), which has recently begun to include heating system retrofits.

Millions of dollars are spent on energy-conserving retrofits each year in single-family homes. The WAP is probably the largest single retrofit program in the United States. Until recently, states and WAP operators used simple priority lists for selecting from a small list of allowed retrofits. The list of allowed retrofits was recently enlarged and now includes heating system retrofits as well as building shell retrofits. The priority list approach is simple and easy to implement but has inherent limitations that often result in the selection of less-than-optimum retrofits.

The problem with priority lists is that they cannot adequately account for the range of characteristics found in individual houses. Priority lists are generally developed for protypical house designs, but retrofit energy savings are quite sensitive to small differences in building characteristics. For instance, adding R-19 ceiling insulation to a house that already has R-5 insulation will save 50% more energy than adding the same amount of insulation to an identical house with R-7 ceiling insulation. The problem for the home owner and for WAP is essentially the same; if the best retrofits for each particular house are not installed, then less energy savings for the investment will be realized. A retrofit audit is a tool for evaluating a number of retrofits on a house-by-house basis so that the best retrofits can be selected.

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The purpose of this paper is to describe the more important technical and practical problems that were encountered in developing and implementing the audit. This paper consists of three main sections and a summary. The first section describes the characteristics of retrofit audits and the advantages of audits over priority lists. The second section discusses technical problems encountered in developing and implementing the audit. These technical problems include inadequate theoretical models for some retrofits and difficulties in obtaining certain kinds of data. The third section discusses practical considerations in implementing an audit.

THE AUDIT

A retrofit audit is a tool for estimating the costs and energy savings of retrofits. At the minimum, it involves collection of selected data on a house, use of procedures for estimating retrofit costs and energy savings, and calculation of some sort of economic characterization (e.g., simple payback period) of the retrofits. With an economic characterization of each retrofit, the most economically attractive retrofits can be selected.

The audit developed for the Wisconsin tests was performed in several steps: (1) The auditor visited the house to collect the data needed to estimate retrofit energy and cost savings. The data included characteristics of the house and its heating system. (2) The weatherization service provider gathered the previous year's heating fuel billing history. (3) The data were used in audit calculations to estimate the energy savings and the discounted benefit-to-cost (B/C) ratio of each individual retrofit. (4) The retrofits were ranked by B/C ratio. (5) Interactions among retrofits were evaluated and used to recalculate B/C ratios and to adjust retrofit rankings. (6) Retrofits with B/C ratios above a specified minimum value were performed. Except for the first step, all steps can be performed by office workers. A field crew, which generally does not include the auditor, performs the retrofits.

The audit is described in detail in ref. 1, except for the handling of infiltration control work. As part of step 1 above, the auditor used a blower door to measure the infiltration rate of the house at 50-Pa depressurization. The measurement was used in making energy savings estimates for infiltration control work (step 3). In addition, the auditor's observations were passed on to the field crew to guide their infiltration control work. The details of this method are described in ref. 2.

Presently, weatherization providers in most states use priority lists to select the retrofits to be installed in a house. A priority list is a sequence of retrofits that are to be performed on each house in order. A typical priority list might be: (1) caulk and weatherstrip to reduce infiltration, (2) insulate ceiling, (3) insulate water heater, and (4) install storm windows. Some retrofits are not applicable to a particular house (e.g., a house that already has storm windows); so not all retrofits are done in every case.

Some states have more sophisticated priority lists. Wisconsin, for example, has an 11-step priority list, with some retrofits being invoked only if certain conditions exist in the house. For example, ceiling insulation is the second retrofit on Wisconsin's priority list, but it is applicable only to houses with less than R-4 ceiling insulation. Ceiling insulation is listed again as retrofit 7 for houses with less than R-11 ceiling insulation and again as retrofit 11 for houses that have between R-11 and R-19 ceiling insulation. Few houses will get near retrofit 11 before all budgeted monies have been spent.

Although priority lists are clearly less complicated to implement than audits, audits develop retrofit priorities that are more accurate and flexible. The better accuracy of audits occurs mainly because the retrofit energy savings estimates are customized for the house to which they are applied. The example described in the Introduction, in which a small difference in preretrofit insulation makes a large difference in potential energy savings, is common to many retrofits. Occupant behavior and heating system efficiency also affect potential energy savings. Finally, when both heating system and building shell retrofits are considered for the same house, there are strong interactions among retrofits.

A priority list is based on the same kinds of energy savings estimates as are made in an audit. The difference is that a priority list must be based on a typical or average house. Since very few houses will closely match the average house, seldom will a list of optimum retrofits for a particular house match the priority list. However, there are problems that reduce the accuracy of the energy savings estimates made in audits. The priority list approach is subject to the identical problems, but these problems are generally not given much attention because the errors introduced by treating all houses the same are much larger.

The audit developed and tested for this study produces estimates of B/C ratio for each retrofit. This information can be used to guide decisions on how many retrofits to perform on each house. For instance, a B/C ratio less than one means that the present value of the retrofit is less than the cost of the retrofit. Installing such a retrofit seldom makes sense.

The recommended retrofit expenditures ranged from zero to >$2500 per house when our audit was applied to 35 houses in Wisconsin. This variation resulted from the variability found in low-income homes. In contrast, a priority list provides no real guidance on when to quit doing retrofits on a particular house until one either reaches the end of the list or runs out of money.

An audit also requires and provides information that is useful for managing a retrofit program. The costs of retrofits are needed to estimate retrofit B/C ratios. Comparison of actual retrofit costs with expected retrofit costs can be used to improve the accuracy of B/C ratio estimates or to identify retrofit providers who are particularly efficient or inefficient at performing certain retrofits. In addition, keeping track of retrofit and repair costs leads naturally to improved estimates of management and overhead costs. Finally, since an audit will provide energy savings estimates, program performance can be monitored, in part, by the audit results.

TECHNICAL PROBLEMS

All the advantages discussed above argue for the use of retrofit audits; however, substantial technical improvements could be made in the available audits. The technical improvements fall into two categories: improved retrofit energy savings models and improved ways to get needed data. These two approaches to improving audit accuracy are discussed below.

Retrofit Energy Savings Models

Studies of the WAP have revealed average energy savings in the range of 6 to 14%.[3-5] These studies report very large variations in savings across households. Hirst et al.[6] report little correlation between expected and actual energy savings in a study of the Bonneville Power Administration's Residential Weatherization Program. Various explanations of these results have been formulated. These include: (1) the occupants opted for increased comfort instead of lower fuel bills by raising the thermostat setting after the retrofits, (2) the retrofits were not installed properly, and (3) the predictions were not accurate. The first two explanations are credible, but experience in developing the audit shows that the last explanation is at least part of the problem.

Building shell retrofit energy savings estimates are generally made as is done by the Residential Conservation Service (RCS) Model Audit.[7]

$$\text{Energy savings} = \frac{\text{HDD} \times 24 \times \Delta\text{UA}}{\text{SE}} \; (\text{C}) \; , \qquad (1)$$

where HDD is the average number of base 65°F heating degree-days, ΔUA is the retrofit-induced reduction in the heat loss rate of the house (Btu/h-ft^2), SE is the seasonal fuel utilization efficiency of the heating system, and C is an empirical correction factor to account for "errors inherent in the established 18.3°C (65°F) based method."[8]

Equation 1 shows that there are four components (HDD, ΔUA, C, and SE) in an energy savings estimate. Each of these parameters offers opportunities for improving audit accuracy. The correction factor can make a profound difference in savings estimates. ASHRAE recommends values of C between 0.8 and 0.6,[8] but values between 0.2 and 1.6 have been inferred from measurements on individual houses.[9] Unfortunately, C is not a physical quantity; it cannot be measured or estimated in the course of an audit.

The best prospect for overcoming shortcomings of the traditional heating degree-day method is the variable base degree-day (VBDD) method.[8] In terms of the VBDD method, Eq. 1 would be written as

$$\text{Energy savings} = \frac{24 \times \Delta UA \times DD_{Tb}}{SE}, \qquad (2)$$

where DD_{Tb} is the average number of base Tb heating degree-days. The principal impediment to use of the VBDD method in retrofit audits is that there is presently no method available for estimating the base temperature, Tb, of a house within the constraints of a practical retrofit audit. ASHRAE describes a method for estimating Tb for a house,[8] but it is too complex to be used in an audit. Additional work to develop and test methods for using the VBDD method in retrofit audits holds promise in improving retrofit savings prediction accuracy.

Although the VBDD method is not presently available, there is room for improvement in estimating SE and ΔUA. The intention of the audit we developed was to make the best possible house-specific retrofit savings estimates. To this end, we considered methods for estimating SE for individual houses from measurements of gas- and oil-heating system steady-state efficiency (SSE). It was soon apparent that there was no sensible, defensible method of doing this.

Further reflection on the problem showed that SSE was more appropriate in Eq. 1 than SE. The presence of SE in Eq. 1 is an artifact of its derivation from the ASHRAE heating degree-day method. This method uses a parameter, k (equivalent to SE of Eq. 1), which is "a correction factor which includes the effects of rated full load efficiency, part load performance, oversizing and energy conservation devices."[8] A parameter such as SE (or k) is needed to estimate seasonal heating fuel use, but it is inappropriate when estimating retrofit energy savings.

A retrofit that reduces the heat loss rate of a house, such as adding storm windows, will save energy by reducing the amount of heat the heating system must add to the house. The relationship between the heat added to the house and the fuel consumed while heating the house is closely described by SSE. Another way to look at it is that the SE is the heat needed to replace the heat lost through the building shell divided by the fuel needed to produce that heat plus the fuel consumption of the heating system while not providing heat (e.g., the pilot) and the fuel needed to replace heat loss <u>induced</u> by the heating system.

Only that part of the fuel consumption needed to replace heat lost through the shell will be reduced by insulating a house. The relation between that heat loss and the required fuel consumption is an efficiency that is slightly less than SSE. Thus, using SSE in Eq. 1 will give more accurate shell retrofit savings estimates than using SE. SSE was used in the audit we field tested in Wisconsin. (It bears noting that SSE is always larger than SE, so energy savings estimated using SSE will always be smaller than those estimated using SE.)

The final parameter in Eq. 1 is ΔUA. In many cases, estimates of ΔUA are inaccurate because of an inadequate understanding of the interaction of the retrofit with the building. One of the most common retrofits, addition of ceiling insulation, will illustrate the situation.

Ceiling insulation works by reducing the heat flux through the ceiling into the attic. The driving force behind the heat loss is the temperature difference between the house and the attic. Most ceiling insulation calculations account, at least in part, for the fact that the attic is a more or less closed space that is warmer than the outside air. However, most calculations do not account for heat sources in the attic such as solar heating of the attic or the leakage of warm household air around the insulation and into the attic. These mechanisms result in the attic being warmer and the temperature difference between the house and attic being less than otherwise would be expected. Another related cause of overestimated ΔUA is that attic ventilation is often increased as part of a ceiling insulation retrofit (to avoid moisture problems). This tends to lower the postretrofit attic temperature and thus to offset some of the savings of adding insulation. Incorporating these effects into ceiling insulation savings estimates is feasible but will require research on attics. The cost of the needed research and development is surely a small fraction of the cumulative costs of continuing to install costly and largely ineffective amounts of insulation in houses that have these characteristics.

Some heating system retrofits, such as the vent damper, are inadequately understood. The vent damper works by reducing heat loss up the chimney when the furnace or boiler is not being fired. The RCS Model Audit uses low and high vent damper energy savings of 7 and 10% of annual space heating fuel consumption. Energy savings from >14% to no savings for individual houses have been measured.[10] Zero to 14% savings is too large a range to characterize by a single value, such as 7%. We know of only one effort to relate vent damper energy savings to characteristics of the house,[11] and the accuracy of the method has not been tested.

Vent damper energy savings are believed to result from reducing infiltration induced by hot air rising up the chimney. This means that the savings depend very strongly on furnace or boiler location and on how much infiltration the air that escapes up the chimney causes. If a furnace is located in an unheated crawlspace or outside, there should be no energy savings.* When a furnace is located in a heated living space, a vent damper should save the most possible energy; unfortunately, neither theory nor experimental results are available which allow us to confidently predict the savings under these conditions. Accurately predicting energy savings of a vent damper for the common situation of a furnace located in an unheated but closely connected space, such as a basement, will require not only a better understanding of vent dampers, but a much better understanding of the heat and air movement between living spaces and such closely coupled spaces.

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*A vent damper on a boiler in this situation might save some energy by reducing air flow through the boiler.

Although vent dampers and ceiling insulation are among the most common energy conservation retrofits in use, until they and other retrofits with similar problems are adequately understood, predictive methods will continue to give unreliable estimates. As long as predictive methods (e.g., audit calculations) are inaccurate, programs and individuals who wish to save energy will find themselves achieving less energy savings than they could with accurate predictions on all retrofits.

One final shortcoming of the predictive methods used in audits is that they are presently incapable of accounting for uneven heat distribution in houses. Some houses are heated unevenly as by a wood stove or by a poorly designed air, steam, or hot water distribution system. The methods used in virtually all audits assume that the house is evenly heated as by a well designed forced-air system. Most houses have spaces which are not intentionally heated (e.g., basements or closed-off rooms) but which are warmed by their close connection with the house and equipment located therein (e.g., furnaces, water heaters, ducts, and pipes). These unintentionally heated spaces can significantly affect the energy savings achieved by retrofits.

Audit Data

One method of dealing with unknowns such as the behavior of unintentionally heated spaces is to make educated guesses. In the audit, we made educated guesses for basements. For this purpose, we invented three basement categories: intentionally heated, unconditioned, and unheated. Intentionally heated basements are defined as those which were kept as warm as any other living space. Unconditioned basements are those which were warmed by equipment located in them but otherwise not heated. Unheated basements are those which had no heat sources in them. Energy savings from insulation of intentionally heated basements were estimated in the same manner as is done with any other living space. Insulation of unconditioned basements was assumed to save one-third as much energy as insulating an intentionally heated basement. Insulating unheated basements was assumed to save no energy. This method was easy to implement since the categories were clear (in most cases), but it relied on several reasonable but otherwise unsupportable assumptions.

Other parts of the audit required educated guesses by the auditors. The most important of these was estimating the lifetime of a retrofit or an existing piece of equipment. In the audit, the life-cycle benefits of each retrofit were estimated. The annual energy savings and the expected life of the retrofit are the principal components of that estimate. In most cases, we know how to estimate the annual energy savings better than we know how to estimate the life of a retrofit. The problem is most acute with heating system retrofits. An example will illustrate the situation.

Consider the hypothetical case of a 17-year-old gas furnace that is in good condition, shows no signs of rust or wear, and is relatively efficient involves replacing the pilot with an intermittent ignition device (IID). The question is how long an expected life can be assigned to the IID retrofit. A new gas furnace is said to have a life expectancy of 20 years.[11] On one hand, the age of the furnace would suggest that a 3-year expected life would be appropriate. On the other hand, the condition of the furnace suggests that it might well give good service for another 17 years. In such a case, the decision on whether or not to install an IID is essentially decided by which expected life the auditor chooses.

The situation is a little simpler with new equipment. A variety of high-efficiency (90-95%) furnaces has recently become available. Since there is no track record for these furnaces, so it is difficult to predict a furnace life. In the audit we used the oldest age of the furnace for which the manufacturer would provide full replacement or repair if it failed.* While this full replacement or repair warranty age is simple, the average life of the equipment is likely to be much longer since a manufacturer cannot afford to replace or repair under warranty more than a small fraction of the equipment he sells.

The estimates of retrofit and equipment lives are important to the recommendations produced by this audit. Further, the lower the discount rate chosen to calculate the present value of future benefits, the more important the retrofit life becomes. Much of the information needed to predict these lives may be available in manufacturers' files or in the experiences of repair and service personnel. What is needed is a systematic effort to draw the information together in a coherent form so that it can be built into audits.

The IID retrofit presents another interesting savings estimation problem. The estimation procedure used in the audit has based on a pilot gas consumption rate of 800 Btu/h, which is about the minimum practical pilot gas consumption rate. Existing pilots use gas at up to about 2.5 times that rate. Consequently, the audit procedure will usually underestimate the savings achieved by replacing the pilot with an IID. If a method were available to quickly estimate the gas consumption rates of pilots on individual boilers or furnaces, better estimates of IID savings would result. The IID frequently showed up as a highly ranked retrofit when the audit was field tested, but if pilots often use much more than 800 Btu/h, we may still be underutilizing this retrofit.

PRACTICAL PROBLEMS

The problem of estimating retrofit life expectancy also has an auditor behavior dimension. In implementing the field test, we asked the auditors to use their judgment to gauge the life expectancy of the heating system. They were told to assign the expected life to one of three categories: 1-5 years, 5-10 years, and more than 10 years. This approach was largely unsatisfactory.

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*This approach is conservative, but it seemed imprudent and unjustified to assume a longer life.

The expected life of the retrofit has a profound effect on the retrofit B/C ratio, yet these categories are quite wide. Further, we were unable to give the auditors good advice on how to make these judgments. The variability of auditor judgment is illustrated by the case of two homes with quite similar furnaces. The homes were audited by different auditors who assigned different expected lives to the two furnaces. The judgment of a third auditor was that each furnace had the same expected life.

Occupant Behavior and Equity Issues

Some occupant behaviors can reduce space heating energy consumption and consequently reduce retrofit energy savings. Some of these are thermostat nighttime setback, not heating unused rooms, and keeping the house interior at a lower temperature during all hours. Nighttime setback generally saves between 5 and 15% of the space heating fuel (depending on the amount and duration of the setback). Unheated rooms reduce space heating fuel consumption by acting as insulation between the heated rooms and the outside walls, ceiling, and floor of the unheated room. Keeping the house colder saves even more energy. When occupants use these practices, the potential energy savings of most retrofits are reduced. Conversely, some people keep their homes much warmer than average. Retrofit audits could be designed to account for these lifestyle differences and thus give more accurate savings estimates.

To redesign the audit to reflect lifestyle differences raises some difficult questions of equity. The WAP has two stated purposes: (1) to reduce national energy consumption and (2) to reduce the impact of higher fuel costs on low-income families. Both of these objectives can be helped by using an audit to choose the best retrofits, and can be further helped by the technical improvements to the audits. However, including prediction corrections for nighttime setback and not heating unused rooms will result in more retrofits being performed on houses where the occupants do not use such conservation practices and fewer where occupants are trying to save energy.* To many people, it would seem unfair to help those who do not try to save and not help those who try to conserve. Of course, to do otherwise would reduce the energy savings achieved by the program and would indeed be contrary to the goals of the program. This is clearly not a problem that an audit can solve; the audit just brings the problem into focus.

A similar equity issue that has caused considerable debate is whether the same amount of money should be spent on each house or whether retrofit dollars should be spent on the houses where they will produce savings most cost-effectively. The perspectives seem to be: (1) we should spend retrofit dollars where they are most effective; (2) treating everyone fairly means

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*We encountered this phenomenon in estimating energy savings for heating system retrofits. Most heating system retrofit savings are driven by the size of the space heating fuel bill. As a result, houses with large fuel bills, often those where energy conservation was not practiced, got most of the heating system retrofits.

spending the same amount on each house, even if that expenditure achieves very little energy savings on some houses; and (3) spending more on houses which the owners have not weatherized rewards those who do not take care of themselves and punishes those who do. Again, an audit can be designed to respond to a preferred perspective, but the choice of perspective is a policy decision.

Policy Issues

Another policy issue the audit brings to the forefront is whether or not to do retrofits that have B/C ratios less than one.* The results of implementing the audit on 35 houses in Wisconsin is a useful vehicle for discussing the issue. Figure 1 summarizes the audit predictions. Each plus sign on Fig. 1 represents an individual retrofit. The vertical distance between each plus and the one to the left of it is the average net life-cycle (present-value) savings, that is, 1/35

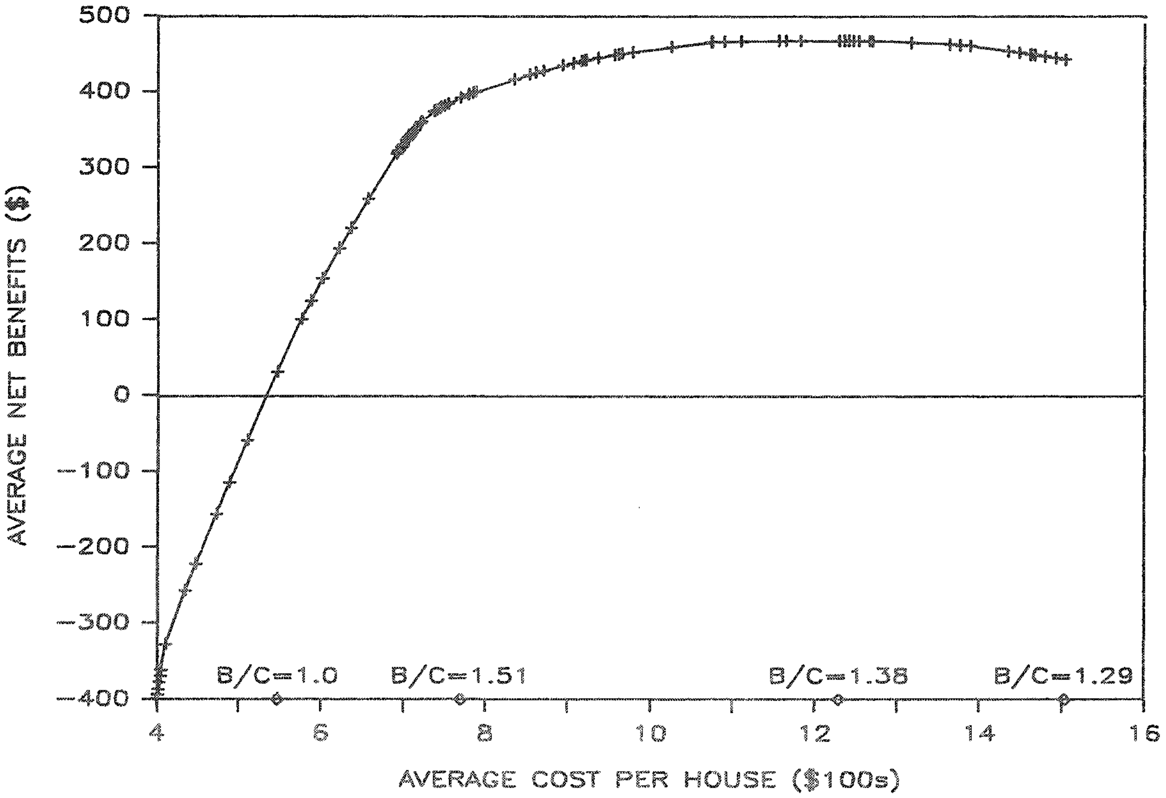

Fig. 1. Audit predictions for 35 houses in Wisconsin, net benefits vs costs (average per house).

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*Discussion of this issue needs to be prefaced by acknowledgment of the fact that the audit, as implemented, used a 7% discount rate in calculating B/C ratios. The WAP Rules call for using an undiscounted B/C ratio; so some retrofits to which this audit assigns a B/C ratio less than one would have a greater than one B/C ratio if evaluated by the WAP Rules.

of the predicted life-cycle dollar savings of the retrofit minus the cost of the retrofit. The horizontal distance between pluses is the cost of the individual retrofit divided by 35.

The general features of Fig. 1 are: (1) based on previous Wisconsin experience, we assumed an estimated cost per house of $400 to get the houses into the program and audited, (2) the expenditure of an additional $125 per house (on average) repays the initial investment and the costs of the retrofits to that point, (3) total expenditures of slightly less than $800 per house (on average) save an average of $1200 ($400 net) per house and achieve the highest overall B/C ratio (1.5), and (4) at an average expenditure of slightly more than $1200 per house, the net benefits begin to decline because the individual retrofits selected beyond this point have benefits that are less than the retrofit cost (B/C less than one).

The shape of the curve in Fig. 1 is important. The general shape of the curve is the result of using an audit that systematically chooses high B/C retrofits first; the specific numbers are the result of local conditions such as climate, fuel prices, and housing stock. The question is when to stop doing retrofits. It is obvious that installing retrofits with B/C ratios that are less than one does not make sense, but what to do instead depends on the purpose of the program. From the home owner's point of view, he would be better off if the money that would be spent on a below-one B/C retrofit were put in a bank account and used to pay a little of each month's fuel bill while the money lasted. The objective of reducing national energy consumption would be best served by spending the money on another house, which will save more energy and money.

The reduced national energy consumption objective would be still better served by selecting a minimum individual retrofit B/C ratio that may be substantially greater than one. The highest overall B/C ratio occurs where the B/C ratio of the next retrofit first drops below the overall B/C ratio of all preceding retrofits. (For the example of Fig. 1, this occurs for an average expenditure per house of somewhat less than $800 and an overall B/C ratio of about 1.5.) At this point, the WAP could reduce national energy consumption more cost-effectively by starting to retrofit a new group of houses than by continuing on these. Here the goal of reducing national energy consumption is plainly at odds with the interests of the individual home owners. The audit did not cause this conflict and it cannot solve it, but it does bring it into focus.*

Audit Implementation

A number of minor but bothersome problems were encountered in implementing the audit. All of these problems seem to result from the newness of the audit and the very short time available to implement and field test the audit. A brief review of these problems shows the need for a measured pace when implementing a new and quite different method of selecting retrofits.

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*Similar issues have been raised recently by the Government Accounting Office.[12]

All the auditors and field crews had considerable experience with the methods in use in Wisconsin, but the audit and some of the retrofits were quite different than they had formerly used. Each auditor had two days of training on collecting data for the audit. Each field crew was walked through the newest retrofit, infiltration reduction with a blower door.

This amount of training was all that was possible given the project schedule, and it turned out to be less than was needed. One auditor damaged a furnace while attempting to measure its steady-state efficiency. Several infeasible mechanical retrofits were recommended as a result of auditor inexperience with heating systems. The field crews had trouble performing infiltration control work according to instructions. The audit recommended no infiltration reduction work on half the houses and much less than usual for the others. Despite training and written instructions, the field crews spent much more time and money than they should have.

SUMMARY

This paper summarized the characteristics of a retrofit audit and reviewed the technical and practical problems encountered while developing and field testing the audit. An audit is different from the priority list method in that it uses detailed characteristics of the individual houses to estimate energy savings. The results of these and other audit characteristics allow selection of more cost-effective combinations of retrofits than the priority list method can achieve.

Development of the audit revealed weaknesses of some of the models used to estimate savings for individual retrofits. The principal impediment to developing more accurate energy savings estimates is that we do not have an adequate physical understanding of some retrofits. Improving the situation will require experimental work directed at characterizing the behavior of the retrofits and developing more reliable predictive methods. Audit accuracy can also be improved by developing better ways to collect or estimate certain important data, such as retrofit lifetimes. Incorporating what we already know about occupant behavior (such as thermostat night setback) could also substantially improve audit prediction accuracy, but the equity implications of accounting for such behaviors should be weighed against the value of the improved predictions.

An audit used to select retrofits can do more than improve energy savings achieved by a program. It can be used to better tailor the program's operation to its goals. On the other hand, for a program like the WAP which has multiple goals, the audit shows that, beyond some point, the separate goals lead to different management activities. For the case of the WAP, the problem might be posed as: Should we serve more people with fewer retrofits and maximize the reduction of national energy consumption, or should we maximize the savings for those who get served by the program but serve fewer people and do less than we could to reduce national energy consumption?

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